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UltrasoundToGo RTD 2013

FNSNF

Efficient 3D US Beamformer: Delay Calculation and Apodization

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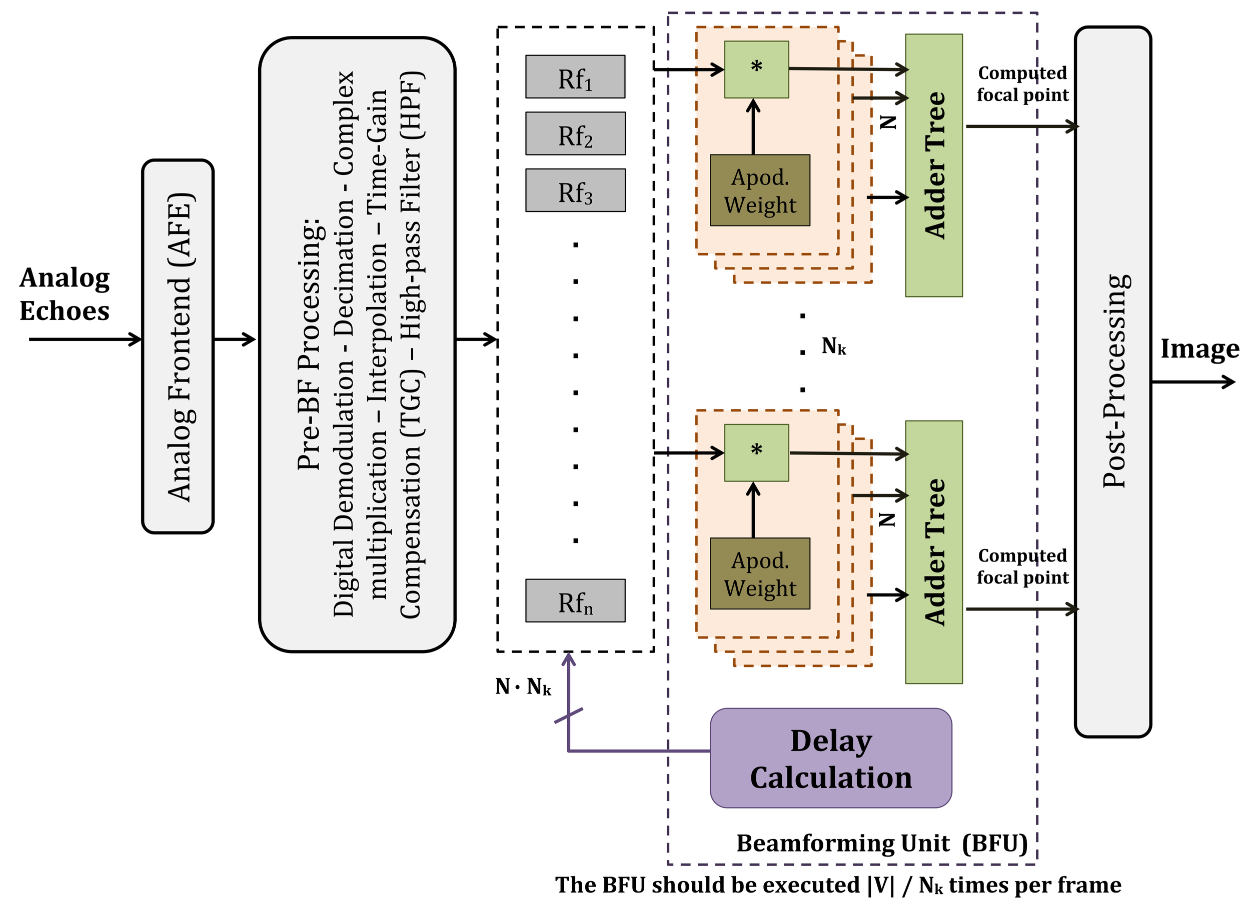
UltrasoundToGo

- Medical ultrasound (US) imaging is one of the most common and advantageous diagnostic techniques that is used in a wide range of applications.
- Volumetric US imaging:
  - Pros
    - ✧ More expressive imaging in obstetrics.
    - ✧ Better functional assessment in cardiology.
    - ✧ Faster acquisition time by scanning the whole volume at once.
    - ✧ Reduced dependency on trained sonographer.
  - Cons
    - ✧ Bulky. ✧ Expensive. ✧ Power hungry.
- **UltrasoundToGo** minimizes the cons of the 3D US imaging by demonstrating a high performance, portable, and low power signal processing platform.
- **Integrated Systems Laboratory (LSI)** focus:
  - ✧ Hardware design, FPGA-based demonstrator.
  - ✧ Matlab as a testing and investigation tool for different imaging modes, settings, and parameterizations.
- **Beamforming** is the core of the US imaging process, and it is the most computationally expensive stage.
- **Beamforming** is basically composed of two main processes;
  - ✧ Delay Calculation. ✧ Apodization.

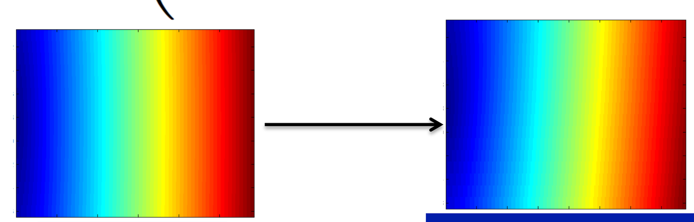


Architectural diagram of a generic US imaging system

Delay Calculation

- **Motivation**
  - ✧ To beamform 128×128×1000 voxel volume at a reconstruction rate of 15 volume/s using a 100×100 element probe ⟶ **2.5 Tera delay samples/s** are required.
  - ✧ There is no satisfactory answer for **portable**, **low-power**, **low cost** 3D US imaging system that has the **flexibility** to be up-scaled to exploit the **full-resolution probe readout**.
- **Proposed Approach**

$$t_p(O,S,D) = \frac{r}{c}\left(1+\sqrt{1+\frac{x_D^2+y_D^2}{r^2}-\frac{2x_D\sin\theta+2y_D\sin\phi\cos\theta}{r}}\right)$$



Ref. delay | Required delay

Steering Approach

$$t_p(O,S,D) - t_p(O,R,D) = \frac{r}{c}\sqrt{1+\frac{x_D^2+y_D^2}{r^2}-\frac{2x_D\sin\theta+2y_D\sin\phi\cos\theta}{r}} - \frac{r}{c}\sqrt{1+\frac{x_D^2+y_D^2}{r^2}}$$

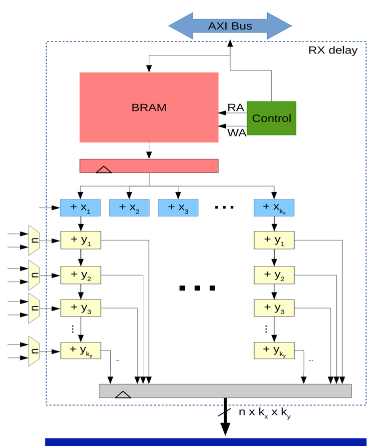
$t_p(O,S,D)$: The required delay; $t_p(O,R,D)$: Ref. delay (Pre-computed). Using 1st order Taylor approximation:

$$\approx -\frac{x_D sin\theta}{c} - \frac{y_D sin\phi cos\theta}{c}$$

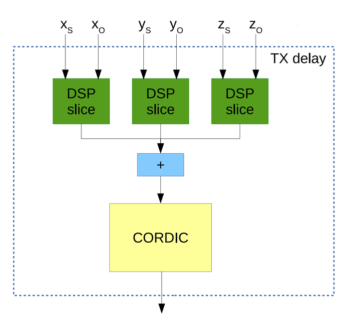
The steering coefficient (Pre-computed)

Critical calculations: Two additions

- **FPGA Architecture**



Rx block



Tx block

- **Results**
  - ✧ The results show the possibility to fit the whole delay computation for a 100 * 100 elements probe in a single FPGA (Virtex 7).
  - ✧ In order to optimize and integrate the whole BF process, There are ongoing studies on the brand new UltraScale architecture (2.5X LUTs/registers + 1.4X BRAM + 432Mb of UltraRaM) .. ***Demo***

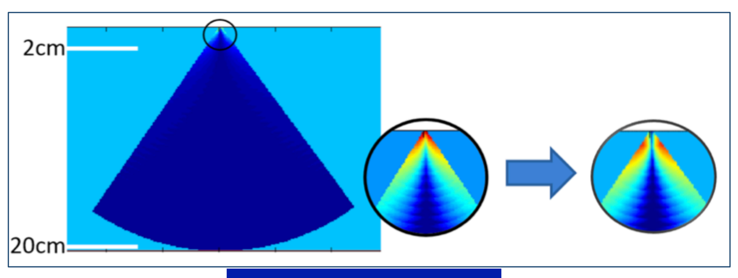
Under submission

Virtex 7 XC7VX1140T-2 Synthesis Results and Estimations for the TABLESTEER architecture.

Mode	Supported Channels $N_x \times N_y$	Logic LUTs	Memory LUTs	Regs	BRAM	DSP	Clock	Offchip DRAM BW (est.)	Thruput	Frame Rate
3D-14b-200x8x8-1X	100×100	63%	0.1%	13%	5.7%	3.2%	372 MHz	32.5 GB/s	4.8 TD/s	29.0 fps
3D-14b-50x16x16-1X	100×100	27%	0.1%	11%	1.7%	3.2%	328 MHz	28.7 GB/s	4.2 TD/s	25.4 fps
3D-16b-100x8x16-1X	100×100	66%	0.2%	13%	3.1%	3.2%	337 MHz	33.7 GB/s	4.3 TD/s	26.3 fps
3D-18b-100x8x16-1X	100×100	70%	0.4%	14%	3.0%	3.2%	343 MHz	38.7 GB/s	4.4 TD/s	26.8 fps

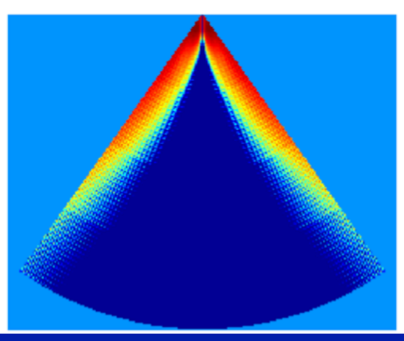
Apodization

- **Motivation**
  - ✧ The approximation in the proposed delay calculation approach causes inaccuracy close to the probe surface and at broad angles (**100 samples off**).



Inaccuracy map

  - ✧ However, a tighter apodization reduces the inaccuracy to within the constructive interference threshold.



Percentage of elements to be apodized for bounding the inaccuracy to 2 delay samples off *

Under Review

W, H, x_c, and y_c Equations For a Single Region Of The Volume

$$W(r,\phi,\theta) = 0.5(\frac{13r}{140} - \frac{\theta+37}{3.5} - \frac{\phi+37}{3.5} + 19)\ ,\quad (140 \le r < 1500)\wedge(1\le\theta\le 18)\wedge(19\le\phi\le 37)$$

$$H(r,\phi,\theta) = 0.5(\frac{13r}{140} + \frac{\theta+37}{3.5} + \frac{\phi+37}{3.5})\ ,\quad (140 \le r < 1500)\wedge(1\le\theta\le 18)\wedge(19\le\phi\le 37)$$

$$x_c(r,\theta) = 49 - \frac{3r}{420} + \frac{\theta+37}{10.5}\ ,\quad (140\le r < 1500)\wedge(1\le\theta\le 18)$$

$$y_c(r,\phi) = \begin{cases} 49 - \frac{3r}{420} + \frac{\phi+37}{10.5}\ , & (140\le r<1500)\wedge(19\le\phi\le 33) \\ 51\ , & (140\le r<1500)\wedge(34\le\phi\le 37)\end{cases}$$

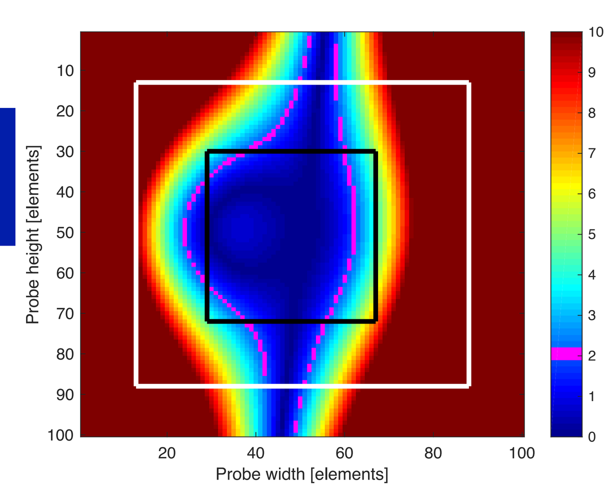
* *Based on a phase offset threshold of 90° between constructive and destructive interference, and considering that the sampling frequency is 8fc.*

- **Proposed Approach**
  - ✧ The proposed apodization scheme accounts for both;
    a. The side lobes due to the physical characteristics of piezoelectric transducer (expanding typical apodization).
    b. The further discarding of the elements that have sampling error above 2 samples.
  - ✧ We studied the volume and derived for each voxel the typical expanding apodization window (white rectangle) and the set of elements that incurs delay inaccuracy of > 2 samples (region outside of the magenta contour).
  - ✧ We built by regression an initial set of equations that define the apodization window (width, height, center abscissa, center ordinate) for different locations in the volume. This yields four equations as a function of r, θ, φ.
  - ✧ We run a script that exhaustively analyzes the volume to drive refinements of these equations, in order to trim or expand the apodization windows to achieve better results (i.e. discarding as many "inaccurate" elements as possible while keeping as many of the "accurate" as possible).
  - ✧ The black rectangle shows the proposed apodization window.

Expanding Apodization

Trimmed Apodization (Square)

Probe face inaccuracy distribution for reconstructing voxel S at r = 8mm, , θ = −26°, φ = −3° .



- **Results**

	Elements Apodized Away	Elements Kept (Accurate Delay)	Elements Kept (Inaccurate Delay)	Memory
Expanding Apodization	2.5%	82.3%	15.2%	2.58 Mb
Trimmed	38.2%	58.1%	3.6%	12.1 Mb
Trimmed, square	38.3%	58.0%	3.7%	2.58 Mb