Row-Column Addressed 2-D CMUT Arrays with Integrated Apodization

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Publication date:
2014

Document Version
Peer reviewed version

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Citation (APA):
Row-Column Addressed 2-D CMUT Arrays with Integrated Apodization

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Agenda

• Background and motivation
• CMUT row-column arrays with integrated apodization
• 3-D imaging experiments
• Conclusion
Background and motivation
Row-Column addressing

- The 2-D array is essentially comprised of two orthogonal 1-D arrays.
- Transmit focusing is performed in a line in one dimension, while receive focusing is performed in a line in the orthogonal dimension.
- Connections: $N^2 \rightarrow 2N$
- High frame rate, high energy
Edge effects

- The elements span the whole length of the array
- No electronic control along the length of the elements
- Edge effects become prominent

These edge waves create additional "ghost" echoes that compromise the image quality!

Figure from: M. F. Rasmussen et al. 3D ultrasound imaging performance of a row-column addressed 2D array transducer: a simulation study, Proc. of SPIE Vol. 8675, 2013
Motivation and purpose

**Pros:** High resolution, real-time 3-D imaging can be performed with row-column addressed arrays with low channel count.

**Cons:** The long elements inherently produce edge effects, which compromise the image quality. No electronic apodization is possible along the length of the elements.

**Solution:** Apodization must be integrated in the transducer itself if row-column arrays are to produce high quality 3-D images.

CMUT technology provides a platform for such an integrated apodization.
CMUT row-column arrays with integrated apodization
Fabrication: Process flow

a) 

[Diagram showing layers: Si, SiO₂, Al]
Fabrication:
32+32 row-column arrays
Validation of integrated apodization: Transducer layout

Standard 32+32 row-column array

Hann apodized 32+32 row-column array
Validation of integrated apodization: Experimental setup
Validation of integrated apodization:
Result

The total energy of the waves after the main wave is reduced by 34 %
Result of first iteration of integrated apodization

- Apodization can be integrated in the transducer using CMUT technology
- It effectively mitigates the problem of edge waves
- The Hann apodization reduces the energy emitted from the array

The concept of the integrated apodization works, but the layout must be re-designed to avoid reduction of the emitted energy
Integrated apodization for 3-D imaging: 64+64 Layout

- 64 row channels
- 64 column channels
- 4 channels provide bias for the apodized regions
- The central region is not apodized

The apodization is decoupled from the central transducer aperture
Integrated apodization for 3-D imaging: Effect of apodization on image quality

Point scatterer

Vessel phantom
3-D imaging experiments
Mounting and wire-bonding

Coated wire-bonds

CMUT array

1 cm
Mechanical fixture and electronics

CMUT array

Connector cable

DC voltage supplies
Mechanical fixture and electronics

- Pre-amplifiers in the receive circuit (9 dB voltage gain)
- All 128 channels can transmit and receive simultaneously
- The Synthetic Aperture Real-time Ultrasound Scanner (SARUS) is used to transmit and receive the signals
Acoustical characterization

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Std</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency in immersion</td>
<td>2.72</td>
<td>0.26</td>
<td>MHz</td>
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<tr>
<td>-6 dB fractional bandwidth</td>
<td>80</td>
<td>5</td>
<td>%</td>
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<tr>
<td>Transmit pressure peak-to-peak</td>
<td>61.4</td>
<td>7.6</td>
<td>kPa</td>
</tr>
<tr>
<td>Sensitivity at 2.5 MHz</td>
<td>0.212</td>
<td>0.063</td>
<td>μV/Pa</td>
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<tr>
<td>Pull-in voltage</td>
<td>100</td>
<td>2</td>
<td>V</td>
</tr>
<tr>
<td>DC bias</td>
<td>80</td>
<td>-</td>
<td>V</td>
</tr>
<tr>
<td>AC excitation amplitude</td>
<td>50</td>
<td>-</td>
<td>V</td>
</tr>
</tbody>
</table>

Impulse Response

Spectrum

Amplitude

Time [μs]

Amplitude [dB]

Frequency [MHz]
3-D imaging of wire (0.3 mm diameter)

- Full synthetic aperture imaging (single element emission) is employed
- 62 transmit events
- 62 elements used in receive

- -6 dB lateral FWHM: 1.91 mm
- -6 dB axial FWHM: 0.71 mm
Conclusion

• Row-column addressing greatly reduces the number of channels needed for performing real-time, 3-D imaging
• Row-column addressed arrays produce edge waves due to the lack of electronic control along the long elements
• Apodization can be integrated in the transducer using CMUT technology
• This apodization effectively reduces the edge waves without altering the electronics, number of channels or beamforming in any way
• Conventional Hann apodization reduces the energy emitted from the array
• Moving the apodization to the element ends decouples the apodization from the central transducer aperture
• 3-D imaging was performed with a 64+64 CMUT array with integrated apodization
Thank you for your attention!