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Advances in Coherent Image Formation and Volume Imaging

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Introduction

- This presentation will describe two new areas imaging –
  - **INFocus coherent image formation**
  - **Real-time volumetric imaging**
  - Both are enabled by the **ACUSON SC2000™** ultrasound system, a high information rate platform that is designed and built for these technologies

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Outline

- **Ultrasound pulse echo imaging**
- **Beamforming**
  - TX beamforming
  - RX beamforming
  - Conventional beamforming vs. IN Focus
- **INFocus**
  - Geometric argument
  - Line of action insight
  - Fourier argument
- **Volume Imaging**
- **Clinical examples**

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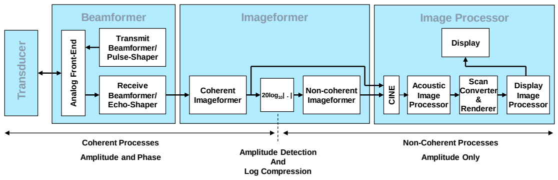
Block Diagram of an Ultrasound System



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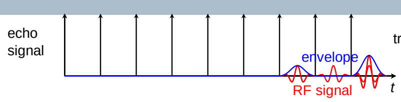
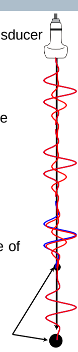
How an Ultrasound Systems forms an Image (1/2)





- The ultrasound system transmits a short pulse along a beam line
- The pulse propagates at 1540 m/s in tissue
- Frequencies are in the MHz range, λ: 0.1 mm – 1 mm
- Inhomogeneities (scatterers, interfaces) scatter or reflect the ultrasonic pulse
- In a B-mode ("brightness") image, the log-compressed envelope of the receive signal is mapped to brightness
- Many lines are acquired to fill an image

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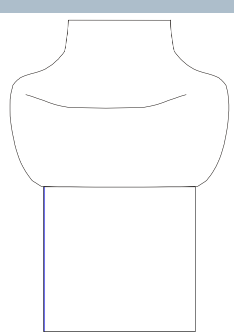
How an Ultrasound Systems forms an Image (2/2)



Beamforming Basics

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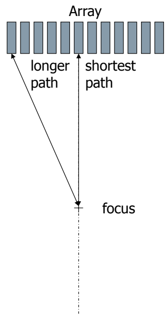
- Today's medical ultrasound system use arrays where each element is connected to a transmitter and receiver
- A beam is formed by creating interference patterns
- In pulse echo imaging, there is transmit (TX) beamforming and receive (RX) beamforming
- If the medium is linear and time-invariant, the interference pattern does not have to be created in real-time.
  Instead, multiple acquisitions can be stored and then superimposed to recreate the interference pattern.
  (**S**ynthetic **A**perture **F**ocusing **T**echnique)



TX Beamforming Wave Propagation

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0 dB, + 0 dB, –
-60 dB

- 16 elements
- 2λ spacing
- Focus at 64λ

RX Beamforming (1/2)

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0 dB, + 0 dB, –
-60 dB

- 16 elements
- 2λ spacing
- Focus at 64λ
- Steered at 45°

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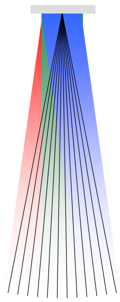
RX Beamforming (2/2)

- TX beamforming can only support 1 focus per transmit event
  (You cannot manipulate the propagating waves.)
- RX beamforming is not limited to a single focus.
- Delays can be readjusted for any depth
  → dynamic receive beamforming
- Receive foci can be steered away from the TX beam location
  → parallel receive beams
- ACUSON SC2000™ can form up to 64 parallel beam



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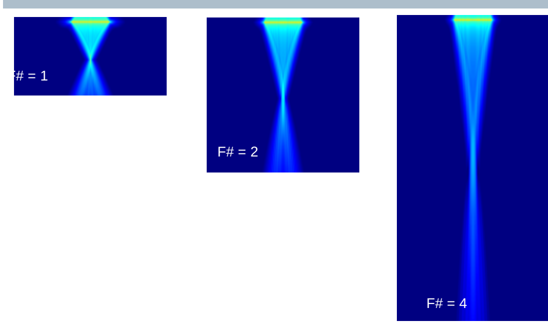
F-number = Focal Depth / Aperture Width



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IN Focus Coherent Technology

- IN Focus is a real-time Coherent Image Formation technology that provides dynamic transmit focus at all depths
- Never again out of focus
  - Focal zone image quality at all depths
  - Eliminates the requirement to shift the focal zone during conventional imaging
  - Less repetitive stress
- Enabled by the ACUSON SC2000 ultrasound system massive parallel beamformation capability and a Coherent Imageformer

IN Focus Coherent Technology

- Each point is imaged with a variety of different transmit angles - angle diversity
- Phase and amplitude data is preserved from each beam
  - Combined to retrospectively synthesize a focus at every point in the image
- Frame rate advantage
  - Massive receive beam acquisition per each firing requires fewer transmits events

Transmit focus at every point in the image!!

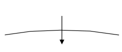
Summary of Points from IN Focus Animation

- Conventional
  - Transmit focused to a point and listen with Receive beam (or maybe a couple of beams) down the middle
- IN Focus
  - Transmit focused or unfocused – listen with Receive beams everywhere transmit goes (requires LOTS of beams)
  - Many “looks” at every point, each with unique Transmit angle
  - Adjust in Imageformer Time, Phase, Amplitude and combine
  - Achieve retrospective Transmit focus at every point in image

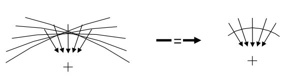
- Hallmark of a focus is converging wavefronts. This happens at one depth for conventional. We build this at all depths for IN Focus

Geometric Argument (1/2)
Synthesizing Converging Wavefronts

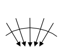
Hallmark of a focus is converging wavefronts. This happens at one depth for conventional. We build this at all depths for IN Focus



Conventional away from focus, Single wavefront not converging on this point of image



INFocus creates converging wave at all points From set of waves traveling at multiple angles



Conventional at focus, Wavefront is converging at single focus point

I call this the “Spirograph” picture

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Conventional Focusing

CP US CRM

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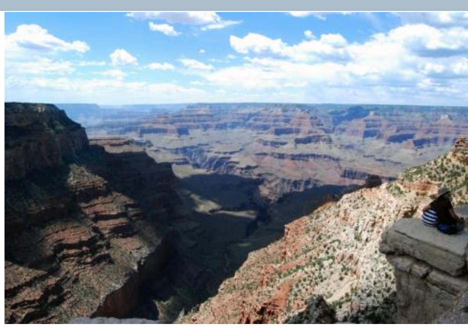
IN Focus Coherent Technology



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Fourier Argument (1/3) Lateral Response as Transform of Aperture Function

- Fourier argument is the next level of “how it works”
- Enables in-the-field-of-view focal depth for good harmonic generation
- Classic Fourier Transform relationship between aperture and lateral response <u>at focus</u>: (from Goodman, Introduction to Fourier Optics 5.2.1)

$$U_f = \phi(u) \int_{-\infty}^{\infty} U_l \exp\left[-j \frac{2\pi}{\lambda z} xu \right] dx$$

- One step back – <u>away from focus:</u>

$$U_f = \phi(u) \int_{-\infty}^{\infty} U_l \exp\left[j \frac{k}{2z} \left(\frac{1}{z} - \frac{1}{f} \right) x^2 \right] \exp\left[-j \frac{2\pi}{\lambda z} xu \right] dx$$

- Aperture function is multiplied by quadratic phase term proportional to difference of focus and depth inversed

$$\exp\left[j \frac{k}{2z} \left(\frac{1}{z} - \frac{1}{f} \right) x^2 \right]$$

Fourier Argument (2/3)
Physical interpretation of “away from focus term”

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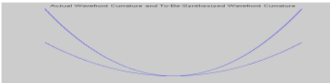
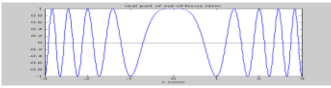


Difference between curvatures leads to Oscillatory multiplier away from point of tangential intersection



Principal of stationary phase says part of the integrand at the stationary phase point will dominate result

Fourier Argument (3/3)

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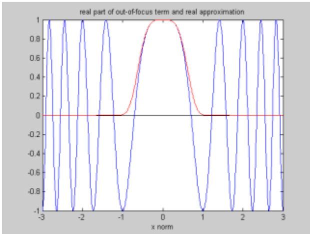
- Approximate away-from-focus by real function

$$\exp\left[j\frac{k}{2z}\left(\frac{1}{z}-\frac{1}{f}\right)x^2\right] \cong \exp\left[-\frac{1}{2}\left(\frac{k}{2z}\left(\frac{1}{z}-\frac{1}{f}\right)x^2\right)^2\right]$$



Superior Image Quality on IN Focus
8V3c* on the ACUSON SC2000 System

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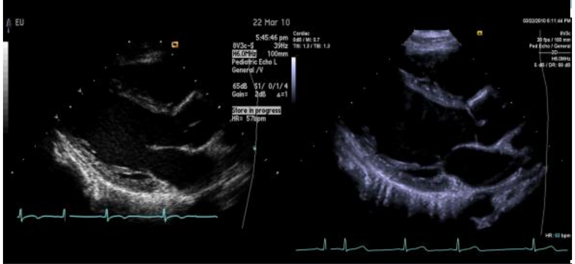

Conventional Focus	ACUSON SC2000 IN Focus
2 parallel beams	32 parallel beams
2-way synthesis	16-way synthesis

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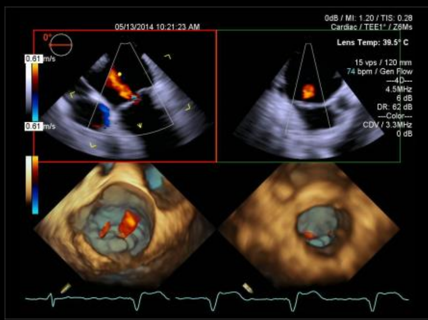
Volume Image Formation



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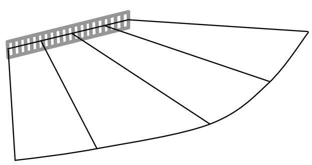
Volume Imaging

1D arrays can steer only in one plane



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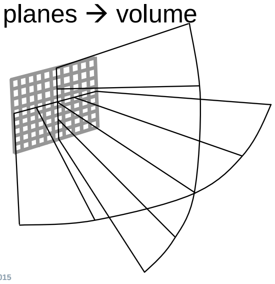
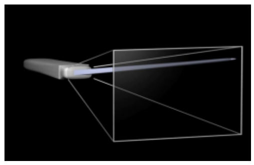
Volume Imaging – 2D Arrays

2D arrays can steer in two planes → volume



Siemens Approach To Volume Imaging

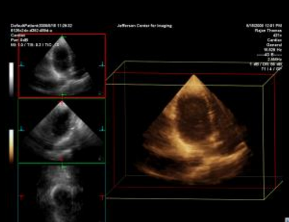
- Can we use the conventional focus imaging w/ 2D arrays?
- \- No
  - Too slow for 3D
  - Limited by the velocity of sound
  - 15 cm image depth at 20 volumes per second allows 256 transmit-receive events



Siemens Approach To Volume Imaging

- Move away from serial, line-by-line acquisition
- Move towards sub-volume-by-sub-volume acquisition
- Similar concept as INFocus – massive parallel receive beams per transmit
- Coherent processing
- Focus is on high volume rate, not tight transmit focus

Volume Imaging *needs Coherent Processing*



- *No Coherent Image Formation*
- *With Coherent Image Formation*

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Volume Imaging – Clinical Examples

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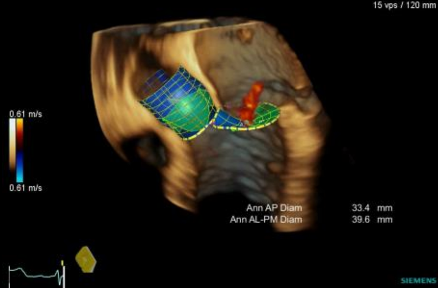
Volume Imaging – Clinical Examples



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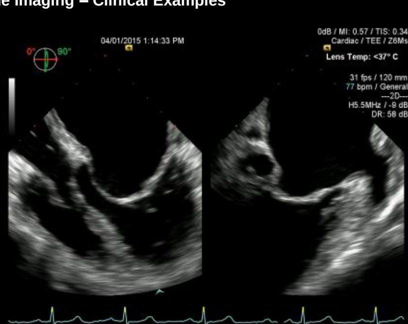
Volume Imaging – Clinical Examples



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Questions?