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sense and simplicity

Microbeamformers for Large-Aperture Ultrasound Transducers

Steve Freeman

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US005229933A

United States Patent [19]

Larson, III

[11] **Patent Number: 5,229,933**

[45] **Date of Patent: Jul. 20, 1993**

[54] **2-D PHASED ARRAY ULTRASOUND IMAGING SYSTEM WITH DISTRIBUTED PHASING**

[75] Inventor: **John D. Larson, III,** Palo Alto, Calif.

[73] Assignee: **Hewlett-Packard Company,** Palo Alto, Calif.

[21] Appl. No.: **442,050**

[22] Filed: **Nov. 28, 1989**

[51] **Int. Cl.**^{5} **G06F 15/00**

[52] **U.S. Cl.** **364/413.25;** 367/104; 128/660.01; 128/660.1; 128/661.01

[58] **Field of Search** 364/413.25; 128/660.01, 128/660.07, 660.08, 660.09, 660.1, 661.01; 367/103, 104; 73/626

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Primary Examiner—Roy N. Envall, Jr.
Assistant Examiner—Laura Brutman

[57] **ABSTRACT**

A two-dimensional phased array ultrasound imaging system distributes signal delays between its probe and its base section. The transducer elements are grouped and relative delays between elements of a group are introduced within the probe. Once the intragroup delays are introduced, the signals from the elements of a group are combined to generate a group signal. A group signal is generated for each group and, collectively, the group signals are transmitted to the base section via a multi-wire cable. Delays between groups are introduced at the base section. This distribution of delays maintains power dissipation within the probe at a tolerable level while requiring only a manageable number of data and signal lines between the probe and base section.

11 Claims, 5 Drawing Sheets

-For 20+ years we've known what sort of processing is needed for good 3D performance. Only recently with modern IC technology is that processing feasible given power & space constraints.

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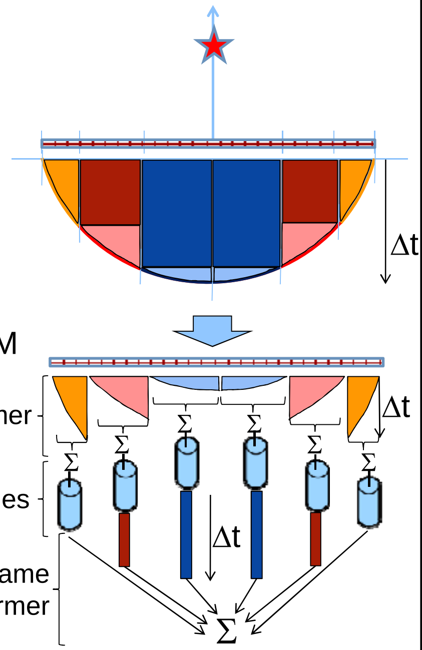
Sub-array Beamforming

- Transducer elements grouped
  - Uniform or non-uniform
- Delay applied between elements in the group → SUM
- Cable to mainframe
- Inter-group delays applied → SUM



Divide & Conquer

-A graphical representation of sub-array beamforming.

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Previous Examples of Microbeamforming

- X4-1/X3-1 – Philips, adult cardiac
- X7-2 – Philips, pediatric
- X7-2t TEE – Philips, 3D Transesophageal Echo
- 4Z1C – Siemens, adult cardiac
- 3V – General Electric, adult cardiac
- X5-1 – ***new,*** Philips, adult cardiac

- All have footprints smaller than ~15mm
  - Limited by acoustic windows
- Resolution is inadequate for General Imaging applications

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Philips X6-1 Design Goals

- Provide good resolution and penetration for GI applications
  - Comparable to 1D curved arrays (e.g. C5-2)
  - Desired center frequency = 3.2MHz
  - Intercostal-capable (limits elevation footprint)
- Allow wide field of view
  - 100x90 degree virtual apex scan format
- 3D volume rate comparable to mechanical probes
- Live X-plane imaging
- Color and PW performance adequate for most situations
- Good ergonomics (not too heavy or bulky)
- **An ALL-IN-ONE transducer**

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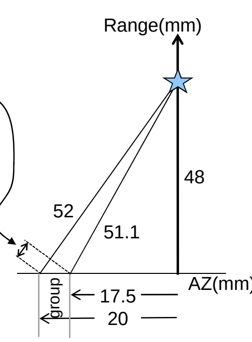
Comparable Resolution to 1D GI array (C5-2)

- Effective azimuth aperture is about 40mm wide
  - Together with frequency dictates resolution
- Split azimuth into 16 groups: 2.5mm/group
- Delay across the group
  - Near-field: F/number = ~1.2
    - → **ΔT = ~1.4us** @ edge (no steering)
  - More than 4λ delay across the group
  - Introduces interference when imaging near-field
    - Grating Lobes
    - Decreased summing gain
- Similar issues in elevation dimension



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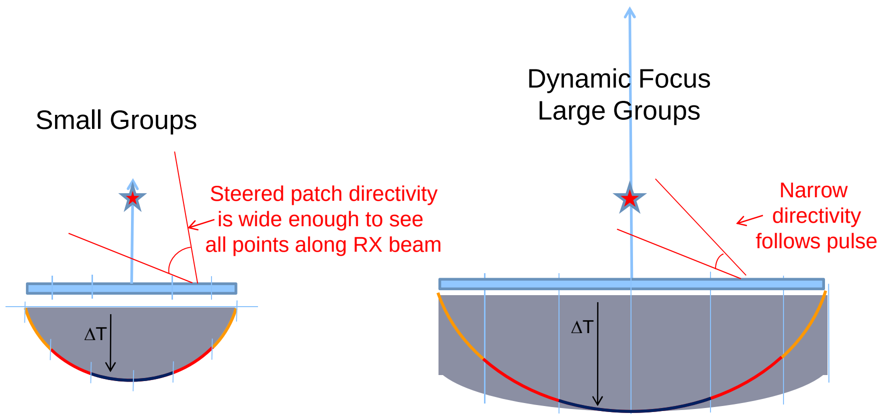
Lots of Elements = Big Groups = High Resolution - requires dynamic RX focus



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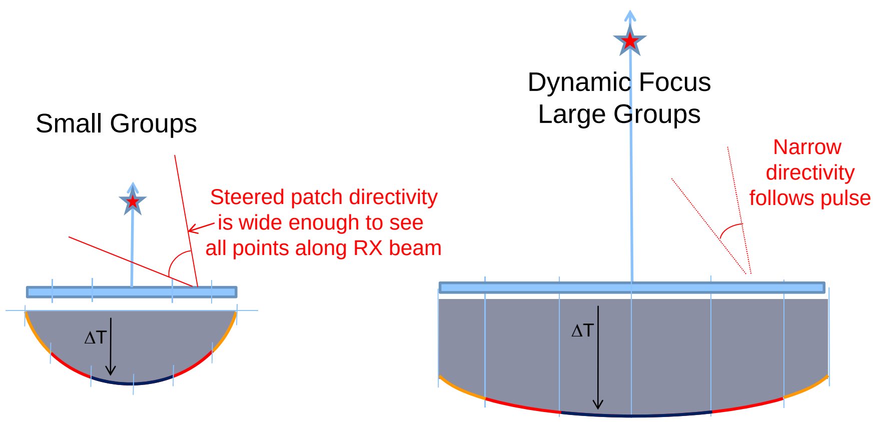

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Dynamic Focusing

- Large array (e.g. non-cardiac) needs large groups
  - Or more mainframe channels
  - Group directivity decreases (narrows)
- Cannot use *fixed* RX microbeamformer delays across the group because it can't track pulse propagation
  - Delay tilt is wrong at all but one range.
- Must make delays dynamic for good focusing
  - Controls grating lobes (due to periodic phase errors)
- Delay updates:
  - Cannot inject noise
  - Can be relatively infrequent (just manage the tilt not the bulk focusing)

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Elevation Focusing Allows:

- Thinner slice thickness
  - IQ reminiscent of annular arrays
  - Better than just expanding aperture (w/no delay changes)
- More consistent contrast resolution throughout image
  - No smearing of out-of-plane structures
- Better focal gain down deep
- No longer a depth-of-field vs. aperture size trade-off
  - Challenging corollary: How big do you make it?
- Much better MPR views than mechanicals (esp. C-plane)
- Elevation compounding improves speckle texture

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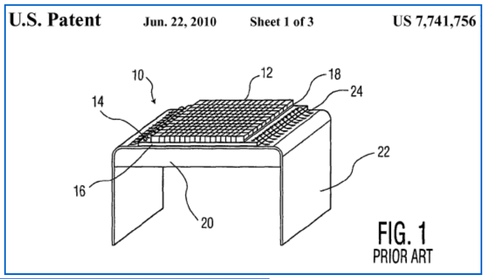
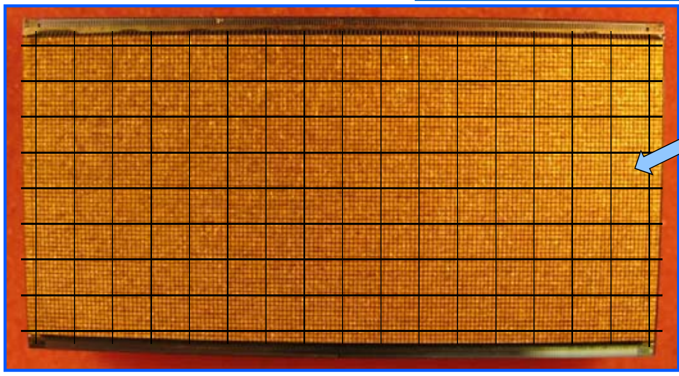
Sensor & ASIC Module

- Flip-chip technique for array interconnect





- 128 Groups

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Microchannel Datapath Components

- High Voltage Transmitter
  - Pulser or linear amplifier
  - Drives element with programmable waveform
  - Ideally would apply apodization (weighting)
- T/R switch
  - Protects LV receiver during TX excitation
- Low-noise RX Amplifier
  - Applies TGC
- RX time-delay
  - Applies intra-group delay

- All of this fits in the shadow of an element

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-See also the Savord paper from the 2003 IEEE Symposium.

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X6-1 Operational Details

- 3.2MHz center frequency
- ~250um pitch 2D array
  - Fully sampled 9212 element 2D array
- Virtual-apex scan format
  - 100-degree AZ, 90-degree EL
- Large Aperture ←→ Better resolution, but…
  - Need more beams to adequately sample space
  - Volume rates are dictated by speed of sound rather than turn-around time for mechanicals
  - Real-time 4D trades resolution (F/number & number of beams) for volume rate

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X6-1 Integration Challenges

- Thermal
  - Passively cooled
  - Severe power budget for TX and RX electronics
  - Iteration of operating parameters & thermal measurements
    - Adjust on-chip behavior based on the imaging mode
- Yield
  - Delicate assembly process
  - In-process testing required to catch process-induced failures
  - Somewhat tolerant of scattered failures
    - Only certain failure modes allowed

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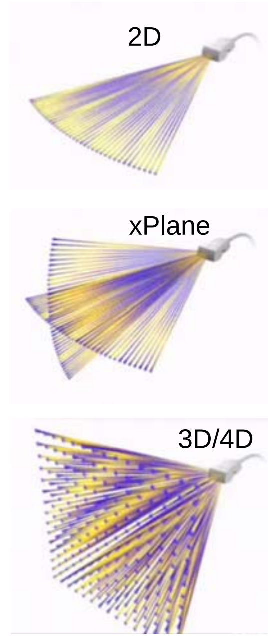
X6-1 Imaging modes

- Excellent thin-slice 2D imaging
- Elevation-compounded 2D imaging
- Color, CPA, and PW flow
- Simultaneous Live xPlane
- High resolution single-sweep 3D
- High resolution MPR
- Live Volume (4D)
- Fetal Echo iSTIC
  - Gated capture of sub-volumes



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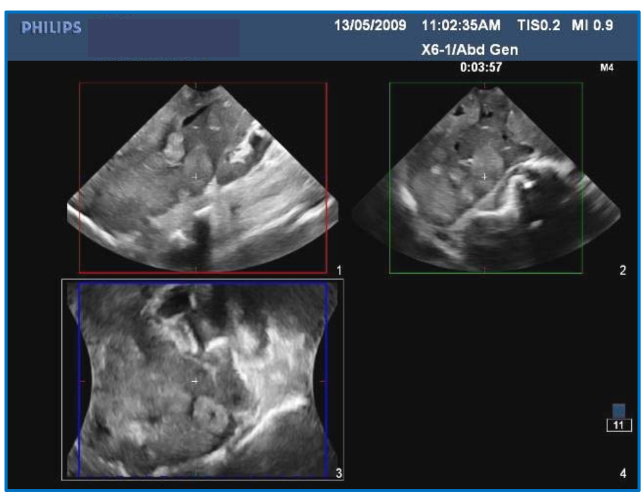
Liver metastases



From Freeman Hospital, Newcastle upon Tyne, UK

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-The C-plane image quality is consistently better than from mechanicals.

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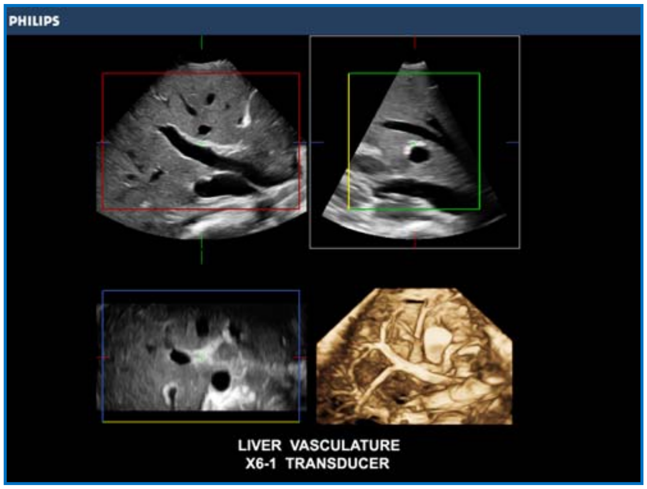
Hepatic vasculature in Invert mode



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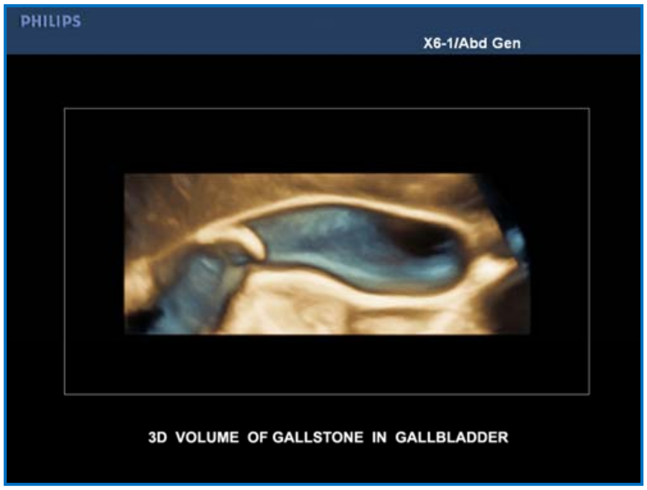
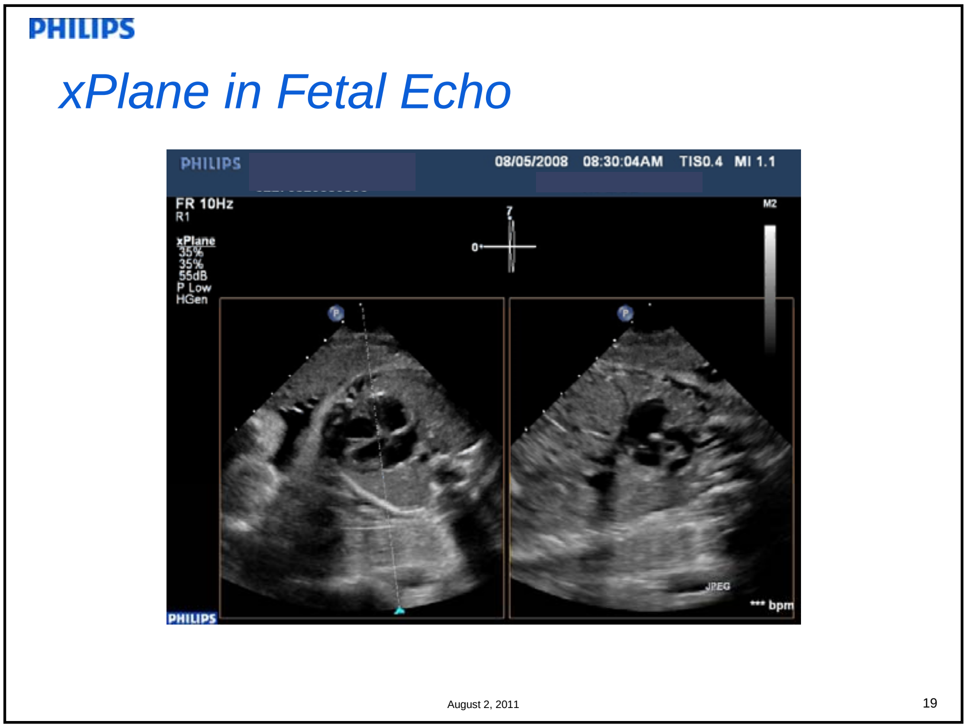
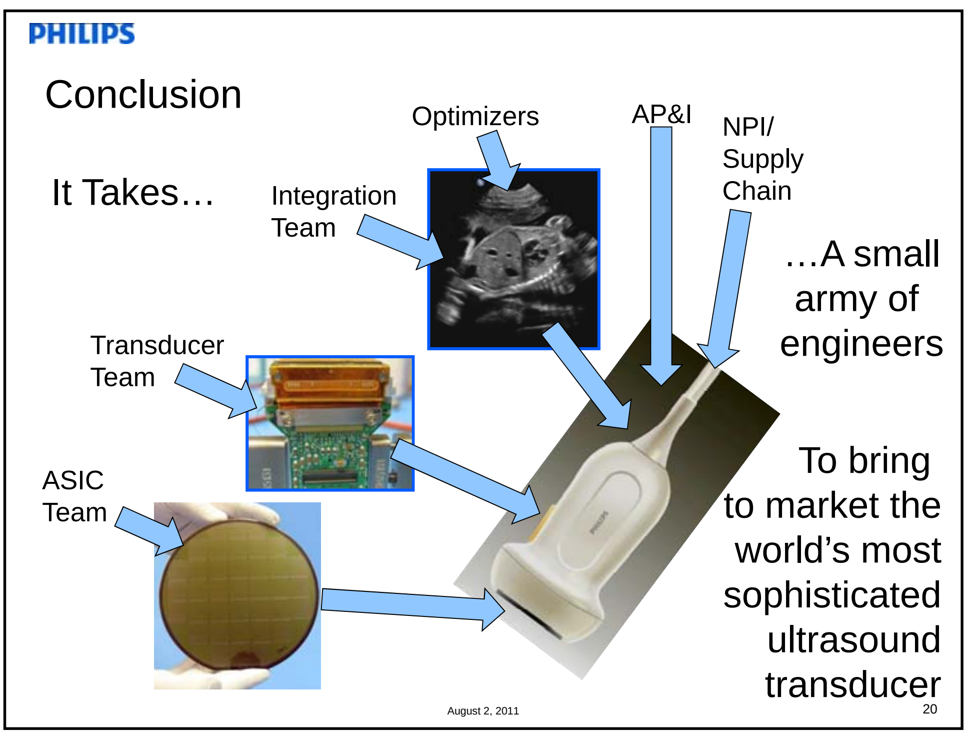
Gallstone rendered in 3D





- Trackball controls transverse tilt angle.
- Both images update in real-time



-The cast of contributors on this project has been immense. Thanks to all of them the X6-1 transducer is a successful, revolutionary advance in the General Imaging ultrasound market.

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Further Information

- Website videos:

http://www.healthcare.philips.com/main/products/ultrasound/Campaigns/xMATRIX/xmatrix_general_imaging.wpd

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- Siemens 4Z1c whitepaper:

http://www.medical.siemens.com/siemens/en_US/gg_us_FBAs/files/misc_downloads/Whitepaper_4Z1c.pdf

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