Phantom and User-friendly Software for Rapid Periodic Quality Assurance of Gray-scale Ultrasound Scanners

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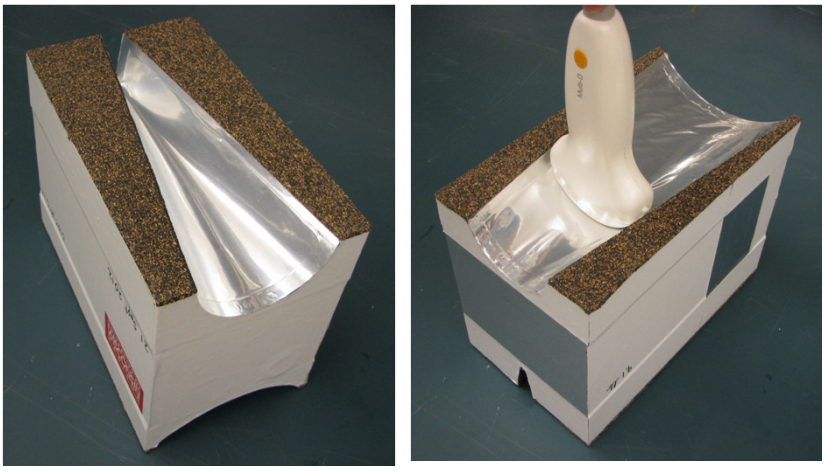
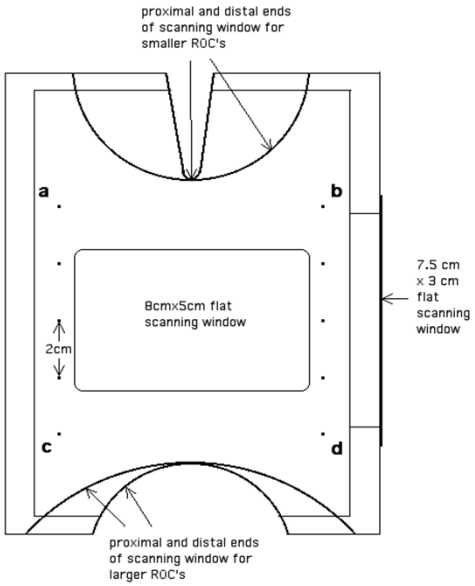
6 August 2013

REVIEW OF PHANTOM DESCRIPTION



Two conical scanning windows and two flat windows



ULTRASONIC PROPERTIES OF TISSUE-MIMICKING MATERIAL

-- Propagation speed 1540 m/s = default assumed speed for nearly ultrasound scanners

– if not 1540 m/s, focusing could be compromised

-- Specific attenuation coefficient (0.5 dB/cm/MHz or 0.7 dB/cm/MHz)

-- Backscatter coefficient (echogenicity) simulating liver ($3x10^{-4} \pm 3$ dB) $sr^{-1}cm^{-1}$ with frequency dependence $(frequency)^n$ where $3 \leq n \leq 4$)

FOUR-YEAR STUDY BY HANGIANDREOU ET AL.:

Three parameters need monitoring

1. **Element or channel failure (EOCF) of a linear or convex (curved) array**

2. **Maximum depth of penetration (MDOP)**
   -- minimum depth at which echo signals become buried in "electronic noise" arising from amplifiers, etc.

3. **Distance measurement accuracy (DMA)**
   -- horizontal and axial dimensions

DISTANCE MEASUREMENT ACCURACY

-- accuracy especially important for obstetrics where fetal measurements are used to predict fetal age and organ volumes

-- Maximum error for *vertical* distance is 1.5% or 1.5 mm whichever is greater

-- Maximum error for *horizontal* distance is 2% or 2 mm whichever is greater

Goodsitt et al., "Real-time B-mode ultrasound quality control test procedures Report of AAPM Task Group No. 1," Med. Phys. vol. 25 pp. 1385-1406 (1998)

1) What is the maximum acceptable error in horizontal distance measurement between two line targets?

20%	a) 1% of the known distance or 1 mm whichever is greater
20%	b) 2% of the known distance or 1 mm whichever is greater
20%	c) 2% of the known distance or 2 mm whichever is greater
20%	d) 3% of the known distance or 2 mm whichever is greater
20%	e) 3% of the known distance or 3 mm whichever is greater

10

c) 2% of the known distance or 2 mm whichever is greater

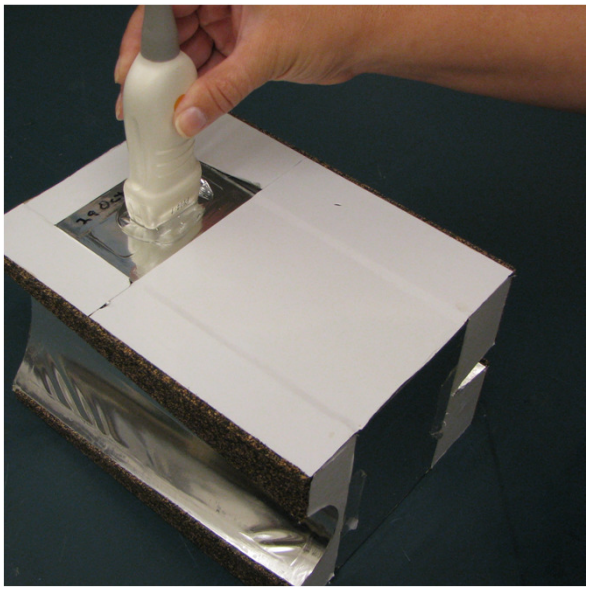
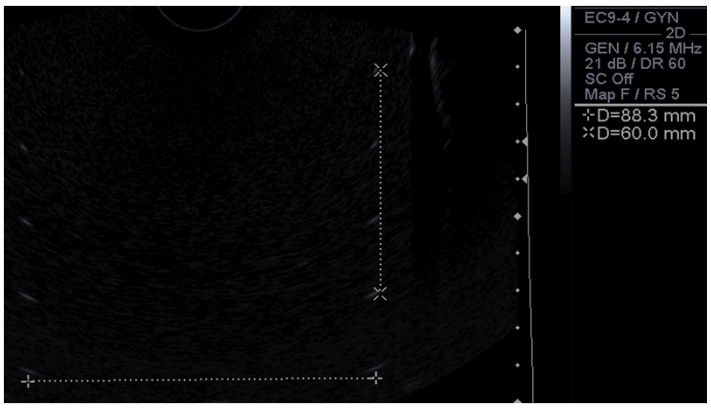


Photo of phased array on QA phantom for DMA

Use of conical scanning window can be important for convex arrays with small radii of curvature

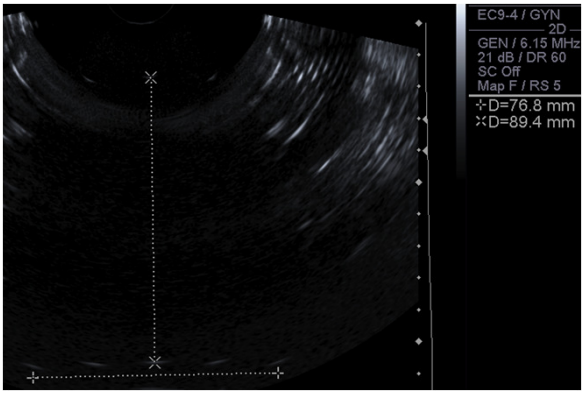
Below is result for a 1 cm ROC transvaginal transducer



Horizontal error of 88.3 mm – 90.0 mm = – 1.7 mm = –1.9%

Common to use flat scanning window with water for transmission

Temporary wall around flat scanning window on QA phantom

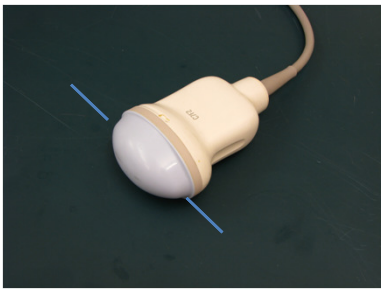


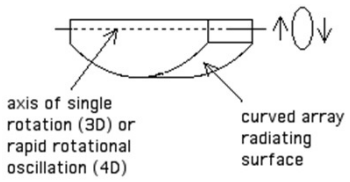
APPARENT horizontal error = (76.8cm – 80.0cm)÷80
= – 4.0% = 2 x maximum acceptable error

Caused by refraction at water-to-scanning-window interface

DMA for 3D/4D transducers (common in obstetrics)

Either convex array or linear array rotated back and forth around axis parallel to the scan plane



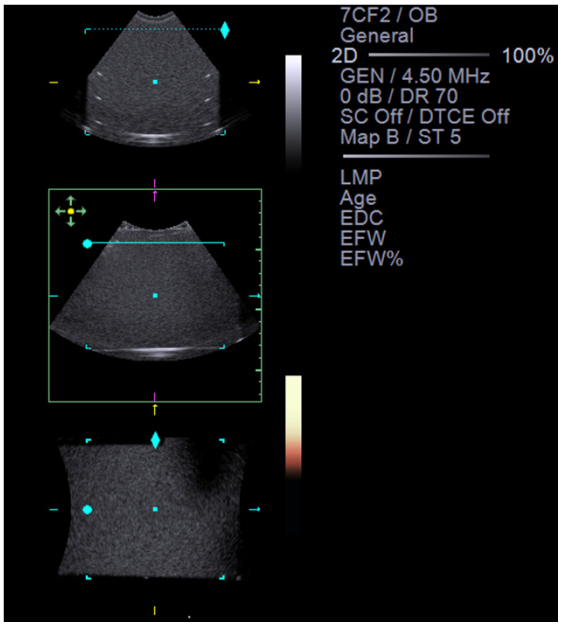


Consider convex array case

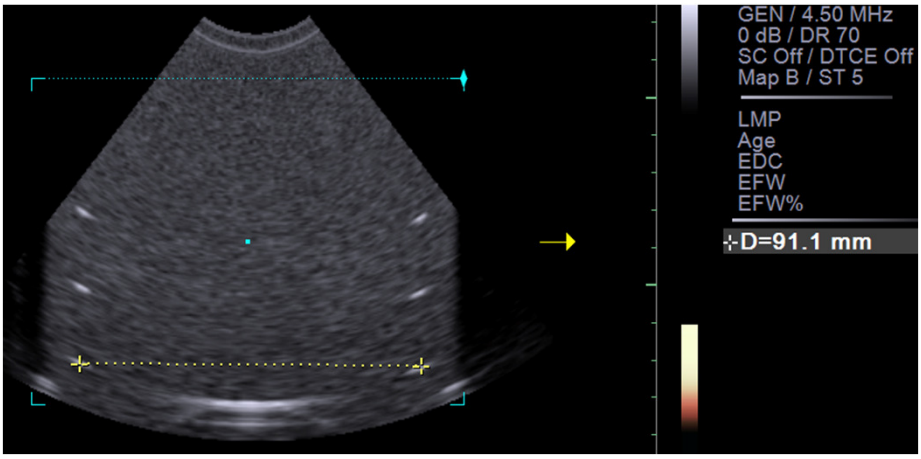
Use 2D mode where array is fixed in position for DMA of the convex (or linear) array

For the mechanically scanned mode use 3D mode and acquire one image set

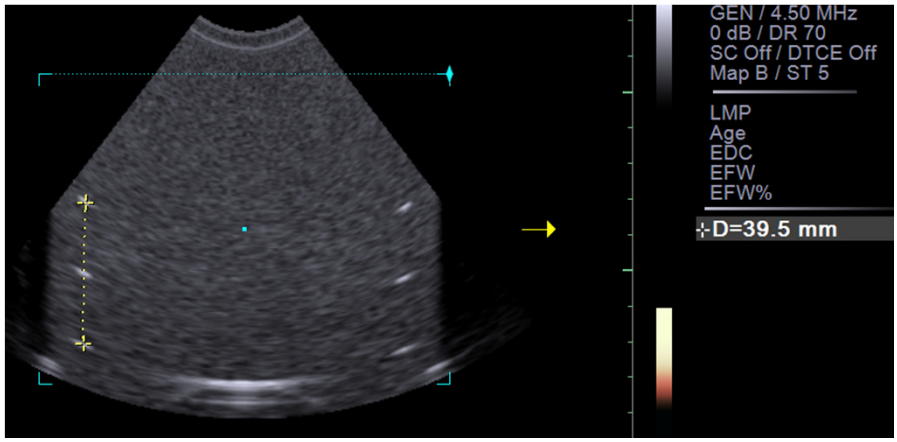
Scan plane perpendicular ➔ to fibers corresponding to mechanical sweep



Three mutually perpendicular images reconstructed from a 3D Scan image set



Horizontal distance measurement corresponding to mechanical sweep



Vertical distance measurement corresponding to mechanical sweep

NOTE: To get 9 cm vertical fiber separation use flat side scanning window

MAXIMUM DEPTH OF PENETRATION

compute averages of cine loops for adequate accuracy

IEC Standard 61391-2 (2010):

- **20 cm phantom depth with uniform ultrasonic properties**
- **propagation speed (1540 ± 15) m s^{-1}**
- **Specific attenuation coefficient (0.7 ± 0.05) dB cm^{-1} MHz^{-1}**
- **At least 50 images in cine loop**

Acquisition of cine loop for MDOP

3) For determining maximum depth of penetration the phantom's sound propagation speed should lie in what range?

20%	a) 1500 ± 5 m/s
20%	b) 1500 ± 10 m/s
20%	c) 1500 ± 15 m/s
20%	d) 1540 ± 15 m/s
20%	e)1540 ± 20 m/s

10

Answer: d) 1540±15 m/s

4) For determining maximum depth of penetration, the phantom's specific attenuation coefficient should lie in what range?

20% a) 0.5 ± 0.05 dB/cm/MHz

20% b) 0.5 ± 1.0 dB/cm/MHz

20% c) 0.7 ± 0.05 dB/cm/MHz

20% d) 0.7 ± 1.0 dB/cm/MHz

20% e) 1.0 ± 1.0 dB/cm/MHz

10

Answer: c) 0.7 ± 0.05 dB/cm/MHz

MDOP is that depth at which SNR = 1

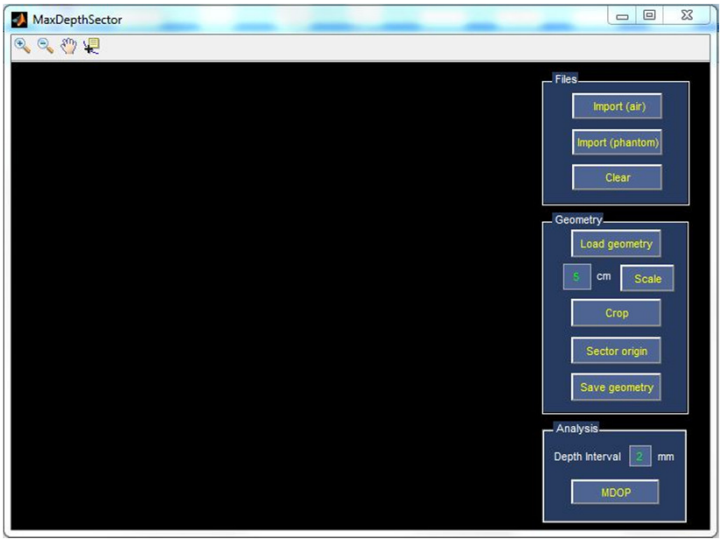
<S> = mean signal at a given depth when imaging phantom

<N> = mean noise at that depth when transducer is held in air

SNR = 1 when <S> = 1.4 x <N>

User-friendly GUI (graphical user interface) software for MDOP

DEMONSTRATION


MaxDepthSector
Files
Import (air)
Import (phantom)
Clear
Geometry
Load geometry
5
cm
Scale
Crop
Sector origin
Save geometry
Analysis
Depth Interval
2
mm
MDOP


MaxDepthSector
433 images averaged
meaganPhantomScanMDOP 4DC7-3/40-GEN-General
03/15/12
1:28:30 PM
Penetration
Freq 3.3M
Depth 18cm
Sector 100%
Gain 100%
FrRate High
FPS 20Hz
Dyn 75dB
Persist 0
Map 4
Chroma 0
Power 0
MI (?)
Clarity Off
Files
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Import (phantom)
Clear
Geometry
Load geometry
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cm
Scale
Crop
Sector origin
Save geometry
Analysis
Depth Interval
2
mm
MDOP


MaxDepthSector
439 images averaged
meaganPhantomScanMDOP 4DC7-3/40-GEN-General
03/15/12
1:25:09 PM
Penetration
Freq 3.3M
Depth 18cm
Sector 100%
Gain 100%
FrRate High
FPS 20Hz
Dyn 75dB
Persist 0
Map 4
Chroma 0
Power 0
MI (?)
Clarity Off
388 / 591
[1 ... 591]
x 1
Files
Import (air)
Import (phantom)
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Geometry
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Crop
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Save geometry
Analysis
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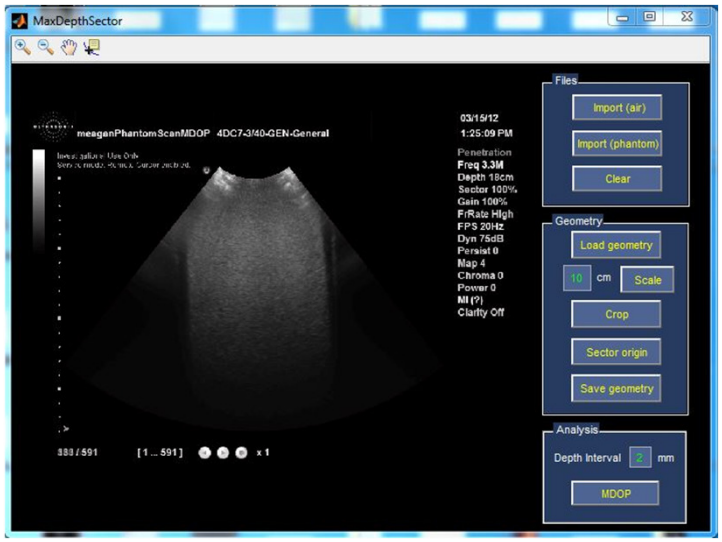
2
mm
MDOP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Geometry
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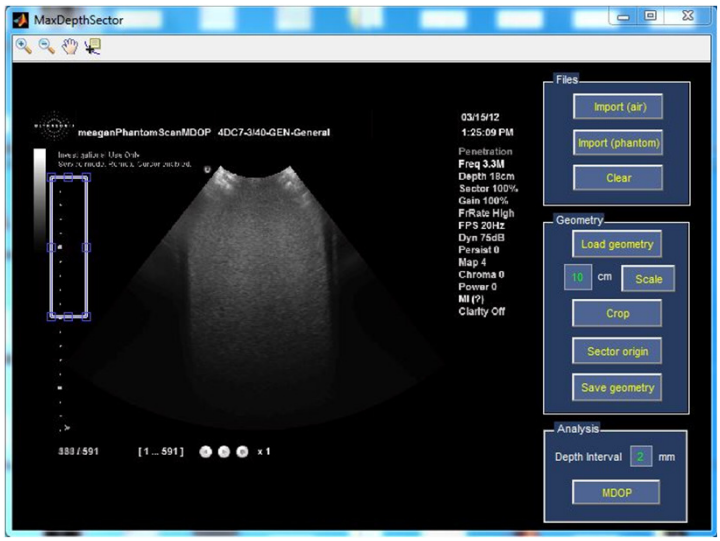
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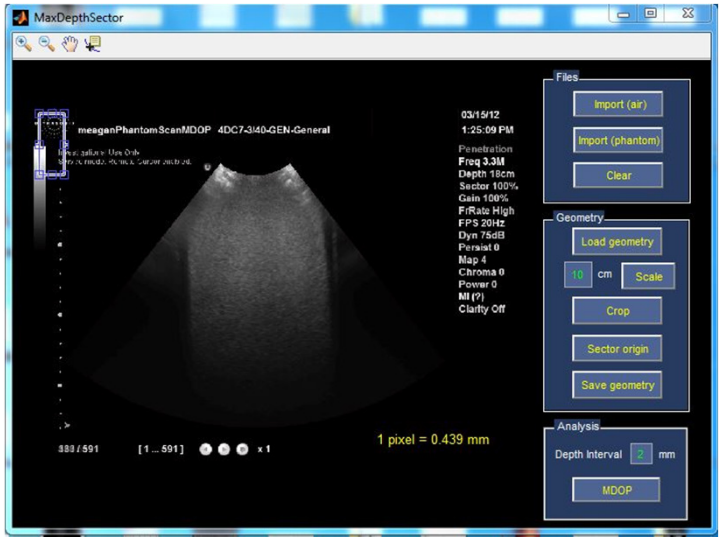
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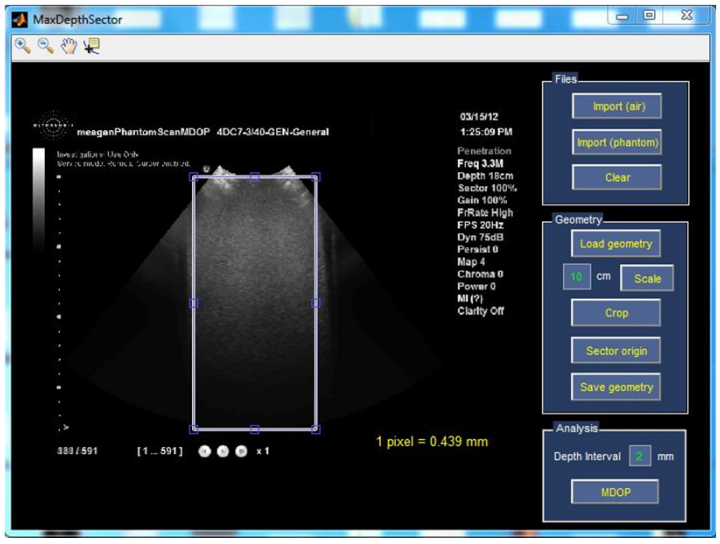
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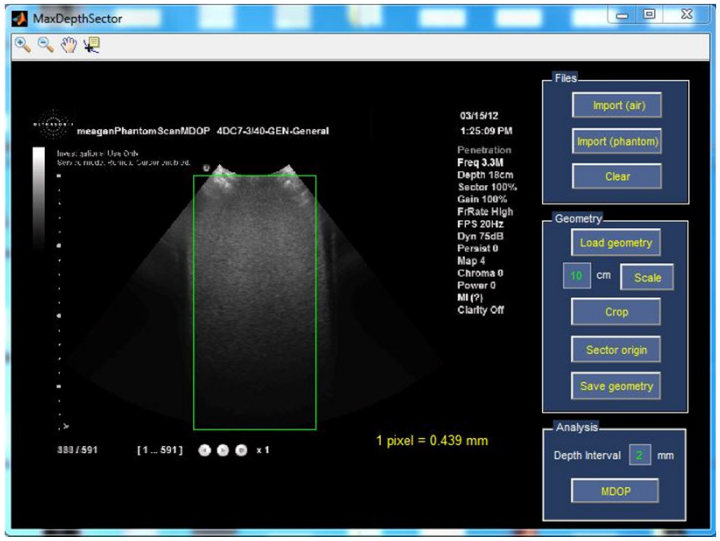
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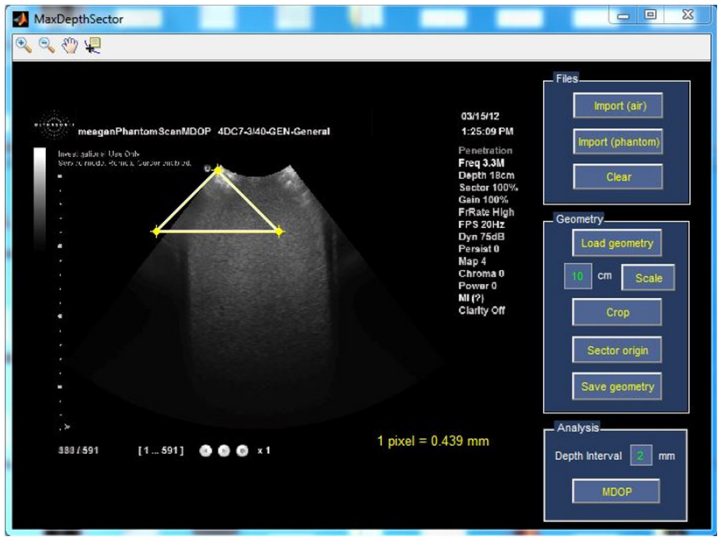
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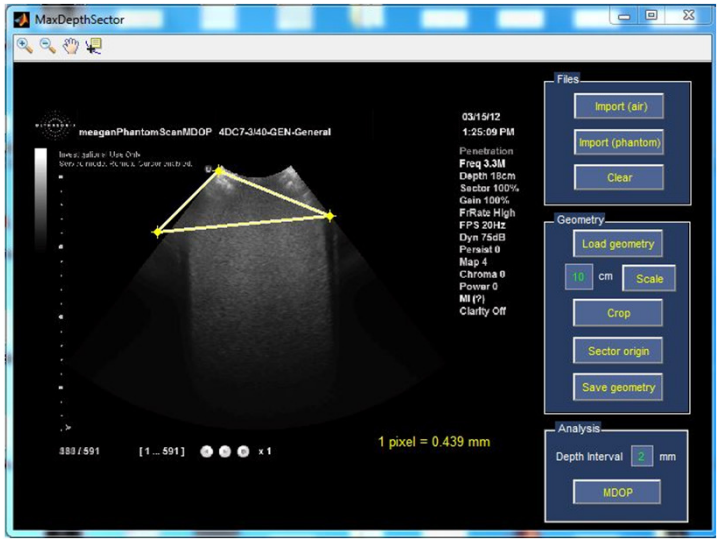
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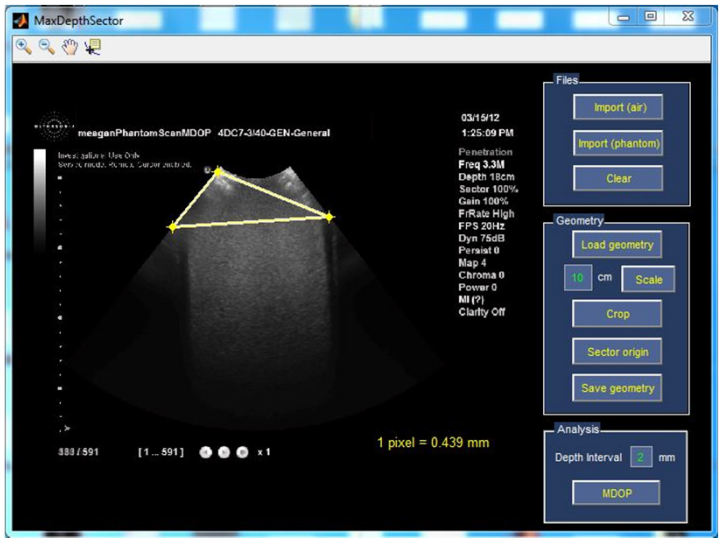
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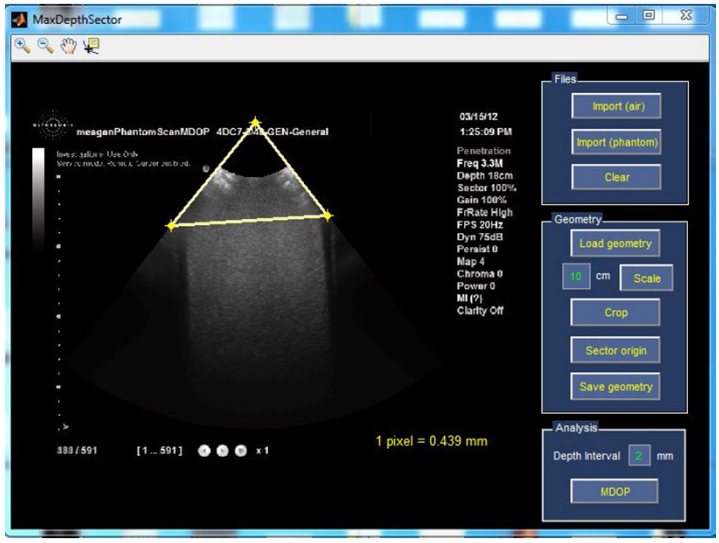
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388 / 591
[1 ... 591]
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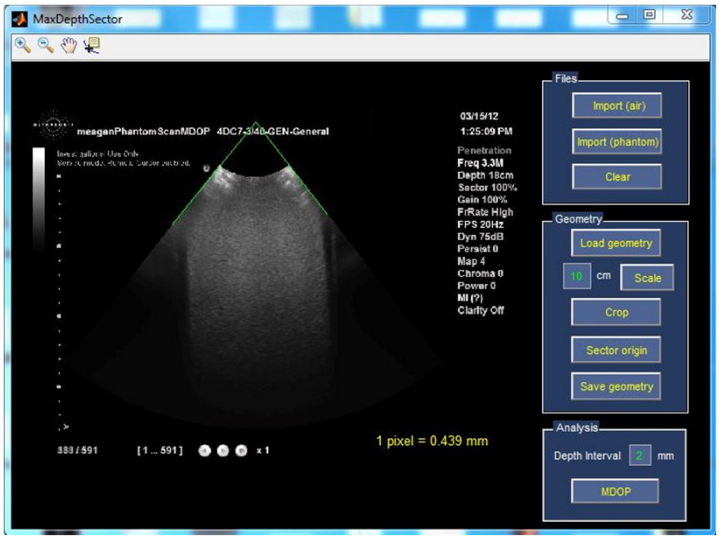
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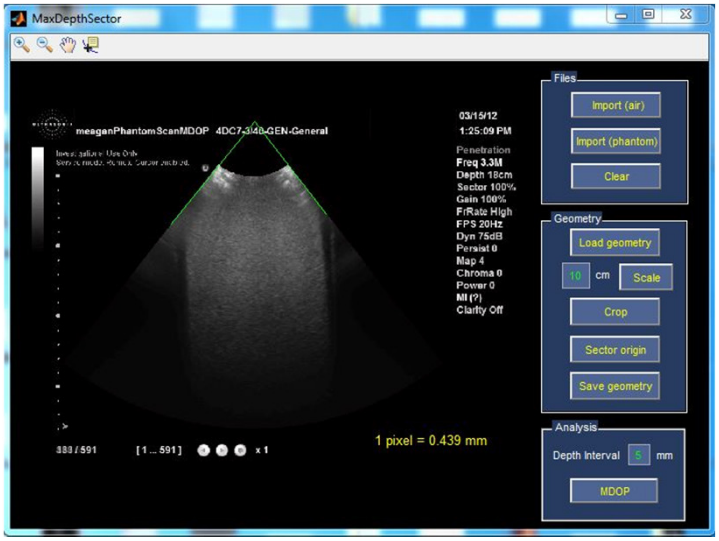


2) Once the mean of a set of cine images with the transducer coupled to the phantom (<S>) and the mean noise (<N>) of a set of cine images with the transducer coupled only with air have been obtained, how does the software compute the maximum depth of penetration (MDOP)?

20% (a) It computes the depth at which <S> = <N>

20% (b) It computes the depth at which <S> = (1/2) x<N>

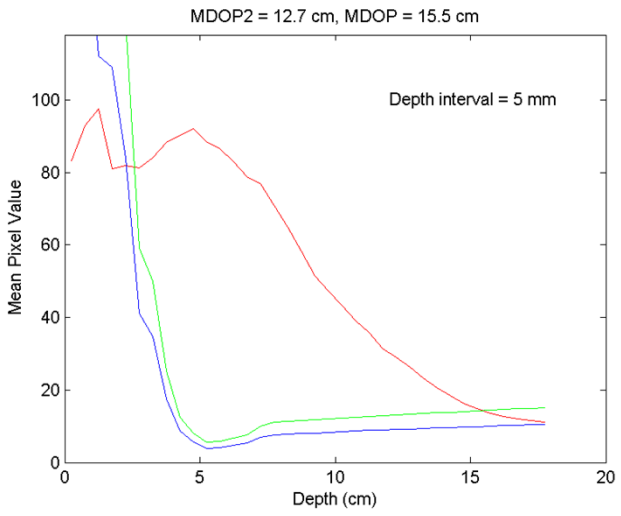
20% (c) It computes the depth at which <S> = <N>/1.4

20% (d) It computes the depth at which <S> = 2 x <N>

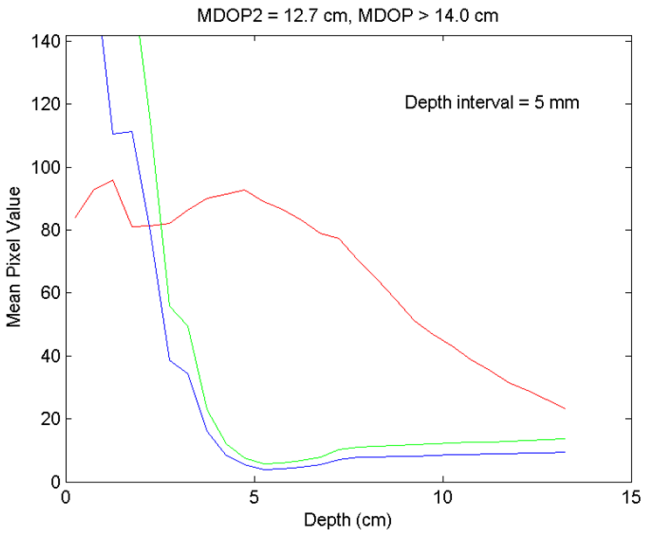
20% (e) It computes the depth at which <S> = 1.4 x <N>

10

Answer: e) <S> = 1.4 x <N>



Red line is <S>, blue line is <N> and green line is 1.4 times <N>



Cause for concern:

-- decrease of 5% in MDOP relative to the benchmark (first) value

Cause to alert scanner manufacturer:

-- decrease of 10% in MDOP relative to the benchmark

Element or channel failure (EOCF)

System setup: Chapter 4 of pending revision of AIUM QA Manual for Gray-scale Ultrasound Scanners -- 2013

1) Obtain cine loop of phantom images

2) Display mean or median image

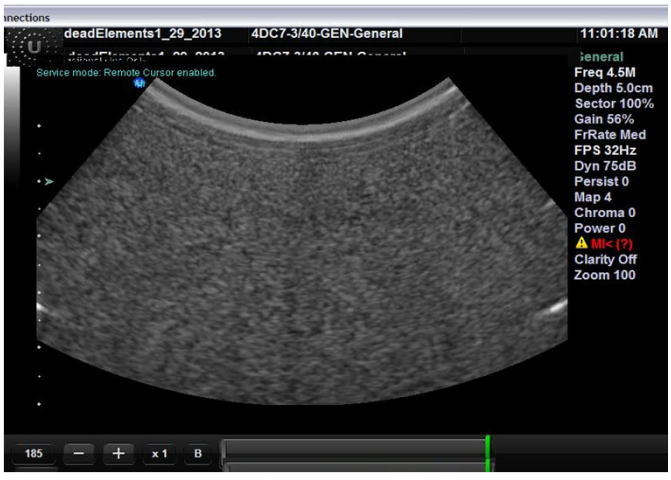
3) Apply analysis criteria being developed at the University of Michigan – may eventually include automated analysis

Cine loop:

-- include plenty of coupling gel over entire radiating surface

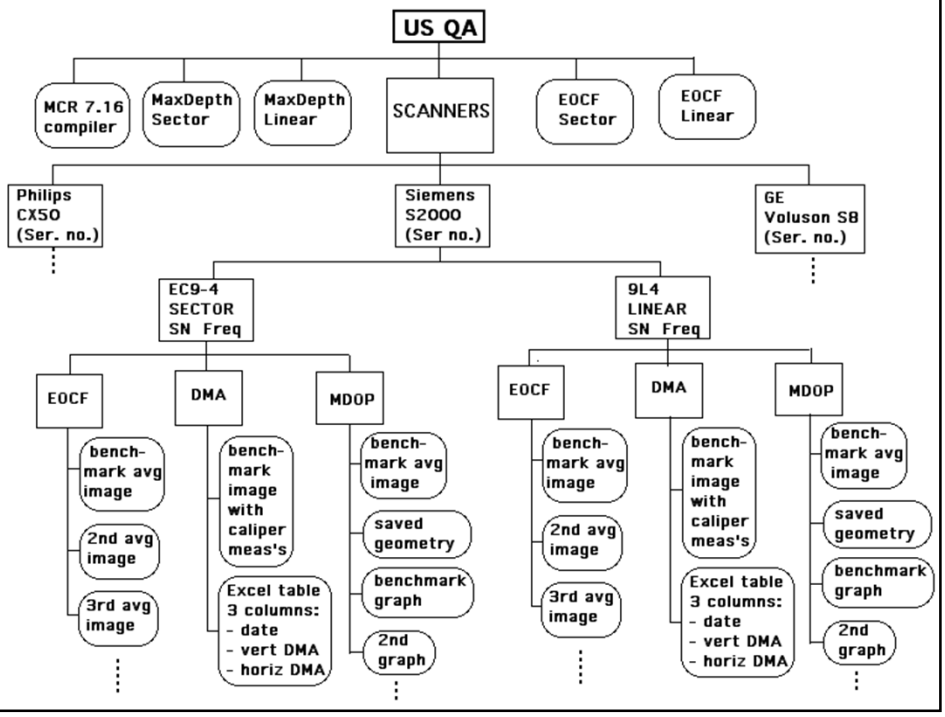
-- draw transducer in elevational direction toward greater ROC's during acquisition

Average of cine loop images with no EOCF



Single image with two central adjacent array elements inactivated

Average of cine loop of images showing distinct shadowing



Personnel time considerations

Storage and transfer of images from scanner to computer is not addressed.

Two components:

1) LEARNING the procedure for acquiring and analyzing data and then producing and filing benchmark results.

   a) Learning methods of data acquisition and analysis for MDOP, generating benchmark results and storing those results in the filing system for one convex array and one linear array: (80 + 15 + 15) = 110 minutes

   b) Generating benchmark results, saving setup procedures and storing results electronically for subsequent transducers: 25 minutes per transducer plus 10 minutes per transducer = 35 minutes per transducer to generate and store benchmark results.

2) PERIODIC RE-MEASUREMENT of EOCF, DMA and MDOP at 6 or 12-month intervals: 25 minutes per transducer

Thus, on the ***first testing day***, the learning session and benchmark production and storage would be 110 minutes for the first curved and linear array plus 35 minutes each for all other transducers.

For example, if there are 8 transducers to be tested, the time required on the first day would be 110 + 6x35 minutes = 320 minutes. The total time on the first day would then be 440 minutes = about 7.5 hours, or about 1 day's work.

Subsequent periodic re-measurements on the same 8 transducers would be 8x25 minutes = 200 minutes = about 3.3 hours.