QUALITY ASSURANCE (QA) PHANTOM FOR GRAY-SCALE ULTRASOUND SCANNERS

- MANY DIFFERENT PHANTOMS AND METHODS FOR MANY DECADES
  -- DISCOURAGING TO CLINICAL PERSONNEL

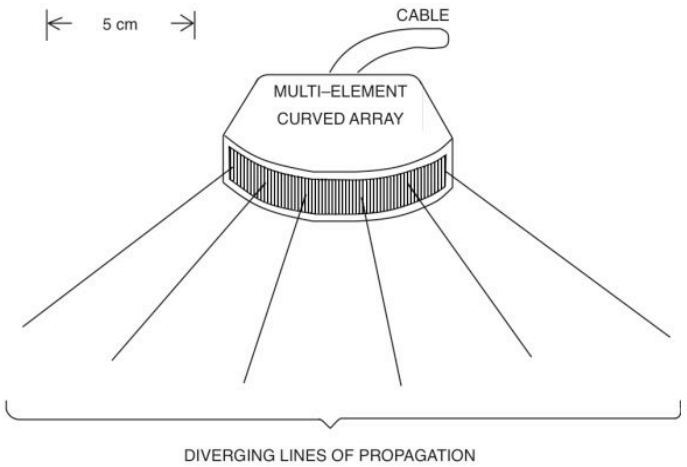
- RECENT 4-YEAR STUDY* AT MAYO CLINIC ASSESSED MINIMUM NEEDED PARAMETERS

  -- 45 SCANNERS & 265 DIFFERENT TRANSDUCERS

* Hangiandreou et al. Ultrasound in Med. & Biol. Vol. 37, No. 8, pp. 1350-1357, 2011

- THREE PARAMETERS WORTH MONITORING FOR ARRAY TRANSDUCERS:

  1. ELEMENT OR CHANNEL FAILURE (EOCF)
  2. MAXIMUM DEPTH OF PENETRATION (DOP)
  3. DISTANCE MEASUREMENT ACCURACY (DMA)
     --- DMA IMPORTANT FOR OBSTETRICS



- LINEAR ARRAYS AND PHASED ARRAYS
  -- FLAT SCANNING WINDOW OK

- CURVED ARRAYS (CONVEX ARRAYS) -- RADII OF CURVATURE 0.5 cm TO 7 cm

  -- NEED CURVED SCANNING WINDOW FOR CONTACT OVER ENTIRE EMITTING SURFACE

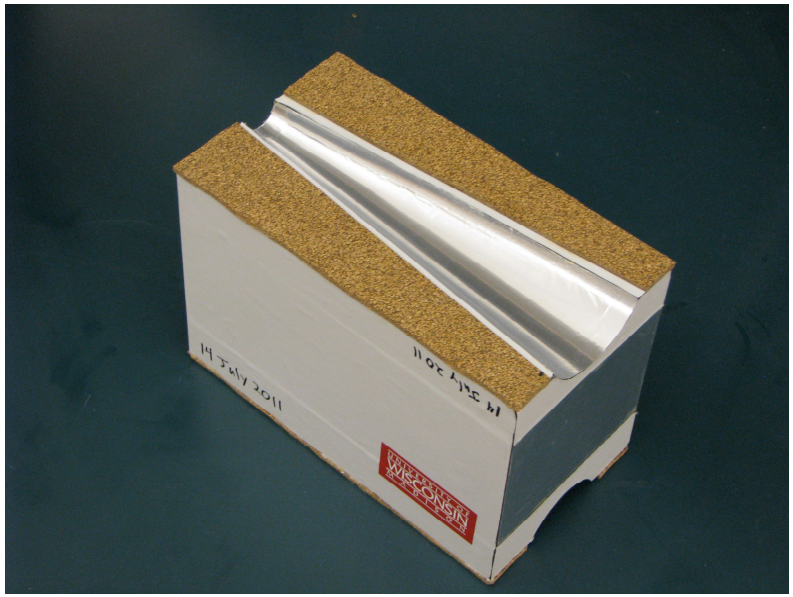
- TO DETERMINE VALUES FOR ALL 3 PARAMETERS, NEED:

  1. SCANNING WINDOWS WITH BROAD RANGE OF RADII OF CURVATURE
  2. TISSUE-MIMICKING (TM) MATERIAL WITH 1540 m/s AND TISSUE-LIKE ATTENUATION AND ECHOGENICITY

PROTOTYPE QA PHANTOM FOR ALL THREE PARAMETERS

-- PHYSICAL PROPERTIES --

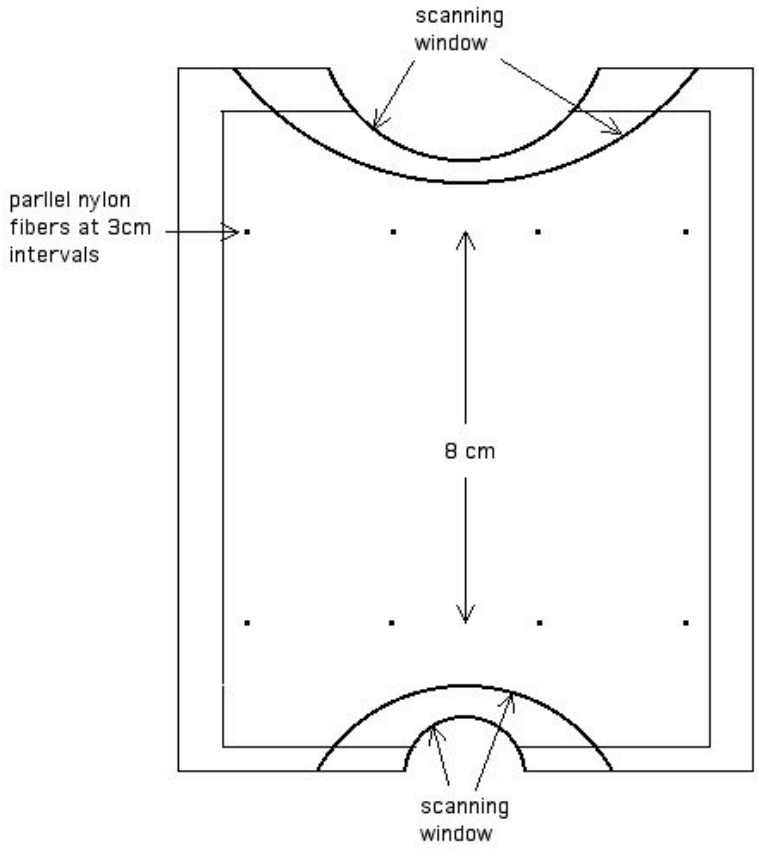
- PROPAGATION SPEED OF 1540 m/s
- ATTENUATION COEFFICIENT ÷ FREQUENCY
  ≈ 0.5 dB/cm/MHz
- TWO CONICAL SCANNING WINDOWS & ONE FLAT WINDOW
  -- COMPLETE CONTACT OF ANY SHAPE EMITTING SURFACE WITH WINDOW
- 8 PARALLEL NYLON FIBERS FOR DISTANCE MEASUREMENT ACCURACY



ONE SIDE HAS CONICAL SCANNING WINDOW FOR SMALLER ROC VALUES

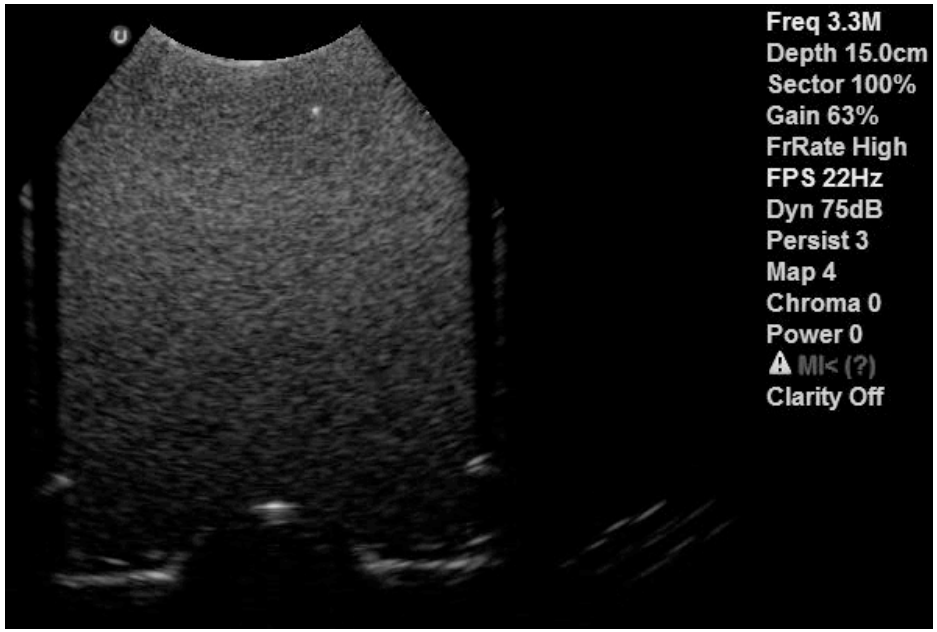
PHANTOM TURNED OVER TO ACCESS CONICAL WINDOW FOR LARGER ROC VALUES

- PLASTIC-COATED ALUMINUM FOIL WINDOWS SUPPRESS DESICCATION -- HEAVIER FORM (WHITE) LINES ENTIRE BOX
- FLEXIBLE WINDOWS AND TM MATERIAL
- CORK LAYERS PREVENT BENCH TOP SLIP



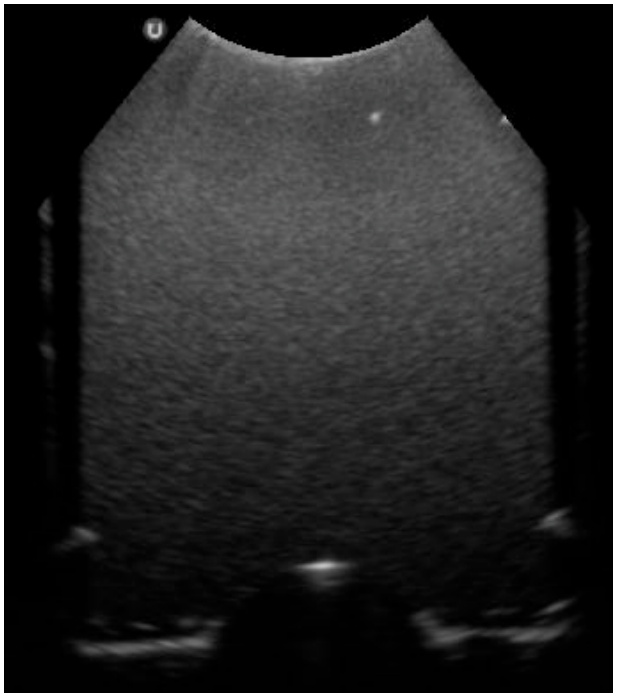
END VIEW OF QA PHANTOM SHOWING
POSITIONS OF 8 PARALLEL FIBERS
FOR DISTANCE MEASUREMENT ACCURACY TEST

ELEMENT OR CHANNEL FAILURE



Convex array average of 3 images obtained while moving the transducer perpendicular to the scan plane

-- 3 adjacent array elements
inactivated simulating dead elements



Average of about 100 images while moving transducer

-- shadowing is more apparent

DISTANCE MEASUREMENT ACCURACY

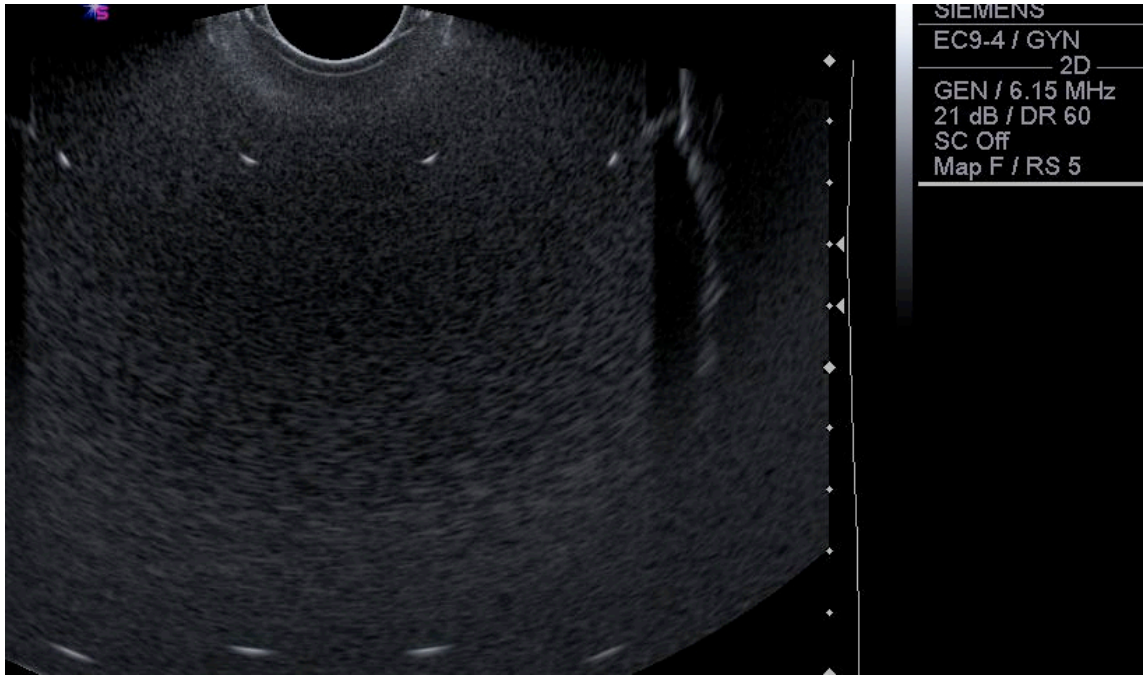
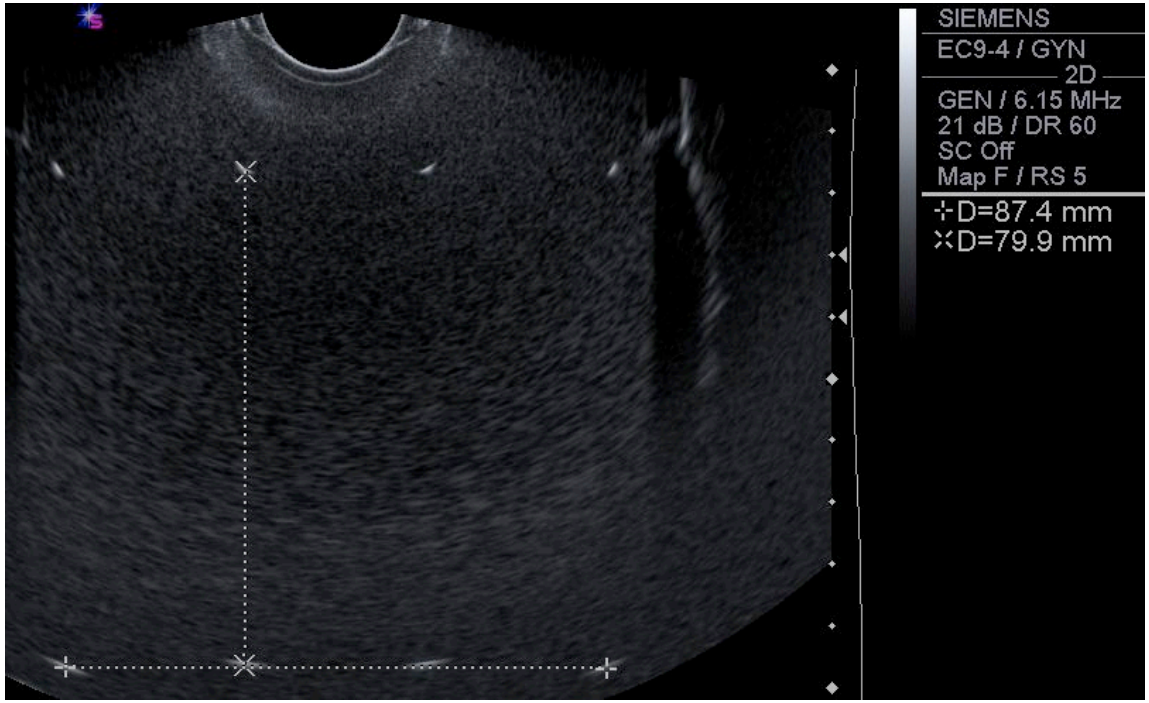


Image of 8 fibers using a 1 cm ROC convex array with about 120 degree sector angle.

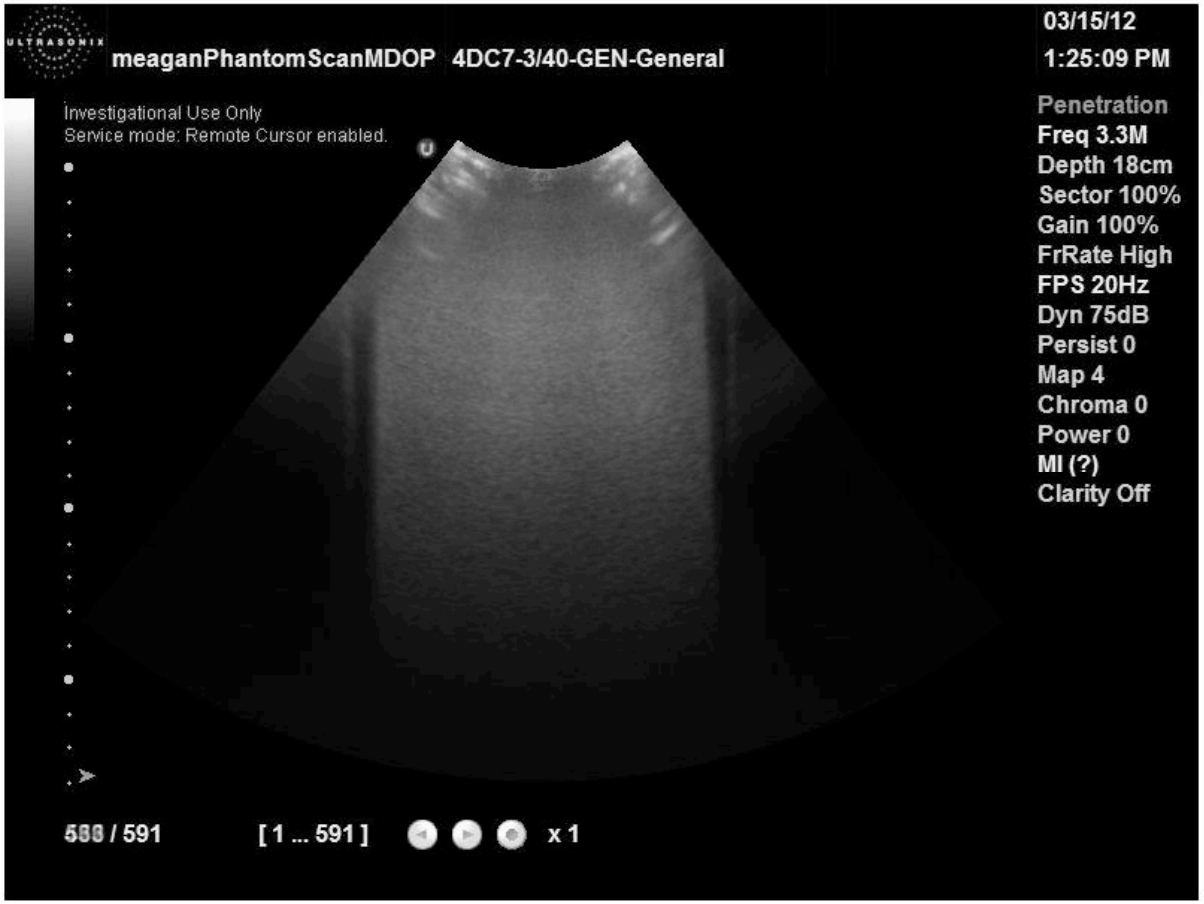
If scanning window were flat and water-filled scanning well used, there would be distance measurement errors due to refraction at the window



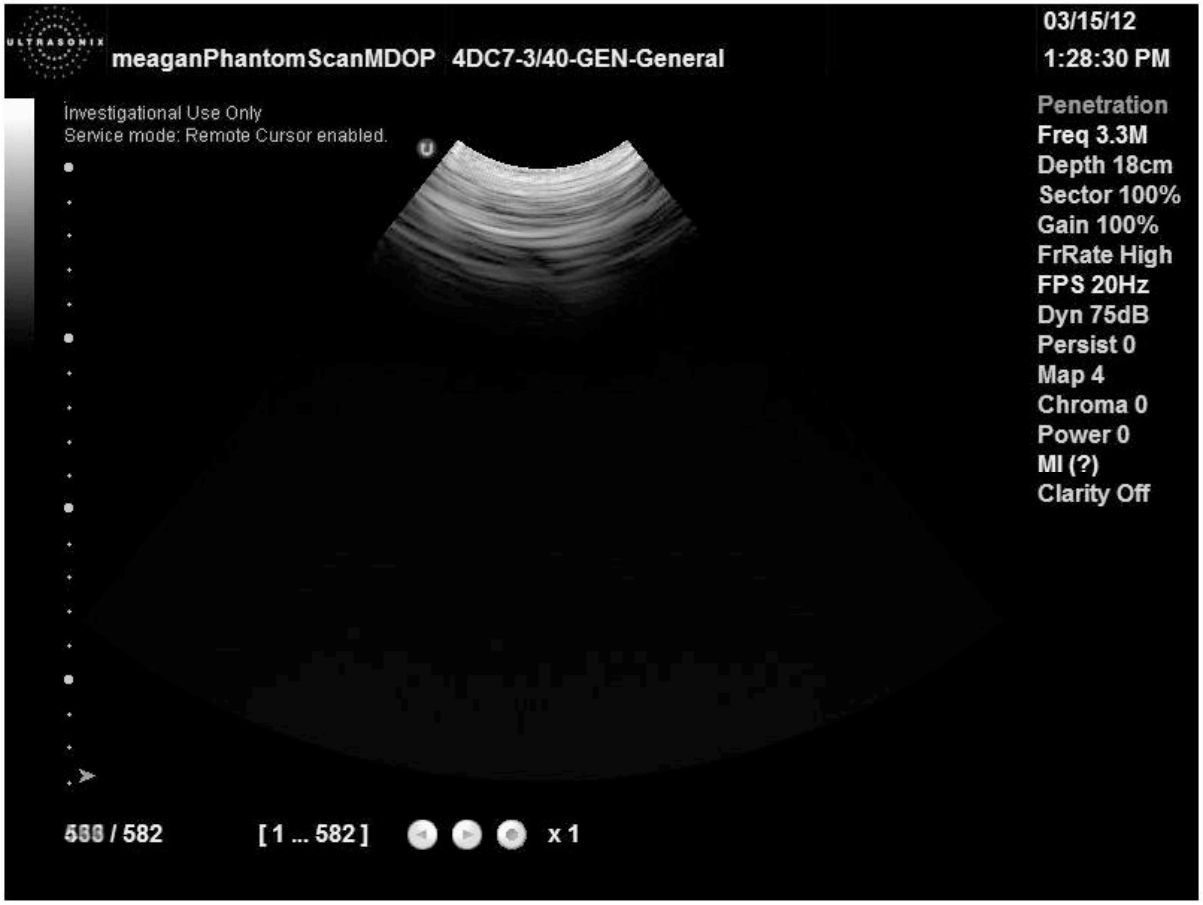
Vertical distance measurement error is negligible

Horizontal measurement error is (87.4 – 90)/90 x 100 = – 2.8%

MAXIMUM DEPTH OF PENETRATION ASSESSMENT

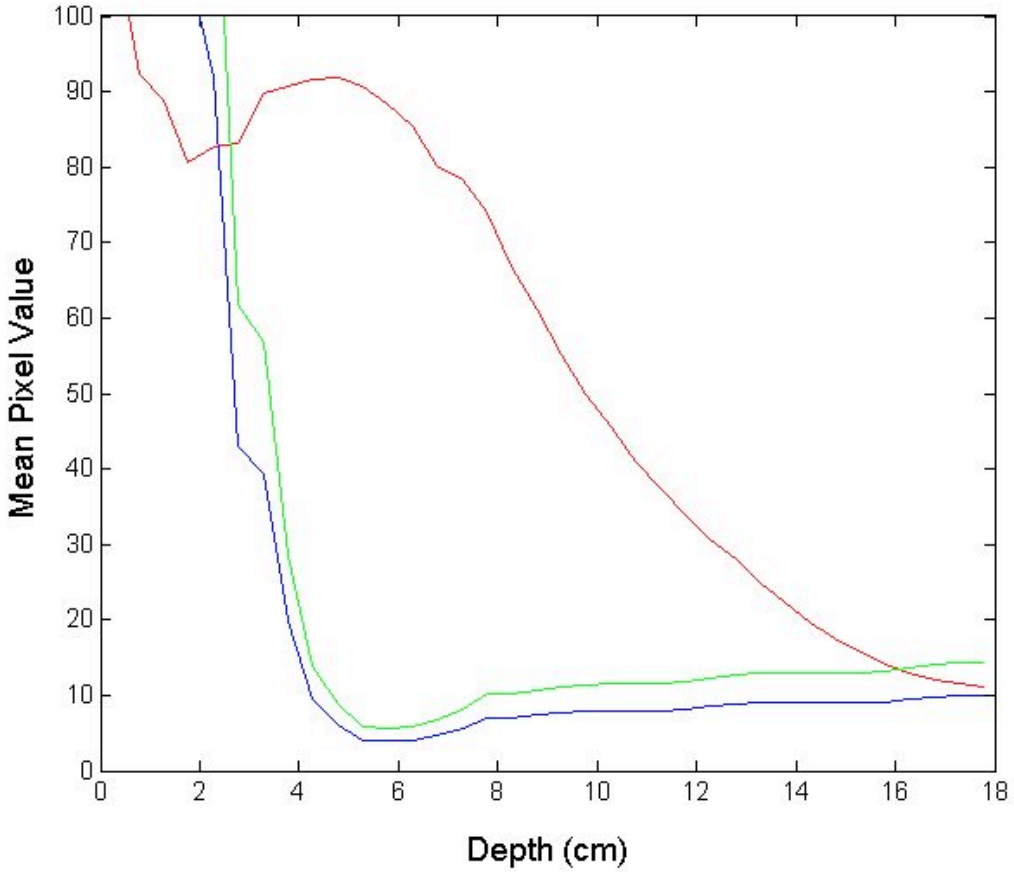


-- Average of 590 frames acquired during continuous translation perpendicular to the image planes



Average of about 590 frames while holding transducer in air
Beyond transducer ring down

-- only electronic noise is averaged



Mean pixel values over 5-mm depth intervals

1) phantom case
2) in-air case
3) in-air case times $(2)^{1/2}$

Green and red curves intersect at 16.1 cm = maximum DOP ⇔ SNR of 1

PERFORMANCE TESTING FOR ANY SHAPE TRANSDUCER *VIA* DETECTABILITY OF ANECHOIC SPHERES

- THREE PHANTOMS:

  1) 2 mm DIAMETER SPHERES FOR HIGHER FREQUENCIES (7-15 MHz)
  2) 3.2 mm DIAMETER SPHERES FOR LOWER FREQENCIES (2-7 MHz)
  3) 4 mm DIAMETER SPHERES FOR LOWER FREQENCIES

- SPHERE ECHO LEVEL < −32 dB RELATIVE TO BACKGROUND

- ATTENUATION COEFFICIENT÷ FREQUENCY ≈ 0.5 dB/cm/MHz
  FOR BOTH BACKGROUND ***AND*** SPHERES

- PROPAGATION SPEED = 1540 m/s

- ONE FLAT SCANNING WINDOW FOR NEARLY
  FLAT EMITTING SURFACES, SUCH AS LINEAR ARRAYS

- CONICAL SCANNING WINDOWS FOR BROAD RANGE OF
  RADII OF CURVATURE (ROC'S) OF CONVEX (CURVED) ARRAYS

- SPHERES RANDOMLY DISTRIBUTED

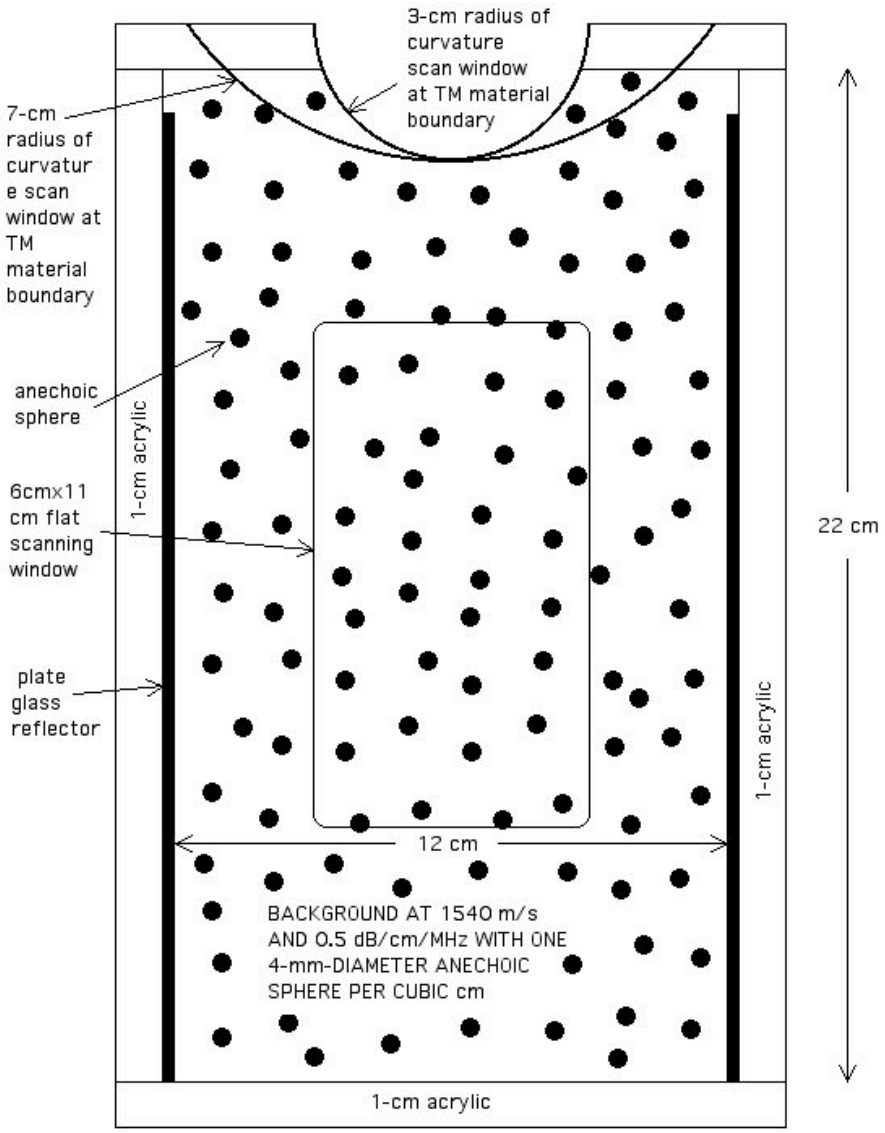
- PARALLEL REFLECTORS PROVIDE FOR ACCESS TO ENTIRE IMAGE SECTOR OF SECTOR SCANNERS

  -- TOTAL INTERNAL REFLECTION OF COMPRESSIONAL WAVES WITH NO MODE CONVERSION BEYOND RAYLIEGH CRITICAL ANGLE

- SOFTWARE QUANTIFIES HUMAN-MIMICKING DETECTABILITY 0F ANECHOIC SPHERES

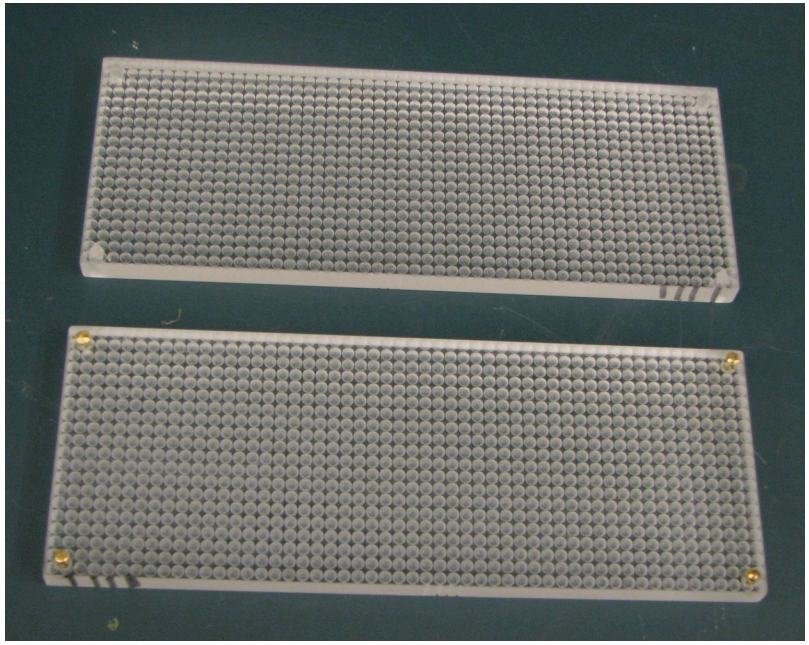
Photo of 4-mm sphere phantom

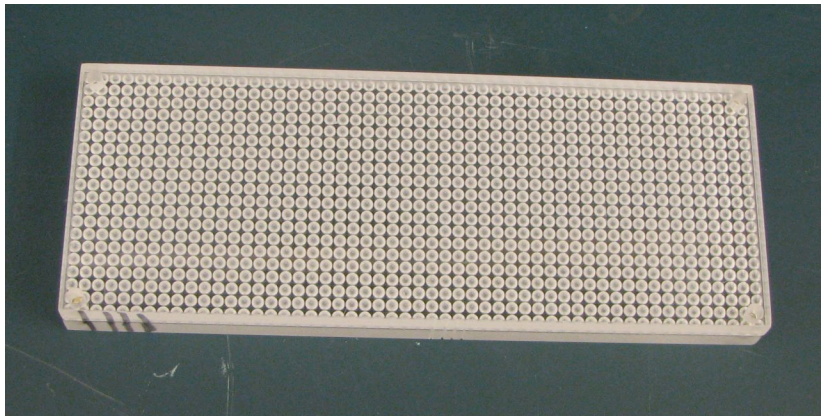
Photo of 2-mm sphere phantom



End view of 4-mm-diameter-sphere phantom

Parallel plate reflectors provide
- *via* total internal reflection -
for extension of the image outside of the phantom





- Two-part mold with 3.2-mm diameter hemispherical depressions
- 4 sets of alignment pegs and holes
- Mold parts lowered into a bath of molten tissue-mimicking (TM) material and brought together to form 1044 spheres
- 8 sets of molds produce more than 8000 spheres

DATA ACQUISITION

- Acquire a set of images where the transducer is translated perpendicular to the scan plane by increments of 1/4 of the sphere diameter D
- Number of images sufficient for adequate statistics

AUTOMATED DATA ANALYSIS

- Computes mean pixel values (MPV's) over square areas with side = 2D/3

  -- centers of MPV's form a square array with spacing D/4
  -- do for all images

- Center of each sphere determined within D/8 for each Cartesian coordinate

  -- MPV centered in ith sphere ≡ S_{Li} is "signal" for the ith sphere

- Computes Lesion Signal to Noise Ratio (LSNR) for each sphere using MPV's

♦ LSNR for the ith sphere:

$$LSNR_i \equiv \frac{S_{Li} - S_{mBi}}{[(1/2)(\sigma_L^2 + \sigma_{Bi}^2)]^{1/2}}$$

-- S_{mBi} is the mean of all background MPV's in the image frame within a radius 2D of the sphere center and NOT influenced by the presence of any sphere

-- σ_{Bi} is the standard deviation of all MPV's contributing to S_{mBi}

-- $\sigma_L^2 \equiv$ standard deviation of all S_{Li} values in depth interval d

-- d is typically 0.5 or 1.0 cm.

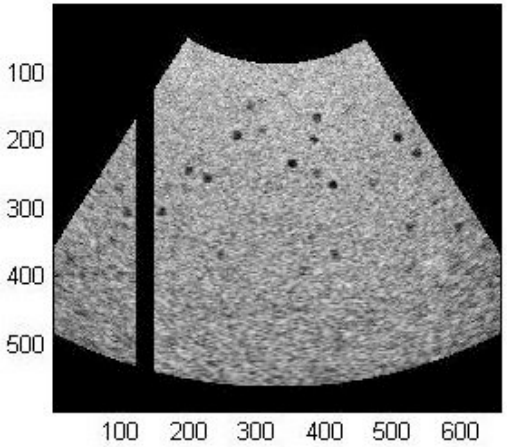
♦ LSNR for depth interval d $\equiv$ $LSNR = (1/N) \sum_{i=1}^{N} LSNR_i$
where N is the total number of spheres detected in the depth interval d (including all image frames)

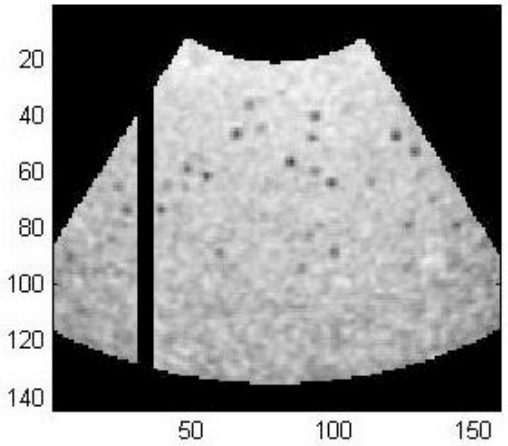
Image of prototype 4-mm sphere phantom using convex array focused at 4 cm

Parallel plane reflectors are perpendicular to the image plane -- alumina on left and plate glass 10 cm to its right

Vertical line of elevated echoes at slightly rough surface of alumina plate

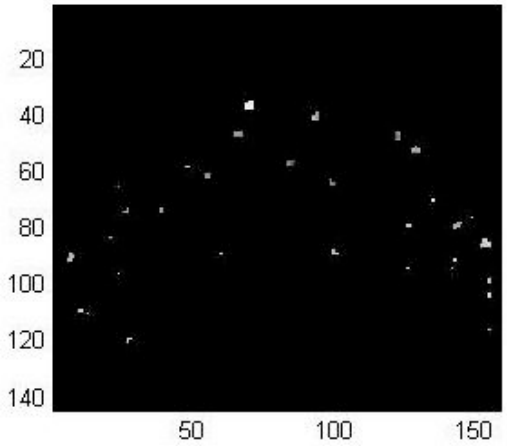
Cropped image with low-level diffuse echoes at the alumina surface removed

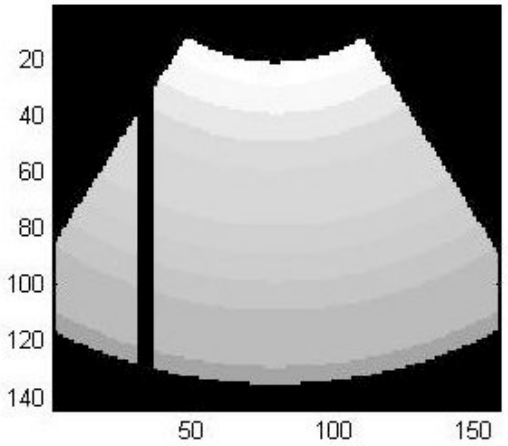




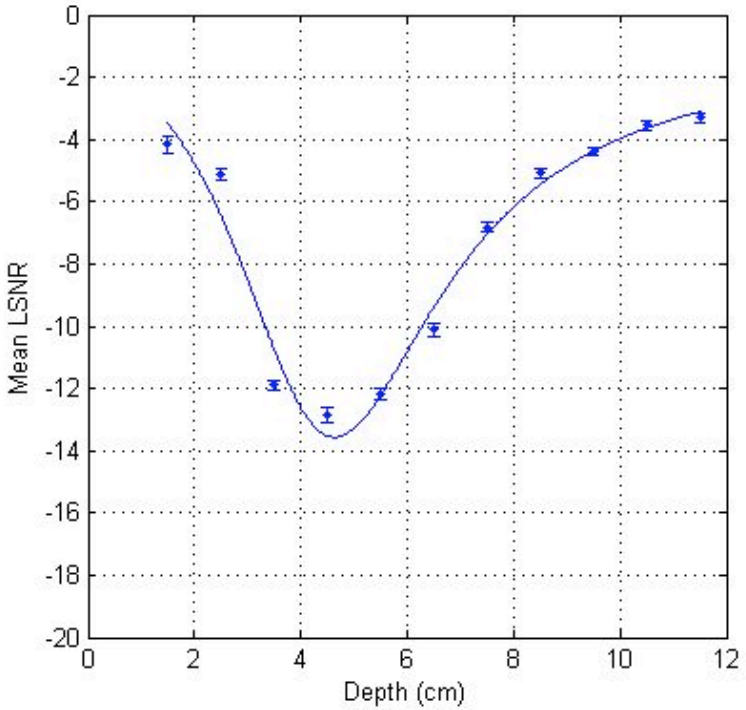
Gray-scale map of overlapping MPV's (squares with sides 2D/3)

MPV sites identified with sphere centers

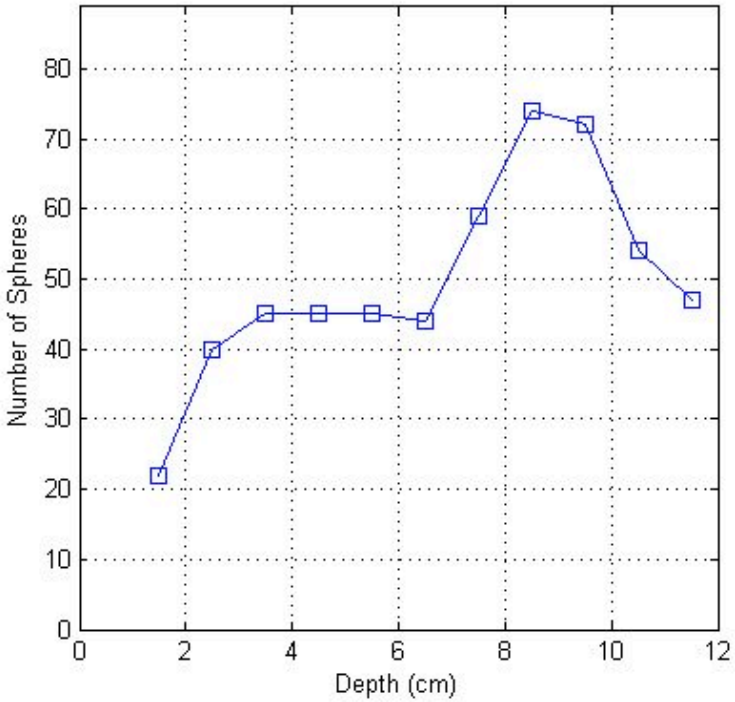




Depiction of 1-cm depth intervals with different levels of gray



Mean LSNR values
as a function of depth
using 50 images



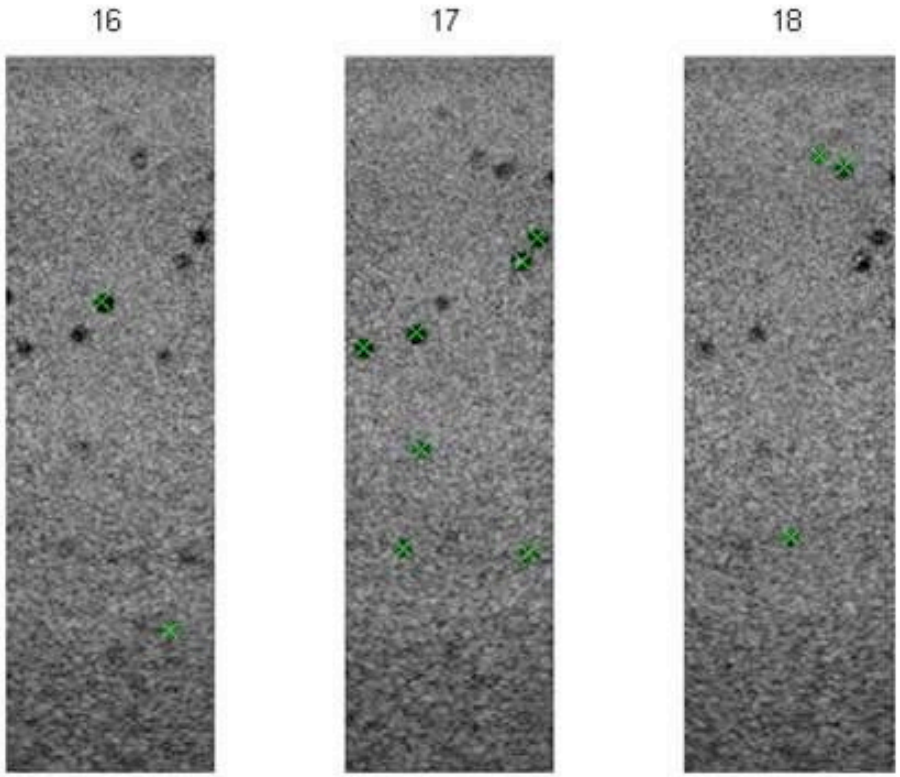
Number of spheres detected
in each 1-cm depth interval

One of 80 parallel linear array images of the 4-mm sphere phantom

Frequency = 4 MHz

Focus at 4 cm

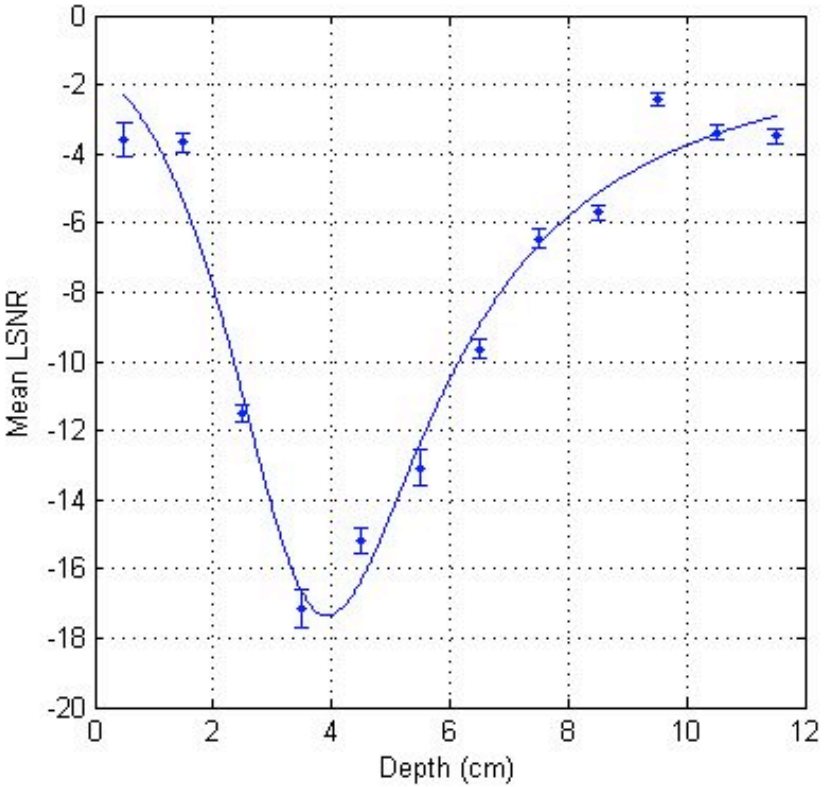
Width of image ≈ 3.7 cm



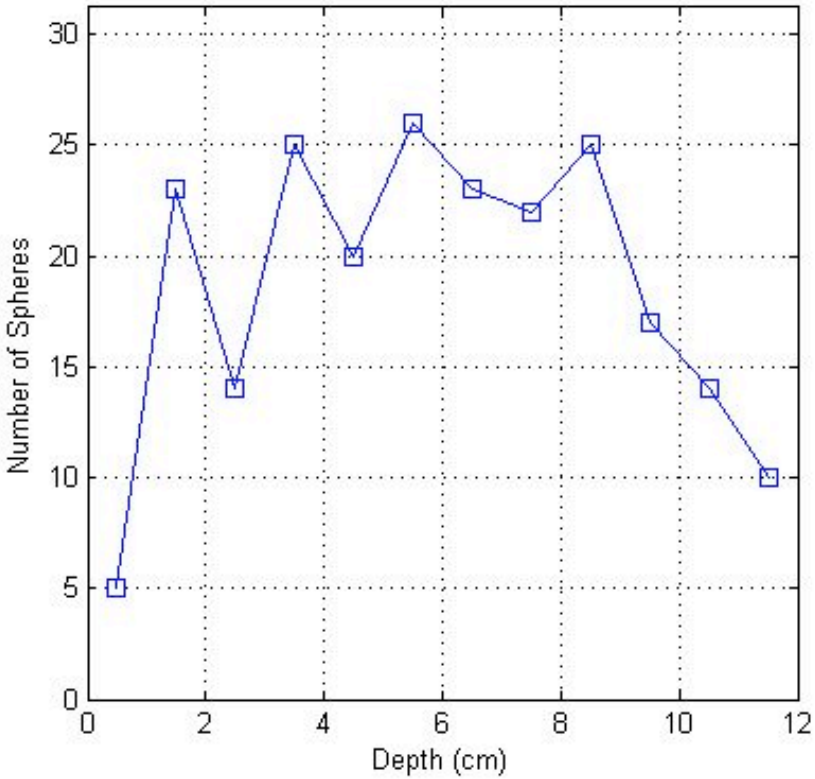
Three successive images of the 80 separated by D/4 = 1 mm.

The green x's identify the determined centers of the spheres identified with the respective images.

Where there are no x's, the sphere center was identified with a nearby image.



Results using all
80 image frames

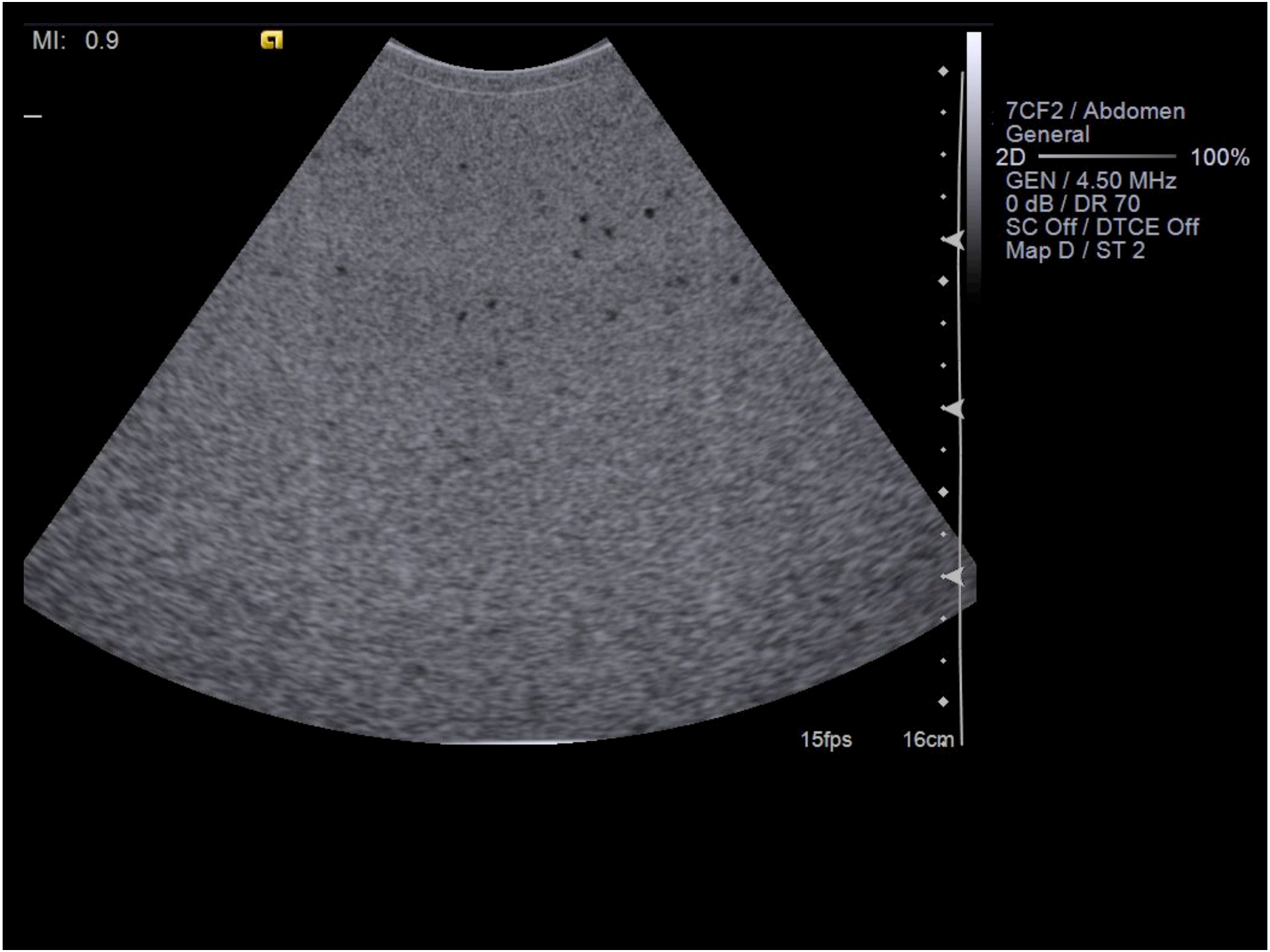


Number of spheres detected
in each 1-cm depth interval

- New phantom with 3.2-mm diameter spheres and twice as many spheres per unit volume (19 July 2012)

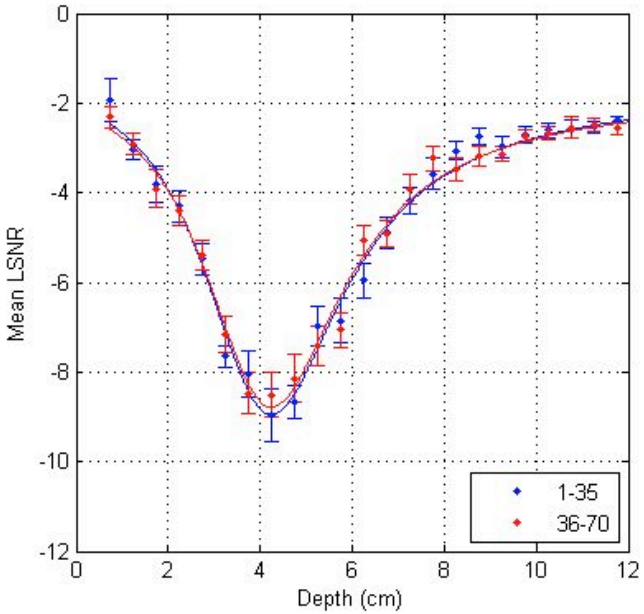
- 3.2 mm half the volume of 4-mm spheres

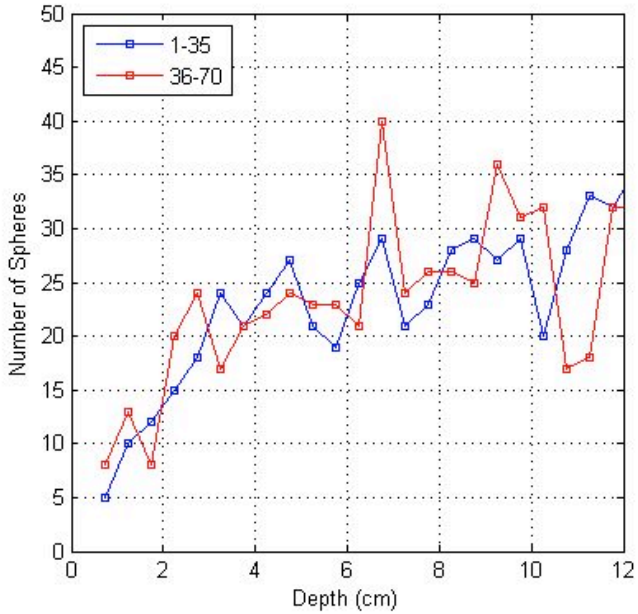
- Larger concentration allows for fewer images to produce adequate statistics


MI: 0.9
7CF2 / Abdomen
General
2D
100%
GEN / 4.50 MHz
0 dB / DR 70
SC Off / DTCE Off
Map D / ST 2
15fps
16cm

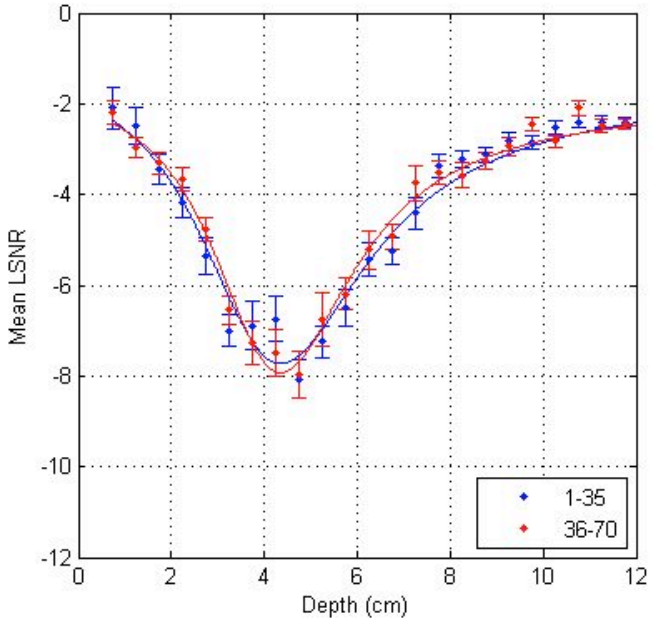
REPRODUCIBILITY STUDY AND COMPARISON FOR DIFFERENT FOCUSING

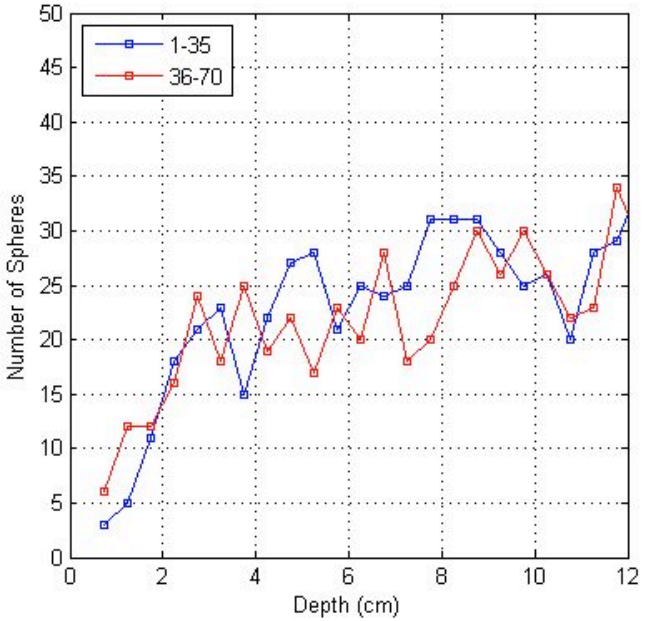
Multiple foci at
4, 8 &12 cm





Single focus
at 10 cm

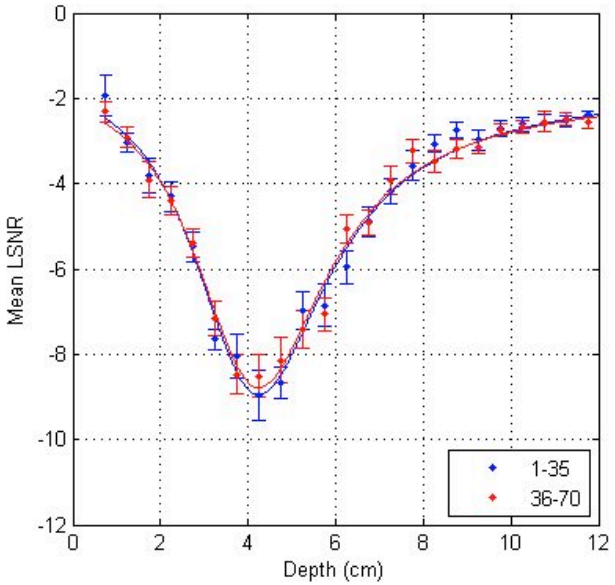


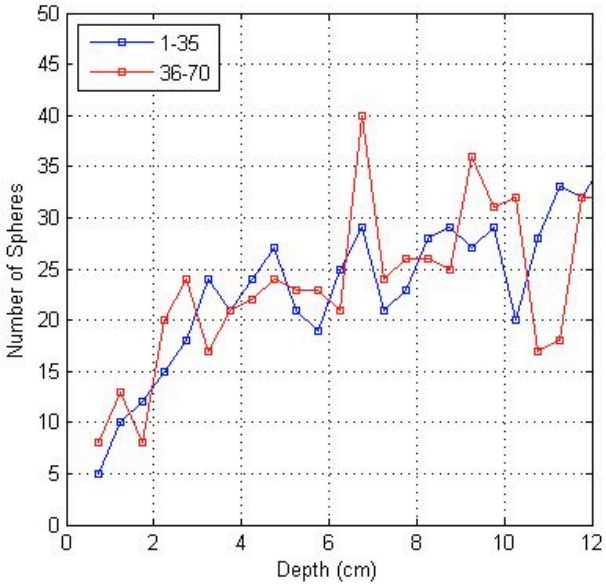


detectability vs depth

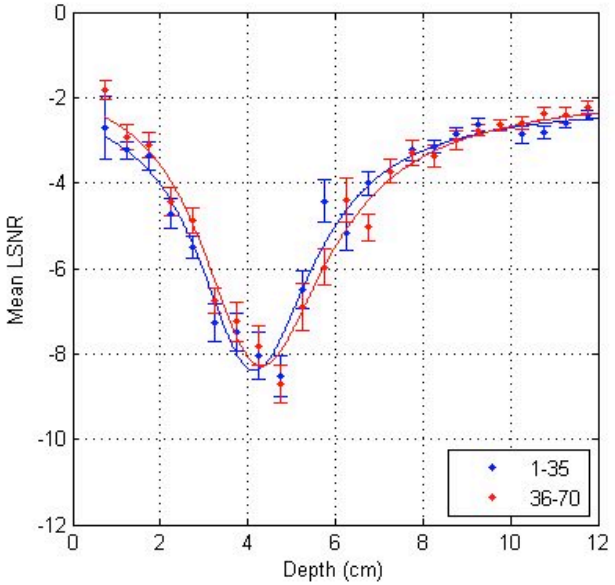
number of spheres in
each 5-mm depth interval

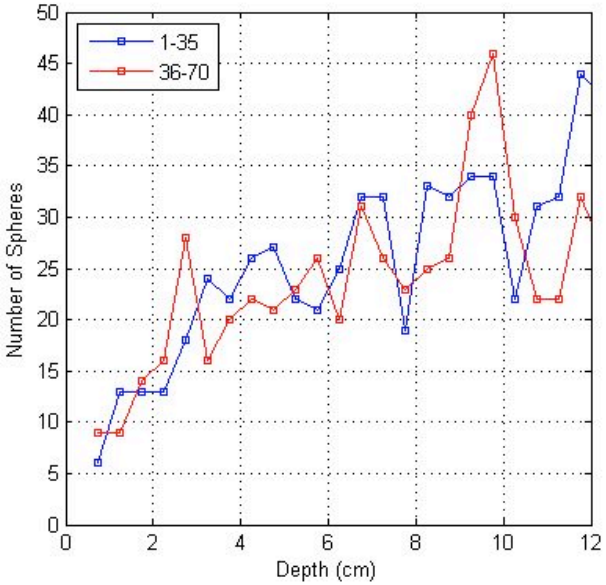
Multiple foci at
4, 8 &12 cm



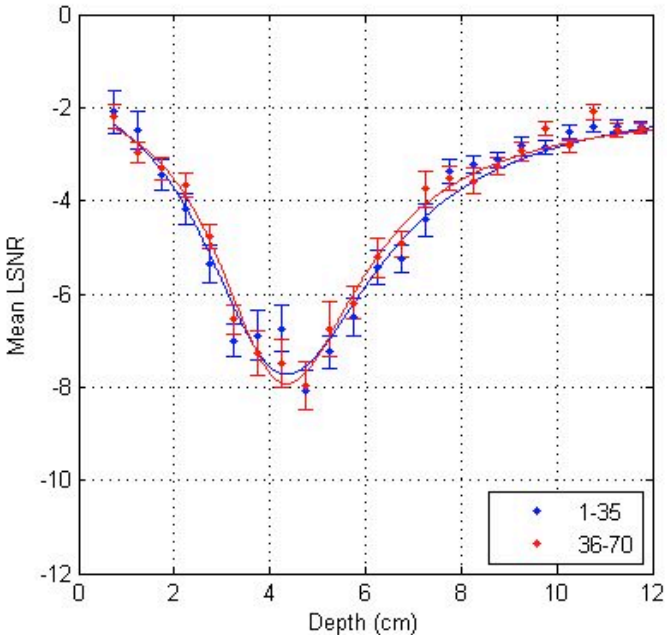


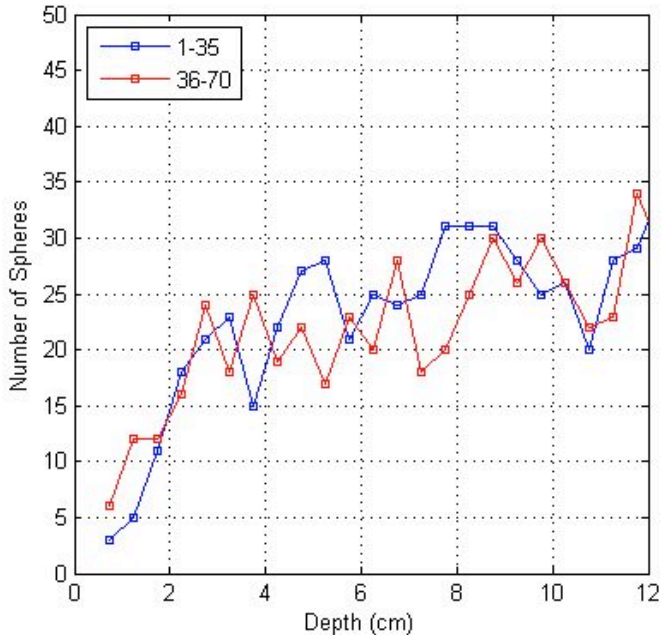
Single focus
at 4 cm



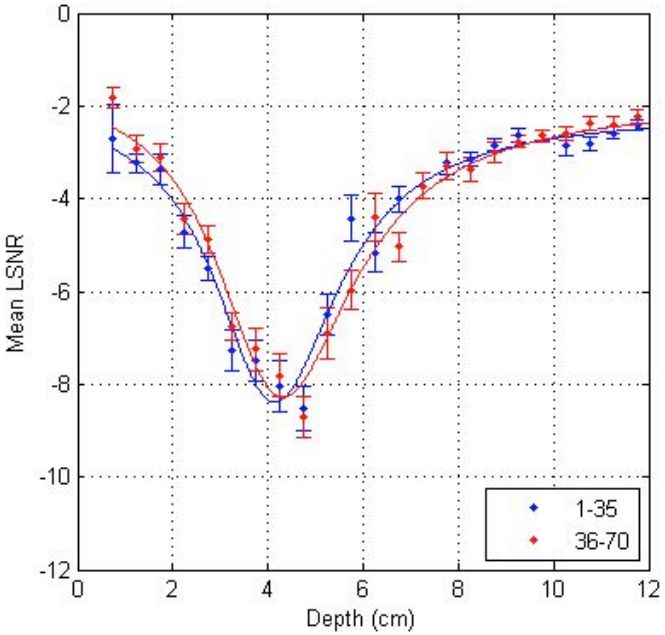


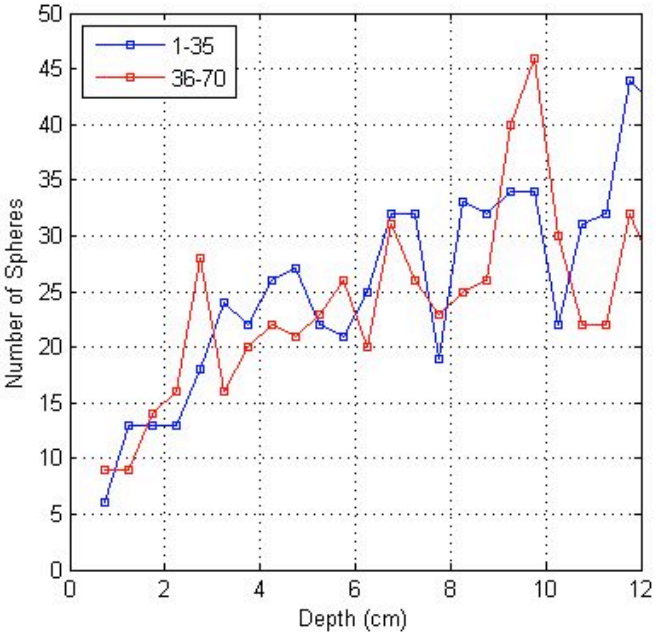
Single focus at 10 cm

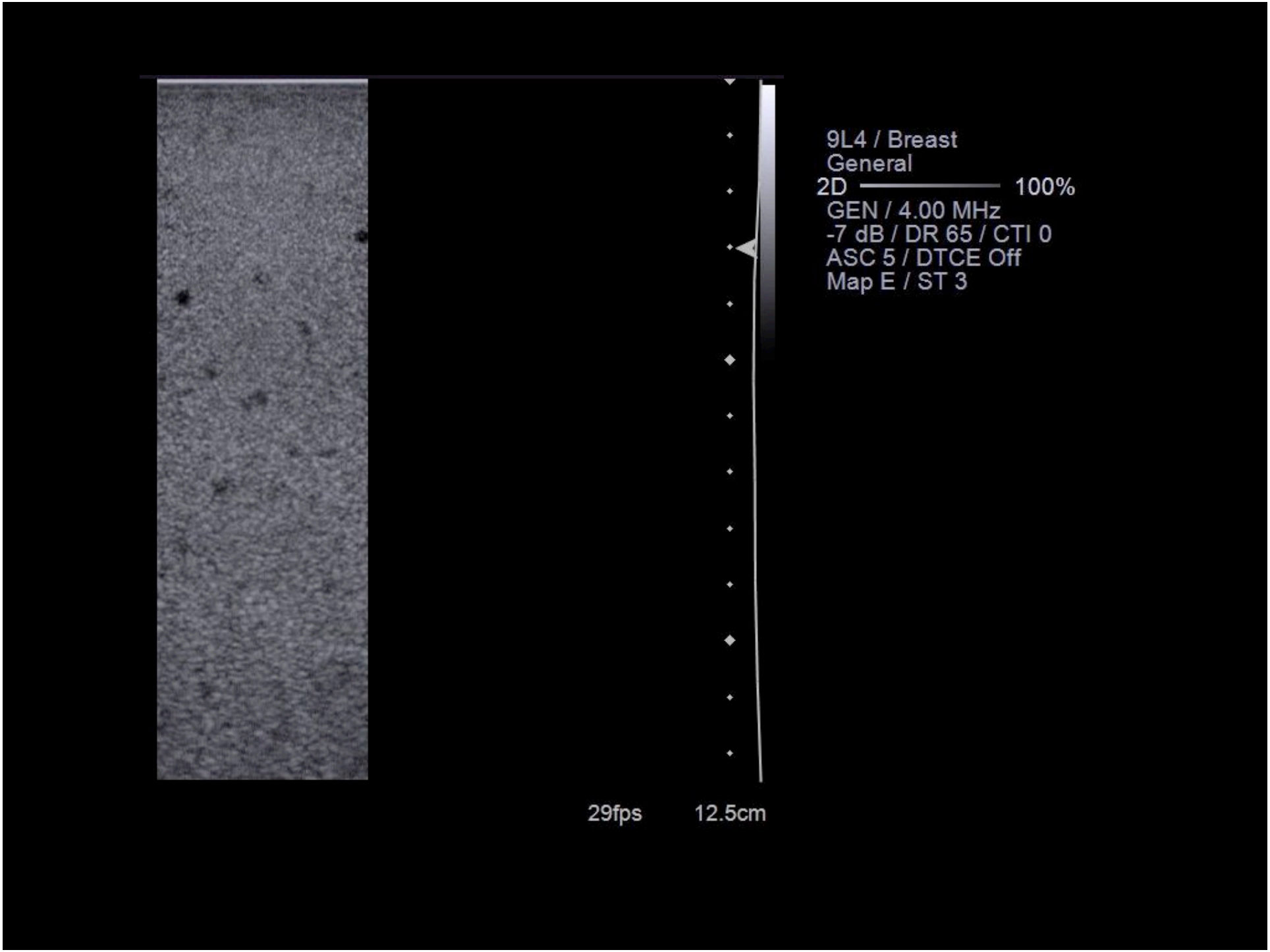




Single focus at 4 cm






9L4 / Breast
General
2D
100%
GEN / 4.00 MHz
-7 dB / DR 65 / CTI 0
ASC 5 / DTCE Off
Map E / ST 3
29fps
12.5cm

Single focus
at 4 cm