Quality Assurance in Medical Ultrasound and Ultrasound Image Simulation

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based on work and lecture of

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Retired from Radboud University Children's Hospital

Nijmegen, The Netherlands

Overview

- **Introduction**
- **Test objects**
- **Quality assurance**
  - Imaging
  - Doppler velocity
- **Conclusions**

Introduction: backgrounds of Quality Assurance

- **The AIUM "100 mm" test object and recommended procedures for its use (Am Inst Ultrasound Med, 1974)**
- **Pulse echo ultrasound imaging systems : performance tests and criteria (P. Carson, Am Inst Physics, 1977)**
- **Method of testing performance of pulse-echo diagnostic equipment (C. Hill, Int Electrotech Comm, IEC, 1977)**
- **Test procedures to determine the performance specifications of ultrasonic real-time equipment (IEC, 1990)**

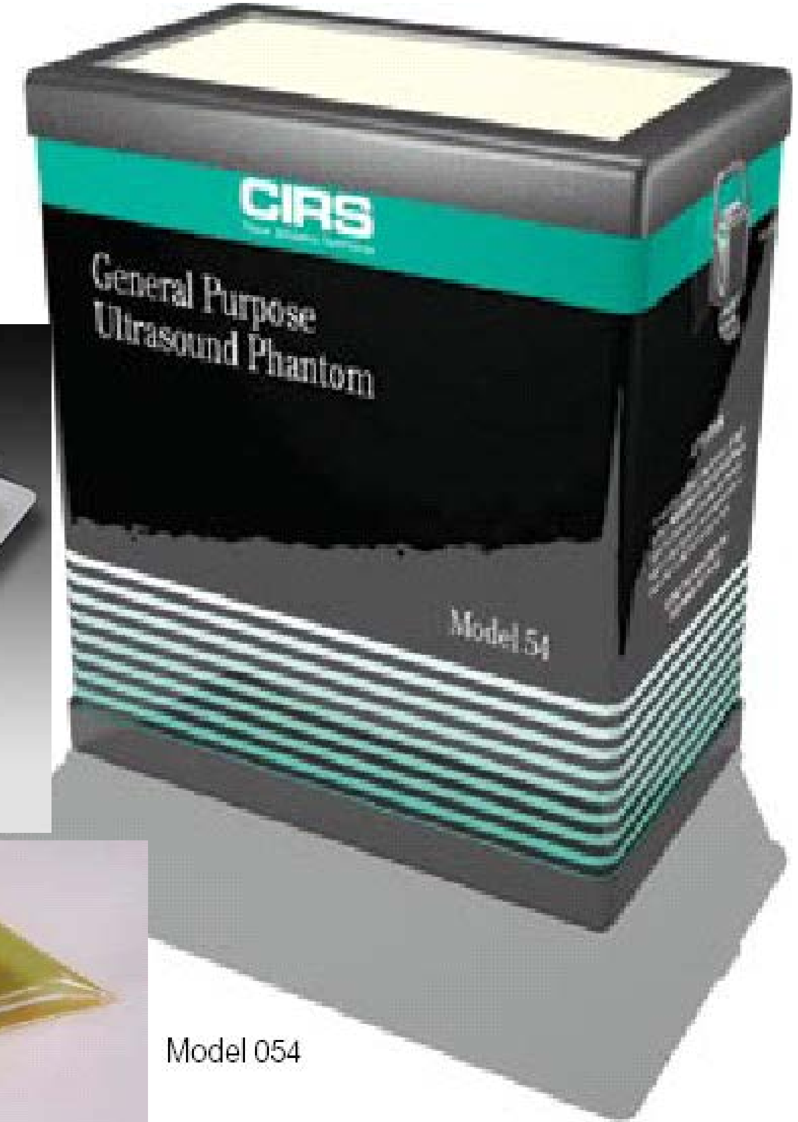
Performance testing: GOALS

- **Predicting performance in clinical applications**
- **Acceptance testing: imaging quality and manufacturers' specifications**
- **Monitoring of equipment during life cycle**
- **Quality assurance procedure**
  - Subjective - (observer + machine) of displayed images.
  - Objective - (measurement software) of stored images.

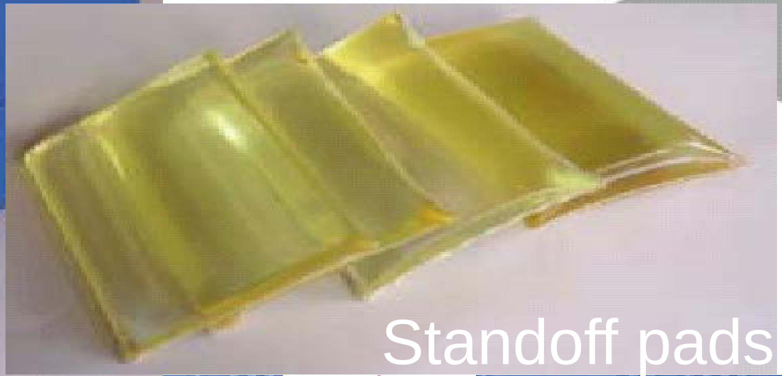
Overview

- **Introduction.**
- **Test objects ("tissue-mimicking phantoms")**

Tissue Mimicking Phantoms



Model 054



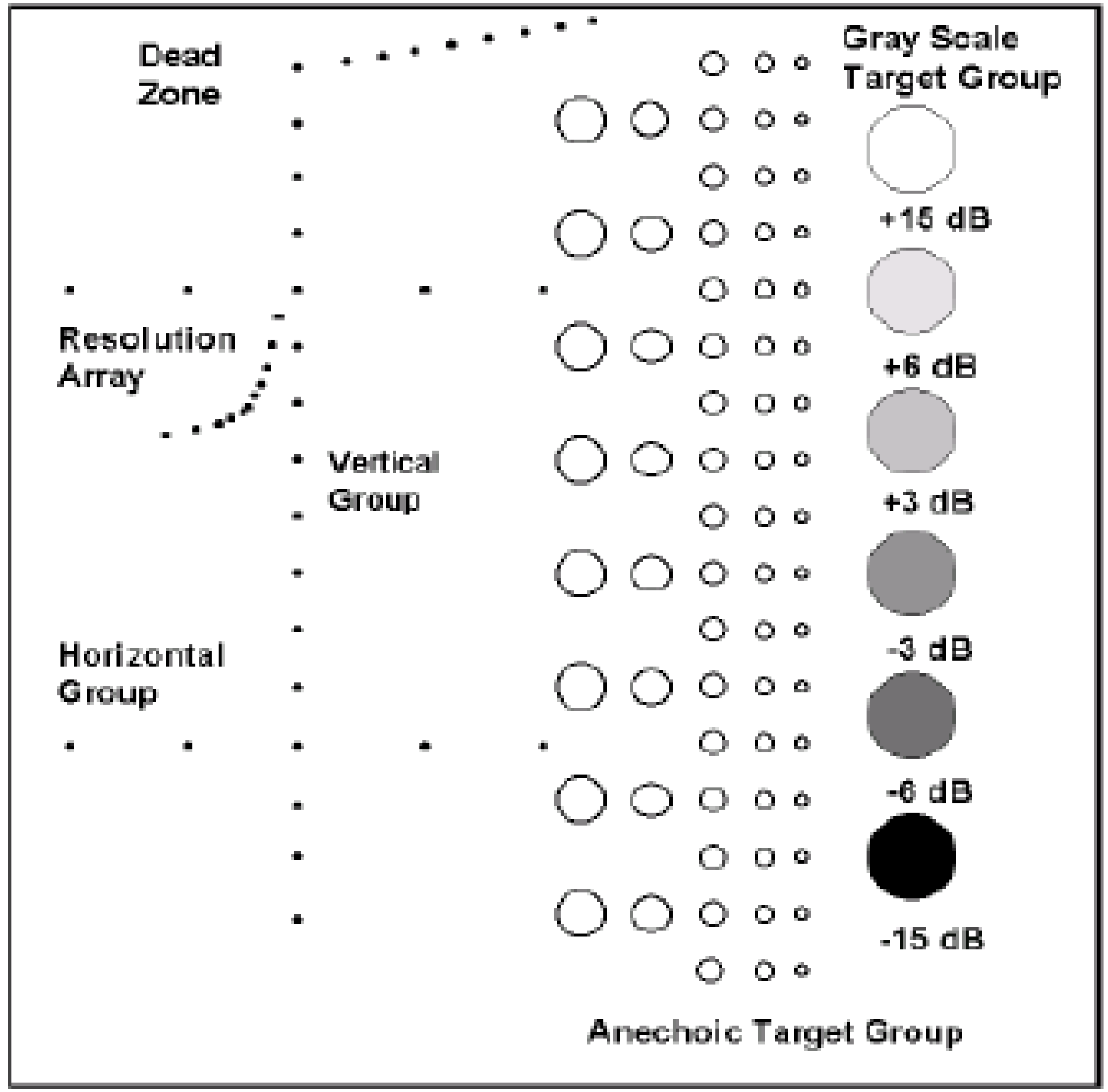
Standoff pads

Tissue-equivalent acoustical parameters

Parameter	Symbol	Magnitude	Unit
Speed of sound	**c**	**≈ 1540**	**[m/s]**
Attenuation coefficient	α	**0.3 to 0.5**	**[dB/cm/MHz]**
Backscattering	**s**	**(1 to 4) 10^{-4}**	**[m^{-1}.sr^{-1}]**

Manufacturer	Address	Web site
ATS Laboratories	Bridgeport, CT 06608, USA	www.atslaboratories.com
CIRS	Norfolk, VA 23513, USA	www.cirsinc.com
Diagnostic Sonar	Livingston, EH54 7BX, UK.	www.diagnosticsonar.com
Gammex RMI	Middleton, WI 535620327, USA	www.gammex.com
Nuclear Associates	Carle Place, NY 11514-1593, USA	www.flukebiomedical.com
Ohmic Inc.	Easton, MD 21601, USA	www.cweb5.com/ohmic

Fantôme ATS



- **Urethane rubber base material including**
  - Thin wires arranged in special patterns
  - Cylindrical objects of known scattering contrast

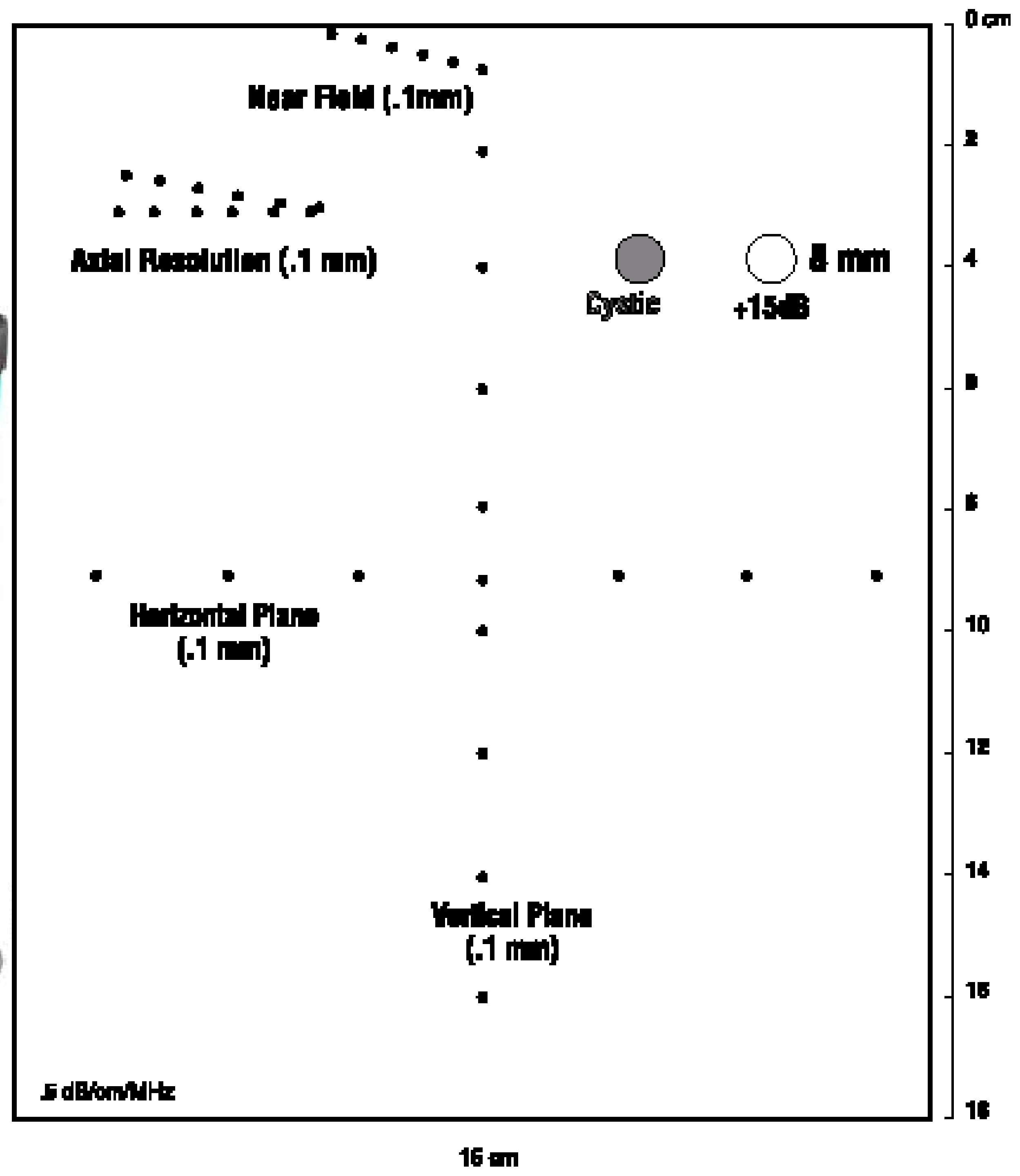
CIRS ultrasound phantom

CIRS, model 054

Zerdine (polymer)

Nylon wire 0.1 mm

Model 054



Overview

- **Introduction.**
- **Test objects.**
- **Quality assurance**
    - **Imaging**

Test Settings

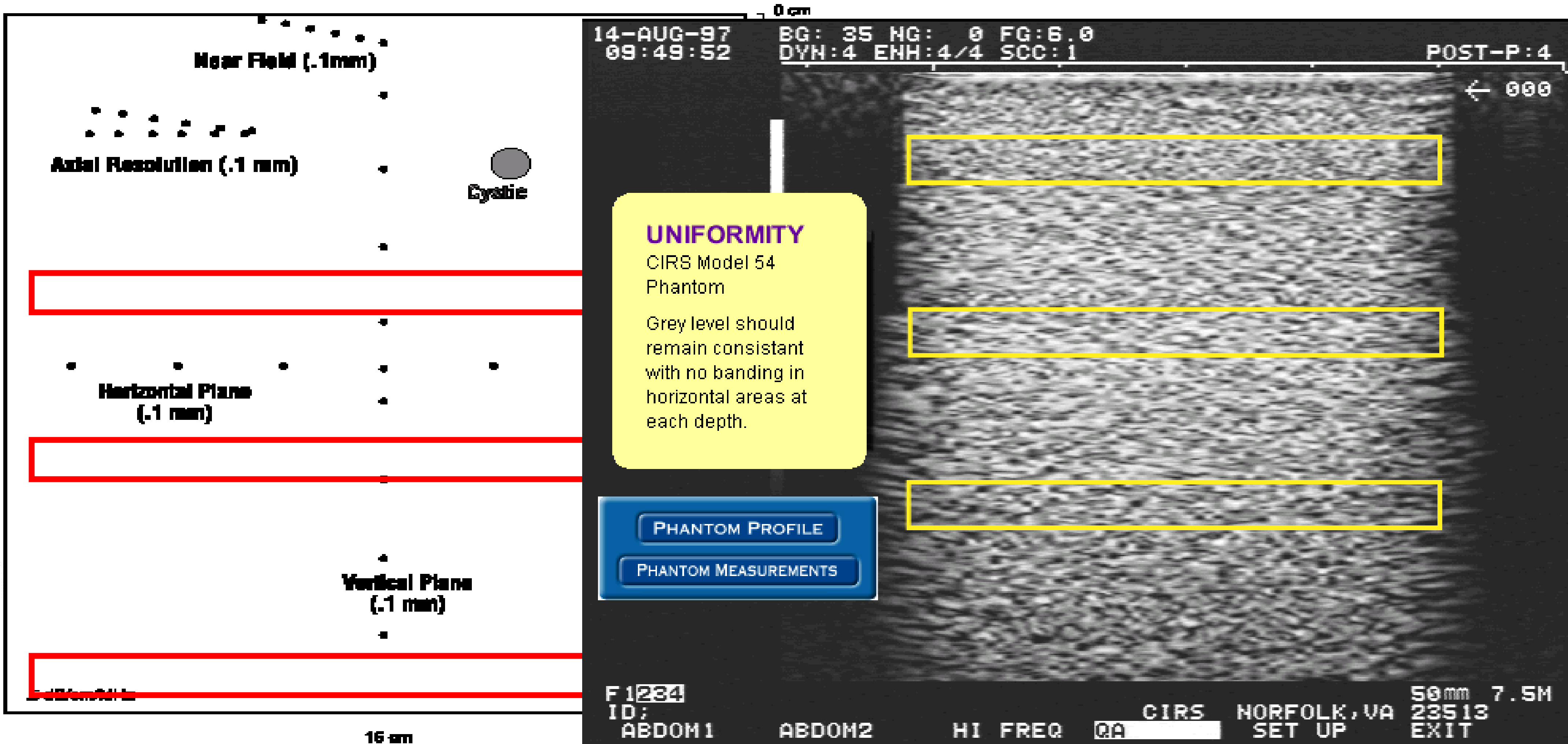
The settings must be reproducible, i.e the read out numbers should be noted

Fixed:

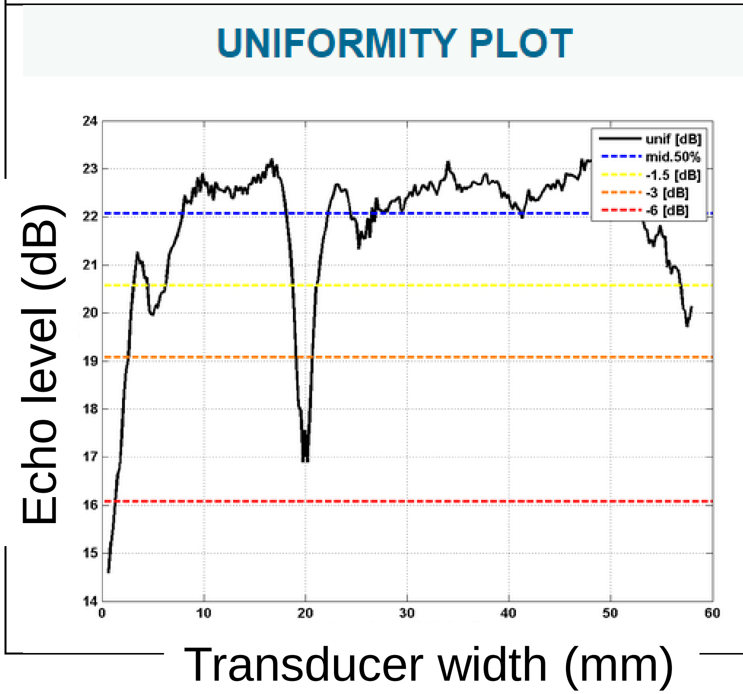
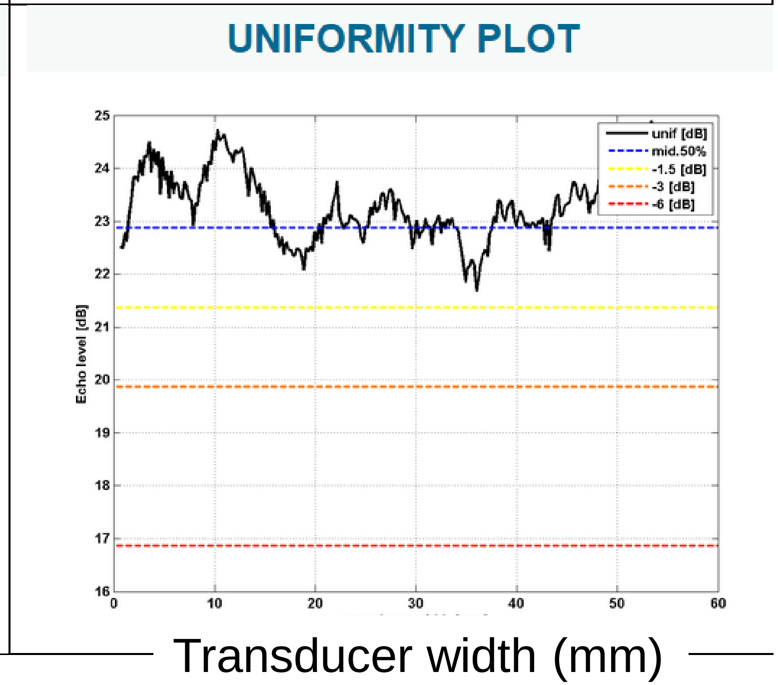
- display: intensity, contrast, sharpness-optimal
- post-processing curve: linear (i.e., log[echo] available!)
- transmit focus at depth of elevation focus
- TGC settings: maximum depth of equal grey level.

Uniformity

- **Grey level should remain consistant with no banding in horizontal areas at each depth**
- **This test is used to detect dead piezoelectrique element.**

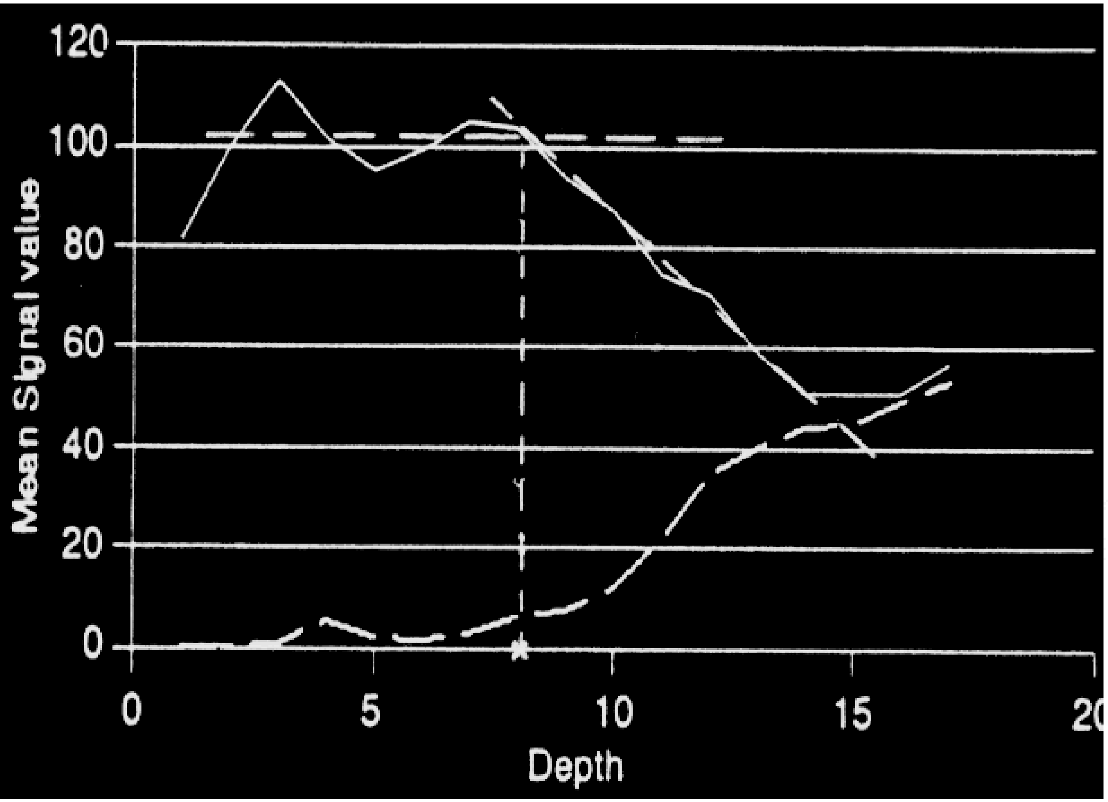


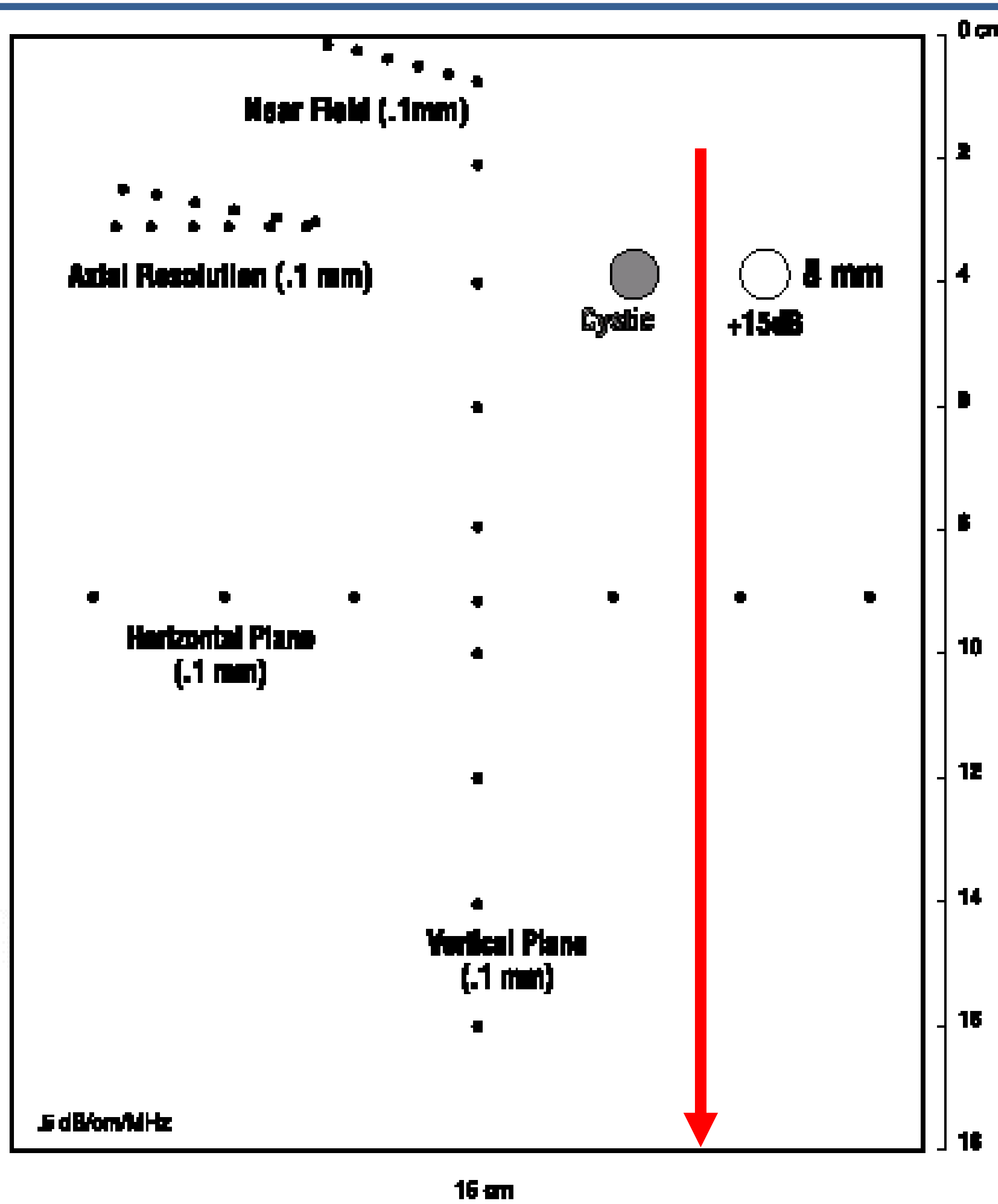
- **This test is used to detect dead piezoelectrique element.**
- **Exemple of test with software Q4US: the probe is working in air**

Probe 1	Probe 2
	

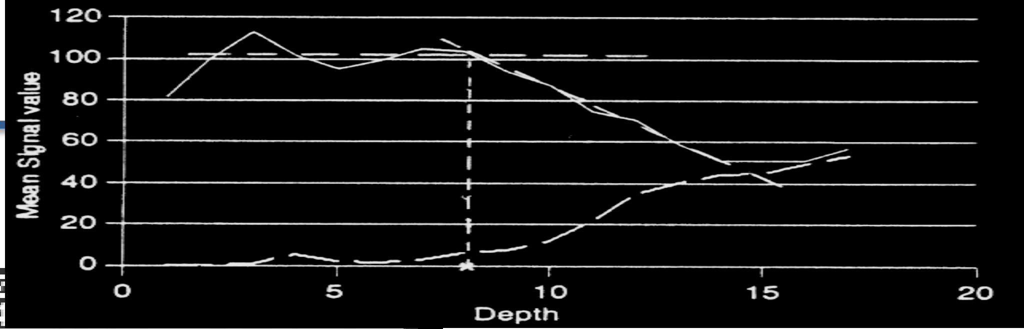
Depth of penetration

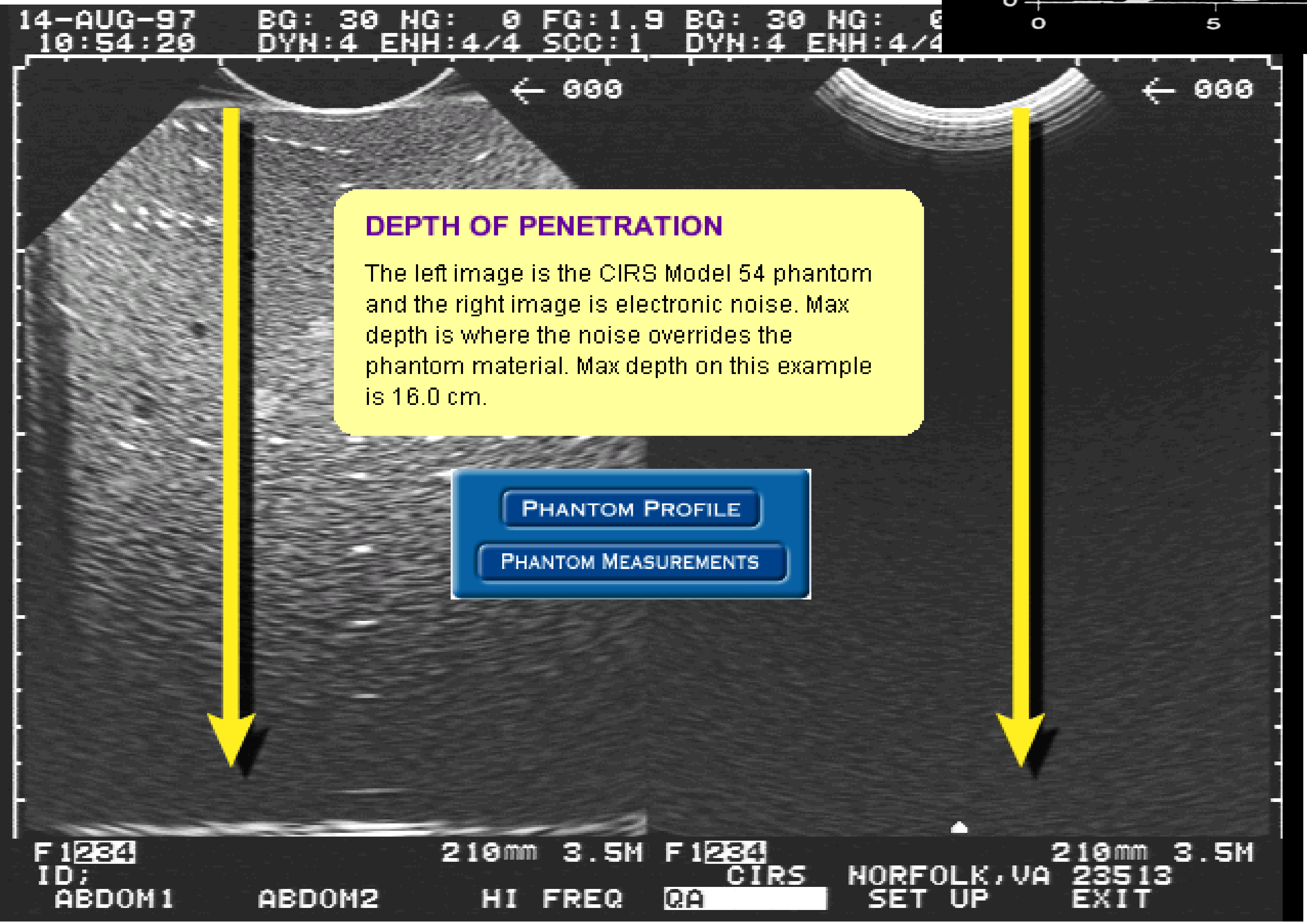
- Max depth is where the noise overrides the phantom material





Depth of penetration





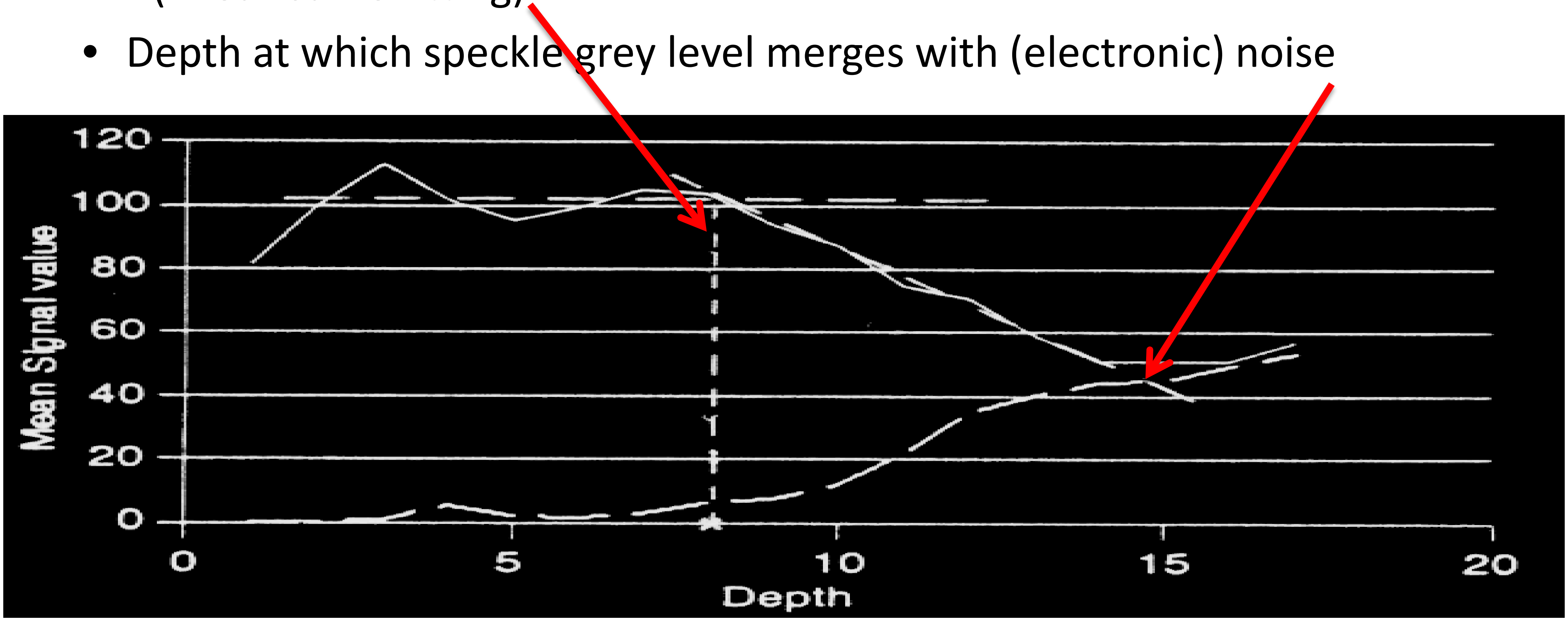
DEPTH OF PENETRATION

The left image is the CIRS Model 54 phantom and the right image is electronic noise. Max depth is where the noise overrides the phantom material. Max depth on this example is 16.0 cm.

Depth of Penetration

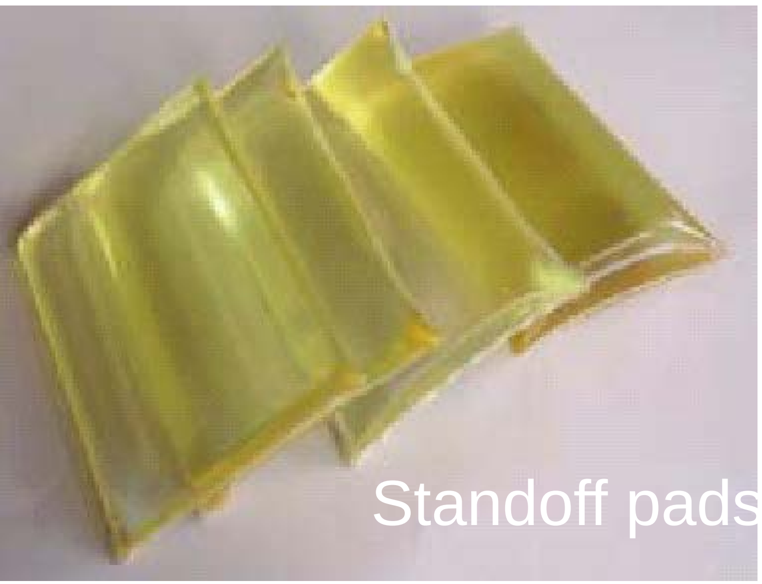
Equivalent to "Sensitivity" of equipment / transducer combination.

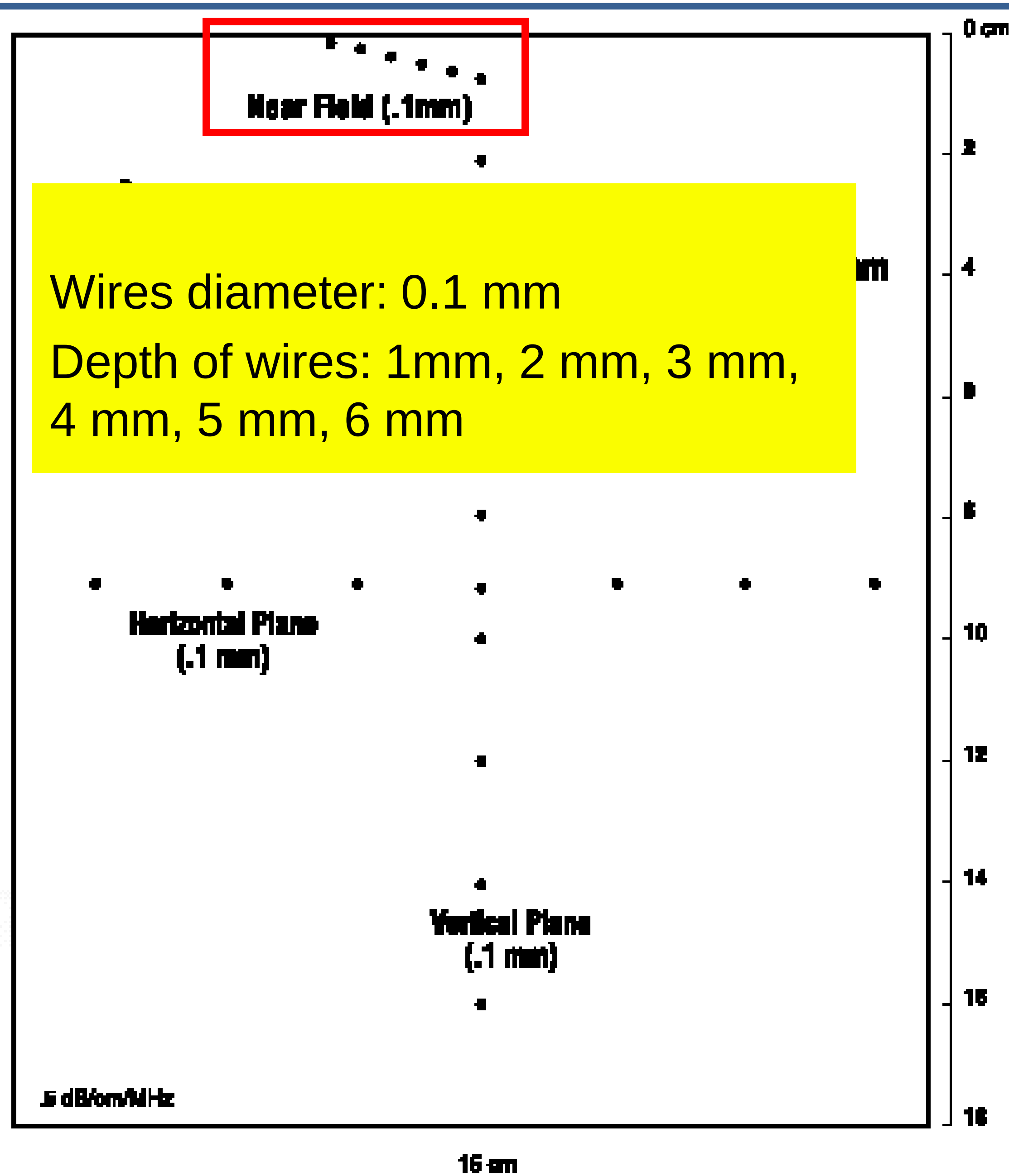
- Depth at which grey level asymptotically starts decreasing (linear curve fitting)
- Depth at which speckle grey level merges with (electronic) noise



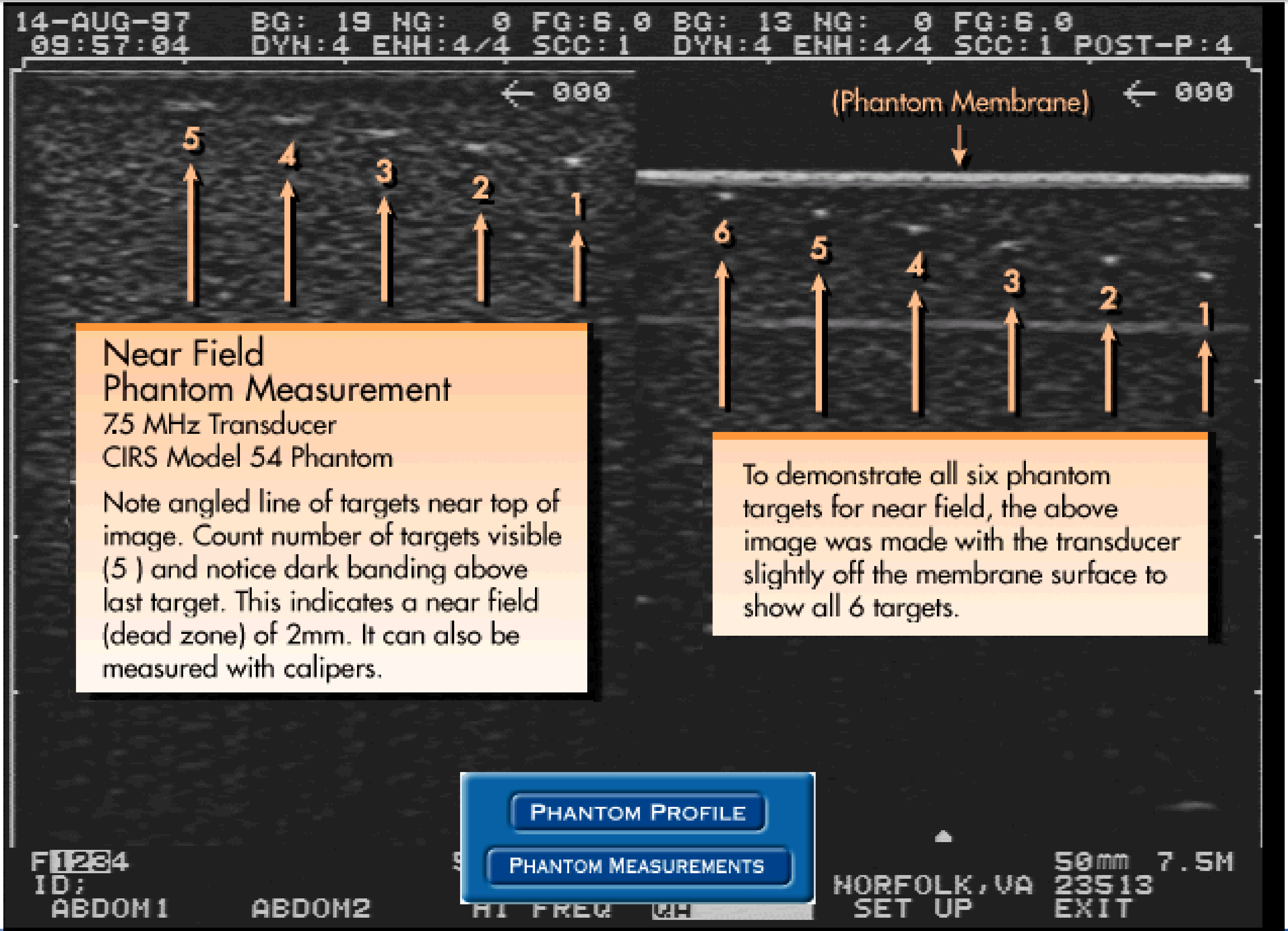
Near Field (dead zone)

Acoustic Standoffs (AC) provide a means of scanning superficial structures within the near field and regions where acoustic coupling with conventional acoustics coupling gels alone may be difficult to maintain.





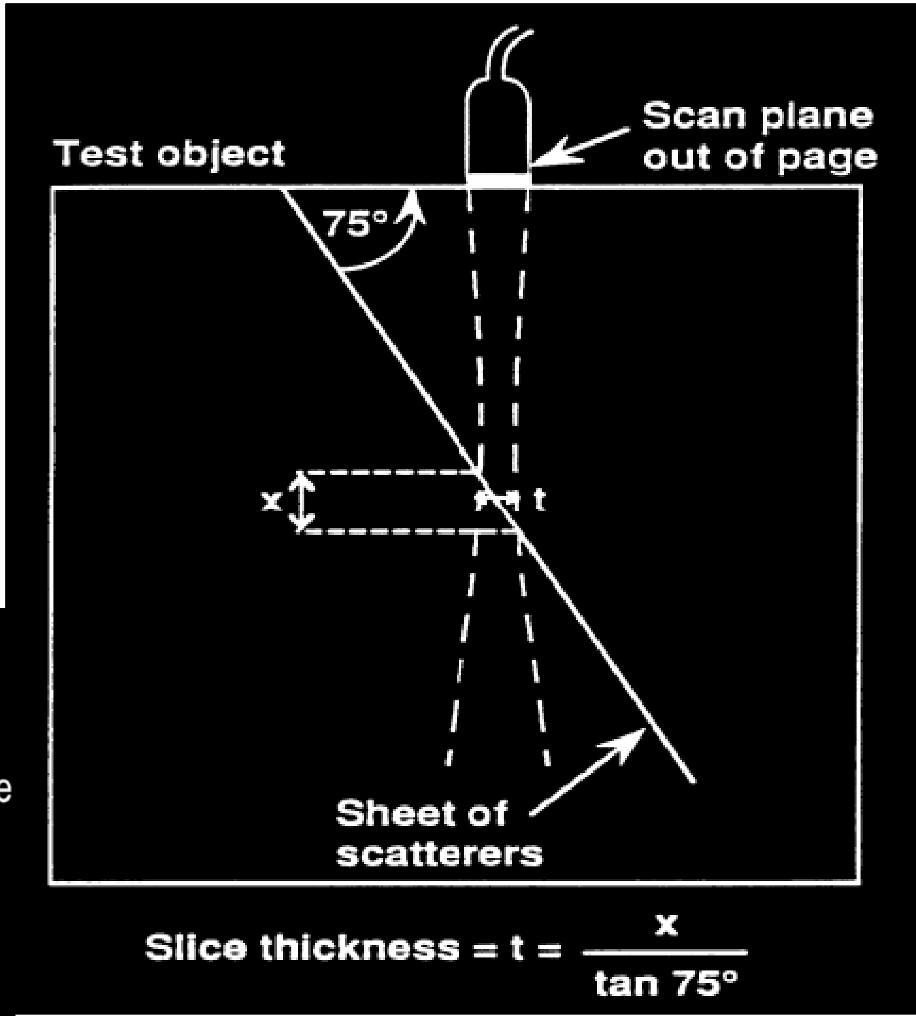
Near Field (dead zone)

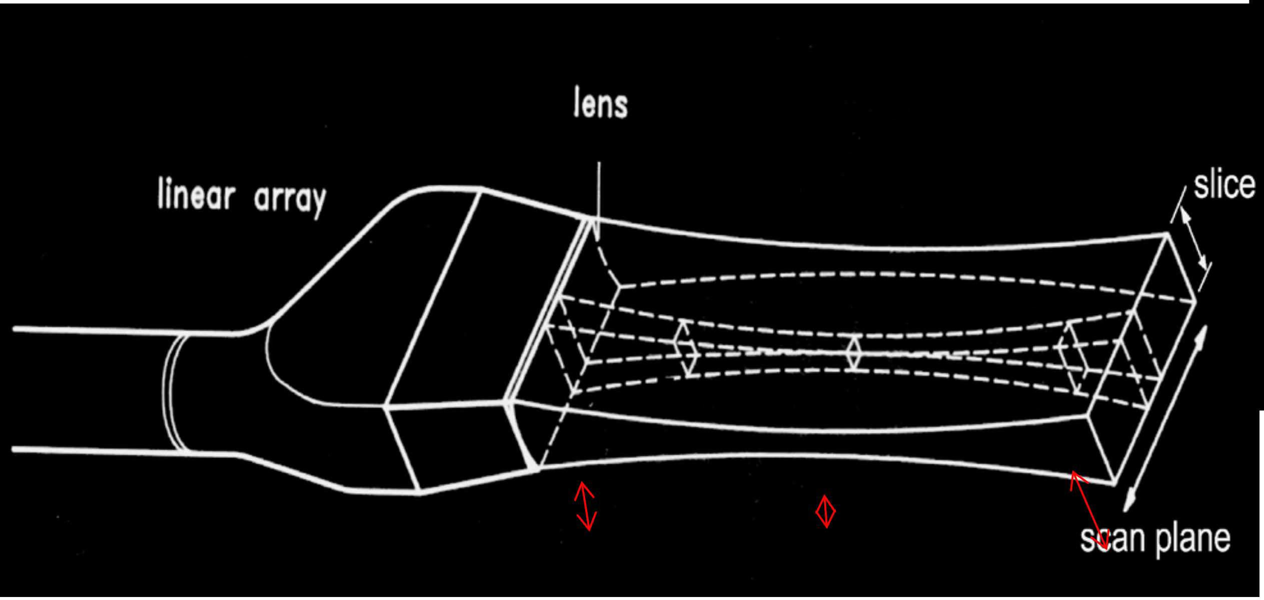


Slice thickness measurement

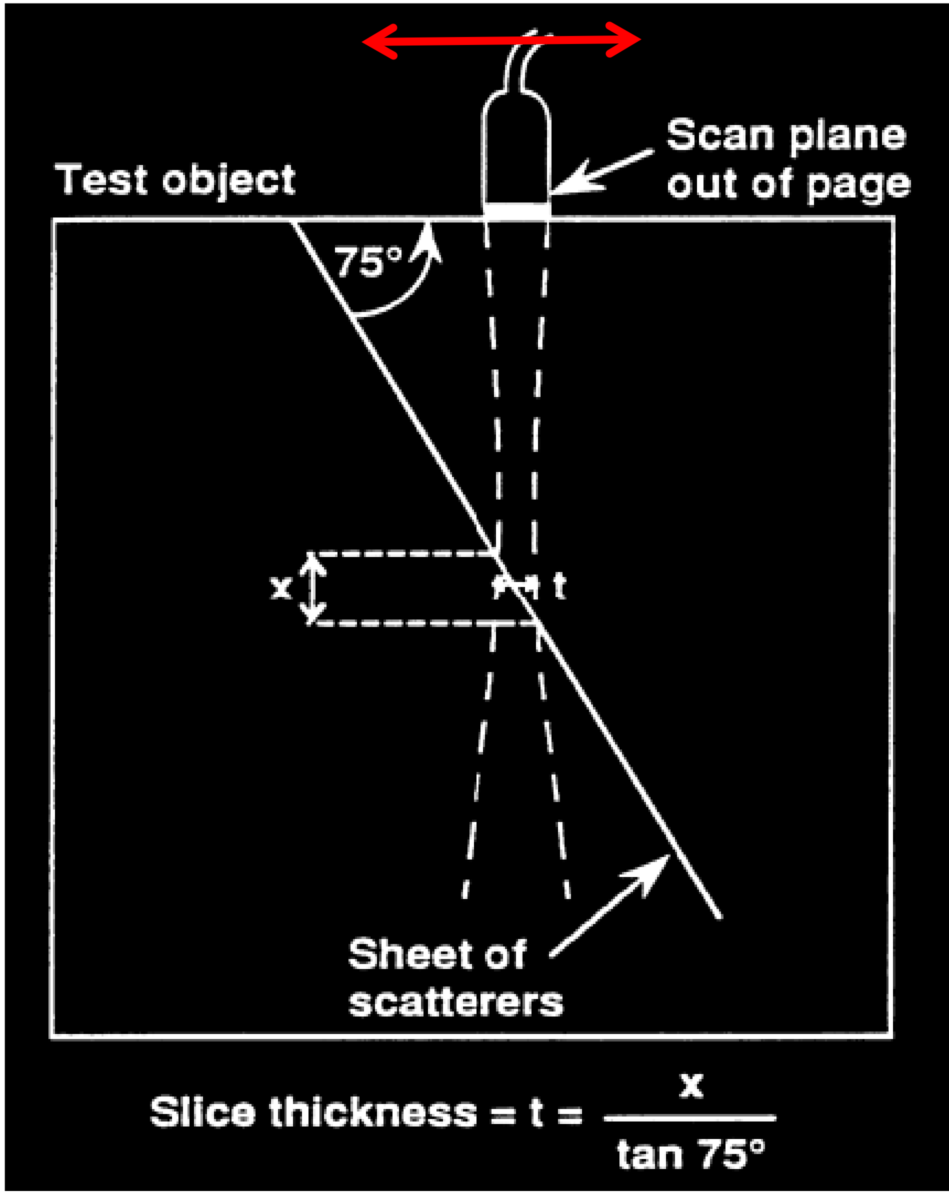
Slice thickness ⇔ Elevation focus

A special phantom is used to measure the depth where the elevation focus is located.





Slice thickness measurement



The examiner moves the transducer over the top of the phantom to estimate where the bar width is minimum (focus area)

Beam profile

- Beam profile ⇔ Lateral focus
- The beam thickness changes with the depth.
- Minimum value is at the focal

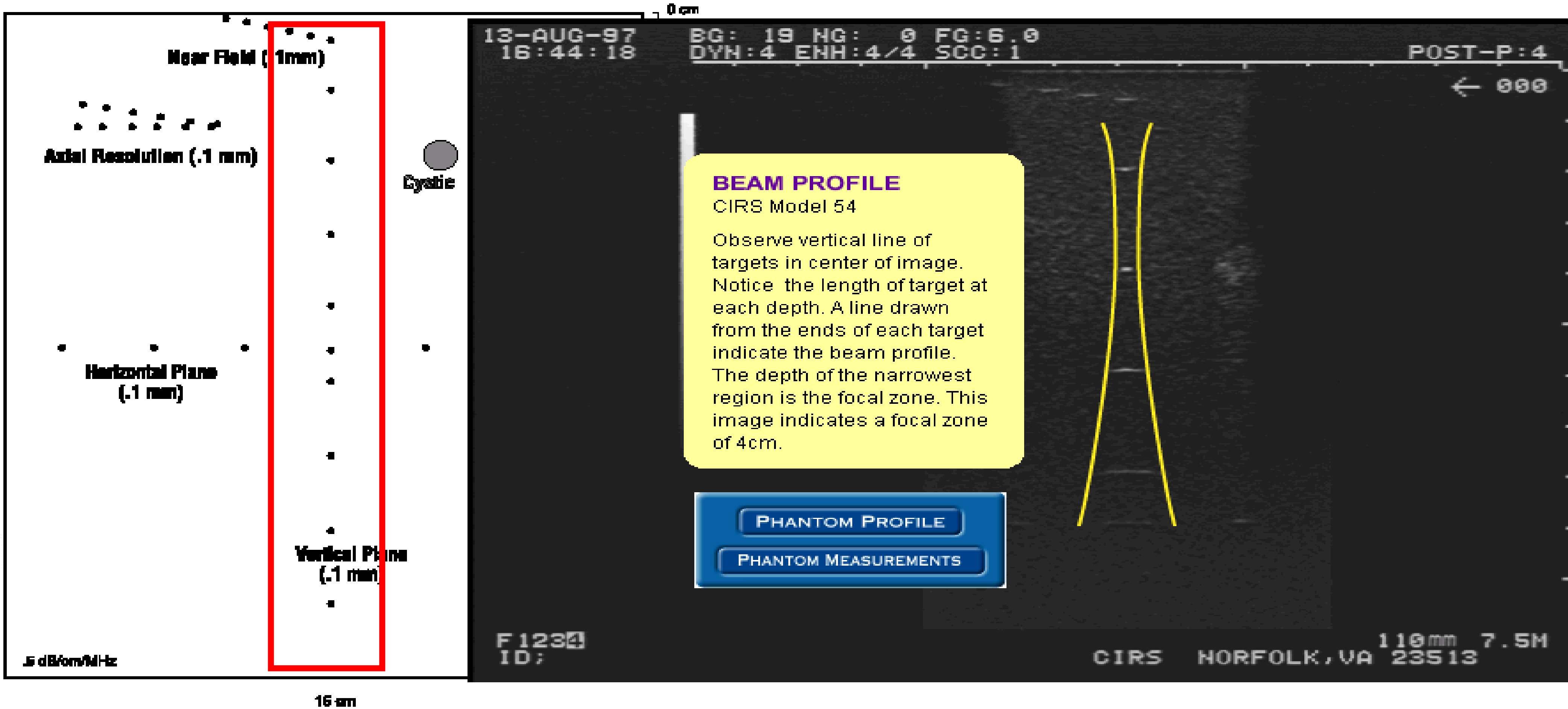
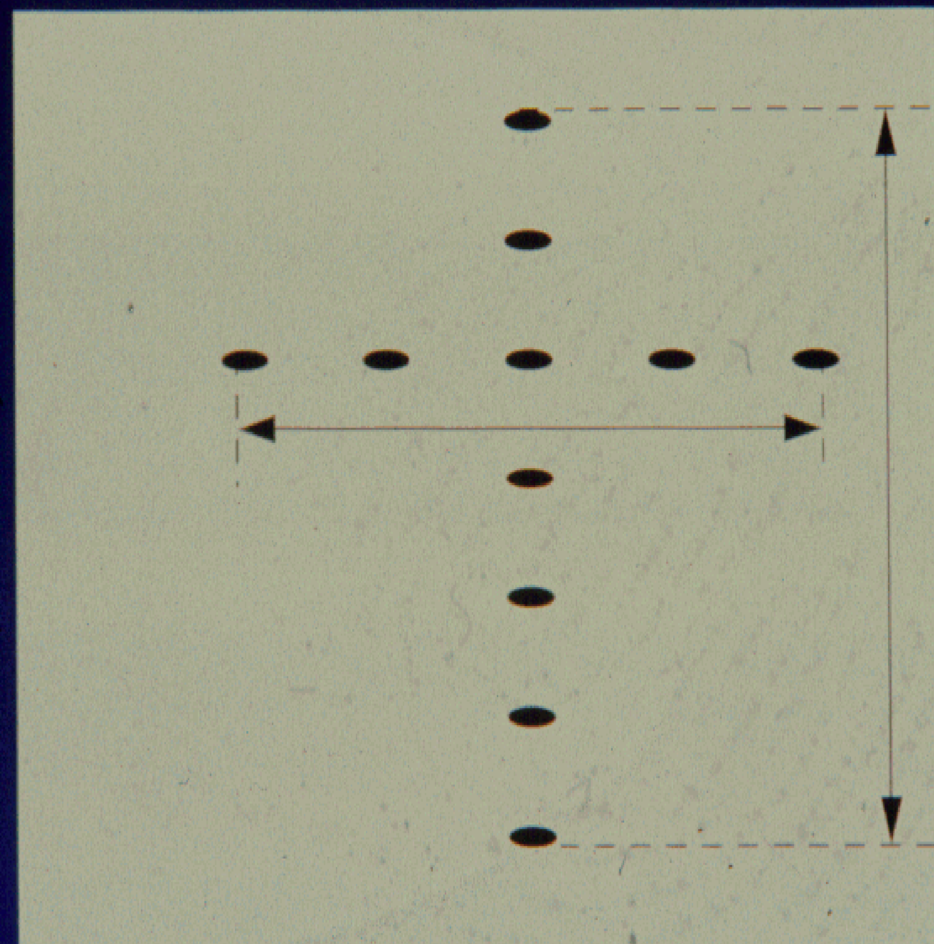


Image Distortion

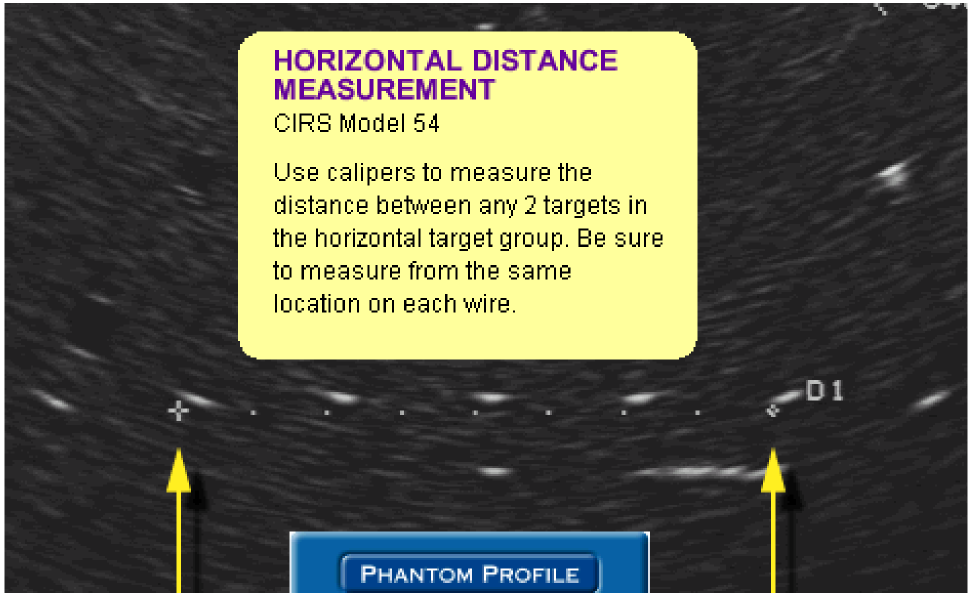
- Horizontal
- Vertical

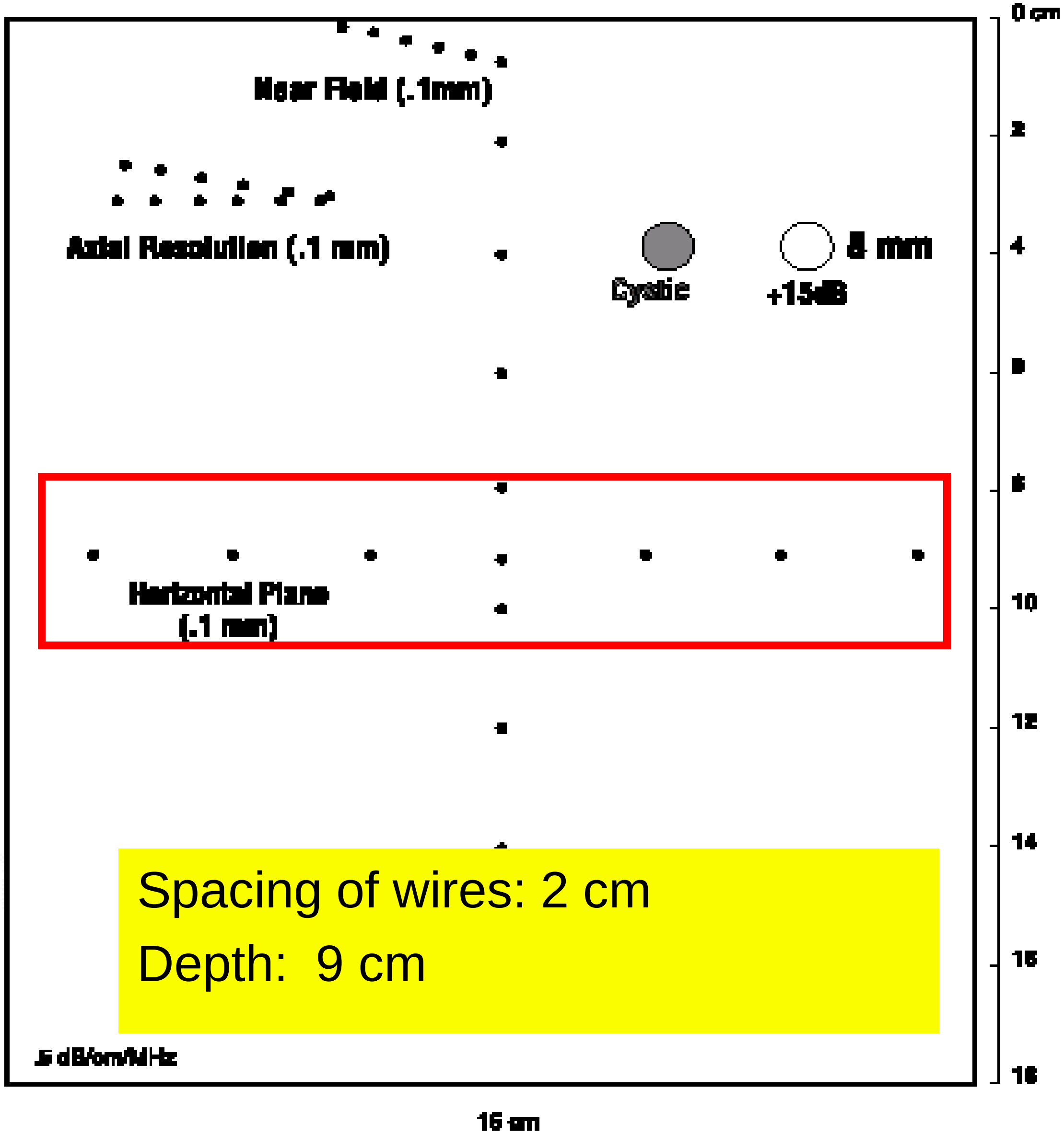
Measurement of distance between outer targets



Horizontal distance measurement

- Calibration of lateral length measurement
- Measurement of distance between outer targets

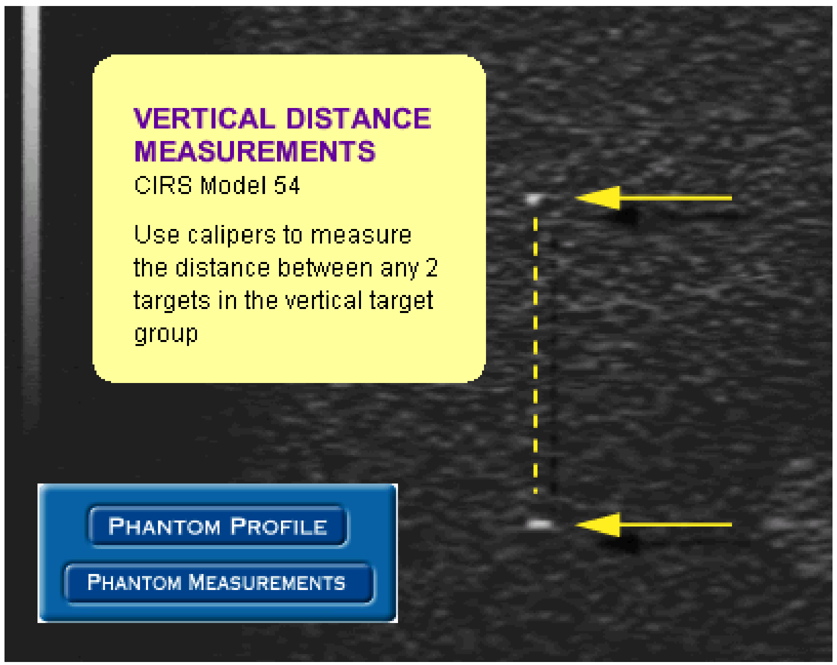


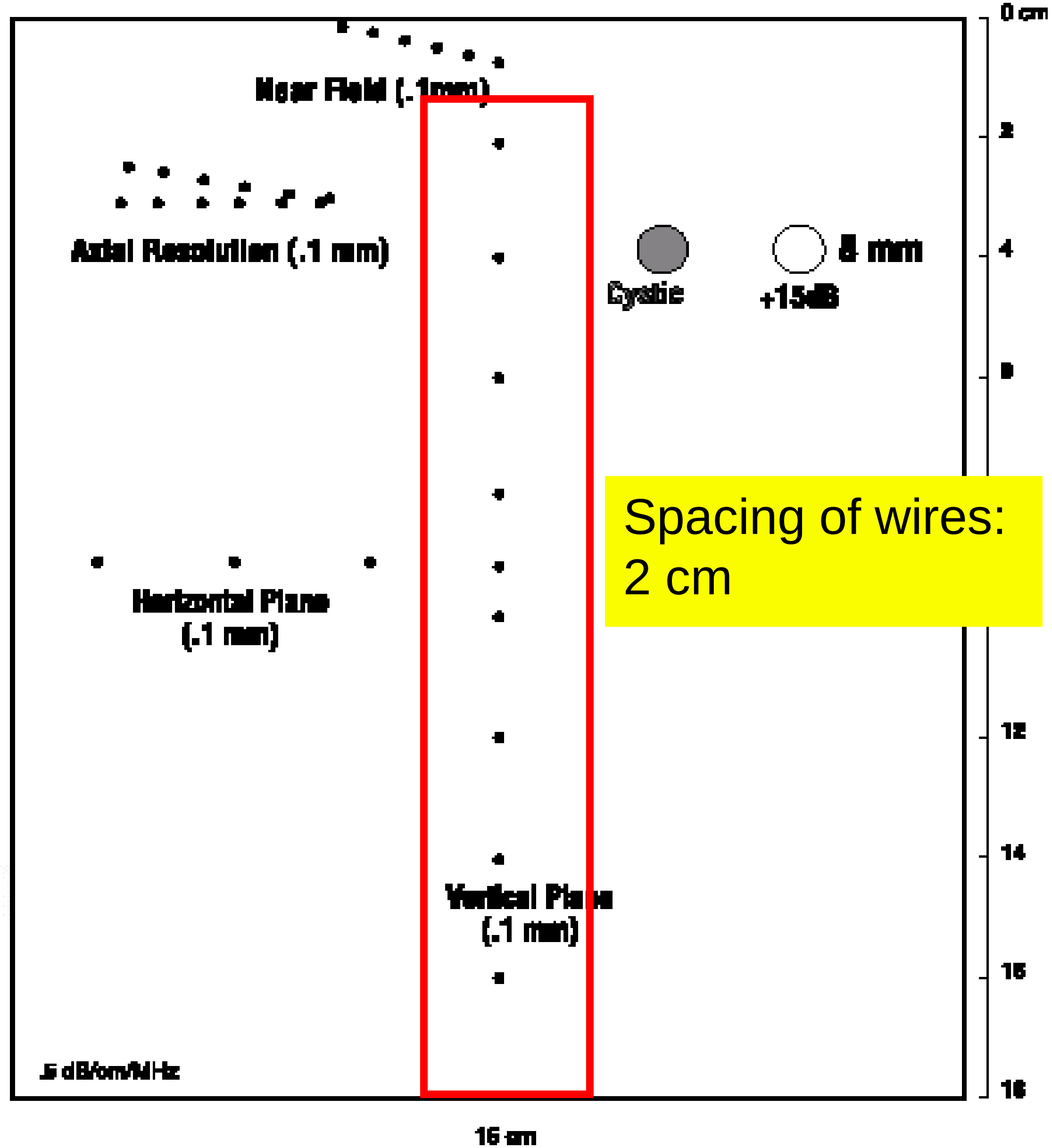


Vertical distance measurement

Calibration of lateral length measurement

The velocity introduced in the scanner is 1540 m/s



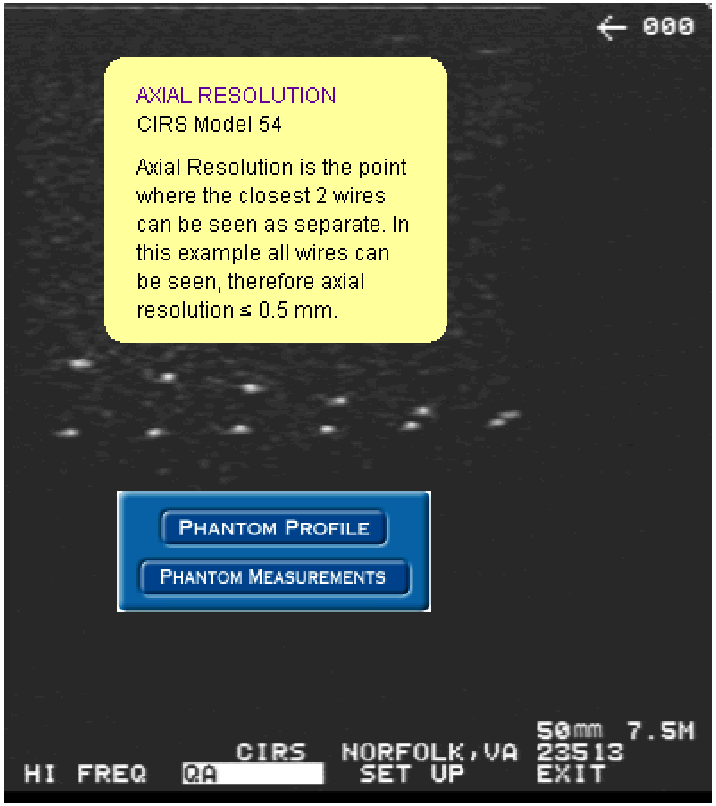


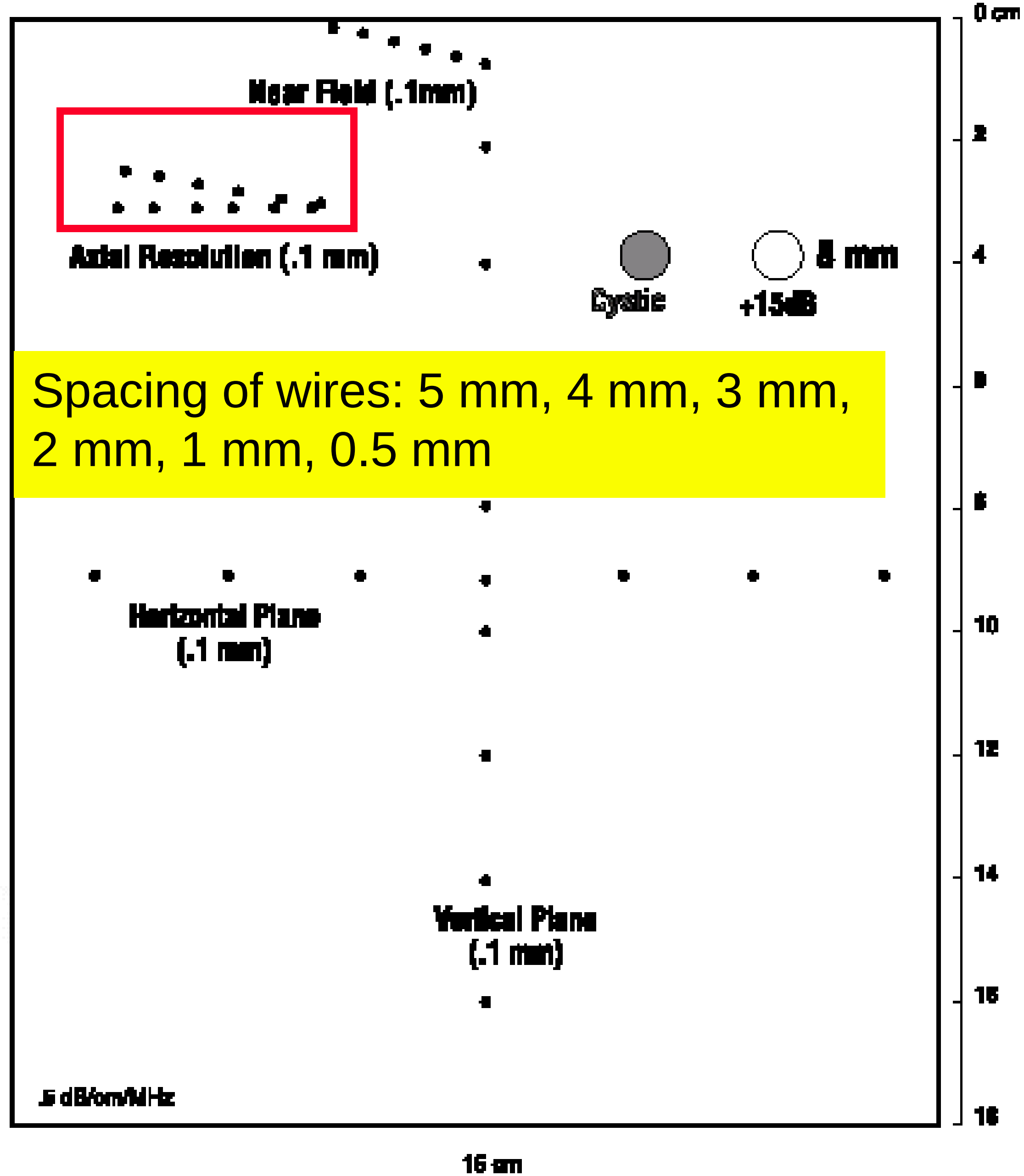
Spacing of wires: 2 cm

Axial resolution

The closest 2 wires separated

The axial resolution depends of the frequency





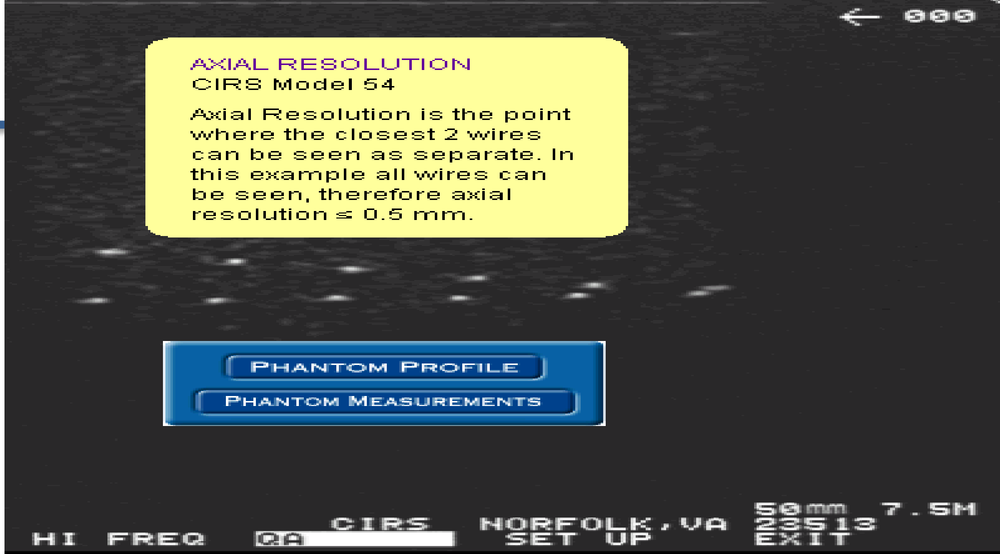
Spacing of wires: 5 mm, 4 mm, 3 mm, 2 mm, 1 mm, 0.5 mm

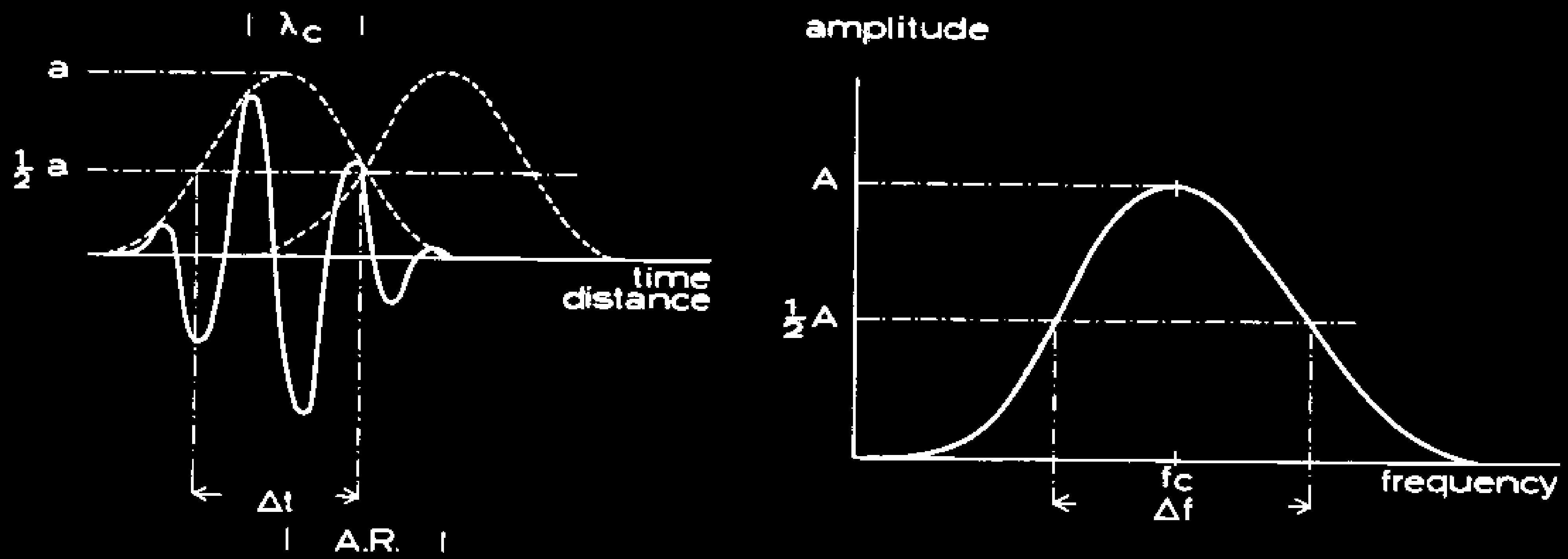
Axial resolution

Full Width at Half Maximum - FWHM

PSF:

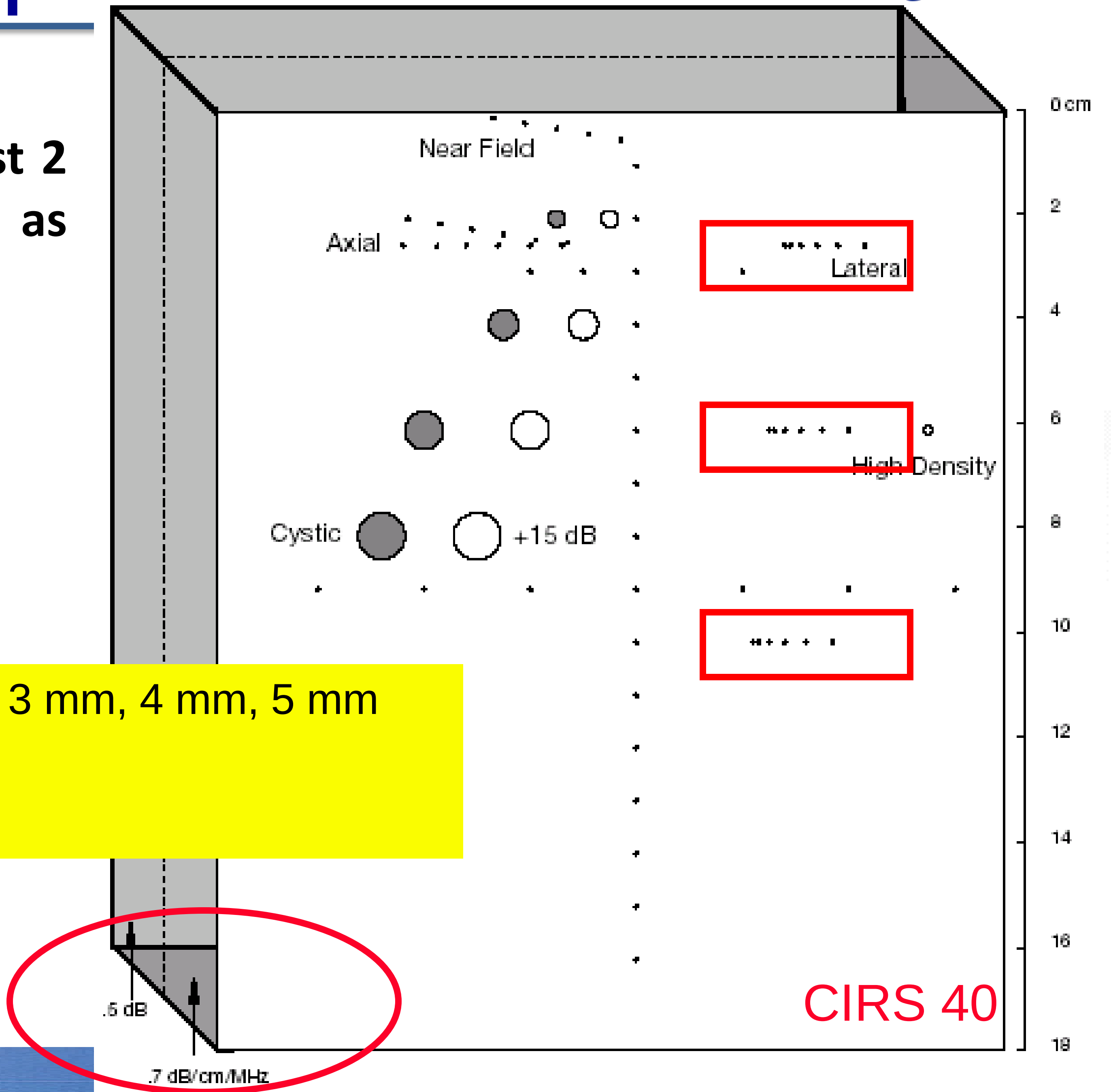
$$\Delta z = 0.66/ \Delta f$$





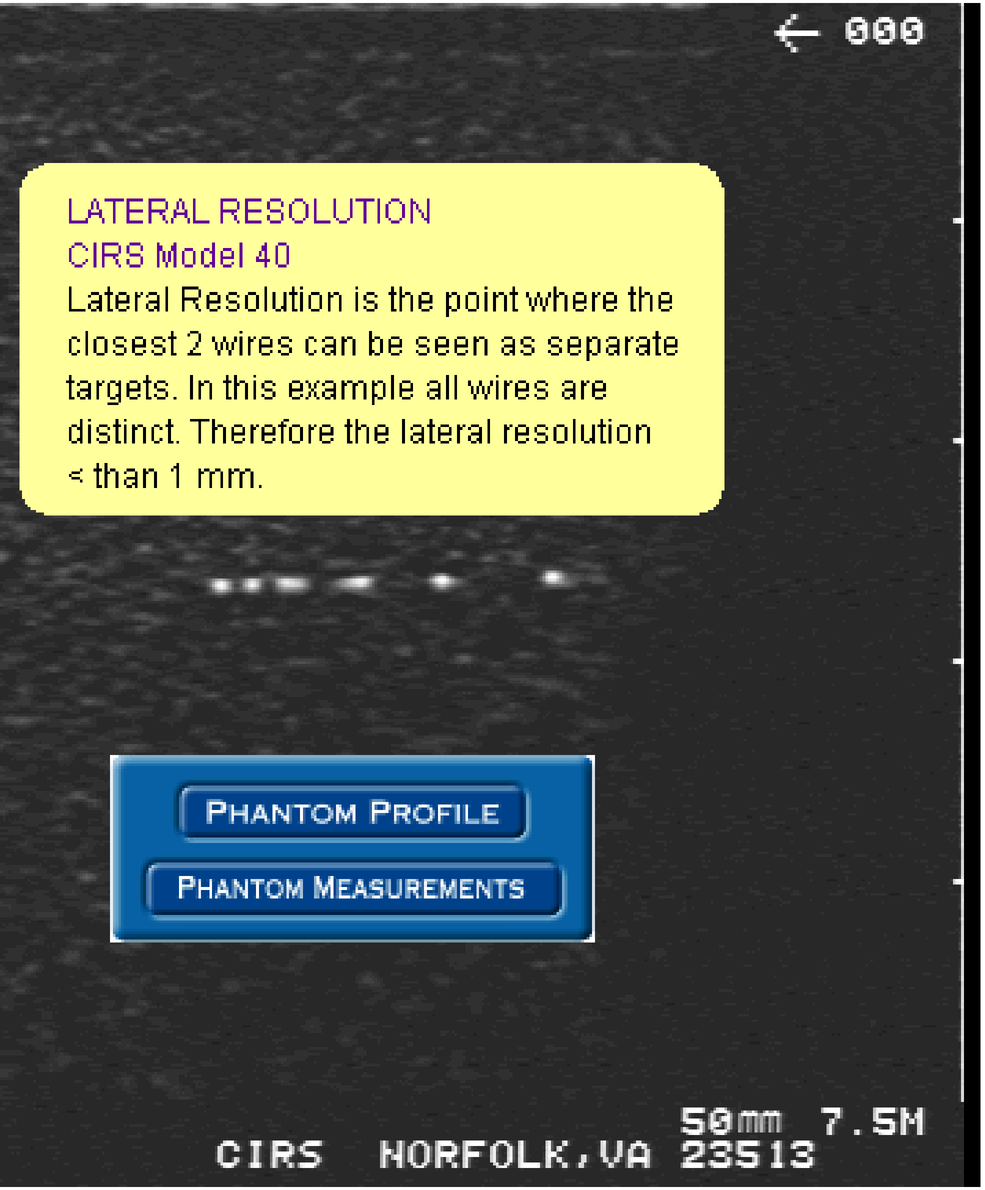
Lateral resolution

- **Distance where the closest 2 wires can be seen as separate targets**



Spacing of wires: 1mm, 2 mm, 3 mm, 4 mm, 5 mm
depth: 2.5 cm, 6 cm, 10 cm

Lateral resolution

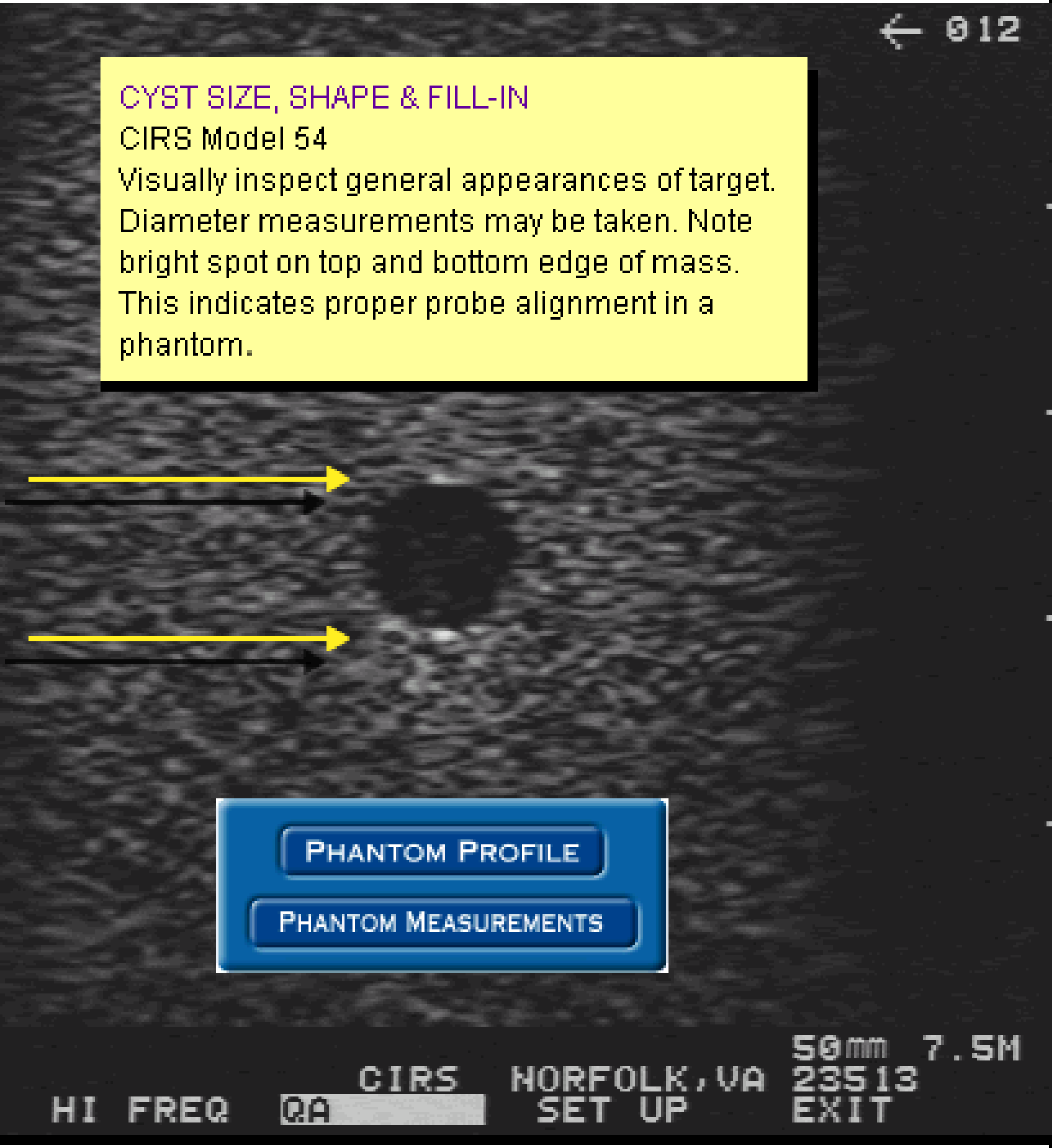


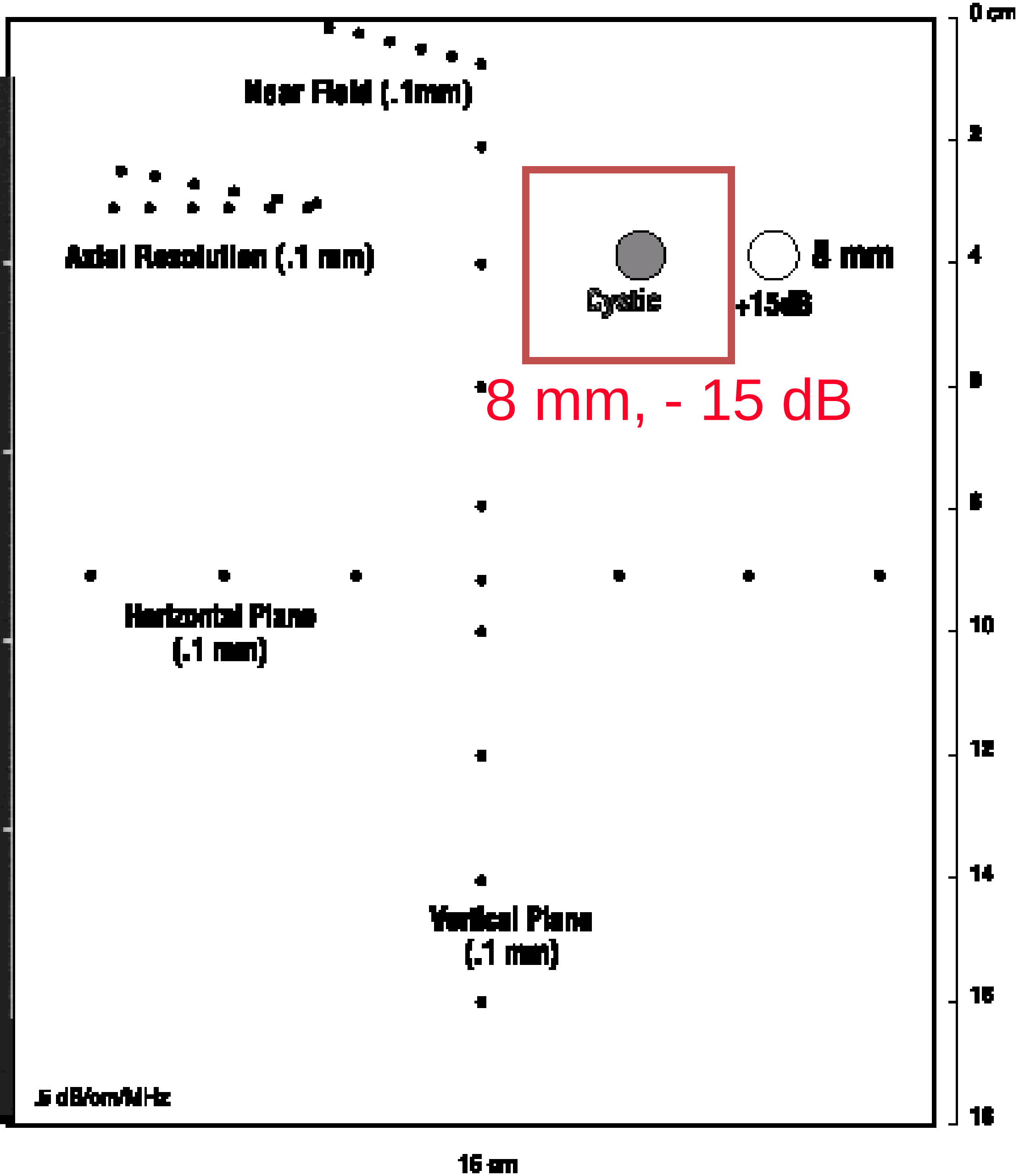
PSF: $\Delta x = 1.02\ c\ F\ /\ f_{ce}\ D$

- **c: velocity**
- **F: focal distance**
- **f_{ce}: transmitted frequency**
- **D : size of transducer**

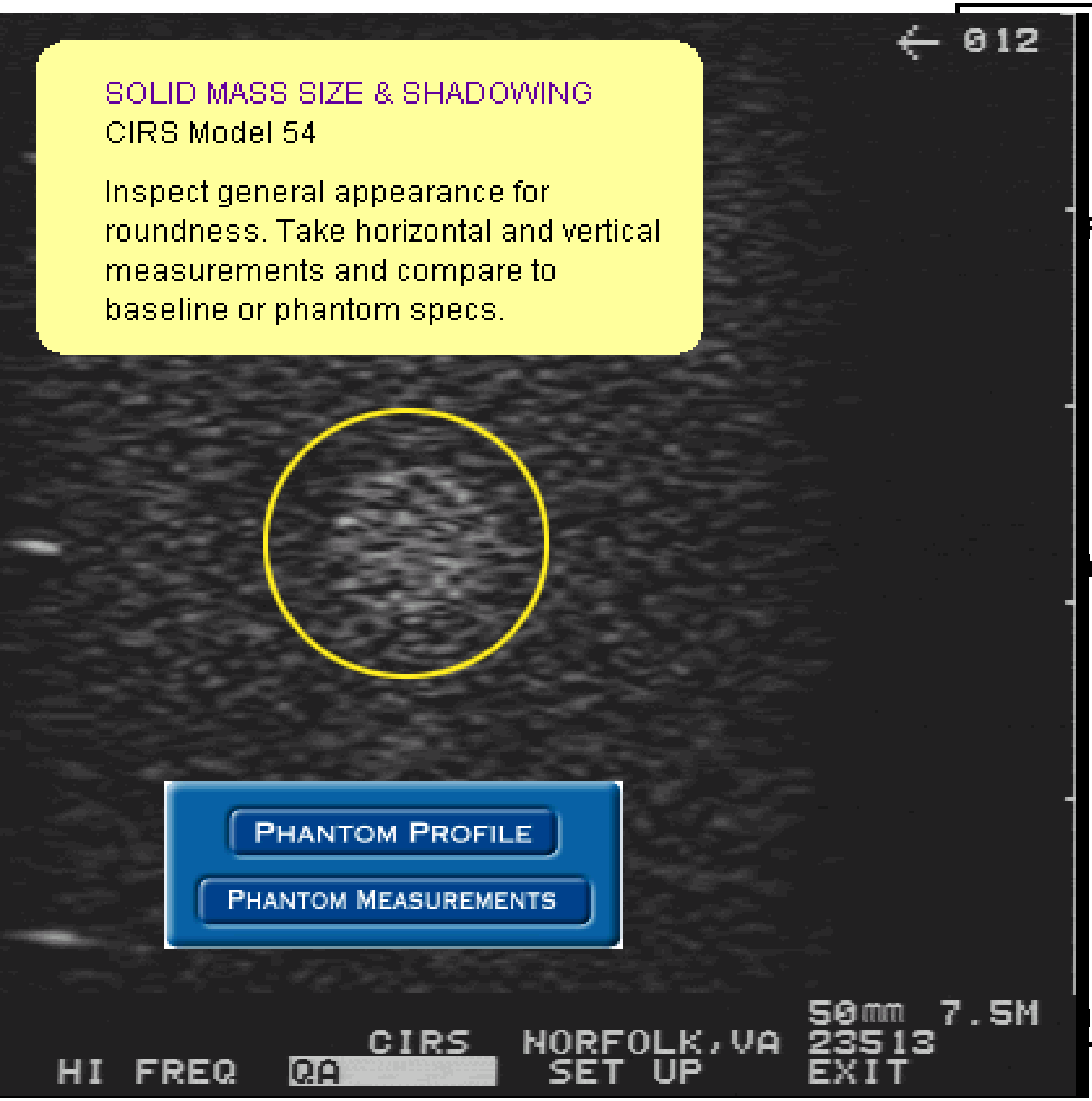
Image of cyst

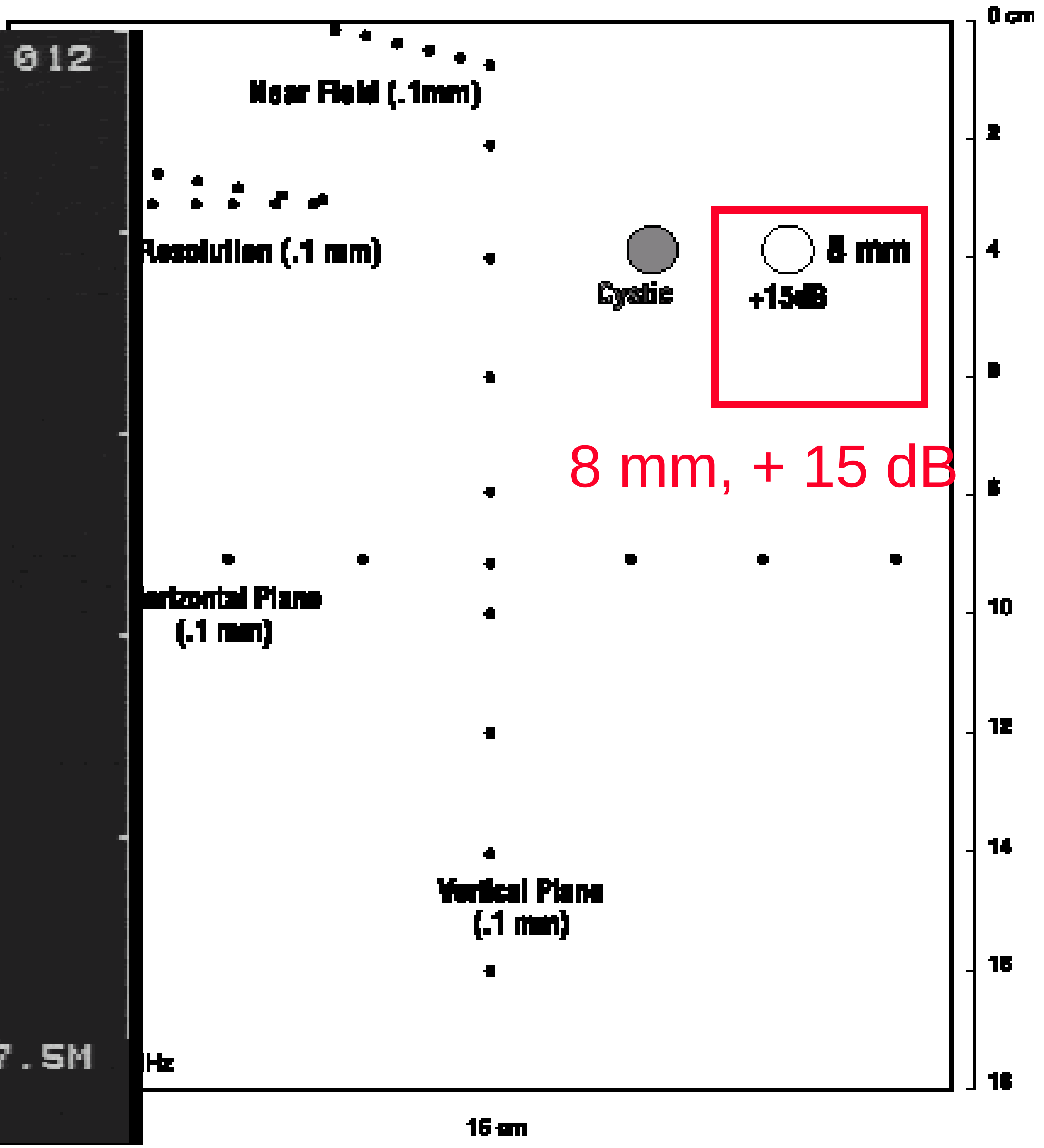
Anechoic area





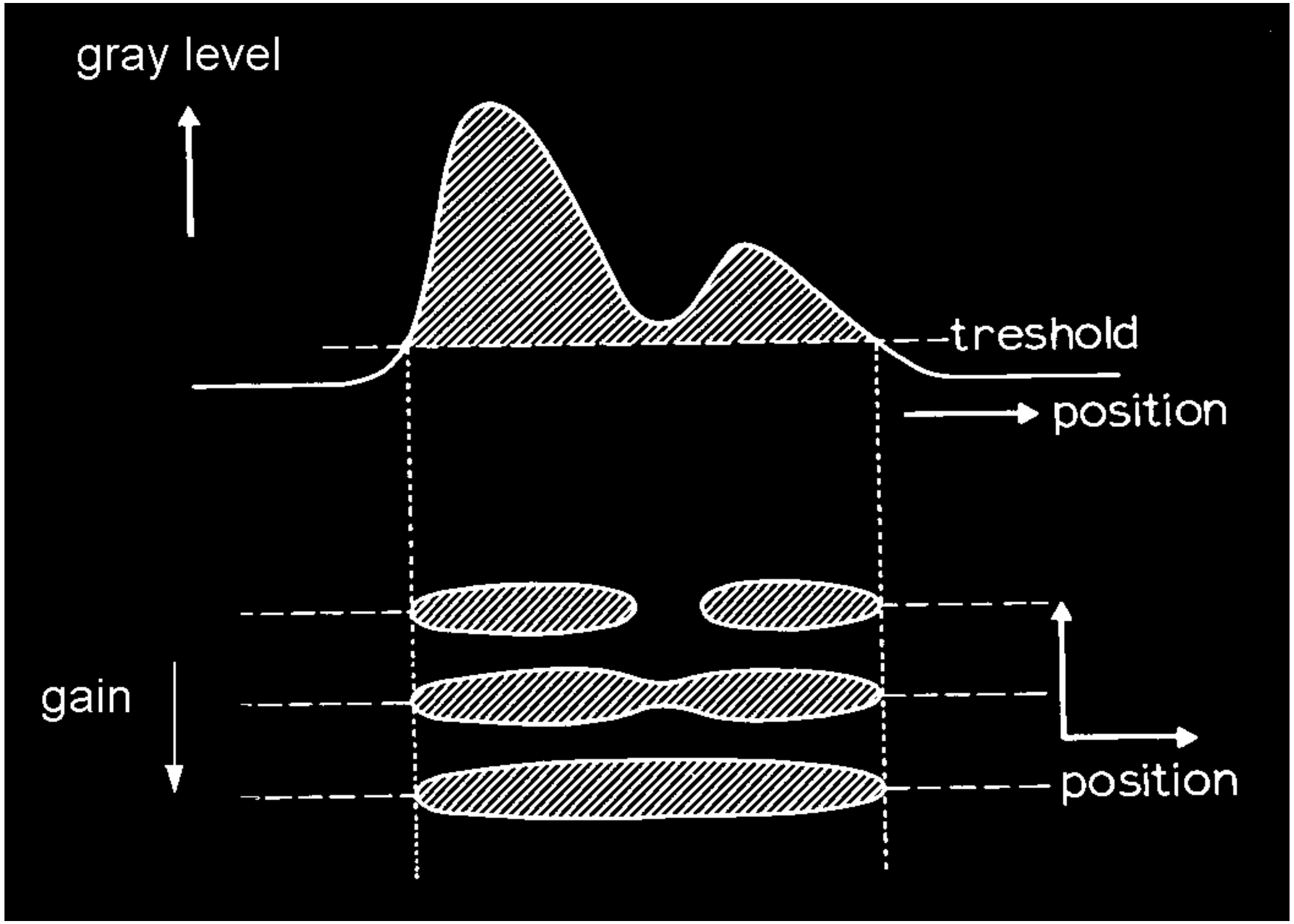
Solid mass and shadow





Subjective resolution vs. gain

- influenced by gain settings



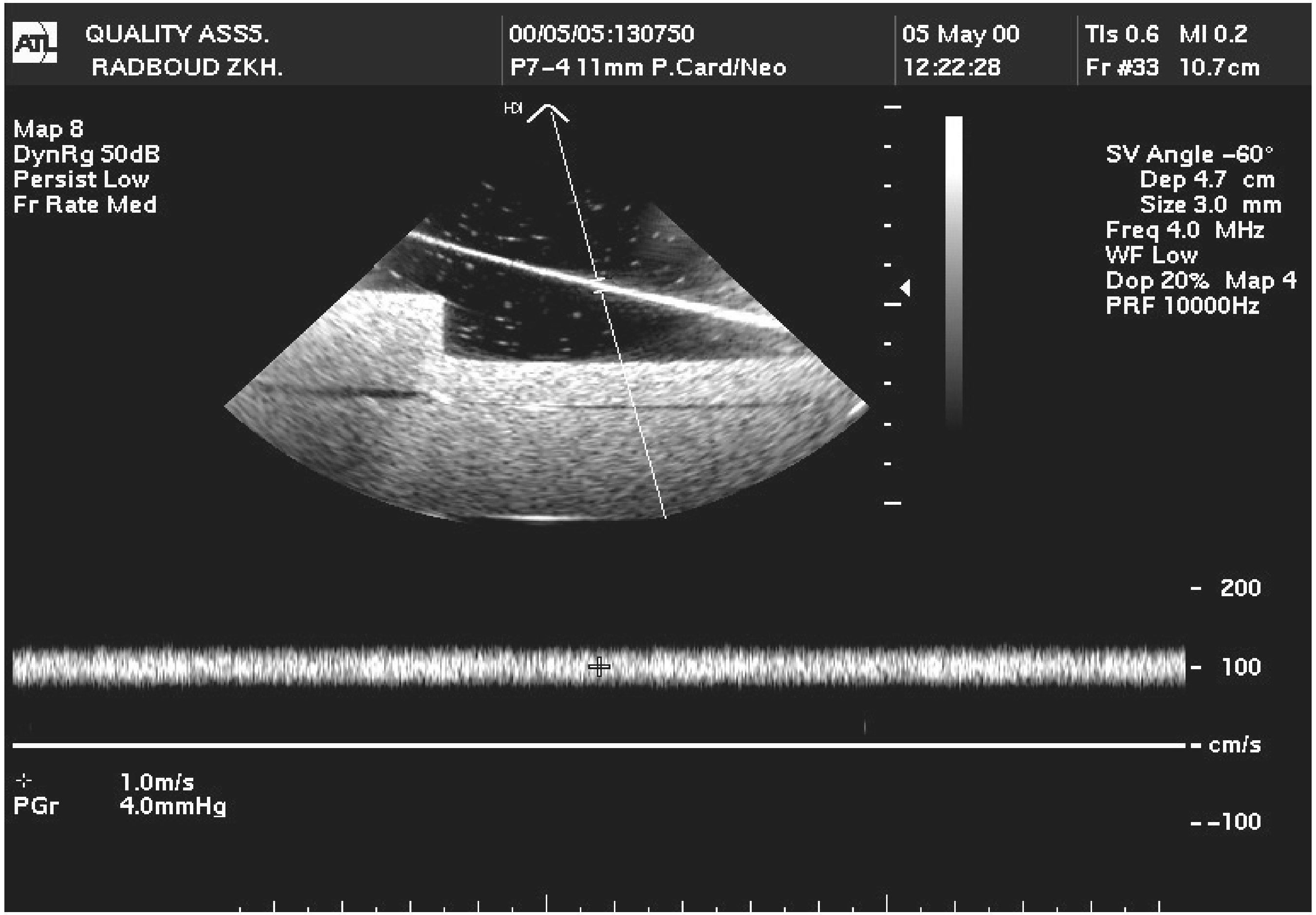
Overview

- Introduction.
- Test objects.
- Quality assurance
  - Imaging
  - Doppler velocity

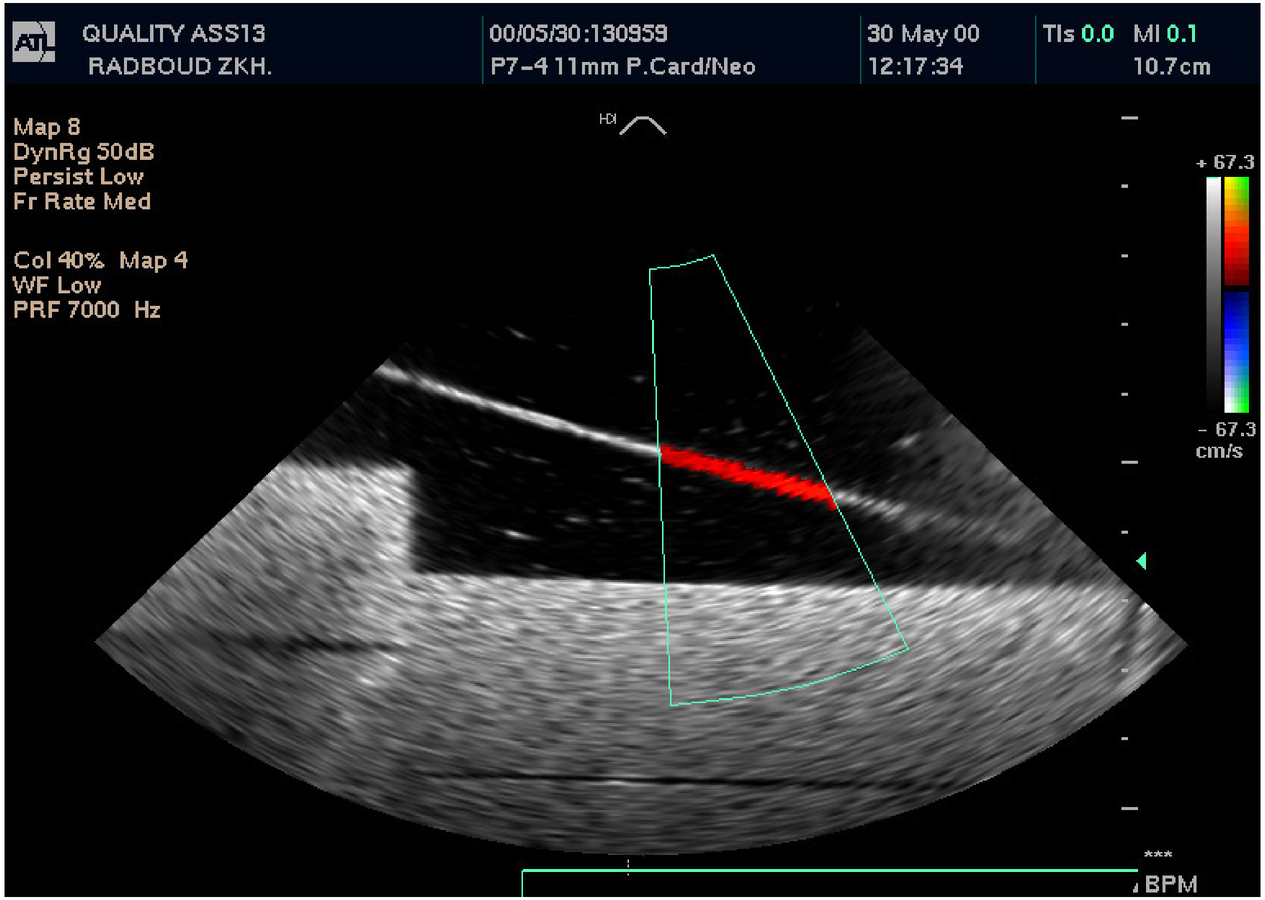
String test object

- Not tissue/blood equivalent
- Physiological signals
- Very stable velocity

angle correction by equipment



Direction indication in 2D color Doppler



Conclusions Quality Assurance

- **Objective assessment to be preferred**
- **Equipment settings to be reproduced**
- **Feasible in clinical practice with some investments**
- **Strict protocol not (yet) internationally accepted**

– References:

» Thijssen et al. Eur J Ultrasound 2002;15:151-61

» van Wijk & Thijssen. Ultrasonics 2002;40:585-91

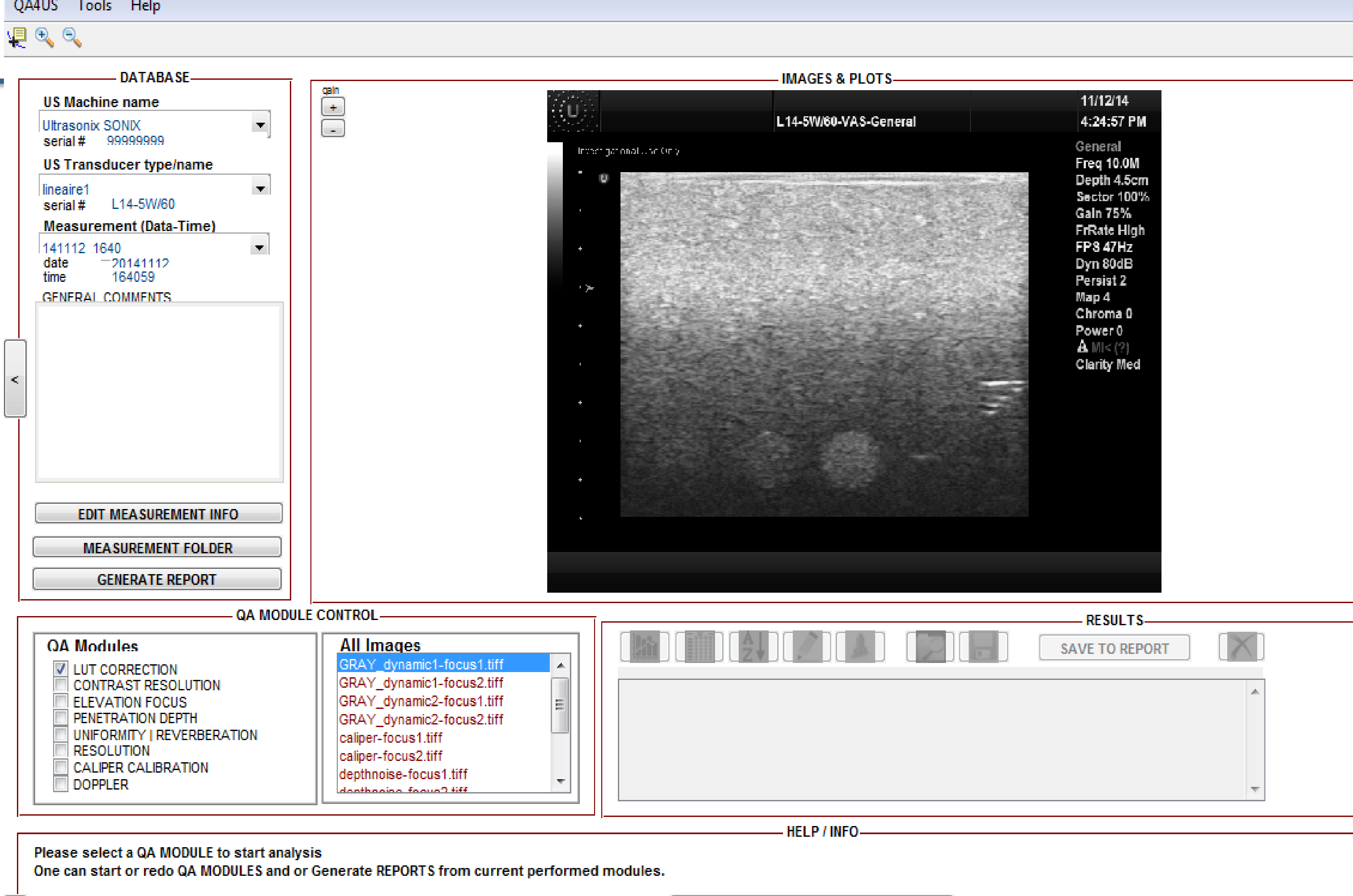
Quality Assurance 4 Medical UltraSound equipment

a software developed by the

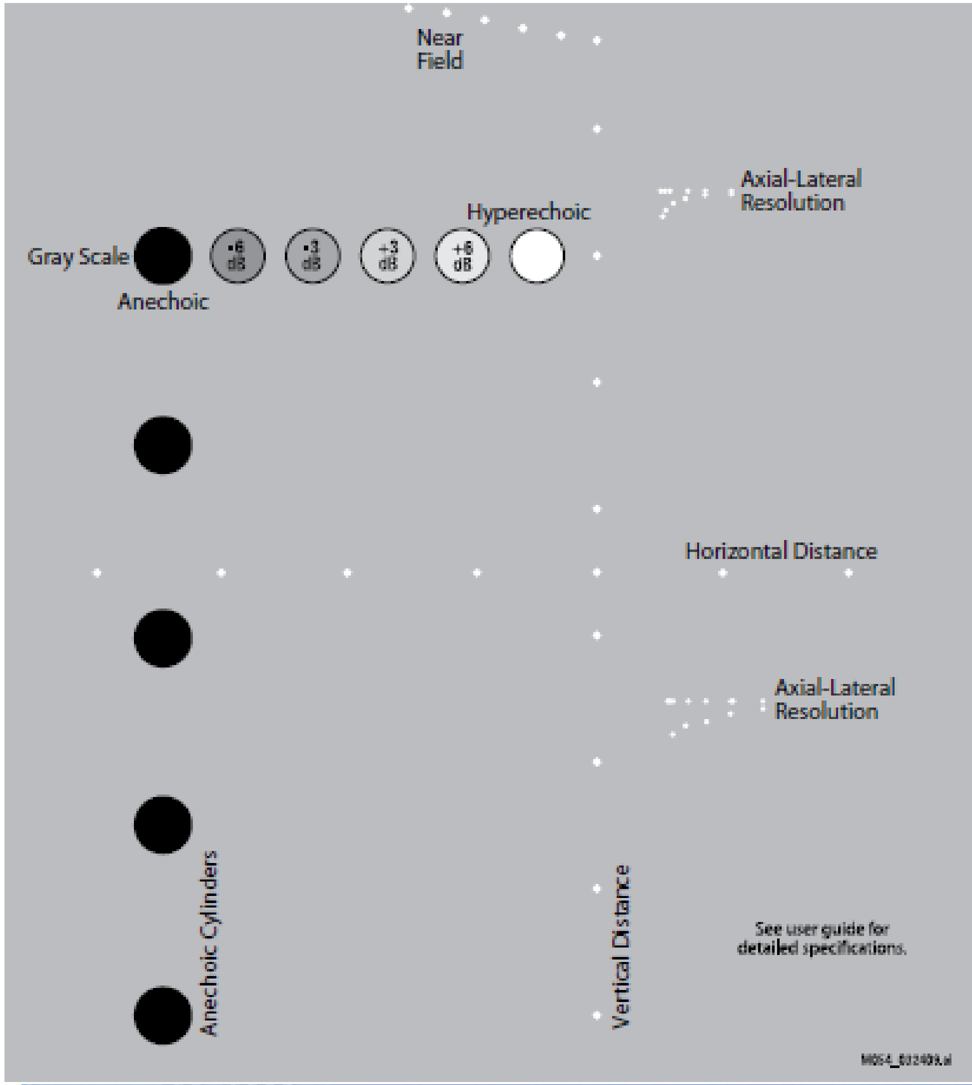
Medical ultrasound Medical Centre

Radboud University Nijmegen Medical Centre

Nijmegen, The Netherlands


QA4US Tools Help
DATABASE
US Machine name
Ultrasonix SONIX
serial # 99999999
US Transducer type/name
lineaire1
serial # L14-5W/60
Measurement (Data-Time)
141112_1640
date 20141112
time 164059
GENERAL COMMENTS
EDIT MEASUREMENT INFO
MEASUREMENT FOLDER
GENERATE REPORT
IMAGES & PLOTS
gain
11/12/14
4:24:57 PM
L14-5W/60-VAS-General
General
Freq 10.0M
Depth 4.5cm
Sector 100%
Gain 75%
FrRate High
FPS 47Hz
Dyn 80dB
Persist 2
Map 4
Chroma 0
Power 0
Clarity Med
QA MODULE CONTROL
QA Modules
LUT CORRECTION
CONTRAST RESOLUTION
ELEVATION FOCUS
PENETRATION DEPTH
UNIFORMITY | REVERBERATION
RESOLUTION
CALIPER CALIBRATION
DOPPLER
All Images
GRAY_dynamic1-focus1.tiff
GRAY_dynamic1-focus2.tiff
GRAY_dynamic2-focus1.tiff
GRAY_dynamic2-focus2.tiff
caliper-focus1.tiff
caliper-focus2.tiff
depthnoise-focus1.tiff
RESULTS
SAVE TO REPORT
HELP / INFO
Please select a QA MODULE to start analysis
One can start or redo QA MODULES and or Generate REPORTS from current performed modules.

- The CIRS Model 054GS General Purpose UltrasoundPhantom



Performance Measurements

- Dead Zone
- Horizontal Distance Accuracy
- Vertical Distance Accuracy
- Depth of Penetration
- Image Uniformity
- Axial Resolution

Creatis

Modality ID : Ultrasonix MPD	Modality type/name: Echographie	for department:
Modality SN : SXMDP1.1-1004.0055	preset name: VAS-general	acquisition date: 12-11-2014

phantom(s) used:	model:
slice thickness phantom multipurpose phantom 1 multipurpose phantom 2 ...	054GS CP de CIRS

PROBE INFO | ID: L14-5W/60	SN: TRA1.0-SLWR.071	name: lineaire1			type: linear / curved / phased		
preset: VAS-General		Application: vasculaire					
Measurement	Gain	Power	Dynamic Range	Frequency (MHz)	Post-Processing / graywedge	Acuisition depth (mm)	In-plane focus depth (mm)
preset levels	75 %	0	80 dB		LUT linéaire	45	
Note necessarily adjustments, with respect to the preset, here:							
Elevation focus							
Contrast Resolution							
Penetration depth							
Resolution							
Caliper calibration							
General comments:							

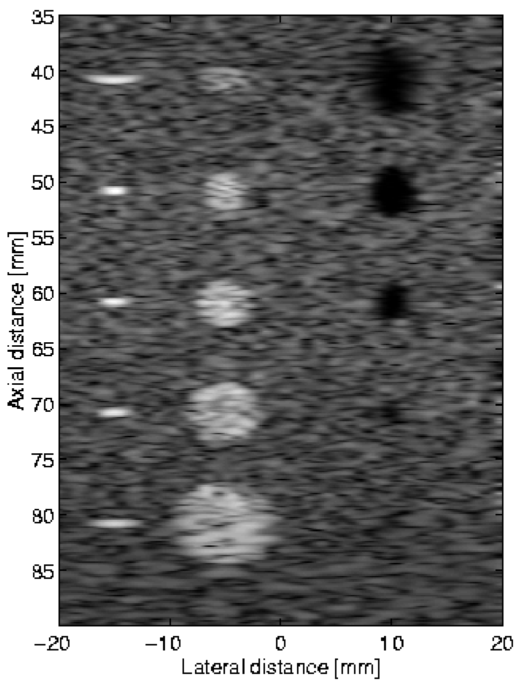
PROBE INFO | ID:	SN:	name:			type: linear / curved / phased		
preset:		Application:					
Measurement	Gain	Power	Dynamic Range	Frequency (MHz)	Post-Processing / graywedge	Acuisition depth (mm)	In-plane focus depth (mm)
preset levels							
Elevation focus							
Contrast Resolution							
Penetration depth							
Resolution							
Caliper calibration							
General comments:							

Simulation in Ultrasound imaging

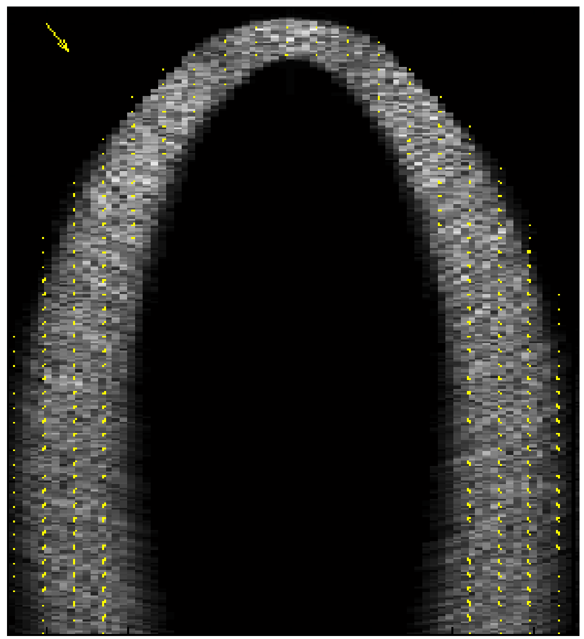
- **to reduce costs: simulations done with one computer replace expensive experiments**

- **to validate some methodologies and control the ground truth**

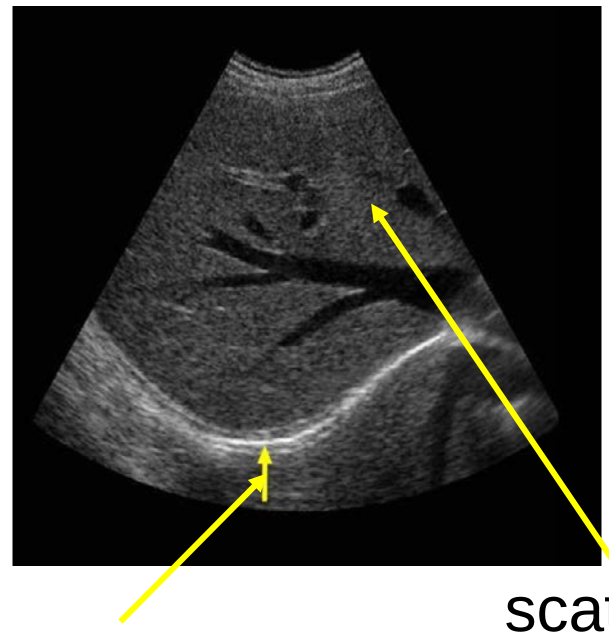
- **Make the simulations realistic**
  - Simple for basic simulations (resolution / contrast)
  - More complication for biological tissues / organs
  - Reproduce complex wave tissue interaction



Simple: resolution / contrast



Complicated : a heart?



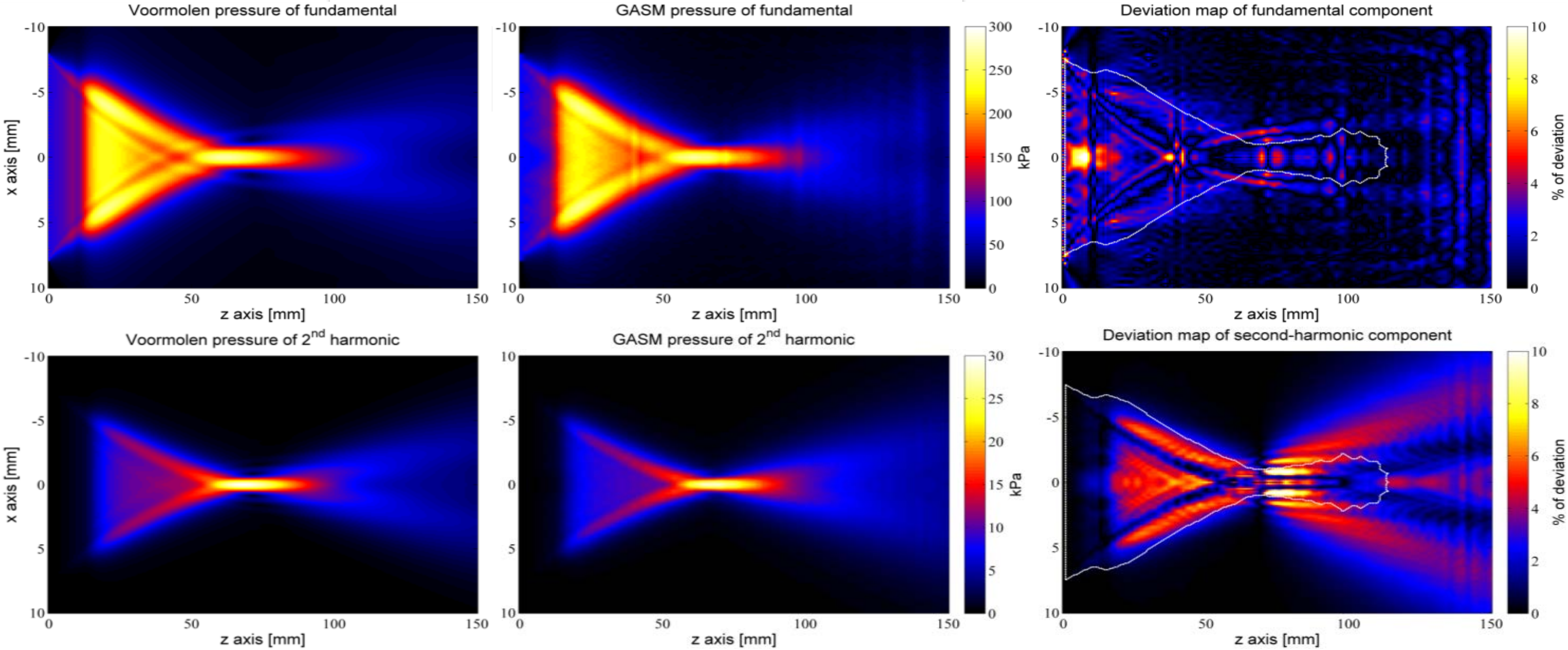
scattering

Specular reflection

The simulation tools

- **Field II: the reference in the domain of linear simulation**
- **CREANUIS : developed at CREATIS, non linear imaging**
- K-wave : developed at Uinversity College London, whole package (non linear, photo-acoustics, tomo…)
- Cole: developed by KU Leuven. Convolutive method, fas**t**

Simulation results



$$D_i = \frac{|p_i^{Ref} - p_i^{GASM}|}{\max(p_i^{Ref})}$$

	Mean deviation	Maximal deviation
D_1	3.7 %	8.1 %
D_2	3.4 %	7.8 %

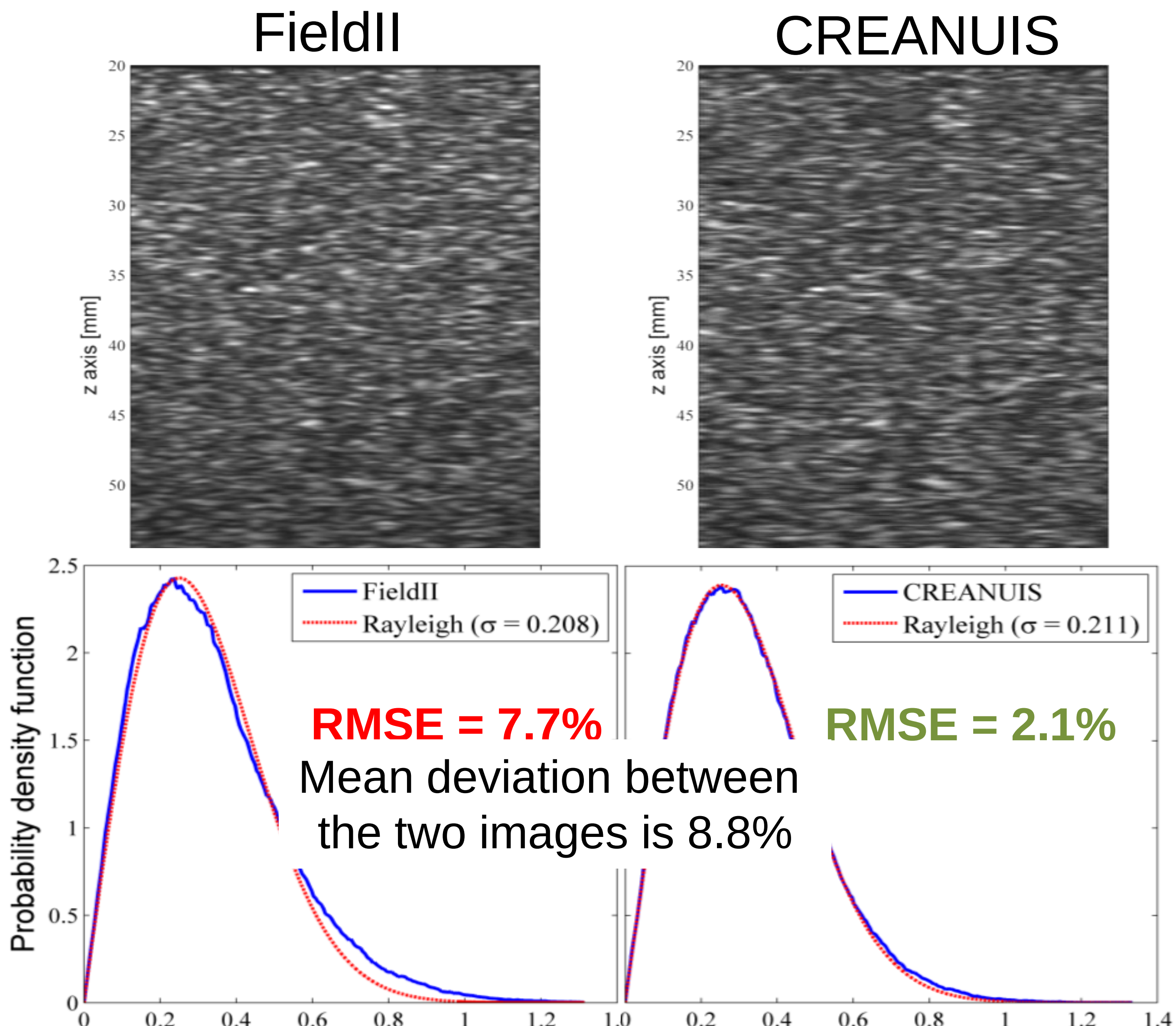
CREANUIS – Comparison with FieldII

Medium
- 30 scatterers/mm^3

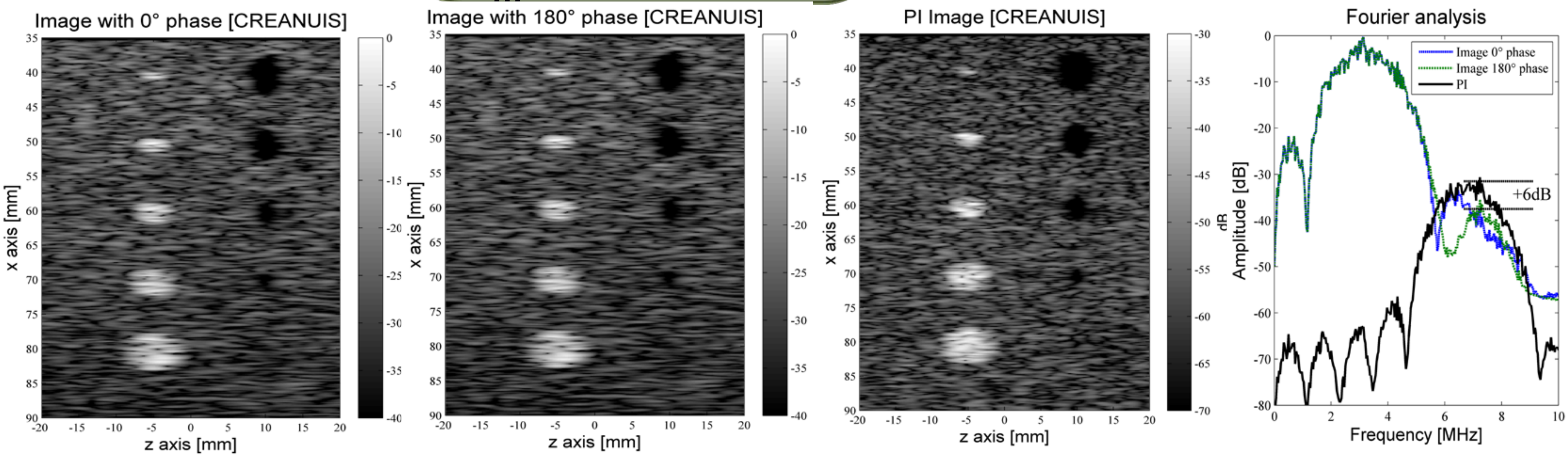
TX signal
- 3-cycle sine at 5 MHz
- Hanning windows
- Focalization at 40 mm

Beamforming
- Hanning apodization in TX and RX

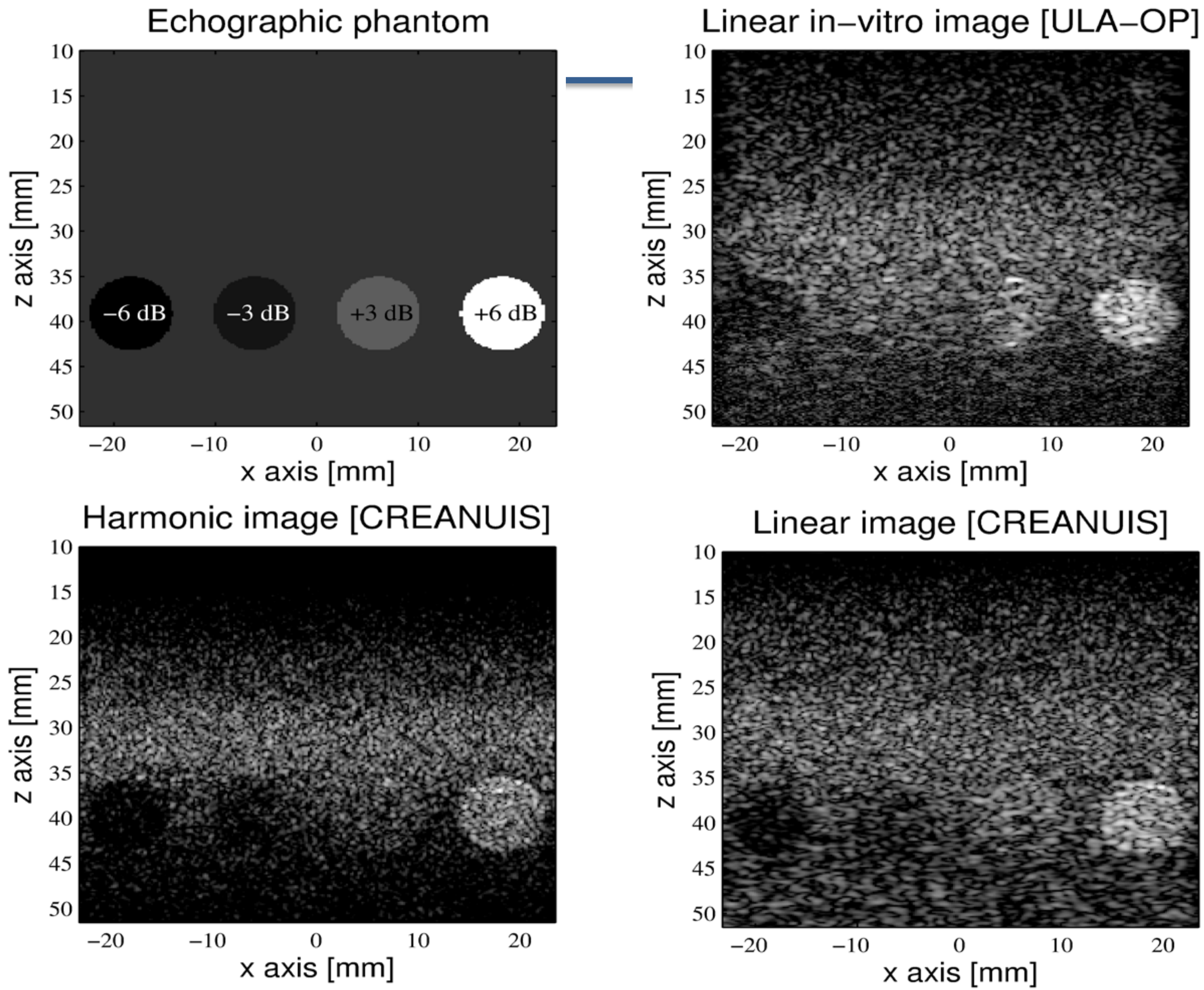
Theoretical probability density function: Rayleigh distribution



- Amplitude modulation
- Second harmonic inversion
- **Pulse inversion**
- ...



Varray *et al.*, UMB 2013



CREANUIS is avalaible : https://www.creatis.insa-lyon.fr/site/fr/CREANUIS