INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4-SMR 471/27

COLLEGE ON MEDICAL PHYSICS

10 - 28 SEPTEMBER 1990

ULTRASOUND FUNDAMENTALS IN BIOMEDICAL APPLICATIONS

&

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ULTRASOUND FUNDAMENTALS

elastic waves $f > 20\,kHz$

IN BIOMEDICAL APPLICATIONS:

FREQUENCY: $1 \leq f \leq 15$ MHz

MEAN VELOCITY: $c \simeq 1540$ m/s

WAVELENGTH: $\lambda = \frac{c}{f}$ $1.5 < \lambda < 0.07$ mm

ACOUSTIC IMPEDANCE: $z = \rho \cdot c$ $[kg/m^2 s]$

where:

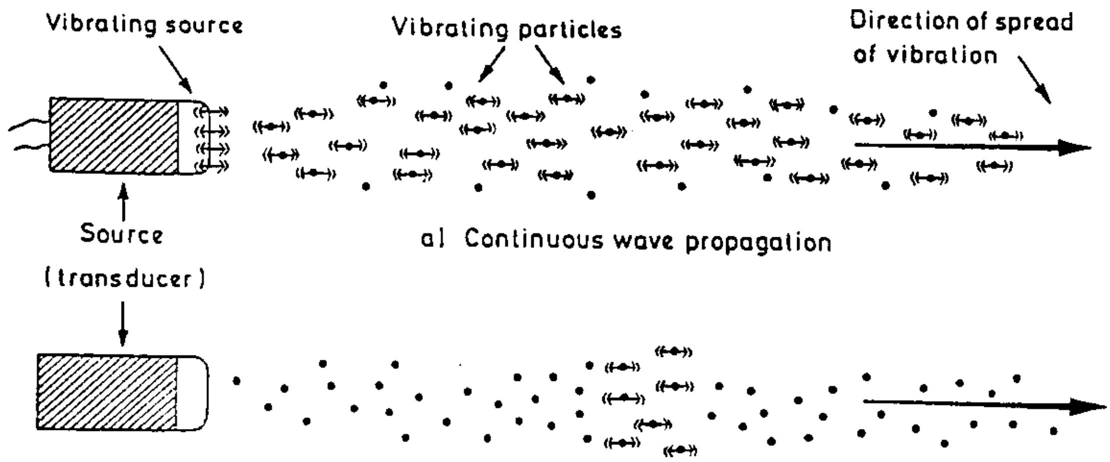
ρ = density of medium

c = propagation velocity

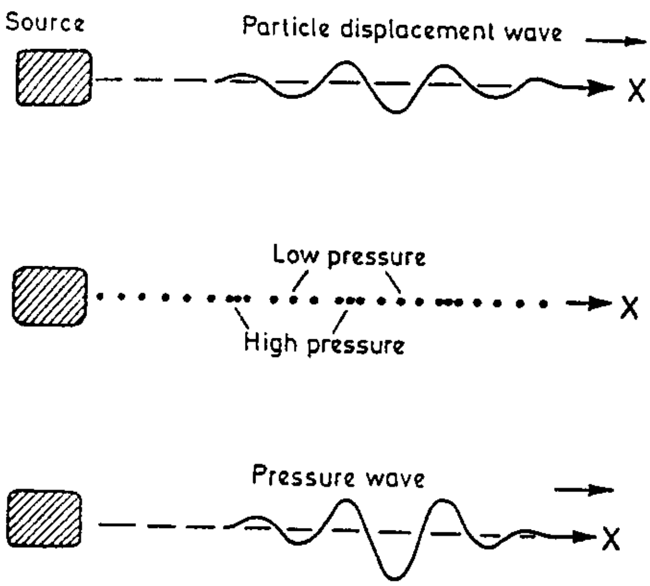
$1.5 \cdot 10^6$ kg/m²s

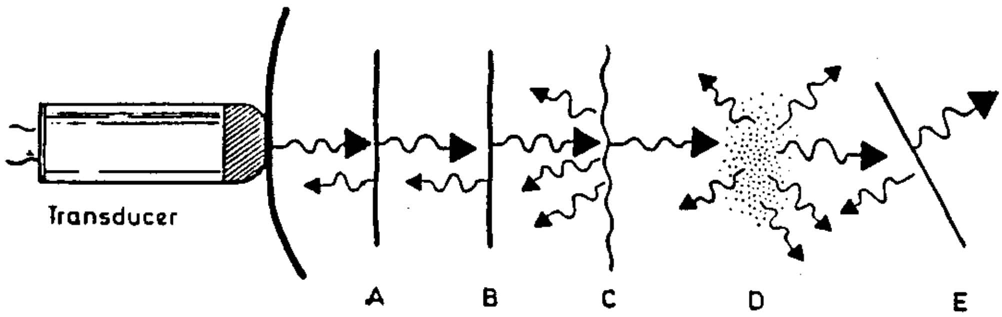
ATTENUATION IN BIOLOGICAL TISSUES:

$0.5 \div 1$ dB cm⁻¹·MHz



b) Pulsed wave propagation




Transducer
A
B
C
D
E

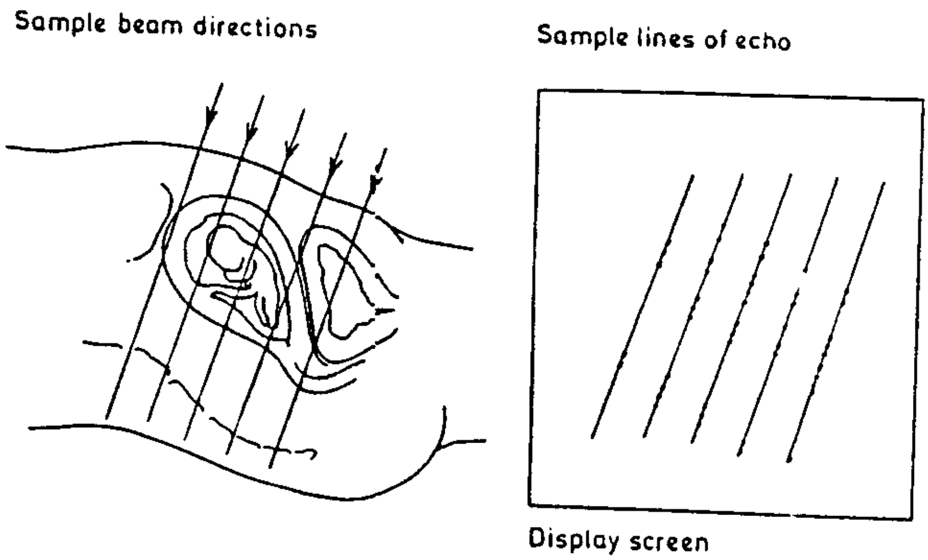

Sample beam directions
Sample lines of echo
Display screen

TABLE 1.1

Properties of some non-biological materials

Material	Density, ρ [kg m^{-3}]	Velocity, c [m s^{-1}]	Characteristic impedance, Z [kg m^{-2} s^{-1}] ($\times 10^{-6}$)	Absorption coefficient, α [dB cm^{-1}] at 1 MHz	Approximate frequency dependence* of α
Air at STP	1·2	330	0·0004	1·2	f^2
Aluminium	2700	6400	17	0·018	f
Brass	8500	4490	38	0·020	f
Castor oil	950	1500	1·4	0·95	f^2
Mercury	13 600	1450	20	0·000 48	f^2
Polyethylene	920	2000	1·8	4·7	$f^{1.1}$
Polymethylmethacrylate	1190	2680	3·2	2·0	f
Water	1000	1480	1·5	0·0022	f^2

* For frequencies below about 10 MHz.

Data chiefly from Kaye and Laby (1968).

TABLE 1.2

Field parameters for plane waves in water: values for 1 W cm^{-2} at 1 MHz

Parameter	Value	Dependence
Heat equivalent	0·24 cal s^{-1} cm^{-2}	(intensity)
Peak particle acceleration, a_0	71 000 gravity	$(\text{intensity})^{1/2}$, (frequency)
Peak particle displacement, u_0	0·018 μm	$(\text{intensity})^{1/2}$, $(\text{frequency})^{-1}$
Peak particle pressure, p_0	1·8 atmosphere	$(\text{intensity})^{1/2}$
Peak particle velocity, v_0	12 cm s^{-1}	$(\text{intensity})^{1/2}$
Radiation pressure,* F	0·069 g cm^{-2}	(intensity)
Velocity, c	1500 m s^{-1}	—
Wavelength, λ	1·5 mm	$(\text{frequency})^{-1}$

* For complete absorption

Data from Wells (1969).

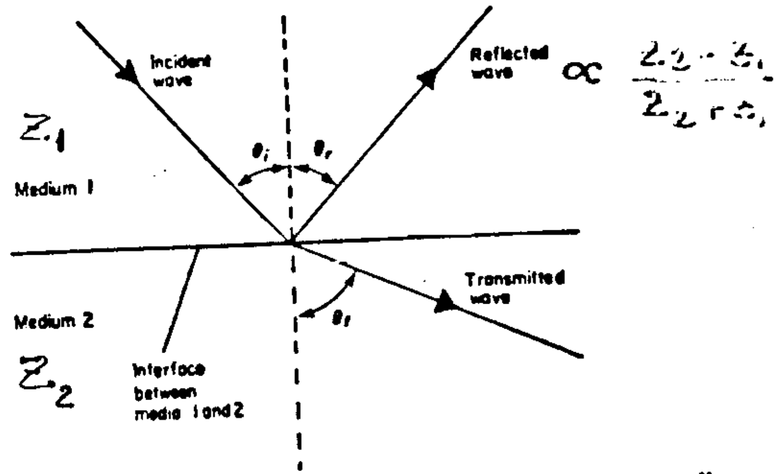


FIG. 1.8 The behaviour of a wave incident on the boundary between two media.

Amplitude of reflected wave

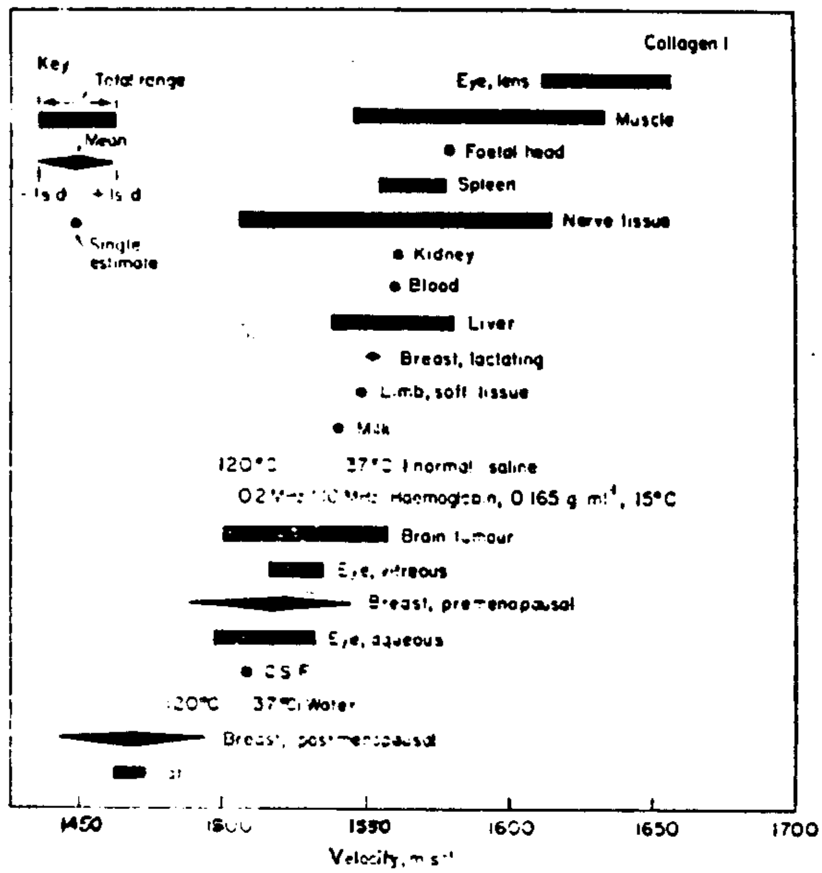
TABLE 1.3

Reflectivities of some plane, non-biological boundaries, expressed in decibels below the level from a perfect reflector

	Air	Aluminium	Brass	Castor Oil	Mercury	Polyethylene	Polymethylmethacylate
Aluminium	0·0						
Brass	0·0	8·9					
Castor Oil	0·0	1·4	0·7				
Mercury	0·0	27	9·8	1·3			
Polyethylene	0·0	1·8	0·4	18	2·1		
Polymethylmethacylate	0·0	3·1	1·5	8·4	2·9	11	
Water	0·0	1·4	0·6	34	1·3	19	8·7

Densities and characteristic impedances of some biological tissues

Material	Density $g\ ml^{-1}$	Characteristic impedance $10^6\ kg\ m^{-2}\ s^{-1}$
Blood	1·06	1·62
Bone	1·38–1·81	3·75–7·38
Brain	1·03	1·55–1·66
Fat	0·92	1·35
Kidney	1·04	1·62
Liver	1·06	1·64–1·68
Lung	0·40	0·26
Muscle	1·07	1·65–1·74
Spleen	1·06	1·65–1·67
Water	1·00	1·52



Collagen I
Key
Total range
Mean
+1s.d
Single estimate
Eye, lens
Muscle
Foetal head
Spleen
Nerve tissue
Kidney
Blood
Liver
Breast, lactating
Limb, soft tissue
normal saline
Brain tumour
Eye, vitreous
Eye, aqueous
20°C
37°C
Water
1450
1550
1600
1650
1700

(b)

TABLE 4.2

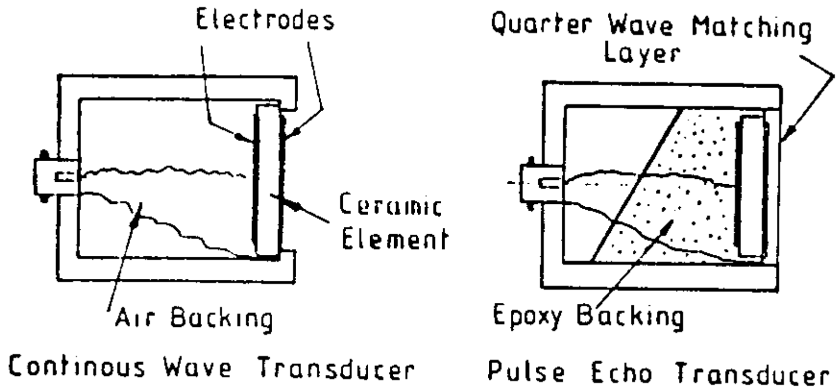
Reflectivities of some plane biological boundaries, expressed in decibels below the level from a perfect reflector

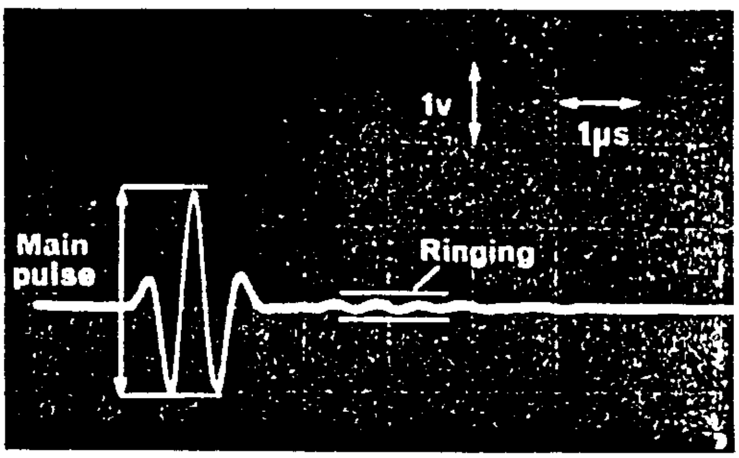
	Blood	Bone	Brain	Fat	Kidney	Liver	Lung	Muscle	Spleen
Bone	5								
Brain	50	5							
Fat	21	4	•						
Kidney	[illegible]	•	•	21					
Liver	38	•	•	20	38				
Lung	[illegible]	•	•	•	•	•			
Muscle	32	5	•	19	32	38	3		
Spleen	38	•	•	20	38	[illegible]	•	38	
Water	30	5	31	25	30	27	3	25	27

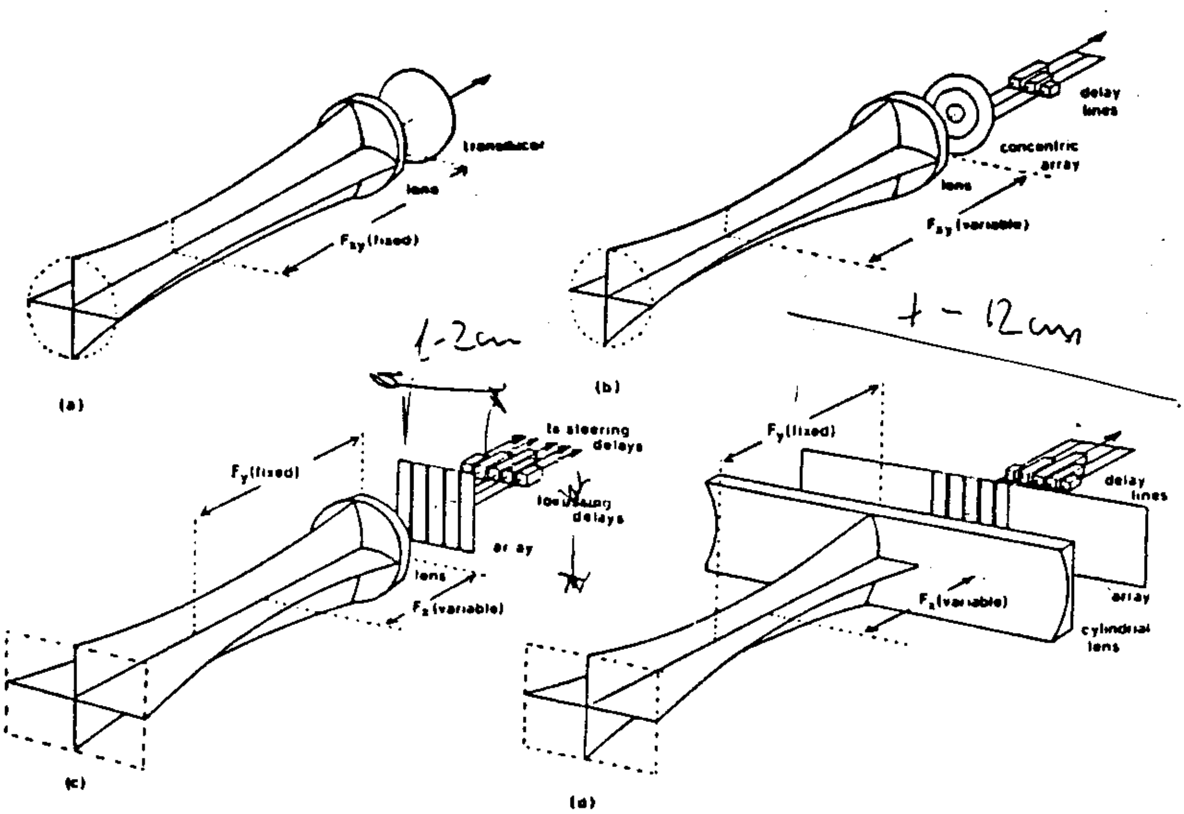
• Indicates that the corresponding boundary is unlikely to be of practical interest.
Based on data from Table 4.1.

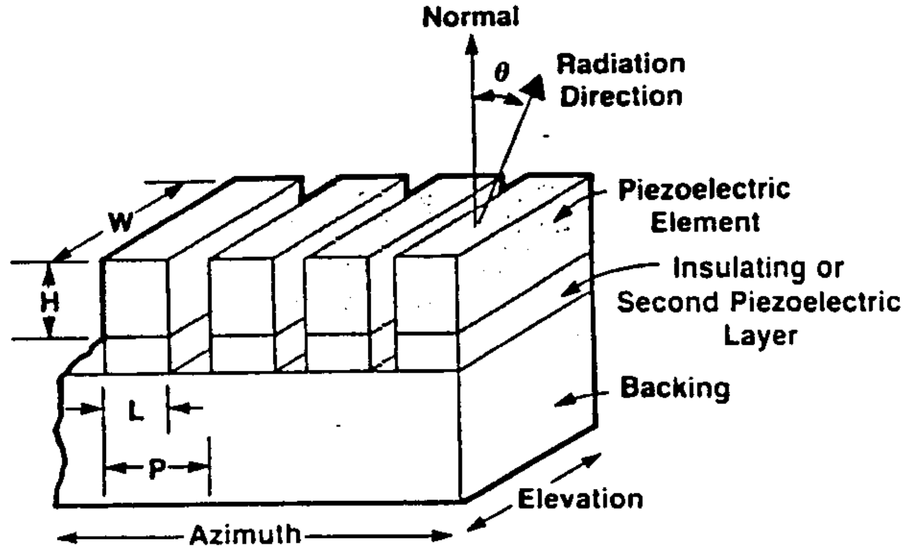
TRANSDUCERS

- SINGLE ELEMENT
- MULTIPLE ELEMENT
  - LINEAR ARRAYS
  - STEERED ARRAYS
  - CONVEX ARRAYS
  - ANNULAR ARRAYS


Electrodes
Ceramic
Element
Air Backing
Continous Wave Transducer
Quarter Wave Matching
Layer
Epoxy Backing
Pulse Echo Transducer


1v
1μs
Main
pulse
Ringing


transducer
lens
F_{sy} (fixed)
delay lines
concentric array
lens
F_{sy} (variable)
(a)
(b)
1-2cm
7-12cm
F_y (fixed)
steering delays
focusing delays
array
lens
F_z (variable)
(c)
F_y (fixed)
delay lines
F_z (variable)
array
cylindrical lens
(d)

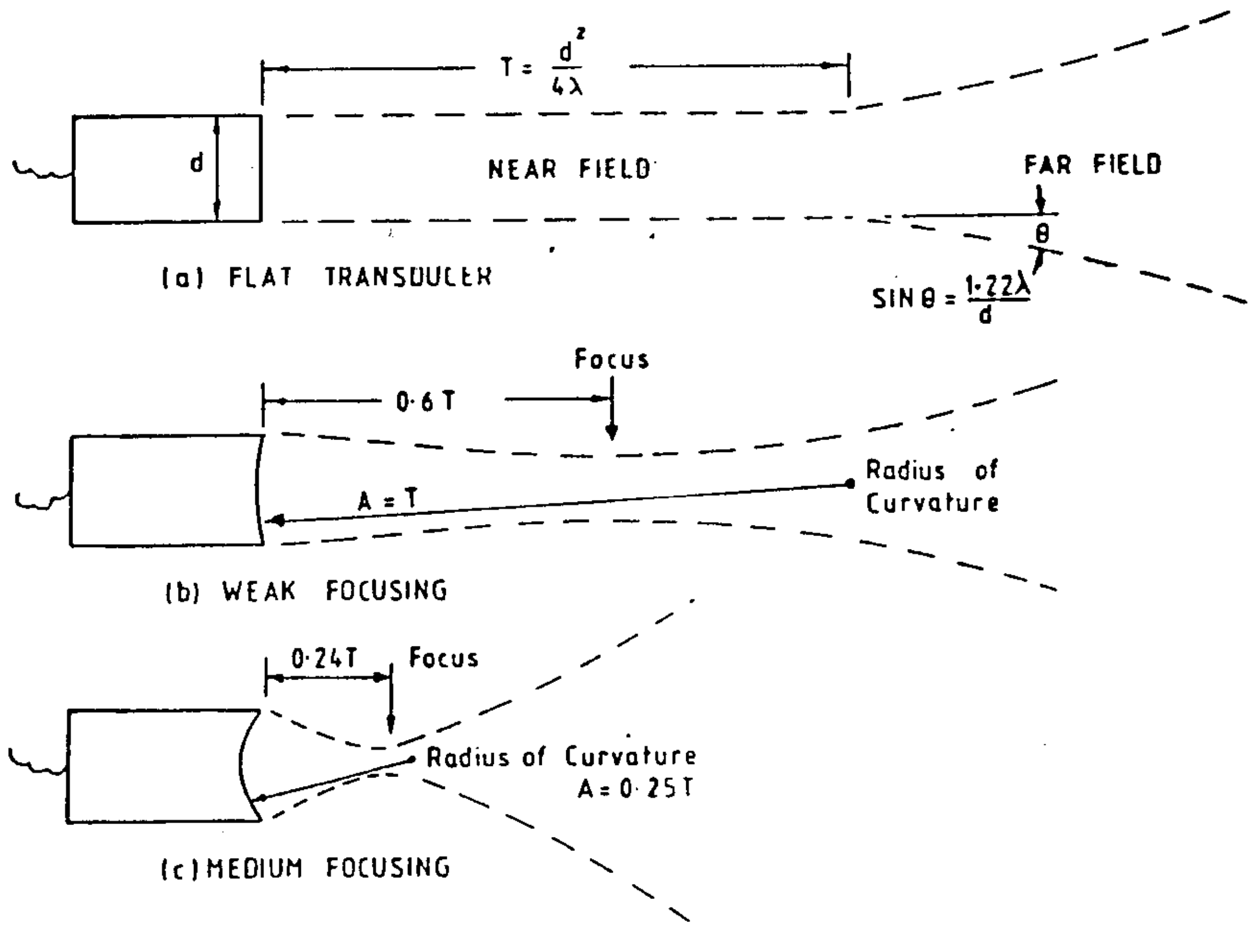

Normal
θ
Radiation Direction
W
H
Piezoelectric Element
Insulating or Second Piezoelectric Layer
Backing
L
P
Elevation
Azimuth

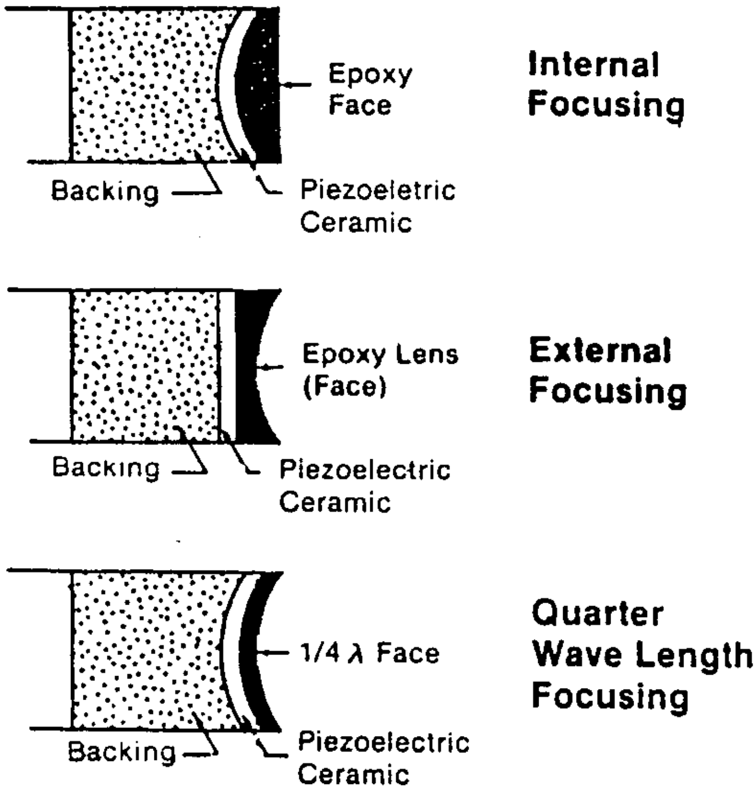
FOCUSSING TECHNIQUES

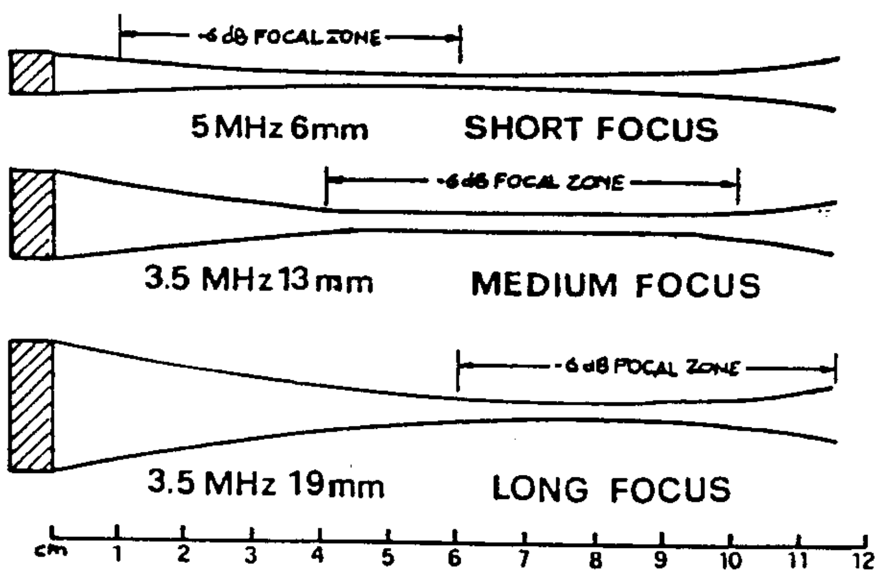
GOAL: To condense the radiated ultrasound energy into a beam of extremely narrow section.

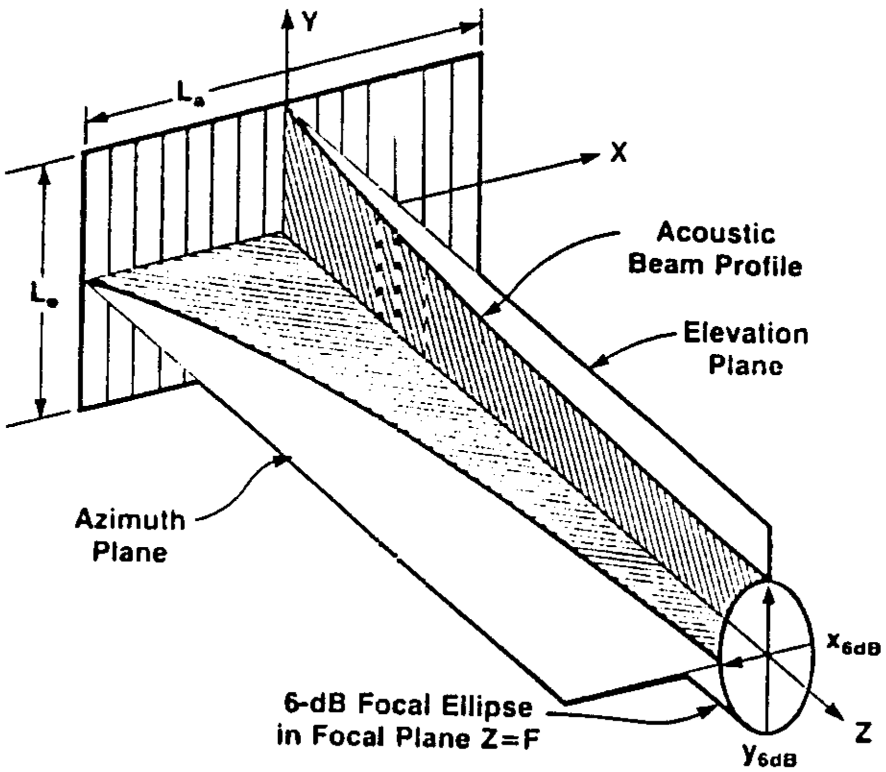
- ACOUSTIC LENSES
  (fixed focus)

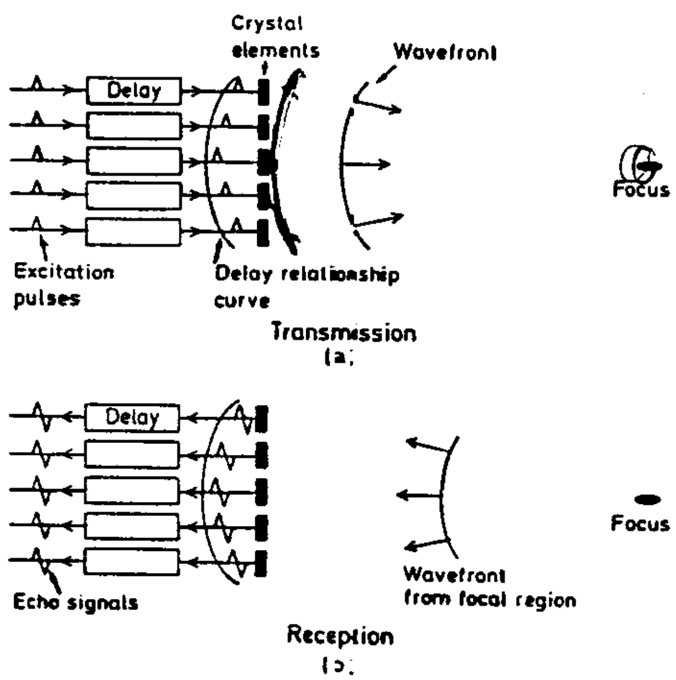
- ELECTRONIC LENSES
  (variable focus)

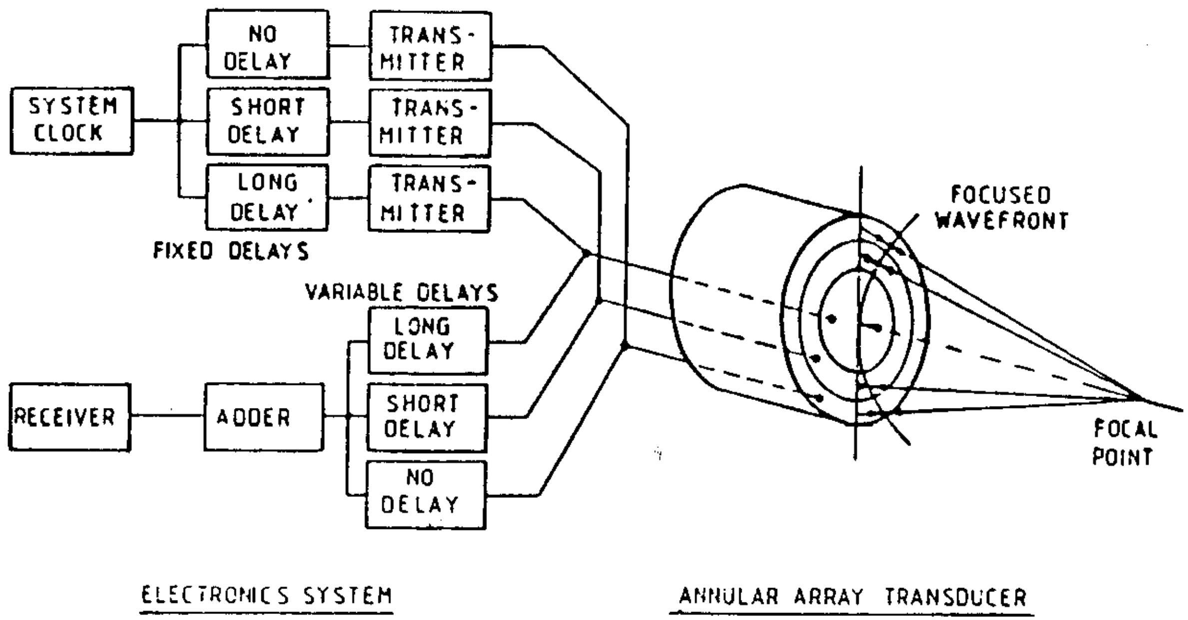

T = d²/4λ
d
NEAR FIELD
FAR FIELD
θ
SIN θ = 1·22λ/d
(a) FLAT TRANSDUCER
0·6 T
Focus
A = T
Radius of Curvature
(b) WEAK FOCUSING
0·24T
Focus
Radius of Curvature
A = 0·25T
(c) MEDIUM FOCUSING


Epoxy
Face
Internal
Focusing
Backing
Piezoeletric
Ceramic
Epoxy Lens
(Face)
External
Focusing
Backing
Piezoelectric
Ceramic
1/4 λ Face
Quarter
Wave Length
Focusing
Backing
Piezoelectric
Ceramic


-6 dB FOCAL ZONE
5 MHz 6mm
SHORT FOCUS
-6 dB FOCAL ZONE
3.5 MHz 13 mm
MEDIUM FOCUS
-6 dB FOCAL ZONE
3.5 MHz 19mm
LONG FOCUS
cm
1
2
3
4
5
6
7
8
9
10
11
12


Y
L_a
X
L_e
Acoustic
Beam Profile
Elevation
Plane
Azimuth
Plane
x_{6dB}
6-dB Focal Ellipse
in Focal Plane Z=F
Z
y_{6dB}


Crystal
elements
Wavefront
Delay
Focus
Excitation
pulses
Delay relationship
curve
Transmission
(a)
Delay
Focus
Echo signals
Wavefront
from focal region
Reception
(b)


SYSTEM CLOCK
NO DELAY
SHORT DELAY
LONG DELAY
FIXED DELAYS
TRANS-MITTER
TRANS-MITTER
TRANS-MITTER
VARIABLE DELAYS
LONG DELAY
SHORT DELAY
NO DELAY
RECEIVER
ADDER
FOCUSED WAVEFRONT
FOCAL POINT
ELECTRONICS SYSTEM
ANNULAR ARRAY TRANSDUCER

USING ULTRASOUND TO OBTAIN IMAGES ...

- Diagnostic ultrasound scanners

SCANNING TECHNIQUES

- <u>MECHANICAL SECTOR SCAN</u>

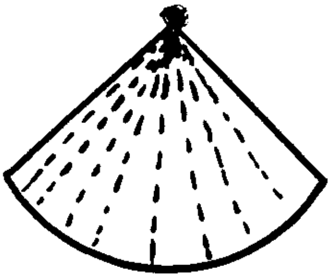
  SINGLE OR MULTIPLE ELEMENT
  ANNULAR ARRAY

- <u>ELECTRONIC SECTOR SCAN</u>

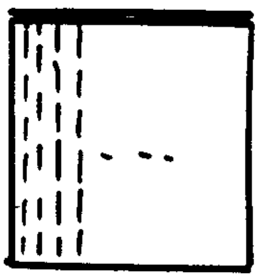
  STEERED (PHASED) ARRAY

- <u>LINEAR SCAN</u>

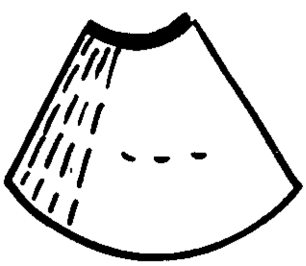
- <u>CONVEX SCAN</u>



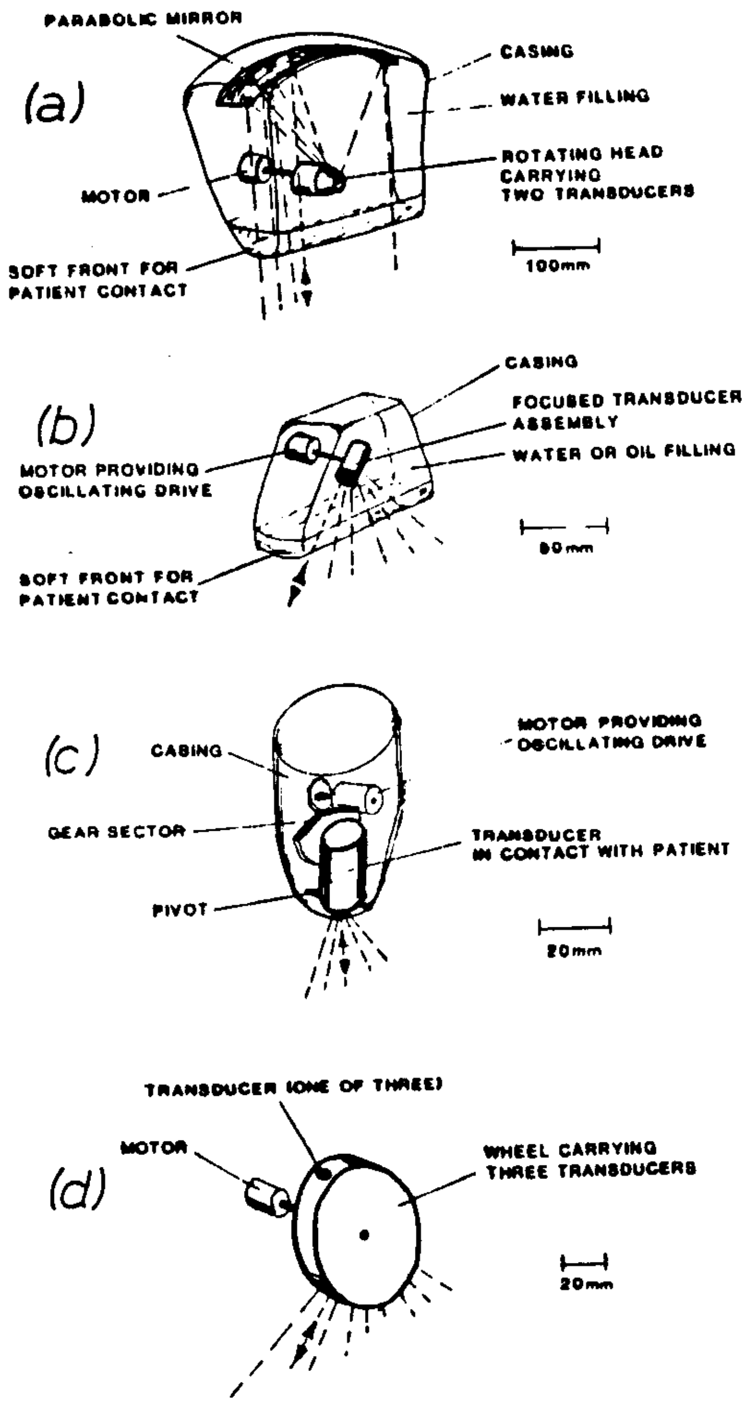
SECTOR SCAN



LINEAR SCAN



CONVEX SCAN



(a)
PARABOLIC MIRROR
CASING
WATER FILLING
ROTATING HEAD CARRYING TWO TRANSDUCERS
MOTOR
SOFT FRONT FOR PATIENT CONTACT
100mm
(b)
CASING
FOCUSED TRANSDUCER ASSEMBLY
WATER OR OIL FILLING
MOTOR PROVIDING OSCILLATING DRIVE
SOFT FRONT FOR PATIENT CONTACT
50mm
(c)
CASING
MOTOR PROVIDING OSCILLATING DRIVE
GEAR SECTOR
TRANSDUCER IN CONTACT WITH PATIENT
PIVOT
20mm
(d)
TRANSDUCER (ONE OF THREE)
MOTOR
WHEEL CARRYING THREE TRANSDUCERS
20mm

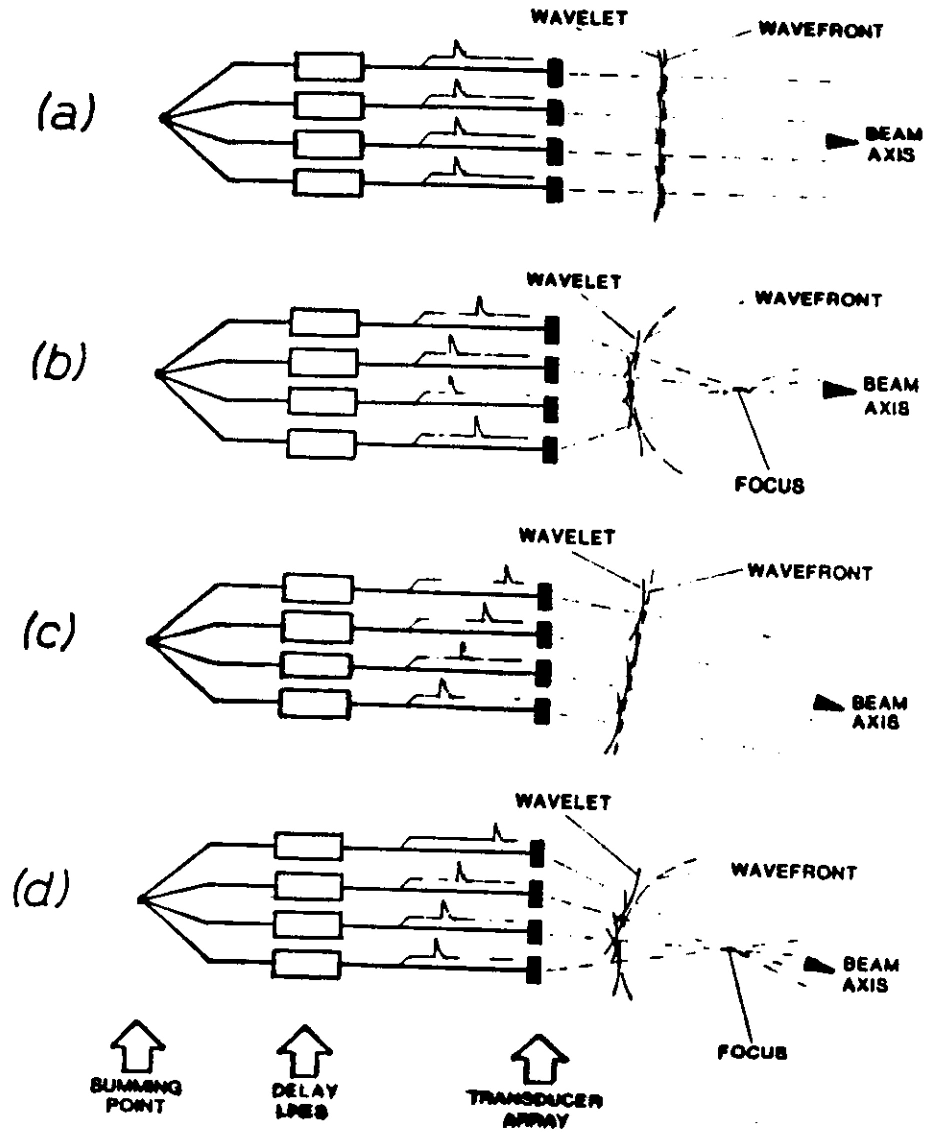


FIGURE 5.5. Synthetic focusing and steering of the ultrasonic beam produced by a transducer array. The long axes of the elements are normal to the plane of the diagrams; viewed in this direction, each element can be considered to emit a circular wavelet (a cross-section through a cylindrical wavelet) in response to electrical excitation. (a) When the elements are excited simultaneously (as indicated by the simultaneous "blips" associated with each electrical connection), the wavelets combine to form a wavefront of which the corresponding beam travels normal to the surface of the array. (b) When spherical time grading is used, the beam is focused. (c) When the elements are excited in sequence, the beam is deviated from the geometrical central axis. (d) When the time grading consists of combined spherical and linear distributions, the beam is simultaneously focused and deviated.

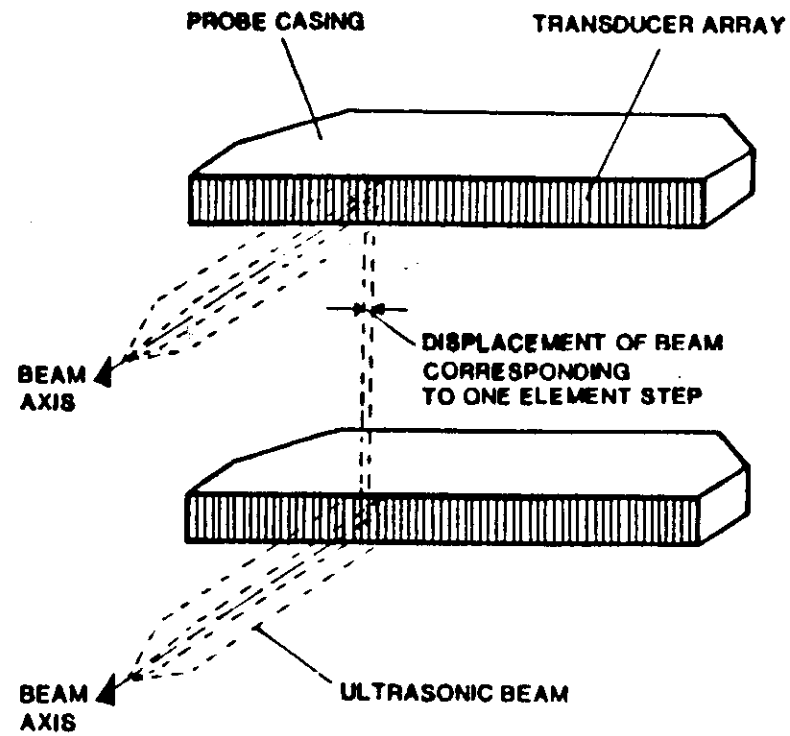
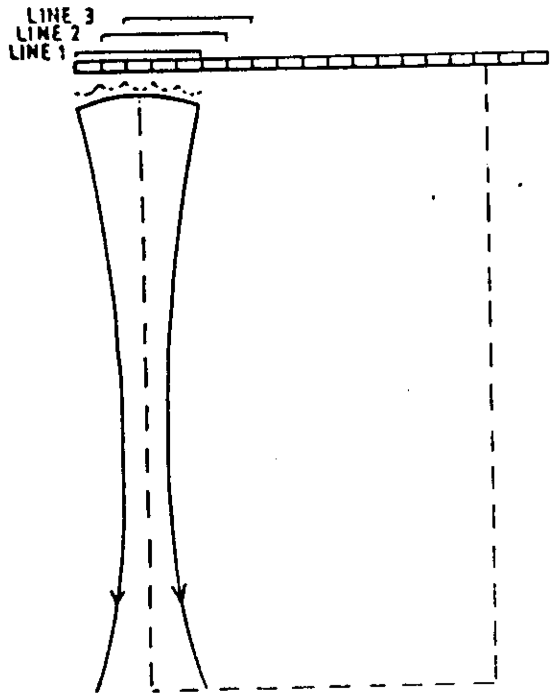
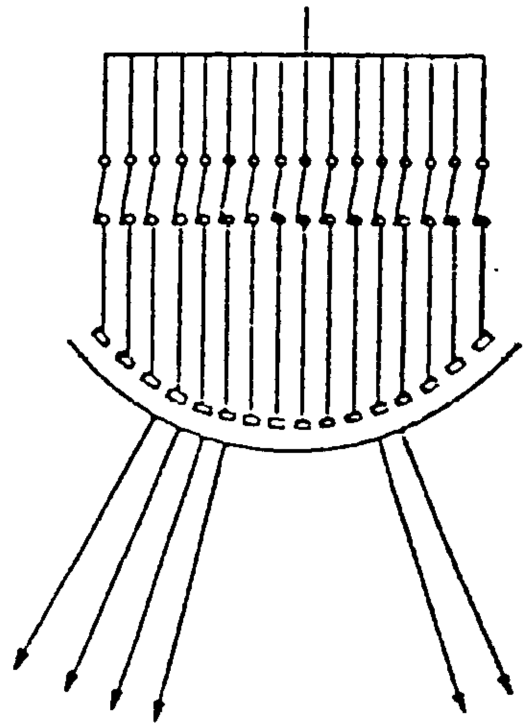
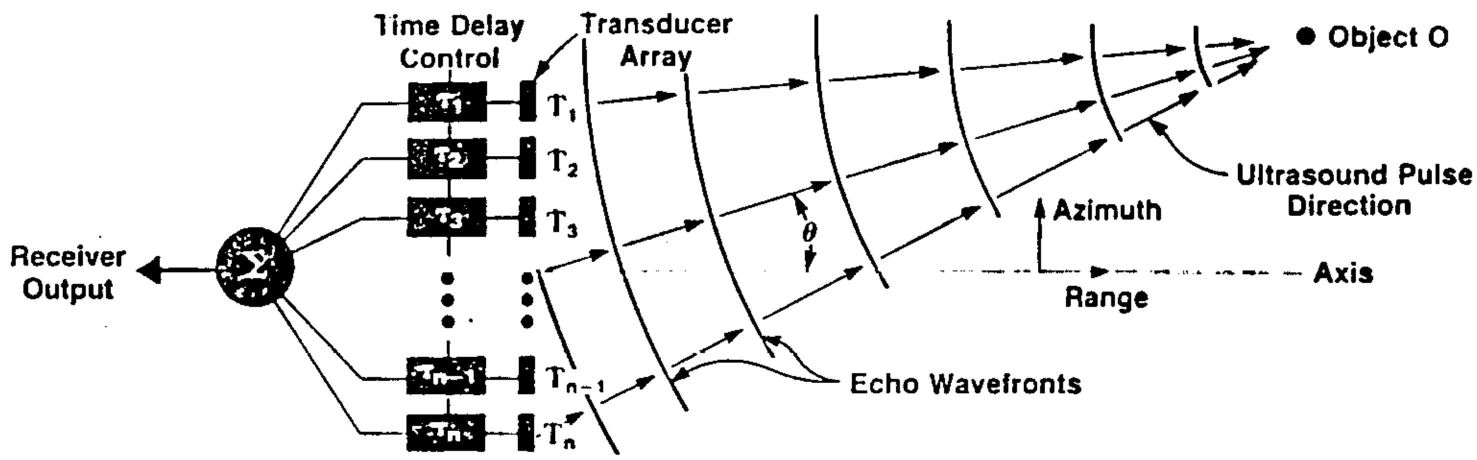
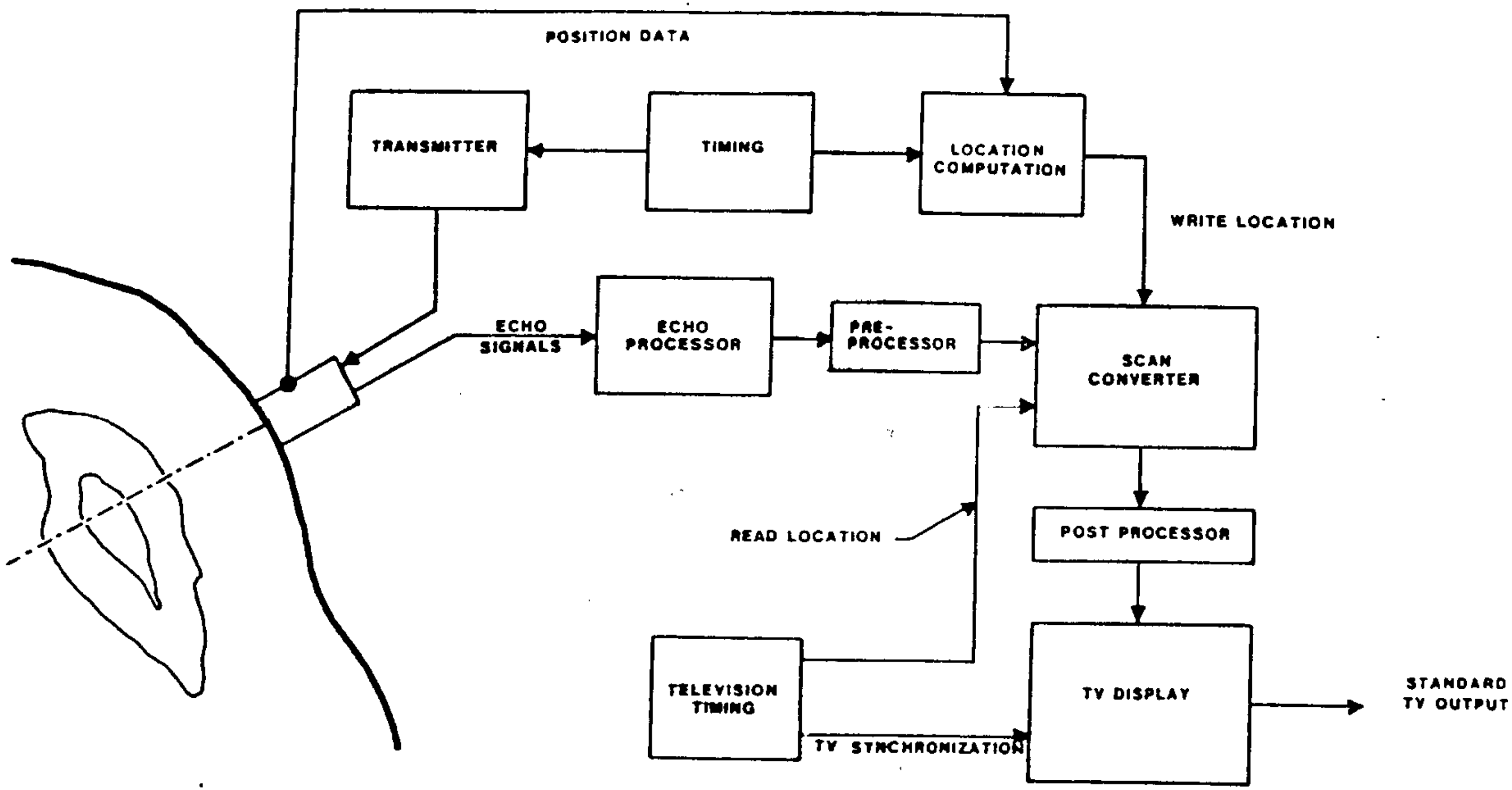


FIGURE 5.4. Linear transducer array operated in groups of four elements (to give an adequate aperture) stepped one element at a time (to give an adequate line density)


LINE 3
LINE 2
LINE 1




Time Delay Control
Transducer Array
Receiver Output
τ_1
τ_2
τ_3
τ_{n-1}
τ_n
T_1
T_2
T_3
T_{n-1}
T_n
θ
● Object O
Ultrasound Pulse Direction
Azimuth
Axis
Range
Echo Wavefronts


POSITION DATA
TRANSMITTER
TIMING
LOCATION COMPUTATION
WRITE LOCATION
ECHO SIGNALS
ECHO PROCESSOR
PRE-PROCESSOR
SCAN CONVERTER
READ LOCATION
POST PROCESSOR
TELEVISION TIMING
TV DISPLAY
STANDARD TV OUTPUT
TV SYNCHRONIZATION

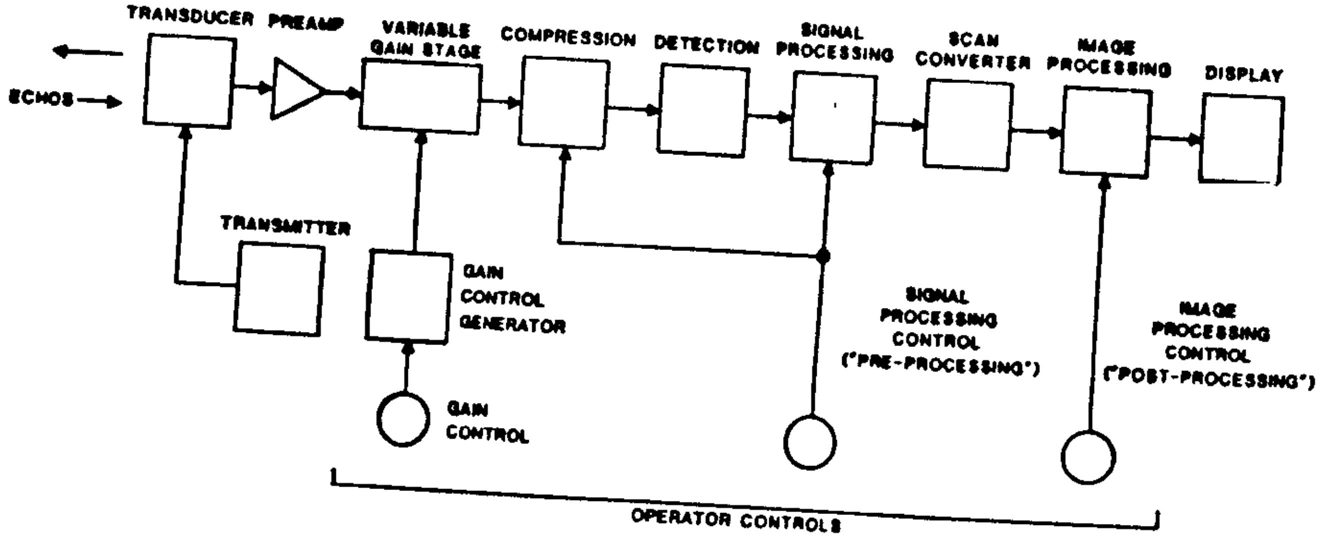


FIGURE 4.6. Echo signal path in imaging system

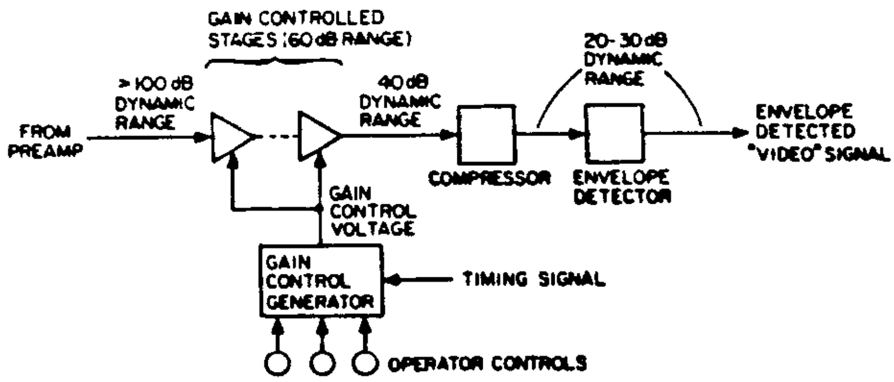


FIGURE 4.7. Variable-gain amplifier attenuation compensation

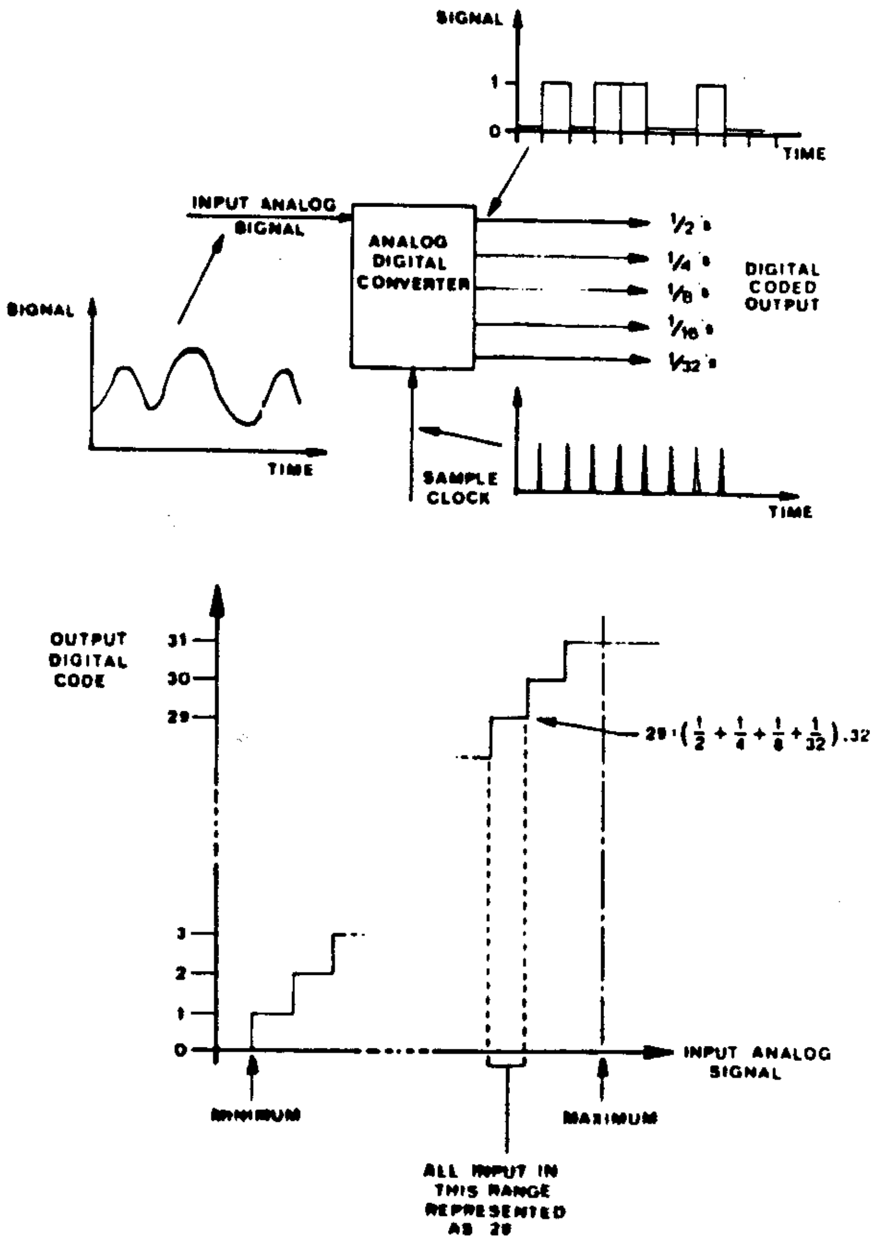


FIGURE 4.8. Quantization of continuous signal

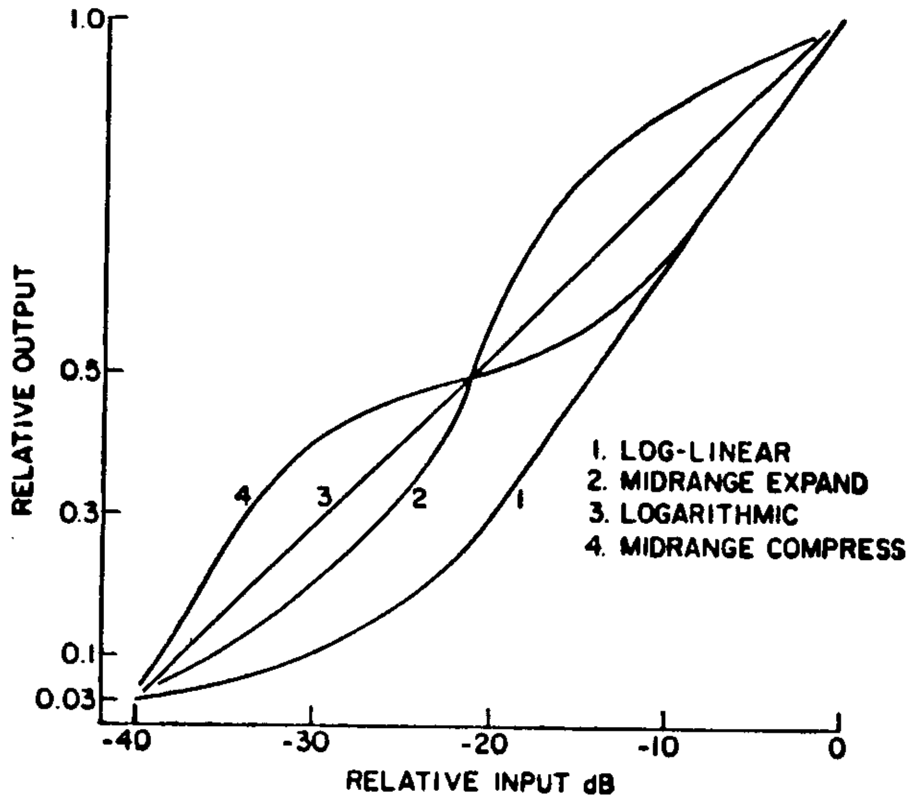


FIGURE 4.9. Preprocessing functions

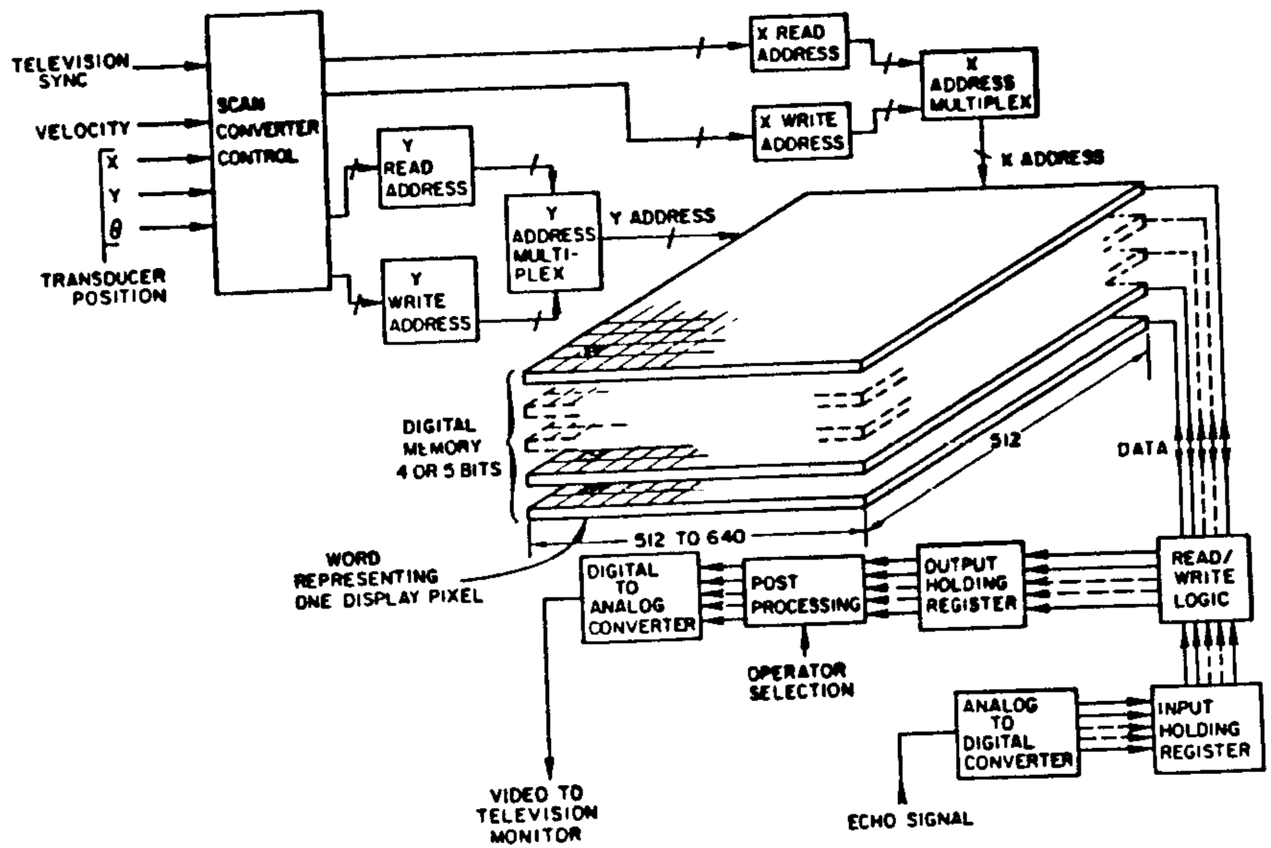
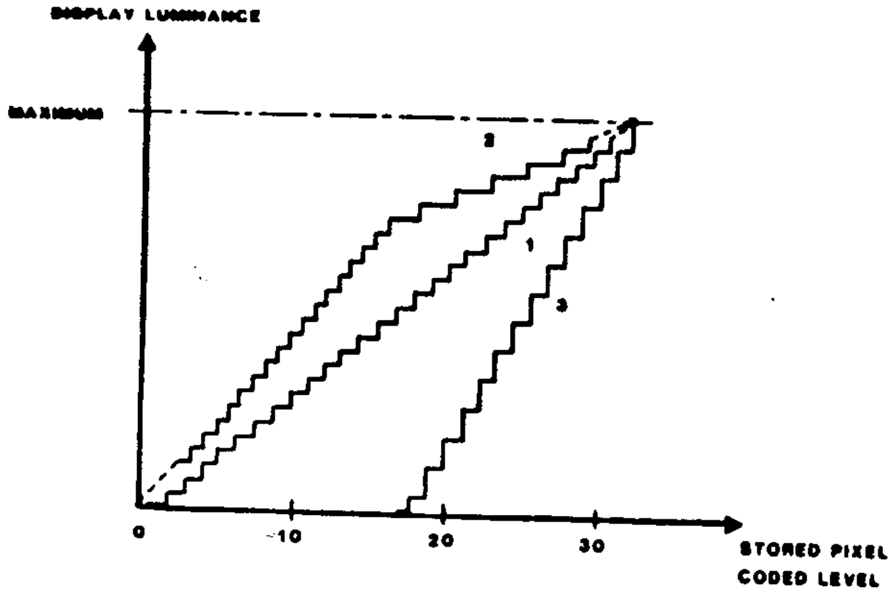


FIGURE 4.11. Digital scan converter construction



1. DIRECT TRANSFER
2. 'WEAK ECHO' EXPAND
3 REDUCED DYNAMIC RANGE

FIGURE 4.12. Post-processing amplitude functions

QUALITY PARAMETERS

- Geometrical resolution

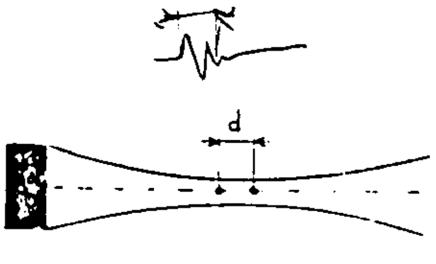
  AXIAL RESOLUTION

  LATERAL RESOLUTION

  ELEVATION RESOLUTION

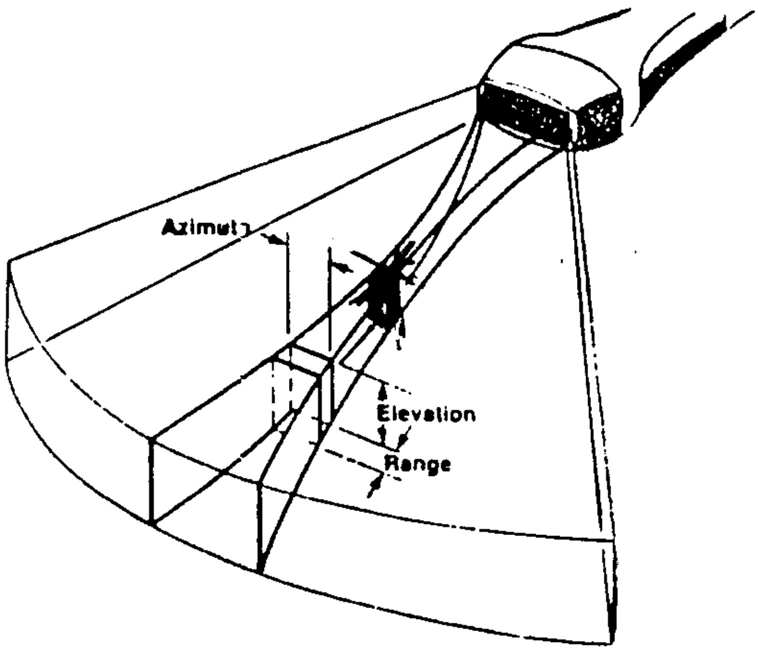
- Contrast resolution

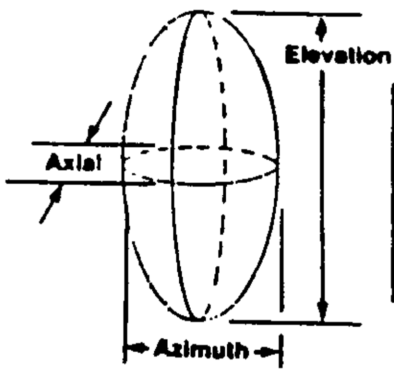
- Uniformity



AXIAL RESOLUTION

LATERAL RESOLUTION





−6-dB Resolution (mm)			
	Center Frequency (MHz)		
	2.5	3.5	5.0
Axial	1.4	0.9	0.9
Azimuth	2.0	2.0	1.4
Elevation	3.5	1.8	1.6

QUALITY ASSURANCE

- THE PURPOSE IS TO ASSURE THAT THE EQUIPMENT IS OPERATING AT THE EXPECTED LEVEL OF PERFORMANCE.

- SOMETIMES IT MAKES POSSIBLE TO PREVENT FAILURES OF THE EQUIPMENT AND TO REDUCE DOWNTIME.

HOW TO DO Q.A. TESTS?

- THE SAME TESTS MUST BE PERFORMED DURING EACH QUALITY CONTROL SESSION
- EACH TEST MUST BE DONE IN THE SAME MANNER (USING THE SAME TRANSDUCER AND WITH THE SAME EQUIPMENT ADJUSTMENT)
- KEEP A LOG OF Q.A. TESTS, MALFUNCTIONS, AND PREVENTIVE MAINTENANCE CALLS
- A QUALITY CONTROL SESSION SHOULD BE PERFORMED AFTER ANY SERVICE CALL.

WHICH PARAMETERS ?

- DISTANCE CALIBRATION (HOR.-VERT.) — NO VERT. AND HORIZ DISTORSION OF THE IMAGE
- DIGITAL CALIPER — LEVEL OF PRECISION OF THE SYSTEM OF DISTANCE MEASUREMEN
- MAXIMUM SENSITIVITY AND UNIFORMITY — THE DEEPEST ECHO SIGNAL YOU MAY DETECT AND DISPLAY AT OPTIMUM SETTINGS; UNIFORMITY OF THE SIGNAL AND OF THE IMAGE IN DIFFEREN AREAS
- GREY SCALE PHOTOGRAPHY — HARD COPY FIDELITY
- SPATIAL RESOLUTION — AXIAL AND LATERAL RES.
- CYST IMAGING CAPABILITIES — DETECTION OF SOLID AND LIQUID CYSTS
- PHISICAL ASPECT OF EQUIP. — CABLES, FILTERS, TRANSD CAMERAS, PROCESSOR

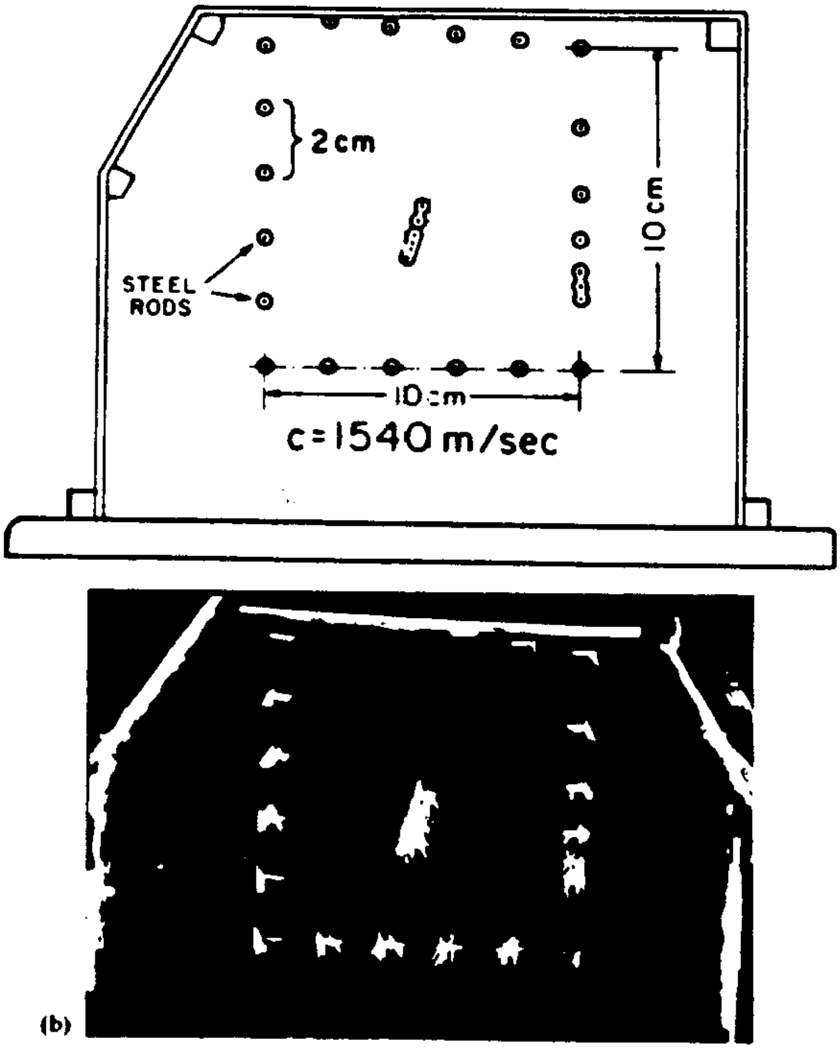
TEST OBJECTS

- TISSUE EQUIVALENT MATERIAL IN ORDER TO TEST THE US EQUIP. UNDER CLINICAL CONDITIONS

TIPICALLY ALL TISSUE MIMICKING PHANTOMS CONTAIN A SOLUTION OF:

- AGAR (POLYSACCARIDE GEL) (3%) (*)
- WATER
- PROPANOL
- GRAPHITE

(*) H.M. BURLEW and others: "A NEW ULTRASOUND TISSUE-EQUIVALENT MATERIAL" in RADIOLOGY vol. 134 n. 2 pages 517-520; febraary 1980



(a)

(b)

FIGURE 12.1. **(a) Schematic of the American Institute of Ultrasound in Medicine Standard 100 mm Test Object.**

(b) Image of the 100 mm test object. Vertical depth markers are compared to inter target spacings to test depth calibration. B mode registration accuracy is checked by imaging a single rod from four different sides of the test object.

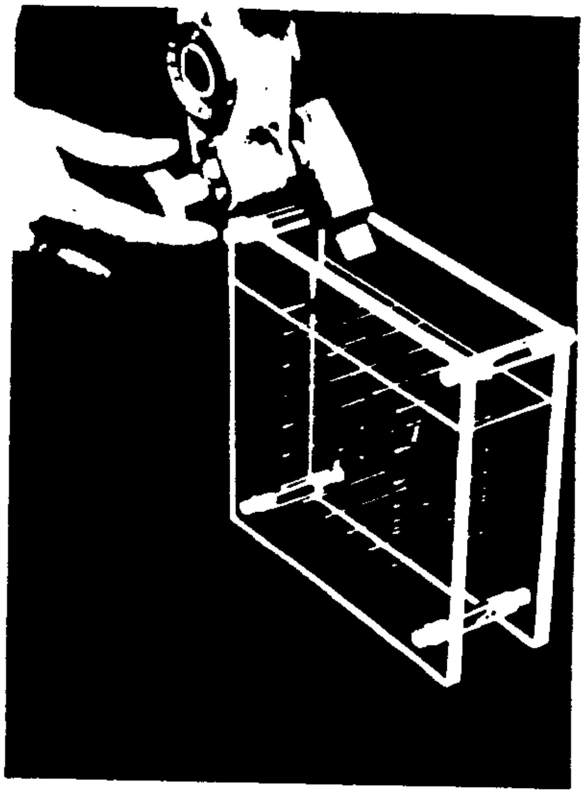


Figure A5-3. A.I.U.M. test object.

TABLE 12.1. Materials employed as tissue simulators

	Speed of Sound MS^{-1}	Attenuation at 1 MHz dB cm^{-1}	Reference
Silastics			
Silicon rubber			
Silicon fluid mixtures	950–970	~ .7	16
Wacker Silgel			14
Plastisols			
Epoxy soya plastisol	1550	3	17
Urethane polymer	1554	1.5	18
Styrene-Butadiene Resin			
(3M flotation pad gel)	1455	.22	24
	1470	.8	18,20
Water-based gels			
(with powder for attenuation)			
Gelatin	1500–1600	.2–1.5	20
Alginic acid			17
Agarose	1500–1600	.2–1.5	21

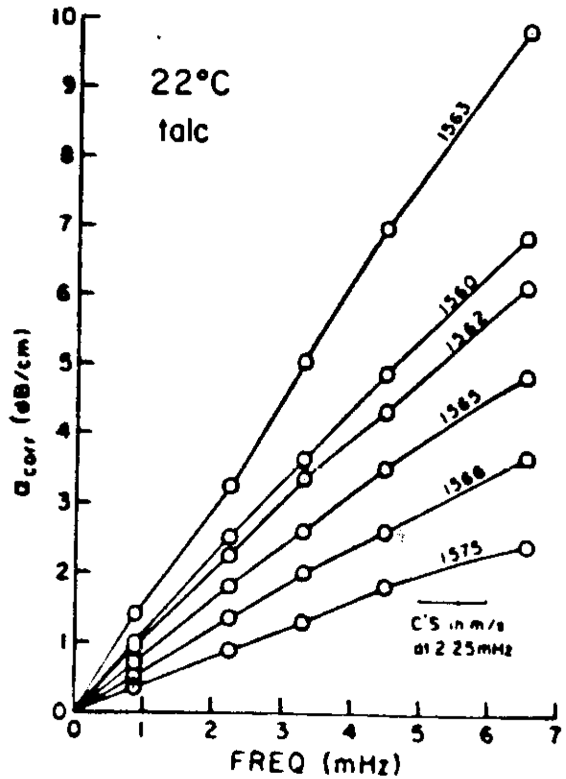


FIGURE 12.4 Attenuation vs frequency in different talc-gel samples. The speed of sound in the material is also shown on the curves.

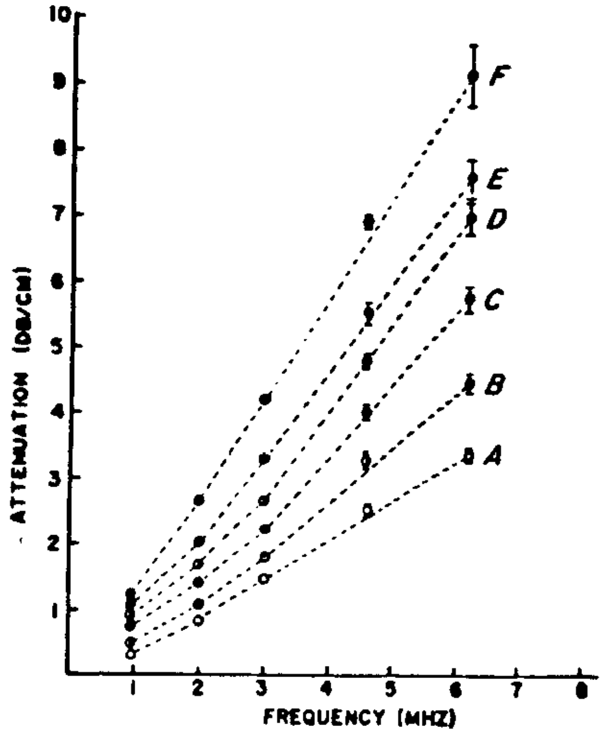


FIGURE 12.3 Attenuation vs frequency in graphite-gel material for five different graphite concentrations ranging from 0.49 g cm^{-3} (A) to 0.187 g cm^{-3} (F).

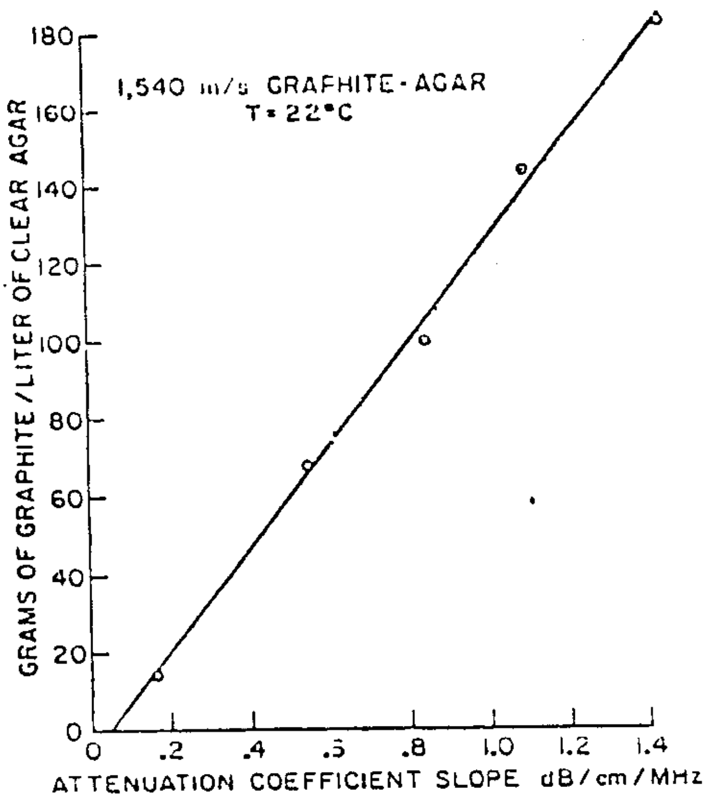


Fig. 2. This graph shows the approximately linear relation between the grams of graphite powder per liter of agar-water-propanol matrix material and the slope of the attenuation coefficient.

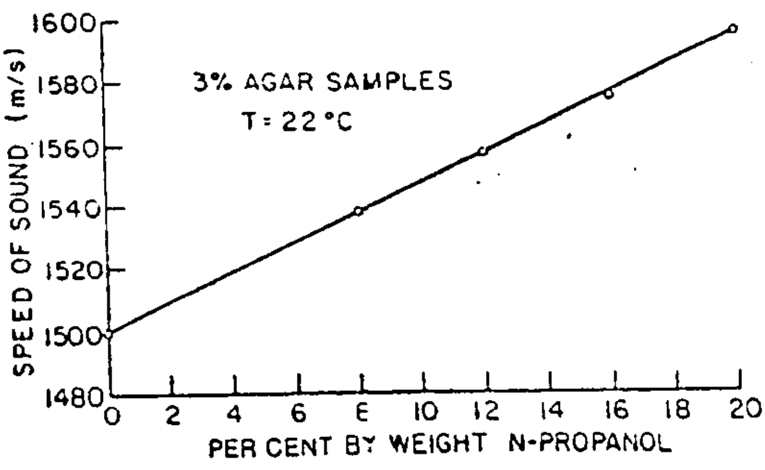
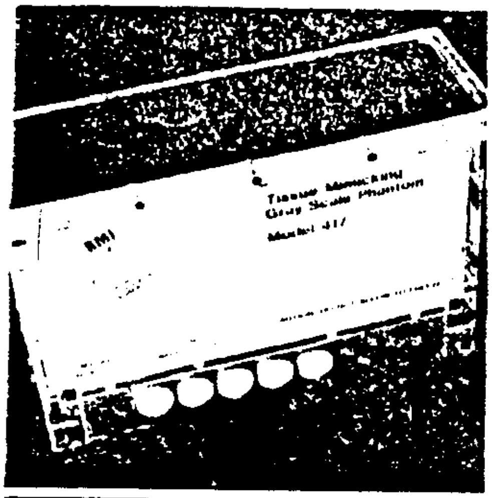
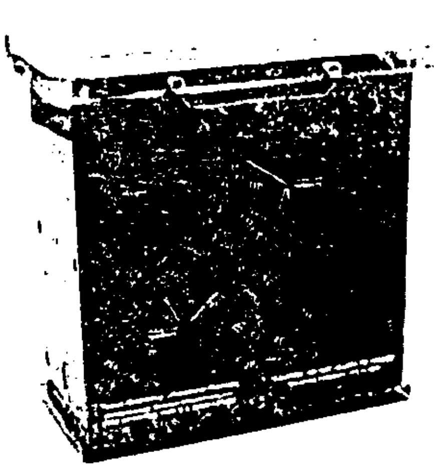


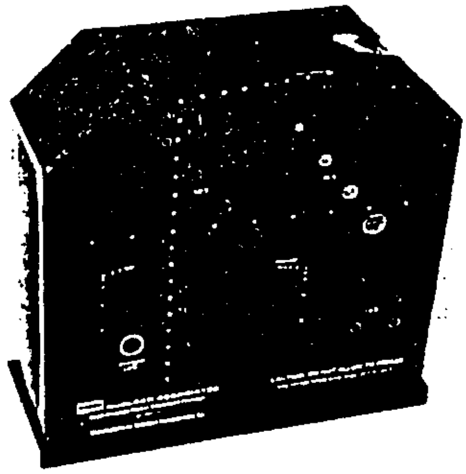
Fig. 4. Speed of sound *vs.* concentration of *n*-propanol at 22°C, showing a linear relation for sample D (TABLE I). Graphs for samples A through E are nearly identical.



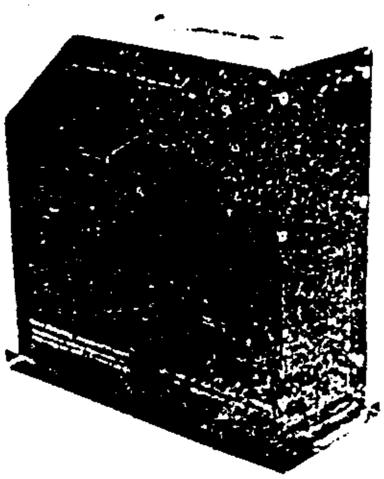
Model 417



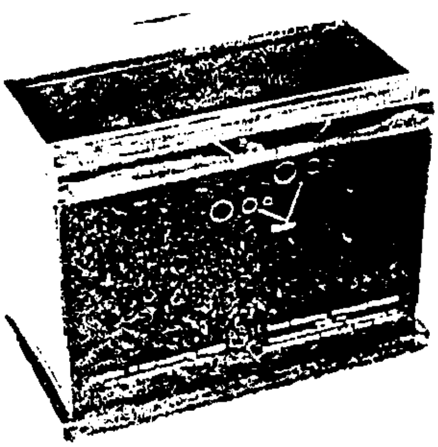
Model 413A



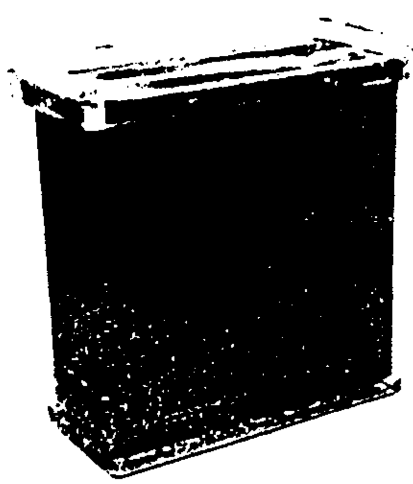
Model 84-317



Model 412A



Model 414B



Model 410B

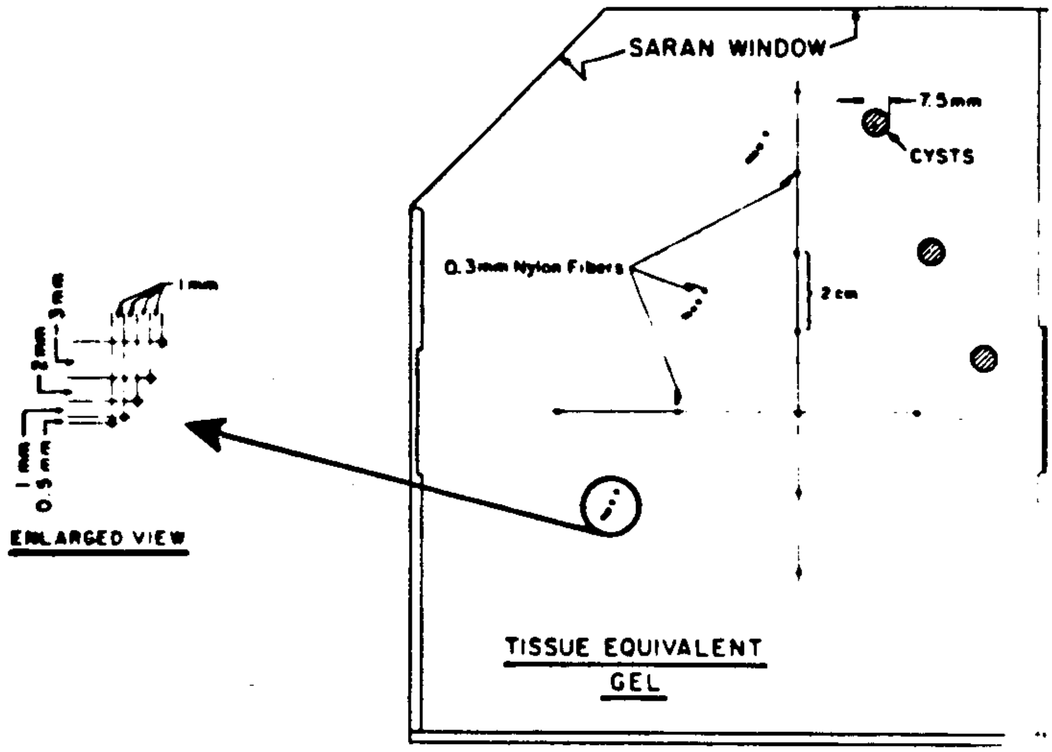


FIGURE 12.5. Test phantom for ultrasonic B-scanners. (Figure from Radiation Measurements, Inc., Middleton, Wisc.)

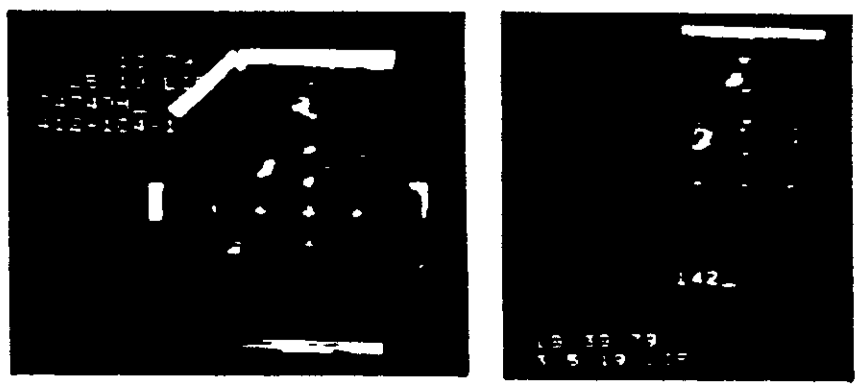
(a)  (b)

FIGURE 12.6. Images of phantom in Figure 5.
(a) Line targets allow depth calibration, resolution and B-scan registration accuracy to be determined.
(b) Texture allows depth of penetration to be estimated.

COMMON CHARACTERISTICS OF TEST OBJECTS:

- A TISSUE EQUIVALENT MATRIX OF AGAR AND GRAPHITE
- REFLECTORS MADE WITH NYLON WIRES (0.2, 0.3 mm
- REFLECTORS ARRANGED IN DIFFERENT CONFIGURATIONS DEPENDING ON THE PARAMETER TO BE MEASURED
- INCLUSIONS OF GEL WITH DIFFERENT CHARACTERISTICS WITH RESPECT TO THE GEL OF THE MATRIX, IN ORDER TO SIMULATE LIQUID OR SOLID CYSTS.

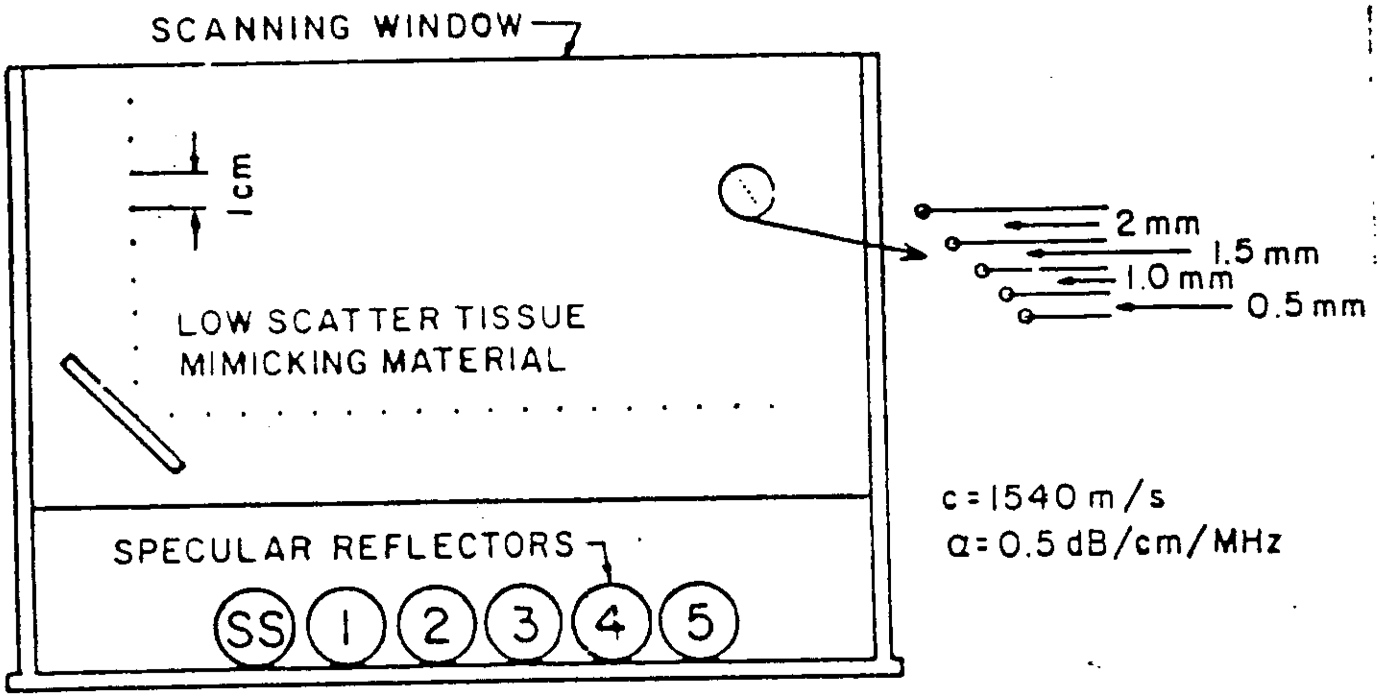
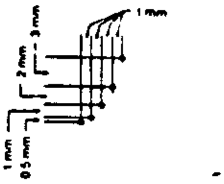


Fig. 2. Schematic of Gray Scale Ultrasound Phantom.

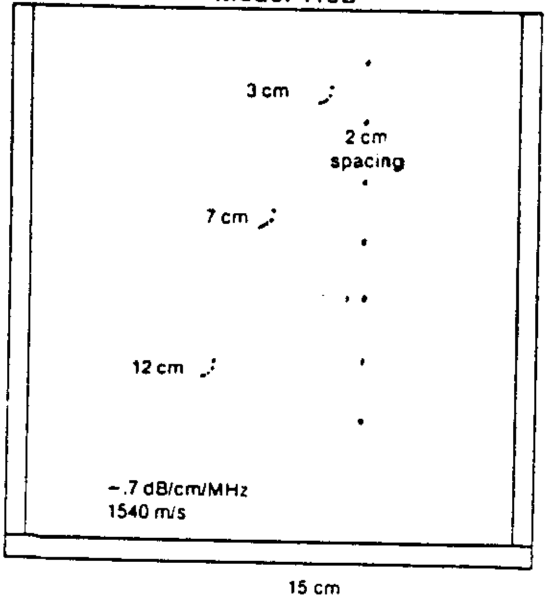
SCHEMATICS OF PHANTOM GEOMETRY



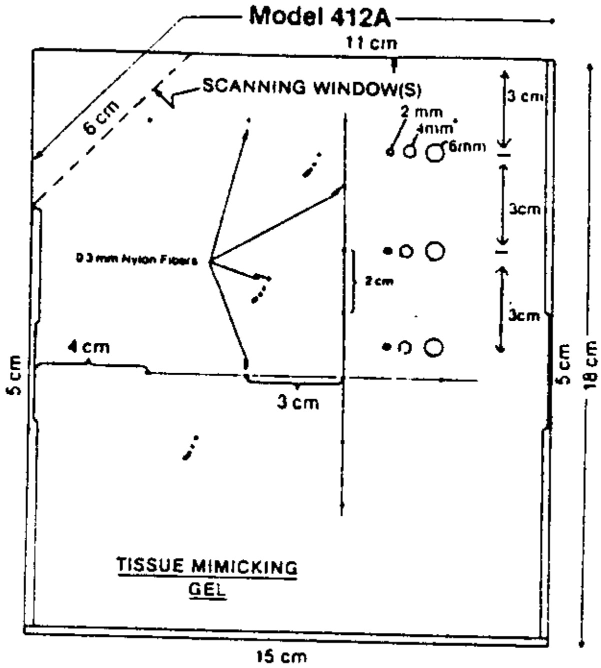
ENLARGED VIEW OF NYLON LINE RESOLUTION PATTERN USED IN THE MODEL 410B, 412A, AND 413A.

Note: Models 410B, 413A, 414B and 417 have water troughs. Models 412A, and 84-317 do not.

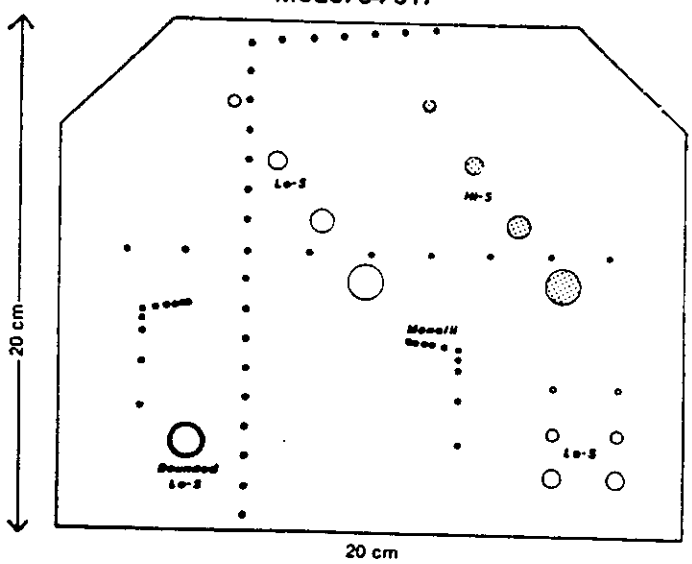
Model 410B



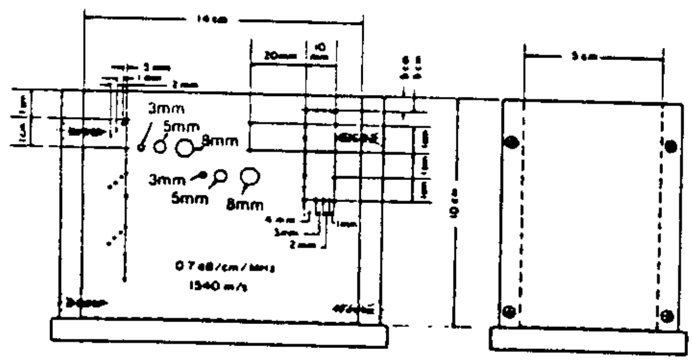
Model 413A
Model 412A



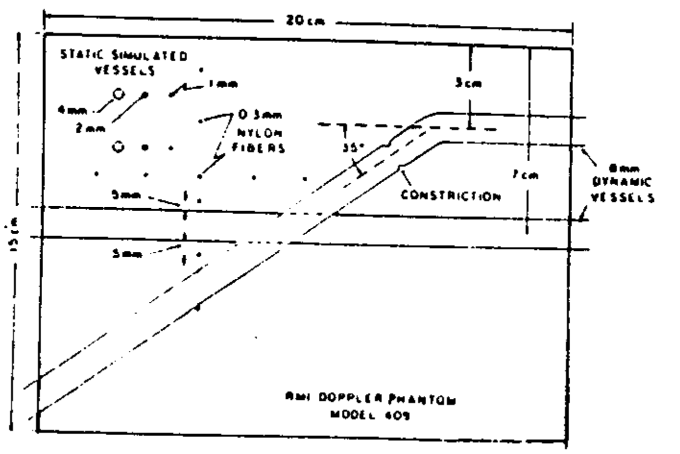
Model 84-317



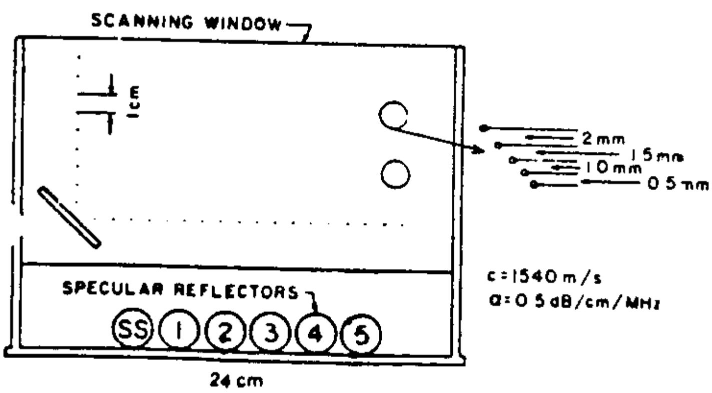
Model 414B

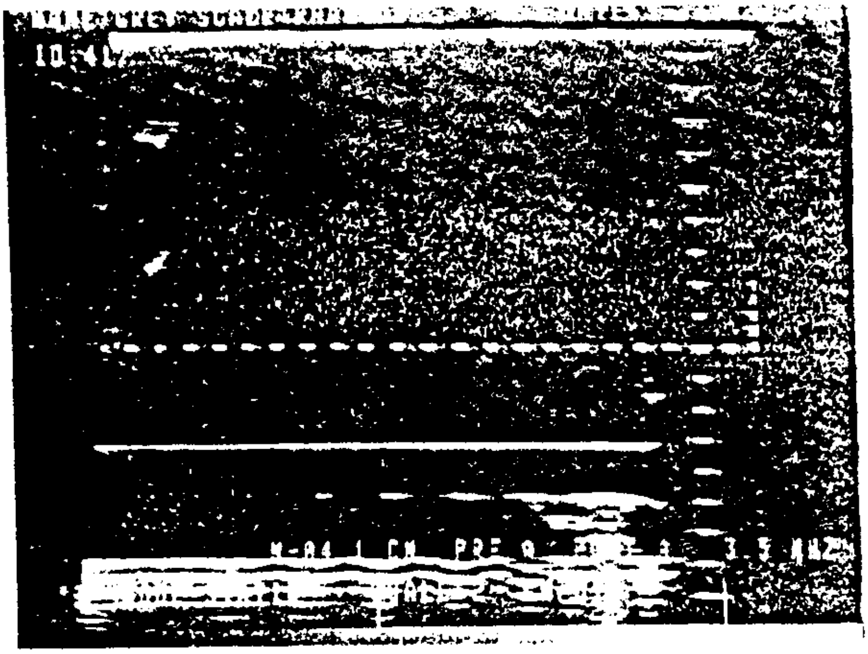


Model 409

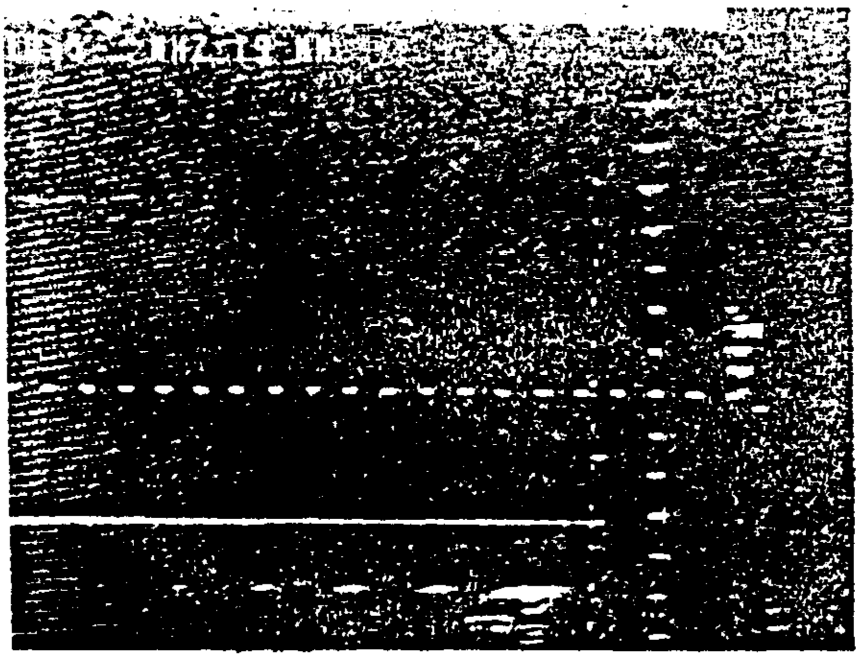


Model 417





7A

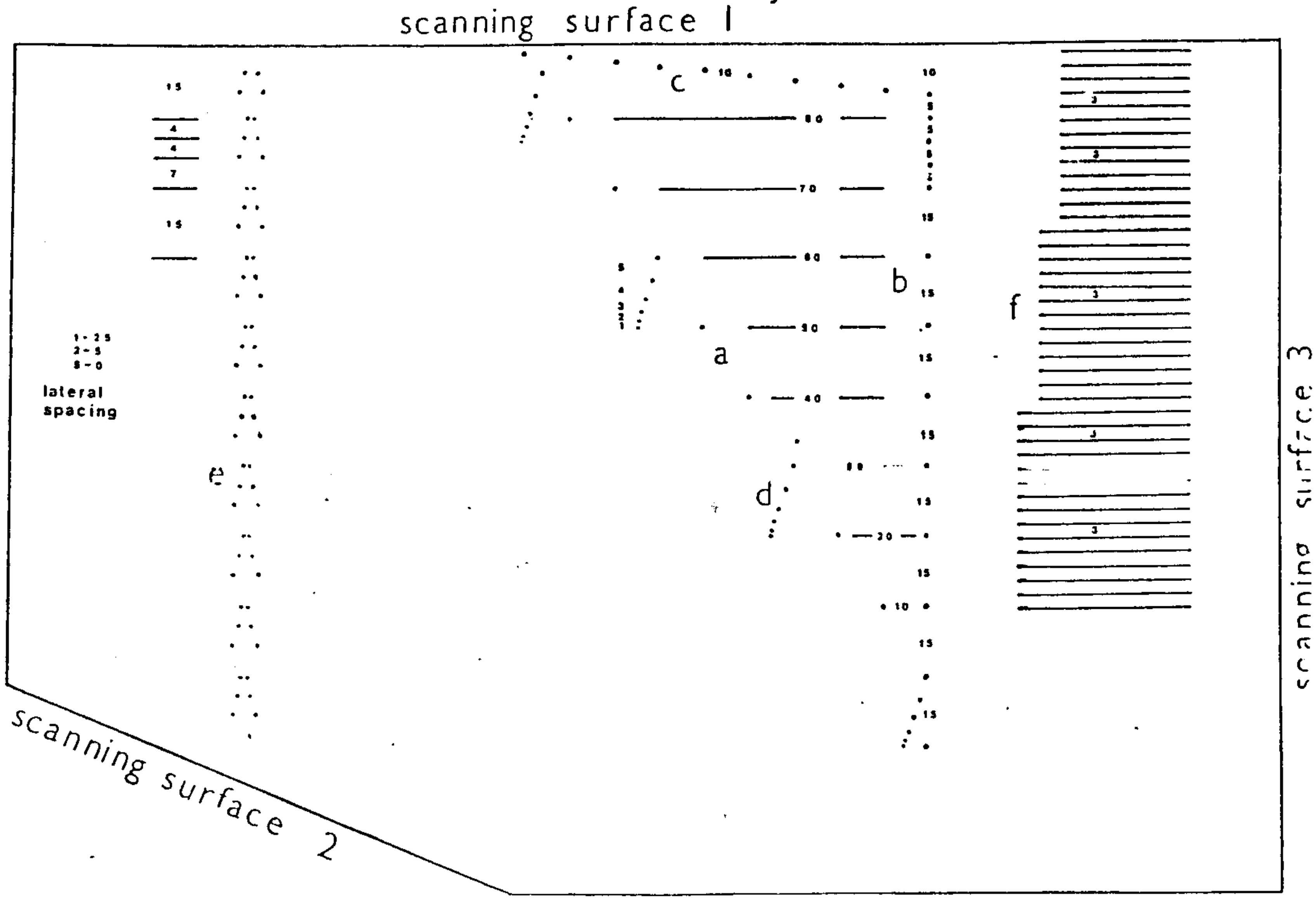


7B

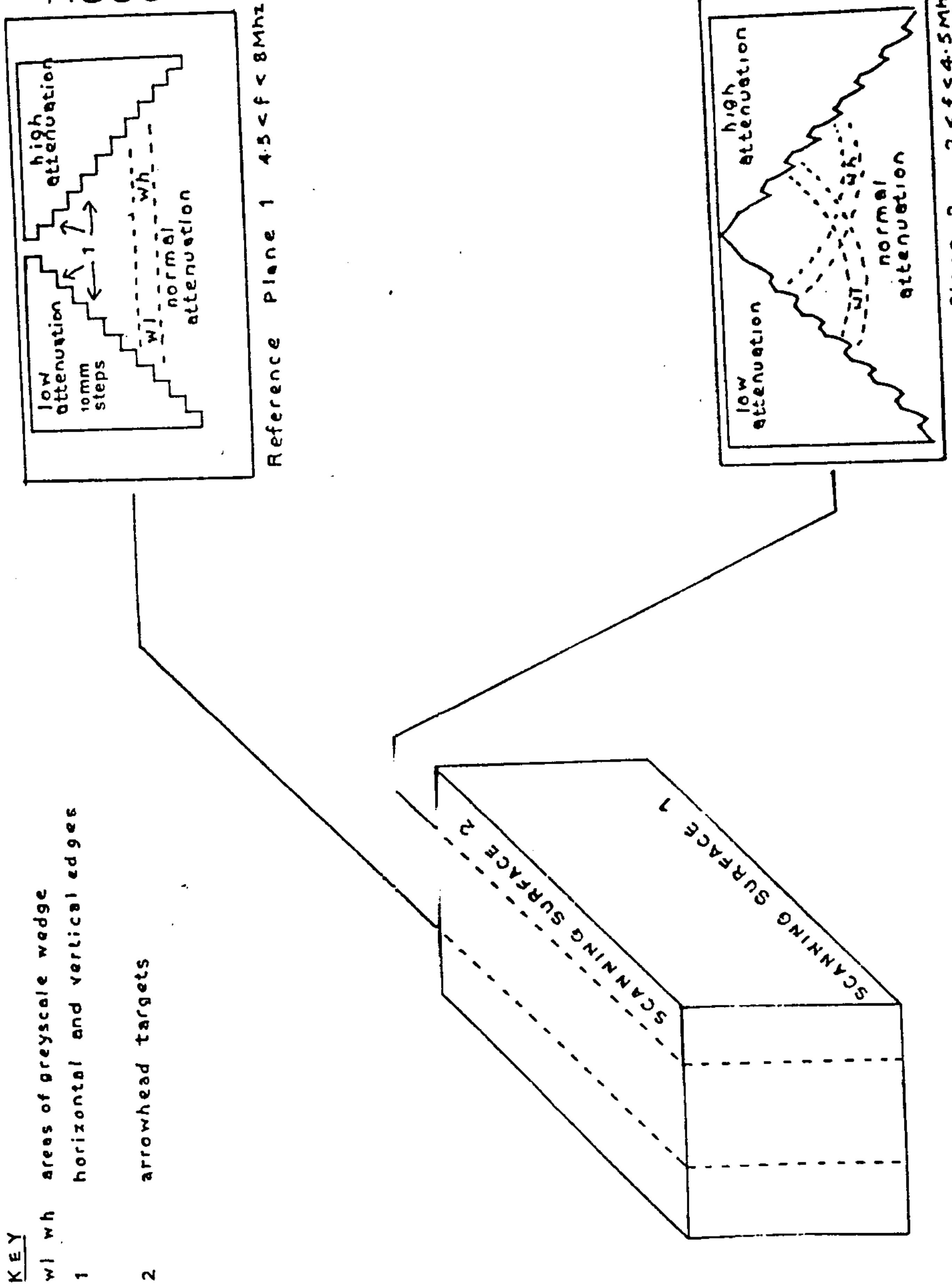
7. Scan using 3.5 MHz transducer (7A) and 5 MHz transducer (7B) showing line ets. Note the beam width pattern in the extended line target column.

rences:

RESOLUTION TEST OBJECT



ACOUSTIC GREYSCALE TEST OBJECT



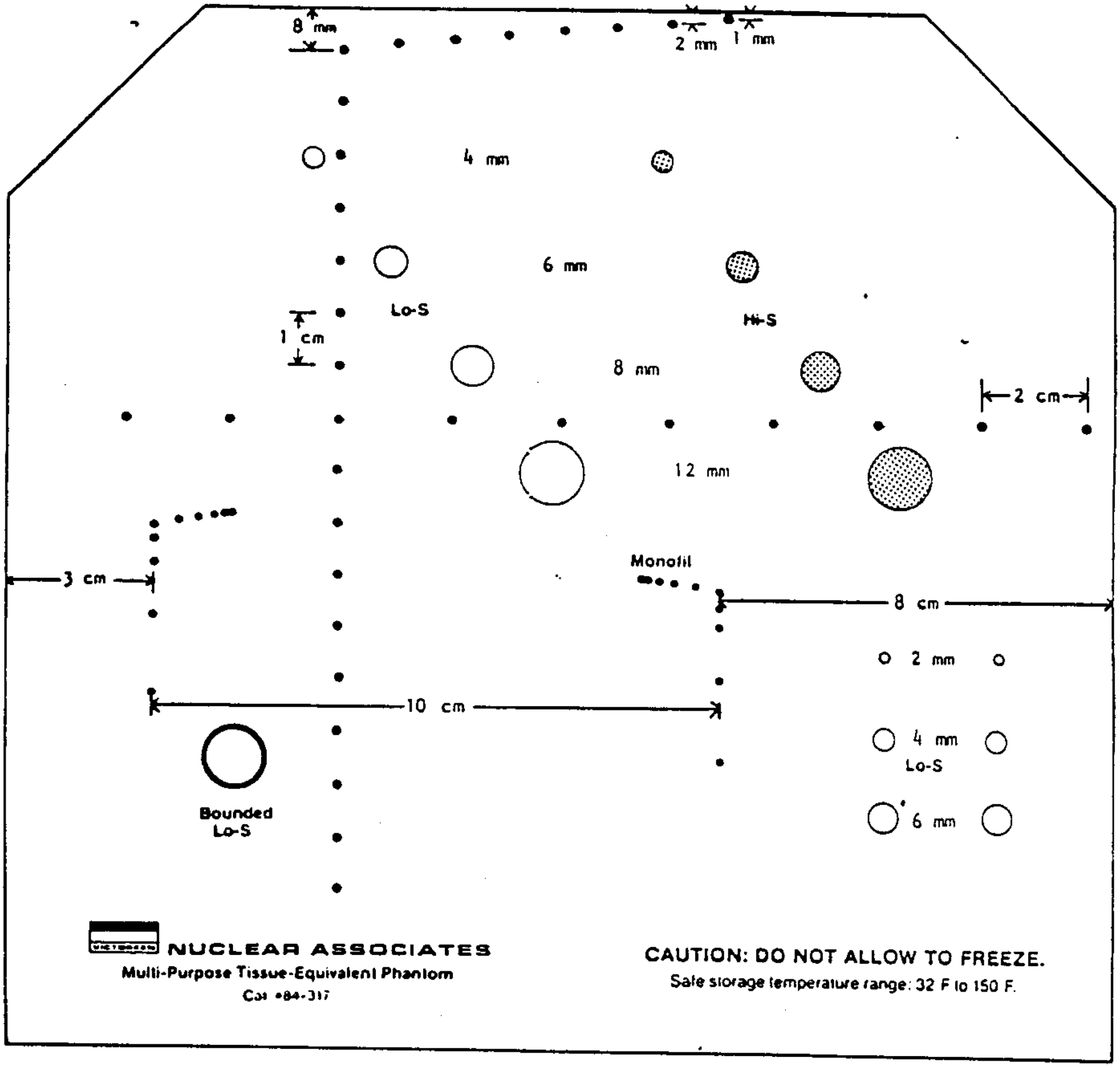


Figure 1.

Internal Targets of Multi-Purpose Tissue-Equivalent Phantom

(Shown 85% of full scale)

EVALUATION PROTOCOL

1. CHARACTERISTICS OF THE ACOUSTIC FIELD
1.1 Sptp Intensity
1.2 Sppa Intensity
1.3 Space/Time Variation of Pulse Intensity
1.4 Distribution of the Pulse Intensity Integral
1.5 Distribution of Peak Intensity

2. PULSE CHARACTERISTICS
2.1 Pulse Waveform
2.2 Spectral Distribution
2.3 Pulse Central (Working) Frequency
2.4 Duty-Cycle

3. GEOMETRICAL CHARACTERISTICS OF THE BEAM
3.1 Beam Shapes
3.2 Variation of Acoustic Pressure along the Beam Axis
3.3 Focal length
3.4 Extent of Focal Zone
3.5 Focal Area

4. SCAN CHARACTERISTICS
4.1 Pulse Repetition Frequency
4.2 Scan Frame Rate
4.3 Number of Acoustic Lines per Scan
4.4 Image Frame Rate

5. GENERAL CHARACTERISTICS
5.1 Dead-Zone
5.2 Axial Resolution
5.3 Lateral Resolution
5.4 Penetration in an Absorptive Medium
5.5 Geometrical Distortion
5.6 Imaging of Cyst-Type Structures
5.7 Accuracy and Linearity of the Measurement System

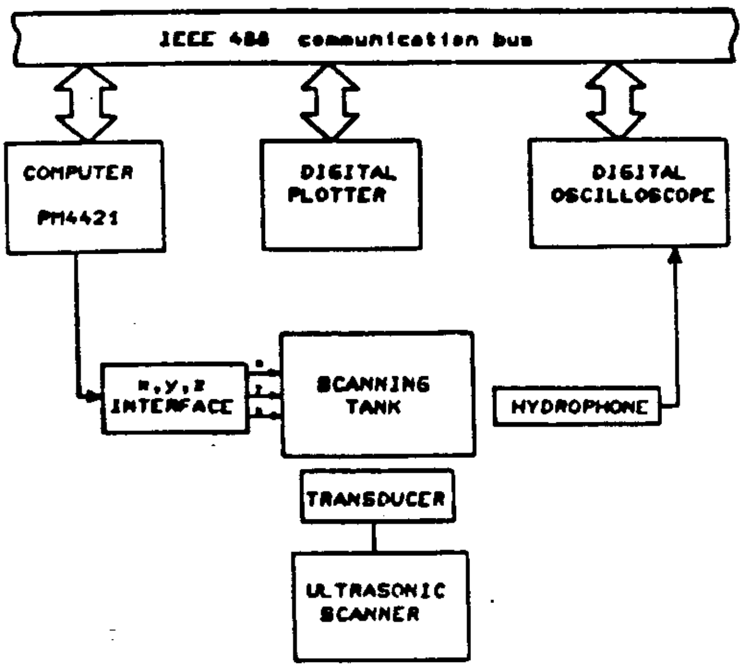


Fig. 1: Struttura del sistema per l'esecuzione delle misure di campo acustico.

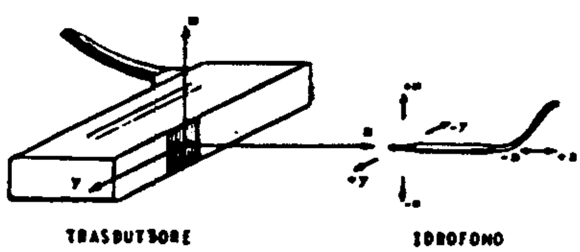
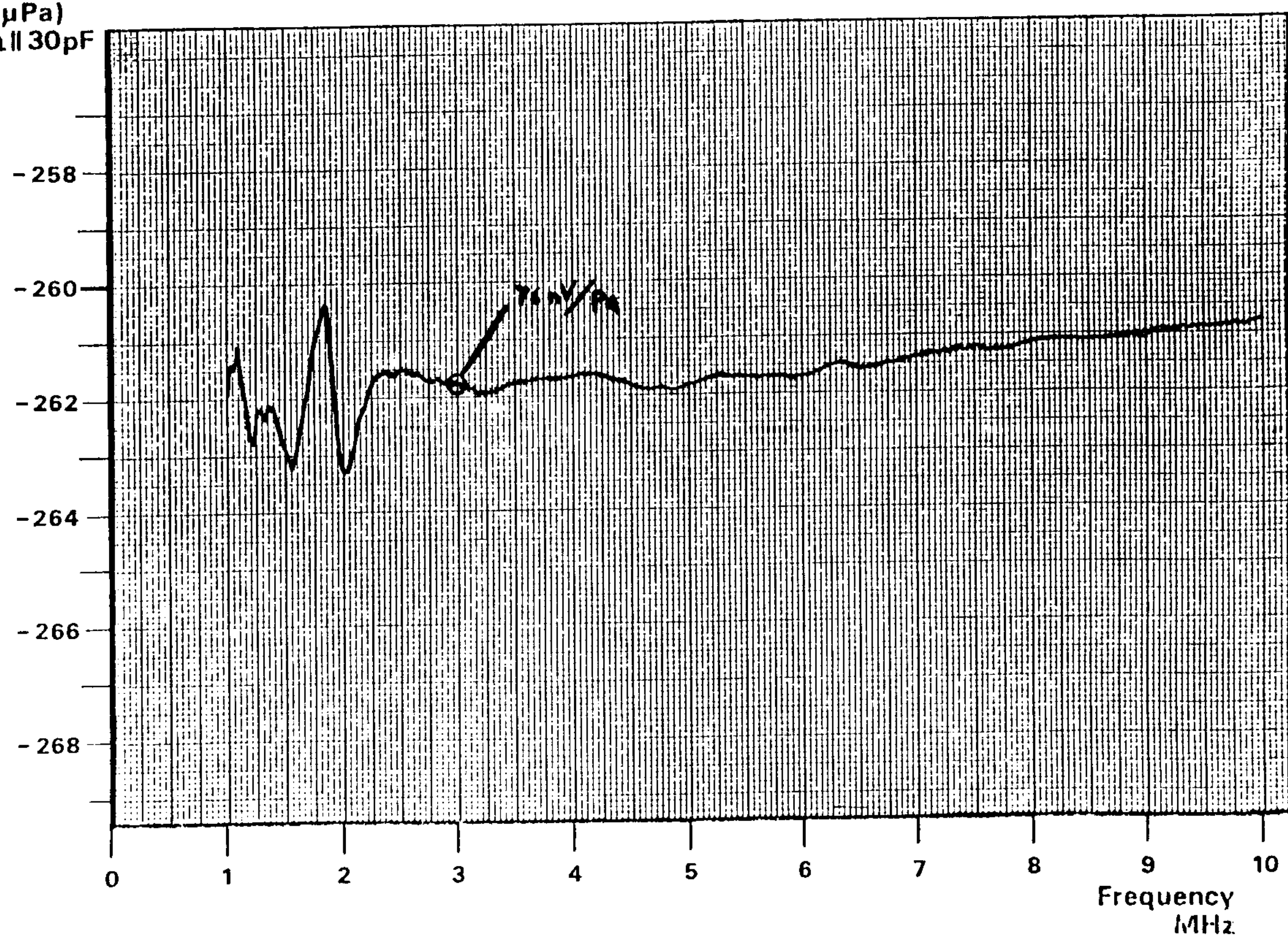


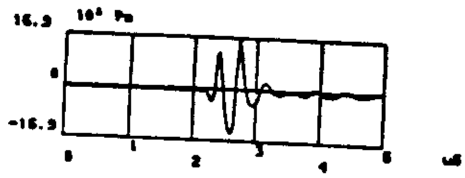
Fig. 2: Sistema di riferimento.

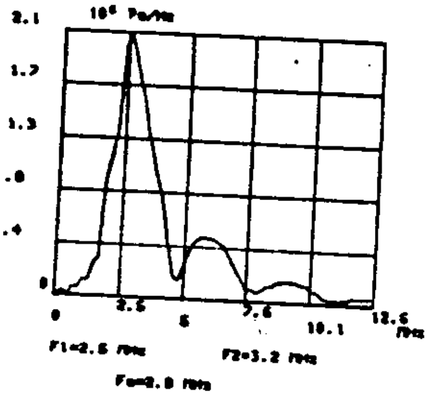
Calibration Chart for PVDF Ultrasonic Probe

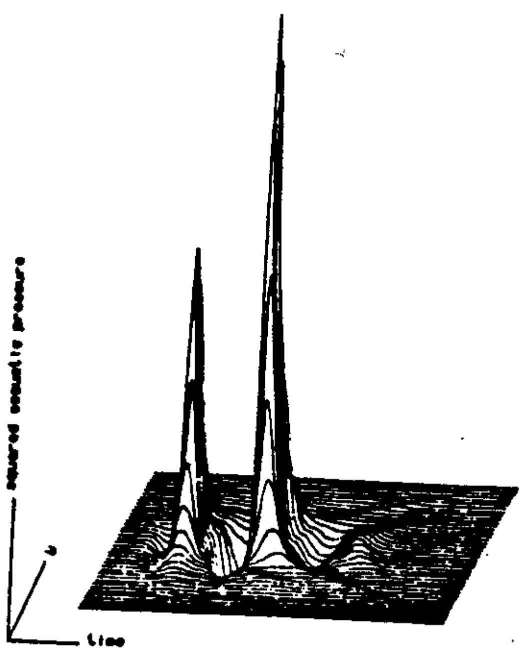
Free Field Frequency Response



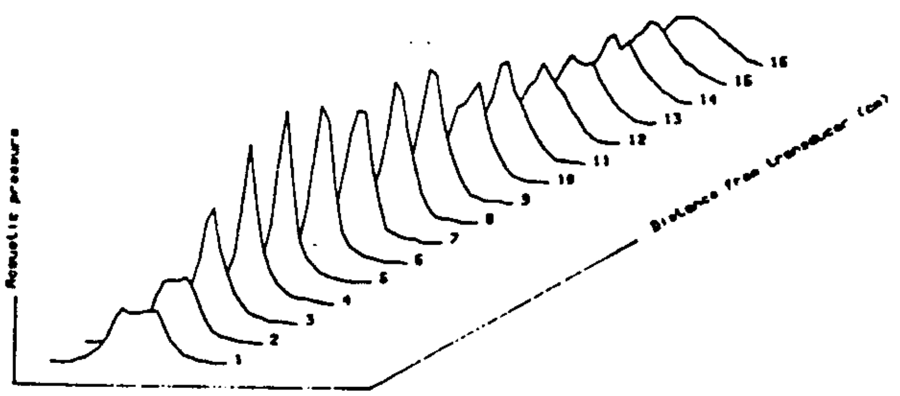
Serial no.:	668
Date:	20.dec87
Sign.:	CAL
Water temp. °C:	25.0
Diam.:	1.0mm
End of cable Capacitance ±5% at 1,6MHz:	116 pF



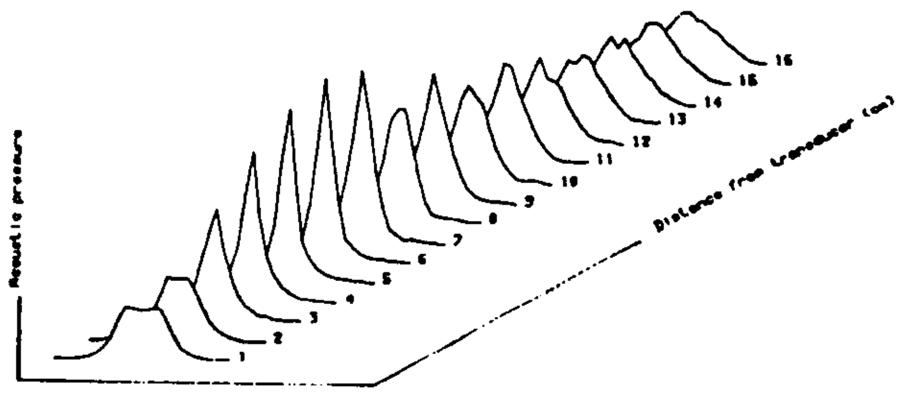




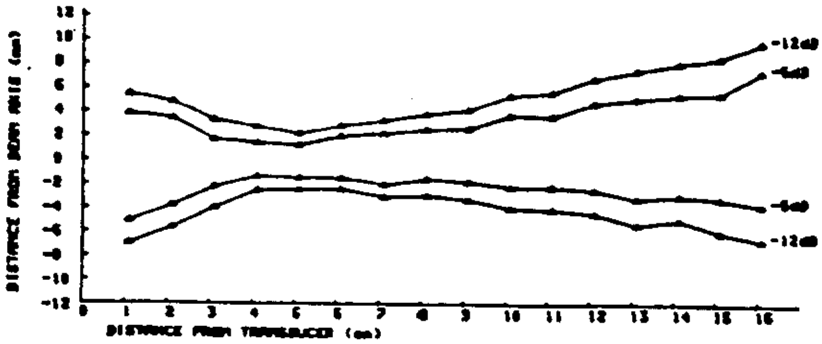
DISTANCE FROM TRANSDUCER : 5 cm



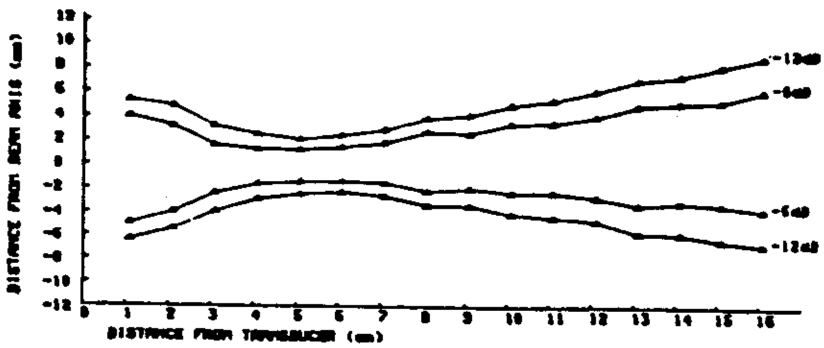
ACOUSTIC PRESSURE ON X-Z PLANE



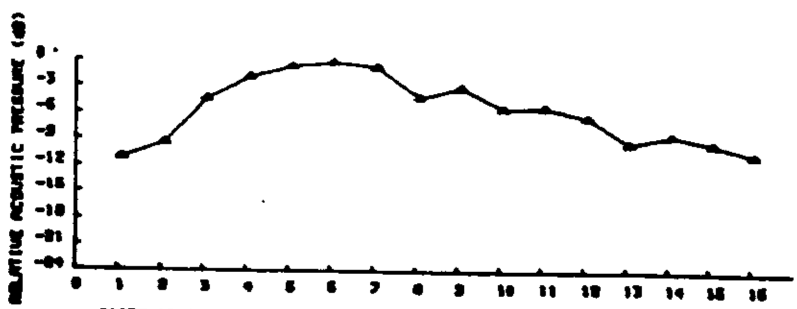
ACOUSTIC PRESSURE ON Y-Z PLANE



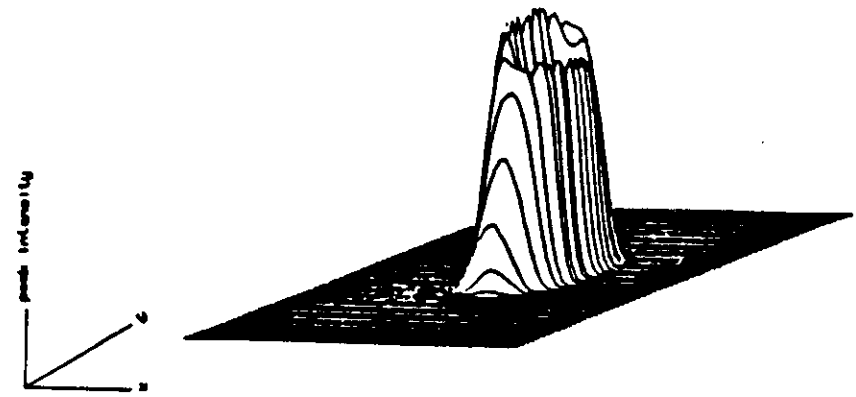
BEAM SHAPE ON ELEVATION PLANE (X-Z)



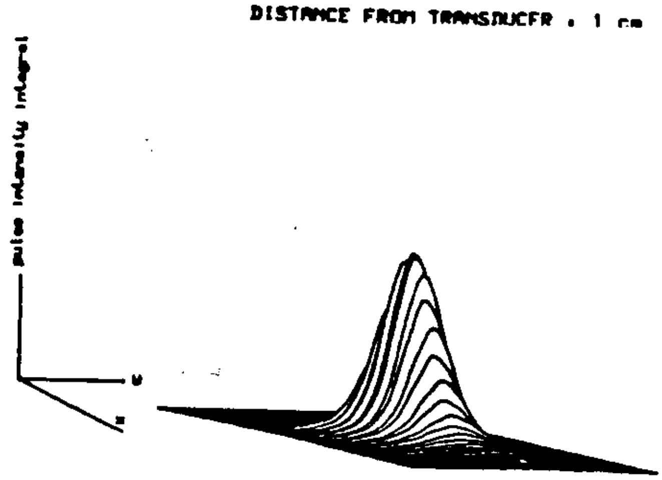
BEAM SHAPE ON SCAN PLANE (Y-Z)



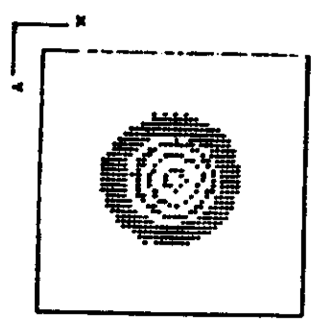
ACOUSTIC PRESSURE ON BEAM AXIS (Z)



DISTANCE FROM TRANSDUCER : 1 cm



DISTANCE FROM TRANSDUCER : 5 cm



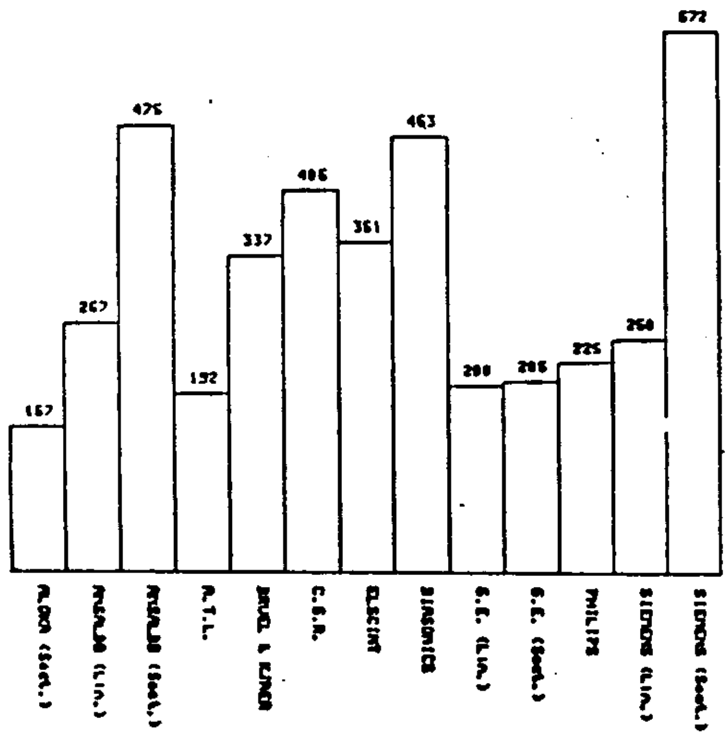
PULSE INTENSITY INTEGRAL
DISTANCE FROM TRANSDUCER, 5 cm
LEVELS, 10%, 25%, 50%, 90% of MAX
SCANNED AREA, 12x12 mm
BEAM CROSS SECTIONAL AREA, 8.42 mm2

RESULTS OF PERFORMANCE MEASUREMENTS

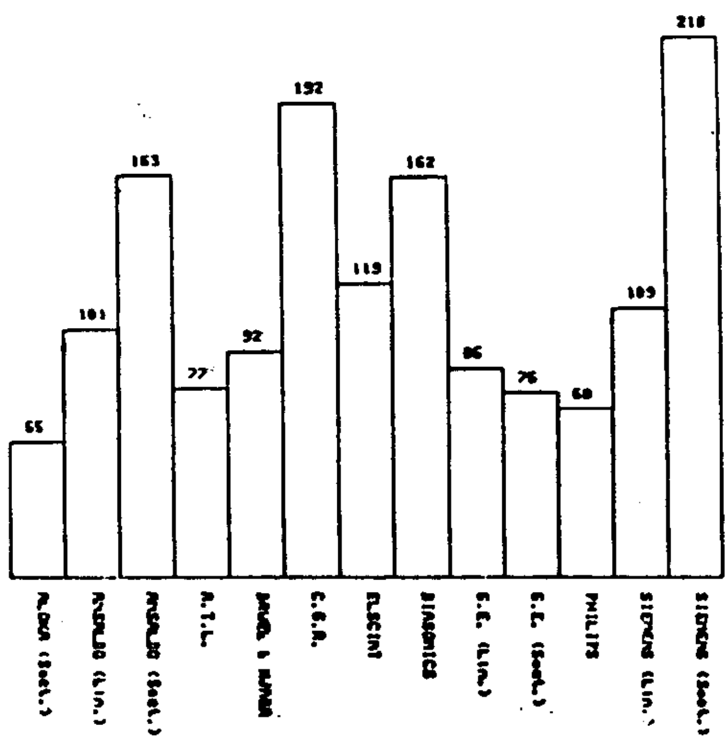
Model: ATL MK308C Transducer: 722A 3.0MHz

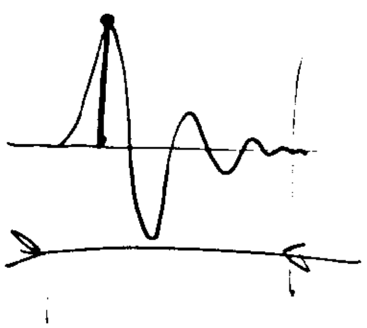
1. Isptp (W/cm2)		192
2. Isppa (W/cm2)		77
3. Centr. Work. Freq. (MHz)		2.8
4. Bandwidth (MHz)		0.7
5. Duty cycle (%)		0.12-0.34
6. Focal Length (cm)		5
7. Focal Zone (cm)		7
8. Focal Area (mm2)		8.4
9. Pulse Rep. Freq. (Hz)		2740-7400
10. Scan Frame Rate (Hz)		14-45
11. No. Acoustic Lines		128
12. Image Frame Rate (Hz)		14-45
13. Dead Zone		<8
14. Axial Resolution (mm) at	3cm	<1
	8cm	<1
	13cm	<1
	18cm	<2
15. Lateral Resolution (mm) at	3cm	<3
	8cm	<3
	13cm	<5
	18cm	<5
16. Penetration (cm)		21
17. Geometrical Distortion (%)		<3
18. Imaging of Cysts		GOOD
19. Measurement System Error (%)		<1

Temporal Peak Intensity (Isptp) (W/cm2)



Pulse Average Intensity (Isppa) (W/cm2)





	Isptp	Isppa	Centr. Work. Freq.	Band width	Duty Cycle	Focal Length	Focal Zone	Focal Area	Pulse Rep. Freq.
	W/cm2	W/cm2	MHz	MHz	%	cm	cm	mm2	kHz
ALOKA	157	55	3.1	0.9	.23-.14	8	8	12.2	2.56-4
ANSALDO sect.	475	163	3.2	1.2	0.19	5	4.5	18.8	<3.78
ANSALDO lin.	267	101	2.9	1.1	.06-.12	5*	4.5*	9.5*	1.4-2.9
A.T.L.	192	77	2.8	0.7	.12-.34	5	7	8.4	2.7-7.4
BRUEL&KJAER	337	92	2.8	0.7	0.13	6	7	13.6	2.7
C.G.R.	406	192	3.0	1.4	[?]	5*	6*	5.9*	[?]
ELSCINT	351	119	3.1	0.9	.04-.43	4.5	5	7.9	1-10
DIASONICS	463	162	2.9	1.2	0.20	7	7	8.9	3.7
GEN. EL. sect.	205	75	3.3	1.0	.17-.21	7*	5.5*	6.4*	3.1-3.9
GEN. EL. lin.	200	85	3.0	1.3	.17-.14	10*	5*	10.5*	3.1-3.9
PHILIPS	225	68	2.9	0.8	0.17	8	10.5	10.5	2.7
SIEMENS sect.	572	218	2.9	1.1	[?]	5.5	7	[?]	[?]
SIEMENS lin.	250	109	3.0	0.5	0.16	8*	8*	12.5*	3.1

(*)=measured at one focus only (see text)