



Scanning Acoustic Microscopy Training

This presentation and images are copyrighted by Sonix, Inc. They may not be copied, reproduced, modified, published, uploaded, posted, transmitted, or distributed in any way, without prior written permission from Sonix.

SONIX

8700 Morrissette Drive
Springfield, VA 22152

tel: 703-440-0222

fax: 703-440-9512

e-mail: info@sonix.com

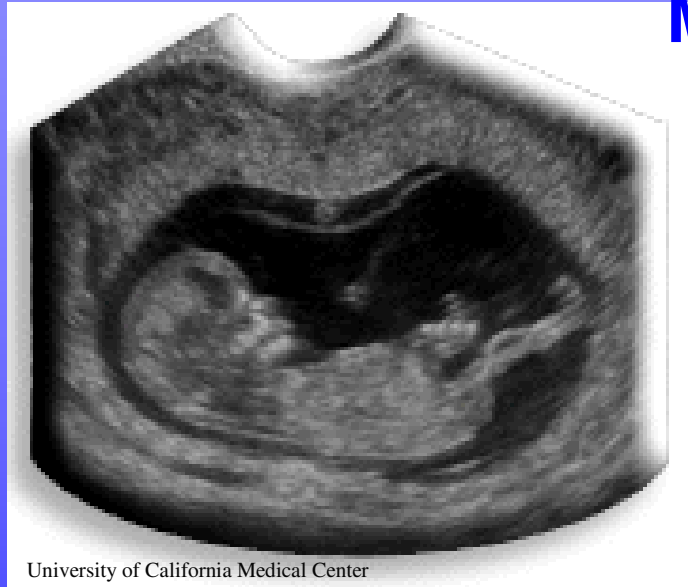
This presentation serves as a brief introduction into the theory and operation of scanning acoustic microscopes.

Ultrasound Inspection, Using an Acoustic Microscope...

- Ultrasound
- Non-Destructive Testing
- Example Images

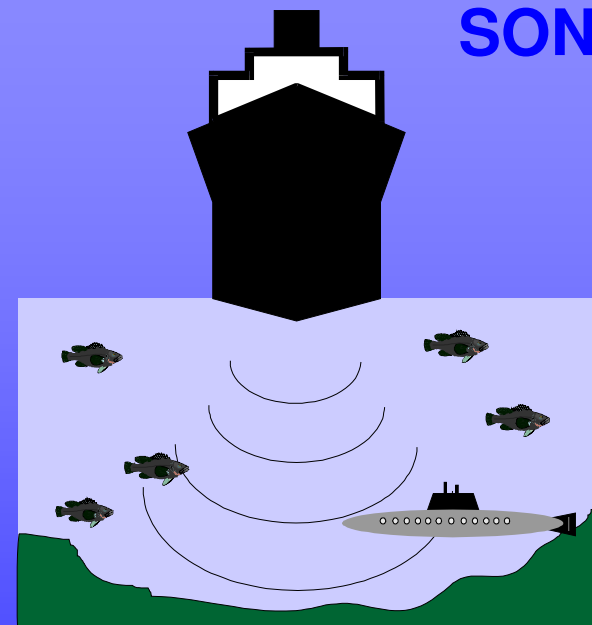


Ultrasound



University of California Medical Center
San Francisco, California

MEDICAL



SONAR

What are Ultrasonic Waves?

Ultrasonic waves refer to sound waves above 20 kHz
(not audible to the human ear)

Non-Destructive Testing



NDT utilizes various non-invasive measurement techniques, such as ultrasonics and radiography to determine the integrity of a component, structure, or material without destroying the usefulness of the item.

Where an Acoustic Microscope is utilized.

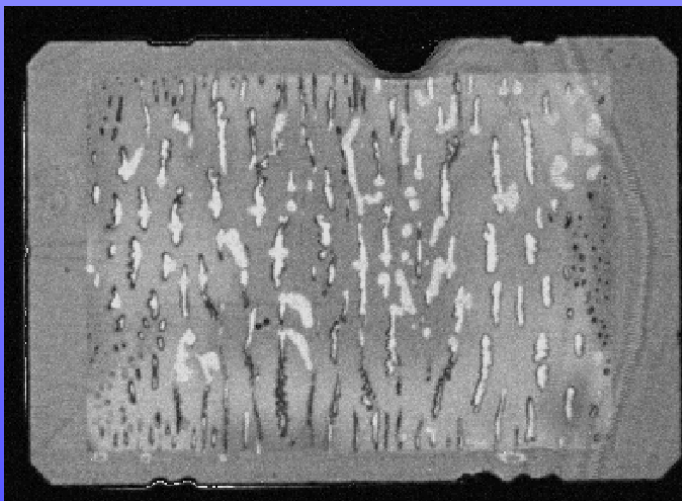
- **Failure Analysis**
- **Reliability**
- **Process Control**
- **Vendor Qualification**
- **Production**
- **Quality Control**
- **Research**

Common Applications

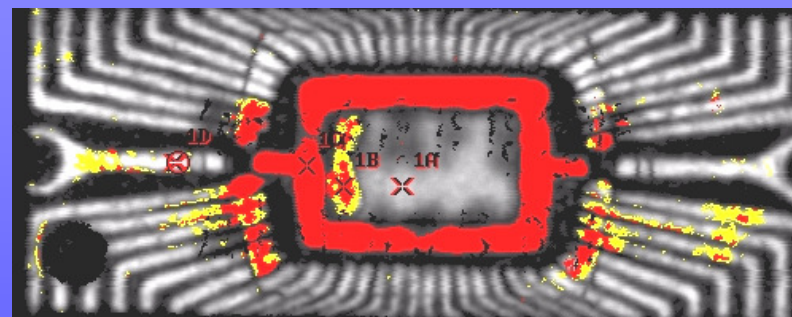
- **Plastic encapsulated IC packages**
- **Flip Chips**
- **Bonded Wafers**
- **Printed Circuit Boards**
- **Capacitors**
- **Ceramics**
- **Metallic**
- **Power Devices/Hybrids**
- **Medical Devices**
- **Material Characterization**

Examples

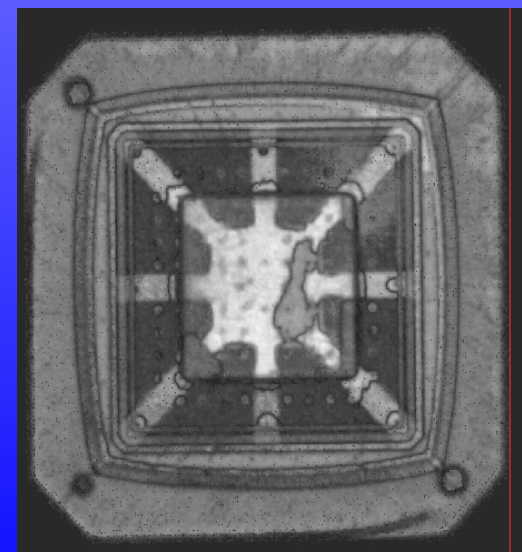
Lid seal voids



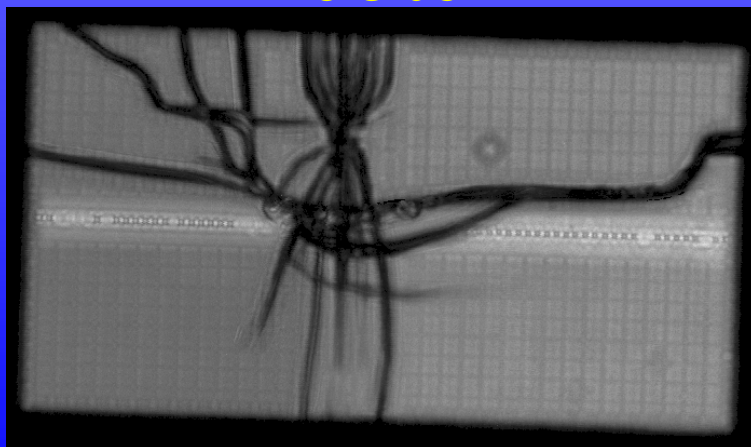
Delamination



BGA die attach

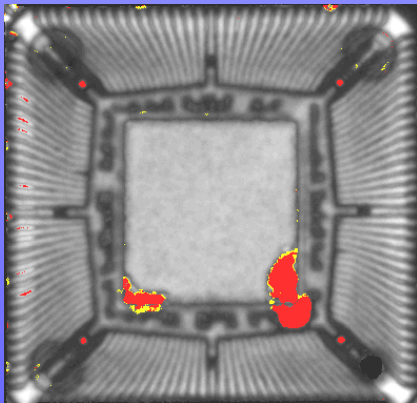


Die Crack

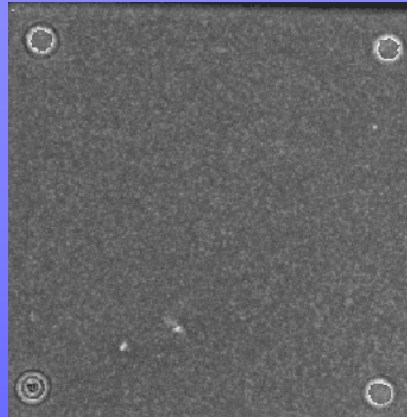


Copyright Sonix, Inc

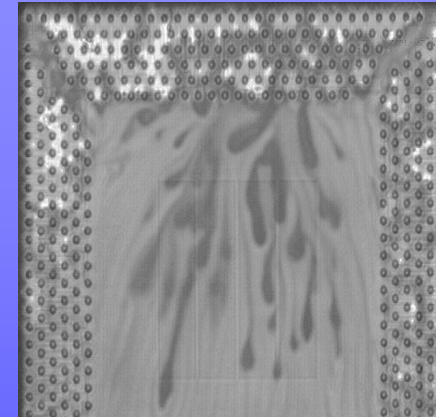
Examples



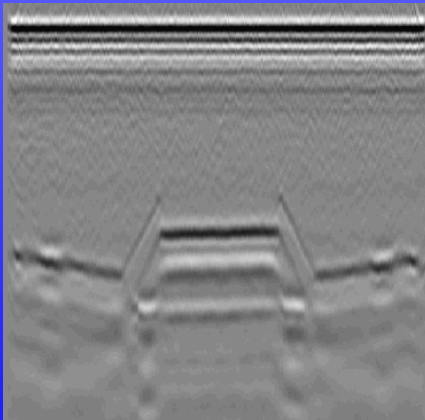
**Die Top
Delamination**



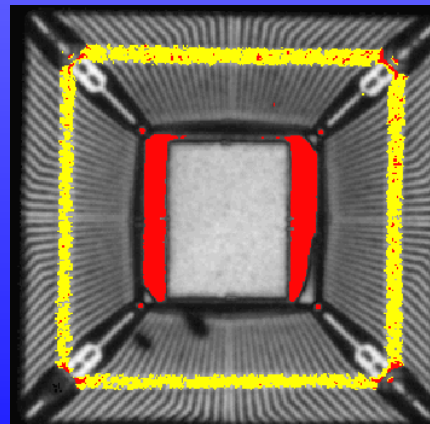
Mold compound voids



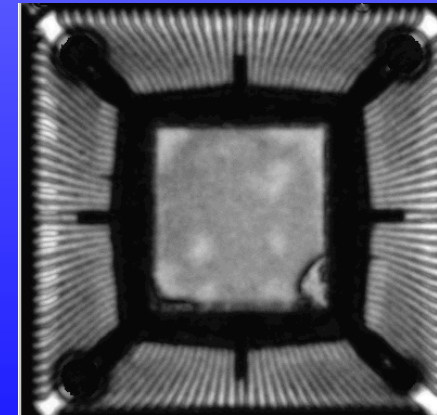
**Flip Chip Underfill
Voids**



Die Tilt, B-Scan



Die Pad delamination

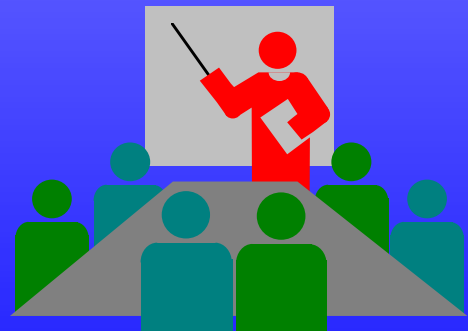


Die Attach Voids

Copyright Sonix, Inc

Ultrasound Inspection

- Theory
- System Components
- Transducers



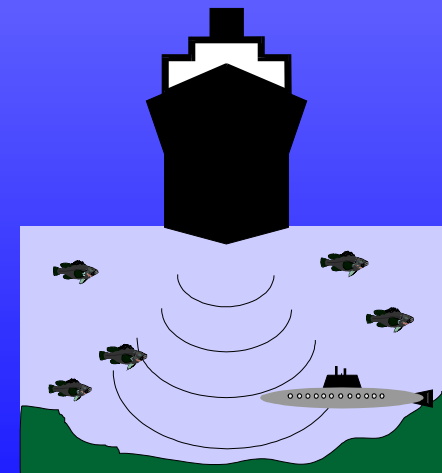
Ultrasonic Waves

Characteristics of Ultrasonic Waves

- Freely propagate through liquids and solids
- Reflect at boundaries of internal flaws and change of material
- Capable of being focused, straight transmission
- Suitable for Real-Time processing
- Harmless to the human body
- Non-destructive to material



University of California Medical Center
San Francisco, California



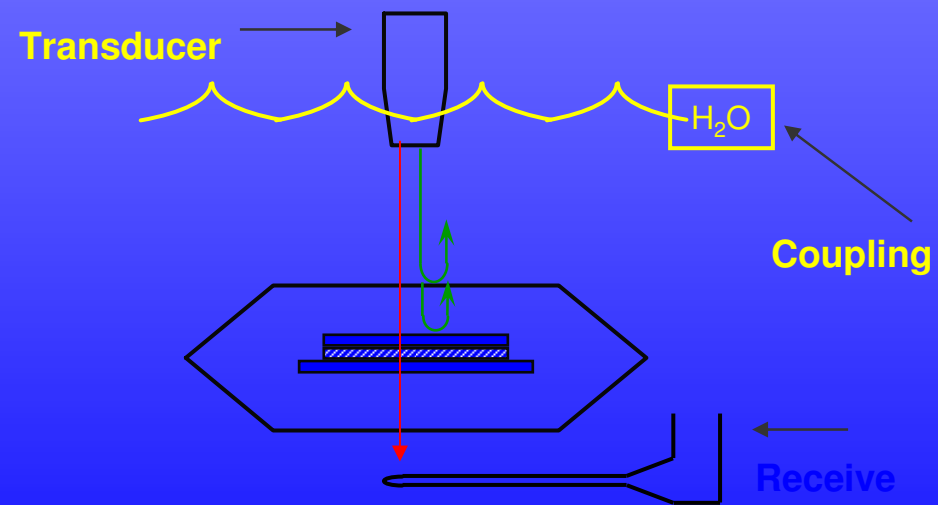
Ultrasonic Inspection

Ultrasound

- A transducer produces a high frequency sound wave which interacts with the sample.
- High frequency sound waves can not propagate through air.
- Couplant- A material used to carry the high frequency sound waves.
 - Water is the most common couplant for immersion testing.

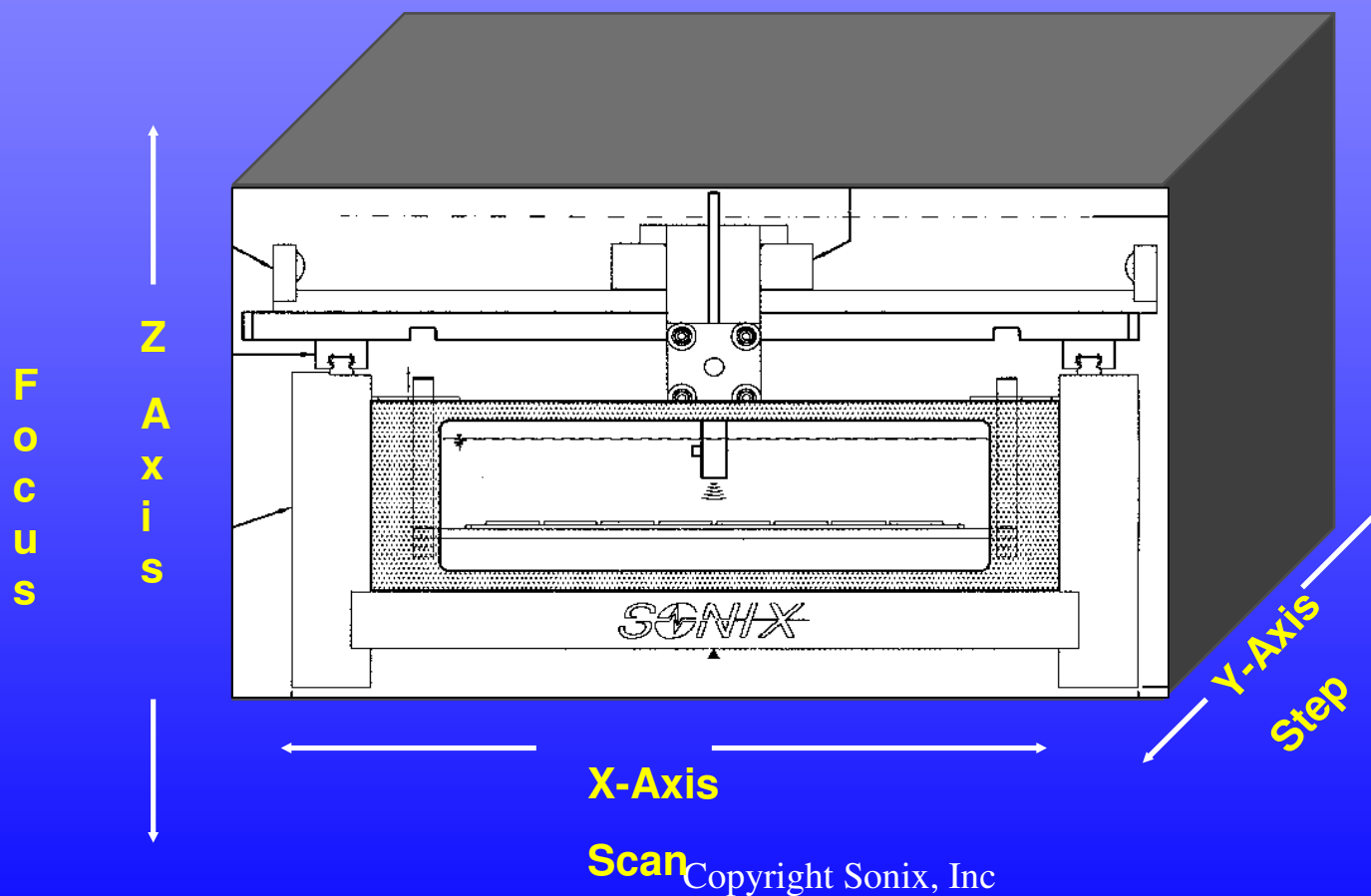
Inspection Modes

- Pulse Echo
- Through Transmission



Scanner

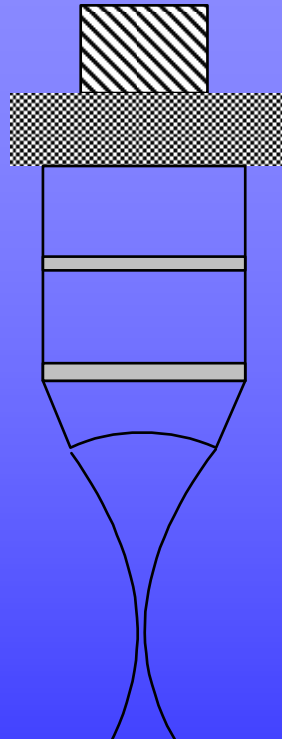
The scanner consists of a three axis system, X, Y, and Z. The motor controller directs the movement of these axes.



Copyright Sonix, Inc

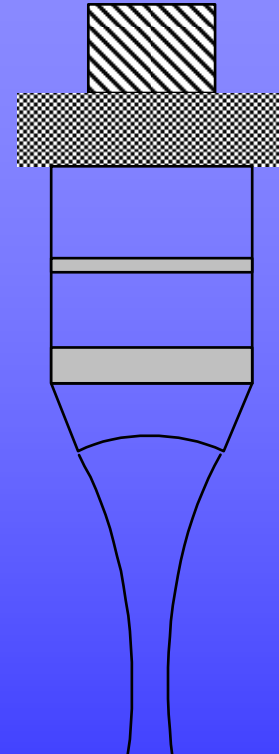
SONIX

Transducers



High Frequency
Short Focus

1. Higher resolution
2. Shorter focal lengths
3. Less penetration
(Thinner packages)



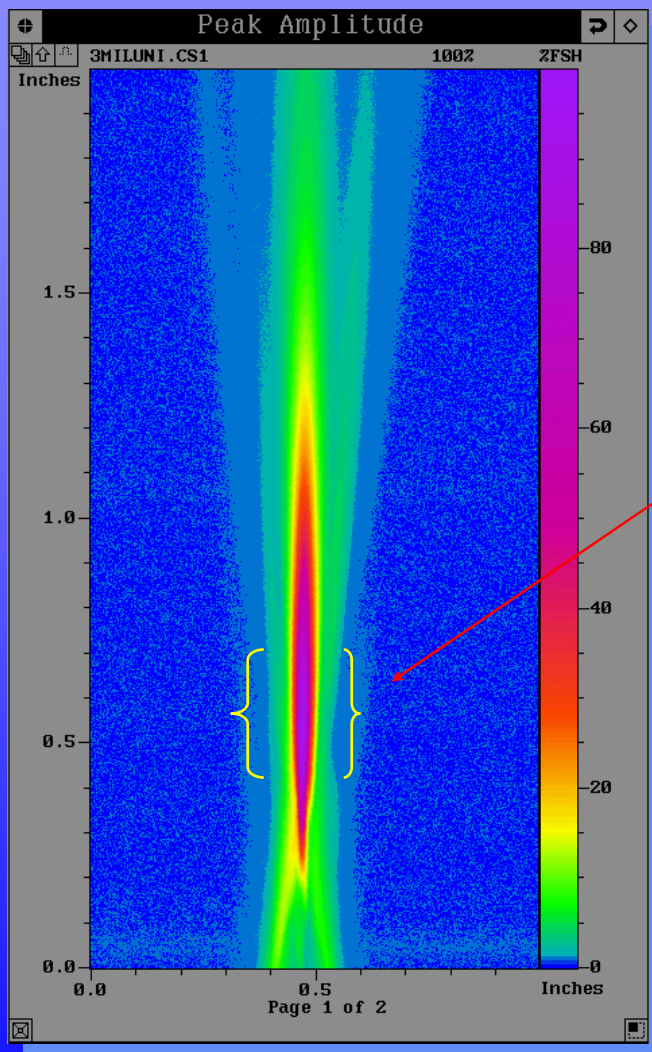
Low Frequency
Long Focus

1. Lower resolution
2. Longer focal lengths
3. Greater penetration
(Thicker packages)

General rules:

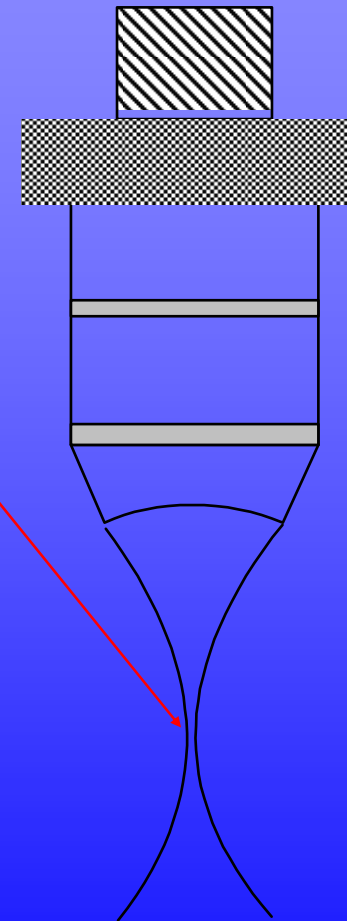
- **Ultra High Frequency** (200+ MHz) for flip chips and wafers.
- **High Frequency** (50-75 MHz) for thin plastic packages. (110MHz-UHF) for flip chips.
- **Low Frequency** (15 MHz) for thicker plastic packages.

Transducer Beam Profile



Depth of Field

The purple region is referred to as the focal area or depth of field of the transducer beam.



SONIX

Typical Transducer Selection

Sample Application

Transducer

T/X Receiver

10 MHz w/0.75" focus

PLCC, QFP, PQFP

15 MHz w/0.5" focus

Power Pak

15 MHz w/0.5" focus

BGA Top

50-75 MHz w/12mm focus

Capacitors

75 MHz w/12mm focus

TSOP

75 MHz w/12mm focus

Flip Chip Underfill

110 MHz w/8mm focus

Flip Chip Interconnect

UHF w/ 5.9 mm focus

Bonded Wafer

110 MHz w/8mm focus

Bonded Wafer

UHF w/ 5.9 mm focus



ABC's Of Acoustics

- Acoustic Reflections
- Acoustic Waveforms
- Image Display

Acoustic Properties

Material	Density (g/cm ³)	Longitudinal Wave Velocity (m/s)	Acoustic Impedance (kg/m ² s) (x10 ⁶)
Water (20 ⁰ C)	1.00	1483	1.48
Alcohol (20 ⁰ C)	0.79	1168	0.92
Air (20 ⁰ C)	0.00	344	0.00
Silicon	2.33	8600	20.04
Gold	19.3	3240	62.53
Copper	8.90	4700	41.83
Aluminum	2.70	6260	16.90
Epoxy Resin	1.20	2600	3.12
Resin (for IC pkg)	1.72	3930	6.76
Glass (Quartz)	2.70	5570	15.04
Alumina (AL ₂ O ₃)	3.80	10410	39.56

Sound Reflection

- **Acoustic Material Properties**

- density (ρ)

- velocity of sound in material (c)

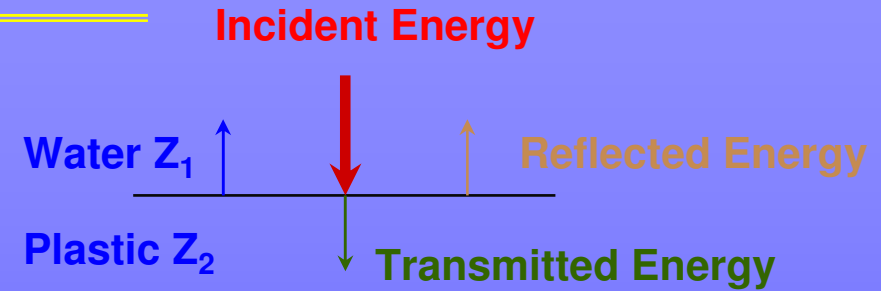
- acoustic impedance ($Z = \rho c$)

Sound Reflection

Whenever a sudden change in acoustic impedance is encountered, like at a material boundary, a portion of sound is reflected and the remainder propagates through the boundary.

Reflection vs. Transmission

$$Z = \rho C$$



Z₁ = ρ C where:
 ρ = 1.00 gram/cm³
 C = 1.5 x 10⁶
 Z₁ = 1.5 x 10⁶

Z₂ = ρ C where:
 ρ = 2.00 gram/cm³
 C = 2.00 x 10⁶
 Z₂ = 4.00 x 10⁶

$$T = \frac{2 (Z_1)}{(Z_2 + Z_1)}$$

$$T = \frac{2 (1.5)}{(4.0 + 1.5)}$$

$$T = \frac{(3.0)}{(5.5)}$$

$$T = .55$$

45% of the sound entering the boundary is reflected.

$$R = \frac{(Z_2 - Z_1)}{(Z_2 + Z_1)}$$

$$R = \frac{(4.0 - 1.5)}{(4.0 + 1.5)}$$

$$R = \frac{(2.5)}{(5.5)}$$

$$R = .45$$



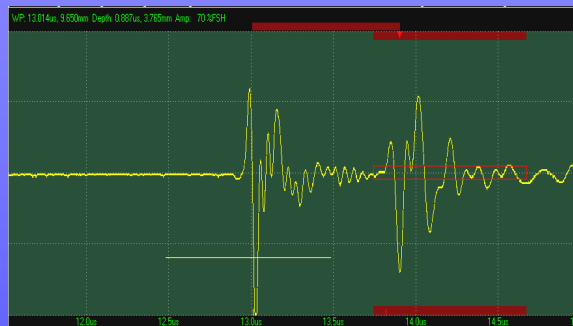
Reflected Sound Information

Measuring the reflected ultrasound can provide:

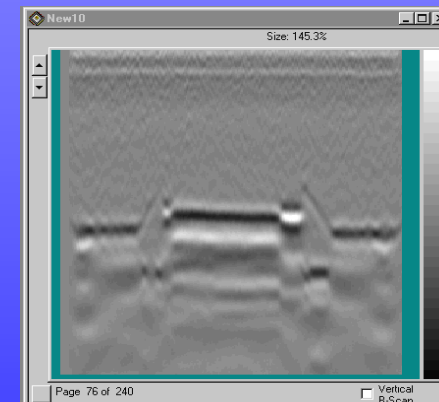
- **Amplitude Information**
- **Polarity Information**
- **Time Information**

ABC's of Acoustics

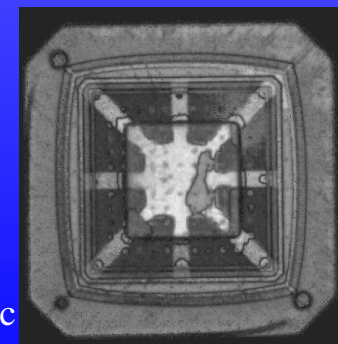
A-Scan- The raw ultrasonic data. It is the received RF signal from a single point (x,y).



B-Scan- A line of A-scans. (Vertical cross-section)



C-Scan- Data from a specified depth over the entire scan area. (Horizontal cross-section)



Copyright Sonix, Inc

SONIX

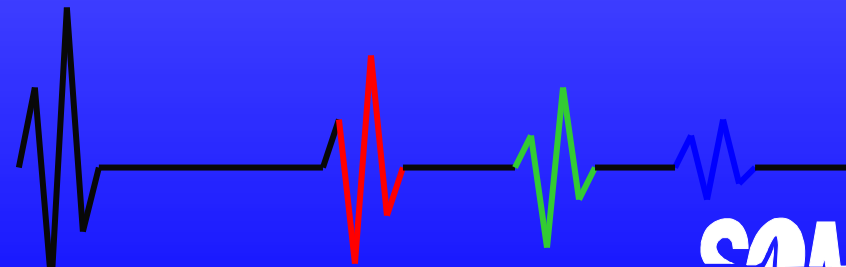
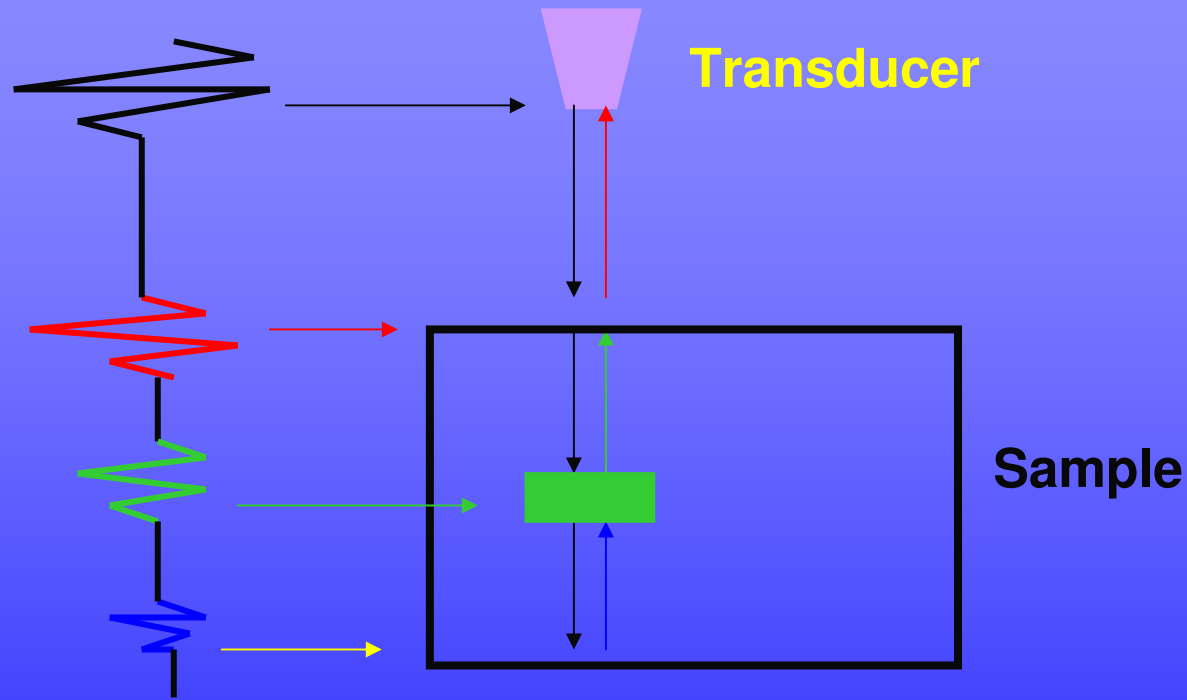
A-SCAN

Initial Pulse

Front surface

Interface of interest

Back surface



Copyright Sonix, Inc

SONIX

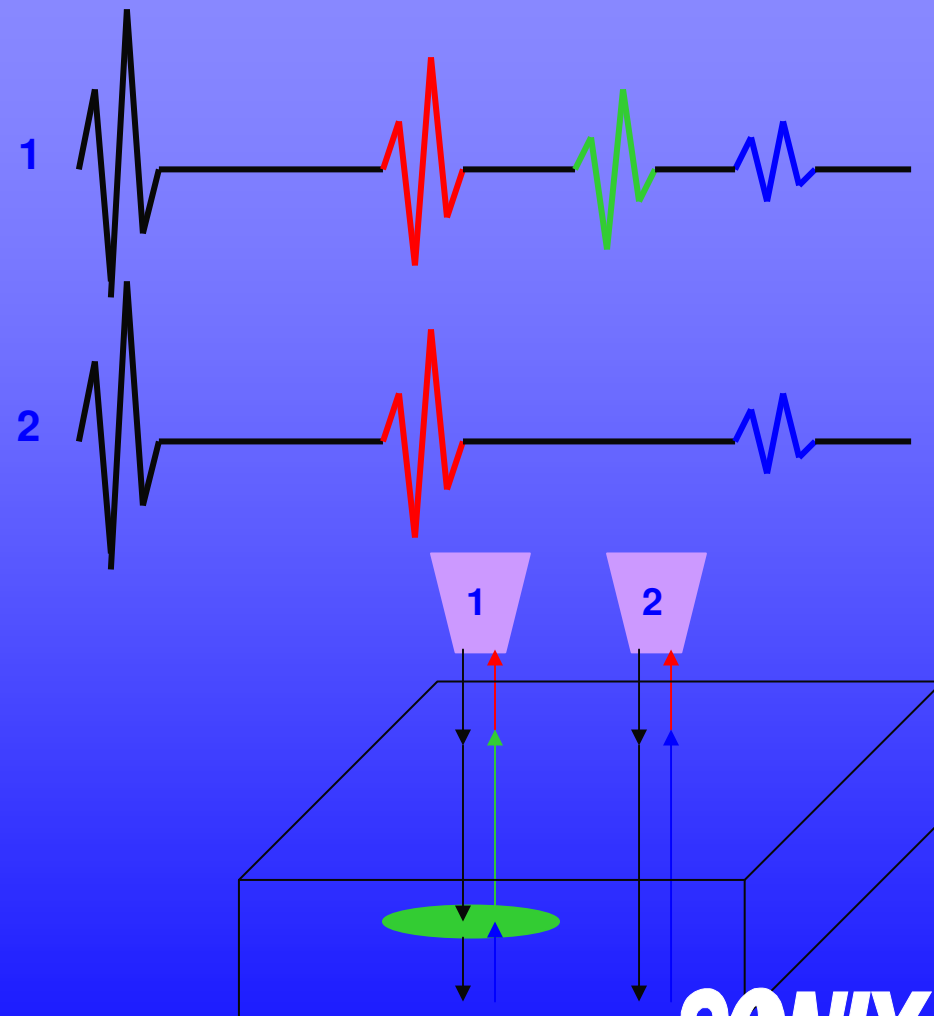
Ultrasonic Waveforms

The Black signal is commonly referred to as the initial pulse or the main bang. This signal occurs at Zero microseconds.

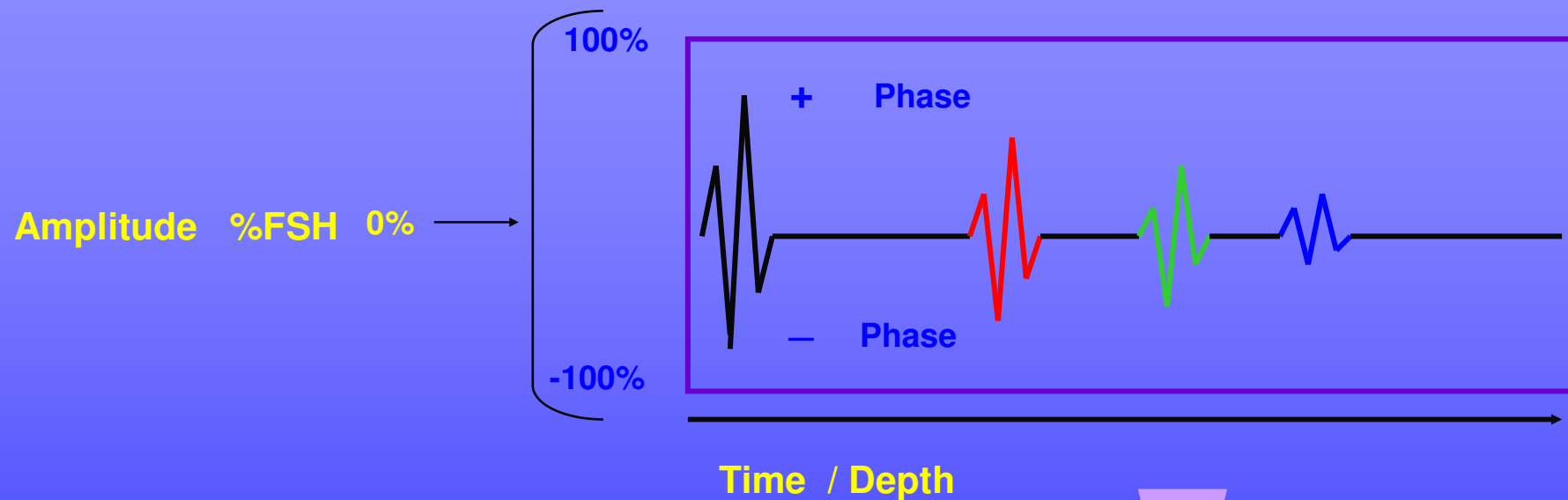
The Red signal is commonly referred to as the front surface. This represents the first interface the sound encounters.

The Green signal would be considered the area of interest. A data gate would be positioned over this signal or group of signals for evaluation.

The Blue signal is commonly referred to as a back wall echo or back surface. Just as the name implies it is the back or bottom of the sample.

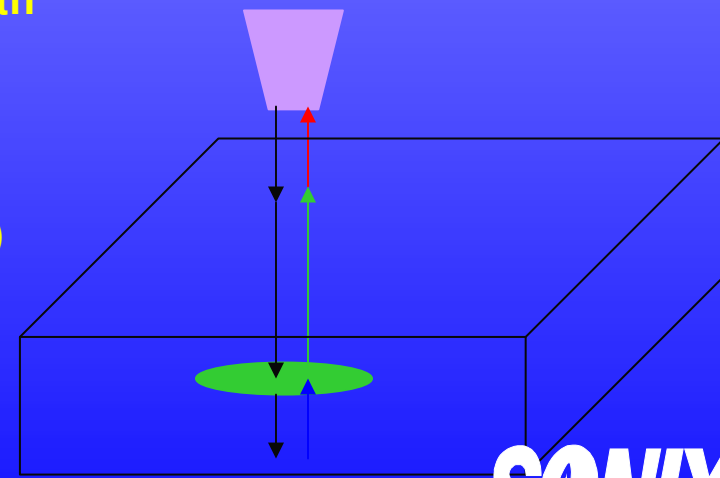


A-SCAN

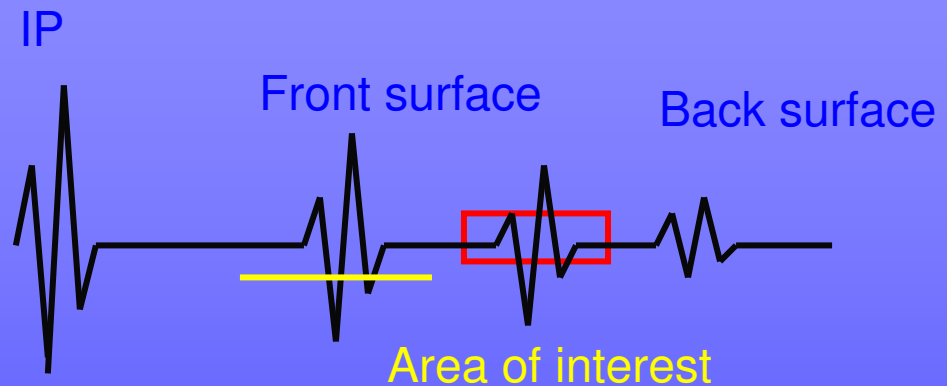
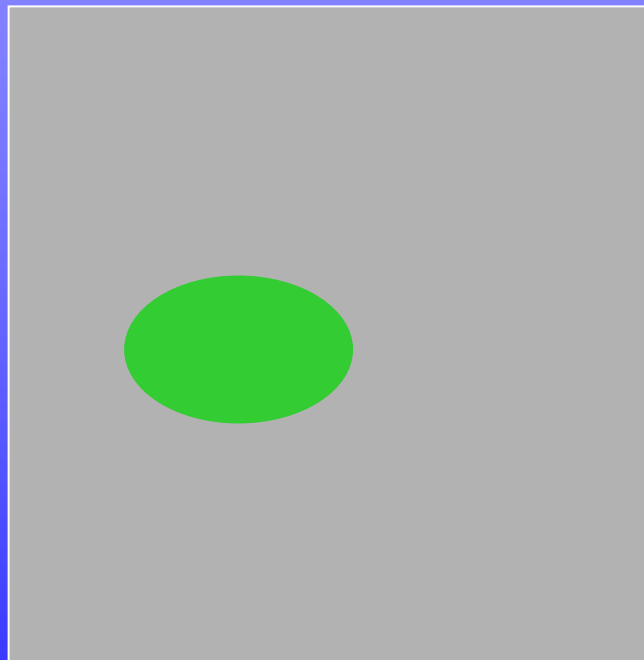


A-Scans provide the following information:

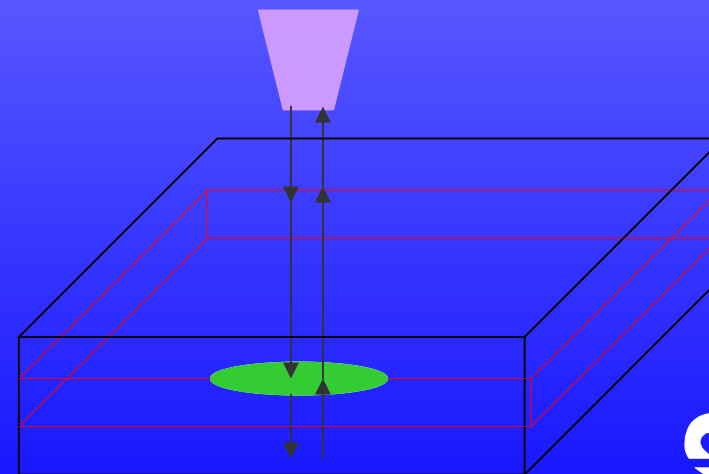
1. Amplitude / % of full screen height (FSH)
2. Phase / positive or negative peak
3. Time / Depth



C-SCAN



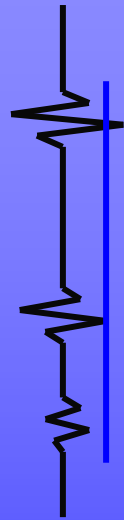
The red box (data gate) indicates the depth of information.



Copyright Sonix, Inc

SONIX

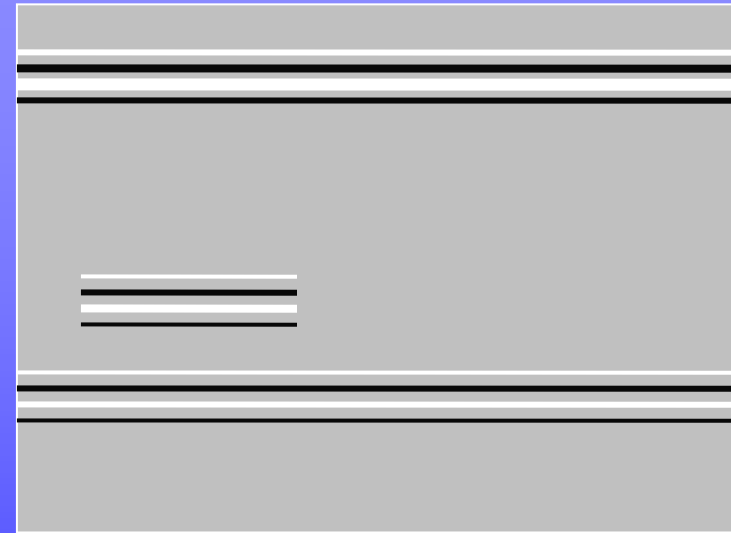
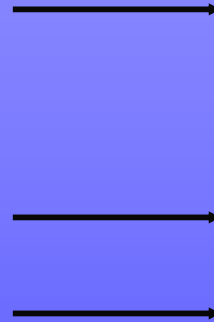
B-Scan



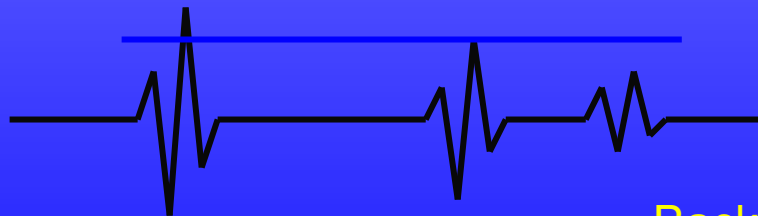
Front surface

Signal from indication

Back surface



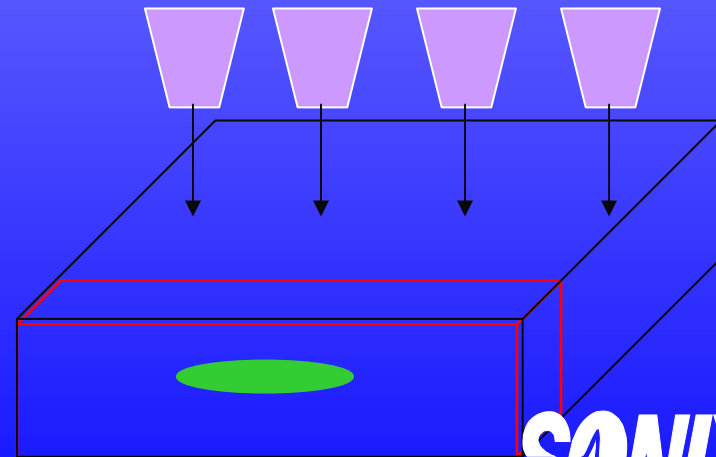
The blue line (B-scan gate) represents the depth of information recorded.



Front surface

Signal from indication

Back surface



SONIX

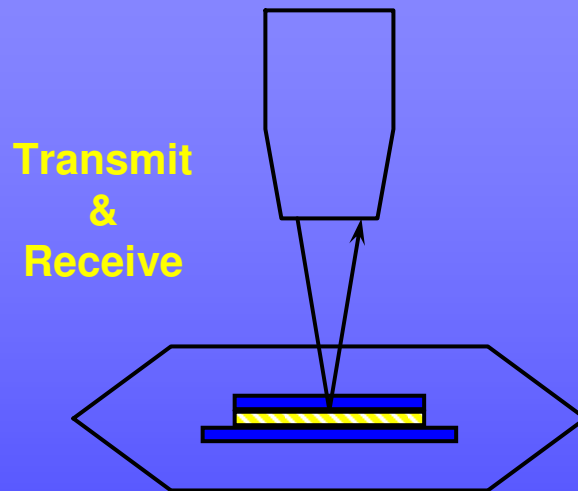
Copyright Sonix, Inc

Inspection Modes

- **Pulse Echo**
- **Through Transmission**

Inspection Modes

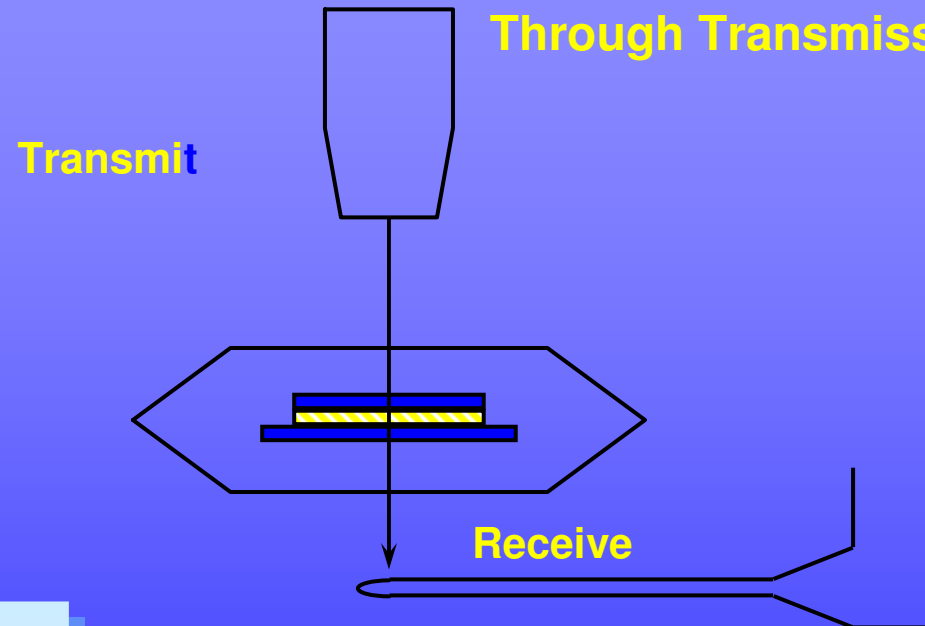
Pulse-Echo



Pulse-Echo - One Transducer

- Ultrasound reflected from the sample is used.
- Can determine which interface is delaminated.
- Requires scanning from both sides to inspect all interfaces.
- Provides images with high degree of spatial detail.
- Peak Amplitude, Time of Flight (TOF) and Phase Inversion measurement

Through Transmission

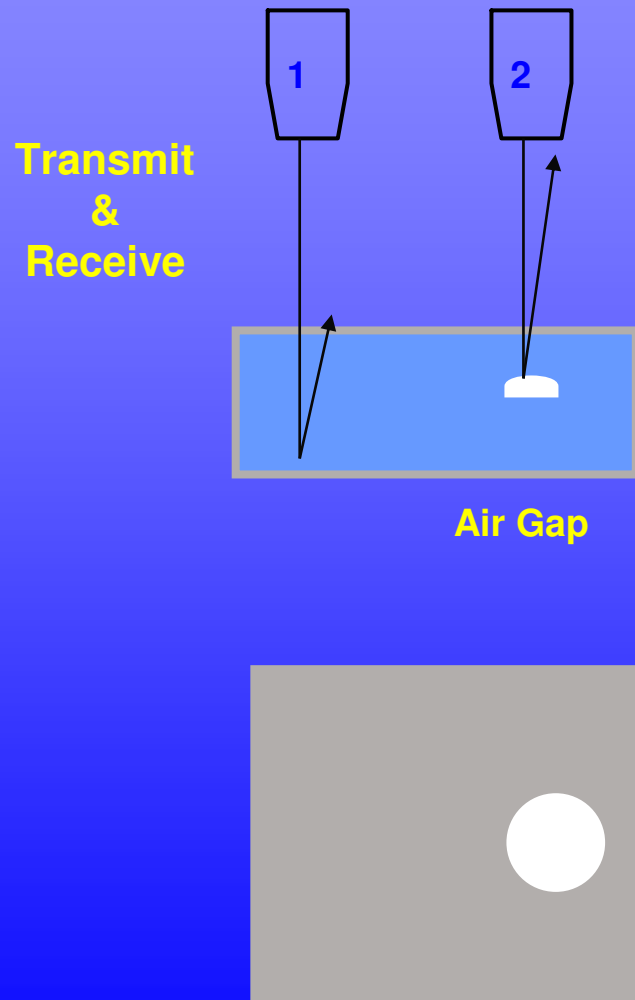


Through Transmission - Two Transducers

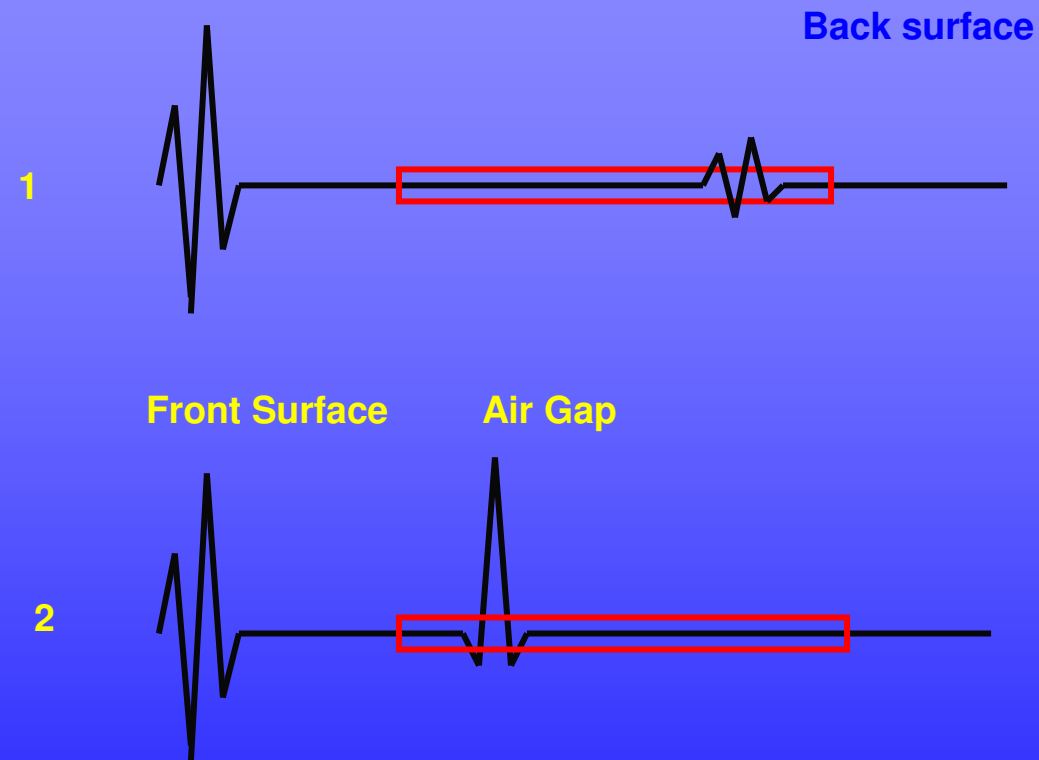
- Ultrasound transmitted through the sample is used.
- One Scan reveals delamination at all interfaces.
- No way to determine which interface is delaminated.
- Less spatial resolution than pulse-echo.
- Commonly used to verify pulse-echo results.

Inspection Modes

Pulse-Echo

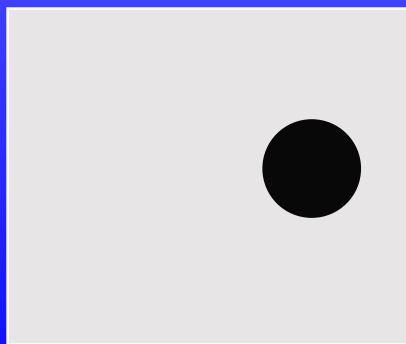
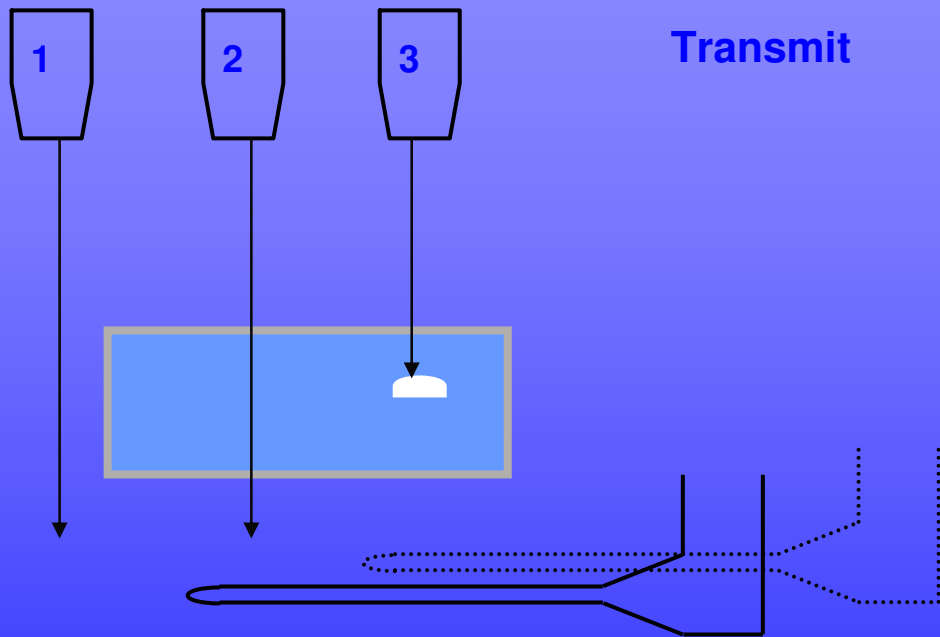


Front Surface

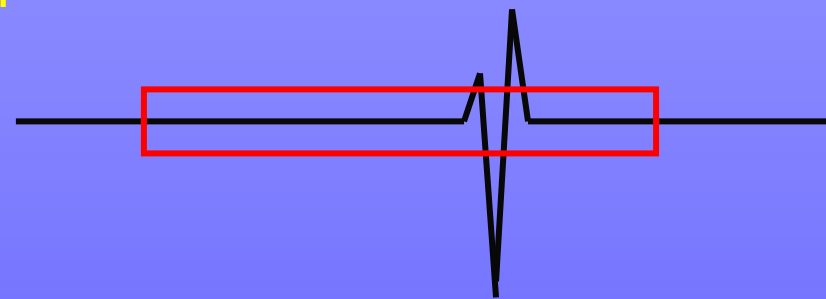


Inspection Modes

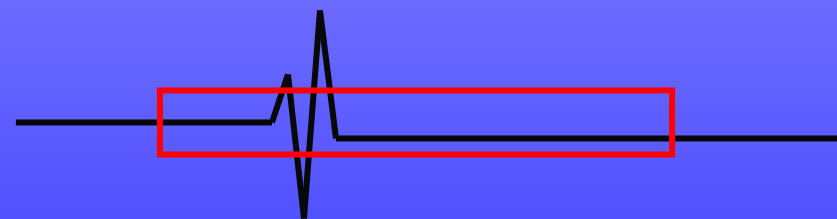
Through Transmission



1



2



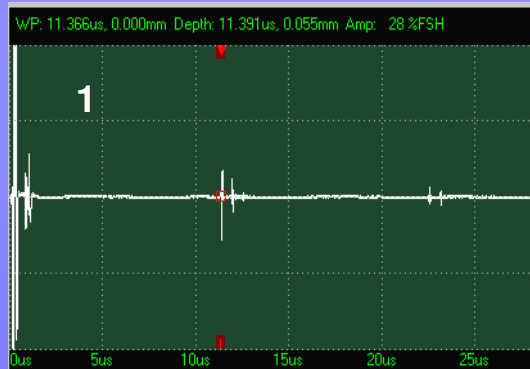
3



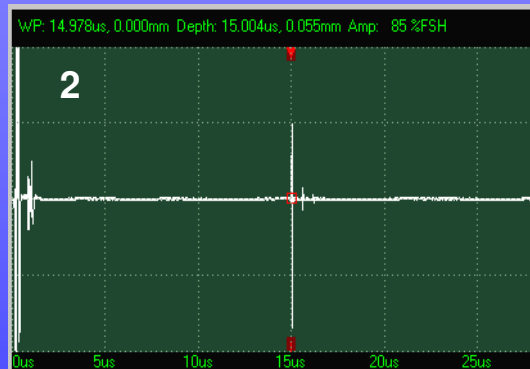
Focusing Sound

Focusing the Transducer

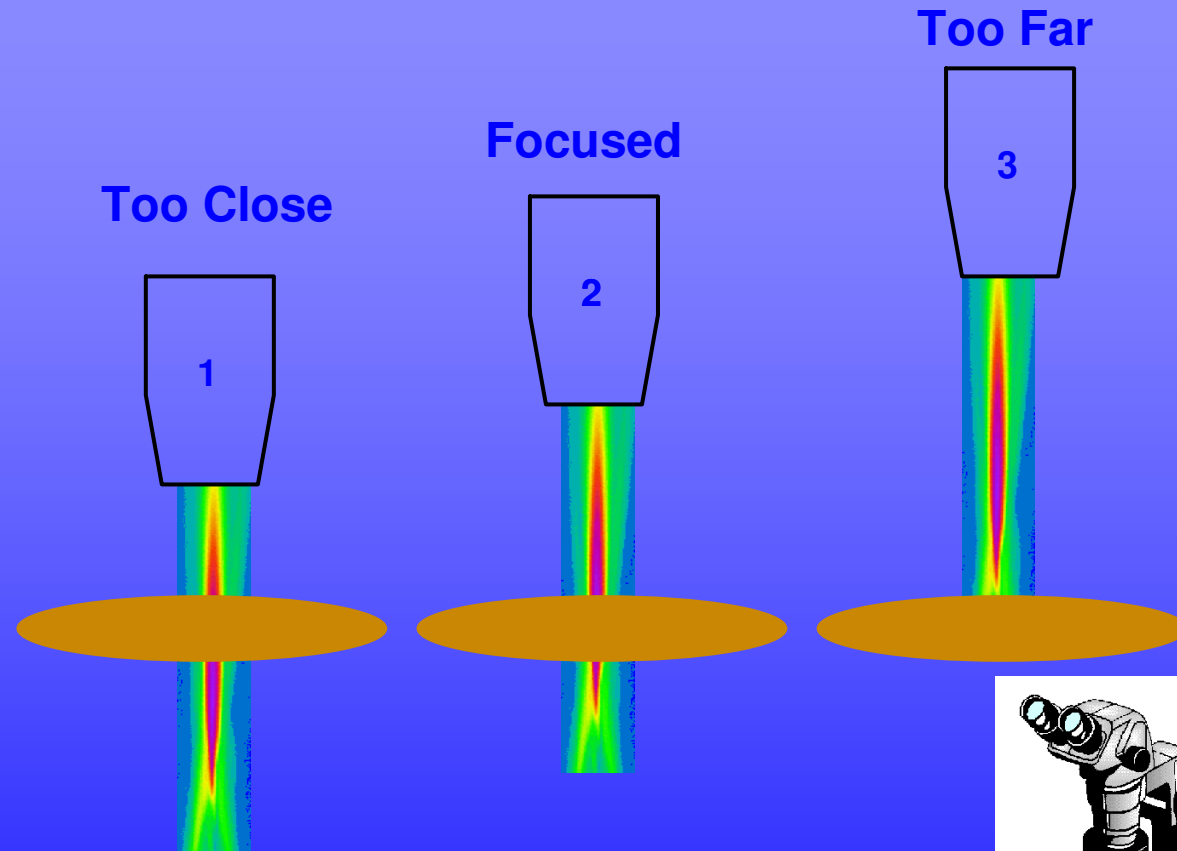
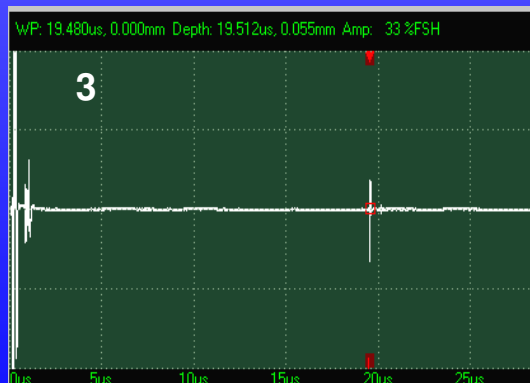
Too Close



Focused



Too Far



Focusing an ultrasonic transducer is similar to focusing an optical microscope.

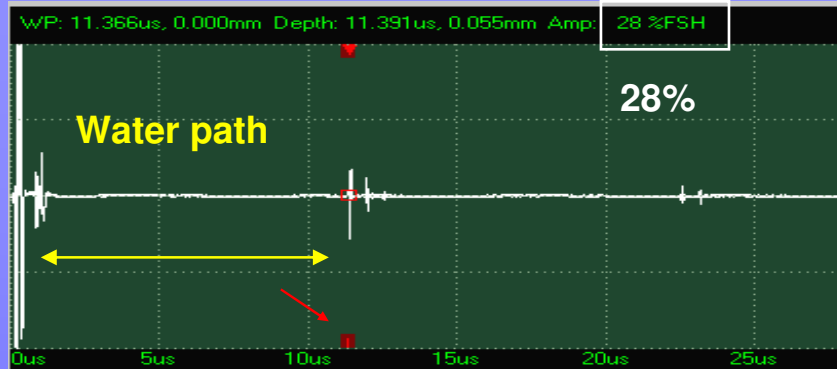
When optimum focus is reached the signal will reach a maximum peak. (See the A-scans images to the left)



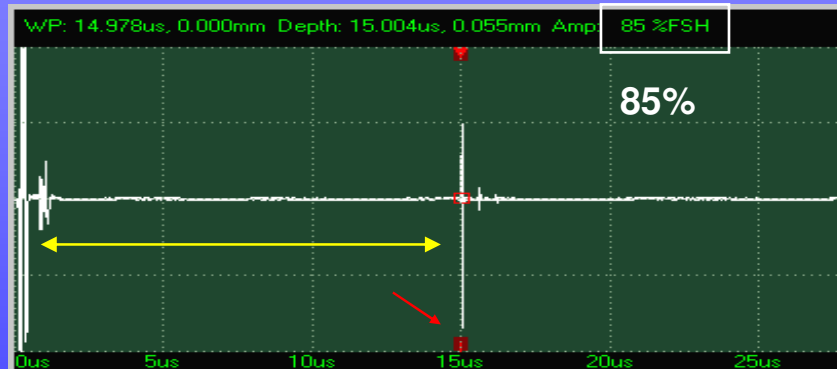
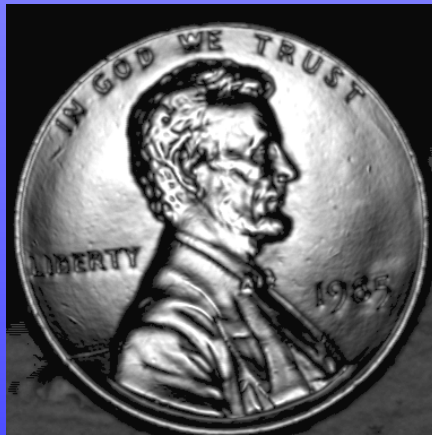
SONIX

Copyright Sonix, Inc

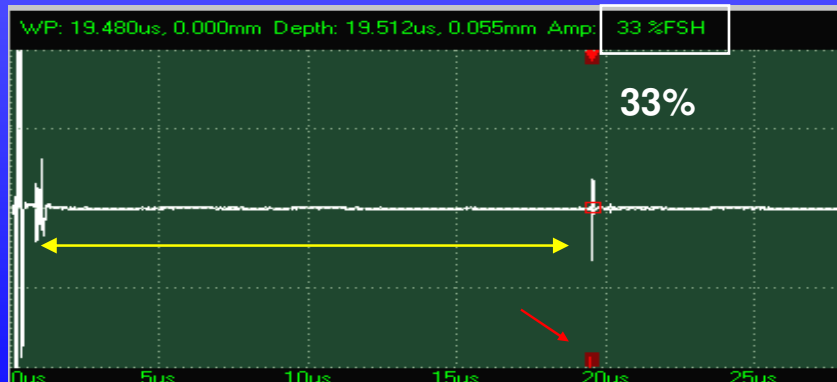
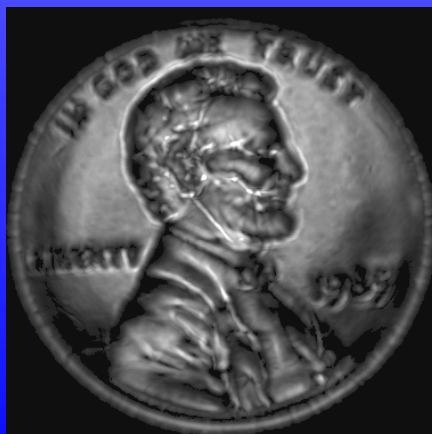
De-focused-- too close



Correct focus



De-focused-- too far



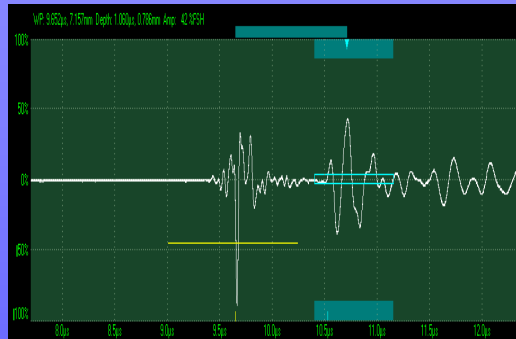
1. Note the time in microseconds of the signal at the different focus locations. (Red arrow)

2. Also note the amplitude of the signal. (white box)

When the signal is not in focus the amplitude is lower compared to that of correct focus.

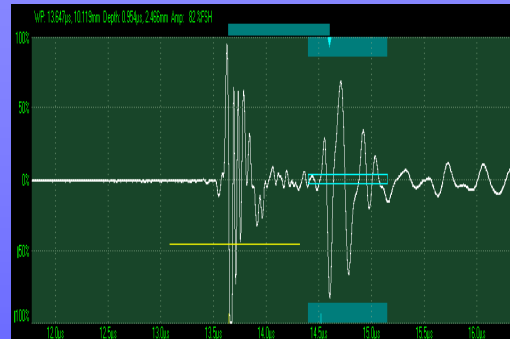
Focusing Sound

De-Focused - Too Close



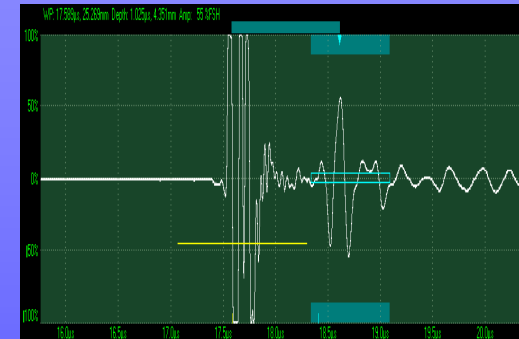
Amplitude = 42% Time = 10.5 us

Focused on Die

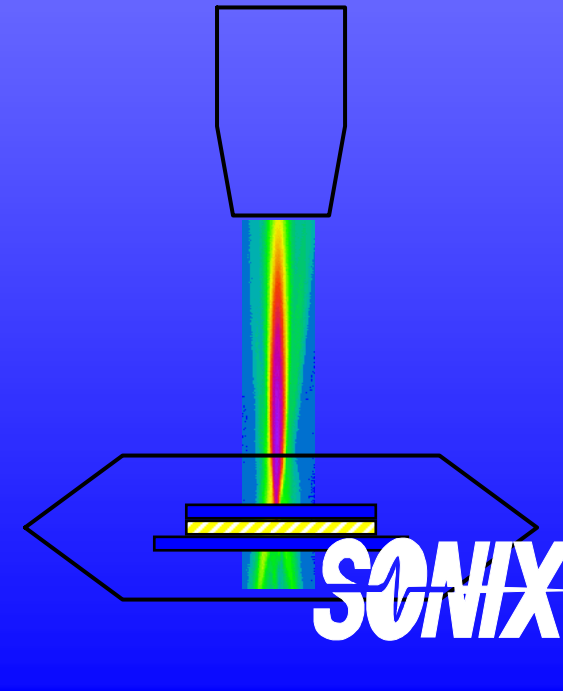
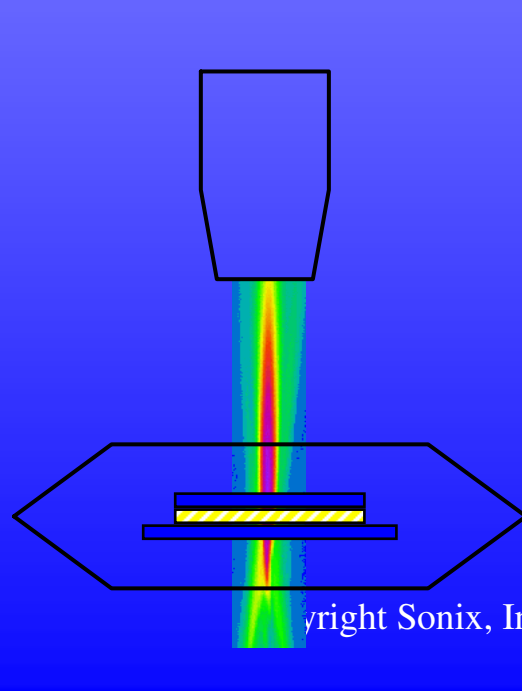
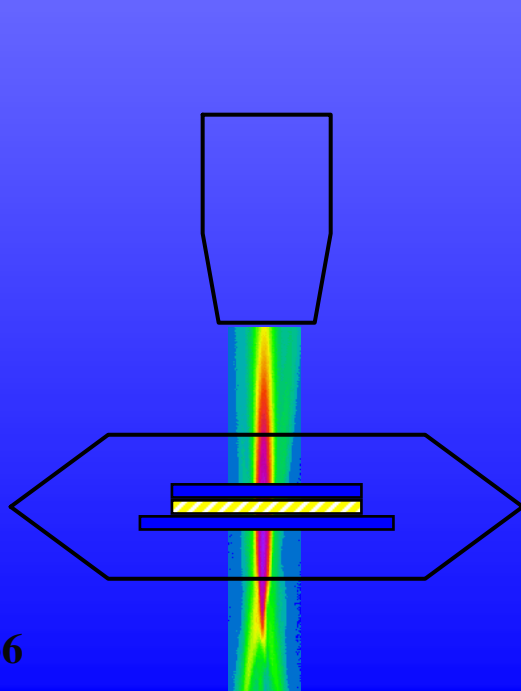


Amplitude = 82% Time = 14.5 us

De-Focused - Too Far Away



Amplitude = 55% Time = 18.5 us



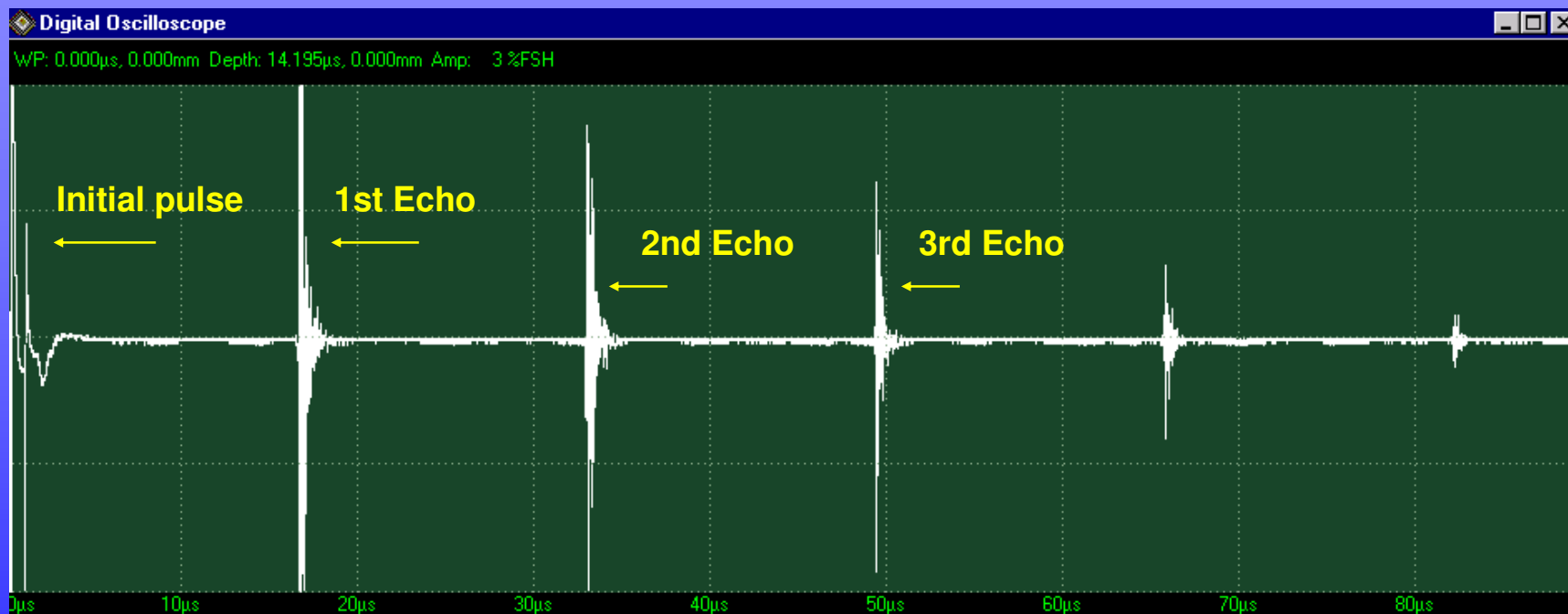
Copyright Sonix, Inc



Practical Application

- Digital Oscilloscope
- Front Surface Follower
- Data Gates

Digital Oscilloscope



The 1st set of echoes is the area of interest, gate placement will be on this group.

Multiple Echoes

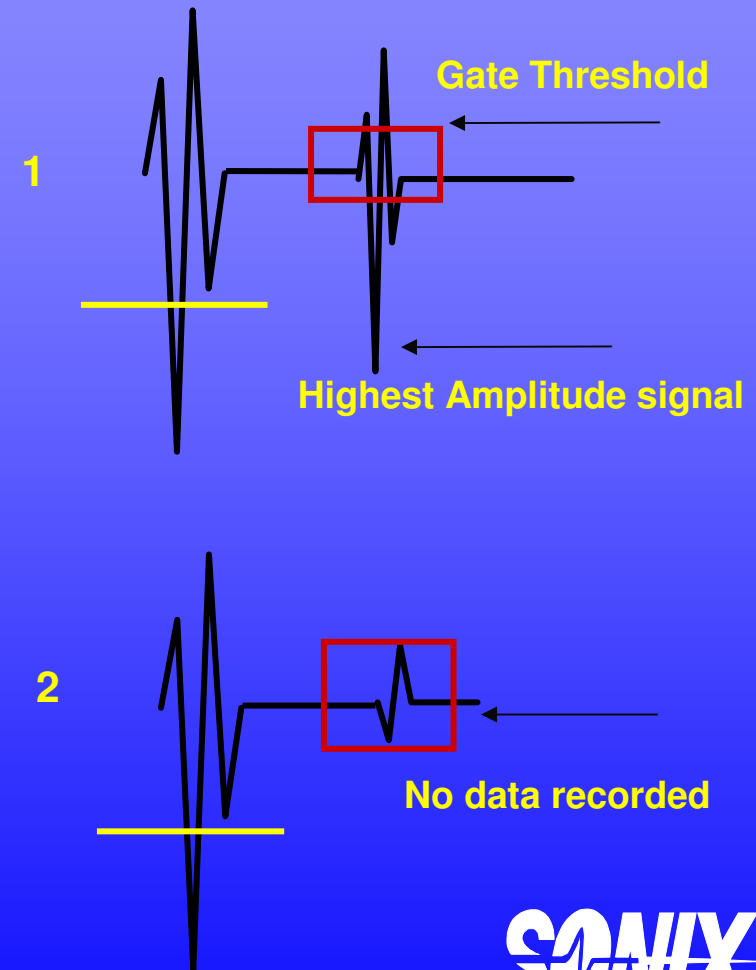
Copyright Sonix, Inc

SONIX

Gates

Gates are used to collect information at desired interfaces within the sample.

- The gate is placed over the signal or signals of interest.
- The absolute value of the highest amplitude signal which breaks the gate threshold within the gated region is recorded. (Figure 1)
- If no signal breaks the gate threshold no data is recorded. (Figure 2)
- Signal amplitude can be increased or decreased by adjusting gain.



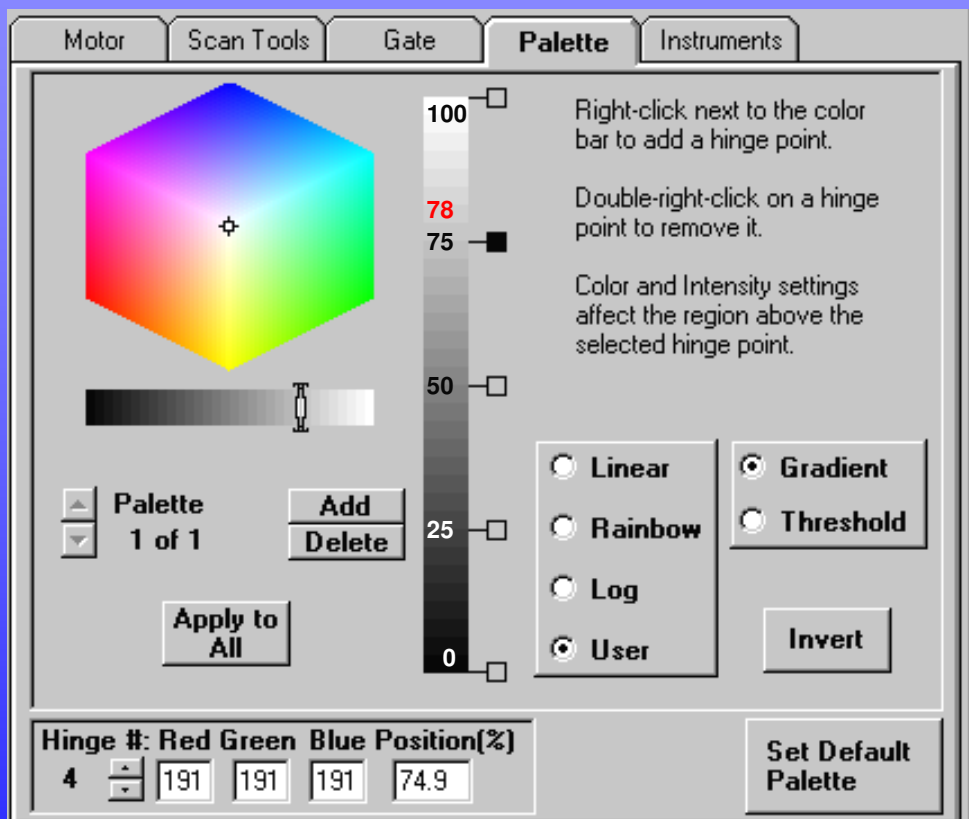
Practical Application

- **Image Data**
 - **Peak Amplitude**
 - **Time of Flight (TOF)**
 - **Phase Inversion**

Peak Amplitude

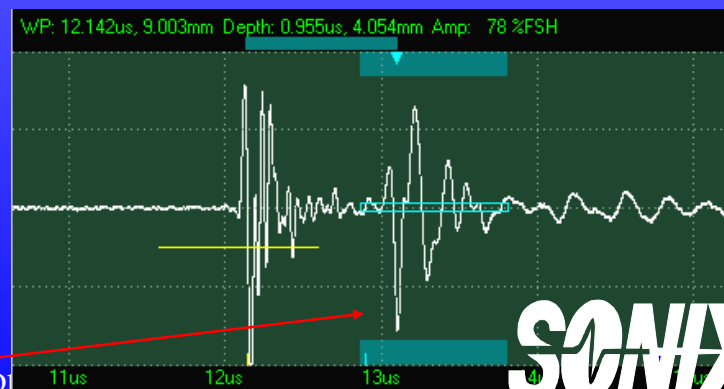
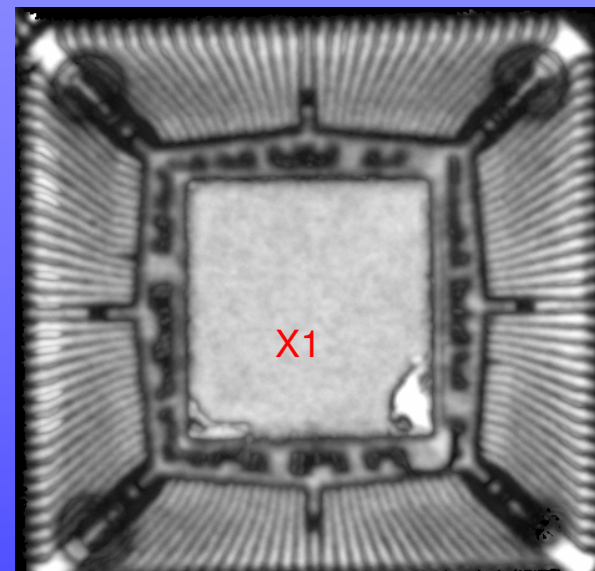
Peak amplitude imaging is used when defects result in changes in the amount or strength of ultrasound reflected. It is the most common type of imaging technique.

Peak Amplitude



Signal height is measured in absolute value for Peak Amplitude images.

Peak Amplitude

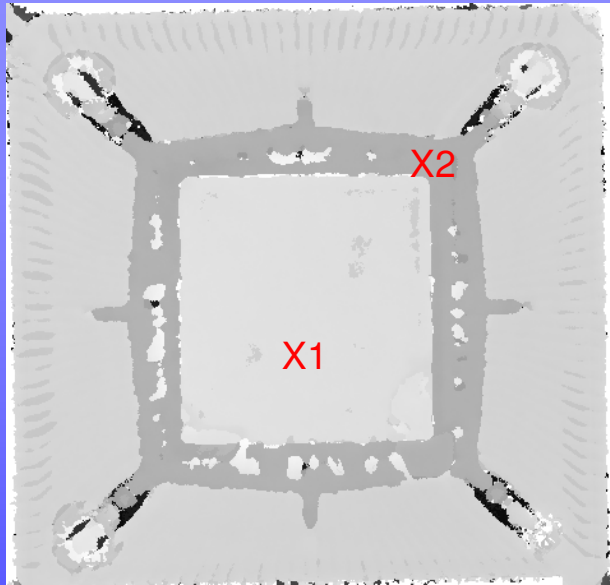


SONIX

Time Of Flight

Time of Flight (TOF) imaging works by measuring changes in the time it takes sound to reflect off a particular interface. Most commonly used to measure die tilting.

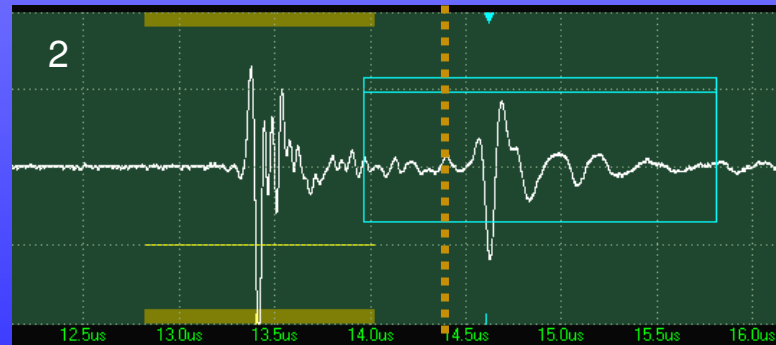
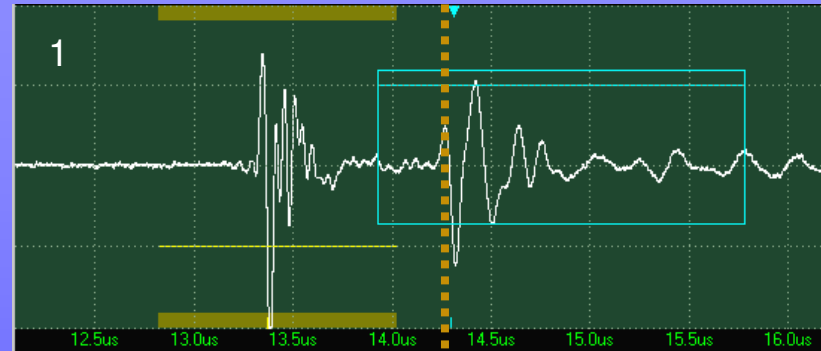
Time Of Flight



Time of Flight images provide a relative depth within a sample.

Structures which appear white or light gray are closer to the surface of the sample.

Structures which appear darker shades of gray or black are deeper within sample.



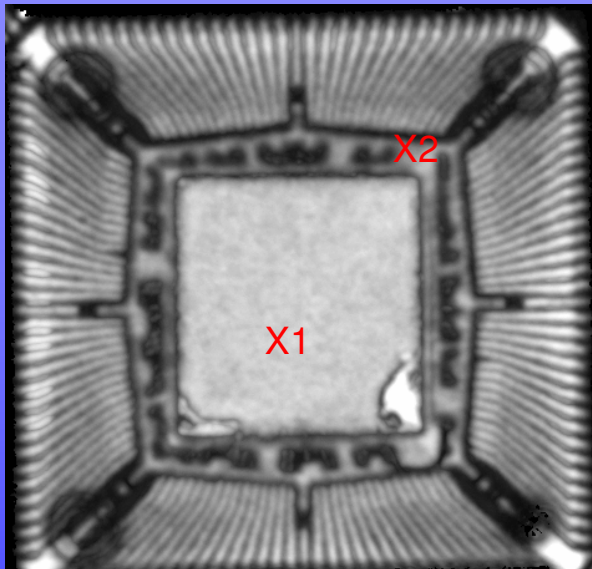
The peak signal for location 1 occurs at 14.2 microseconds (light gray) while the peak signal for location 2 occurs at 14.6 microseconds (dark gray).

Copyright Sonix, Inc

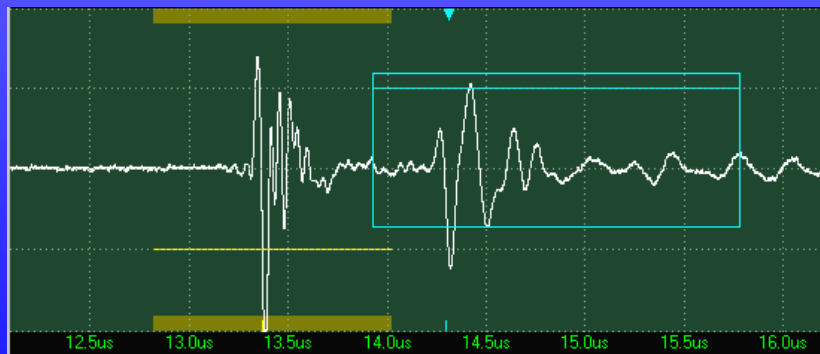
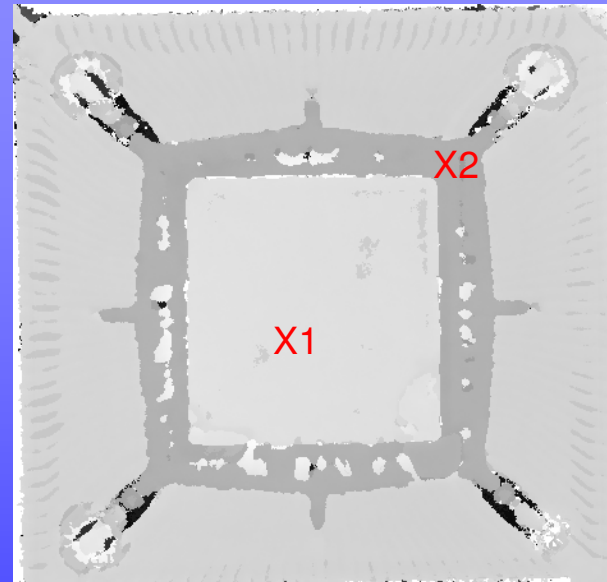
SONIX

Peak Amplitude vs. TOF

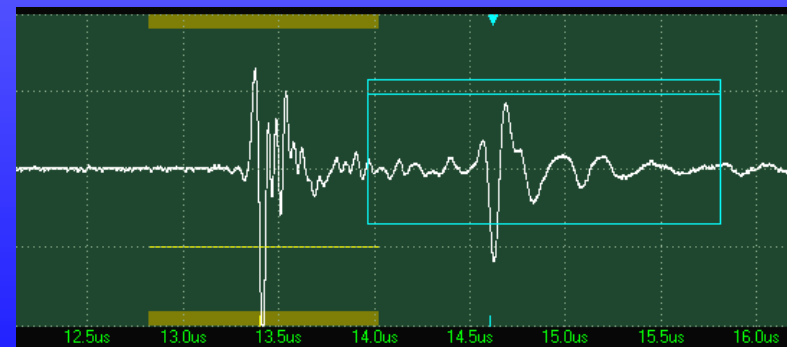
Peak Amplitude



Time of Flight



Amplitude = 73% Time = 14.2 microseconds



Amplitude = 67% Time = 14.6 microseconds

Copyright Sonix, Inc

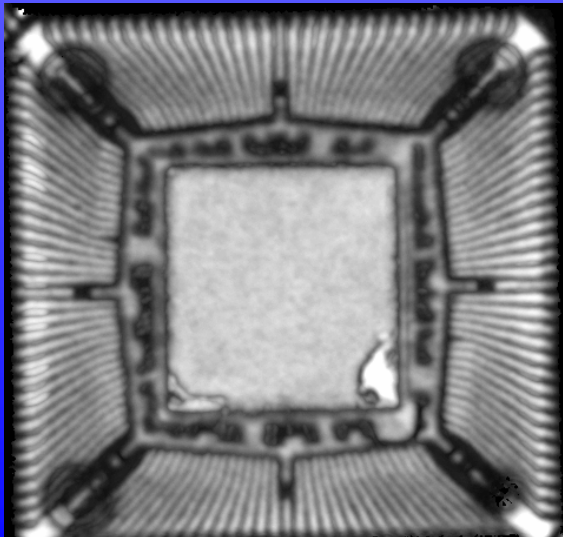
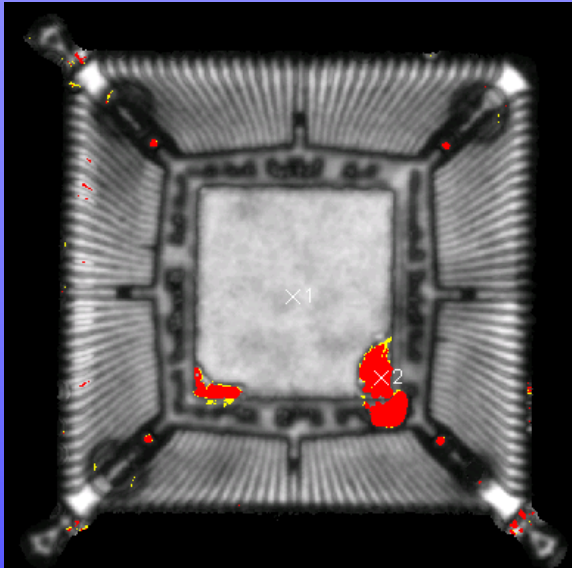


Phase Inversion

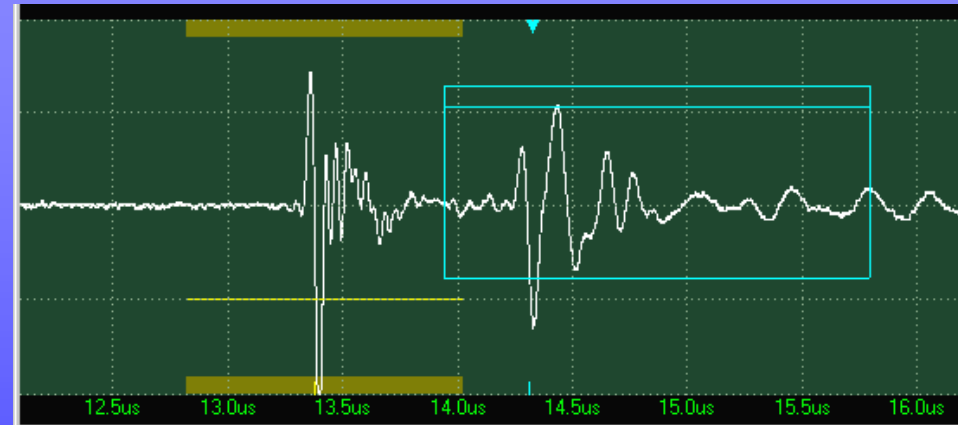
Phase Inversion imaging is used when defects cause changes in polarity (phase) of the signal. Most commonly used for top and back side imaging of plastic encapsulated devices.

Do not use phase inversion imaging for flip chip, bonded wafer or die attach imaging.

Phase Inversion



Normal

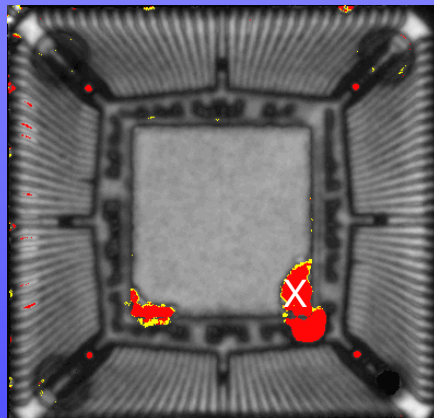
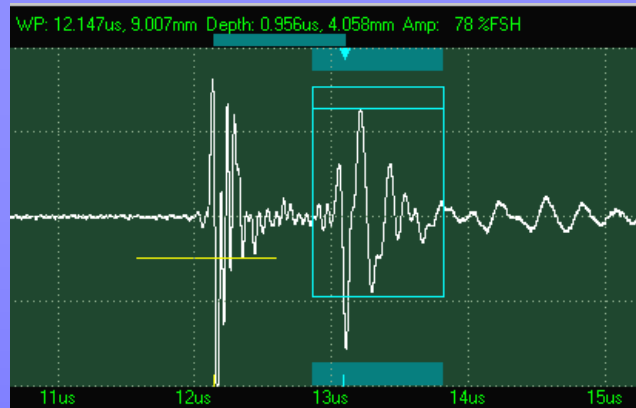
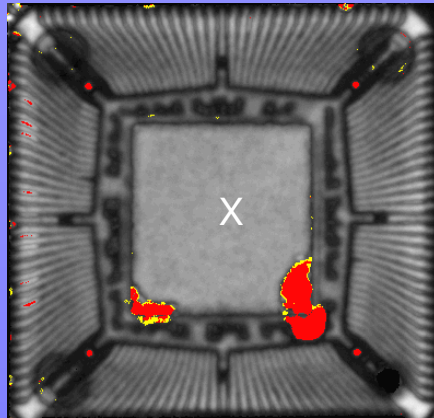


Phase Inverted

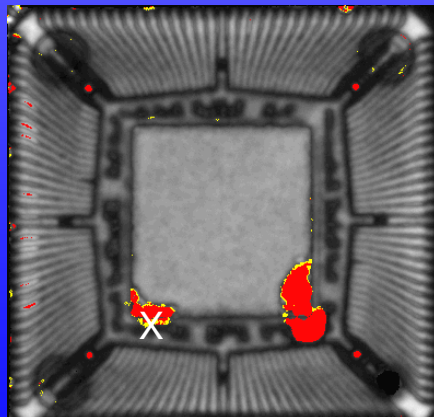
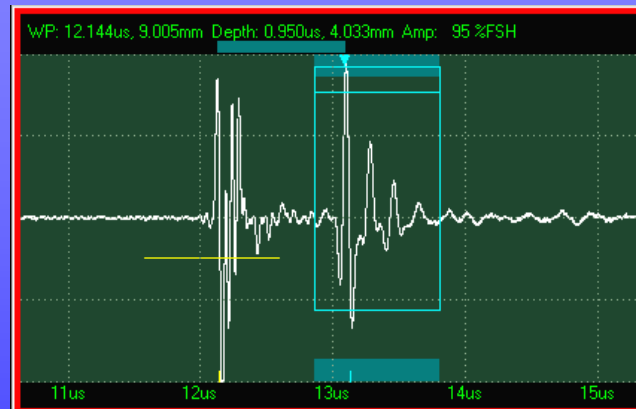


SONIX

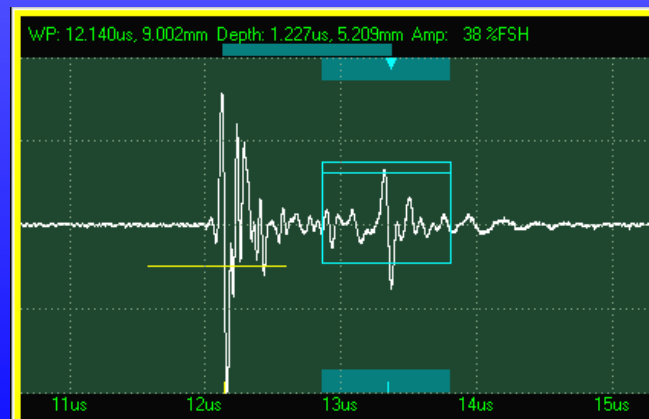
Phase Gate



RED

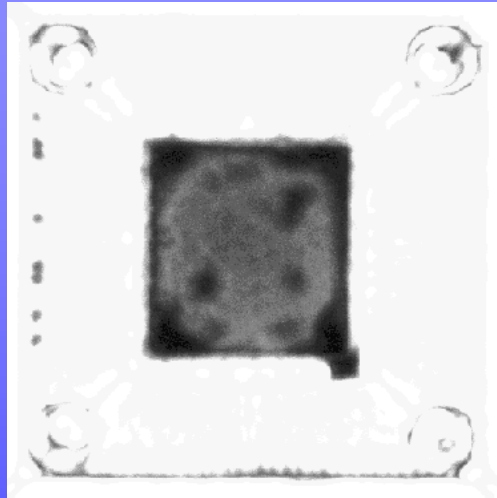


Yellow

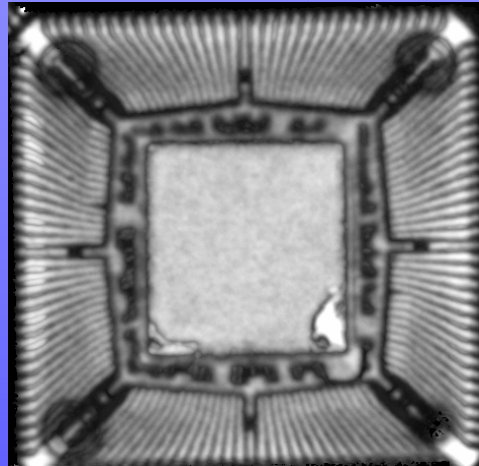


Sonix uses a proprietary algorithm to detect phase inversion. This method is independent of signal amplitude as long as the signal is not saturated (100% screen height).

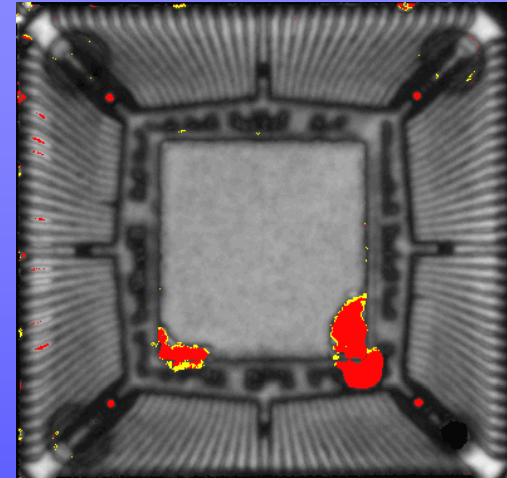
Image Comparison & Correlation



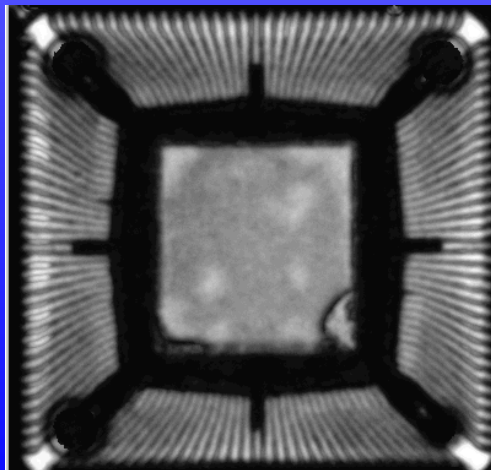
Through Transmission



Peak Amplitude Image
of Die Top



Phase Inversion Image
of Die Top



Peak Amplitude Image
of Die Attach