ULTRASONICS: 5

Production - Magnetostriction and Piezoelectric methods – Detection – Piezoelectric, Acoustic grating – Non Destructive Testing – pulse echo system -reflection and transmission modes – Modes of data presentation- A, B and C scan displays – Sonogram.

SCIENCE

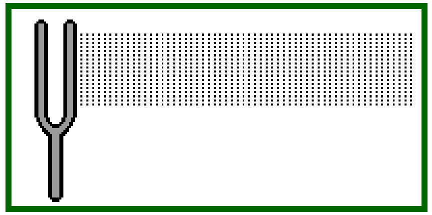
- PHYSICAL
  - LIGHT (Optics)
  - ELECTRON (Electronics)
  - . . .
  - SOUND (Acoustics)
    - Musical Acoustics
    - Architectural Acoustics
    - Engineering Acoustics
    - Underwater Acoustics
    - Bio-acoustics/Medical Acoustics
- CHEMICAL
- LIFE
- . . .

NATURE OF SOUND IN AIR

Sound in air is longitudinal with

Compressions (Condensations)

And Rarefactions



The human hearing range is about

20 Hz - 20,000 Hz.

Frequencies below 20 Hz are infrasonic.

Frequencies above 20,000 Hz are ultrasonic.

Sound waves of frequencies above the audible range are called ultrasonic waves or ultrasound

They are not audible to human ear

Bats and some animals can detect

$\lambda = v/f$ $\lambda = 330/20000$ $\lambda = 1.65\text{cm}$

Wavelength is too small.

Marine applications, medical diagnostics, non-destructive testing, engineering applications

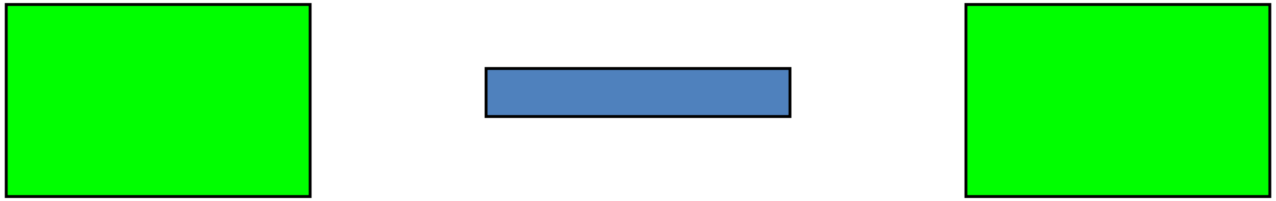
Ultrasonic production

Mechanical generators (Galton’s whistle and siren

Magnetorstriction generator

Piezo electric generator

Magnetostriction oscillator



Magnetostriction effect

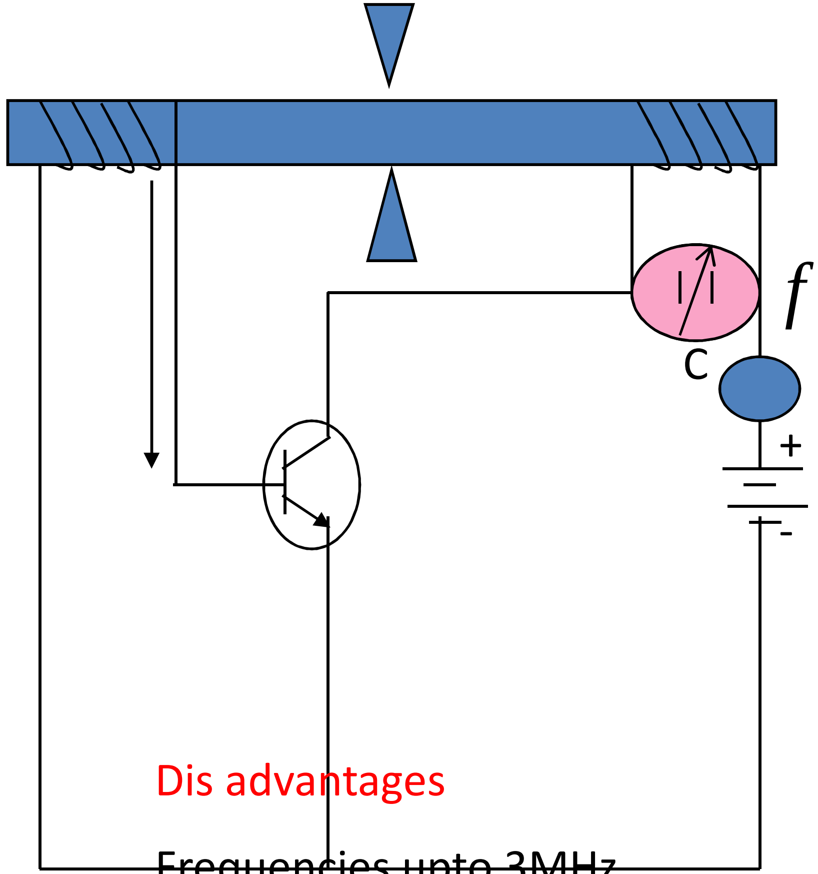
When a ferromagnetic rod of iron or nickel is placed in a magnetic field parallel to its length the rod experiences a small change in its length.

The change in length of the rod depends upon the strength of the magnetic field and the nature of the material.

Independent of the direction of the magnetic field

This effect is very small and can be detected with a sensitive device

$$n = \frac{1}{2l}\sqrt{\frac{E}{\rho}}$$



$$f = \frac{1}{2\pi\sqrt{LC}}$$

Advantages

Simple

At low frequencies, very large power output is possible without any risk of damage to the oscillatory cicuit

Dis advantages

Frequencies upto 3MHz

Depends on temperature

Loss of energy due to eddy current and hysteresis losses

Uses

High power applications such as drilling, welding, grinding etc

Speaker (voice coil)

Piezo-electric oscillator

Crystal

Piezo electric effect

Inverse piezo electric effect

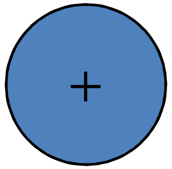
Piezo electric crystal

Piezo electric oscillator

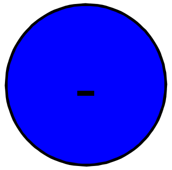
What is a crystal?

- A class of materials arranged in a definite, geometric pattern in three dimensions (table salt and sugar are common examples)
- Quartz Crystal is silicon and oxygen arranged in a crystalline structure (SiO_2).
- SiO_2 is also found abundantly in nature in a non-crystal structure (“amorphous”) as sand.

A method for predicting the behavior of a crystal: The unit cell



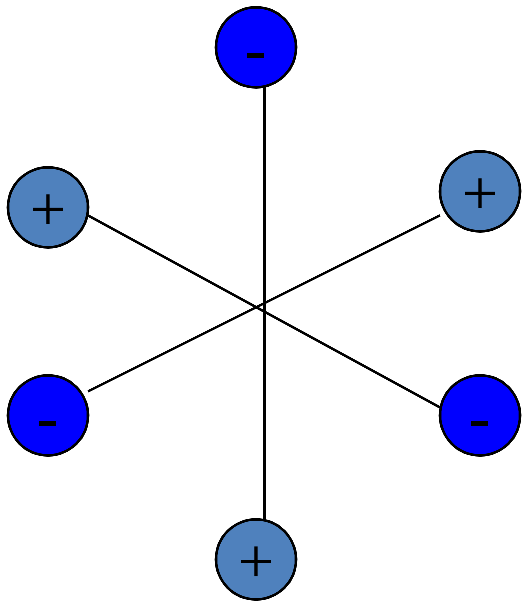
Represents silicon atom



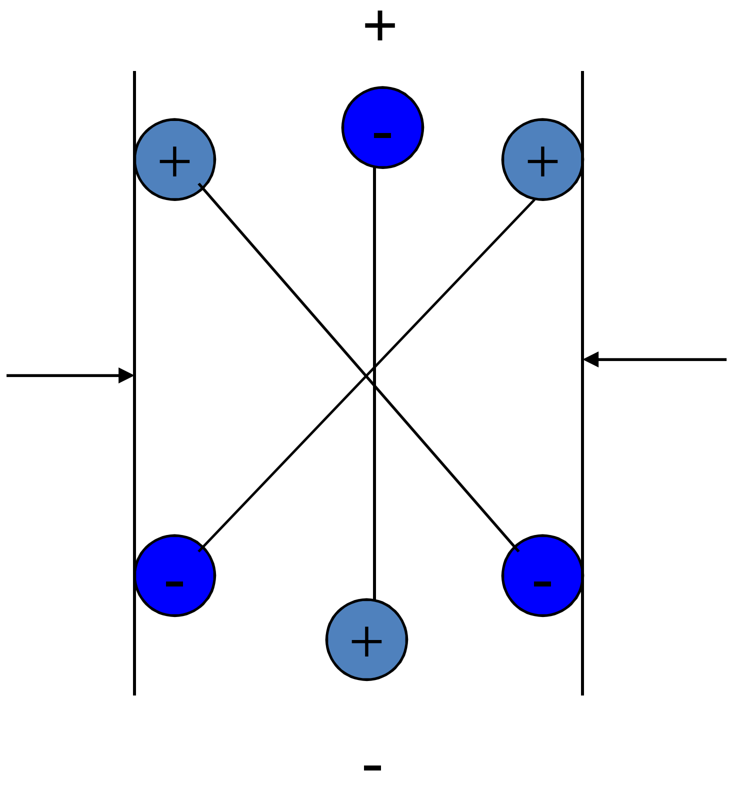
Represents oxygen atom

Not actually correct, but this method allows a good understanding of quartz crystals

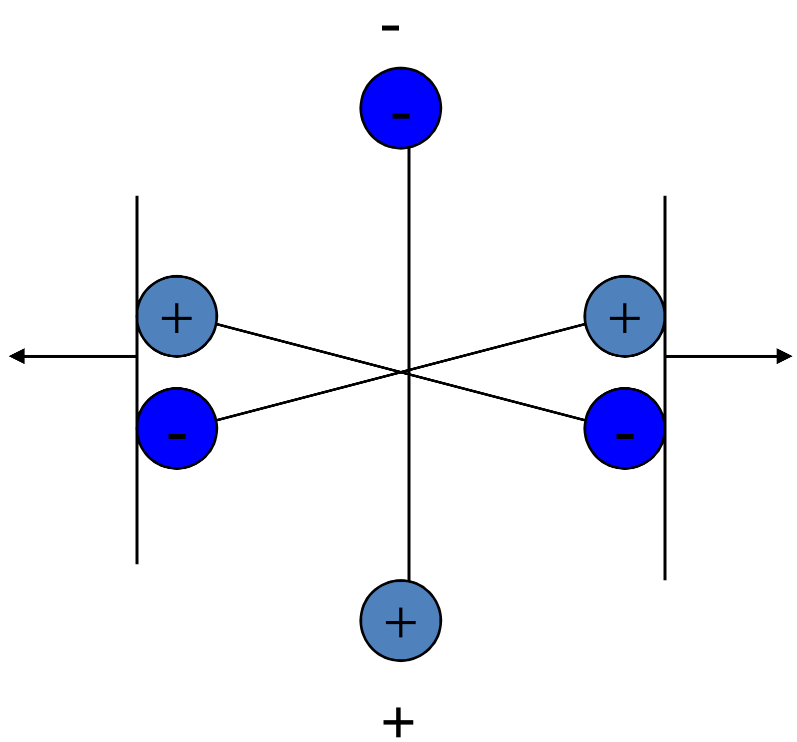
The unit cell of crystal silicon dioxide



A pushing force:
(compression)

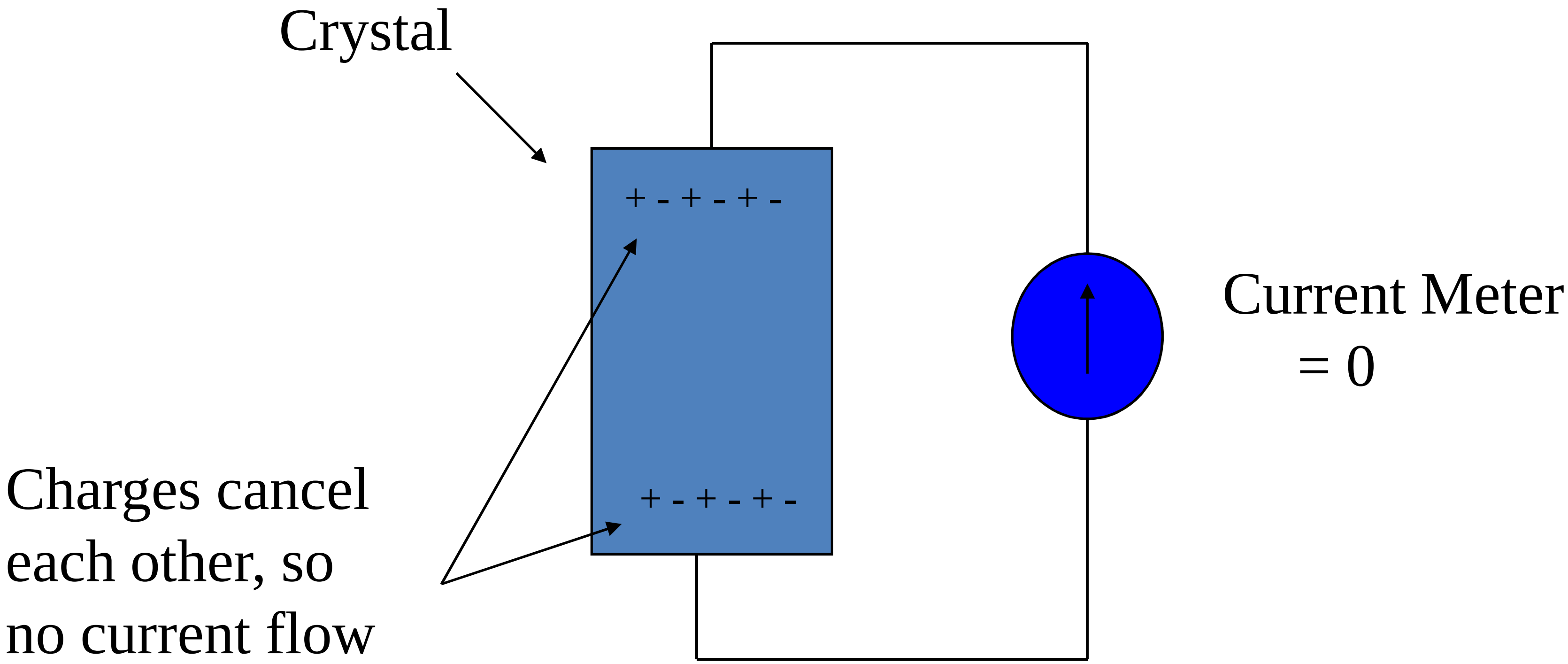


A pulling force:
(tension)



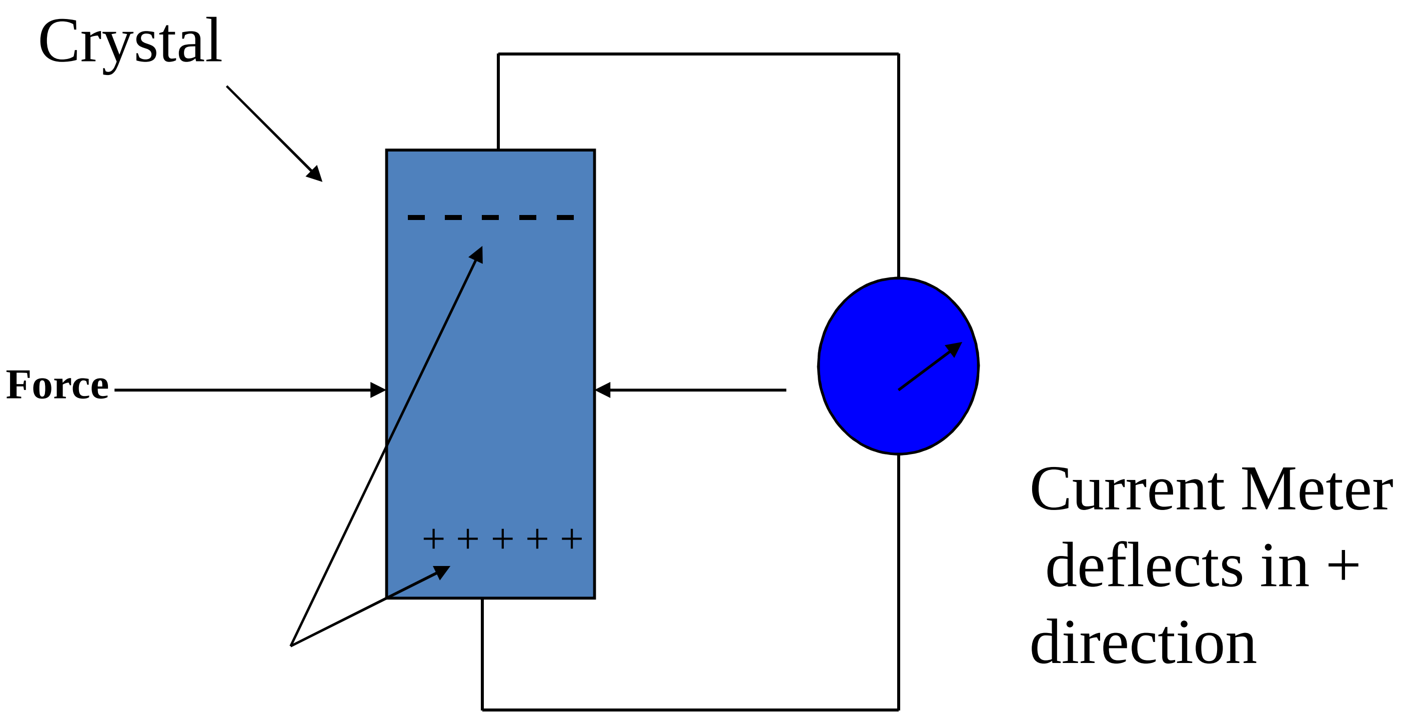
The Piezoelectric Effect

Crystal material at rest: No forces applied, so net current flow is 0



The Piezoelectric Effect

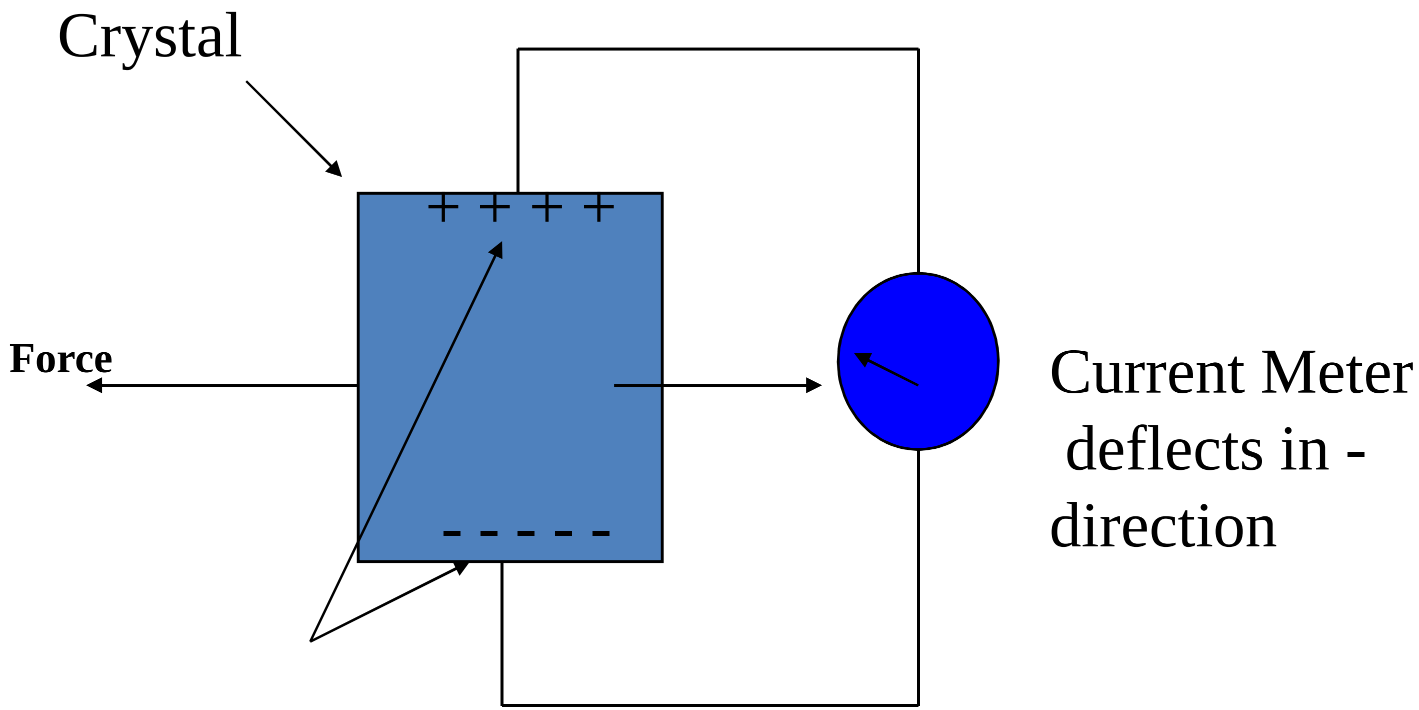
Crystal material with forces applied in direction of arrows………..



Due to properties of symmetry, charges are net + on one side & net - on the opposite side: crystal gets thinner and longer

The Piezoelectric Effect

Changing the direction of the applied force………..



…. Changes the direction of current flow, and the crystal gets shorter and fatter.

Piezo-electric effect

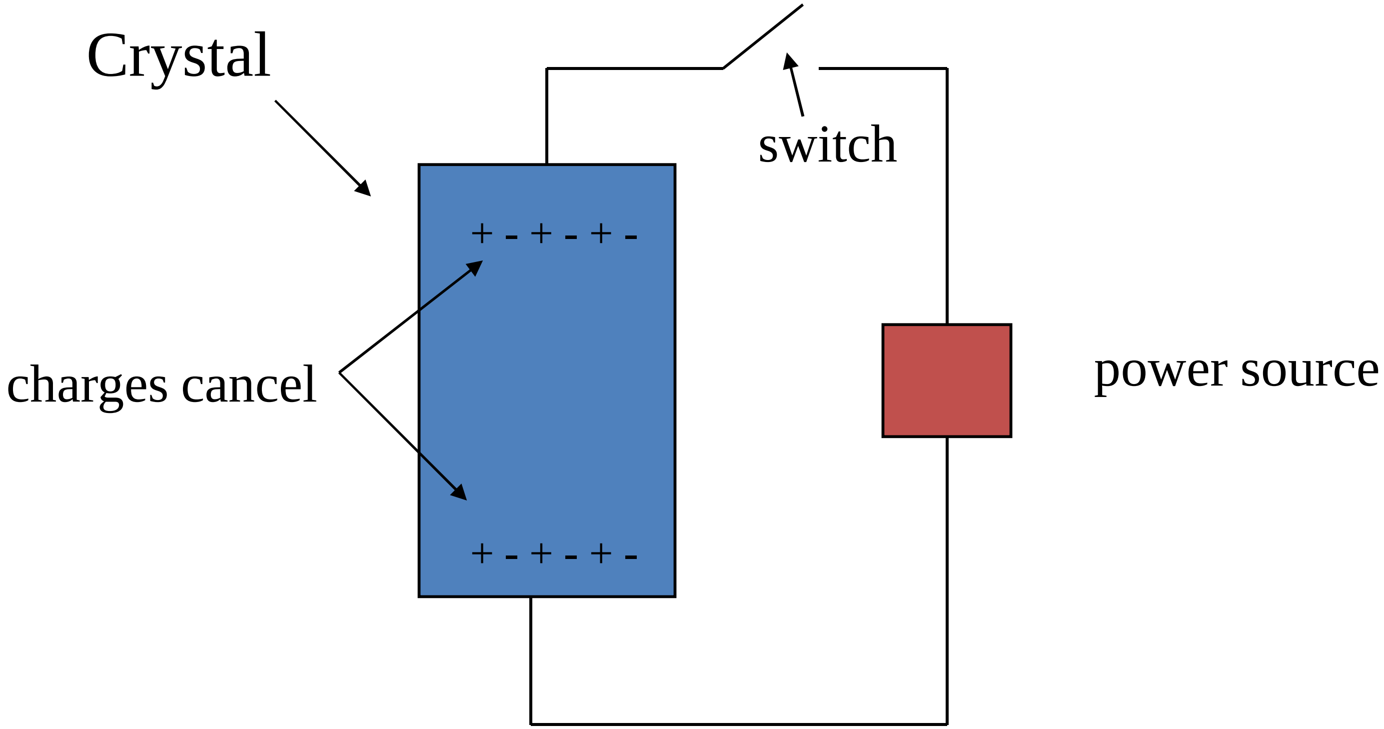
When one pair of opposite faces of certain crystals such as quartz is subjected to pressure, in the other pair of opposite faces, opposite electric charges are developed. When the faces are subjected to tension instead of pressure, the sign of the developed charges reverse

The electromechanical nature of piezoelectric material

- In general, if you deform a piezo crystal by applying a force, you will get charge separation: Think of a simple battery.
- Taking it one step further, what would happen to the crystal if you applied an electrical force that results in the exact same current flow from the proceeding circuit?

The electromechanical effect

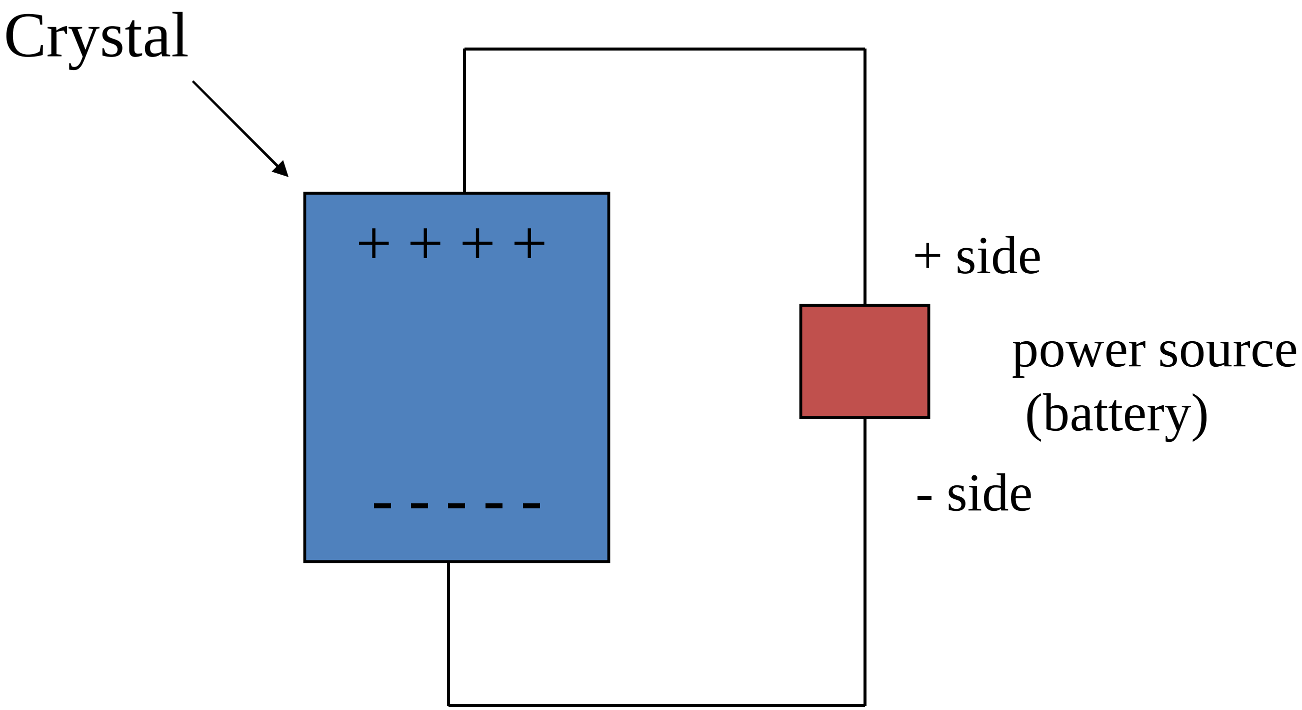
Now, replace the current meter with a power source capable of supplying the same current indicated by the meter….



…. With the switch open, the crystal material is now at rest again: the positive charges cancel the negative charges.

The electromechanical effect

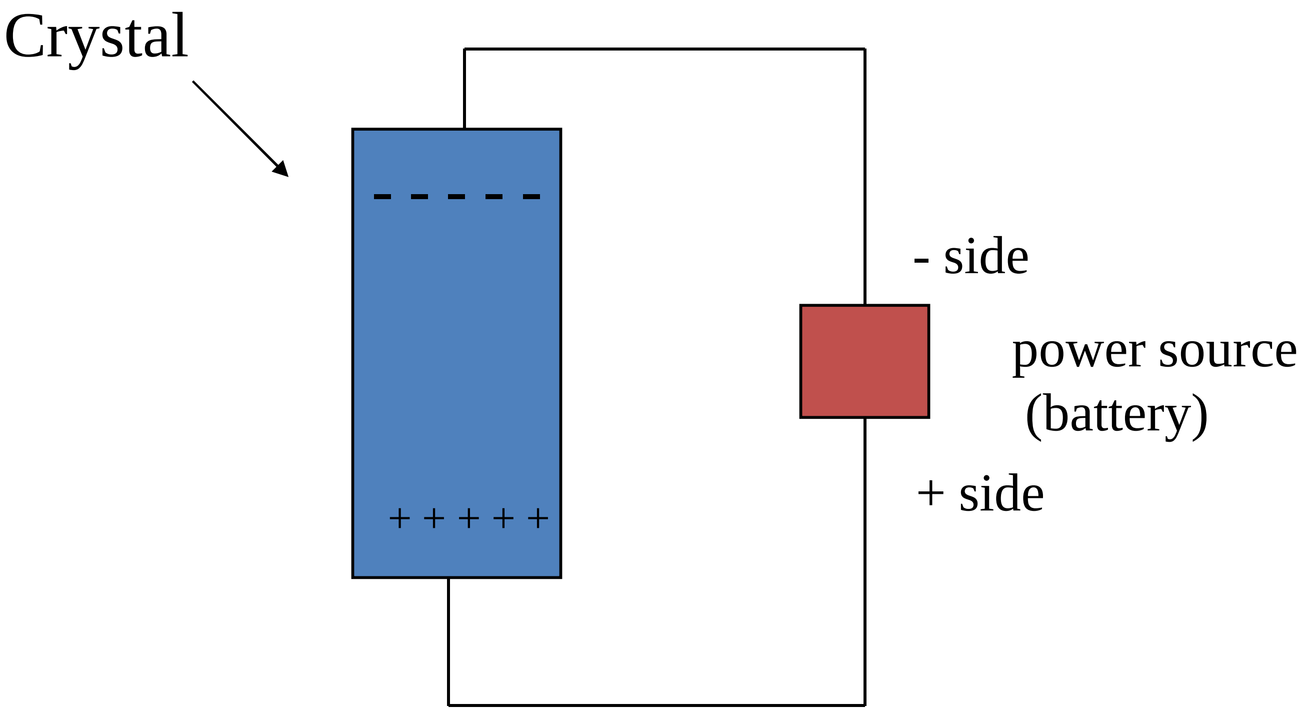
When the switch is closed, and you apply the exact amount of power to get the same current that resulted when you squeezed the crystal, the crystal should deform by the same amount!!



…. and, the crystal should get shorter and fatter.

The electromechanical effect

What will happen if you switched the battery around??



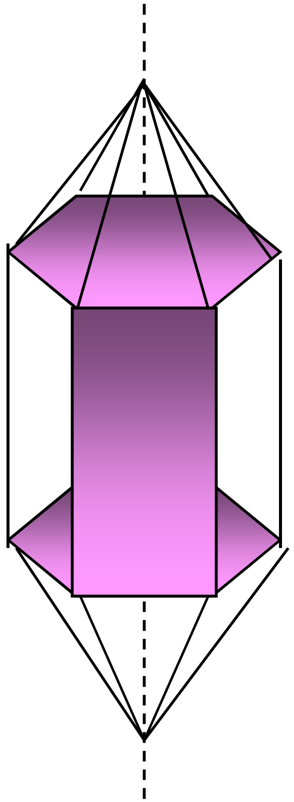
…. the crystal should get longer and skinnier.

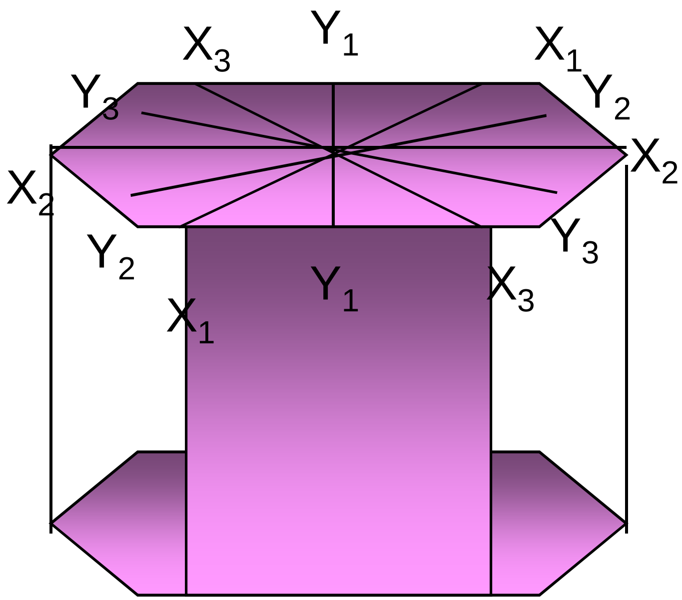
Inverse piezo-electric effect

If an electric field is applied to one pair of opposite faces of a quartz crystal, alternative mechanical expansion or contraction (pressure) is produced across the other pair of opposite faces of the crystal. This is known as inverse piezo-electric effect

Summary of the Piezoelectric & Electromechanical Effect

- A deformation of the crystal structure (eg: squeezing it) will result in an electrical current.
- Changing the direction of deformation (eg: pulling it) will reverse the direction of the current.
- If the crystal structure is placed into an electrical field, it will deform by an amount proportional to the strength of the field.
- If the same structure is placed into an electrical field with the direction of the field reversed, the deformation will be opposite.



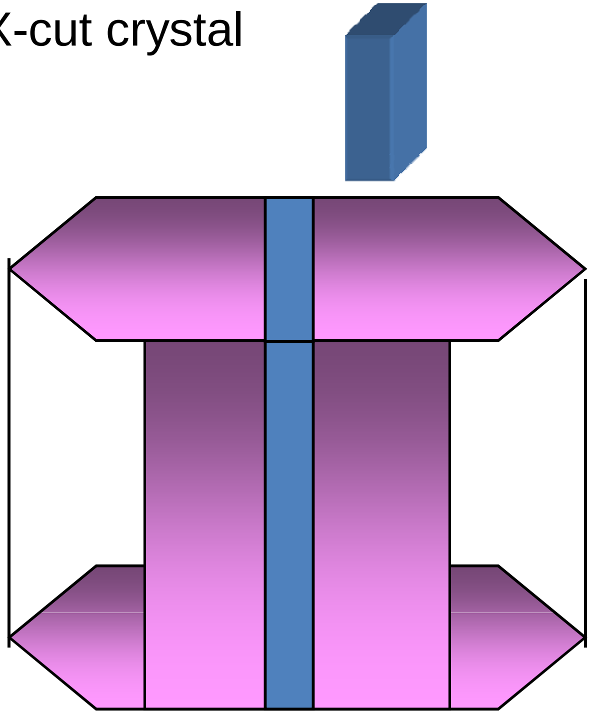


X-axis electrical axis

Y-axis Mechanical axis

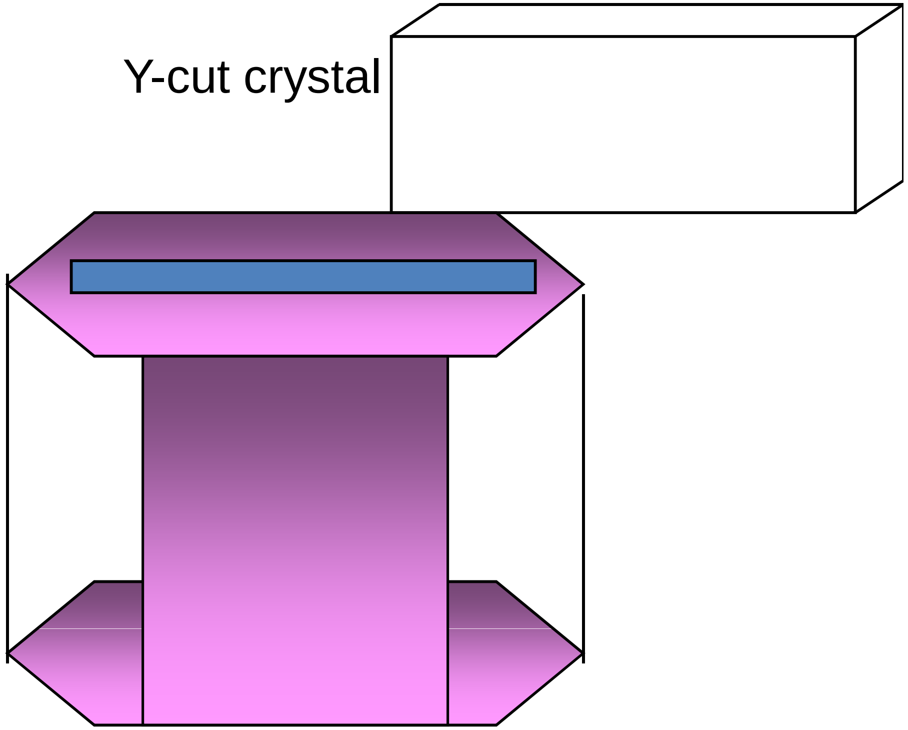
Z-axis Optical axis

X-cut crystal



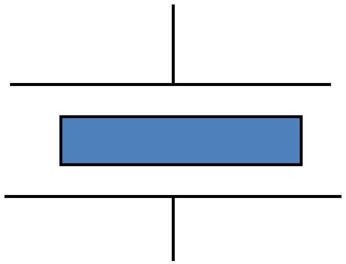
Cut perpendicular to X

Y-cut crystal



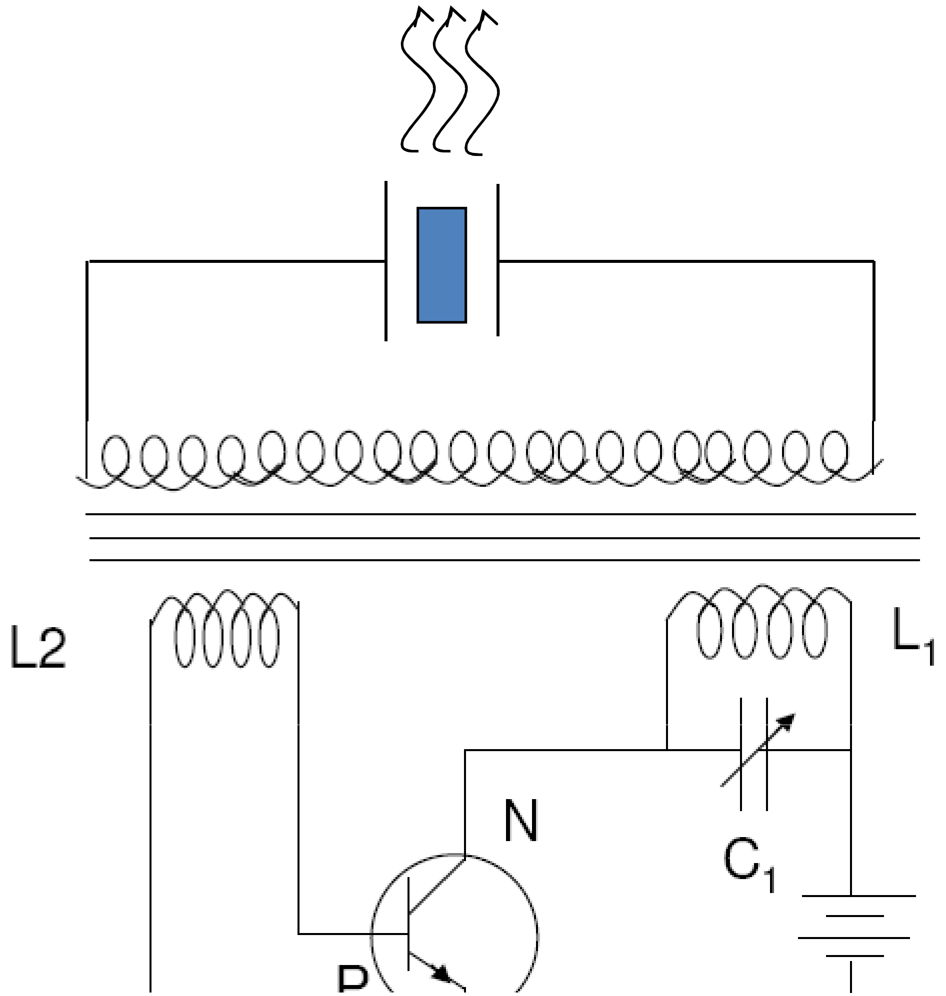
Cut perpendicular to Y

Thickness is high



$$f = \frac{v}{2l}$$

Thickness less than 1mm



$$f = \frac{n}{2l}\sqrt{\frac{E}{\rho}}$$

$$f = \frac{1}{2\pi\sqrt{(L_1 + L_2 + \;.\;)C_1}}$$

Frequency as high as 500MHz

Breadth of resonance curve is small, so get stable and constant frequency

Insensitive to temperature and humidity

Output is very high

Expensive

Cutting and polishing is difficult

Properties of ultrasonic waves

Frequencies higher than 20kHz

Diffraction is negligible

Highly energetic

Partially discontinuous if there is any change in the medium

When absorbed by medium it generates heat

Detection of Ultrasonic sound

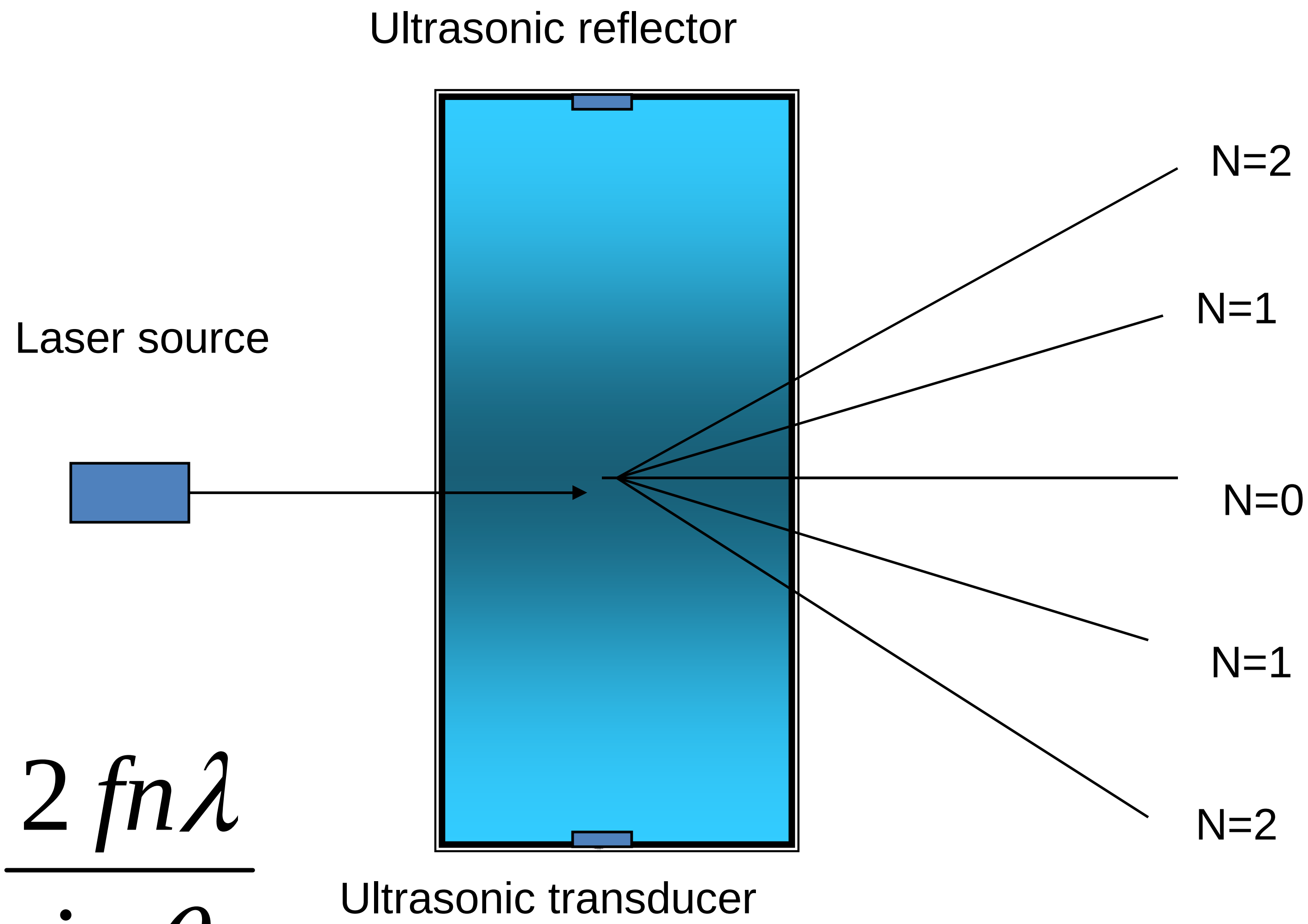
Thermal method

Piezoelectric or quartz crystal method

Kundt’s tube method

Sensitive Flame method

Determination of ultrasonic waves in liquids using acoustic grating



$$v = \frac{2fn\lambda}{\sin\theta_n}$$

Applications of ultrasonic waves

- Depth of sea
- SONAR
- Ultrasonic signaling
- Detection of flaws in metals
- Soldering and metal cutting
- Formation of alloys
- Cleaning
- Ultrasound scanning for movement of internal organs of a human body

Properties of ultrasonic waves

Frequencies higher than 20kHz

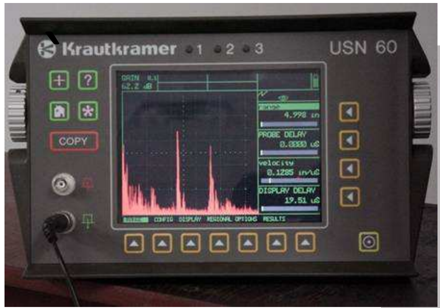
Diffraction is negligible

Highly energetic

Partially discontinuous if there is any change in the medium

When absorbed by medium it generates heat

Ultrasonic Testing



Introduction

- Ultrasonic testing uses high frequency sound energy to conduct <u>NDT examinations and make measurements.</u>
- Ultrasonic examinations can be conducted on a wide variety of <u>material forms</u> including <u>castings, forgings, welds, and composites.</u>
- A considerable amount of information about the part being examined can be collected, such as the presence of <u>discontinuities, part or coating thickness; and acoustical properties</u> can often be correlated to certain <u>properties of the material.</u>

Principles of Ultrasonic Inspection

- Ultrasonic waves are introduced into a material where they travel in a straight line and at a constant speed until they encounter a surface.
- At surface interfaces some of the wave energy is reflected and some is transmitted.
- The amount of reflected or transmitted energy can be detected and provides information about the size of the reflector.
- The travel time of the sound can be measured and this provides information on the distance that the sound has traveled.

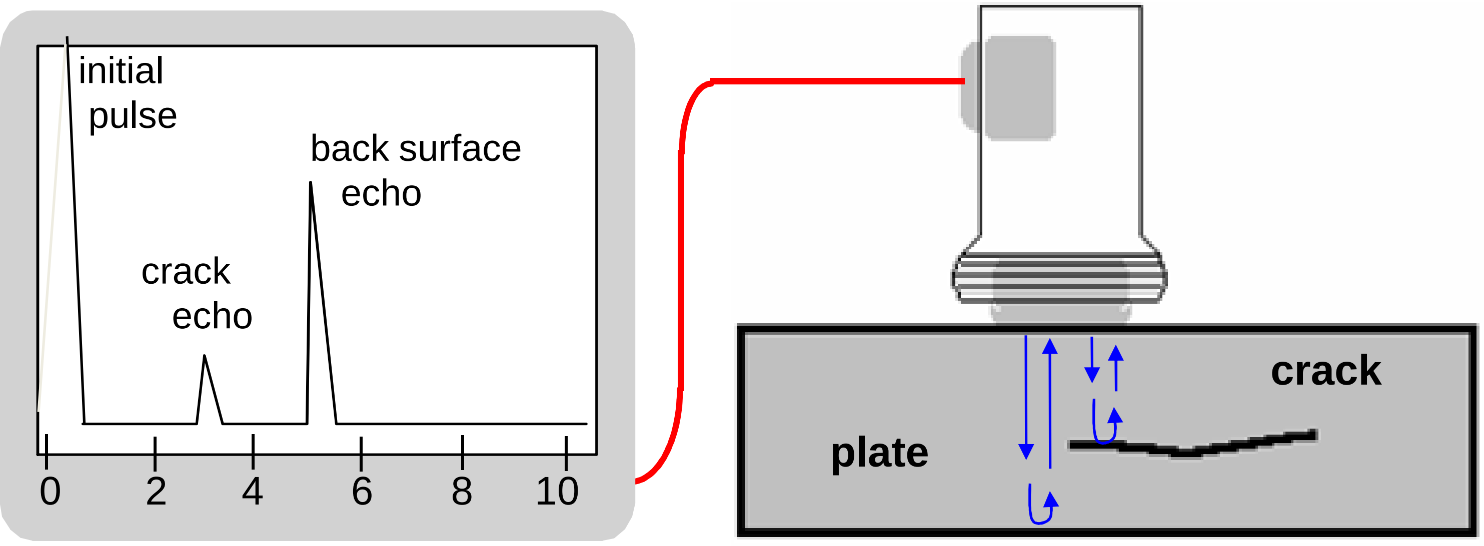
Test Techniques

- Ultrasonic testing is a very versatile inspection method, and inspections can be accomplished in a number of different ways.
- Ultrasonic inspection techniques are commonly divided into three primary classifications.
  - **Pulse-echo and Through Transmission**
    (Relates to whether reflected or transmitted energy is used)
  - **Normal Beam and Angle Beam**
    (Relates to the angle that the sound energy enters the test article)
  - **Contact and Immersion**
    (Relates to the method of coupling the transducer to the test article)

Each of these techniques will be discussed briefly in the following slides.

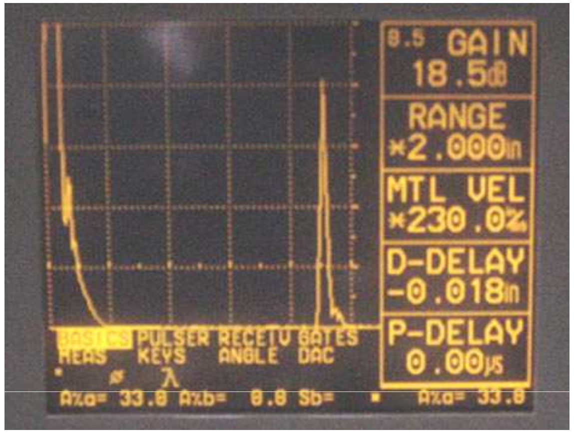
Test Techniques - Pulse-Echo

- In pulse-echo testing, a transducer sends out a pulse of energy and the same or a second transducer listens for reflected energy (an echo).
- Reflections occur due to the presence of discontinuities and the surfaces of the test article.
- The amount of reflected sound energy is displayed versus time, which provides the inspector information about the size and the location of features that reflect the sound.



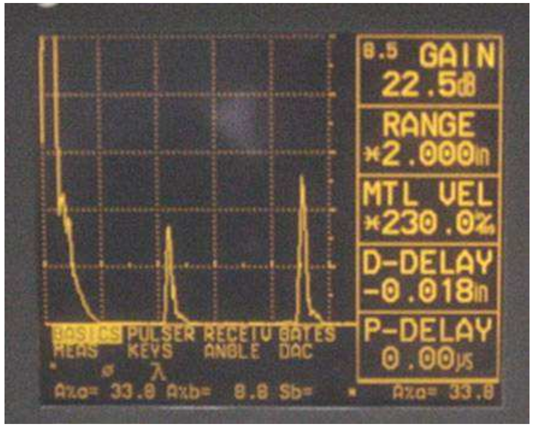
UT Instrument Screen

Test Techniques – Pulse-Echo (cont.)



Digital display showing signal generated from sound reflecting off back surface.

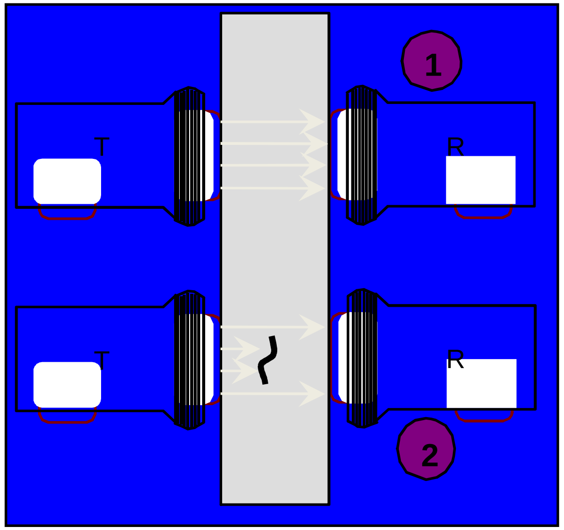
Digital display showing the presence of a reflector midway through material, with lower amplitude back surface reflector.

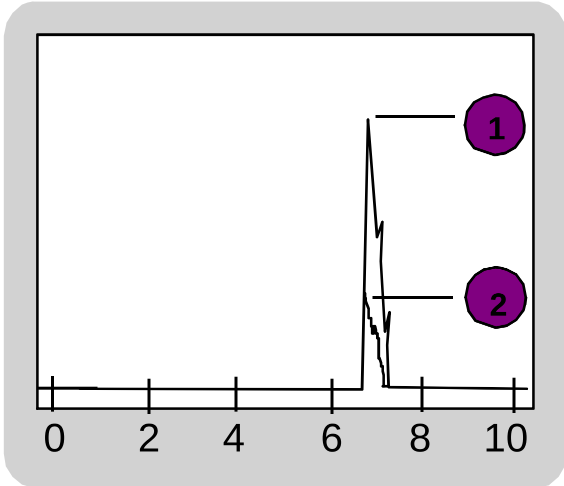


The pulse-echo technique allows testing when access to only one side of the material is possible, and it allows the location of reflectors to be precisely determined.

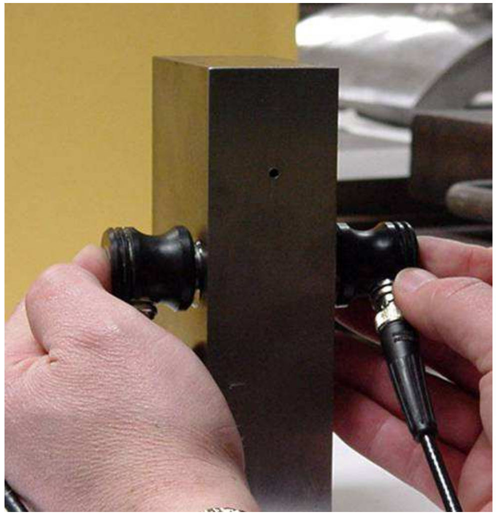
Test Techniques – Through-Transmission

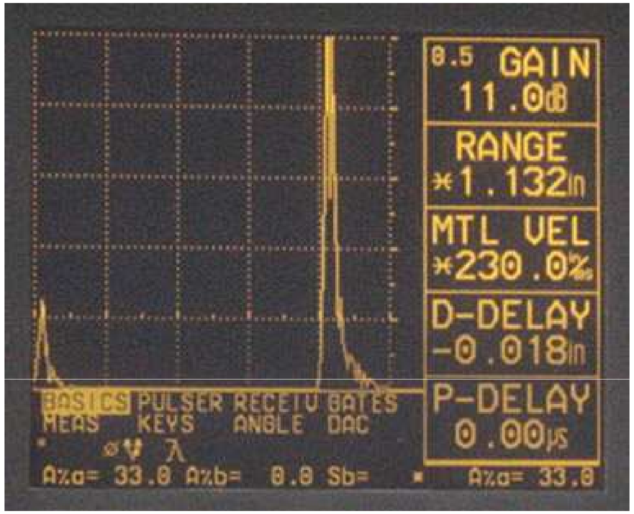
- Two transducers located on opposing sides of the test specimen are used. One transducer acts as a transmitter, the other as a receiver.
- Discontinuities in the sound path will result in a partial or total loss of sound being transmitted and be indicated by a decrease in the received signal amplitude.
- Through transmission is useful in detecting discontinuities that are not good reflectors, and when signal strength is weak. It does not provide depth information.



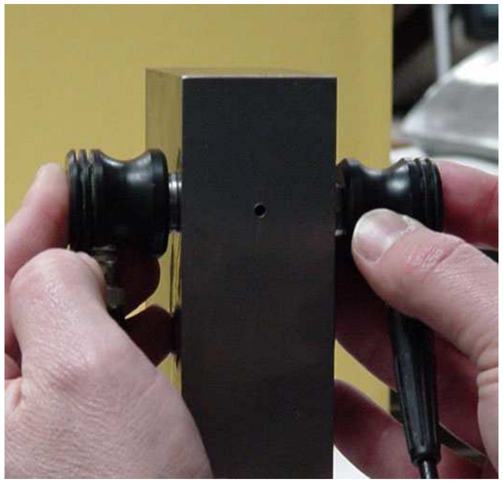


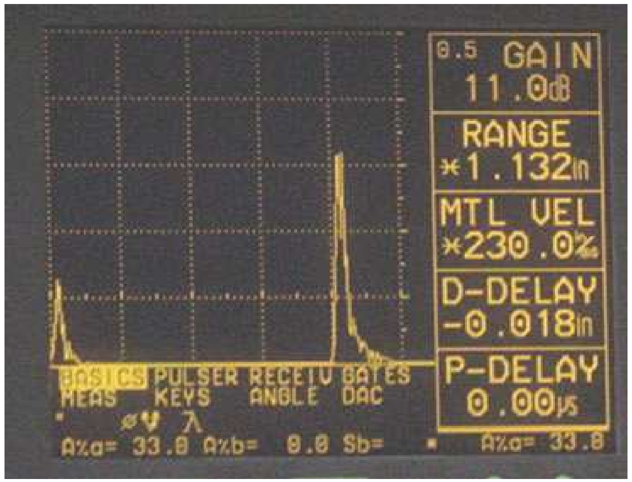
Test Techniques – Through-Transmission





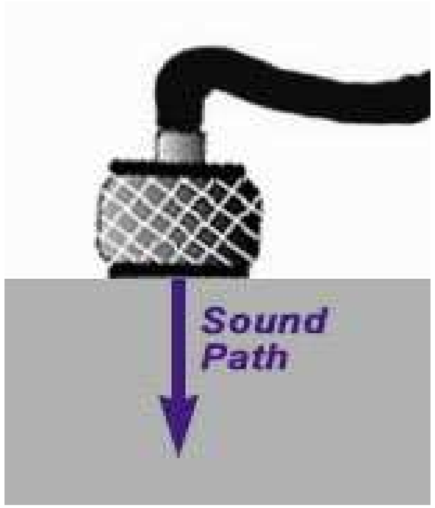
Digital display showing received sound through material thickness.

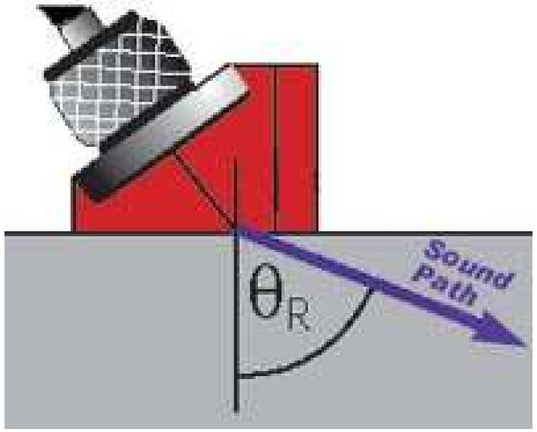




Digital display showing loss of received signal due to presence of a discontinuity in the sound field.

Test Techniques – Normal and Angle Beam

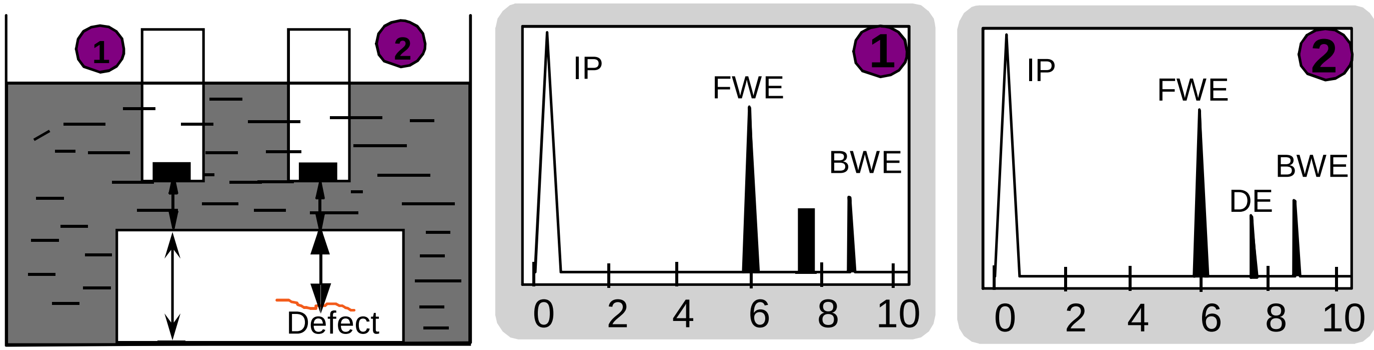




- **In normal beam testing, the sound beam is introduced into the test article at 90 degree to the surface.**
- **In angle beam testing, the sound beam is introduced into the test article at some angle other than 90.**
- **The choice between normal and angle beam inspection usually depends on two considerations:**
  - **The orientation of the feature of interest – the sound should be directed to produce the largest reflection from the feature.**
  - **Obstructions on the surface of the part that must be worked around.**

Test Techniques – Contact Vs Immersion

- **To get useful levels of sound energy into a material, the air between the transducer and the test article must be removed. This is referred to as coupling.**
- **In contact testing (shown on the previous slides) a couplant such as water, oil or a gel is applied between the transducer and the part.**
- **In immersion testing, the part and the transducer are place in a water bath. This arrangement allows better movement of the transducer while maintaining consistent coupling.**
- **With immersion testing, an echo from the front surface of the part is seen in the signal but otherwise signal interpretation is the same for the two techniques.**



IP = Initial Pulse
FWE = Front Wall Echo
DE = Defect Echo
BWE = Back Wall Echo

Inspection Applications

Some of the applications for which ultrasonic testing may be employed include:

- **Flaw detection (cracks, inclusions, porosity, etc.)**
- **Erosion & corrosion thickness gauging**
- **Assessment of bond integrity in adhesively joined and brazed components**
- **Estimation of void content in composites and plastics**
- **Measurement of case hardening depth in steels**
- **Estimation of grain size in metals**

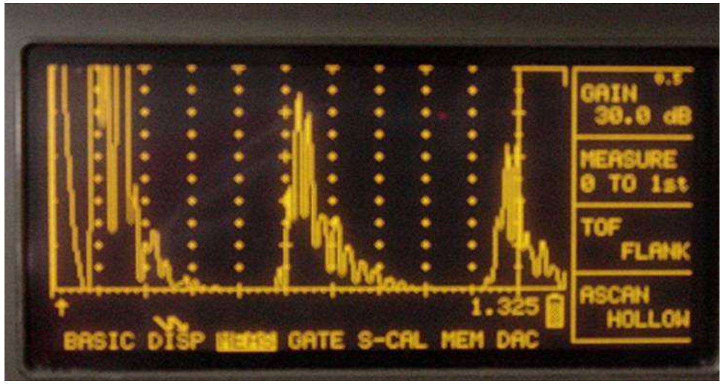
On the following slides are examples of some common applications of ultrasonic inspection.

Thickness Gauging

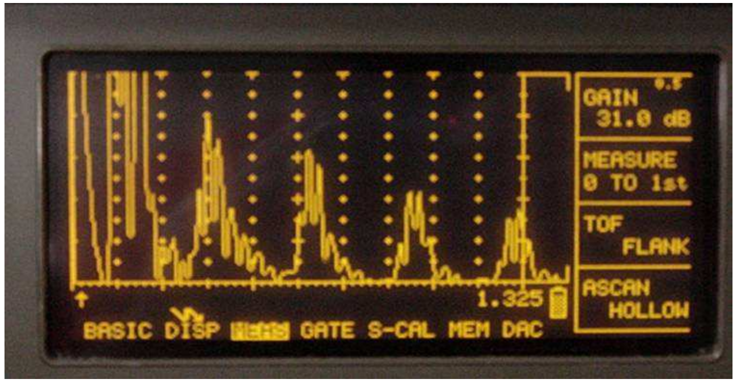
- Ultrasonic thickness gauging is routinely utilized in the petrochemical and utility industries to determine various degrees of corrosion/erosion.
- **Applications include piping systems, storage and containment facilities, and pressure vessels.**

Flaw Detection - Delaminations

Contact, pulse-echo inspection for delaminations on 36” rolled beam.



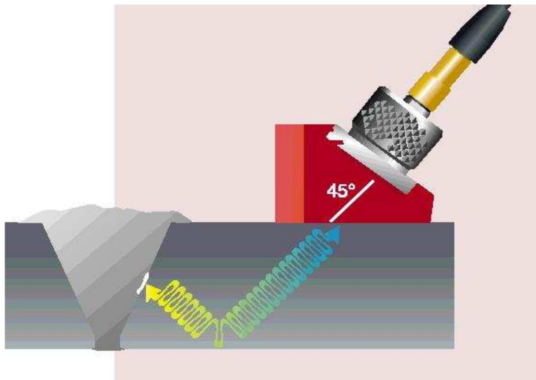
Signal showing multiple back surface echoes in an unflawed area.

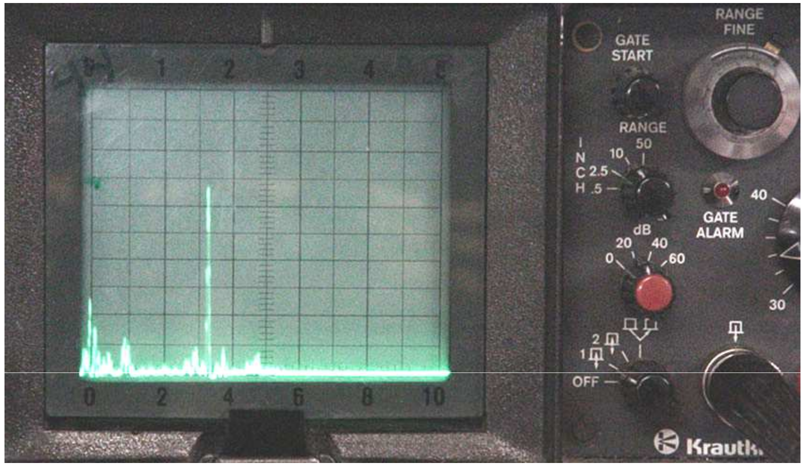


Additional echoes indicate delaminations in the member.

Flaw Detection in Welds

- One of the most widely used methods of inspecting weldments is ultrasonic inspection.
- Full penetration groove welds lend themselves readily to angle beam shear wave examination.





Images of a Quarter Produced With an Ultrasonic Immersion Scanning System

Gray scale image produced using the sound reflected from the front surface of the coin

Gray scale image produced using the sound reflected from the back surface of the coin (inspected from "heads" side)

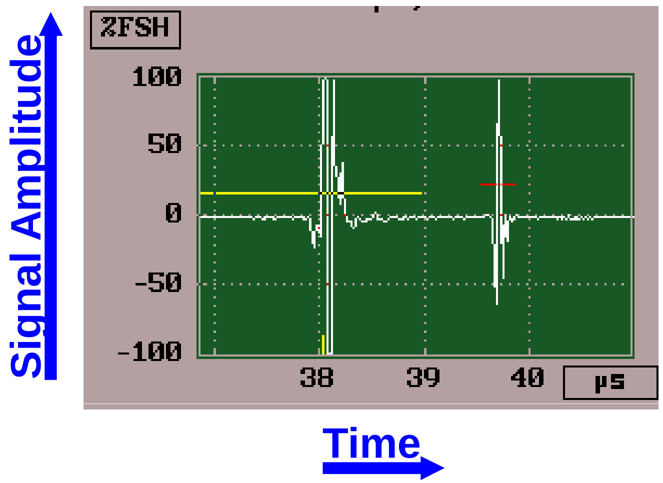
Data Presentation

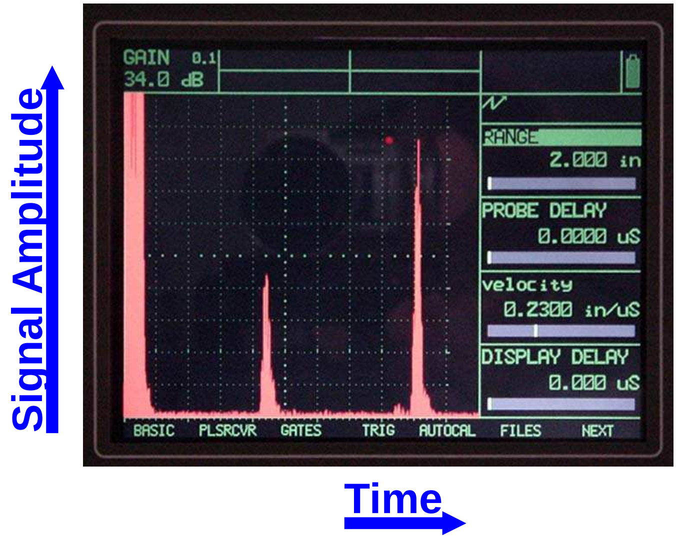
- Information from ultrasonic testing can be presented in a number of differing formats.
- Three of the more common formats include:
  - A-scan
  - B-scan
  - C-scan

These three formats will be discussed in the next few slides.

Data Presentation - A-scan

- A-scan presentation displays the amount of received ultrasonic energy as a function of time.
- Relative discontinuity size can be estimated by comparing the signal amplitude to that from a known reflector.
- Reflector depth can be determined by the position of the signal on the horizontal sweep.



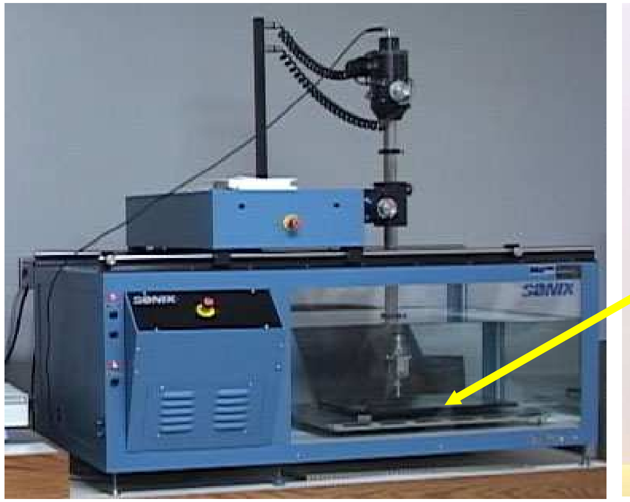


Data Presentation - B-scan

- B-scan presentations display a profile view (cross-sectional) of a test specimen.
- Only the reflector depth in the cross-section and the linear dimensions can be determined.
- A limitation to this display technique is that reflectors may be masked by larger reflectors near the surface.

Data Presentation - C-scan

- The C-scan presentation displays a plan type view of the test specimen and discontinuities.
- C-scan presentations are produced with an automated data acquisition system, such as in immersion scanning.
- Use of A-scan in conjunction with C-scan is necessary when depth determination is desired.



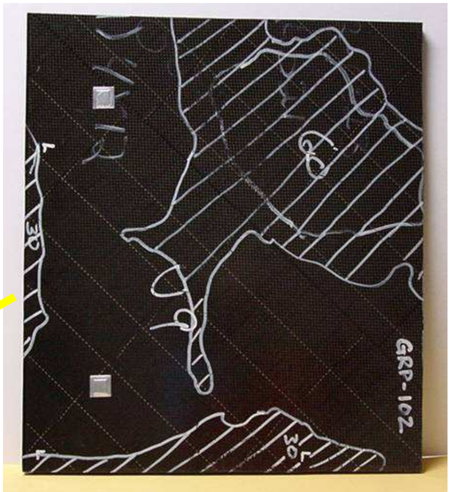
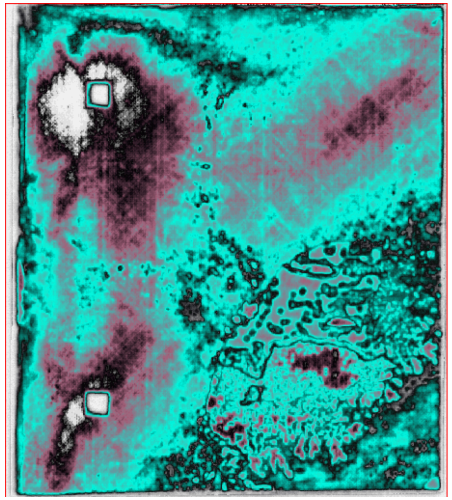


Photo of a Composite Component



C-Scan Image of Internal Features

Advantage of Ultrasonic Testing

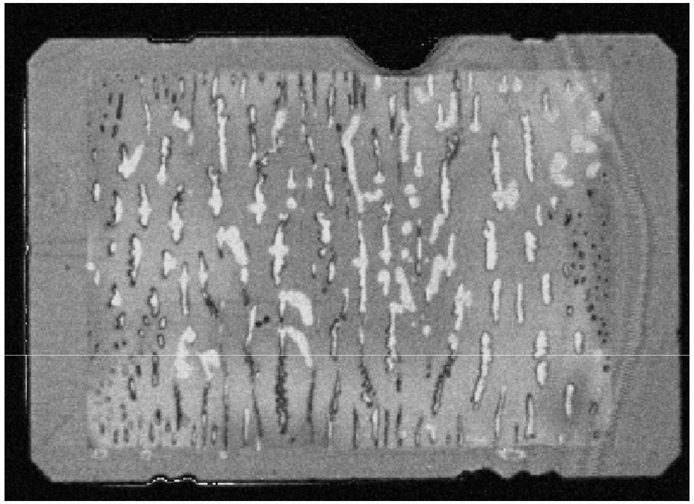
- Sensitive to both surface and subsurface discontinuities.
- Depth of penetration for flaw detection or measurement is superior to other methods.
- Only single-sided access is needed when pulse-echo technique is used.
- High accuracy in determining reflector position and estimating size and shape.
- Minimal part preparation required.
- Electronic equipment provides instantaneous results.
- Detailed images can be produced with automated systems.
- Has other uses such as thickness measurements, in addition to flaw detection.

Limitations of Ultrasonic Testing

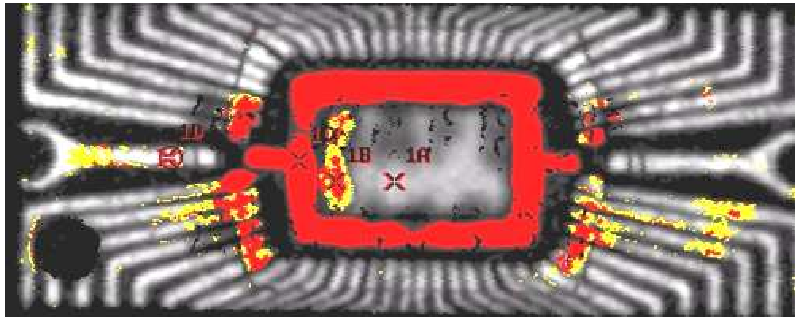
- Surface must be accessible to transmit ultrasound.
- Skill and training is more extensive than with some other methods.
- Normally requires a coupling medium to promote transfer of sound energy into test specimen.
- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
- Linear defects oriented parallel to the sound beam may go undetected.
- Reference standards are required for both equipment calibration, and characterization of flaws.

Examples

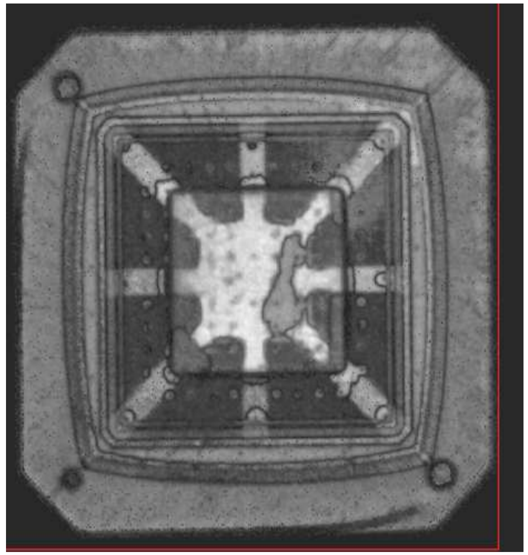
Lid seal voids



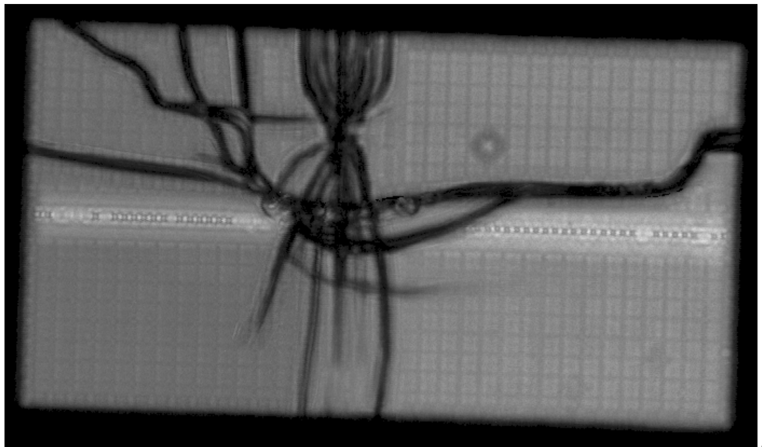
Delamination



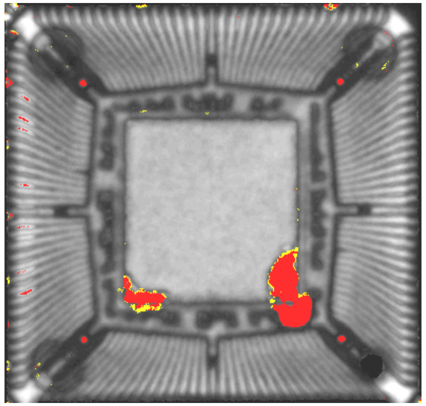
BGA die attach



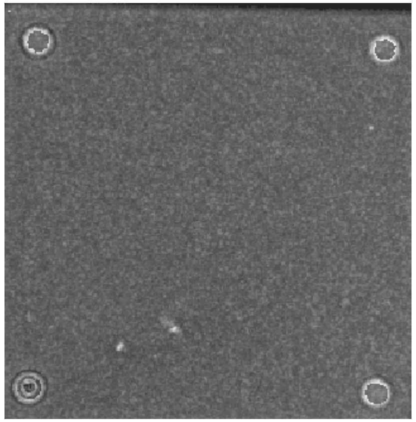
Die Crack



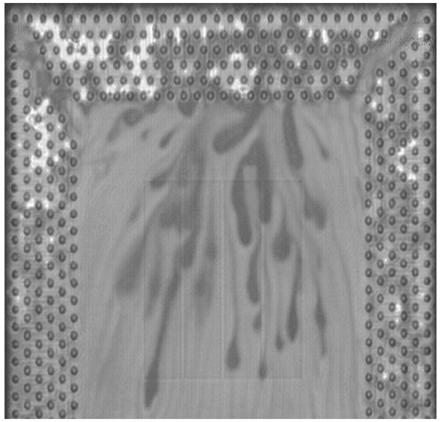
Examples



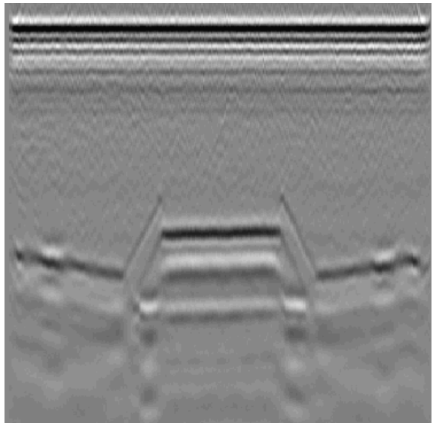
Die Top Delamination



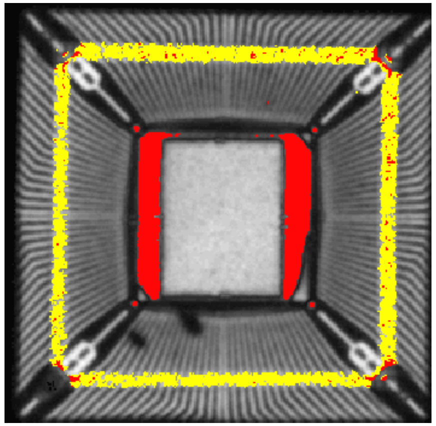
Mold compound voids



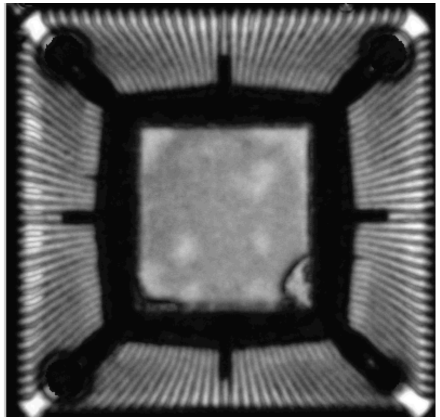
Flip Chip Underfill Voids



Die Tilt, B-Scan



Die Pad delamination



Die Attach Voids

Ultrasound equipment and test

What is an Ultrasound Test?

- An ultrasound test is a radiology technique, which uses high-frequency sound waves to produce images of the organs and structures of the body. The sound waves are sent through body tissues with a device called a transducer. The transducer is placed directly on top of the skin, which has a gel applied to the surface. The sound waves that are sent by the transducer through the body are then reflected by internal structures as "echoes." These echoes return to the transducer and are transmitted electrically onto a viewing monitor. The echo images are then recorded on a plane film and can also be recorded on videotape. After the ultrasound, the gel is easily wiped off.
- The technical term for ultrasound testing and recording is "sonography." Ultrasound testing is painless and harmless. Ultrasound tests involve no radiation and studies have not revealed any adverse effects.

For what purposes are ultrasounds performed?

- Ultrasound examinations can be used in various areas of the body for a variety of purposes. These purposes include examination of the chest, abdomen, blood vessels (such as to detect blood clots in leg veins) and the evaluation of pregnancy.
- In the chest, ultrasound can be used to obtain detailed images of the size and function of the heart. Ultrasound can detect abnormalities of the heart valves, such as mistral valve prolapse, aortic stenosis, and infection.
- Ultrasound is commonly used to guide fluid withdrawal aspiration) from the chest, lungs, or around the heart.

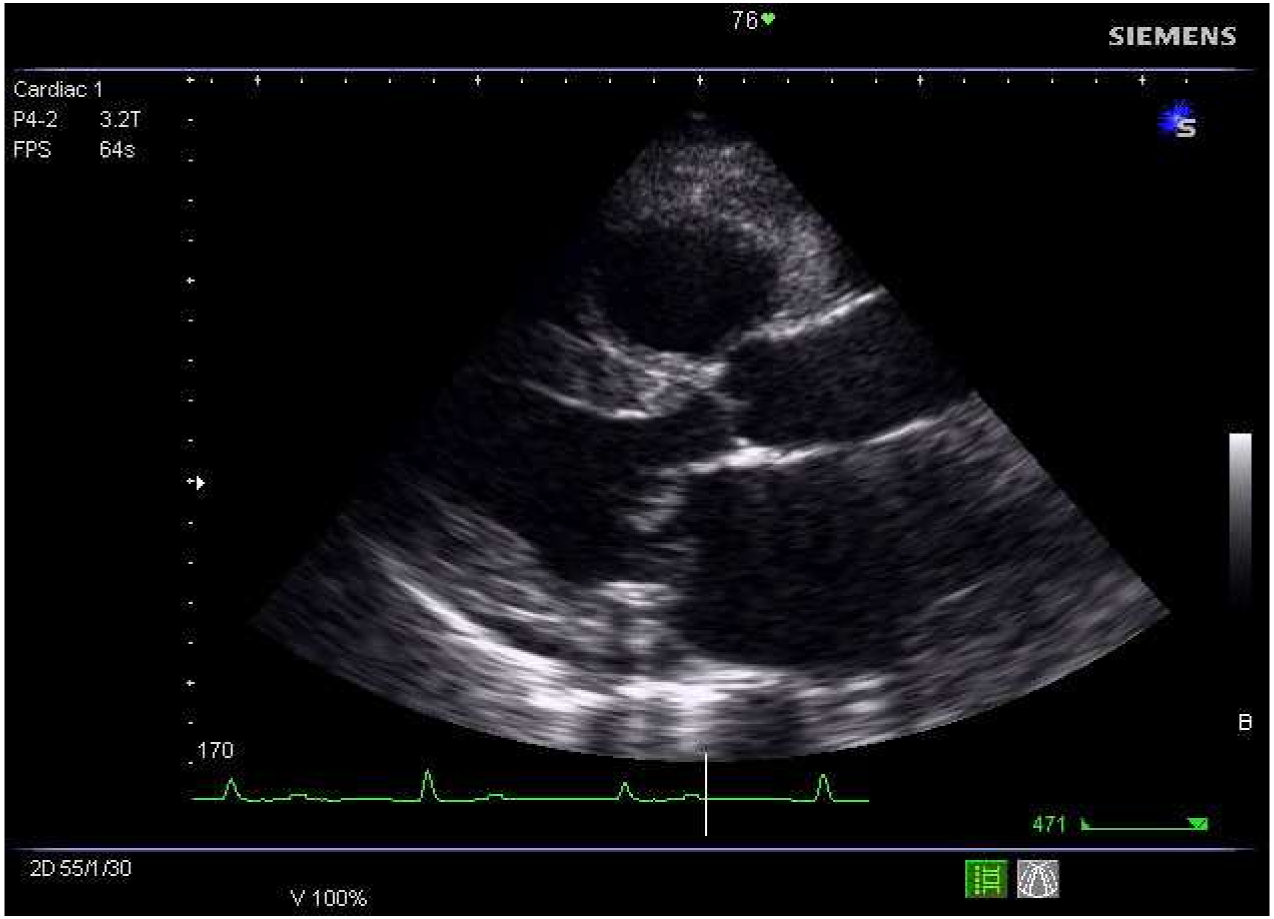
Major Uses of Ultrasound

- Ultrasound has been used in a variety of clinical settings, including obstetrics and gynecology, cardiology and cancer detection.
- The main advantage of ultrasound is that certain structures can be observed without using radiation.
- Ultrasound can also be done much faster than X-rays or other radiographic techniques.

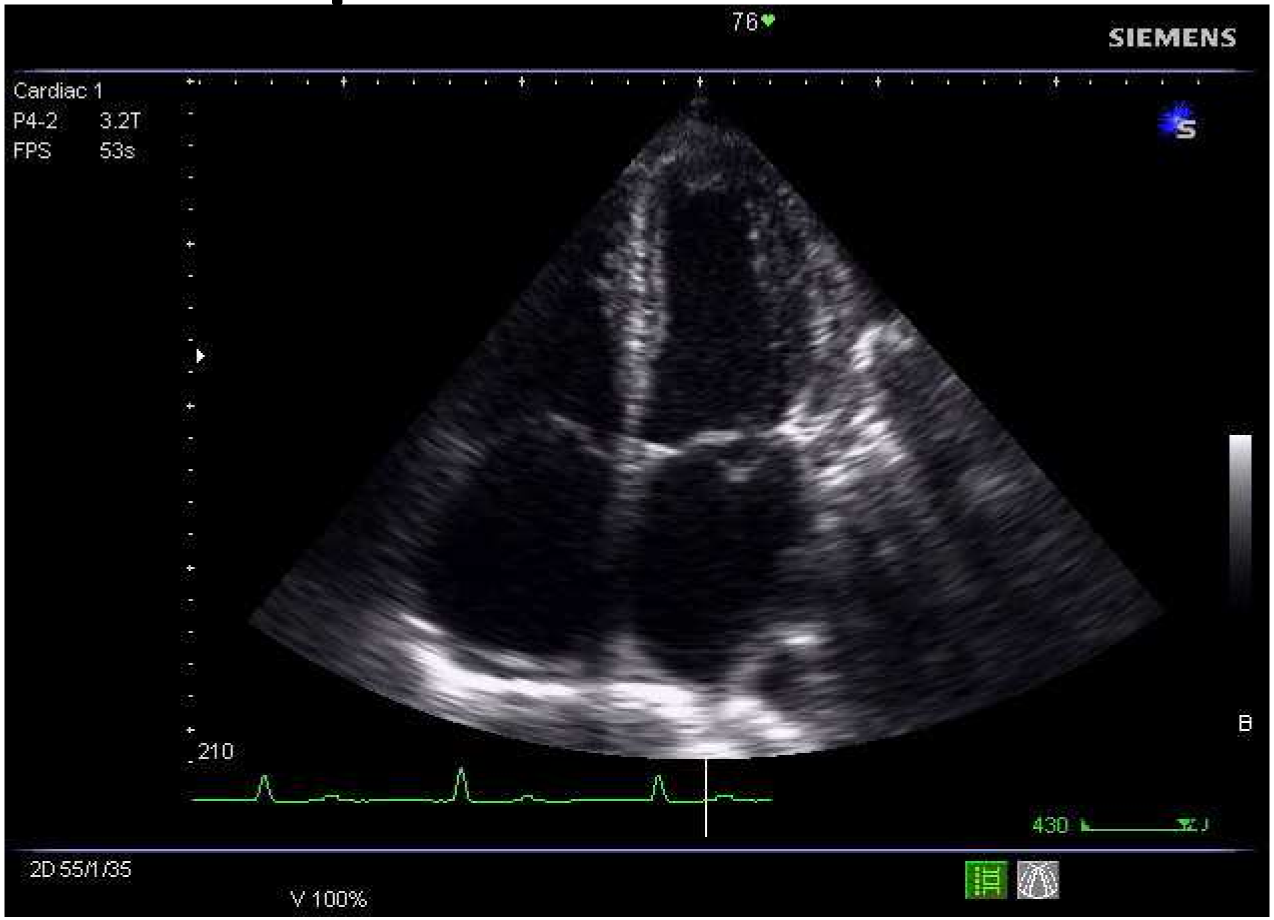
some uses for ultrasound:

- **Obstetrics and Gynecology**
  - measuring the size of the fetus to determine the due date
  - determining the position of the fetus to see if it is in the normal head down position or breech
  - checking the position of the placenta to see if it is improperly developing over the opening to the uterus (cervix)
  - seeing the number of fetuses in the uterus
  - checking the sex of the baby (if the genital area can be clearly seen)
  - checking the fetus's growth rate by making many measurements over time
  - detecting ectopic pregnancy, the life-threatening situation in which the baby is implanted in the mother's Fallopian tubes instead of in the uterus
  - determining whether there is an appropriate amount of amniotic fluid cushioning the baby
  - monitoring the baby during specialized procedures - ultrasound has been helpful in seeing and avoiding the baby during amniocentesis (sampling of the amniotic fluid with a needle for genetic testing). Years ago, doctors use to perform this procedure blindly; however, with accompanying use of ultrasound, the risks of this procedure have dropped dramatically.
  - seeing tumors of the ovary and breast
- **Cardiology**
  - seeing the inside of the heart to identify abnormal structures or functions
  - measuring blood flow through the heart and major blood vessels
- **Urology**
  - measuring blood flow through the kidney
  - seeing kidney stones
  - detecting prostate cancer early

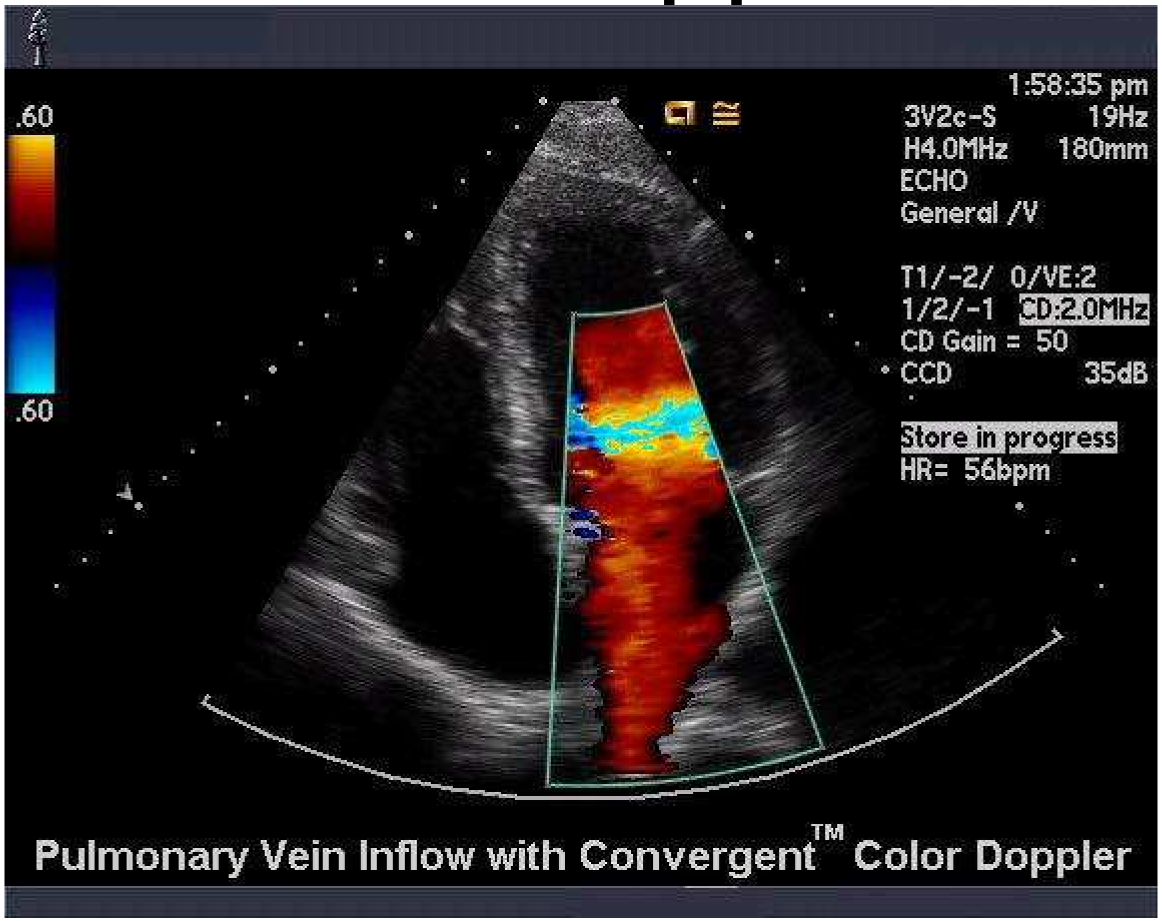
HEART
Parasternal View



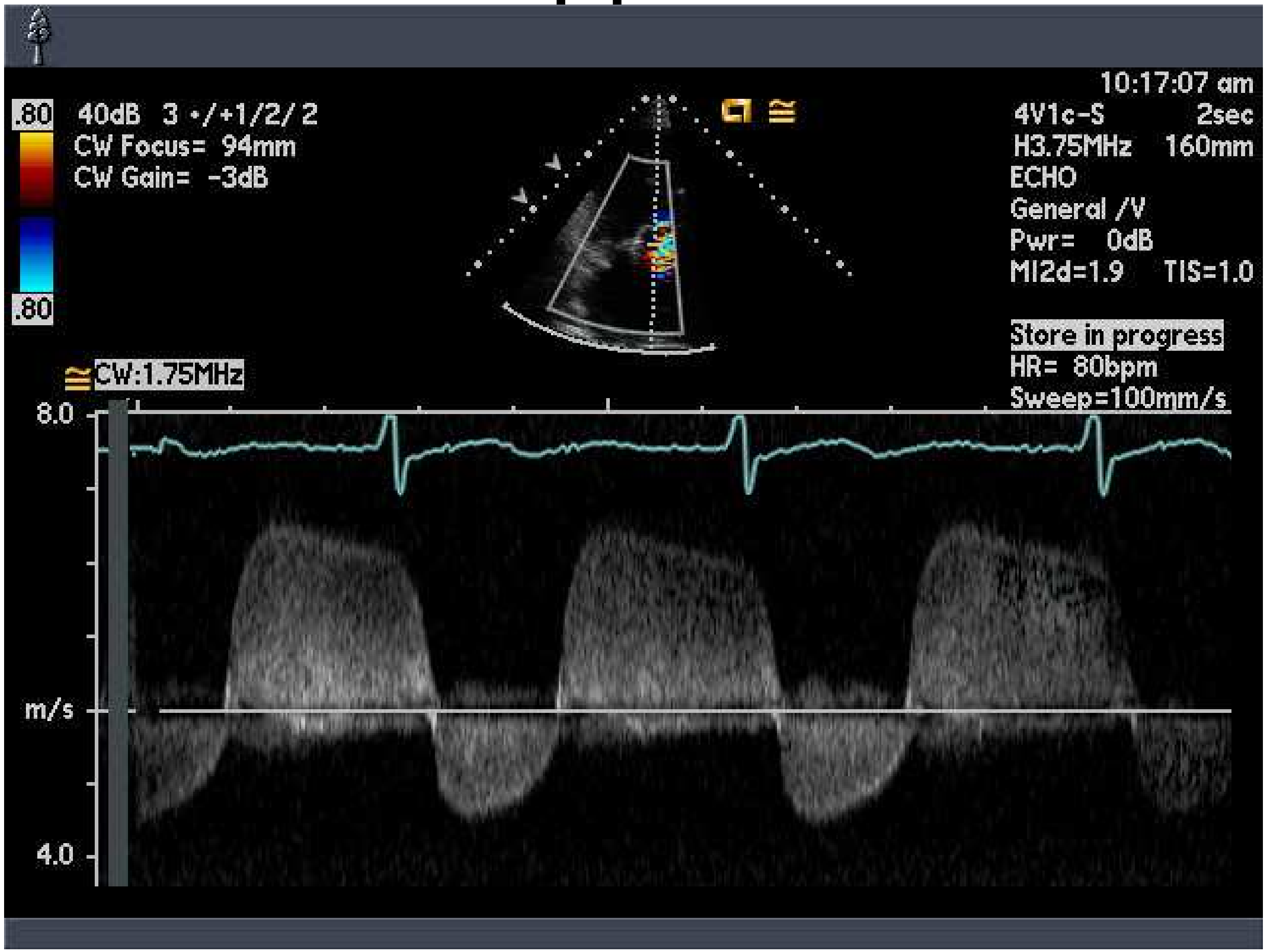
HEART
Apical View



Heart with Color Doppler

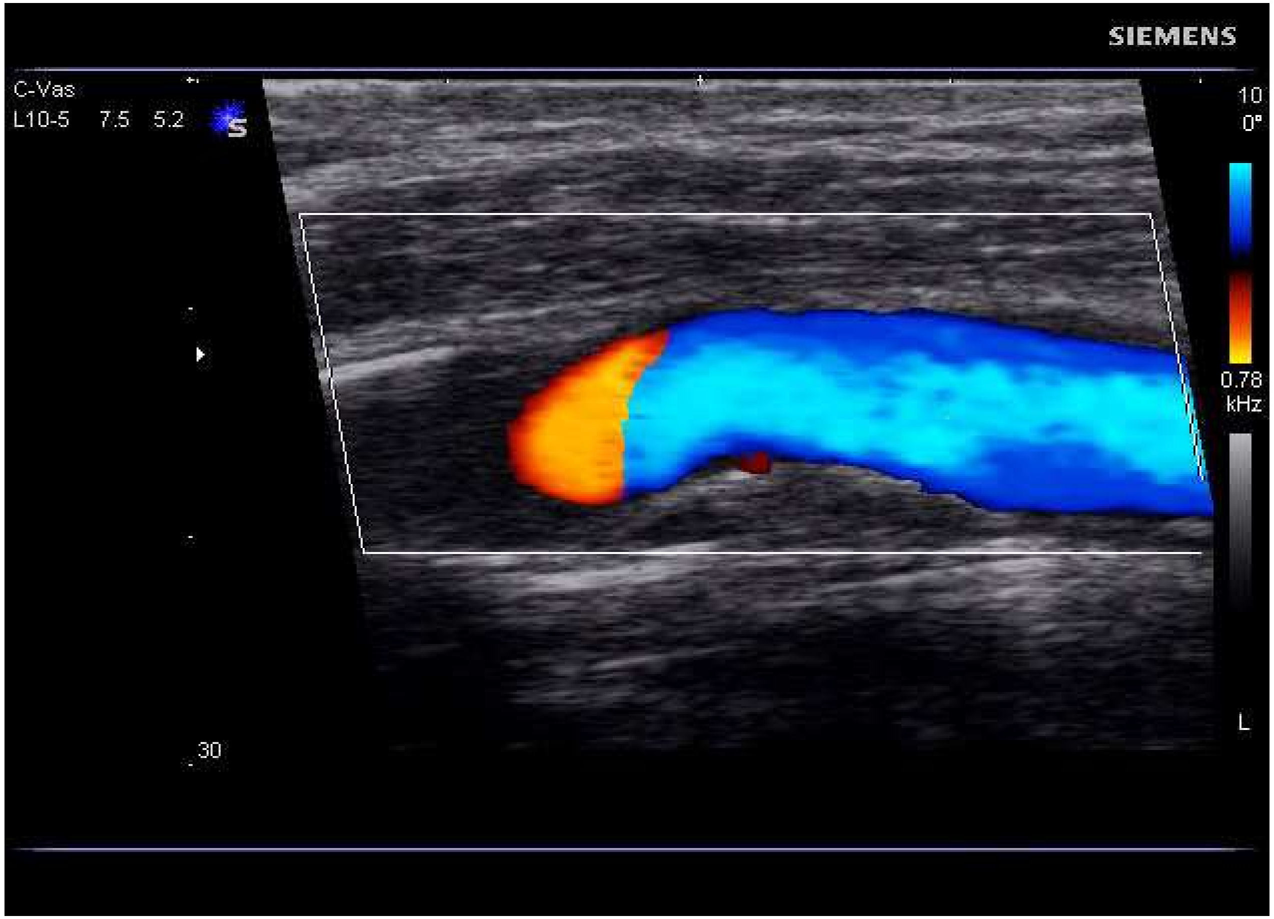


Heart w/ Color and Spectral Doppler

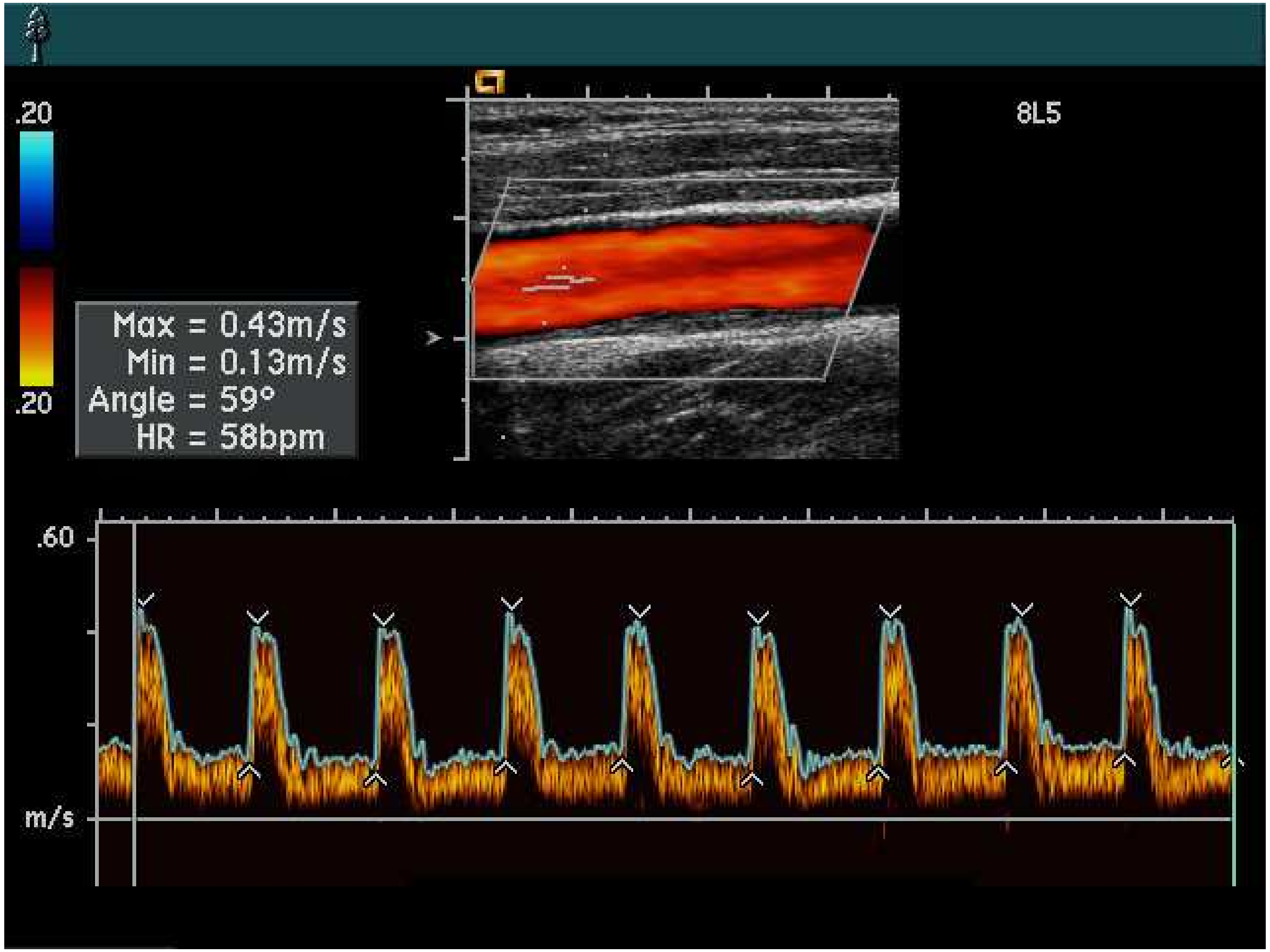


Carotid Bifurcation with Color Doppler

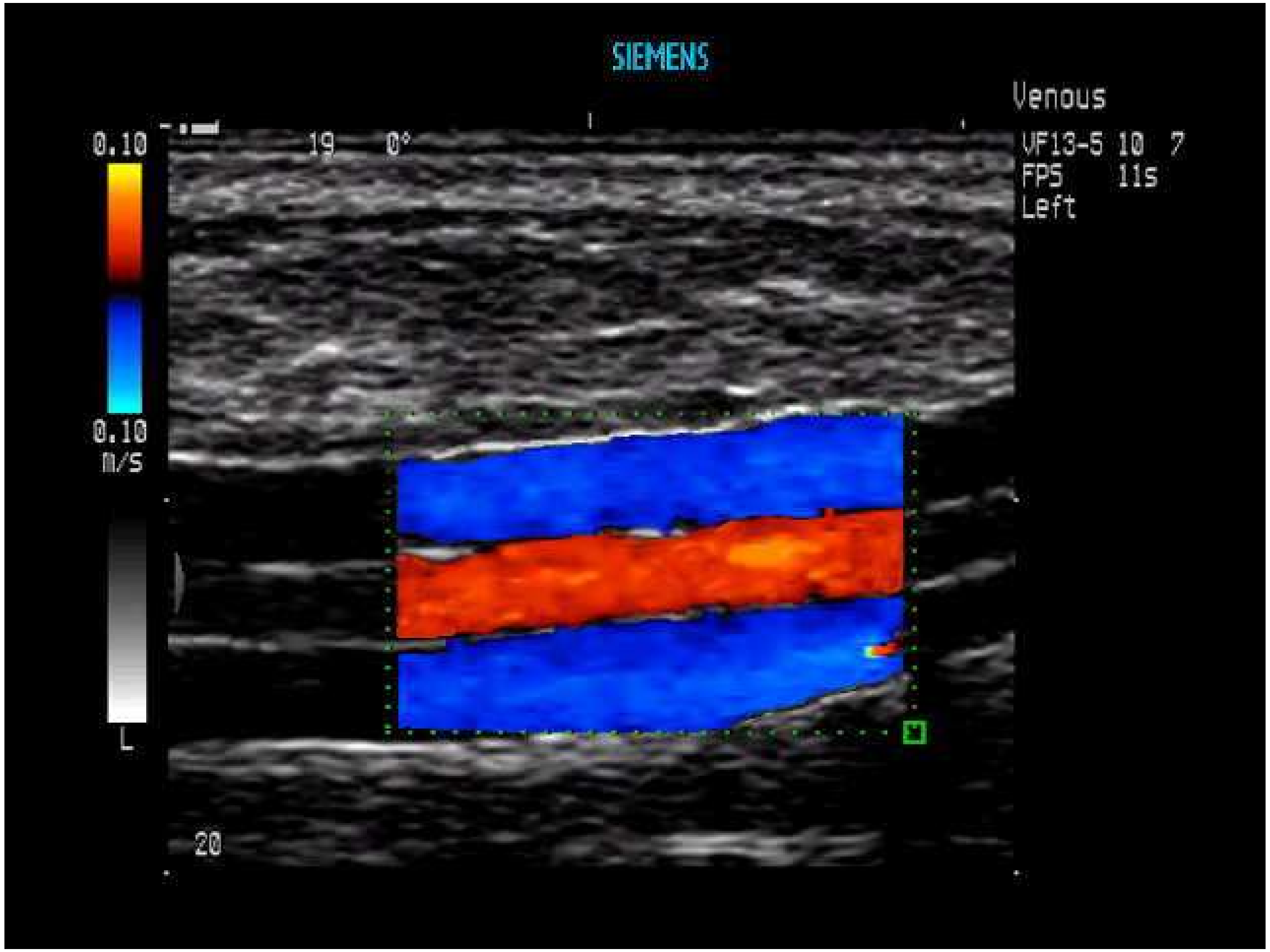
Carotid Artery Occlusion



Carotid Artery with Color & Spectral Doppler

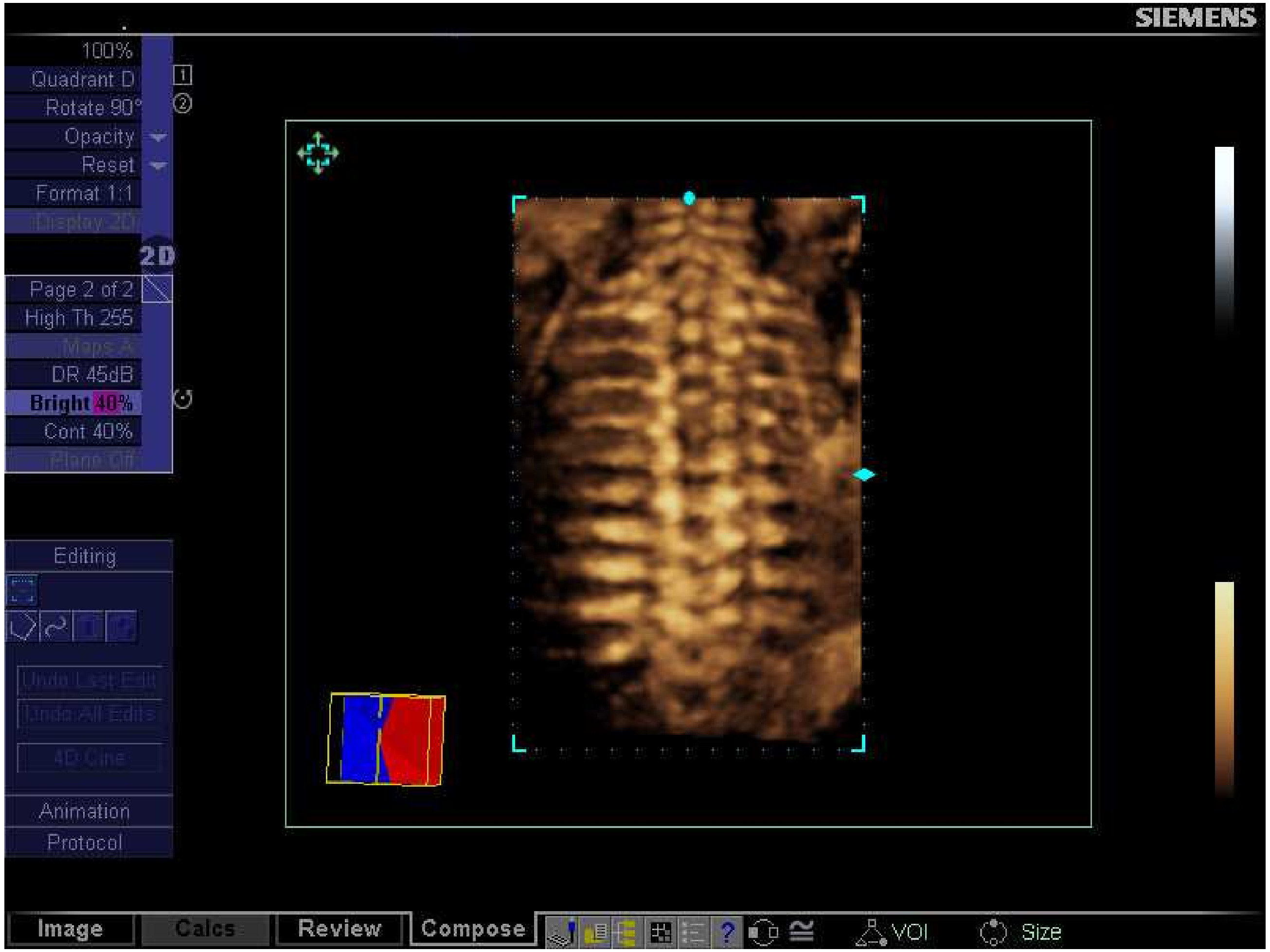


Calf Vessels with Color Doppler



4D Fetal Face

4D Fetal Spine



4D 1st Trimester

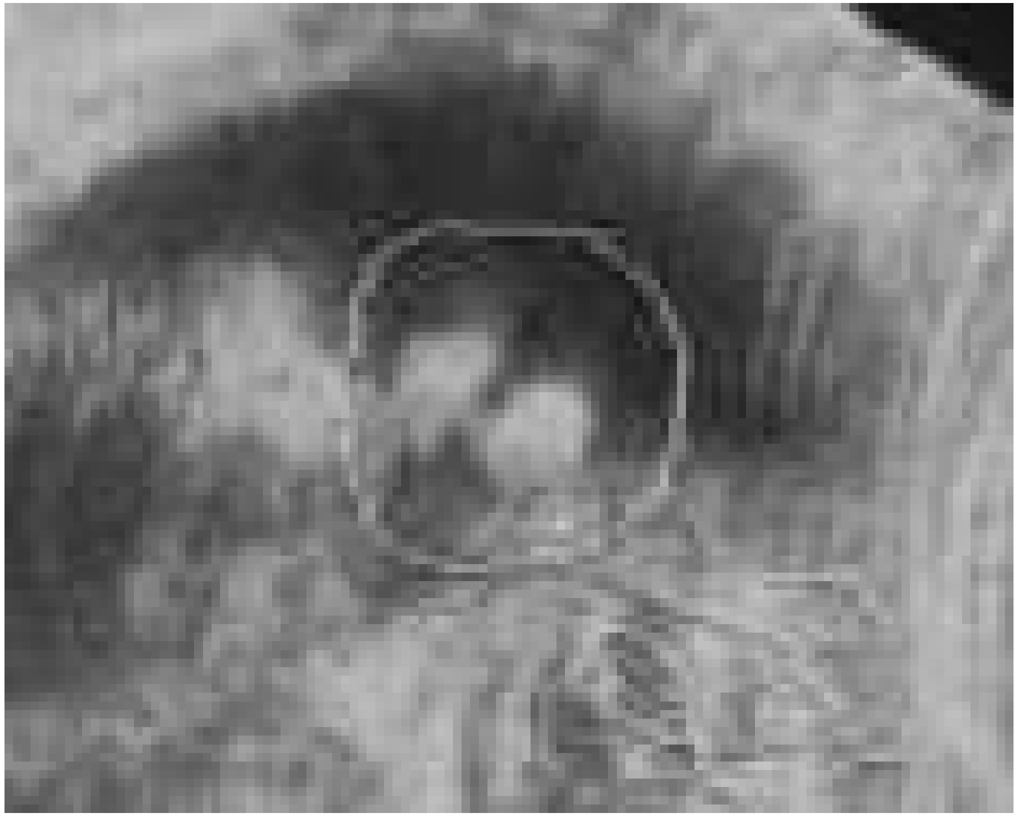
9 Week Fetus


SIEMENS
Early OB
6EV4 65
Distance
Single
9W0d
UNDO
MSD
9W3d
CRL 26.0
BPD
HC
AC
FL
D1= 26.0mm
L
60

Fetal Sex-Girl

Fetal Sex-Boy

Fetal Sex-Girl



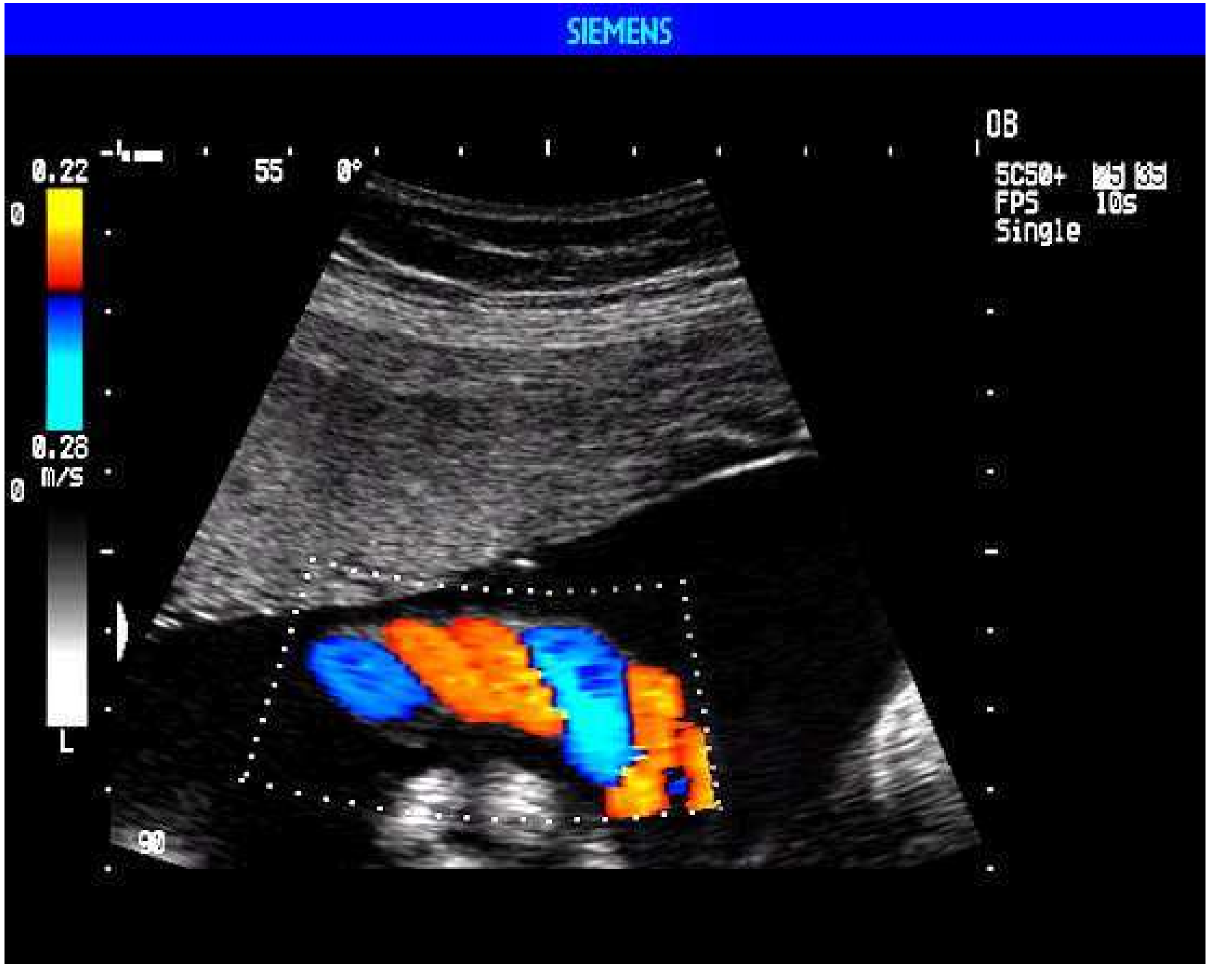
Fetal Sex-Boy

Twins-6 Weeks

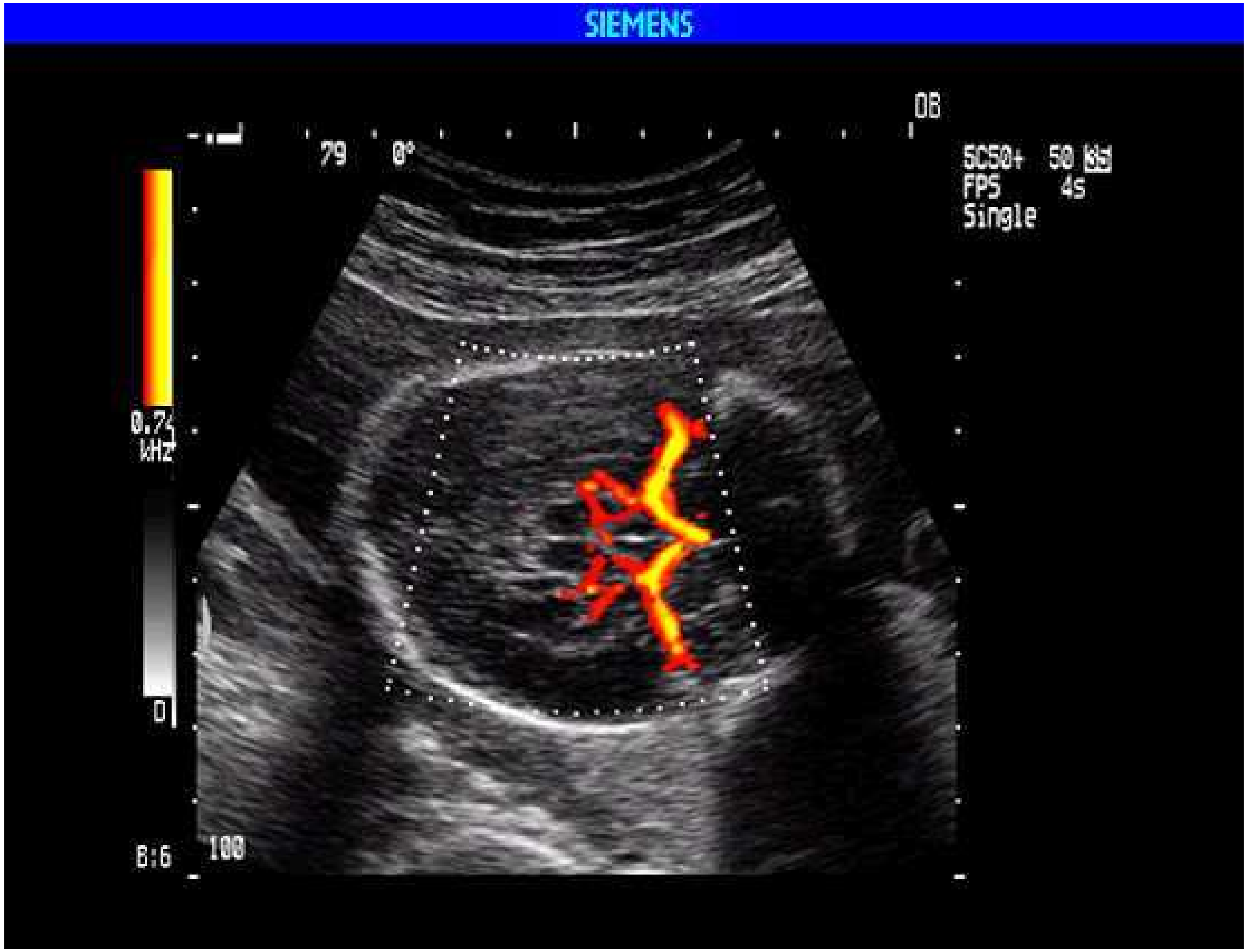
Twins- 8 Weeks

Twins-12 Weeks

Umbilical Cord with Color Doppler



Circle of Willis with Color Doppler



Fetal Profile & Brain

Fetal Cervical Spine

Fetal Spine