X-Ray Inspection of BGA Packages

Don Naugler
V.J. Electronix, Inc.
234 Taylor St.
Littleton, MA 01460

VJ ELECTRONIX
A VJ Technologies Company

Topics

- History of X-Ray Radioscopy
- Evolution of Modern X-Ray Systems
- Basic Inspection Techniques
- 3D Inspection
- Inspection in the Production Environment

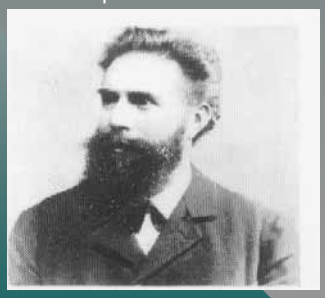
Introduction

History of X-Ray Radioscopy

(Special thanks to Jim Wheelis)

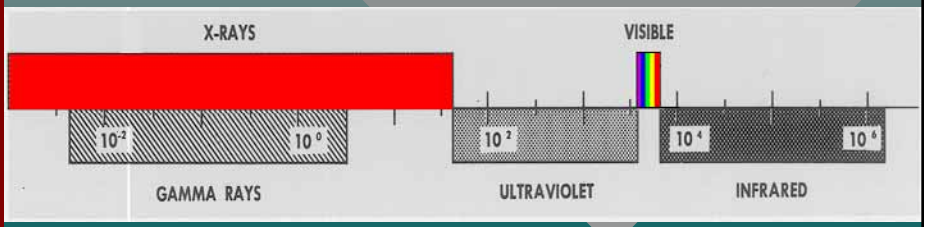
November 8, 1895

- Dr. Wilhelm Konrad **Roentgen** discovers an unknown ray emitted from a Crooks tube that caused a nearby material to glow.
- This event was not only the discovery of *X*-rays but the first observed fluoroscopic event !



Electromagnetic Energy

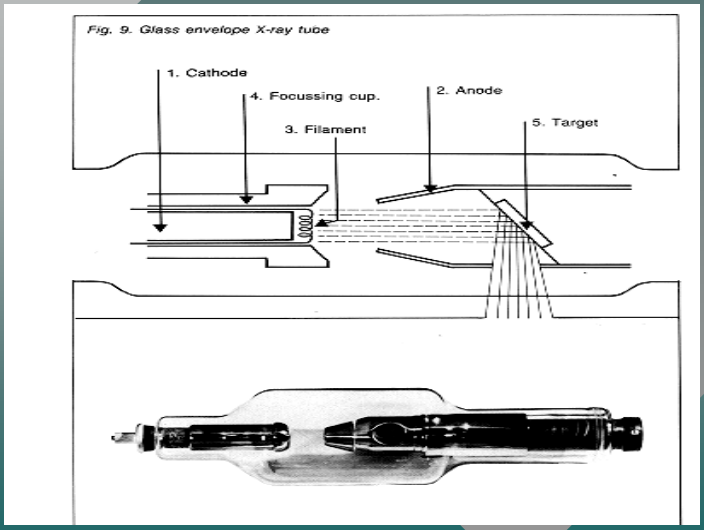
- X-ray
- Gamma
- Light
- Radio
- Micro



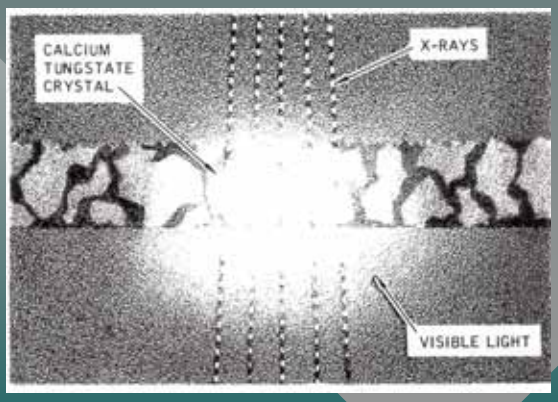
C.H.F. MULLER

- Developed X-ray the Tube 1896---1923

MODERN X-RAY TUBE



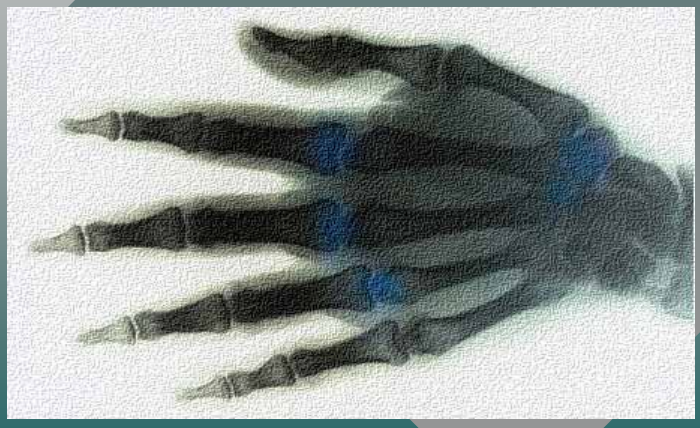
FLUOROSCOPIC SCREEN



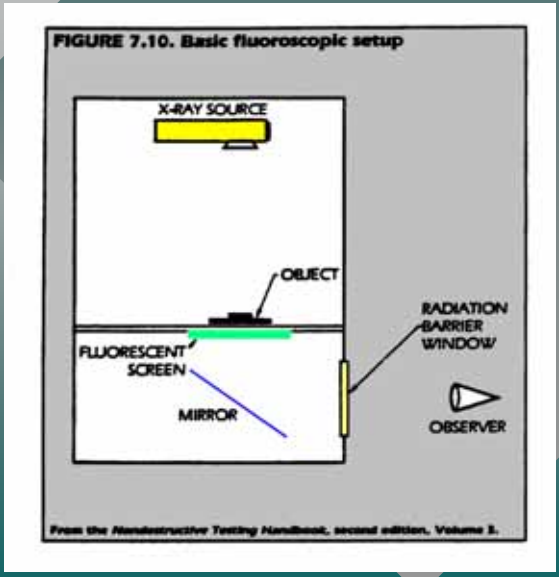
FLUOROSCOPY

– The visual observation on a fluorescent screen of the image of an object exposed to penetrating, ionizing radiation.

First Fluoroscopic Image



Fluoroscope



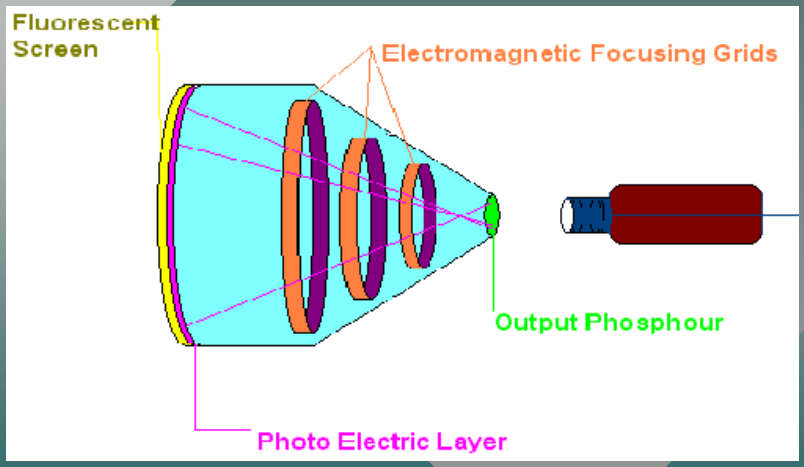
RADIOSCOPY *per ASTM E586*

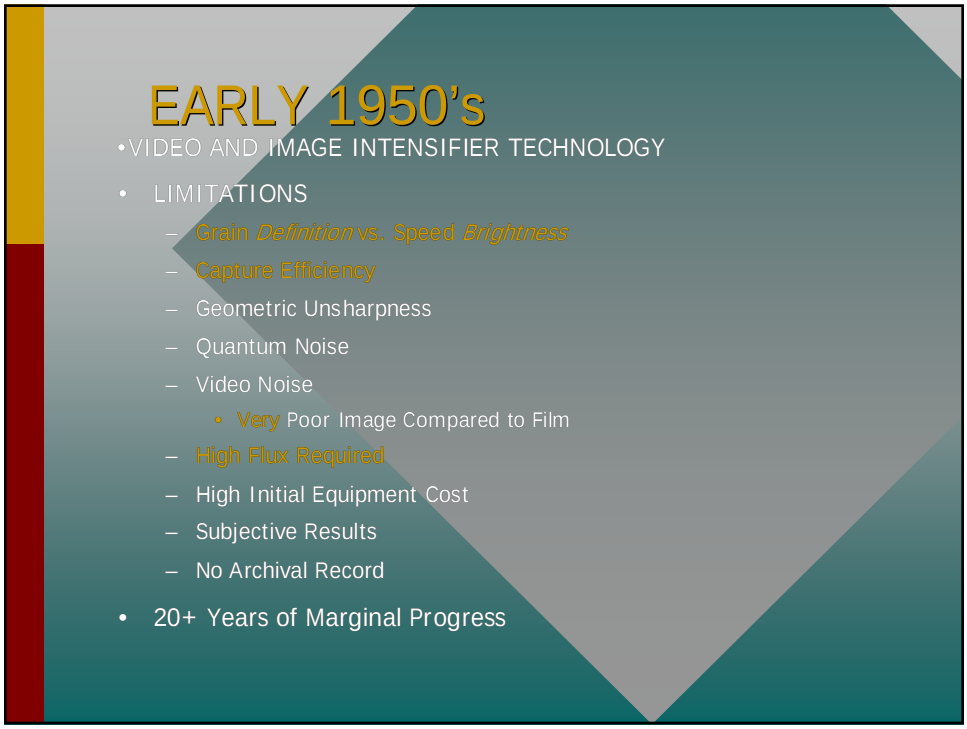
- The electronic production of a radiological image that follows very closely the changes with time of the object being imaged.
- MARKETING TERM
  - RTX Real-time X-ray
  - RTR Real-time Radioscopy

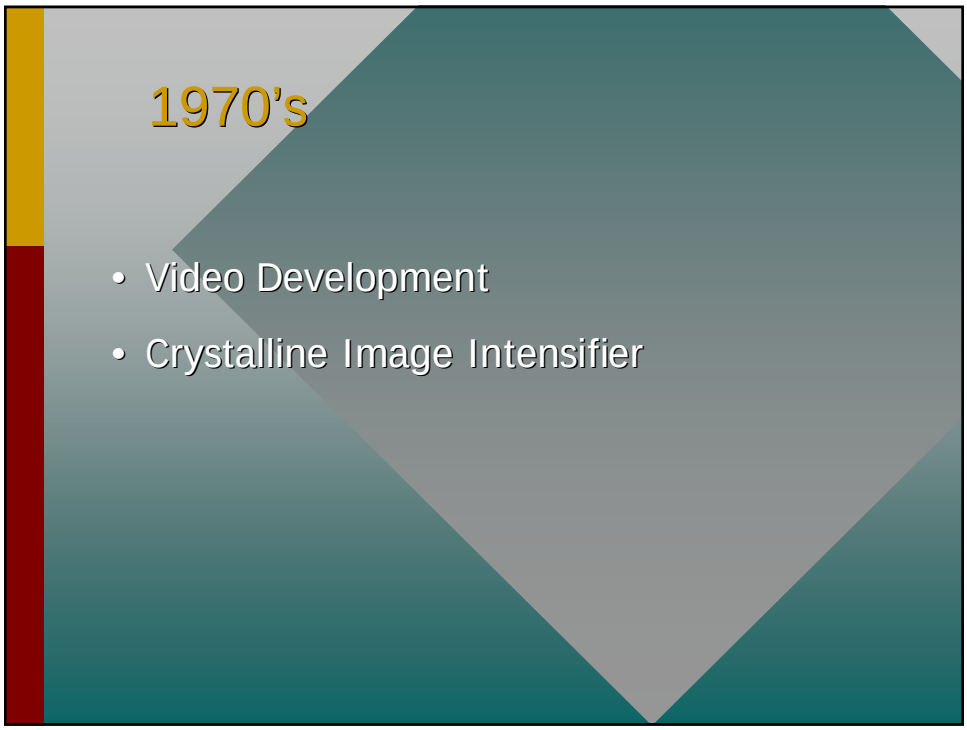
First Radiograph

ra·di·o·graph
An image produced on a radiosensitive surface, such as a photographic film, by radiation other than visible light, especially by x-rays passed through an object or by photographing a fluoroscopic image.

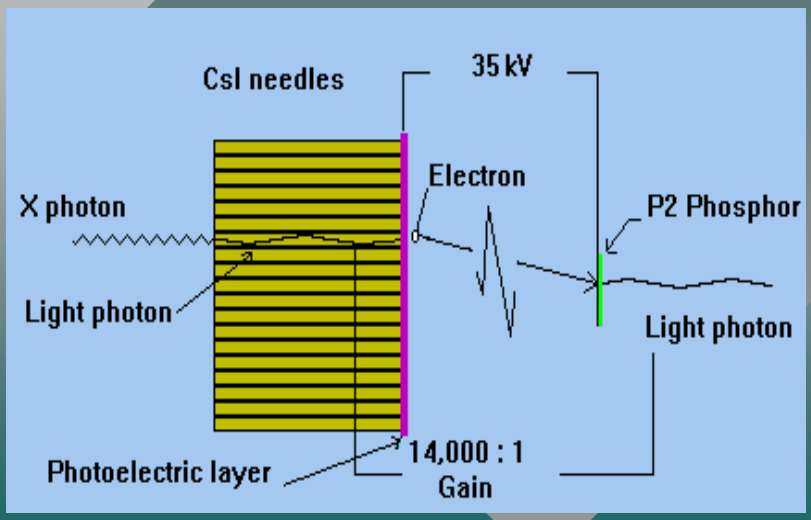
IMAGE INTENSIFIER



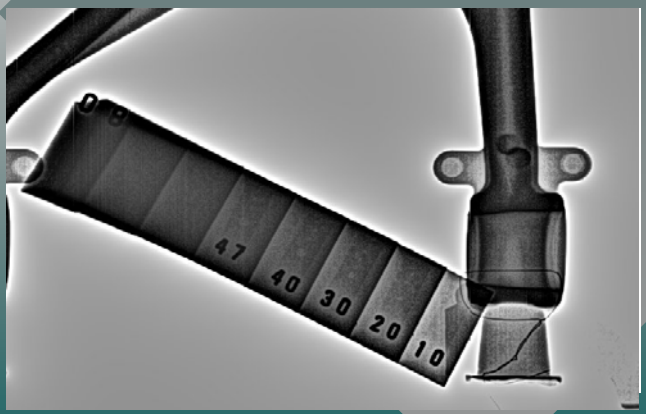

EARLY 1950's
•VIDEO AND IMAGE INTENSIFIER TECHNOLOGY
• LIMITATIONS
– Grain *Definition* vs. Speed *Brightness*
– Capture Efficiency
– Geometric Unsharpness
– Quantum Noise
– Video Noise
• Very Poor Image Compared to Film
– High Flux Required
– High Initial Equipment Cost
– Subjective Results
– No Archival Record
• 20+ Years of Marginal Progress


1970's
• Video Development
• Crystalline Image Intensifier

Crystalline Image Intensifier



2000 The Digital Century



Advances in Detector Technology

- Analog
  - XRV (X-ray Sensitive Vidicon Cameras)
  - Image Intensifier / Camera Combinations
  - Digital Cameras
- Digital
  - Linear Diode Array
  - Area Array (Amorphous Silicon Flat Panel)

X-Ray Detectors

- X-Ray Camera
  - Limited FOV (1" typical)
  - Limited Resolution (typically 8 Lp/mm)
  - High Energy Level requirement (75 kv @ 100 μA typical)
  - Analog Camera – Frame Grabber converts to 8 bit signal
  - 256 Grayscale

X-Ray Detectors

- Image Intensifier with Analog Camera
  - II FOV typically 4" (dual 2 – 4 inch common)
  - High Frame rates
  - 40 Lp/mm or greater resolution
  - Low Energy Level Required for visible image
  - Frame Grabber converts to 8 bit signal
  - 256 Grayscale
  - X-ray > Electrons >Phosphor > Light > Collimator > Zoom Lens >CCD

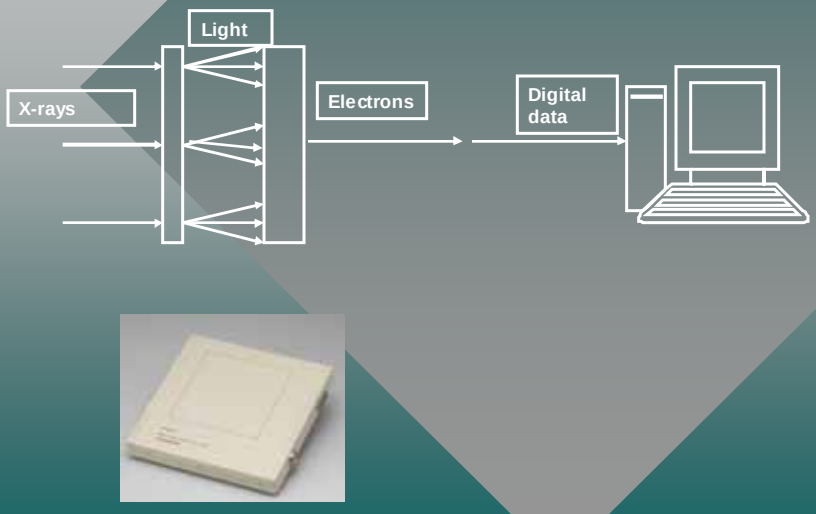
X-Ray Detectors

- Image Intensifier with Digital Camera
  - All the benefits of the II with Analog camera plus:
    - 12 bit signal = 4096 Grayscale
    - Higher Resolution ($1K^2$ vs. 752 x 482)
    - Better image quality retention (image kept as digital signal)
  - But:
    - Still the same limitations typical of an Image Intensifier:
      - X-ray > Electrons >Phosphor > Light > Collimator > Zoom Lens >CCD

X-Ray Detectors

- CMOS (Digital) Panel
  - High (Contrast) Resolution
  - Little or no loss in image quality due to signal conversions
  - Flat Image
  - 12 bit – 4096 grayscale
  - Image acquisition frame rate slow (1/10 of II)
  - High Energy Level Requirement

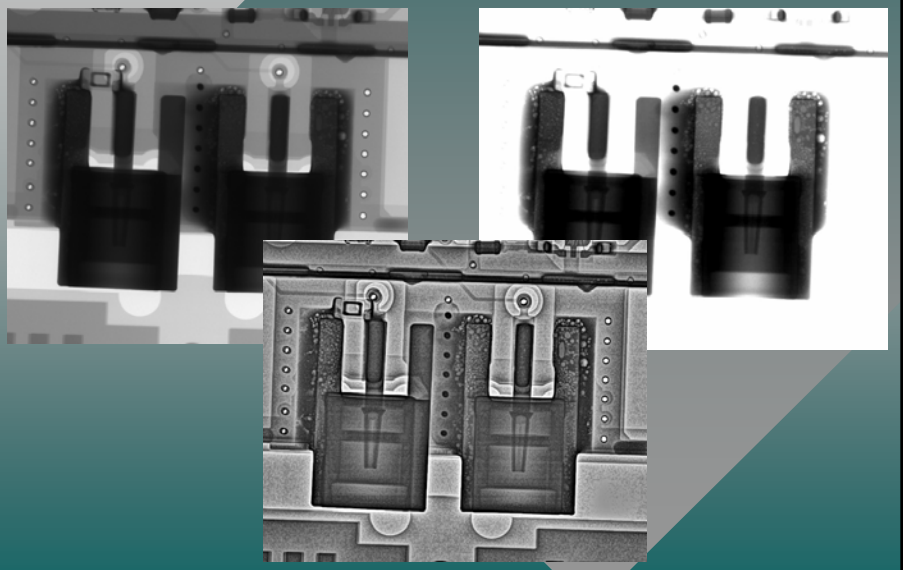
Typical working of a digital detector system

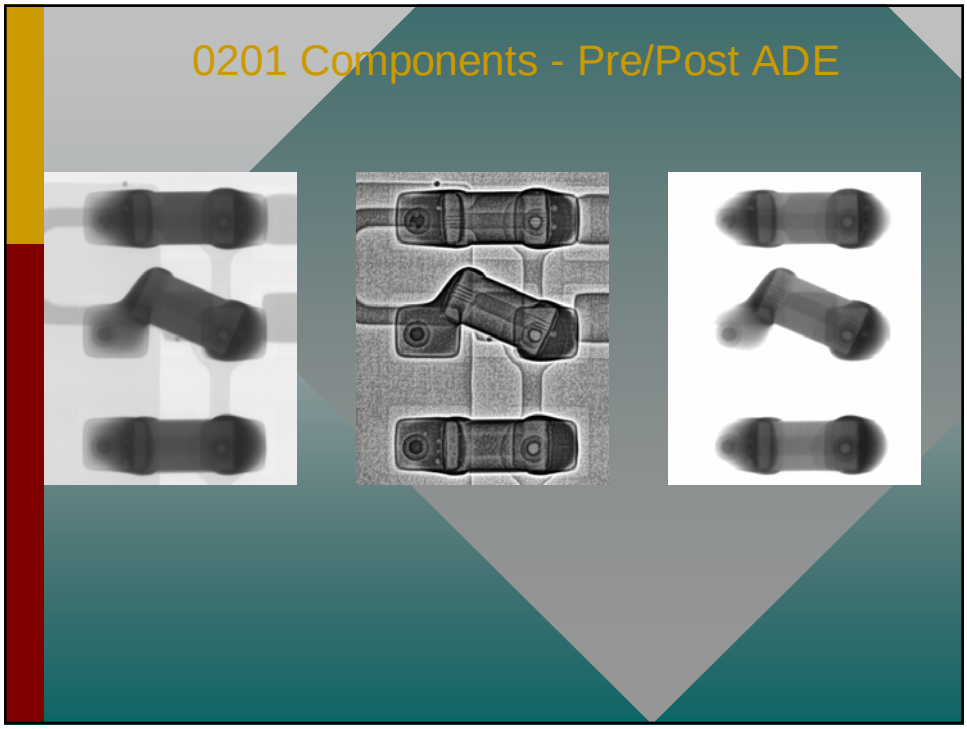


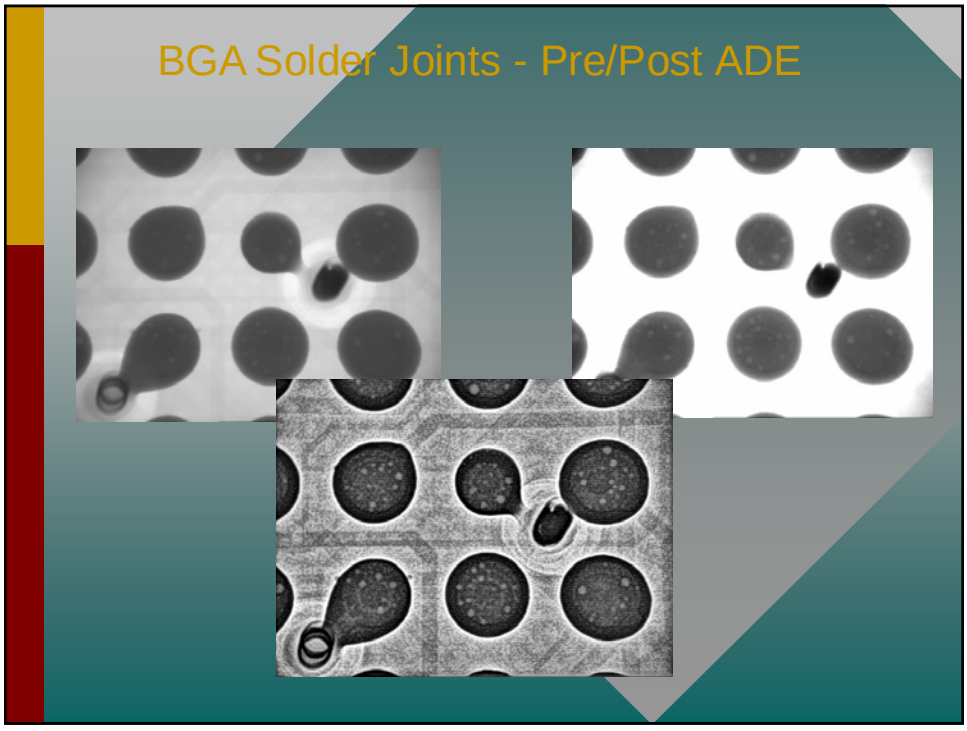
Gray Scale Acuity

• Human Eye	16 steps	4 Bit
• Image Intensifier	64 steps	6 Bit
• Digital Arrays	4096 steps	12 Bit

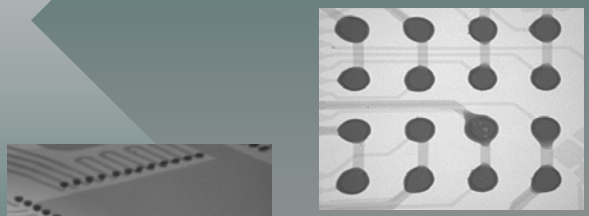
Automated Defect Enhancement

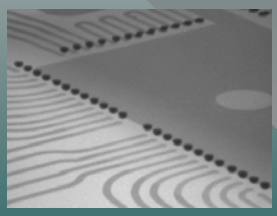


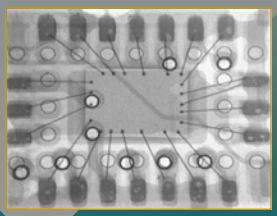

0201 Components - Pre/Post ADE


BGA Solder Joints - Pre/Post ADE

Applying X-ray for Electronics Inspection







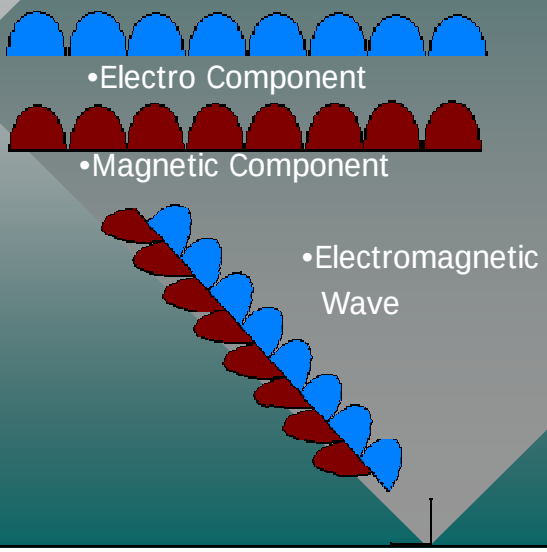
Electromagnetic Energy

- **Photon**, small unit of light energy or **electromagnetic radiation**. Max Planck and Albert Einstein, Nobel Prize winners in physics, discovered that light, which usually travels in waves, sometimes behaves as if it were made up of a stream of small quantities, or quanta, of energy. The energy, *E,* of a photon is calculated using the equation $E = h\upsilon$, where *h* is a universal constant (Planck's constant) and υ is the **frequency (number of vibrations per second)** of the light.
  - "Photon," Microsoft® Encarta® 98 Encyclopedia. © 1993-1997 Microsoft Corporation. All rights reserved.

X-ray Imaging

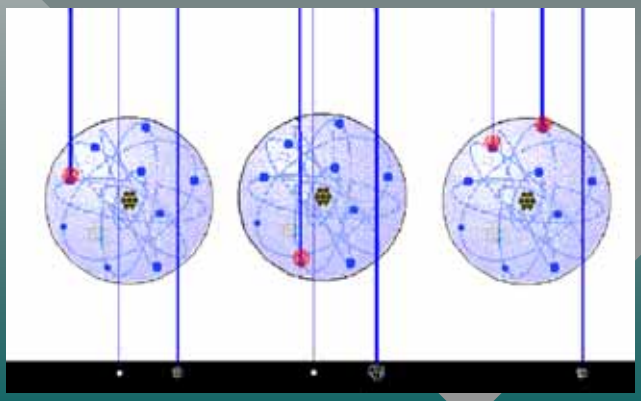
- **How do we put x-ray to work?**

Wave Length and Frequency



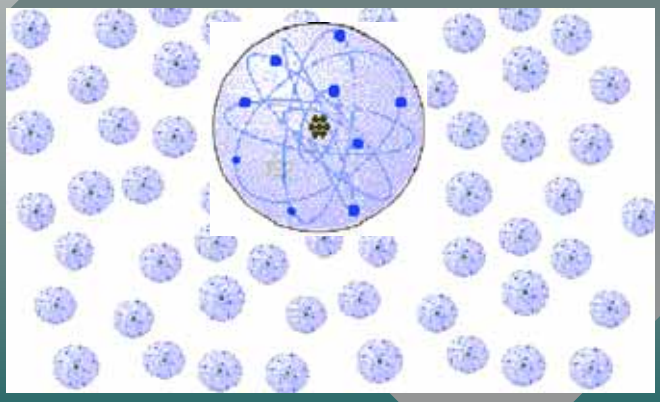
Attenuation / Absorption

- X-rays are absorbed in material by chance
- The study and description or this phenomena is known as Quantum Mechanics



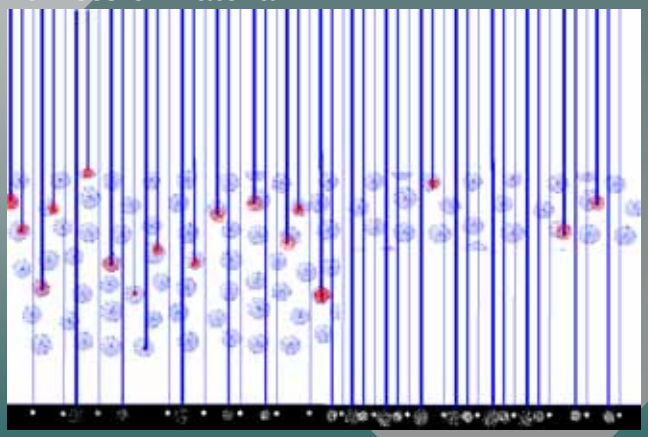
Attenuation / Absorption

- Solids have more space than material
- Inter atomic space
- Inter molecular space



Attenuation / Absorption

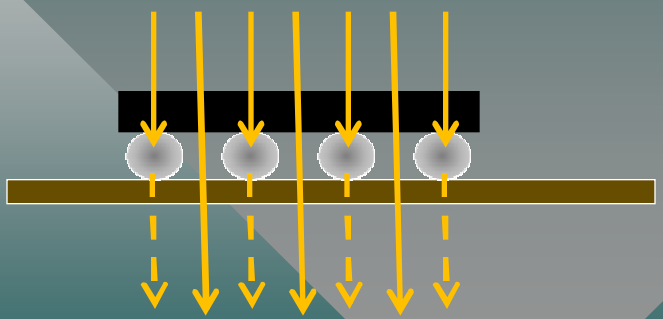
- Density of material
- Thickness of material



- Brightness is effected by capture efficiency (wave length) and number of photons (Quantum)

Attenuation / Absorption

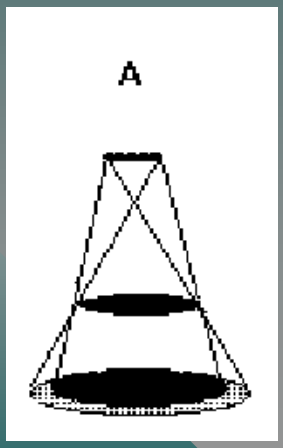
- Density of material
- Thickness of material



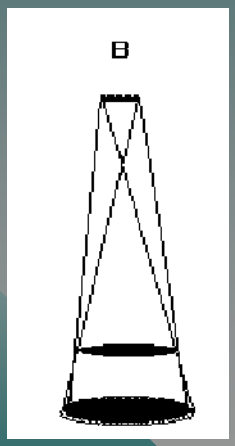
Magnification

- Geometric Magnification
- Optical Magnification
- Digital Magnification
- Total System Magnification

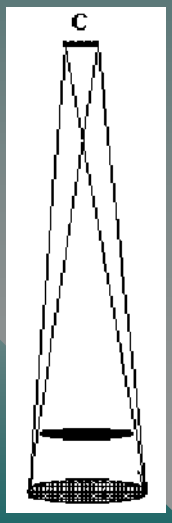
Focal Spot vs. Unsharpness



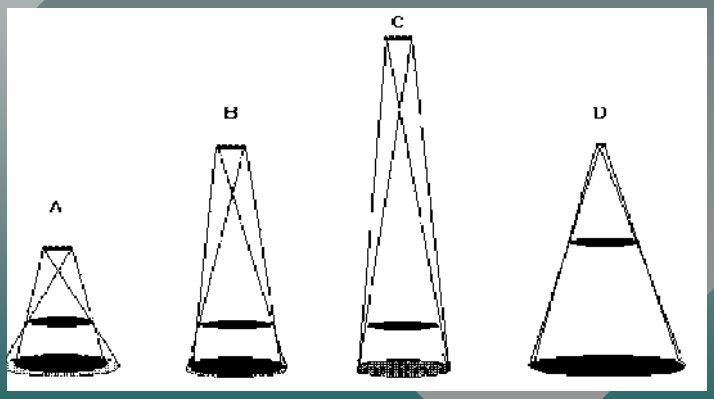
Focal Spot vs. Unsharpness



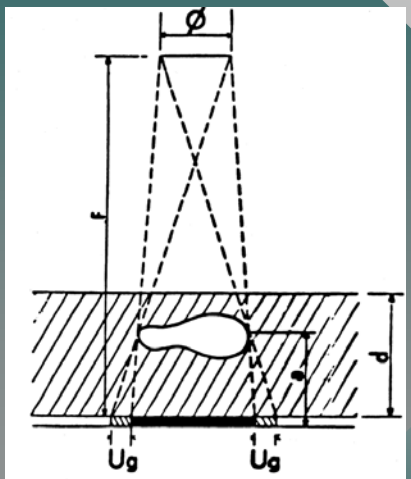
Focal Spot vs. Unsharpness



Focal Spot vs. Unsharpness



Radiographic Geometric Unsharpness Formula

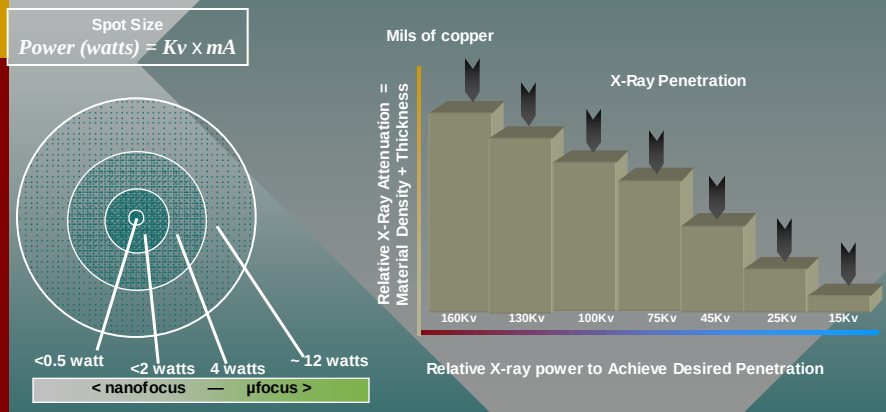


Ø = diameter of source
F = focus-to-film-distance
a = defect-to-film distance
d = thickness of object

$$U_g\,(max) = \frac{Ø \times d}{F - d}$$

Relationship of X-Ray Power to Spot Size

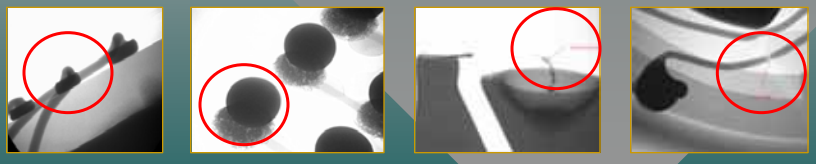
- The relationship of *spot size* (nanofocus - µfocus) to *power* (Kv, mWatts) on X-ray *penetration*:



The nanofocus spot size grows to microfocus size as the power to penetrate materials of relative density and/or thickness is increased, e.g. CBGA solder joints, RF Shielding, double-sided boards, etc.

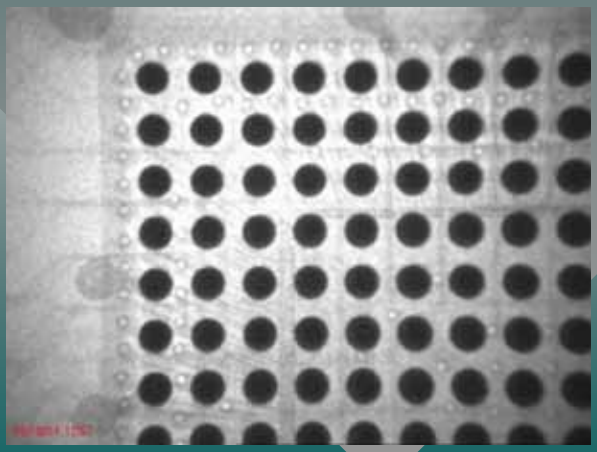
Magnification

- Why is *magnification* important with respect to the *application*?
  - Magnification gives the ability to find minute defects that would normally not be visualized



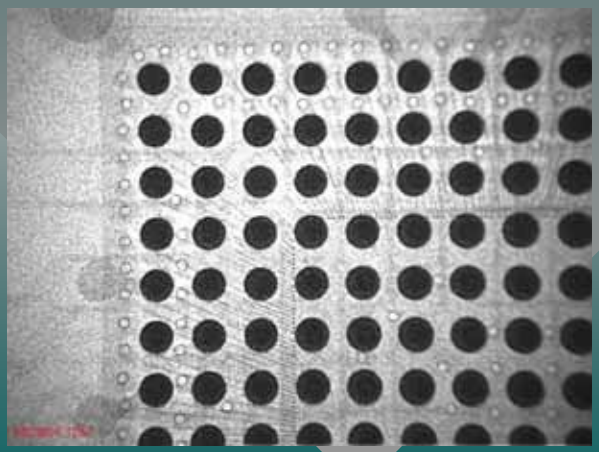
Special Filters and Enhanced Imaging

- Base Image



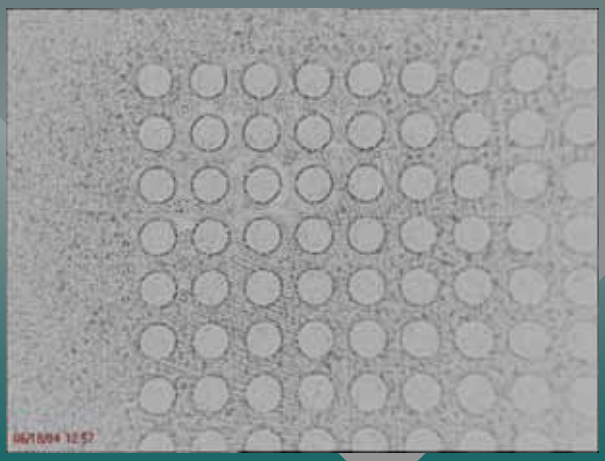
Special Filters and Enhanced Imaging

- Sharpen Filter



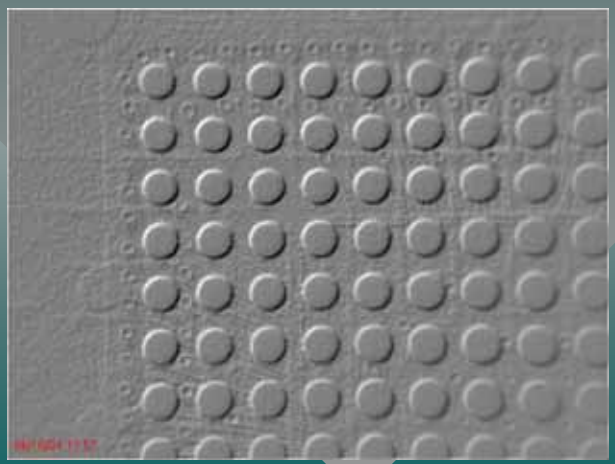
Special Filters and Enhanced Imaging

- Edge Filter



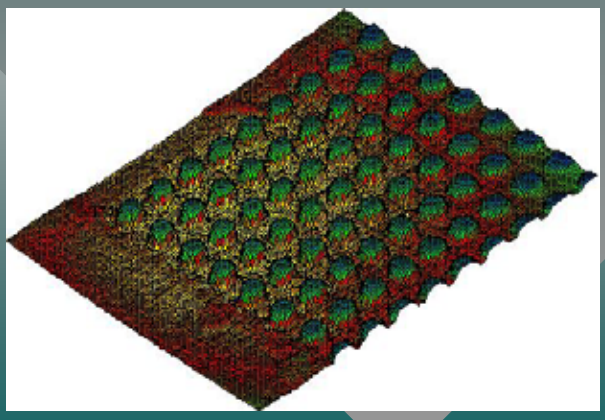
Special Filters and Enhanced Imaging

- Relief Filter

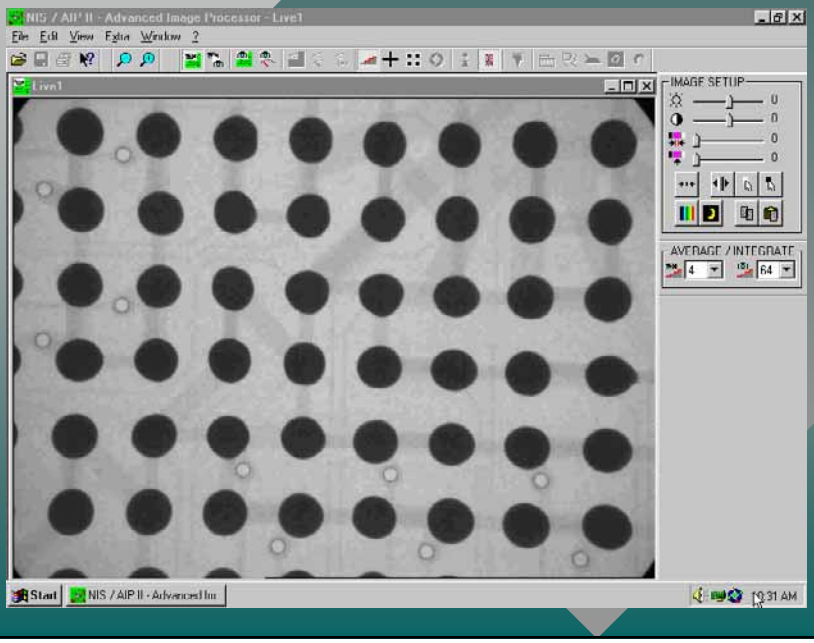


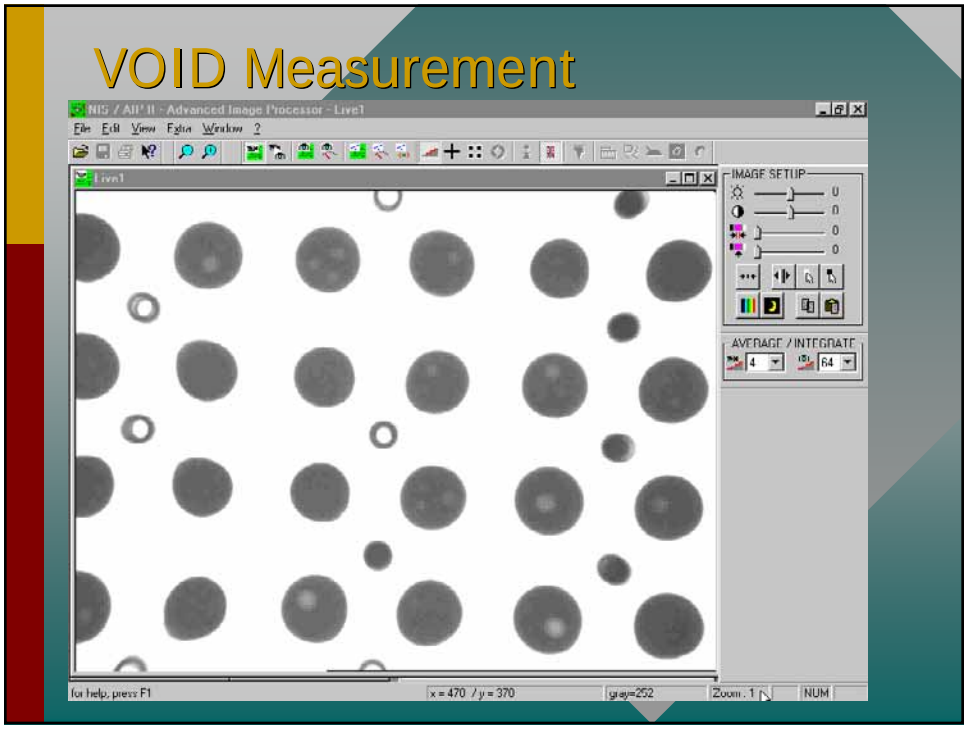
Special Filters and Enhanced Imaging

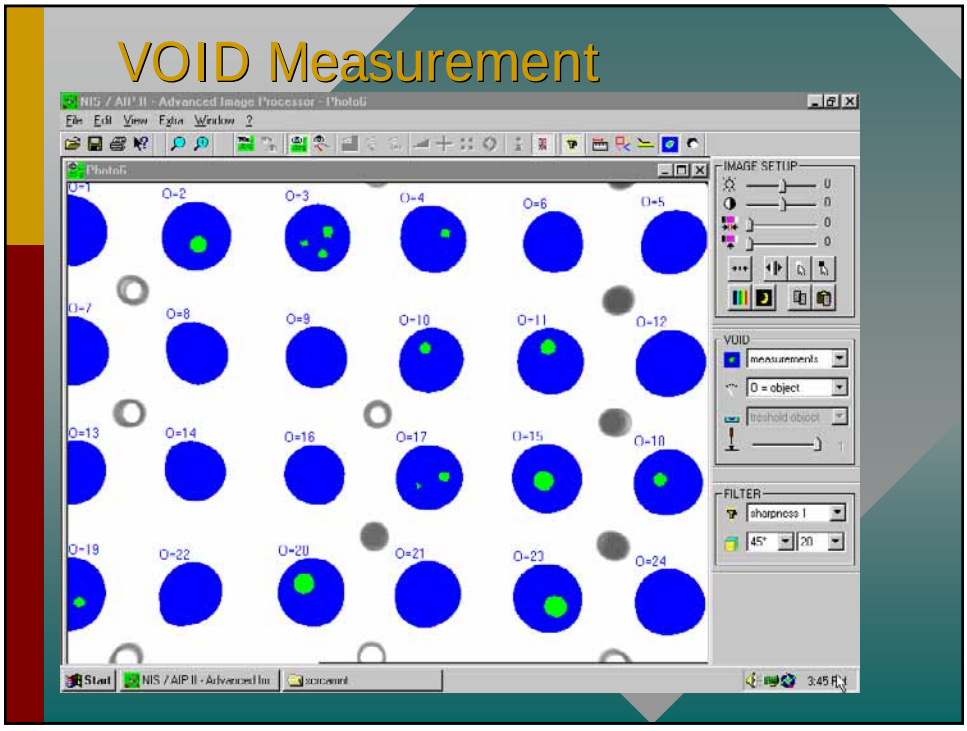
- 3D Contrast Display



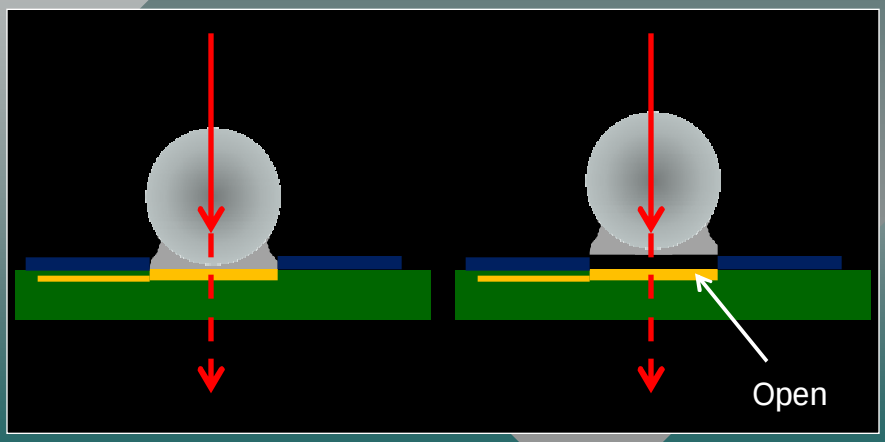
BGA Inspection




VOID Measurement


VOID Measurement

Finding the Open



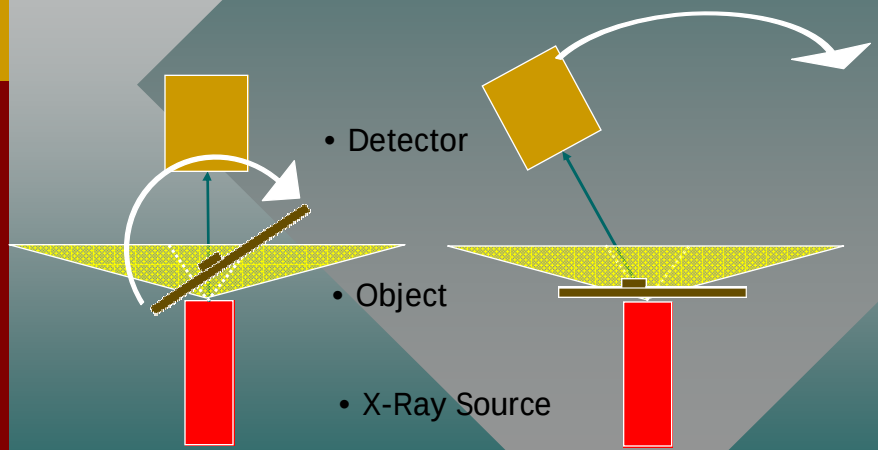
3D X-ray

- Off Axis Viewing
- Virtual 3D
- Laminography and Tomosynthesis
- Volume or Axial Computed Tomography
- Swing or Limited Axis Computed Tomography
- Planar Computed Tomography

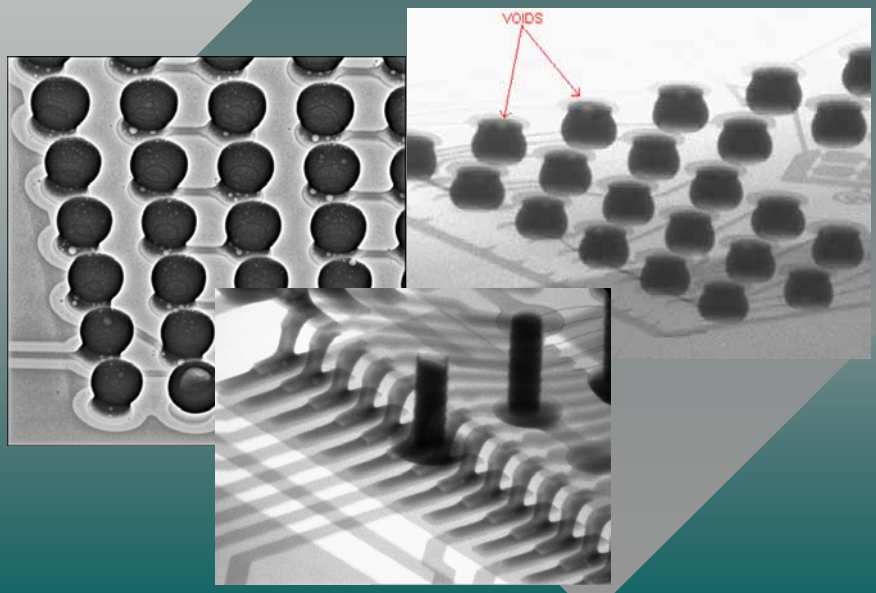
Off Axis Viewing

- X-Ray Source has a beam angle of 70 to 170 degrees
- Center of beam (focal spot) is aimed at center of point of interest
- Either product or detector moves about the area of interest
- Through Transmission Image

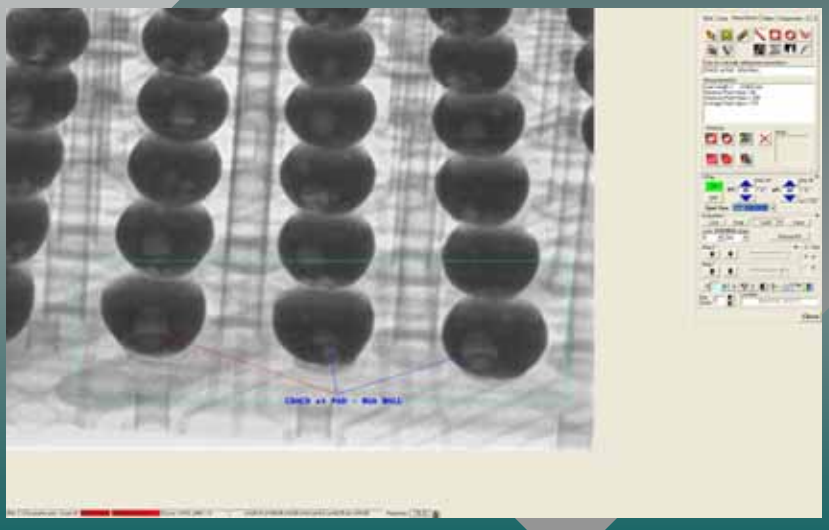
Off Axis Viewing



Off-Axis Viewing



Identify the crack (non-wet)



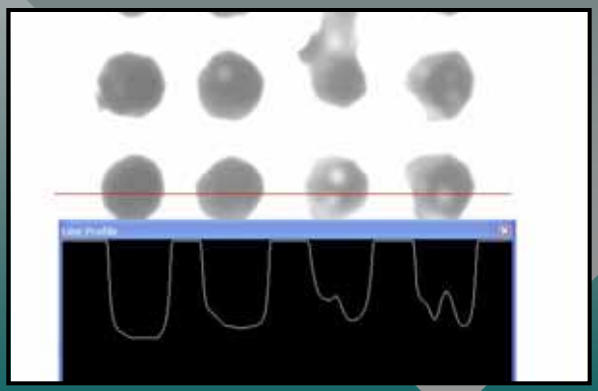
Virtual 3D

Popular Pseudo-3D tools

- Interpretation gray scale reading
  - Absorption rate is translated into height information
  - the vertical ***location*** and ***extend*** of defects remain unknown
  - Helps in highlighting variations in density
  - Provides Operators with alternative view

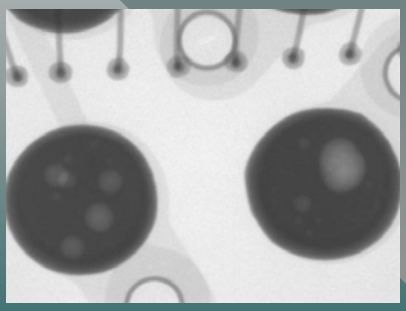
Line Profile

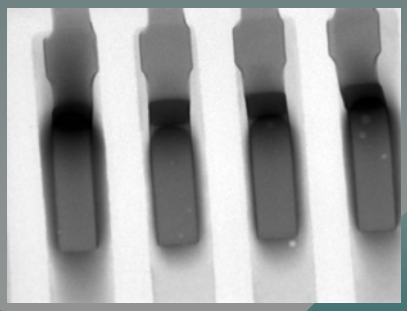
- Basis for most software enhancement
- Grey scale value by pixel is graphed and/or manipulated



"Virtual 3D"

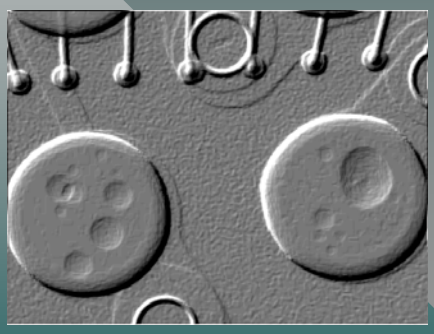
Captured Image

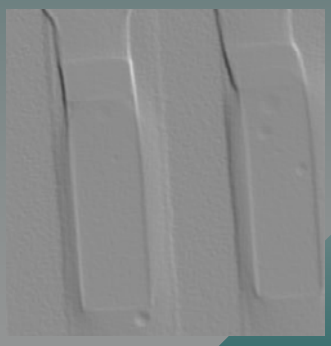




"Virtual 3D"

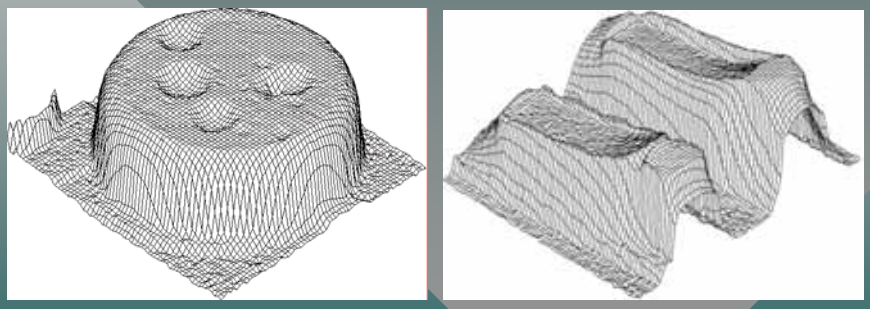
Relief





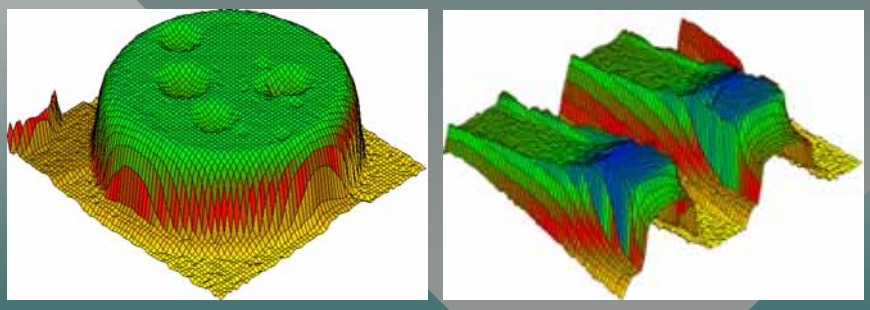
Virtual 3D

Wire Frame



Virtual 3D

Wire Frame or Contour Model

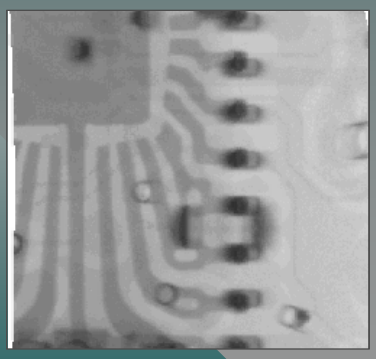


3D X-Ray Inspection

- Laminography
- Tomosynthesis
- CT (Computed Tomography)

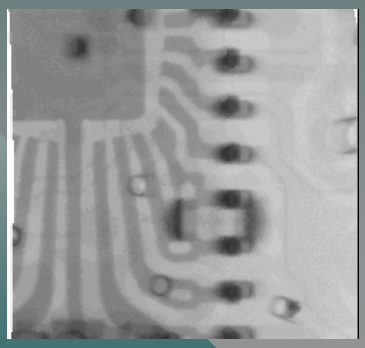
Advantage of 3d X-ray

- **Double sided PCB**

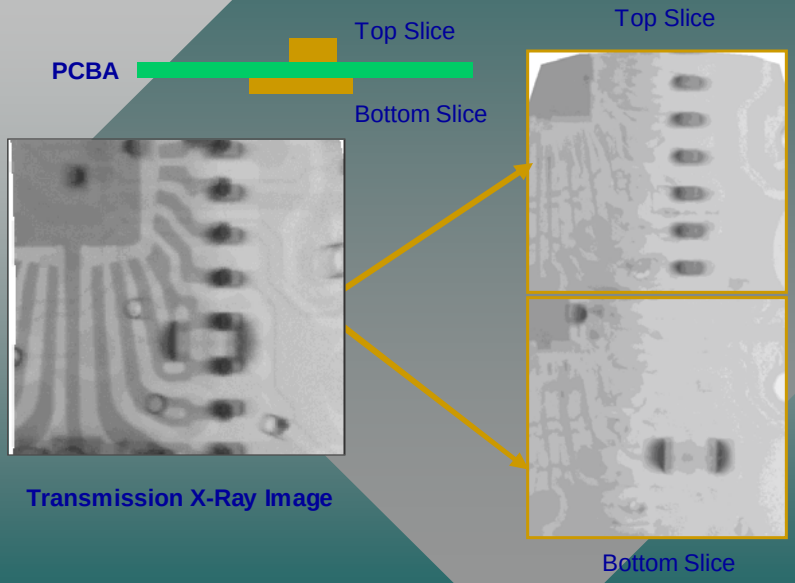


Digital Tomosynthesis

- Acquire multiple off-axis Image to separate top and bottom components



2-Sided Image Separation



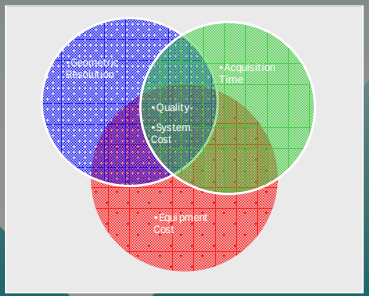
Computed Tomography

- General Features
- Techniques
  - Volume or Axial
  - Swing
  - Planar

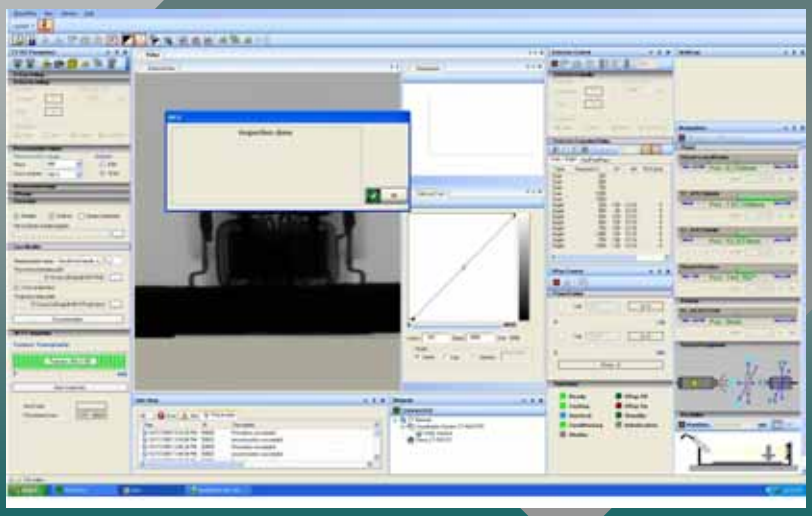
Computed Tomography

General Features

- Data Acquisition Software
- Reconstruction Algorithms
- Hardware
- Data Visualization



Data Acquisition Software

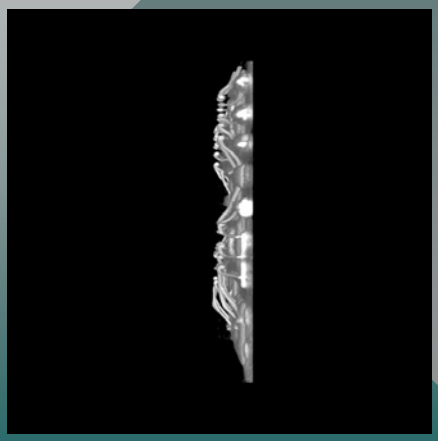


General Requirements

Hardware

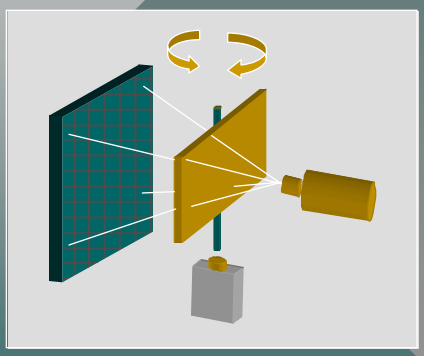
- Requires highly stability X-Ray source
- High dynamic and stable detector
- Ultra High Resolution Motion Control that is matched to the detector
- System structural integrity required for optimal image quality

Volume CT 3D Model



- Multi Chip Module
- Approximately 25 mm in X and Y
- 100 slices selected for this application
- Each bond wire is .001”/ 25 µm thick

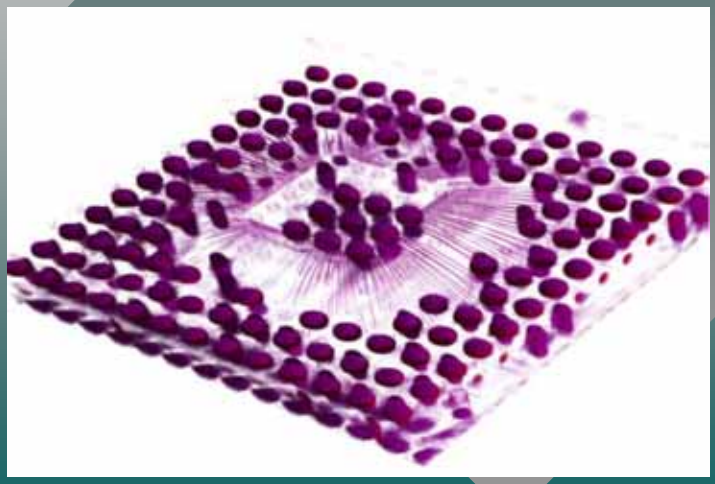
Swing CT



- Sample Rotates up to 130 degrees
- Full Reconstruction algorithms can be applied

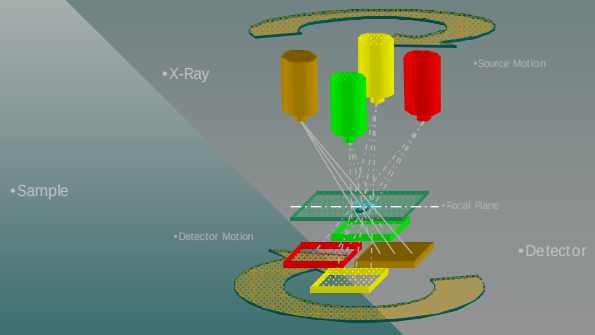
Swing CT

Reconstructed Image



Planar CT

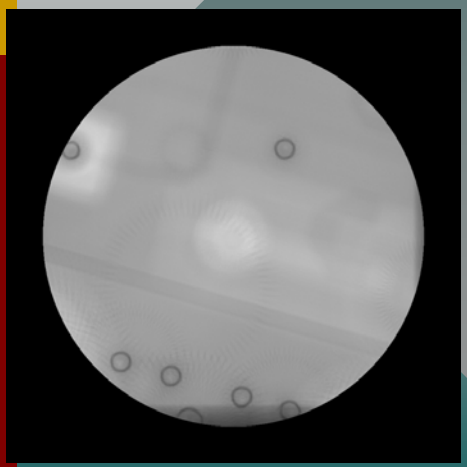
- Theory of Operation



Planar CT

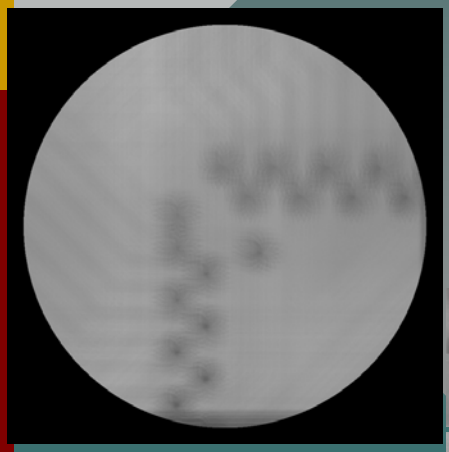
- Specifically designed for Objects that are difficult to rotate axially and perform a reconstruction.
  - Module Assembly and Bare Board inspection
  - Ability to separate side 1 from side 2
  - Z-axis location of defects in BGA balls
  - Detect Inner layer defects
  - Verify Blind and Buried via interconnects
  - Void inspection of Through Hole components

Planar CT



- Printed Circuit Board
  - .062”/ 1.57mm total thickness
  - 100 slices selected for this application
  - Each copper etch is .001”/ 25 µm thick

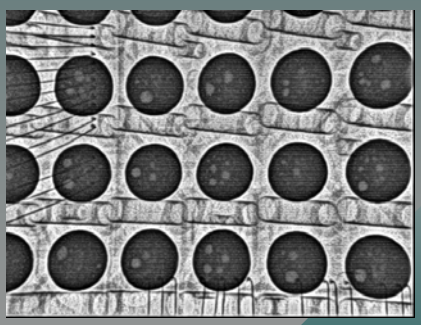
Planar CT



- PCB:
  - .062”/ 1.6 mm Z axis
- Solder Bumps:
  - .004” / 100µm X/Y
  - .002” / 50µm Z
- 50 slices

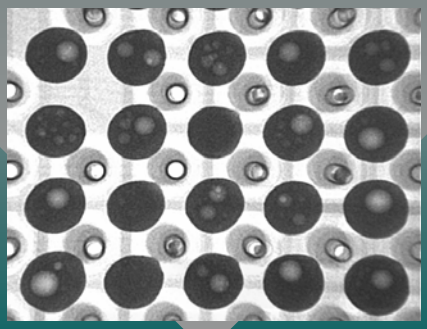
Every Day BGA Inspection

- Voids
- Solder Joint Area
- Solder Joint Shape
- Missing/Shorts
- Alignment



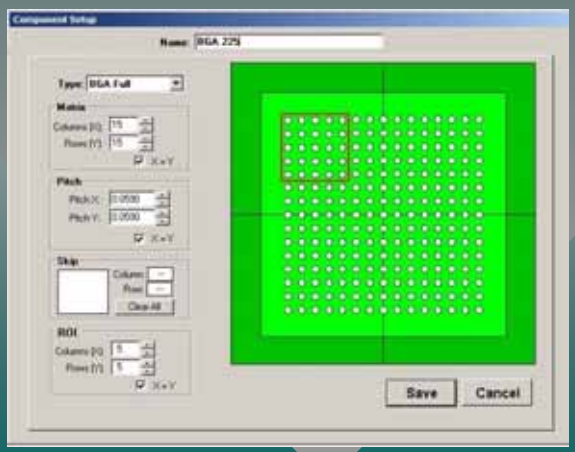
Inspection Paramters

- Magnification
  - Throughput vs. Detail
- Penetration
  - kV
  - mA



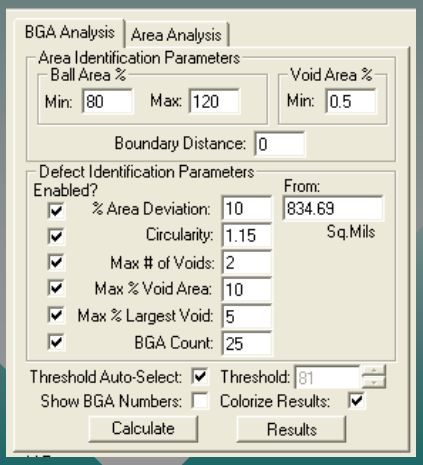
Inspection Parameters

- Define the array
- ROI



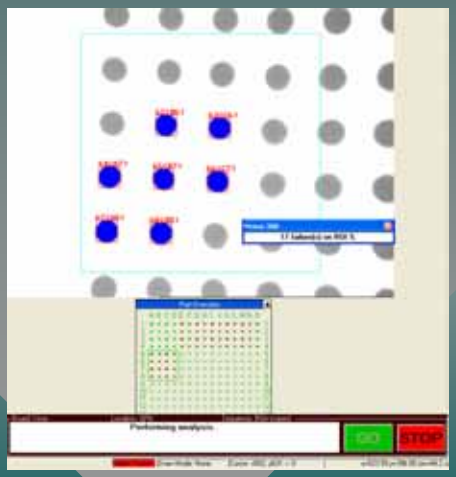
Inspection Parameters

- Pass / Fail Criteria
  - Min/Max Diameter
  - % Deviation
  - Void Area
    - % of total
    - # of voids

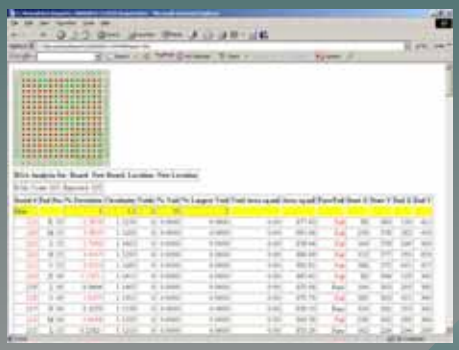


Analyze the Image

- Pass / Fail Criteria
  - Min/Max Diameter
  - % Deviation
  - Void Area
    - % of total
    - # of voids



Generate Reports



- Pass / Fail
- Obvious Defects
- Consistency
  - Low volume → Opens?
- Areas of Concern
  - Corners vs. Center

Summary

- X-ray Inspection in Production
  - New Product Qualification
  - Process Control
- Failure Analysis
  - High Magnification
  - Off Axis Viewing
- 3D X-ray Inspection
  - Greatest detail available