- When asked this riddle, 80% of kindergarten kids got the answer compared to 17% of Stanford University seniors.

- What is greater than God, More evil than the devil, The poor have it, The rich need it, And if you eat it you will die?

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SUPERMAN Looks At The HP17BII+

A high tech noninvasive examination technique suitable for exploring calculators

Richard J. Nelson

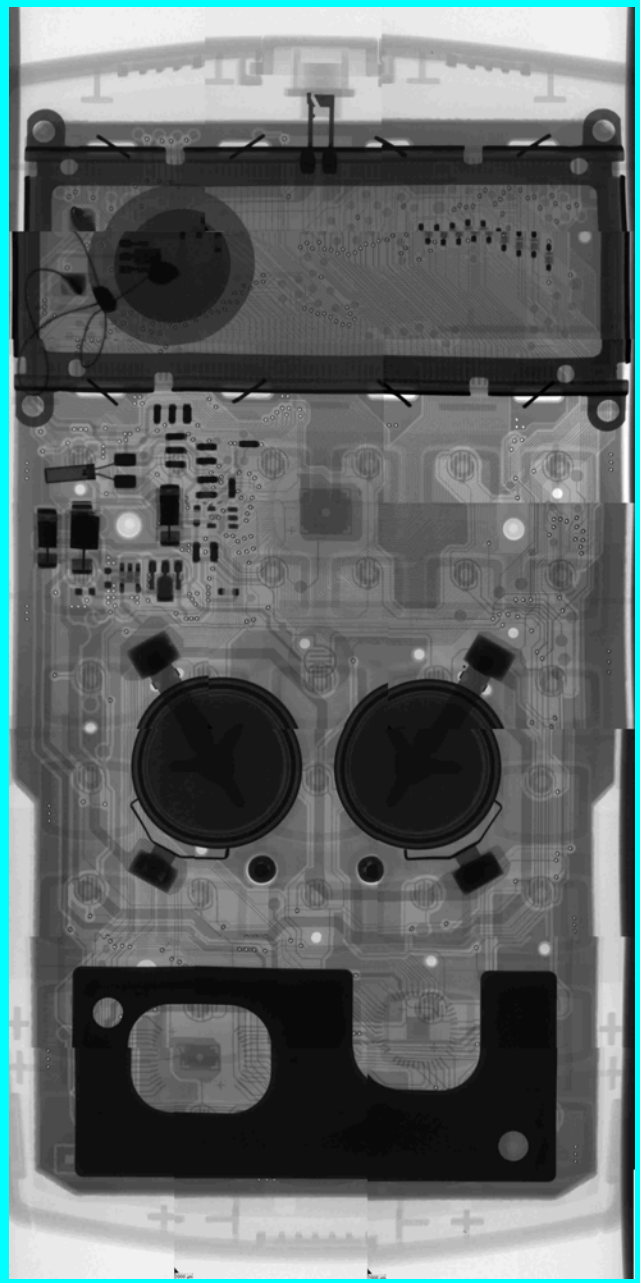
Historical Techniques

- Photograph calculator using a 35 mm camera with macro lens for magnification.
- Project 35 mm slides using a zoom lens onto a large screen for magnification.
- Use a video camera with close up lens projected onto a large screen for magnification.

- These techniques require taking the calculator apart to examine the circuitry and physical layout.

How Clark Kent Sees The Machine

How Superman Sees The Machine



X-Ray Basics 1

1. ***X-Ray tube, detector, and computer.***
2. Point source is desired for small specimens.
3. Motorized specimen and detector desired.
4. Computer controls movements, processes images, and writes images to multiple media and/or network.
5. Modern machines are made to be used hourly and routinely. X-Ray tube is of the “open” type.

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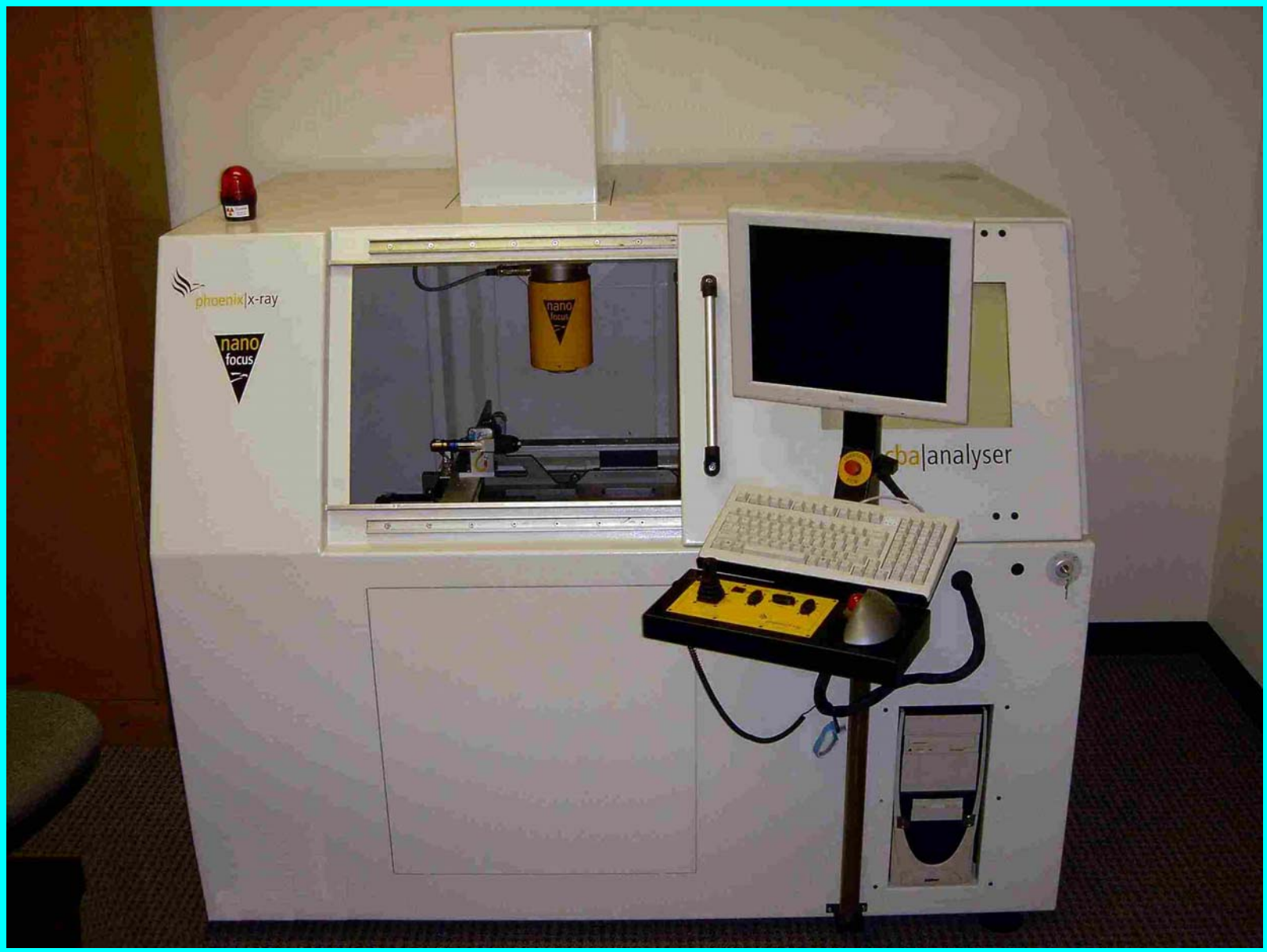
Phoenix PCB|X-ray System



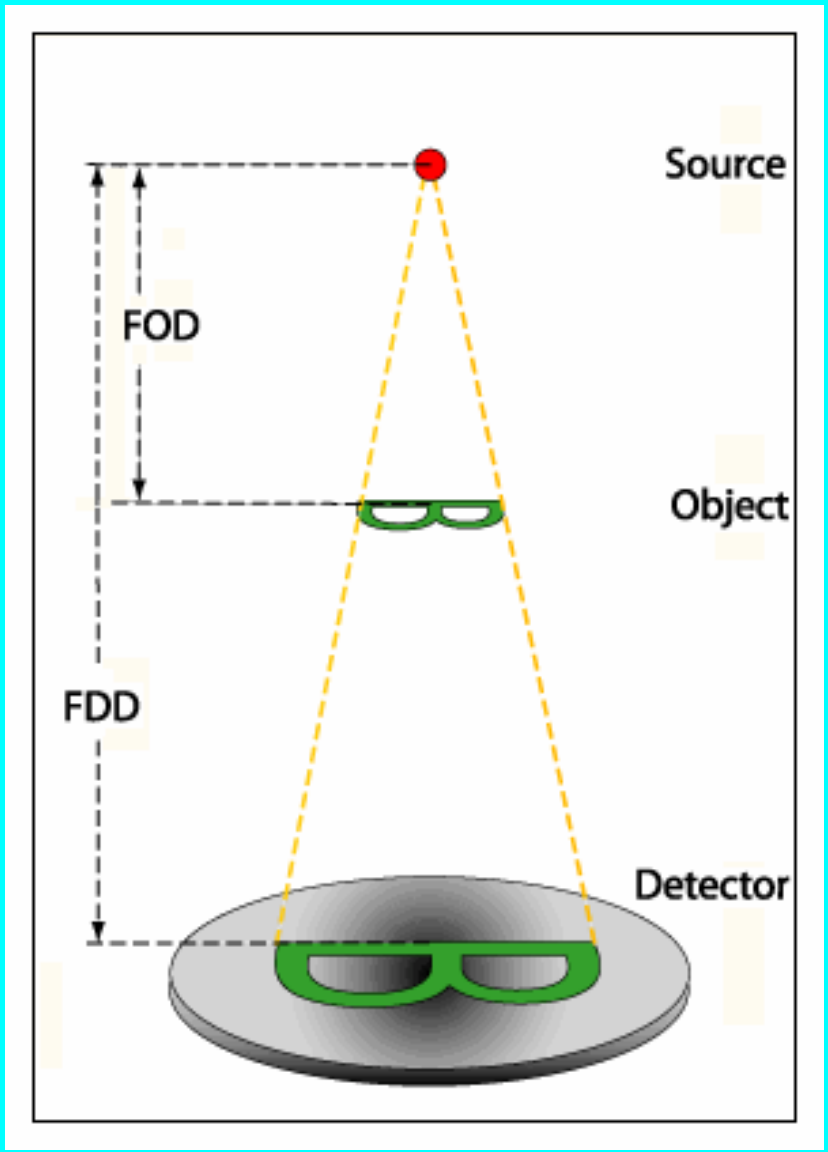
X-Ray Tube

- This is an Open tube.
- High vacuum pump is above the X-ray tube.
- Rough vacuum pump is in
- cabinet below.
- X-rays emit from bottom.
- Specimens may touch the bottom of the tube for maximum geometric magnification.

X-Ray Basics 2

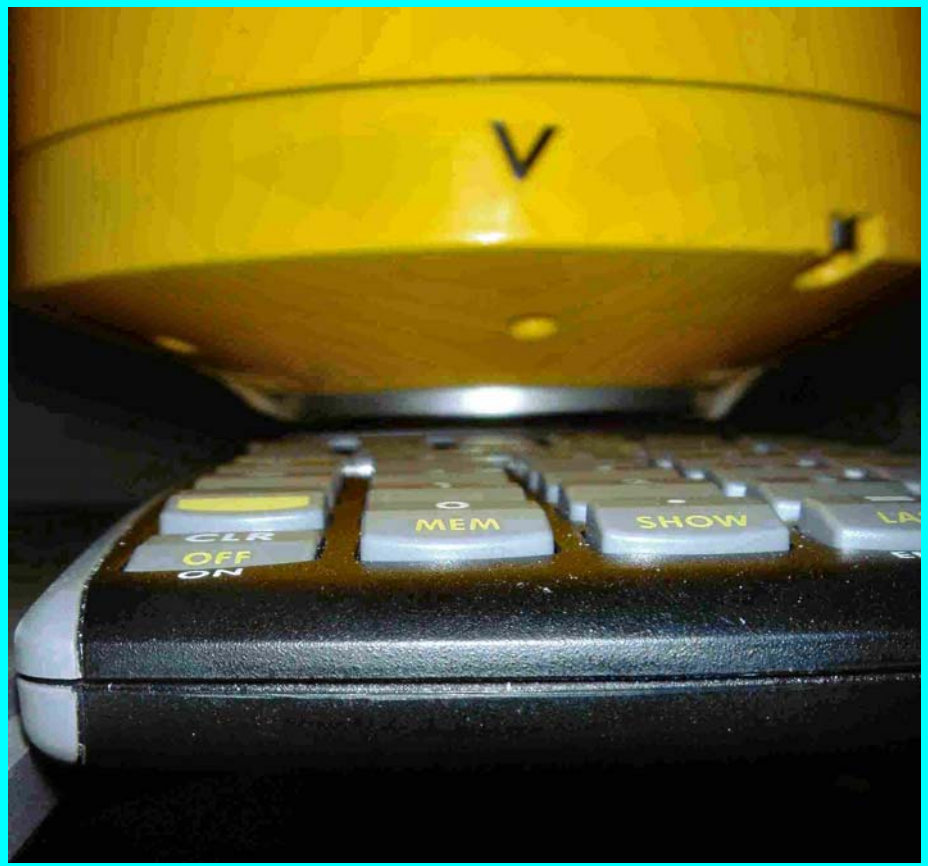
1. X-Ray tube, detector, and computer.
2. ***Point source is desired for small specimens.***
3. Motorized specimen and detector desired.
4. Computer controls movements, processes images, and writes images to multiple media or network.
5. Modern machines are made to be used hourly and routinely. X-Ray tube is of the “open.” type.

Geometric Magnification



- Geometric Magnification Mgeo = FDD/FOD, where:
- FOD = Focus to Object Distance.
- FDD = Focus to Intensifier Distance.
- FOD for phoenix x-ray tubes is as small 0.4 mm, FOD.
- Practical systems are limited to about 1 mm so that a geometrical magnification of 2500 may be achieved.
- 1600 X is more reasonable.

For Maximum Magnification You Must Be Really Close



- Moving the calculator up to the X-Ray tube requires that the “driver” pay attention or an “accident” may occur. The calculator will loose.
- The x-ray tube is steel and is usually not harmed.

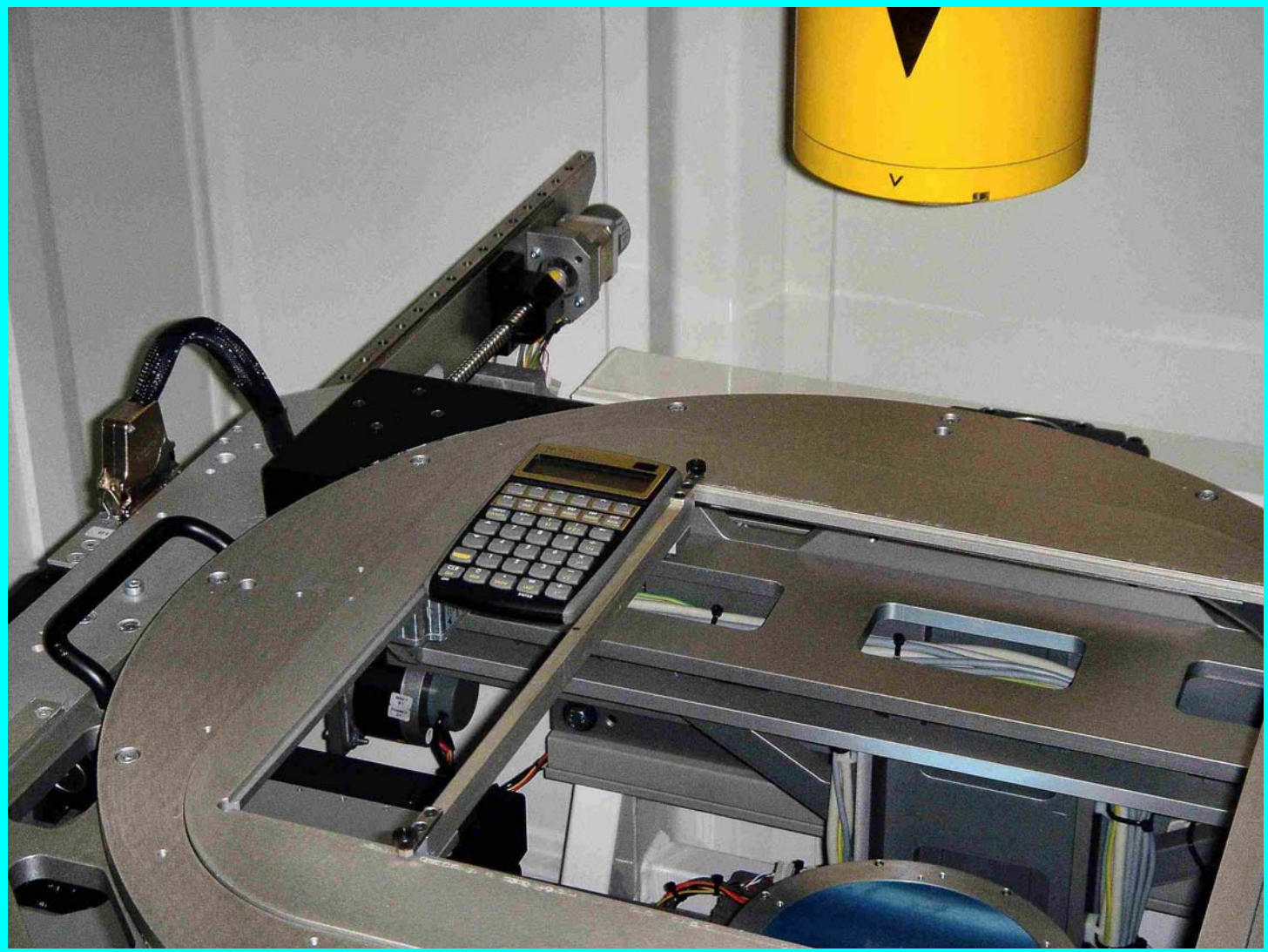
PCB Measurement Units

- Biomedical Engineering fields use mixed English and Metric units. Small parts are measured in the following.
- – – – – millimeters – – – – mils – – – – microns – – – –
- The average human hair diameter is 0.0254 mm, 1 mil, or 25.4 microns.
- PCB traces may be etched with 1 mil traces and 1 mil spacing. Too-small-to-read text of 4 points is 55.56 mills high (1.411 mm & 1,411 microns).
- A millimeter, mm, is 39.37 mils or 1,000 microns.
- A mil is 0.0254 mm or 25.4 microns.
- A micron is 1/1,000ths of a millimeter or 0.03937 mils.

X-Ray Basics 3

1. X-Ray tube, detector, and computer.
2. Point source is desired for small specimens.
3. ***Motorized specimen fixture and detector desired.***
4. Computer controls movements, processes images, and writes images to multiple media or network.
5. Modern machines are made to be used hourly and routinely. X-Ray tube is of the “open.” type.

A large Mounting Fixture Holds Calculator



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A Laser Shows X-Ray Beam Position

(Photo taken through lead glass window)

Holding Fixture Rotates

(Up to 90 degrees)

Phoenix Detectors Tilt 46 – 77 Degrees

- This system has two different detectors – digital and photo multiplier (provides additional magnification) - each suitable for different materials and applications.
- The specimen does not require clamping.
- The computer is smart enough to track and maintain the area of interest as the fixture is rotated and the detectors are tilted – in the hands of a skilled operator.
- Circuit board vias (plated feed thrus) provide a good indication of detector tilt (46 Deg. Max for our system).

Dual Detector System

- **Square Digital Detector Left**
  - ✓ High Contrast
  - ✓ Slower Speed
  - ✓ Geometric Magnification only
- **Round Photo Multiplier Right**
  - ✓ Uses 8 or 12 bit camera
  - ✓ Fast
  - ✓ Adds magnification 3x to 5X

X-Ray Basics 4

1. X-Ray tube, detector, and computer.
2. Point source is desired for small specimens.
3. Motorized specimen and detector desired.
4. ***Computer controls movements, processes images, and writes images to multiple media or network.***
5. Modern machines are made to be used hourly and routinely. X-Ray tube is of the “open.” type.

Typical Computer Display

“Drivers” Controls

X-Ray Basics 5

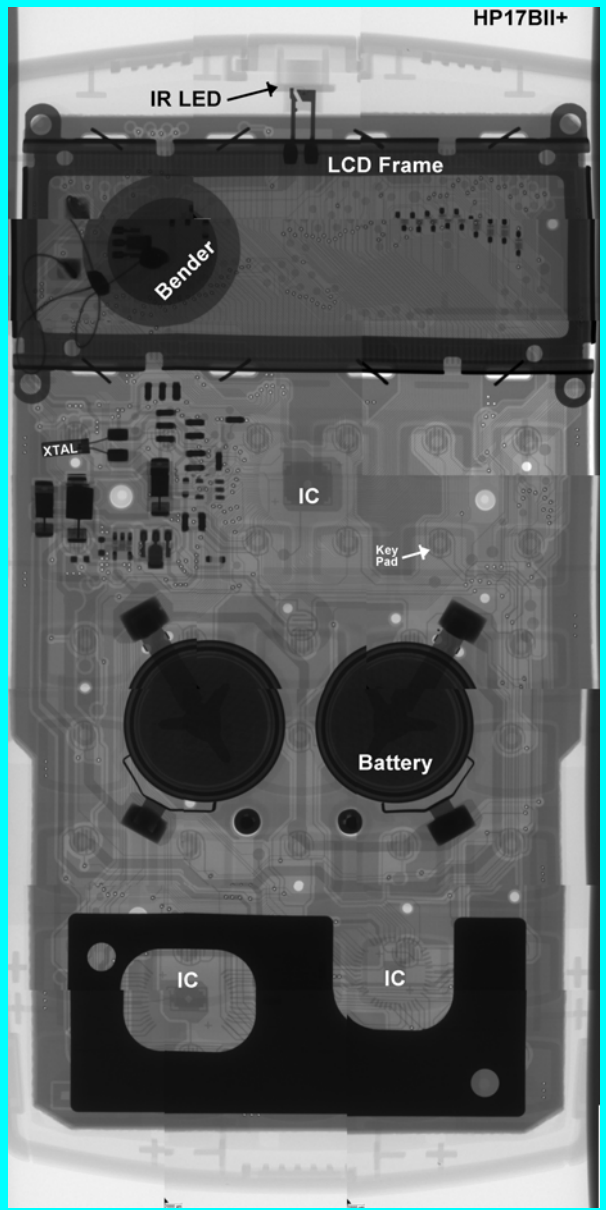
1. X-Ray tube, detector, and computer.
2. Point source is desired for small specimens.
3. Motorized specimen and detector desired.
4. Computer controls movements, processes images, and writes images to multiple media or network.
5. ***Modern machines are made to be used hourly and routinely. The X-Ray tube is of the "open." type.***

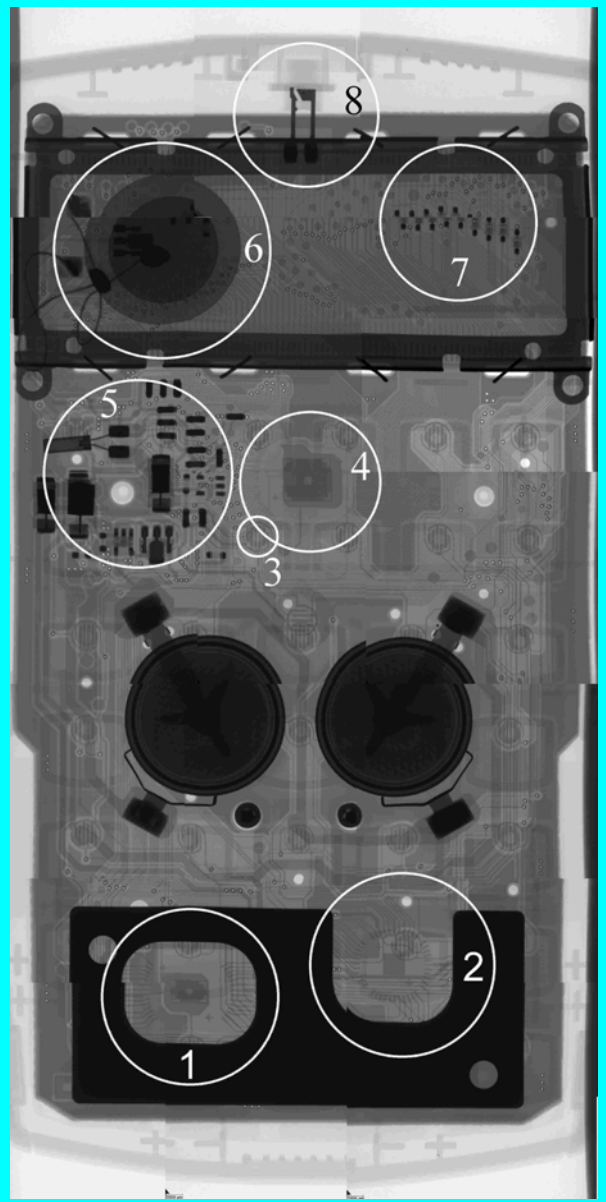
Sealed Vs Open X-Ray Tube

(From Phoenix|X-ray)

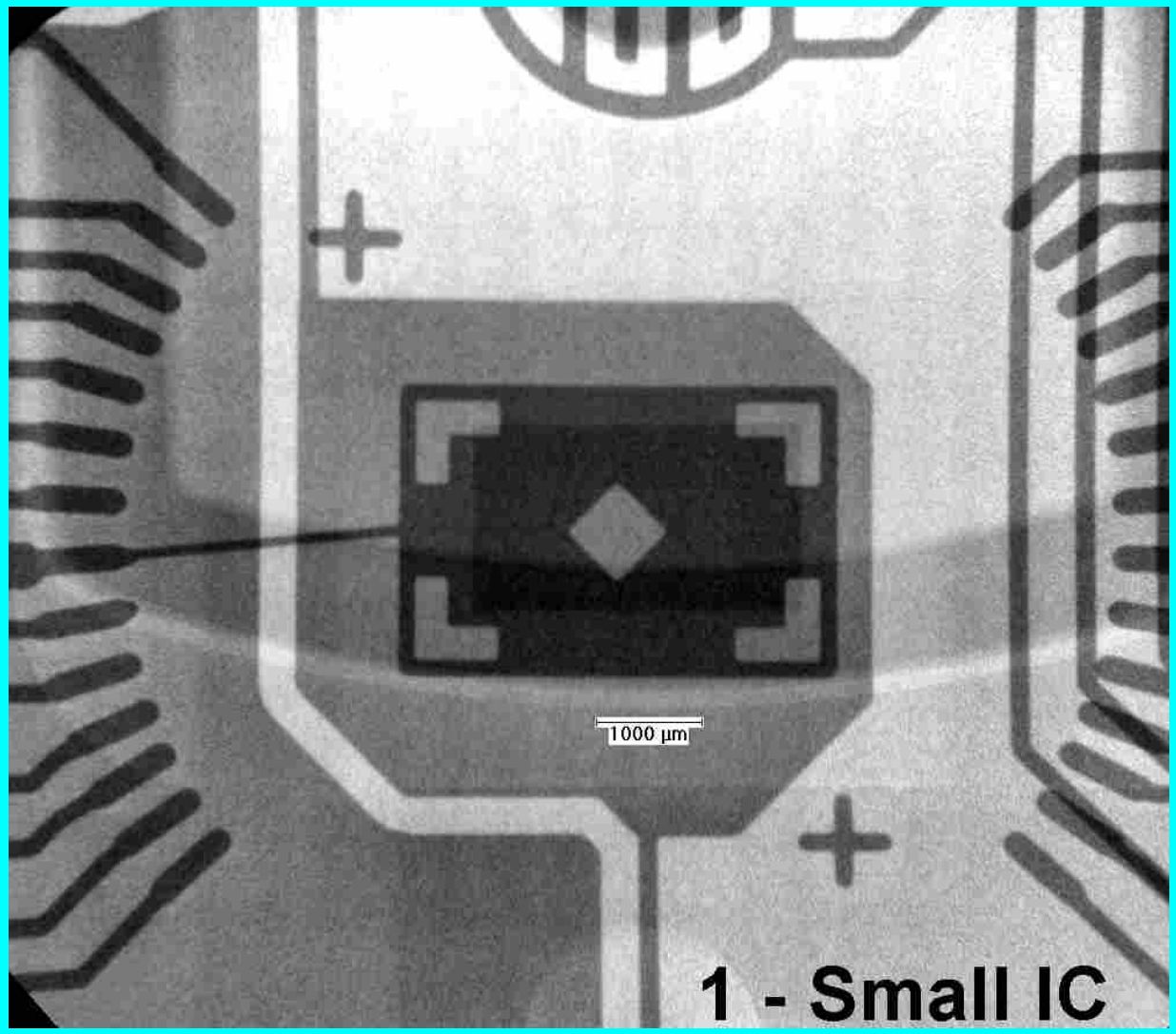
Characteristic	Sealed Tube	Open Tube
Detail Delectability (um)	5 microns	1 micron (0.6)
Geometric Magnification	70 x	1,600 x
Max. Tube Voltage	80 – 150 KV	100 – 225 KV
Max. Tube Power	5 – 10 Watts	10 – 30 Watts
Main Costs of Ownership	Replacement Tubes	Preventative Maintenance
RJN Cost Comment	–	*Vacuum System*

HP17BII+ Areas Of Interest



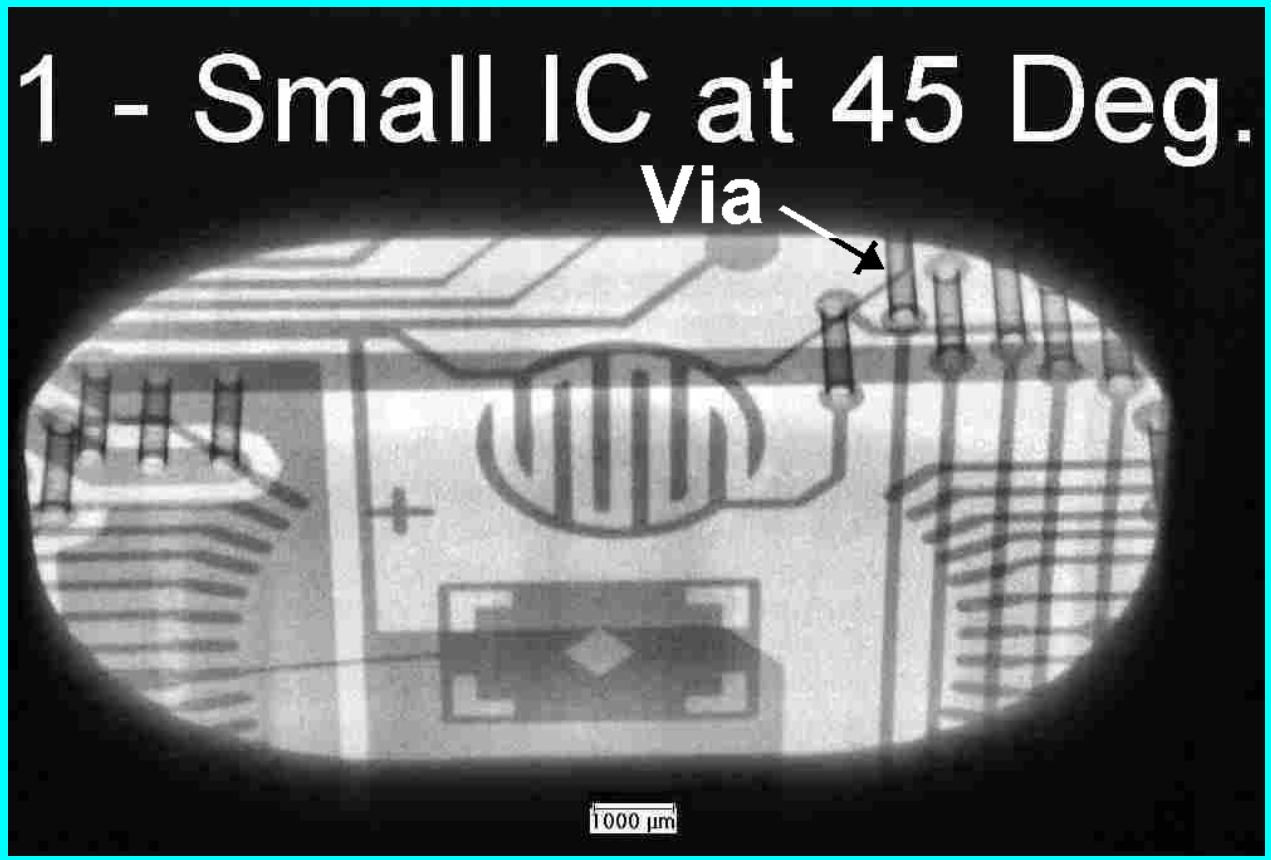


A1 – Small IC Lower Left



- IC Has a metal frame or shield 0.160” x 0.110”.
- IC Has 28 leads
- IC lead pads are 11 mils wide.
- + symbols may be targets for assembly.
- Traces are 7.7 mils wide.
- Scale is 1000 microns.

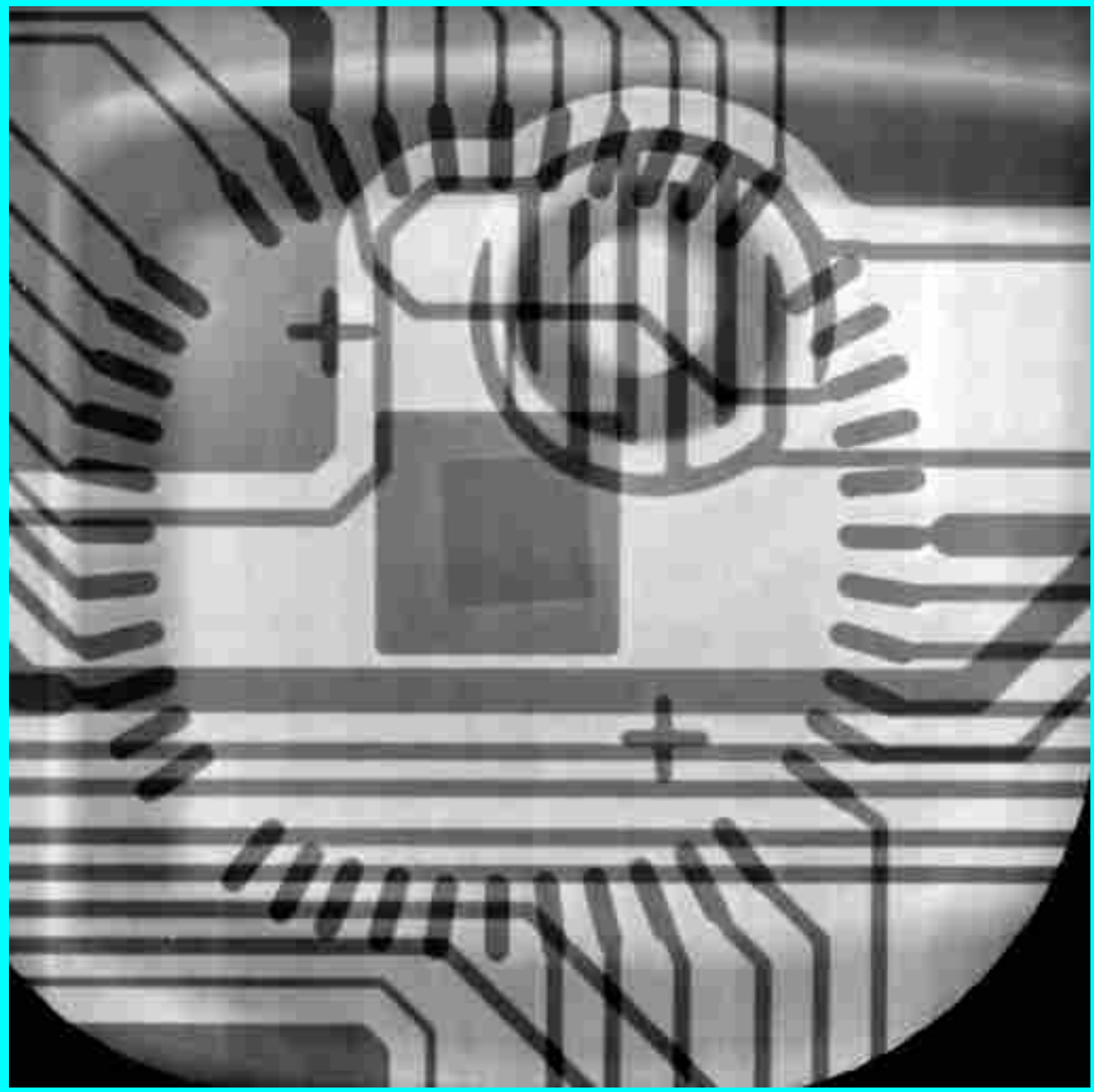
A1 – Small IC Lower Left 45 Deg.



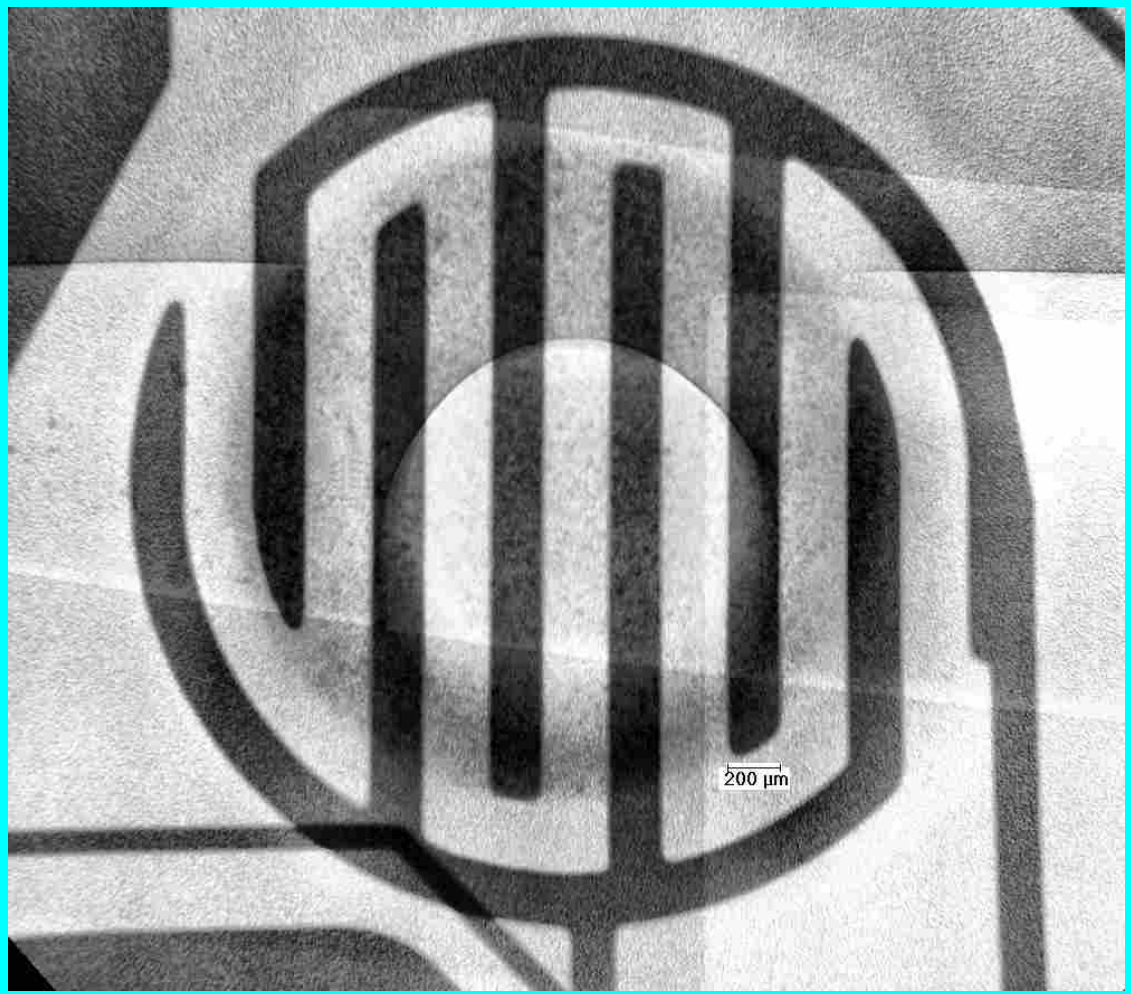
- 11 vias may be seen. These serve as an indication of PCB being tilted.
- Key contact pad is “above” IC.
- No bond wires are visible.

A2 – Small IC Lower Right

- The IC has 44 “pins.”
- The image contrast has been adjusted to show what may be the edge of the package.
- The IC is on the bottom side of the PCB below the = key.



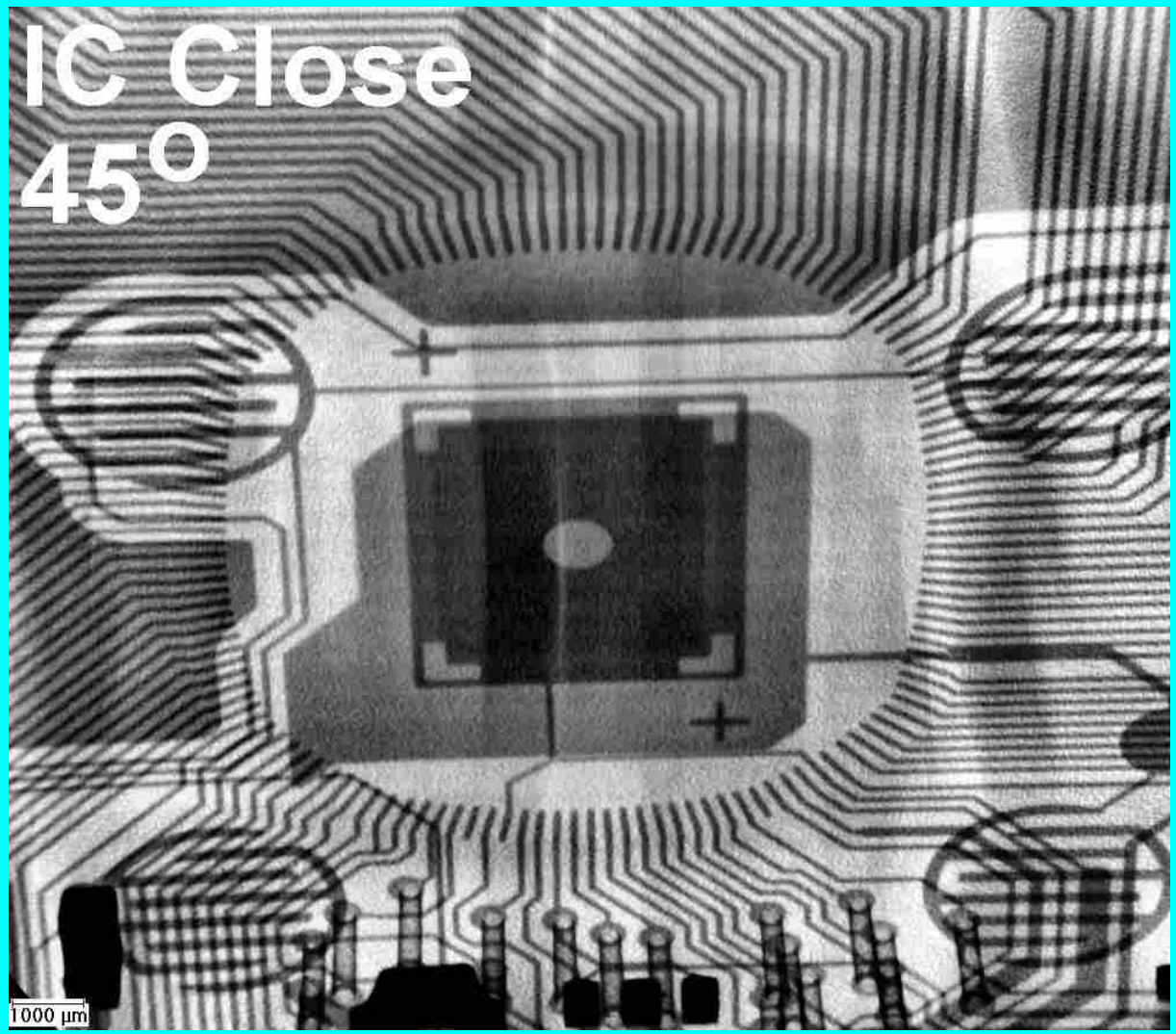
A3 - Key Contact Traces



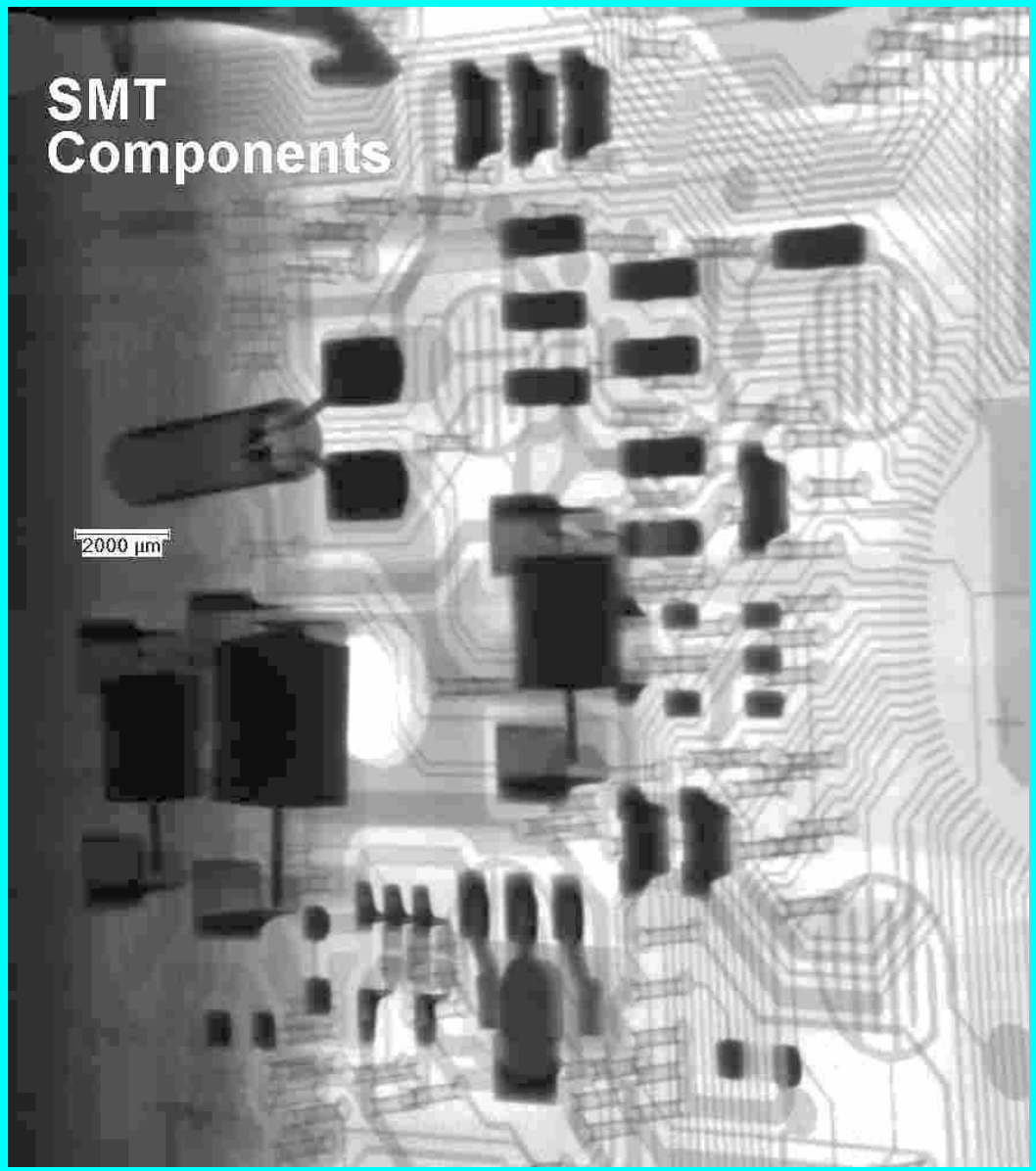
- Circuit traces are 7.7 mils in width..
- Pattern width and height (dia): 0.136”.
- Key contact is made with conductive rubber against this copper pattern.
- Accuracy of measurements is very high because the system is designed for PCB inspection.

A4 – Largest IC On Circuit Board

- No visible bond wires
- This is largest IC with 142 leads – is this the display driver?
- 12 vias may be seen at the bottom of the image.
- Key contacts on top, IC leads on bottom.
- This is similar to the other ICs examined.
- Scale 1000 microns.



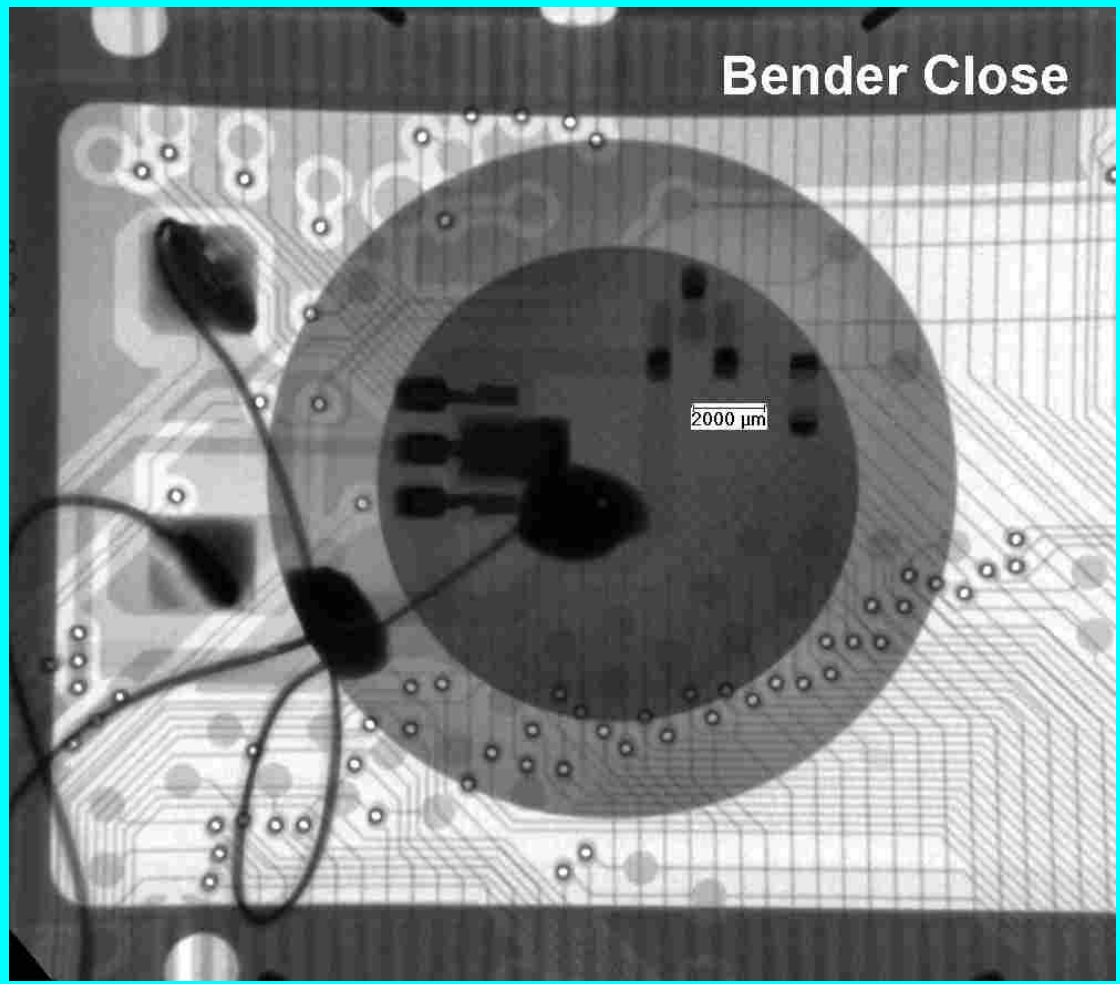
A5 – Crystal & Other Components



- Time base quartz crystal is 1/3rd down on left.
- Assorted SMT chip resistors and capacitors populate the PCB in this area. These parts are on the back side of the PCB.

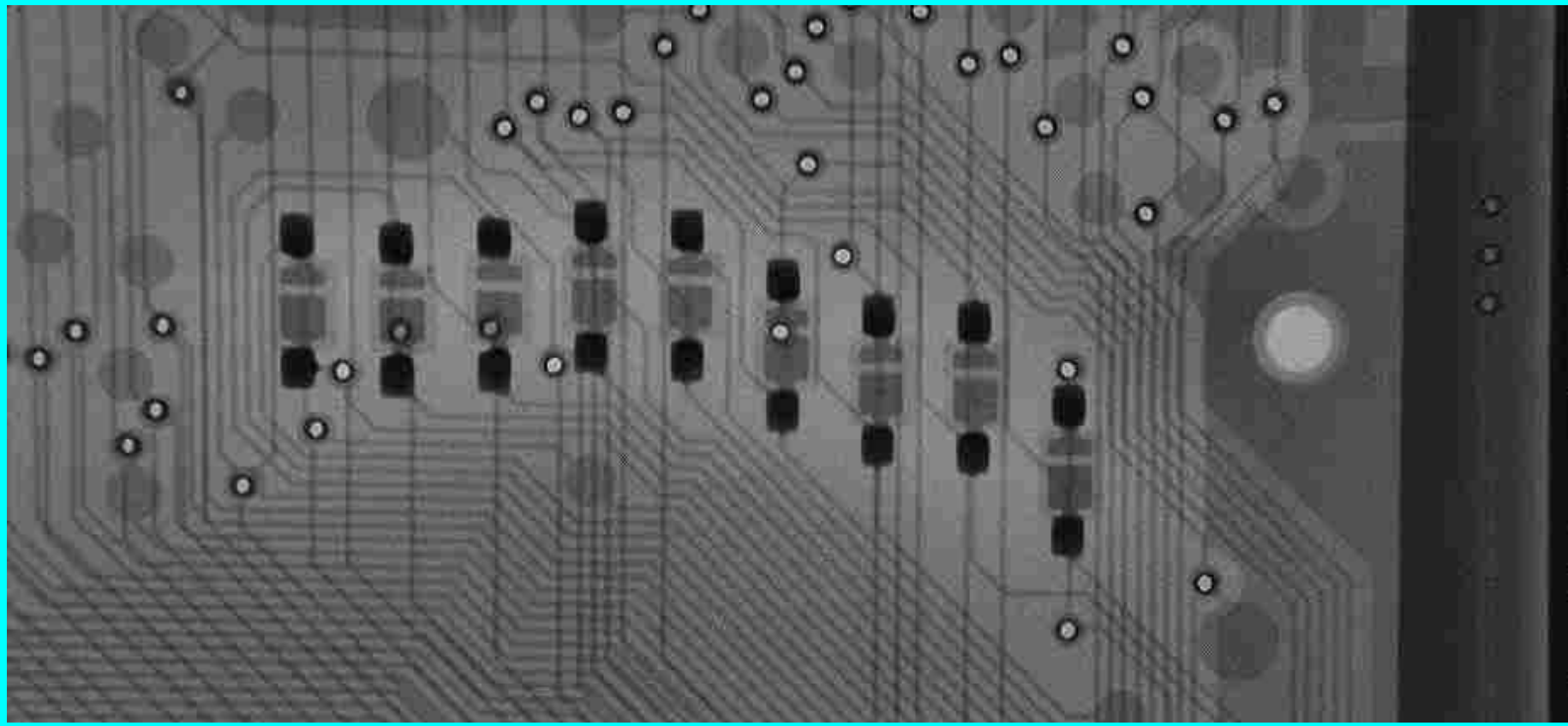
  because the key contact traces have to be on top.

A6 – The Bender Sound Generator



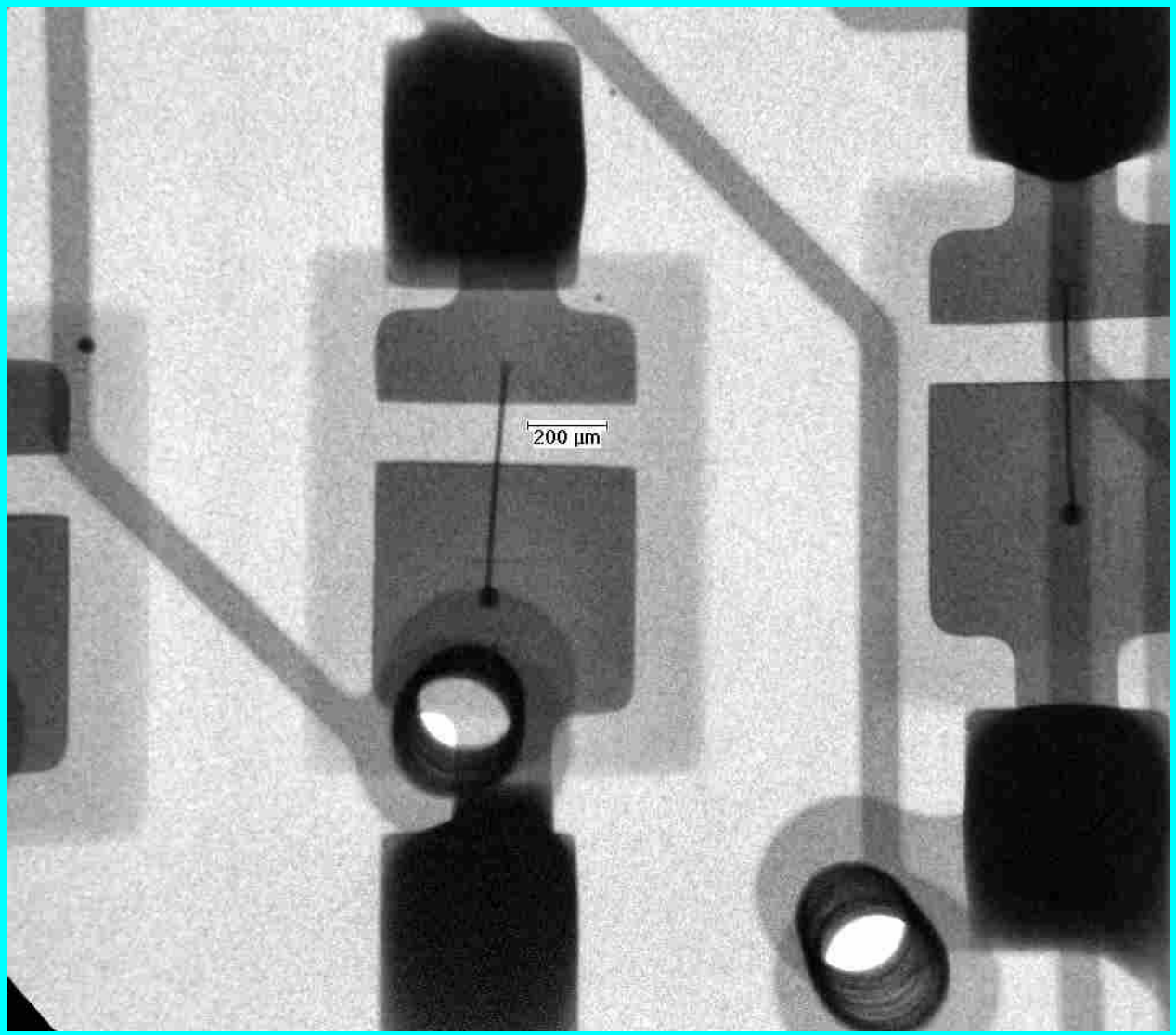
- Piezoelectric material is more transparent to x-rays but the metal electrodes and soldered wire leads are less transparent. Note long wire leads. Scale is 2000 microns.

A7 - Display Area Components



- What are these nine discrete components?
- Are they used for the display?
- What kind of packaging is used?

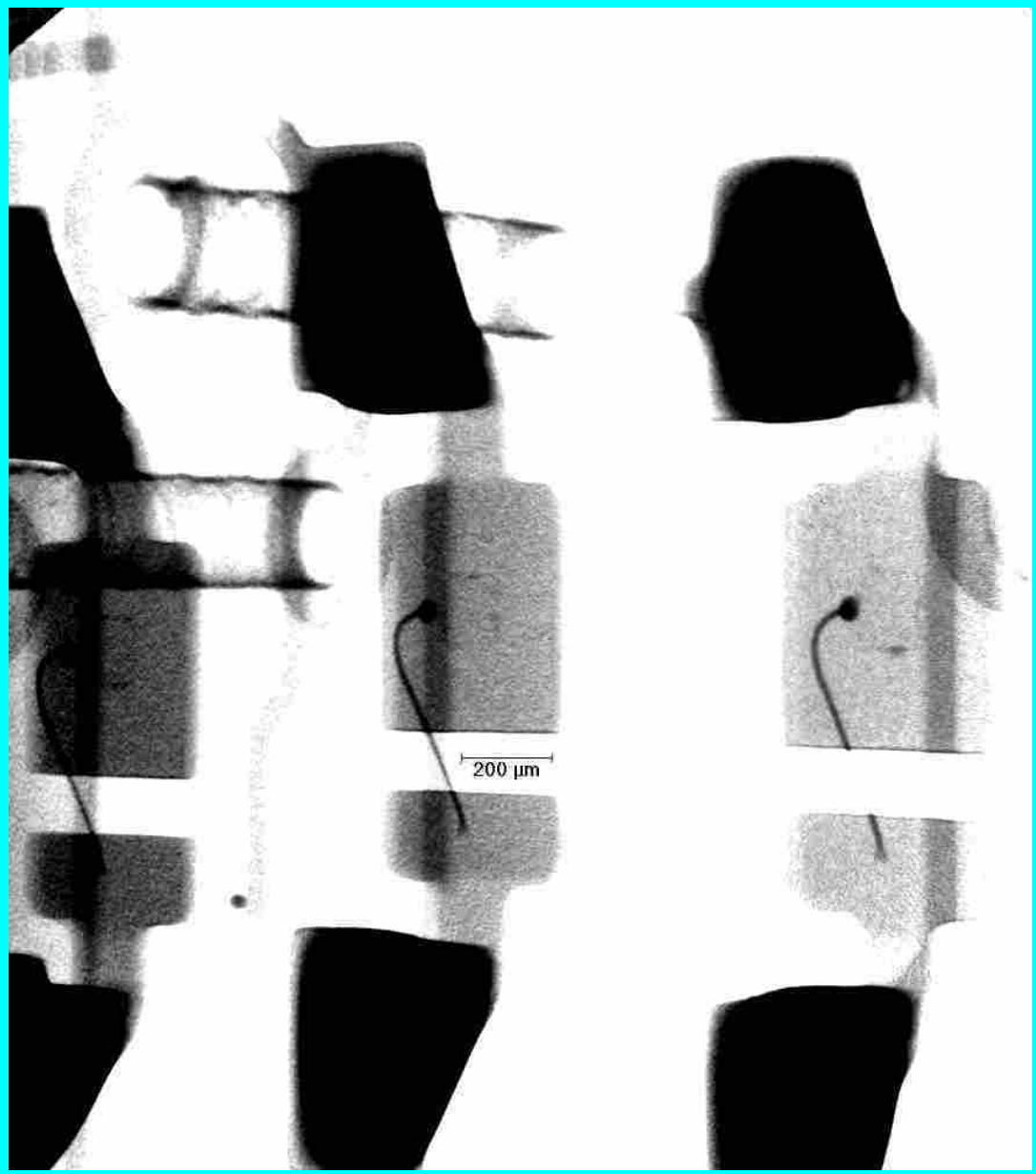
A7 – Display Area Components Magnified



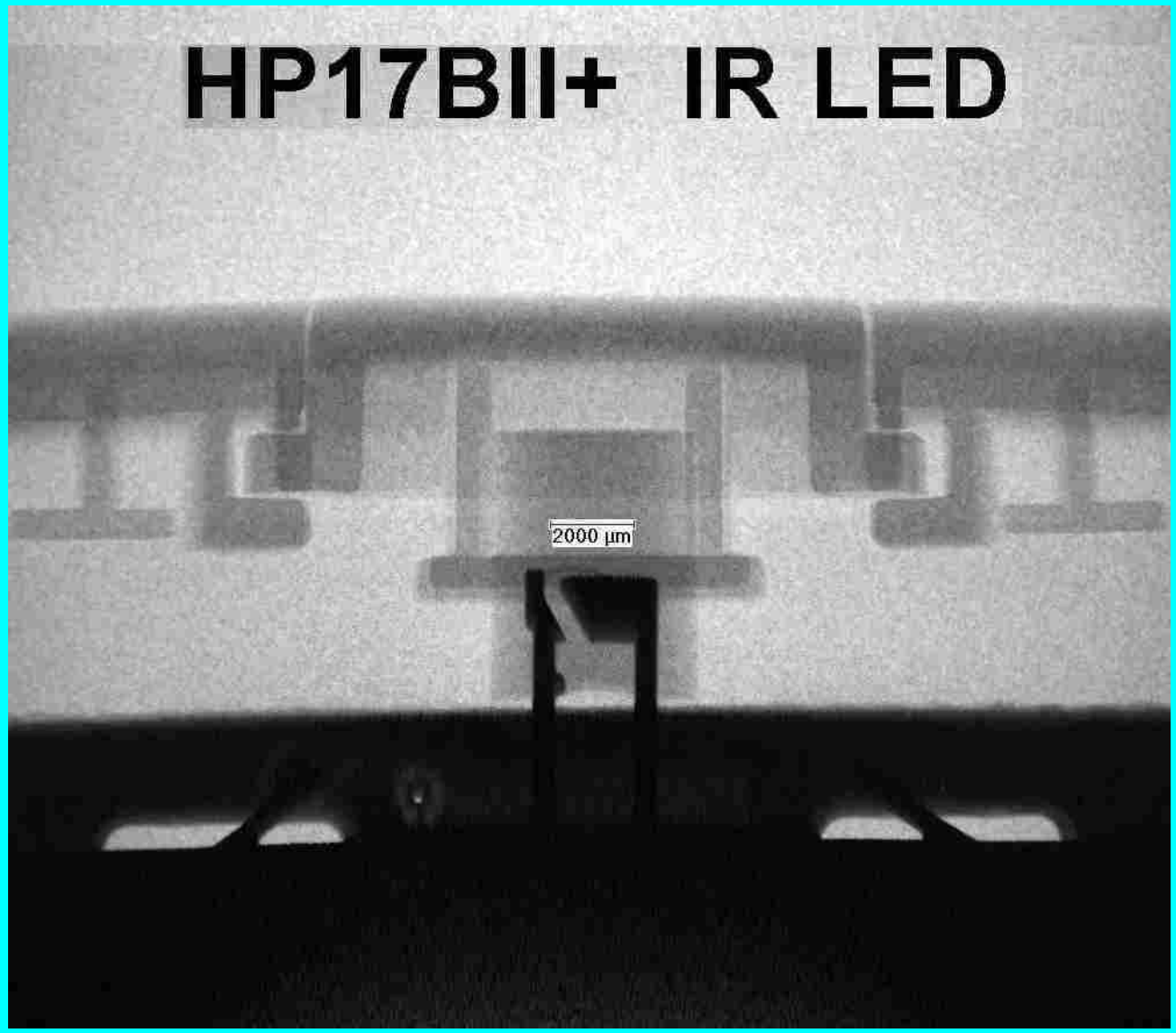
- Here is the first bond wire we have found!
- It sure looks like a diode.
- Note divergent angle of x-rays as illustrated by the two vias.
- Scale 200 microns

A7 – Let's Tilt 45 Degrees

- Note asymmetric lead frame. Is there a die mounted on the upper one?
- Scale is 200 microns. The wire is 25 microns in diameter.
- You can't see this even if you opened the machine.

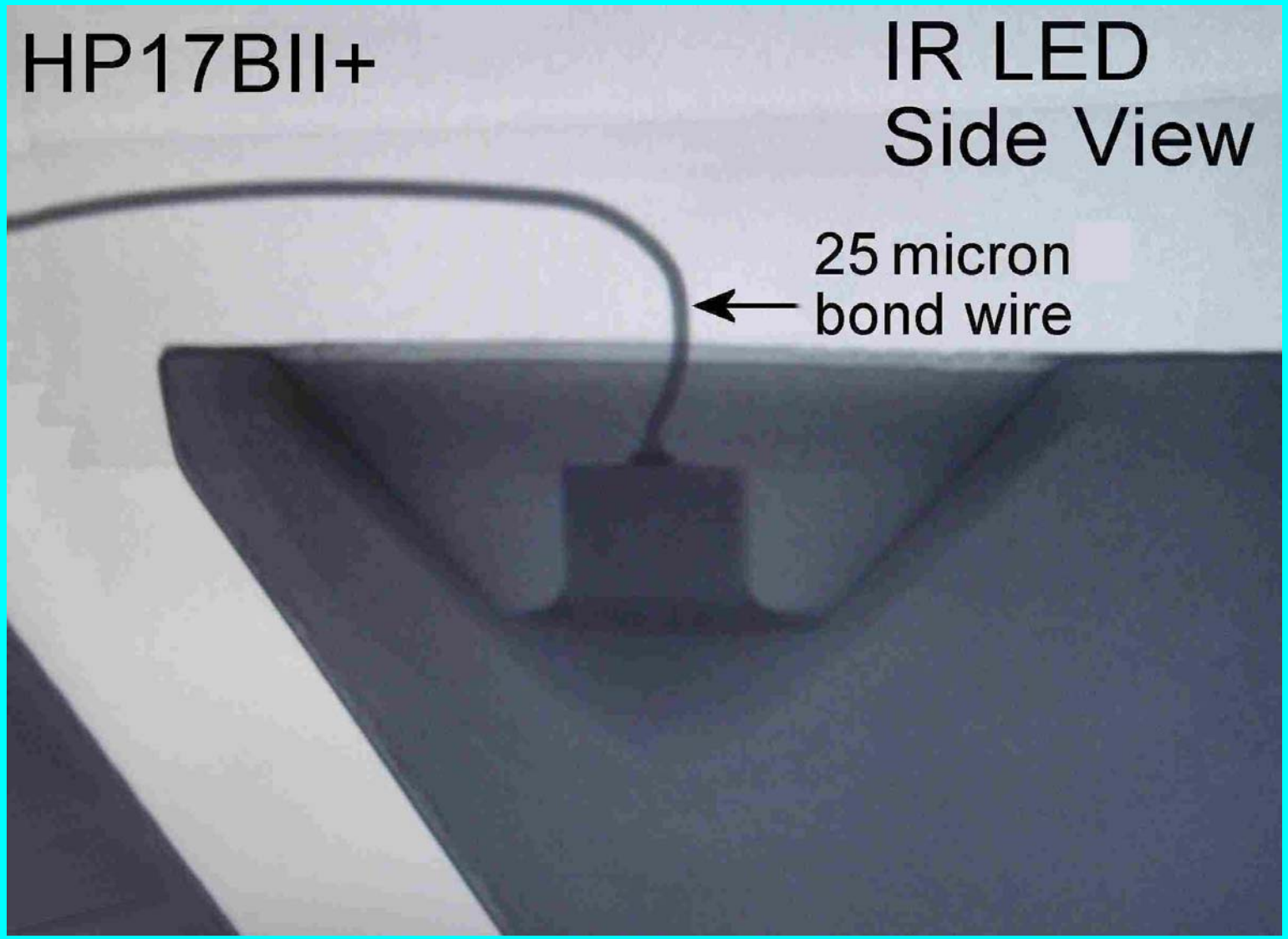


A8 – Printer IR LED



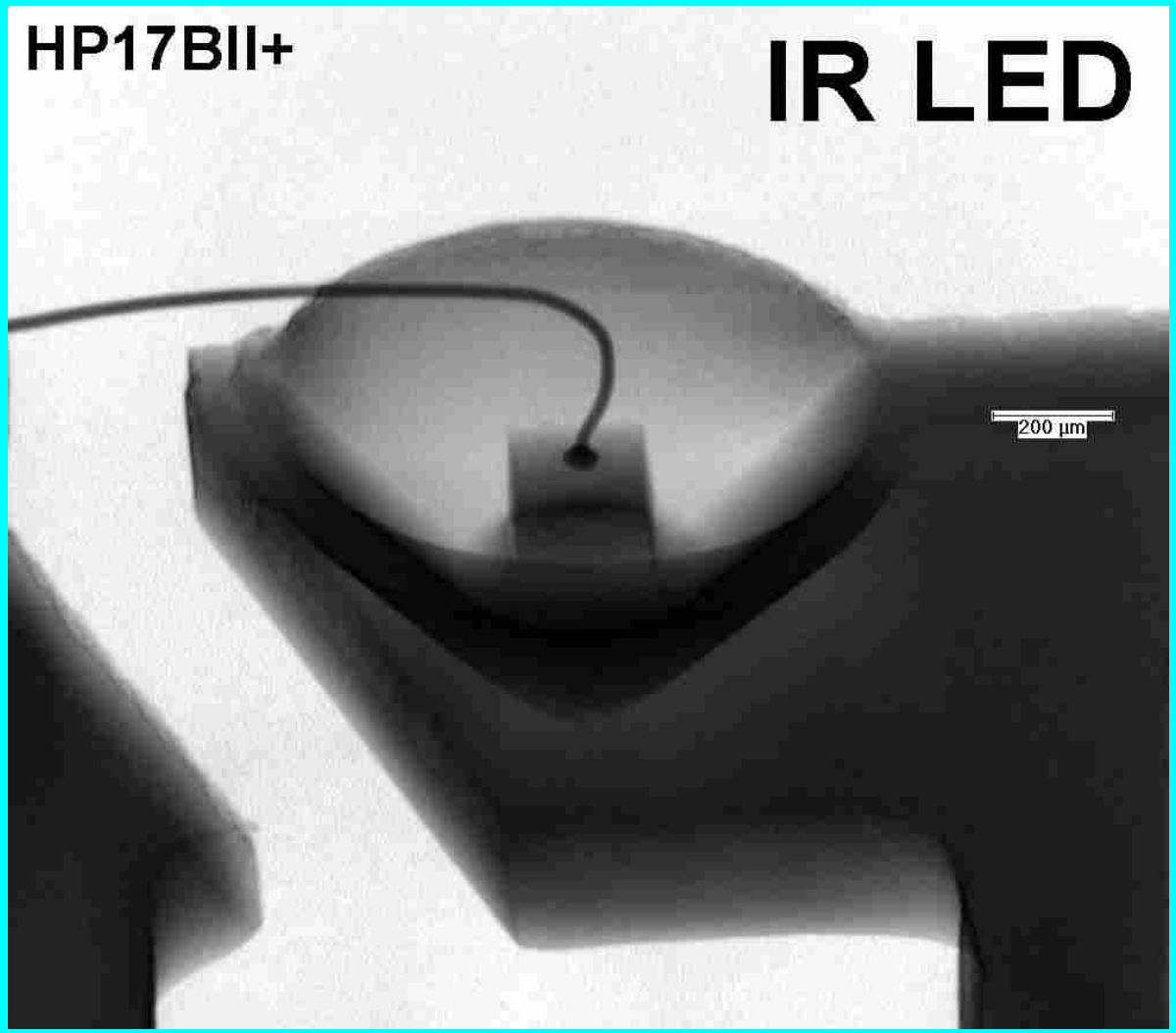
- The IR port cover is clearly visible.
- Note metal LED lead frame.
- The metal LCD display frame is the black area on bottom.

A8 – IR LED Magnified



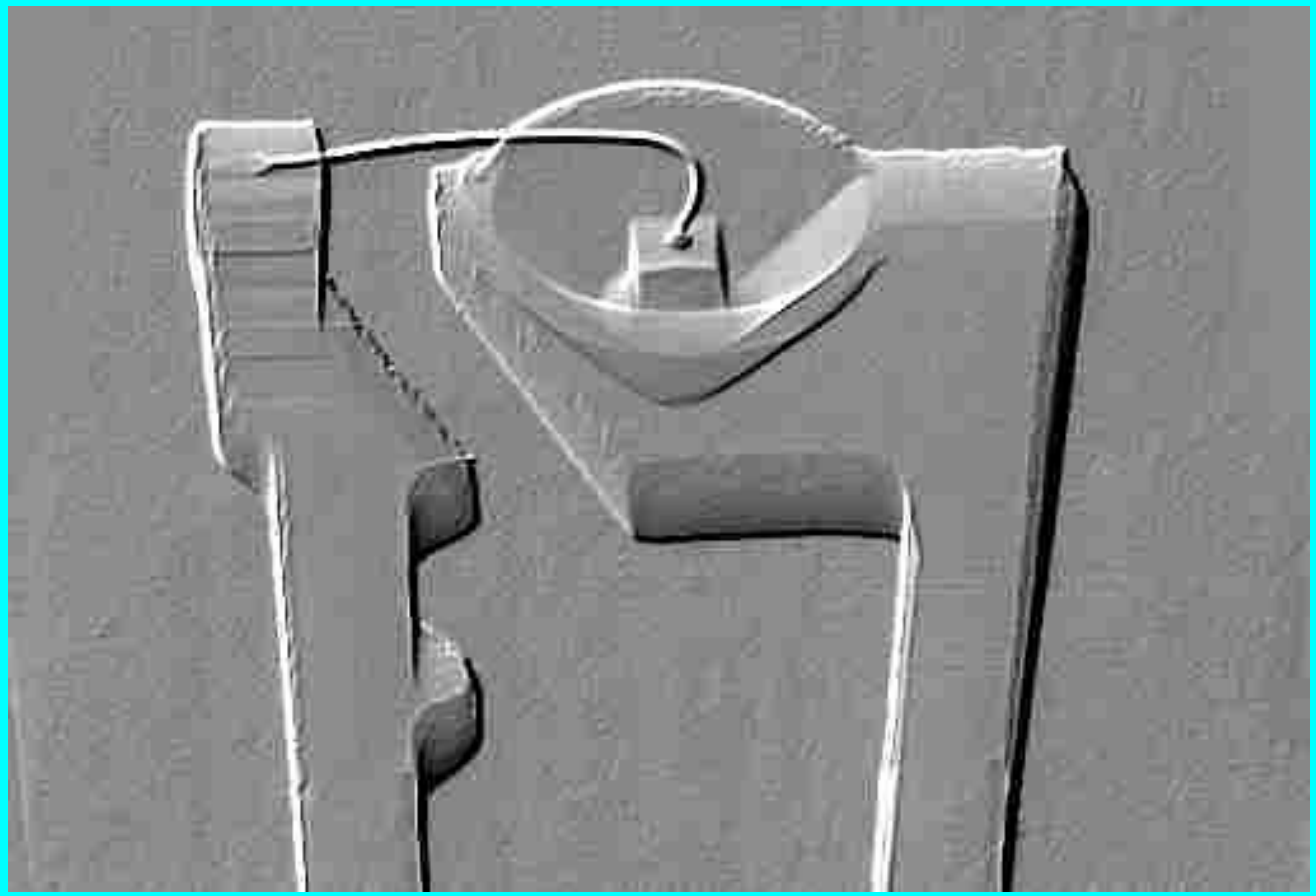
- LED die is clearly visible in metal reflector.

A8 – IR LED Tilted 45 Degrees



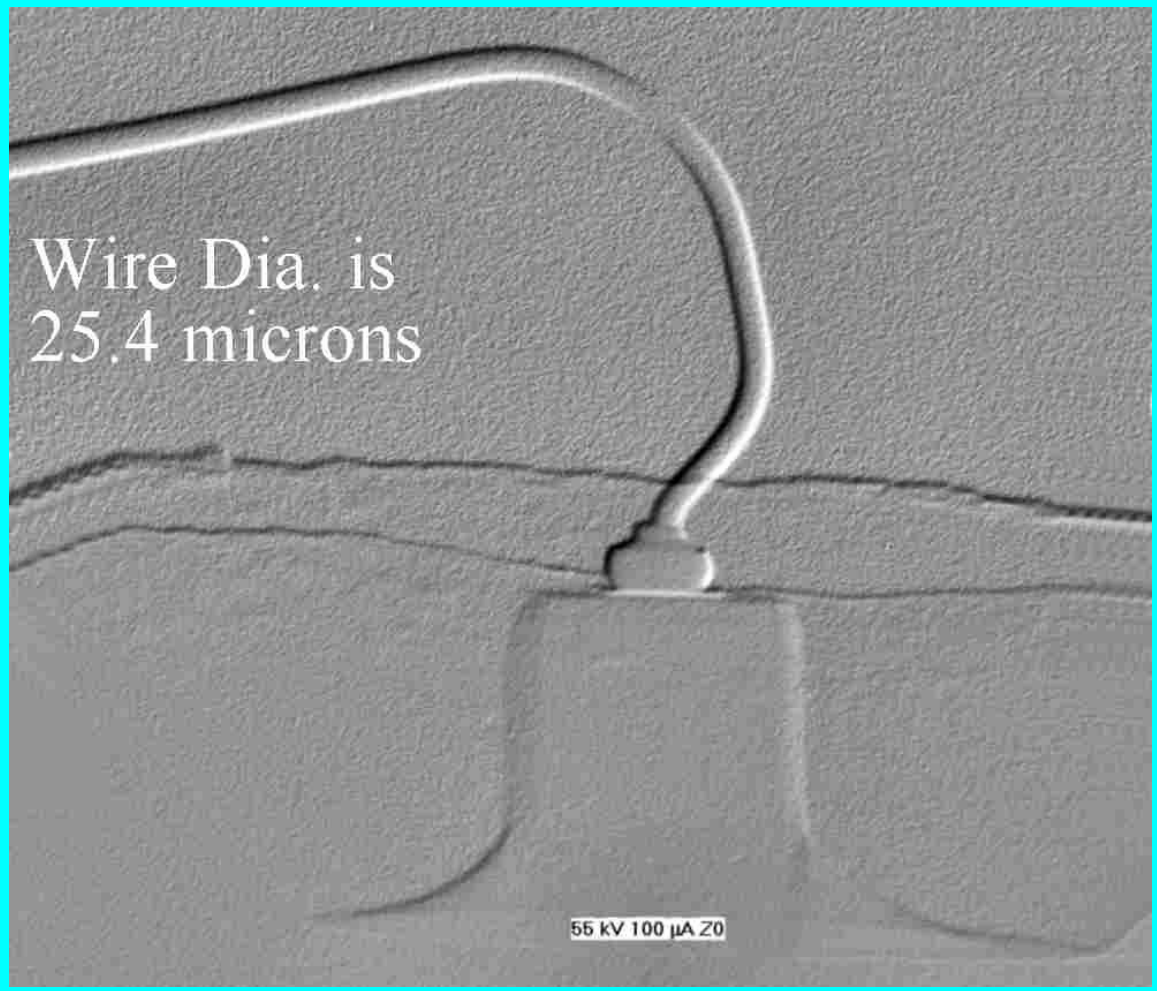
- The shape of the reflector may be seen with the die at the bottom. The scale is 200 microns.

A8 – IR LED Tilted 36 Degrees



- The greater-than-what-your-eye-can-see range of the 256 shades of gray may be post image processed to show the image in a pseudo-3D relief view.

A8 – IR LED At High Magnification



- The Photo Multiplier Detector provides enough magnification to examine the bond wire weld joint.[39]

How Clark Kent Sees An IR LED

Conclusion

- A high quality computer based PCB X-ray system utilizing an open x-ray tube is capable of 1 micron or less resolution and 1600X or more magnification.
- Such a system is suitable for failure analysis, engineering evaluation, inspection purposes and exploring calculators on a daily production basis.
- Since calculators are relatively thin devices with minimal “layers” of structure, a PCB X-ray system provides a great deal of information about the technical details of the machine without opening or disassembly of the machine.
- This is a very nice “tool” and it only costs $350,000.

Special Thanks

- To Brian Dearden of AMF for assistance and training in using the Phoenix PCB x-ray system.

- To David Lehmann of Phoenix|X-ray for encouragement, information, and training in using the Phoenix PCB x-ray system.

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The End

Riddle Answer?

You’re Getting Nothing From Me!