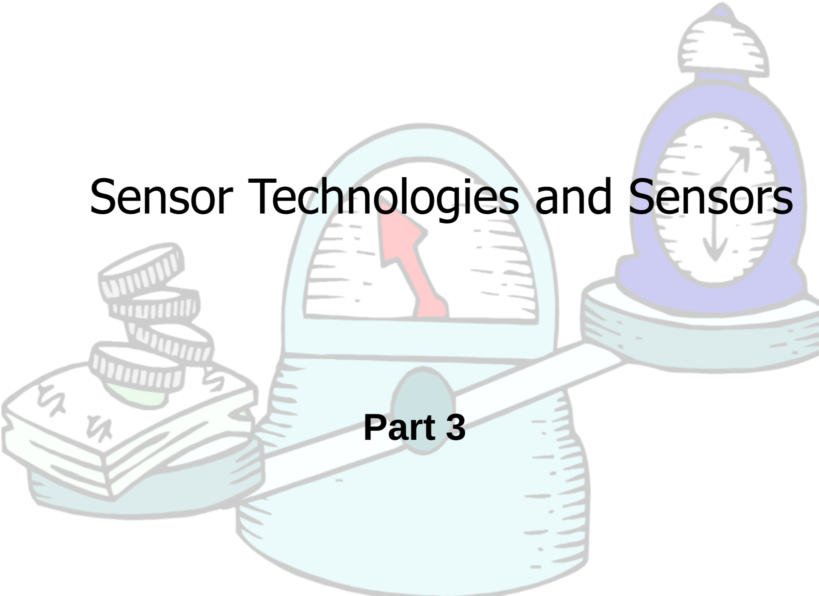
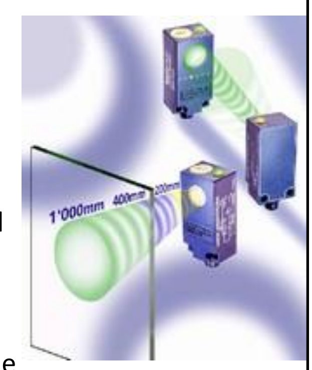
Sensor Technologies and Sensors



Part 3

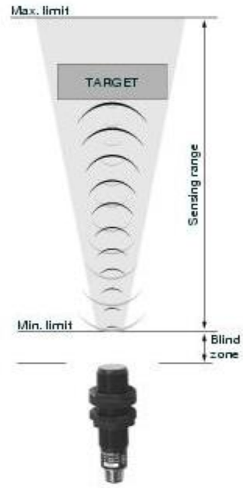
Ultrasonic transducers

- Ultrasonic devices are used for measuring fluid flow rates, liquid levels and translational displacements.
- Ultrasound is a band of frequencies in the range above 20 kHz up to 15 MHz, that is, above the sonic range that humans can usually hear.
- Measurement devices that use ultrasound consist of one device that transmits an ultrasound wave and another device that receives the wave
- Changes in the measured variable are determined either by measuring the change in time taken for the ultrasound wave to travel between the transmitter and receiver, or, alternatively, by measuring the change in phase or frequency of the transmitted wave.



Ultrasonic transducers

- The most common form of ultrasonic element is a piezoelectric crystal contained in a casing. Such elements can operate interchangeably as either a transmitter or receiver. These are available with operating frequencies that vary between 20 kHz and 15 MHz.
- As a piezoelectric crystal, , it generates an ultrasonic wave when an alternating voltage is applied.
- It also works in reverse. When it receives a sound wave, it generates an alternating voltage.



Ultrasonic transducers

- Ultrasonic devices are used in many fields of measurement, particularly for measuring fluid flow rates, liquid levels and translational displacements.
- Ultrasound is also used in medical imaging systems
- **Ultrasound is a band of frequencies in the range above 20 kHz, that is, above the sonic range that humans can usually hear and up to ~ 15 MHz.**
- Measurement devices that use ultrasound consist of one device that transmits an ultrasound wave and another device that receives the wave.
- Changes in the measured variable are determined either **by measuring the change in time taken for the ultrasound wave to travel between the transmitter and receiver, or**,
- **alternatively, by measuring the change in phase or frequency of the transmitted wave.**

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- Also capacitive ultrasonic elements exist. These consist of a thin, dielectric membrane between two conducting layers.
- The membrane is stretched across a backplate and a bias voltage is applied.
- When a varying voltage is applied to the element, it behaves as an ultrasonic transmitter and an ultrasound wave is produced.
- The system also works in the reverse direction as an ultrasonic receiver.
- Elements with resonant frequencies in the range between 30 kHz and 3MHz can be obtained.

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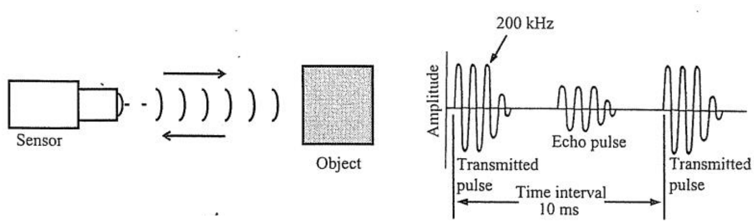
- Sound is transmitted through propagation of pressure in air
- Speed of sound in air is normally 331 m/sec at 0^{o}C and 343 m/sec at 20^{o}C for dry air
- Digital signal processor embedded in sensor calculates distance between sensor and object



| principle of a sonic distance sensor.

Table 13.1 Transmission speed of ultrasound through different media

Medium	*Velocity* (m/s)
Air	331.6
Water	1440
Wood (pine)	3320
Iron	5130
Rock (granite)	6000

- When transmitted through air,
  the speed of ultrasound is affected
  by environmental factors such as temperature, humidity and air turbulence.
  Of these, temperature has the largest effect. The velocity of sound through air varies with temperature according to:

$$V = 331.6 + 0.6T \text{ m/s} \qquad (13.2)$$

- where T is the temperature in °C. Thus, even for a relatively small temperature change of 20 degrees from 0°C to 20°C, the velocity changes from 331.6 m/s to 343.6 m/s.

Table 13.1 Transmission speed of ultrasound through different media

Medium	*Velocity* (m/s)
Air	331.6
Water	1440
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Other factors affecting Ultrasonic waves

- Humidity changes have a much smaller effect. If the relative humidity increases by 20%, the corresponding increase in the transmission velocity of ultrasound is 0.07% (corresponding to an increase from 331.6m/s to 331.8m/s at 0°C).
- Changes in air pressure itself have negligible effect on the velocity of ultrasound.
- Similarly, air turbulence normally has no effect (though note that air turbulence may deflect ultrasound waves away from their original direction of travel).
- However, if turbulence involves currents of air at different temperatures, then random changes in ultrasound velocity occur according to equation (13.2).

Ultrasound as Range Sensor

- $X = v_{sound} . t$
- Where:
  - V_{sound} is known
  - t = 0.5 (time of flight)
  - X is distance between sensor head and object
- Range of sensor varies between 5 cm to 20 m
- Sensor is not appropriate for very short distance measurements
- Frequency response (distance measurement update rate) varies with distance measured
  - In general, it is about 100 Hz

- An obvious difficulty in applying this equation is the variability of v with temperature .
- One solution to this problem is to include an extra ultrasonic transmitter/ receiver pair in the measurement system in which the two elements are positioned a known distance apart. This allows measurement of transmission time of energy between this fixed pair which provides compensation of temp effects

- Medical ultrasonic transducers (probes):
  - Come in variety of different shapes and sizes for use in making pictures of different parts of body
- Technology can be used for measuring:
  - wind speed and direction (anemometer),
  - speed through air or water
  - fullness of tank
  - amount of liquid in tank
    - sensor measures distance to surface of fluid.
- Other applications include:
  - in robots for obstacle avoidance
  - burglar alarms
  - non-destructive testing, and etc

wavelength, frequency and directionality of ultrasound waves

- The frequency and wavelength of ultrasound waves are related according to:

  $\lambda = v/f$
- where λ is the wavelength,
- v is the velocity and
- f is the frequency of the ultrasound waves.
- v is also affected by Humidity and temperature

Attenuation of ultrasound waves

- Ultrasound waves suffer attenuation in the amplitude of the transmitted energy according to the distance traveled.
- The amount of attenuation also depends on the nominal frequency of the ultrasound and the absorption characteristics of the medium through which it travels.
- The amplitude Xd of the ultrasound wave at a distance d from the emission point can be expressed as:

$$\frac{X_d}{X_0} = \frac{\sqrt{e^{-\alpha d}}}{fd}$$

-
- where X_0 is the magnitude of the energy at the point of emission, f is the nominal frequency of the ultrasound
- and α is the attenuation constant that depends on frequency, medium and pollution such as dust

Resolution and Accuracy

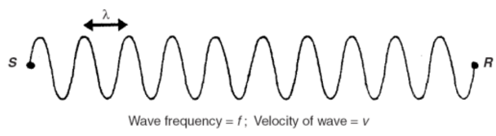
- Best resolution of ultrasonic ranging system is equal to wavelength of the transmitted wave

$$\lambda = v/f$$

- High frequency elements seem to be preferable since λ is smaller, but range is less for higher frequency due to higher attenuation of the wave as it travels from Tx to Rx
- Here frequency choice is a compromise between resolution and range.

Doppler shift effect in ultrasound / FYI/

- Doppler Effect is present in all types of wave motion
- It describes the apparent change in frequency of the wave when there is relative motion between Tx and Rx
- If a continuous ultrasound wave with speed v and frequency f takes t seconds to travel from Source "S" to Receiver "R" ➔ then R receives f.t cycles of sound during t



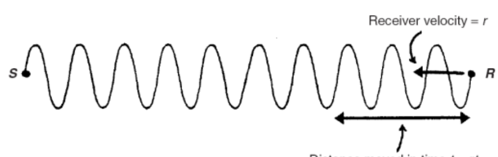
(a)

Doppler shift effect in ultrasound /FYI/

- Now, with R moving towards S at velocity r (S is still stationary) ➔ R will receive rt/λ extra cycles during time t (note r/λ=fnew) and total number of cycles in t is: **f.t+fnew.t**
- Apparent frequency f′ is defined as:

$$f' = \frac{ft + rt/\lambda}{t} = f + r/\lambda = f + \frac{rf}{v} = \frac{f(r+v)}{v}$$

- Frequency difference Δf=f′-f=f.r/v



(b)

- Velocity of the receiver r=v. Δf/f

/FYI/

- When R is moving a way from S with velocity r:

$$\Delta f = f' - f = \frac{f(v+r)}{v} - f = \frac{fr}{v}$$

$$r = v\Delta f / f.$$

$$f' = \frac{f(v-r)}{v}$$

$$\Delta f = -\frac{fr}{v}$$

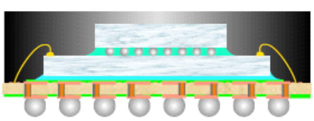
Ultrasonic Imaging

- The main applications of ultrasound in imaging are found in medical diagnosis and in industrial testing procedures.
- In both of these applications, a short burst of ultrasonic energy is transmitted from the ultrasonic element into the medium being investigated and the energy that is reflected back into the element is analyzed.
- Ultrasound is reflected back at all interfaces between different materials, with the proportion of energy reflected being a function of the materials either side of the interface.
- The principal components inside a human body are water, fat, muscle and bone, and the interfaces between each of these have different reflectance characteristics.
- Measurement of the time between energy transmission and receipt of the reflected signal gives the depth of the interface.

- Therefore, in medical diagnosis procedures:
- 1) the reflected energy appears as a series of peaks, with the magnitude of each peak corresponding to the type of interface that it is reflected from
- 2) The time of each peak corresponding to the depth of the interface in the body.
- 3) Thus, a ‘map’ of fat, muscle and bone in the body is obtained. A fuller account can be found elsewhere (Webster, 1998).
- Applications in industrial test procedures usually involve detecting internal flaws (defects) within components.
- Such flaws cause an interface between air and the material that the component is made of.
- By timing the reflections of ultrasound from the flaw, the depth of each flaw is determined.

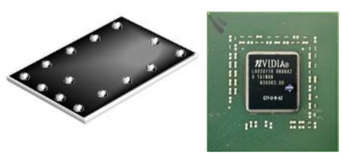
Identifications of Solder Bump Defects in Chip Packages

Examples of Emerging Microelectronic Packages:

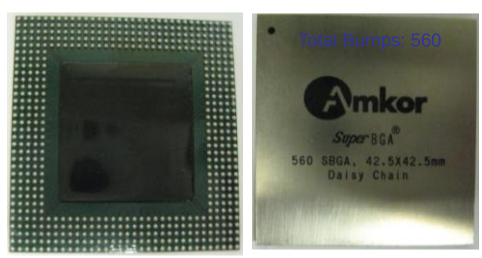

3-D Packaging: Stacked Die


Chip Scale Package


Quad Flat Package (QFP)

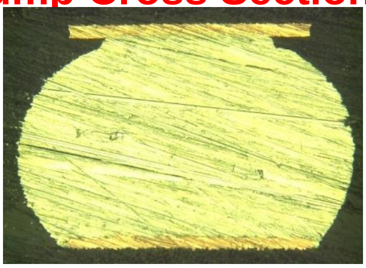

Flip Chip

Ball Grid Array (BGA)

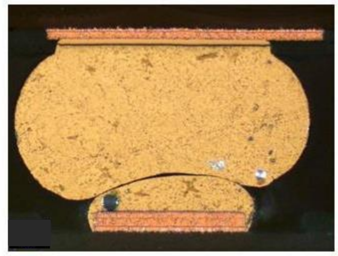


Amkor Super BGA

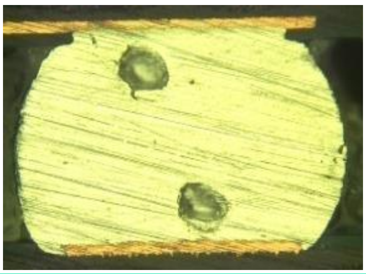
Optical Micrographs of Good and Bad Solder Bump Cross Sections



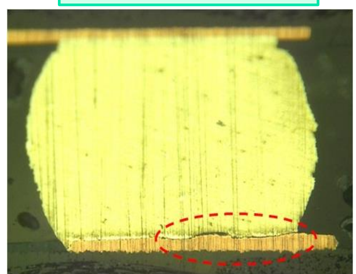
Good Solder Bump



Head-in-Pillow defects

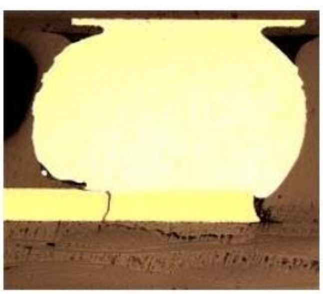


Two medium size voids near the interface

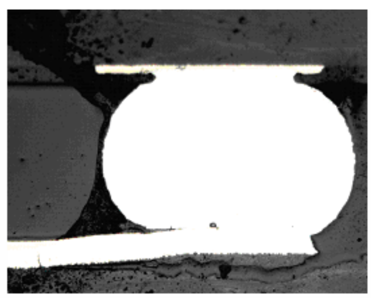


Poor wetting, an intermittent connection

Optical micrographs of Good and Bad Solder Bump Cross Sections



Pad crater with crack initiating at the trace



Crack initiates at the edge of the pad

Inspection of solder bumps is crucial process in microelectronics manufacturing industry.

Laser Ultrasound Inspection (LUI) System

3 US Patents Have Been Issued & 2 Pending

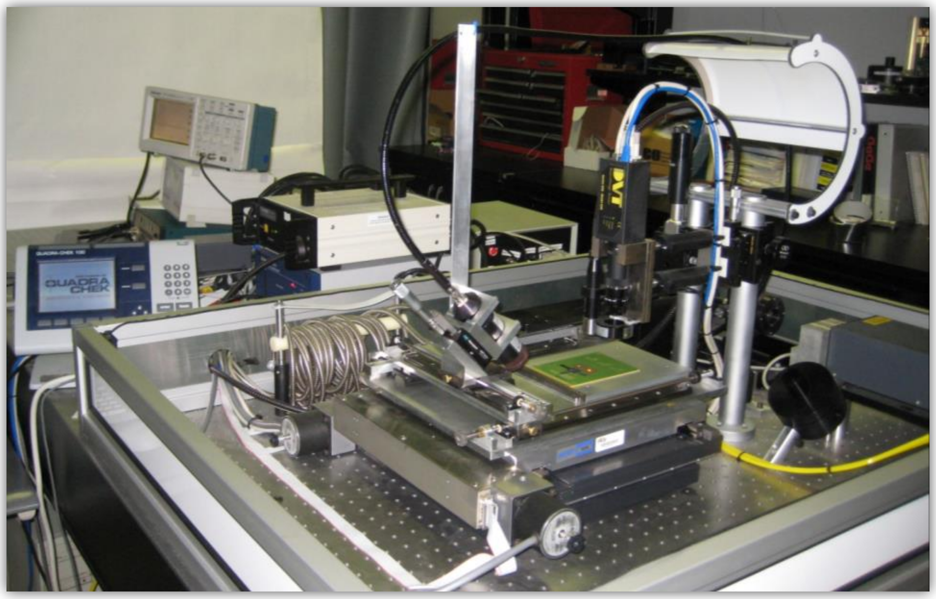


Photo Interrupt

- Uses emitter and detector photo diode pair
- With no obstruction detector is high
- When an object blocks the light the detector is low
- Advantages
  - Simple to interface
  - Inexpensive
  - Reliable

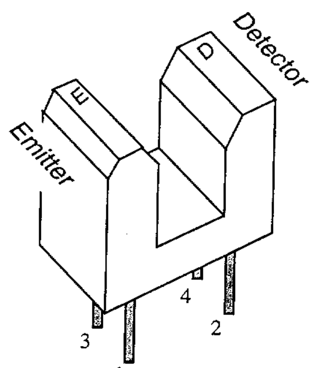


Photo Interrupt
Types

- Wide variety of packages and orientations
- Types
  - Logic (digital ±5 volts)
  - Transistor/diode (analog)
- Manufacturers
  - Fairchild
  - Honeywell

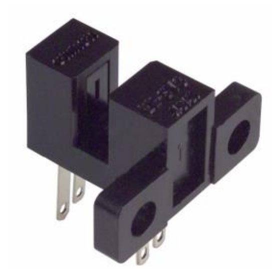
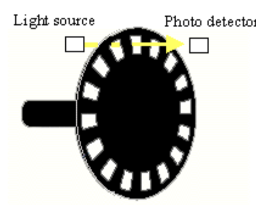
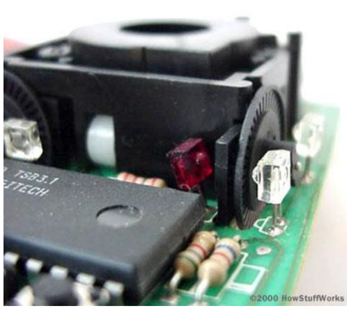


Photo Interrupt
Applications

- Encoder wheel for angular measurements.
- Computer mouse with a ball





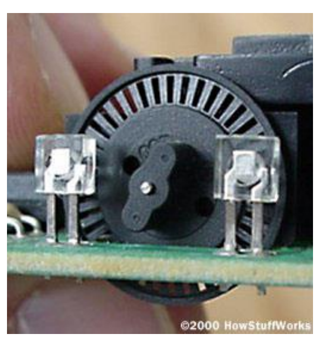
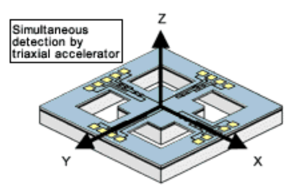


Photo Interrupt
Applications

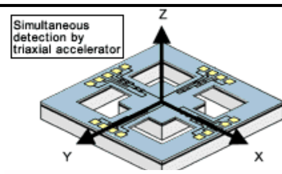
- Detect holes or slots for positioning as in elevators
- Detect the location of products on and assembly line

Accelerometers

- Used to measure acceleration
  - Common SI units meters/second2 (m/s2) or popularly in terms of g-force (1 g is earth's gravity)
- At rest an acceleration will measure 1 g in the vertical direction
- They can come in 1, 2 or 3 axis configurations
  - With 3 axis it gives a vector of the accelerations direction (after accounting for gravity)



Accelerometers



- Because of earth's gravity, the sensor will read 1 to 0 g as the sensor is rotated from being vertical to horizontal.
  - This can be used to measure angle the of tilt
- Each sensor has a range that it works in.
- Most have analog outputs that need amplification
  - Some have built-in amplifiers for direct connection into microcontroller

Accelerometers
Applications

- Can be used to sense orientation, vibration and shocks.
- Used in electronics like the Wii and iPhone for user input.
- Acceleration integrated once gives velocity, integrated a second time gives position.
  - The integration process is not precise and introduces error into the velocity and position.