
BiTS
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Interconnect Sockets and Applications

Ashok Kabadi – AK Technology Leadership
Yoinjun Shi – Twinsolution Technology

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Shanghai
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Agenda

1. **Introduction and Background**
   - Second-Level-Interconnect definition
   - Purpose of interconnect sockets
   - Benefits of sockets

2. **Contact Element**
   - Single-compression Vs Dual-compression
   - Contact resistance theory
   - Examples of calculating resistances
   - Relationship between contact load, contact travel and contact resistance

Agenda

3. Types of Contacts

- Polymer-based
  - Metallized and wire-type
- Particle Interconnect
- Metal-based
  - Spring-loaded
  - Stamped-and-formed
  - Particle and Wire-type
  - Screw-machine
  - MEMS–based
  - Buckling
- Summary

Agenda

4. Contact Element Material

- Contact material requirement
- Types of material and plating
- Contact material selection

5. Printed-Circuit-Board and Hardware Requirements

- Surface finish requirement
- Mechanical tolerances (positional and absolute)
- Keep-Out-Zones (KOZ)

Agenda

6. Electrical Characterization: Signal-Integrity (SI)

- Insertion loss
- Cross-talk
- Current carrying capacity (CCC)
- Impedance (capacitance and inductance)

7. Interconnect Socket and System Design

- Types of interconnect system
- Mechanical hardware design and tolerances
- Force-deflection analysis

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8. Socket Interconnect System Testing

- Daisy-chain packages and CRES test board
- Electrical - Test fixture example
- System qualification -- Environmental test

9. Real-world Examples and Summary of Technologies

10. Design Process Flow and Check-list

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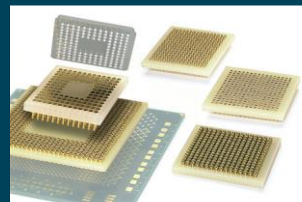
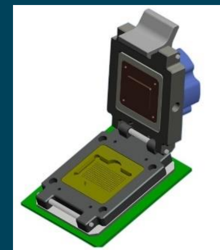
Section 1
Introduction and Background

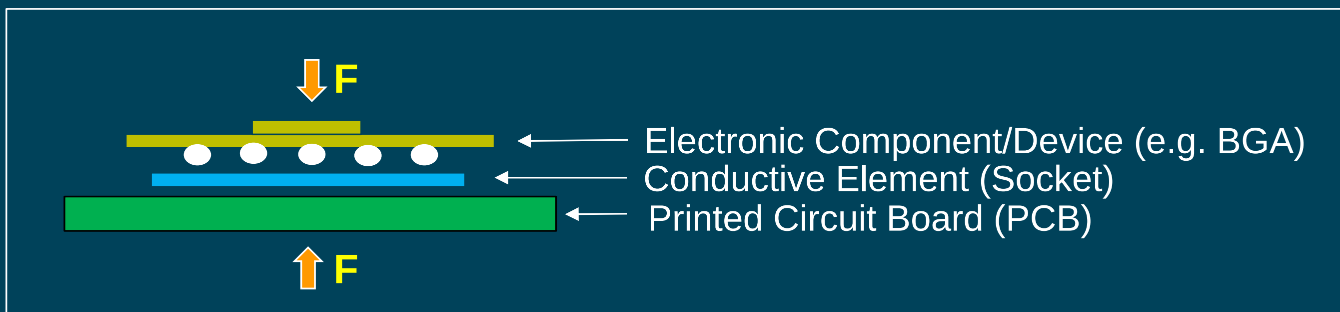
Interconnect Socket Definition

- An electrically conductive interface element placed between an electronic component and a printed-circuit-board to make reliable interconnection between the device and PCB



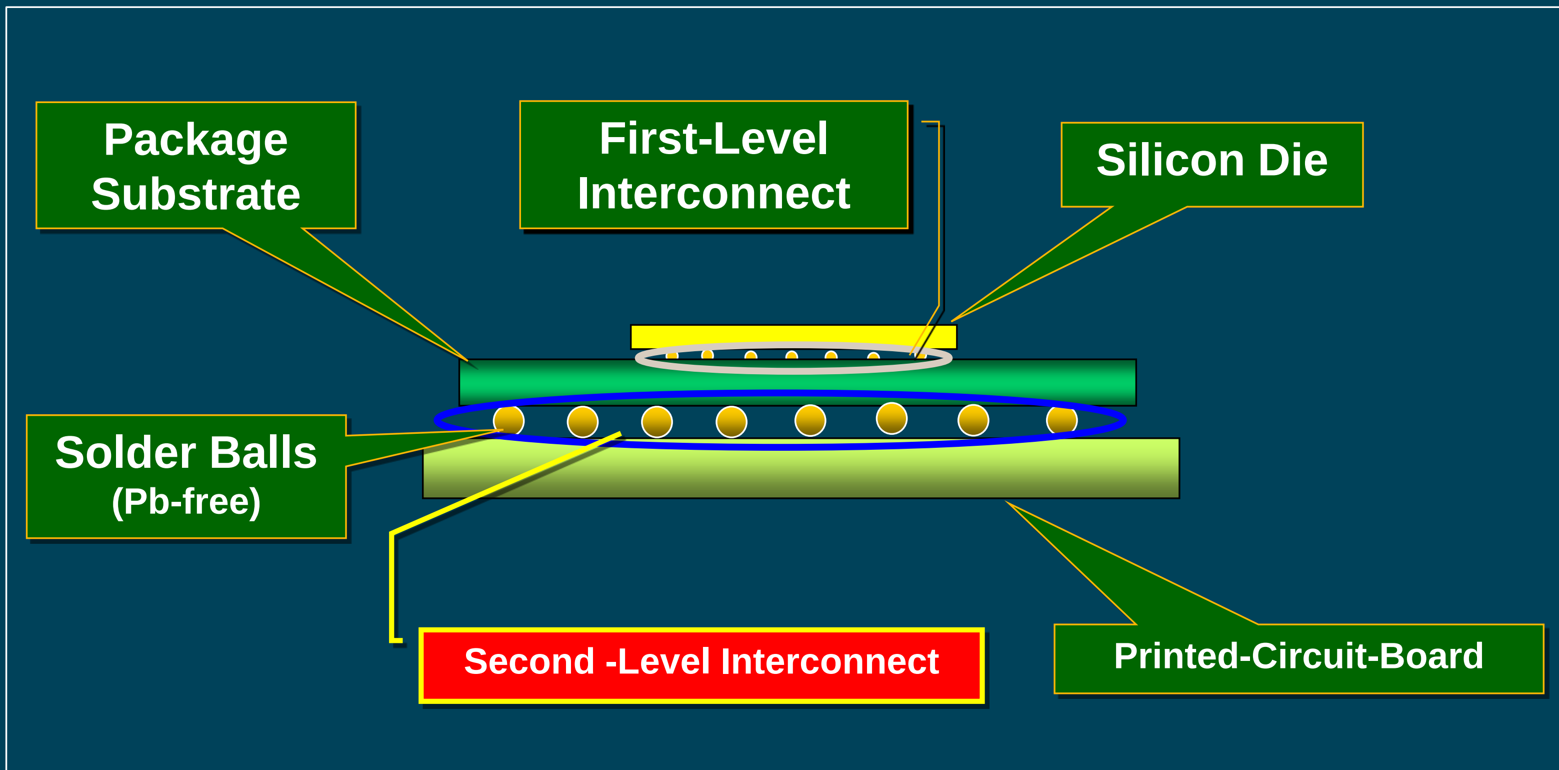



Examples of Interconnect Sockets

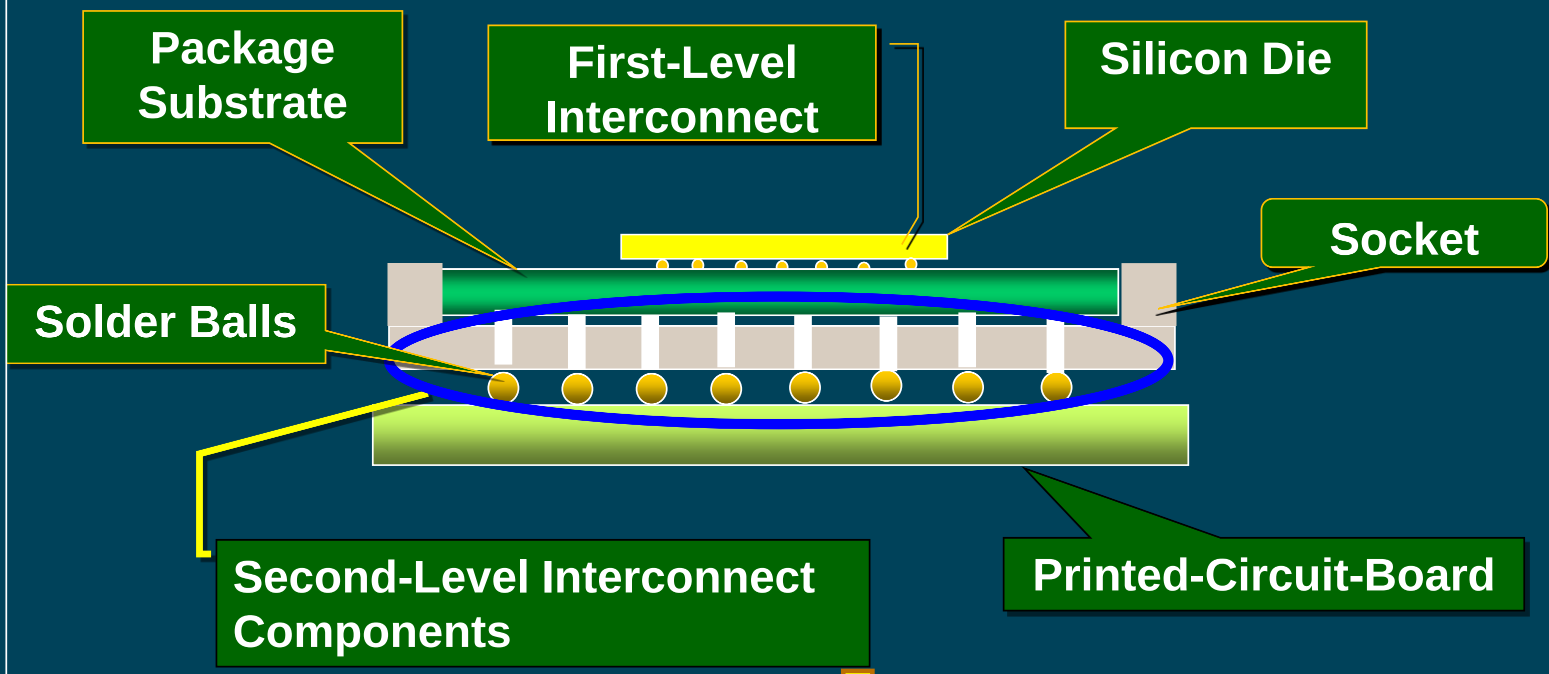


Interconnect Socket Schematic

What is Second-Level-Interconnect (SLI)



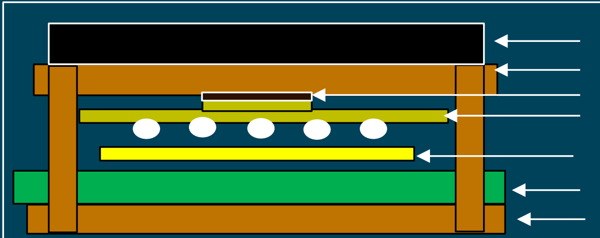
What is Second-Level-Interconnect (SLI)



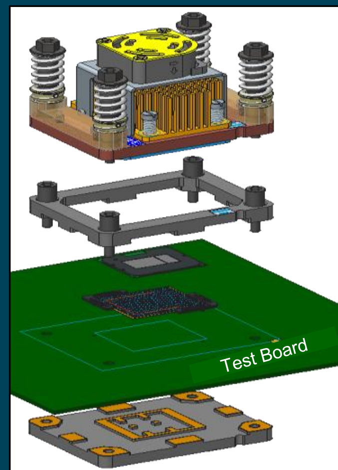
- ❑ **Package substrate**
- ❑ **Package to socket to PCB interconnect system**
- ❑ **PCB** fab

Interconnect System

- Interconnect system solution
  - The Interconnect System is comprised of a conductive socket element and a mechanical hardware system
  - The design of the mechanical hardware is dependent on the type of socket and mechanical properties of the socket



Interconnect Socketing System Schematic



Example of Interconnect Socketing System

Types and Benefits of Sockets

- Test and Burn-in sockets
  - Testing multiple devices using the same socket attached to the same PCB -- cannot be done if the device is soldered
  - Test sockets -- Typically ordered in low volume quantities and require short insertion times
  - Burn-in sockets – Typically ordered in high volume quantities and require high insertion times

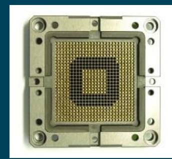
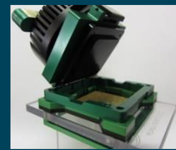
- Validation sockets
  - Used during the first power-on of the new silicon
  - Validation of multiple packaged silicon devices using the same socket attached to same PCB – cannot be done if the device is soldered

Types and Benefits of Sockets

- Validation sockets (Cont'd.)
  - Same socket used during subsequent silicon stepping changes
  - These sockets are typically ordered in medium volume and requires medium number of insertion/removal cycles
- Production sockets for final products
  - Allows PCBs assembled ahead of the first silicon arrival – sockets are typically soldered to PCB
  - Require low number of insertion/removal cycles but are ordered in high volume quantity
  - Low cost/unit
  - High tooling cost

Examples of Different Types of Sockets

- ❑ Test & Burn-in sockets
  - Test: Typically uses machined pogo pins
  - Burn-In: Typically uses stamped-and-formed pins

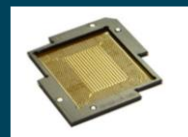



Test Socket


Burn-in Socket

- ❑ Validation sockets
  - Typically uses elastomeric contact or stamped spring pins

Elastomeric



Validation Socket

- ❑ Production sockets
  - Typically uses stamped-and-formed pins


Production Socket

Comparison of Requirements on Test and Burn-in Sockets

Characteristic	Test socket	Burn-in socket
Insertions	100K to 1Million	10,000 Typical
Electrical	High frequency Low inductance (<3nH)	Low frequency High inductance (5 to 13nH)
Production method (housing)	Machined	Injection Mold
Contact technology	Pogo, Particle Interconnect, Fuzz button	Stamped and formed BeCu spring contact
Device insertion times	3 seconds to 5 minutes	8 hours to 1,000 hours
DUT board type	Surface-mount	Through-hole
Typical order size	1 to 100 Sockets	300 to 20K sockets
Typical cost （Each）	$1,000-$6,000	$4~$200
Market Size	$80M~$100M	$250M~$300M

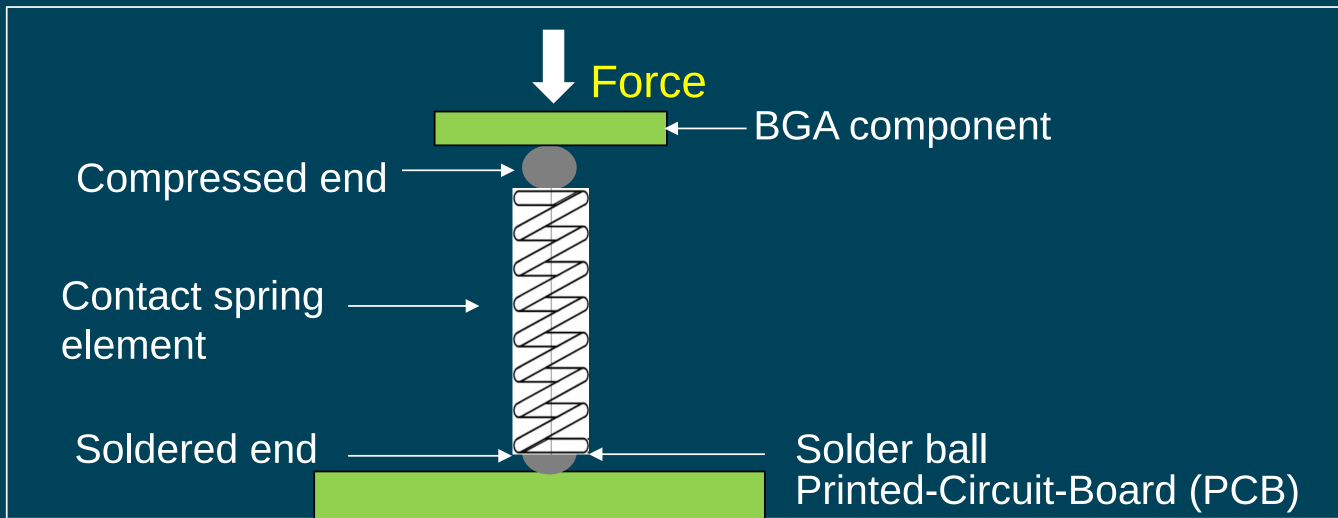
Section 2

Contact Element Fundamentals

Single-compression Socket

Definition:

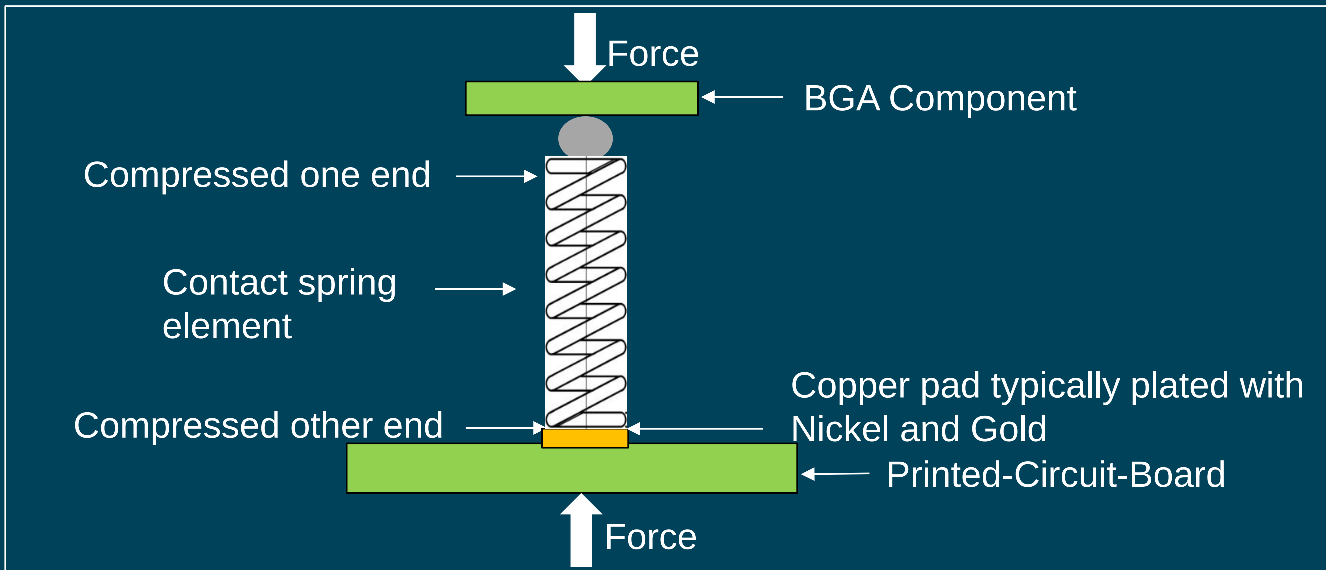
Socket is defined as a single-compression socket when the contact element is soldered to the surface of one device (typically of a PCB) and compressed at the other end where it interfaces with the second device (typically a BGA component)



Dual-compression Socket

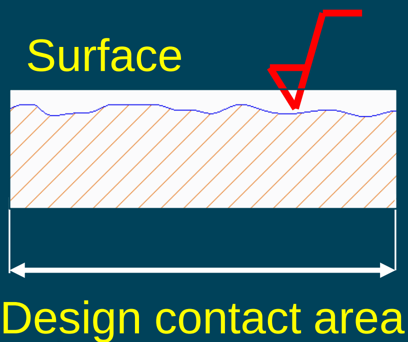
Definition:

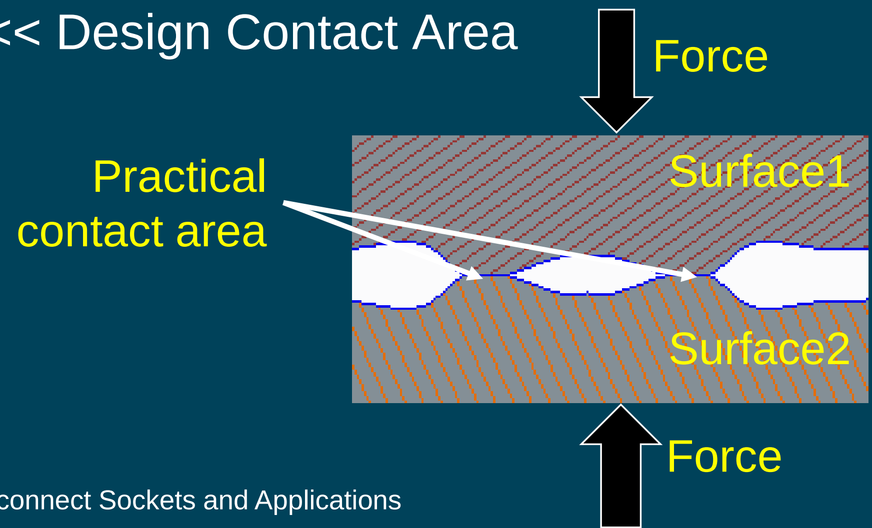
Socket is defined as a dual-compression socket when the contact element is compressed between the two surfaces to make electrical connection. These surfaces are typically BGA device at one end and PCB at other end



Contact Resistance Theory

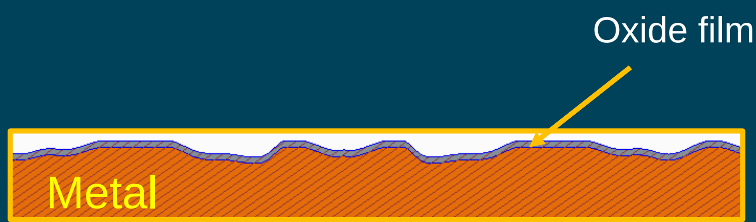
- Contact resistance occurs between
  - Interconnect pin surface and PCB pad surface
  - Interconnect pin surface and solder ball surface
- Higher contact resistance results in thermal and electrical losses
- Practical surfaces have surface roughness due to manufacturing operations
- Practical Contact Area << Design Contact Area

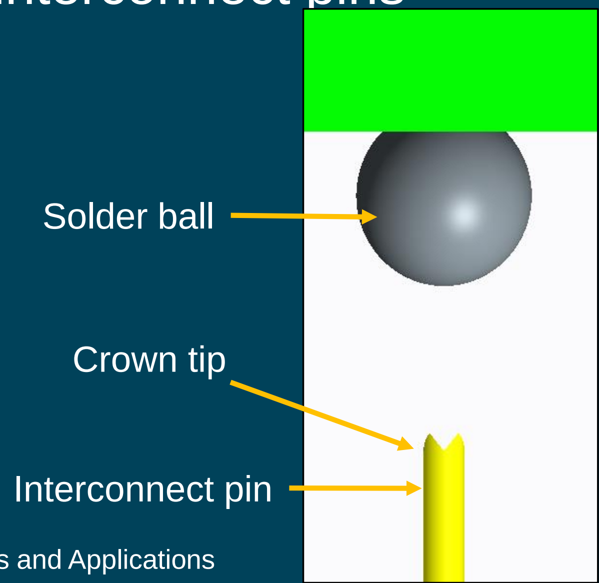




Contact Resistance Theory (Cont'd.)

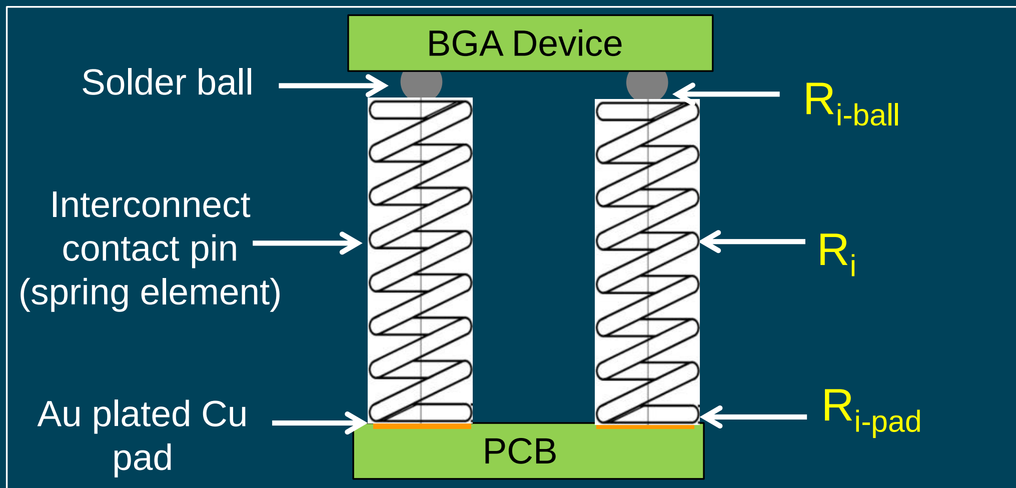
- Thin film forms on metal surfaces (Cu, W, Ag, SAC 305 etc) due to oxidation
- Interconnect pin wiping action is used to break oxide film lowering contact resistance
- Interconnect pin punctures into oxide film lowering contact resistance for vertical interconnect pins





Contact Resistance Theory (Cont'd.)

- Total Contact Resistance = $R_{i\text{-}ball} + R_i + R_{i\text{-}pad}$
  - $R_{i\text{-}ball}$: Contact resistance between interconnect contact pin and solder ball
  - R_i: Bulk resistance of interconnect contact pin
  - $R_{i\text{-}pad}$: Contact resistance between interconnect contact pin and PCB pad



Contact Resistance Theory: Bulk Resistance

- Bulk Resistance $R_i = \frac{\rho L}{A}$
  - ρ: Resistivity of the interconnect material (Ω-m)
  - L: Length of the interconnect (m)
  - A: Cross-sectional area of interconnect (m^2)

Material	Resistivity(Ω-m) at 20°C	Bulk Resistance (mΩ) at 20°C
Copper	1.68×10^{-8}	2.05
Silver	1.59×10^{-8}	1.94
Gold	2.44×10^{-8}	2.98
Tungsten	5.6×10^{-8}	6.84
Stainless Steel	69×10^{-8}	84.34

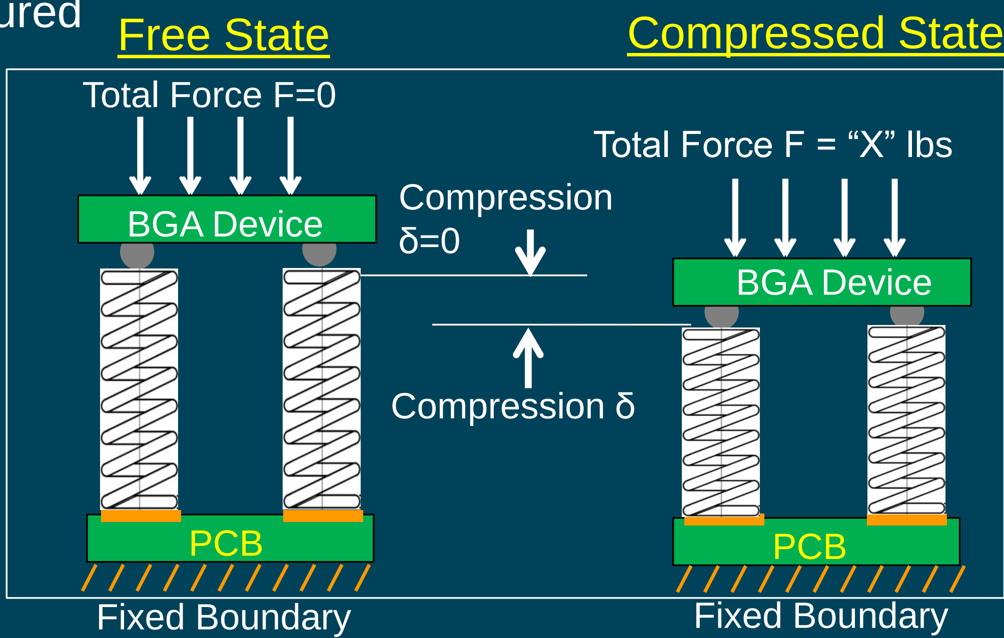
Assumption:

Length of interconnect = 6 mm
Diameter of interconnect = 0.25 mm

For Copper pin of length 6mm and diameter of 0.25mm, bulk resistance (R_i) is very much smaller than the total contact resistance ($R_{i\text{-}ball} + R_{i\text{-}pad}$)

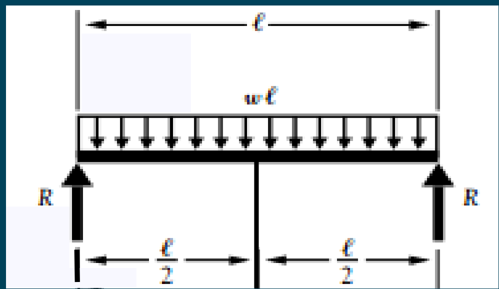
Contact Resistance: Relationship with Force

- ❑ Linear or non-linear behavior of Force/Load and Compression relationship
  - Analyzed using Finite Element Analysis (FEA) and experimentally validated
- ❑ Total Resistance and Force/Load relationship is experimentally measured



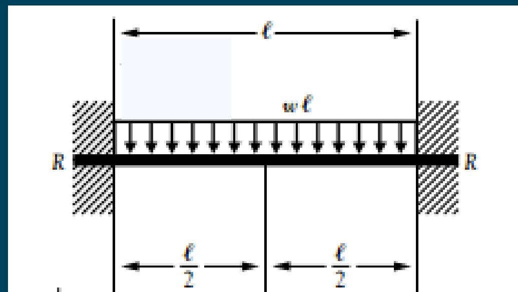
Force-Deflection of Beam-- Fundamentals

Simply Supported Beam
Uniformly Distributed Load



$\mathcal{R} = w*l/2$
Max. deflection (center) = $5wl^4 / 384\, \mathcal{E}\, I$
$\mathcal{E}$ = Young's Modulus of beam material
I = Moment of Inertia of the beam

Beam Fixed at Both Ends
Uniformly Distributed Load



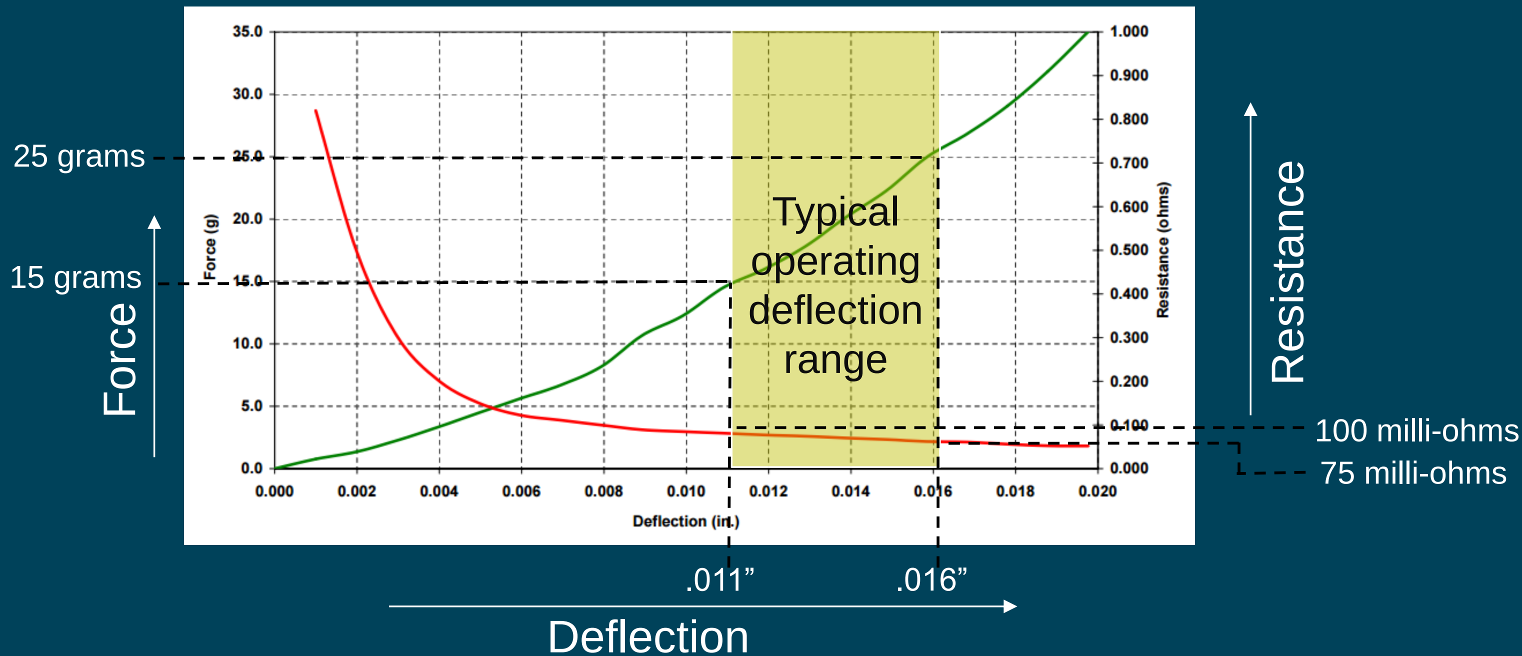
$\mathcal{R} = w*l/2$
Max. deflection (center) = $wl^4/384\, \mathcal{E}\, I$
$\mathcal{E}$ = Young's Modulus of beam material
I = Moment of Inertia of the beam

l = length of the beam
w = unit load
$\mathcal{R}$ = Reaction force

The maximum deflection of the PCB due to socket load can be approximated using one of the formulae above

Contact Resistance – Relationship with Force and Deflection

Typical Force-Deflection and Resistance-Deflection Curve of Socket Contact



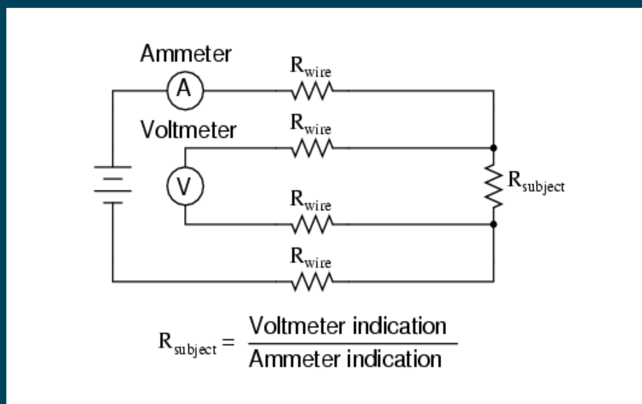
Contact Element Characterization

- Important to characterize contact element performance prior to building an array/socket
  - Typically performed by building a small coupon with 1-4 contact elements
- Mechanical characterization includes
  - Force Vs Compression at room & at high temperature (>100ºC)
  - Maximum force/compression to yield/set
  - Number of cycles to failure (material yielding, tip plating wear, etc)
- Electrical characteristics include
  - Total resistance of contact element at room and at high temperature (>100ºC)
  - Current carrying capability at room and at high temperature (>100ºC)

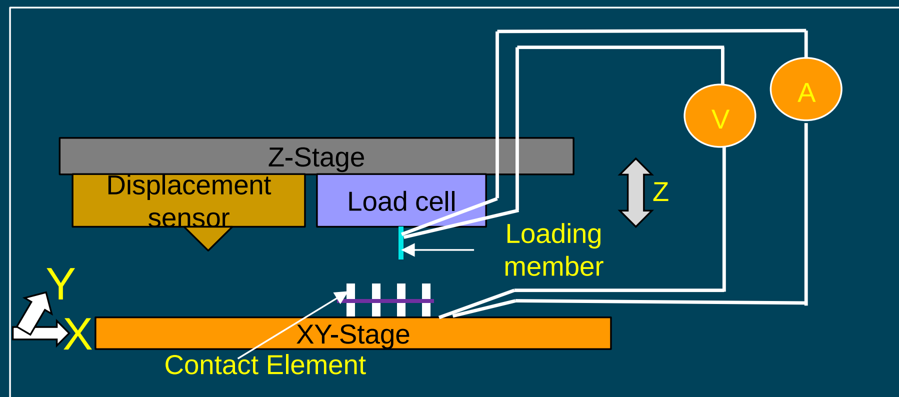
Contact Element Characterization: Experimental Setup

- ❑ Total resistance is measured using 4-wire setup
  - Removing path resistance
- ❑ Setup is used to measure current carrying capability of contact element

4-wire measurement circuit



Typical Set-up



Section 3
Types of Contacts

Polymer-based Contacts

Two types of Contacts:

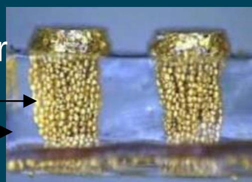
1. Polymer with conductive metal
2. Polymer with embedded metal spring element

1. <u>Polymer with conductive metal</u>

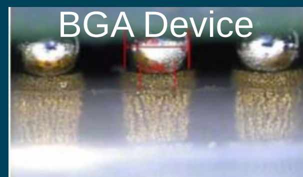
<u>Description:</u>

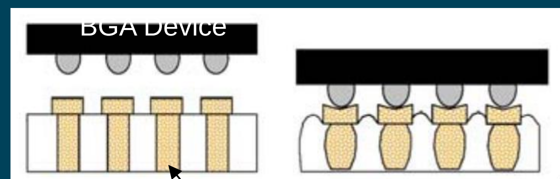
-- Polymer (silicone rubber) filled with conductive powder (Ag or Au)

Metal powder (Ag or Au)
Polymer



Courtesy: ISC





Polymer conductive contacts

<u>Primary advantages:</u>

- No ball damage
- Dual-compression solderless system
- Socket can be easily replaced if damaged
- Custom and mixed pitch
- Excellent electrical characteristics
- Can be scaled down to <0.4mm

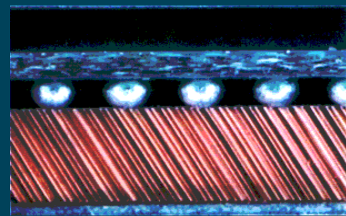
Polymer-based Contacts (Cont'd.)

1. Polymer with conductive metal

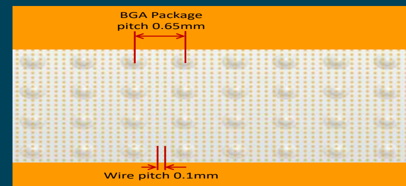
Shin-poly technology

Description:

- A Matrix of vertical wires suspended in a non conductive polymer.
- Suspended in 2 configurations, GB (vertical wires) and MT (angled wires).
- Both with wire pitches as small as .03 mm. (approx. 1mil)

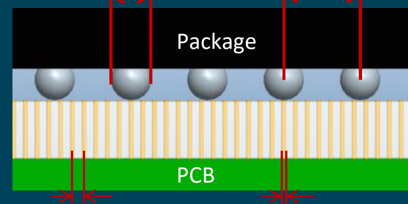


MT Matrix



compression of polymer showing number of wires connecting per BGA

Courtesy: Shin-Etsu Polymer



Schematic of stack-up

Primary Advantages:

- No ball damage
- Socket can be easily replaced if damaged
- Dual-compression solderless system
- Extremely Low Height
- Custom and mixed pitch
- Excellent electrical characteristics
- Can be scaled down to <0.4mm

Polymer-based Contacts (Cont'd.)

1. Polymer with conductive metal INVISIPIN® technology

Description:

- ❑ Manufactured by R & D Altanova, Inc
- ❑ Solderable, individual conductive elastomer pin
- ❑ Pick and place / solder reflow compatible
- ❑ Infinitely configurable

Single contact

Primary advantages:

- No ball damage
- Individual contacts can be easily replaced if damaged
- Dual-compression solderless or soldered system
- Extremely Low Height
- Custom and mixed pitch
- Excellent electrical characteristics
- Can be scaled down to 0.4mm

Courtesy: R&D Altanova, Inc.

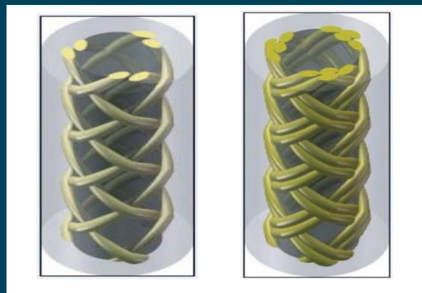
Polymer-based Contacts (Cont'd.)

2. Polymer with metal spring element:

Description:

❑ Continuous wire spring structure supported by elastomer

Courtesy: HCD



6-wire spring 12-wire spring

Primary advantages:

- Drop in replacement for pogo pins
- Consistent resistance values
- Dual compression solderless system
- Custom and mixed pitch
- Can be scaled down to 0.4mm pitch
- Higher cycle life than metal-filled polymers

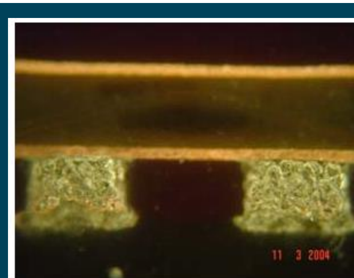
Particle Interconnect

<u>Description:</u>

- ❑ Uses sharp, metallized, particles which have been screened by size.
- ❑ Attached onto contact pads on the surface of conductor using standard masking and electroplating processes.
- ❑ The sharp, embedded particles create a conductive "micro bed-of-nails" that makes many parallel electrical paths by penetrating through any oxide without requiring a wiping action as conventional contacts.

Courtesy: PITek.US

Close-up of Particle Interconnect pads shows controlled stacking of particles to a desired height with clearance between individual particles.



Courtesy: PITek.US

<u>Primary advantages:</u>

- Extremely Low Height
- Custom and mixed pitch
- Excellent electrical characteristics
- Can be scaled down to <0.4mm

Fuzz Buttons®

Description:

- ❑ Contacts are manufactured from a long strand of highly specialized very fine wire
- ❑ The most common wire materials used are either a Gold-plated Beryllium Copper alloy (Au/BeCu) or a Gold-plated Molybdenum (Au/Mo).
- ❑ Au/BeCu offers the lowest signal distortion levels and high mating cycle repeatability
- ❑ Au/Mo is utilized because of its high level of structural stability at temperature extreme

Courtesy: Custom Interconnects

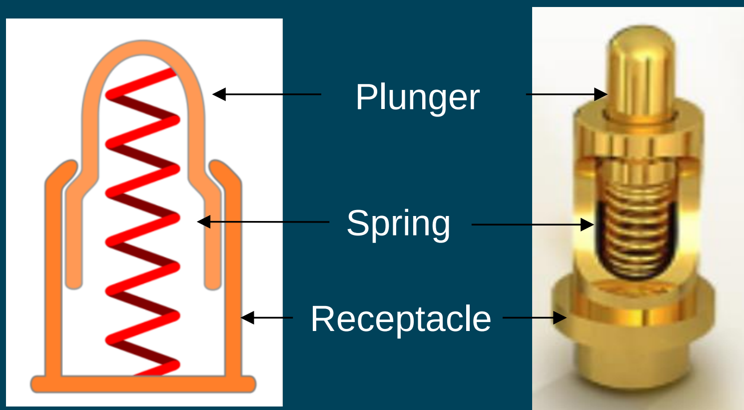
Primary advantages:

- Can be scaled down to 0.4mm pitch
- High current carrying capability
- High cycle life
- Excellent electrical characteristics
- Extreme operating range – (-60°C to 150°C)
- Various diameter and length wires available depending on the application

Spring Pins (machined)

Description:

- ❑ Spring-loaded contact (typically known as pogo-pin) is a device used to establish electrical interconnection between two surfaces. These surfaces could be pads of the printed-circuit boards or solder balls of BGA devices



Typical Plunger Shape Types

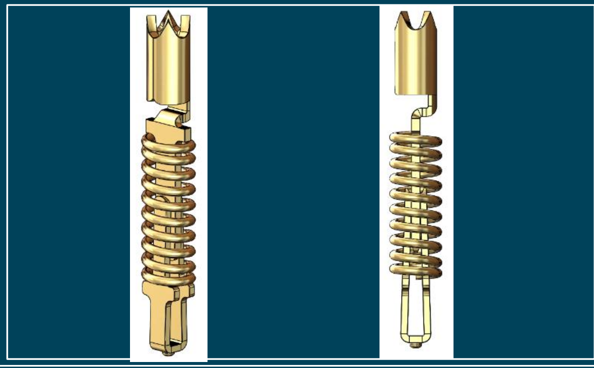
Primary advantages:

- High cycle life
- Consistent resistance value and reliable interconnection
- Can be scaled down to 0.4 and less
- Can withstand higher temperatures

Spring Pin (stamped)

Description:

- ❑ Piece parts are made using stamping process
- ❑ Spring probe pins are assembled using automated machine



Courtesy: IWIN Co. Limited

Primary advantages:

- Short length possible, 0.8mm, good for extremely high speed application
- Small diameter possible, good for finer pitch, 0.15 mm pitch
- Easier for mass production as parts are made by stamping
- High working range, 0.8mm traveling in 3.3 mm length
- Low cost

Stamped-and-Formed Contacts

Description:

- ❑ Made from reels of flat stock material
- ❑ Strips run through stamping and forming die to form socket contacts
- ❑ Contacts are electro-plated and inserted into the housing

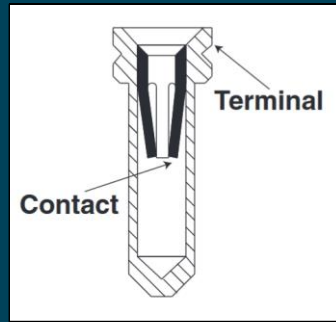
cLGA®
Dual-compression contact
Courtesy: Amphenol InterCon Systems

LGA CPU socket contact
Inside the plastic housing

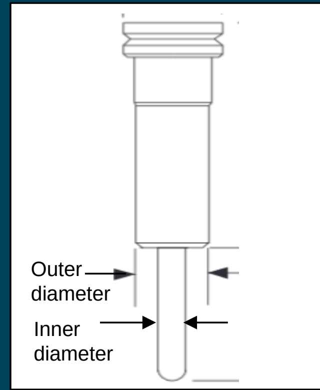
Primary advantages:

- Low-cost
- High-volume application
- Can be single-compression or dual-compression socket
- Applications include production sockets, crimped contacts, etc.

Pin and Socket Contacts



Female Receptacle



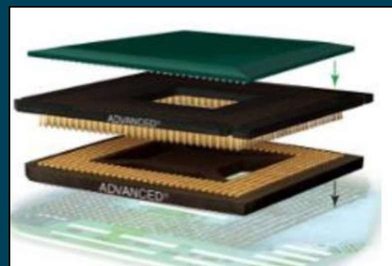
Male Header

Description:

- ❑ Contacts are typically made on a screw machine
- ❑ Comprised of two parts – Female receptacle and Male header
- ❑ Standard contacts can be inserted into a variety of housings to create IO connectors, sockets and board-to-board connectors.

Primary advantages:

- Consistent and reliable contact resistance
- Low tooling cost
- Medium cycle life (insertion/removal)
- Application includes validation socket and board to board interconnect



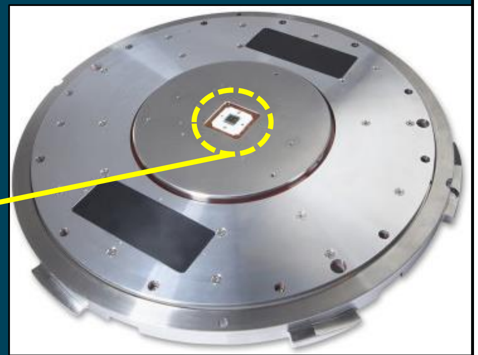
Courtesy: Advanced Interconnection

MEMs-based Vertical Interconnect

Description:
- ❑ Made from 2D MEMs process
- ❑ Contacts are plated
- ❑ One end is soldered down
- ❑ Tips puncture into silicon (Cu) bump

MEMs basic processes:
- ❑ Physical Vapor deposition & chemical deposition
- ❑ Electron beam and Ion beam Lithography
- ❑ Etching processes – Wet and dry etching

Probe Card



Example of vertical interconnect assembled to probe card

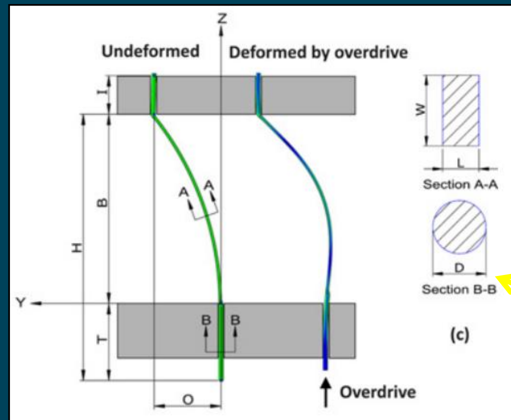
Primary advantages:
- Low force <10gf
- Ultra-fine pitch <150um
- High cycle life
- Application include silicon testing

Courtesy: FormFactor Inc

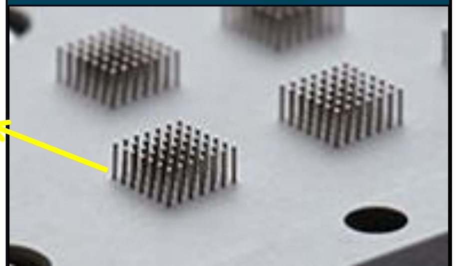
Buckling-based Interconnect

<u>Description:</u>

- ❑ Manufactured from Flat/round wire spool or 2D MEMs
- ❑ Floating pin or one end is soldered
- ❑ Contacts are plated
- ❑ Tips puncture into silicon (Cu) bump



Probe Card



Example of Buckling based interconnect assembled to probe card

<u>Primary advantages:</u>

- Low force <10gf
- Ultra-fine pitch <200um
- High cycle life
- Application include silicon testing

Courtesy: Buckling Beam Solutions

Summary

Type of Contact	Primary Benefits
Polymer-based contacts (filled with metal powder)	- Superior electrical characteristics, can be scaled down to <0.4mm pitch
Polymer-based conductive sheet	- Superior electrical characteristics, can be scaled down to <0.4mm pitch, alignment of sheet to the pads not needed
Polymer based contacts with metal spring element	- Higher cycle life than metal-filled polymer, consistence resistance value
Polymer based contacts -- Invisipin®	-- Superior electrical characteristics, can be scaled down to 0.4mm pitch, dual compression or solder mount, individual pin can be replaced
Particle Interconnect	- Superior electrical characteristics, can be scaled down to <0.4mm pitch,
Fuzz Buttons®	- Superior electrical characteristics, can be scaled down to 0.4mm pitch, high cycle life, extreme temperature operating range
Spring pin (machines)	- High cycle life, can scaled down to <0.4mm pitch (up to 0.2mm), consistence resistance
Spring pin (stamped)	- Low cost, can be scaled down to <0.2mm pitch, high volume production
Stamped and formed contacts	- Low cost, high-volume application, consistence resistance
Pin and Socket Contact	- Consistence resistance, low tooling cost
MEMs-based Vertical Interconnect	- High cycle life, low force, ultra fine pitch <0.15mm
Buckling-based Interconnect	- High cycle life, low force, ultra fine pitch <0.20mm

Section 4
Contact Element Material

Contact Material Selection Factors

- ❑ Material Availability
- ❑ Specific Performance
- ❑ Manufacturability
- ❑ Cost Effectiveness

Socket Contact Selection

Typical Selection Flow

1. Understand Industry Trends

↓

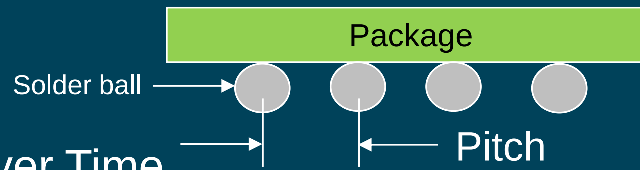
2. Define socket contact requirements

↓

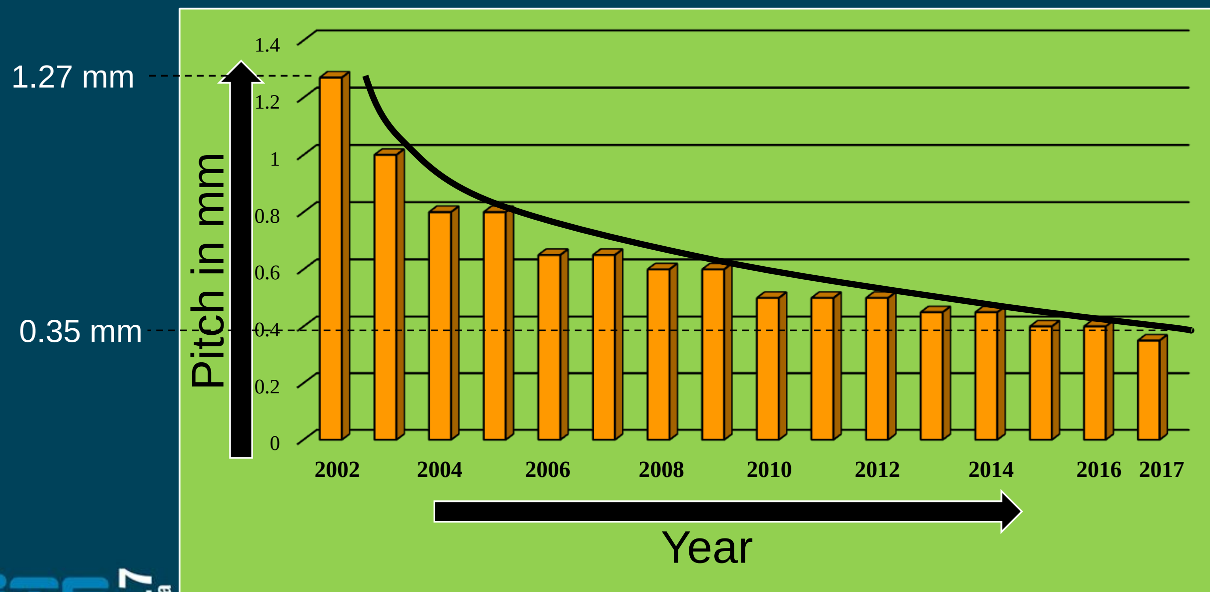
3.Select contact material

1. Understand Industry Trends

- Reduction in pitch over time (center to center spacing)
  - Require reduced contact size
  - Require tighter mechanical tolerances

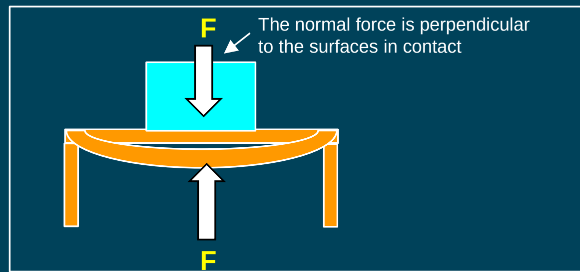


Decrease in Solder ball Pitch Over Time



1. Understand Industry Trends (Cont'd.)

- ❑ Lower normal force
  - Minimize deflection of the socket substrate, package, mechanical hardware and PCB
  - Meet reliability requirements



- ❑ Growing number of pins/socket
  - Exceeding 100 contacts/inch and exceeding 3,000 contacts/socket

1. Understand Industry Trends (Cont'd.)

❑ Single or Dual-compression mount
- Reliable solder joint (for single compression mount)
- Provide repeated insertion removal cycles without taking a set

❑ Higher operating temperatures
- Infotainment systems > 130ºC

❑ Shorter development and manufacturing lead time
- Faster to design and faster to manufacture

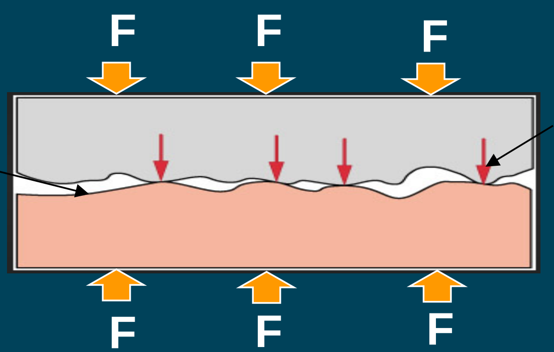
❑ Price
- Lower product cost

2. Define Socket Contact Requirements

- 2a. Mechanical
- 2b. Electrical
- 2c. Material
- 2d. Attachment Process
- 2e. Environment

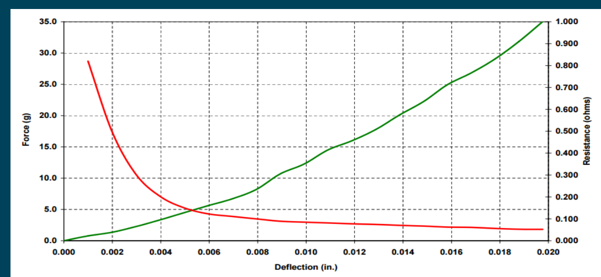
2a. Mechanical Requirements

- ❑ Mating surface material and contact area
  - PCB mating surface , device (BGA) mating surface



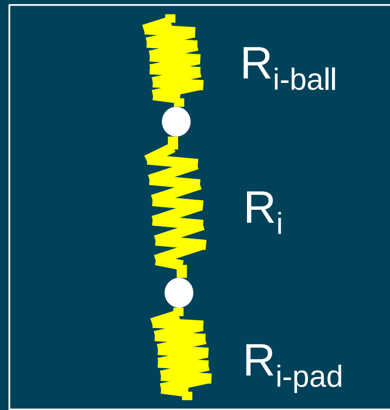
- ❑ Contact normal force
  - Contact geometry
  - Insertion/extraction force

Force/Resistance/Deflection curve



2b. Electrical Requirements

- Total socket resistance
  - Contact resistance (socket contact to ball + socket contact to PCB mating surface)
  - Bulk resistance



- Current Carrying Capacity (CCC)
  - Maximum current allowed for a given temperature rise
  - Higher conductivity materials allow greater current flow with less temperature rise
  - Current carrying capacity depends on contact geometry, contact material and normal force

2b. Electrical Requirements (Cont'd.)

- Signal properties
  - Signal to ground ratio -- ratio determines connector noise
  - Capacitance – energy stored in an electrical field between two charged objects – coupling between two conductors
  - Impedance -- The ratio of voltage to current (AC) of an electrical signal propagating through a circuit component.

2b. Electrical Requirements (Cont'd.)

- Signal properties
  - Inductance -- Energy stored in a magnetic field generated by the current looping through an electrical circuit.
  - Propagation delay -- The signal delay caused by the connector capacitance. Reduced contactor length reduces the propagation delay
  - Cross-talk -- Signals from one line leaking into another conductor because of capacitance or inductive coupling or both – mostly capacitance between two contactors

2c. Material Requirement

- Primary required properties
  - Low contact and bulk electrical resistance
  - Corrosion resistance
  - Low frictional forces – reduces wear and increases cycle life
  - Good spring properties
  - Lower cost
- Typical base contact material
  - Metal – Copper alloys
  - Elastomer – Silicon rubber

2c. Material Requirement (Cont'd.)

- Base material requirement
  - Yield strength. Determines beam deflection allowed within elastic range
  - Conductivity – minimized bulk resistance
  - Hardness – reduces wear and increases cycle life
- Contact interface plating materials
  - Gold (Au)
    - Hard gold or soft gold over Nickel under-plating. Hardness is per knoop hardness – electrolytic gold -- 30 to 40 micro-inches
    - ENIG – Immersion gold over Nickel– 3 to 10 micro-inches of gold

2c. Material Requirement (Cont'd.)

- Contact interface plating materials
  - Palladium (Pd) and alloys
    - Usually over-plated with thin soft gold (approx. 10 micro-inches)
    - Pd and its alloys have higher hardness and durability than gold (Au)
  - Tin (Sn) and its alloys
    - Thickness ranges depending on the process
      - Hot dipping
      - Electro plating

2c. Material Requirement (Cont'd.)

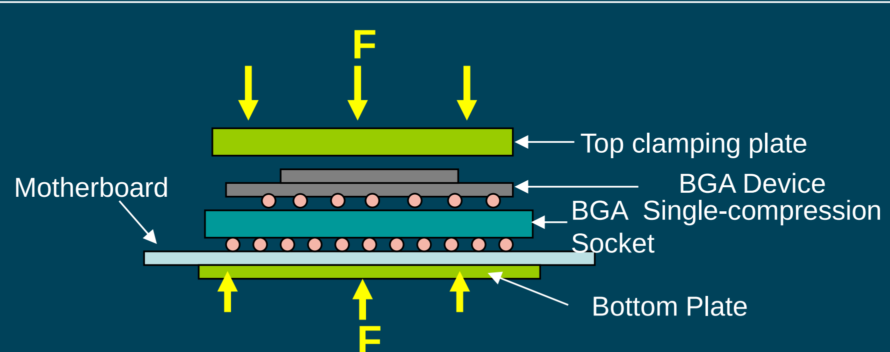
- Contact interface plating materials
  - Silver Ag
    - Typically used on the elastomeric contacts – silicon rubber as base material
  - Nickel (Ni)
    - Common material for under-plating
    - Typical thickness 150 to 200 micro-inches
- Types of plating processes
  - Electrolytic plating
  - Electroless plating
  - Hot dipping

2c. Material Requirement (Cont'd.)

- Housing material
  - Typically thermoplastics (polymer-based) is used to support contacts
    - Provide environmental protection
  - Critical property requirement of housing include:
    - Withstand soldering temperatures with low acceptable warpage (Pb-free process)
    - Dimensional stability
    - Moisture resistance

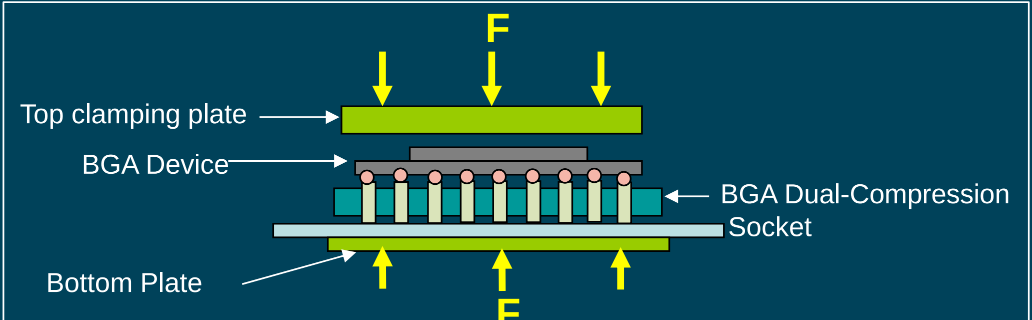
2d. Contact Attachment Process

1. Soldering to PCB, mechanically attaching to device



Soldered-down Socket

2. Mechanically attaching to PCB and device



Dual-compression Socket

2d. Contact Attachment Process (Cont'd.)

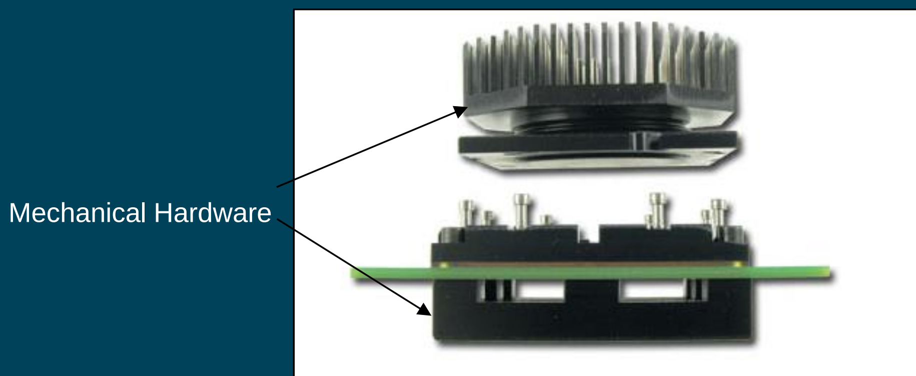
1. Soldering to PCB, mechanically attaching to device
   - Solder process
     - Convection reflow
     - Vapor-phase reflow
     - Manual soldering
     - Wave soldering

   - Mechanical attaching to device
     - Requires custom hardware to make connectivity through compression

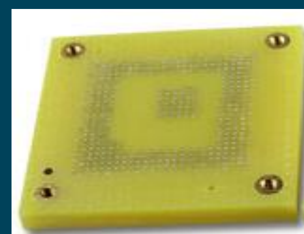
2d. Contact Attachment Process (Cont'd.)

2. Mechanical attachment to PCB

- Solderless contacts. Compression mount on both PCB and device end
- Require custom hardware to make connectivity to PCB and device through compression
- Require higher force to make electrical connection than soldering one end and mechanically attaching other



Courtesy: Ironwood Electronics



Dual Compression, solderless socket

2e. Contact Environmental Requirements

- Common applications include:
  - Consumer
  - Automotive
  - Aircraft
  - Military
  - Computer
  - Telecommunication

2e. Contact Environmental Requirements (Cont'd.)

	Typical operating temperature conditions – Can vary depending on application		Typical life – Can vary depending on application
Category	**Minimum ºC**	**Maximum ºC**	**Approx. Years**
Consumer	0	+100	~ 3
Computer	0	+100	~5
Automotive	-50	+100 to +150	~10
Aircraft	-50	+125	~20
Military	-50	+125	~10
Telecommunication	-40	+100	~15

Types of Tests:

- ❑ Temperature and humidity
- ❑ Gaseous
- ❑ Vibration
- ❑ Shock

3. Contact Material Selection

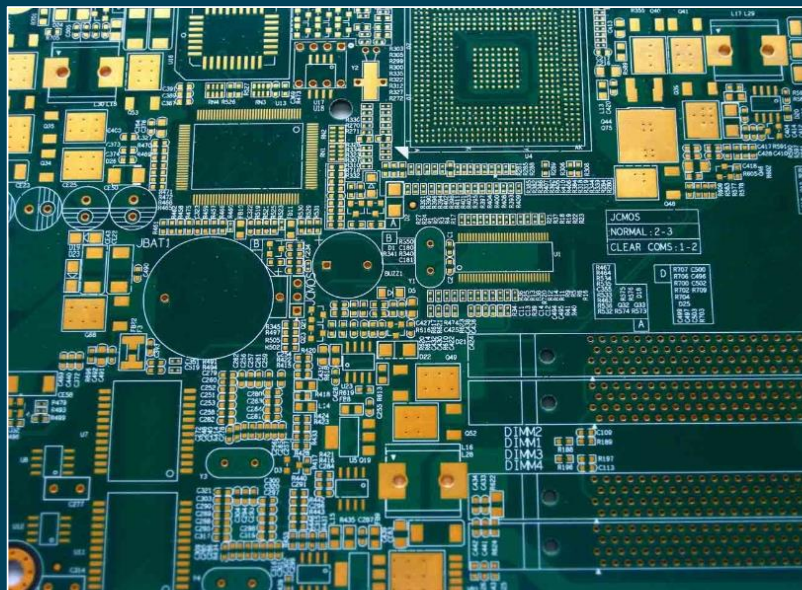
- Contact material plays a significant role in design optimization

Primary Requirements	Contact Material Property
• Cycle life/Durability	• Contact finish, Resistance to taking set
• Reliability	• Contact finish, Stress relaxation
• SI and Current carrying capacity	• Electrical and thermal conductivity
• Deflection under load	• Modulus of elasticity, yield strength
• Normal force	• Modulus of elasticity, mechanical tolerances

Section 5
Printed Circuit Board (PCB) & Hardware Requirement

PCB Surface Finishes

- Overview:
  - PCB surface finish plays an important role in achieving reliable interconnection between the component or device and bare PCB

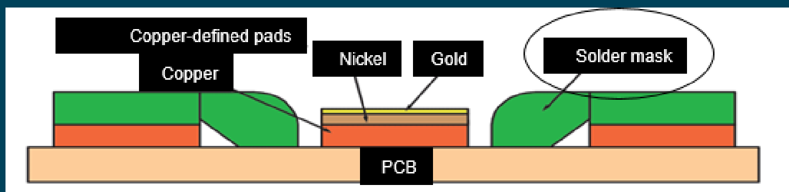


PCB Surface Finishes (Cont'd.)

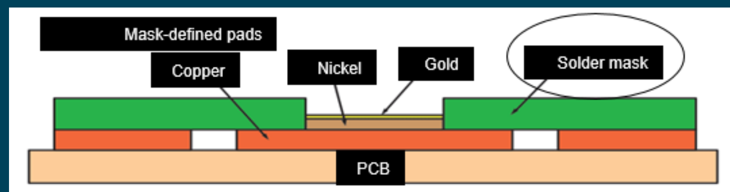
- The primary purpose of the surface finish are:
  - Connectivity between the PCB and component devices
  - Protect the copper area from oxidation prior to assembly (soldering or using interconnect sockets)
  - Promote reliable interconnection for long-term performance

PCB Surface Finishes (Cont'd.)

- Two types of PCB pads:
  1. Copper defined: Solder-mask opening larger than the metal pad
  2. Solder-mask defined: Metal pad larger than the solder-mask opening



Copper-defined Pads



Mask-defined Pads

Primary Factors in Selecting PCB Finish

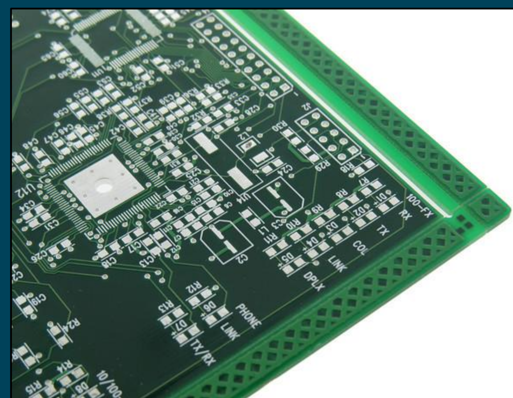
- ❑ Cost
- ❑ RoHS compliant
- ❑ Assembly methods
- ❑ Durability
- ❑ Environment
- ❑ Shelf life
- ❑ Testability
- ❑ Reliability

Types of Surface Finishes

- ❑ Standard Hot Air Solder Level (HASL) & Lead-Free HASL
- ❑ Organic Solderability Preservative (OSP)
- ❑ Immersion silver
- ❑ Immersion tin
- ❑ Gold:
  - Gold – ENIG -Electroless Nickel Immersion Gold
  - Hard Gold
- ❑ Electroless Nickel Electroless Palladium Immersion Gold (ENEPIG)

Standard HASL and Lead-Free HASL

- Typical finish:
  - Standard HASL: Typically Tin-Lead (Sn-Pb)
    - Melts at 183ºC
    - Shelf life: >12 months (very good)
  - Lead-free HASL: Typically Tin-Copper (Sn-Ag-Cu), Tin-Copper-Nickel (Sn-Cu-Ni)
    - Melts at 217ºC to 228ºC
    - Shelf life: approx. 12 months



- Typical thickness:
  - 70-200 micro-inches
  - IPC specifies complete coverage of SMT pads

Standard HASL and Lead-Free HASL (Cont'd.)

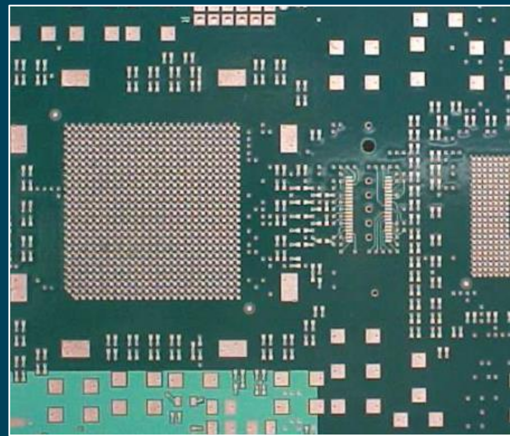
❑ Advantages:
- Low cost
- Readily and widely available
- Easy to rework – Low cost

❑ Disadvantages:
- Uneven surface
- Not good for direct socket interconnection
- Not good for thermal shock
- Potential of solder bridging is high

❑ High-level typical process:
- ❑ Clean → Microetch → Apply Flux → Solder Dip → Knife leveling → Rinsing

Organic Solderability Preservatives (OSP)

- Typical finish
  - Organic Solderability Preservatives
  - Applied directly on Copper



- Typical thickness:
  - Thin coating : 4-20 micro-inches
  - Finish typically is not specified on the fab drawing

Organic Solderability Preservatives (OSP) (Cont'd.)

❑ Advantages:

- Lead-free
- Flat and planar surface
- Simple process and easy to manufacture
- Easy to rework – Low cost

❑ Disadvantages:

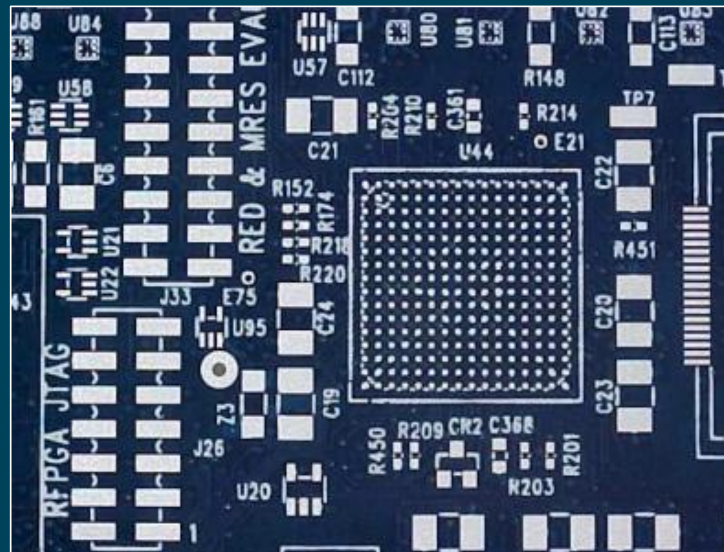
- Short shelf life, less than 6 months
- Exposed Copper during final assembly
- Bare exposed Copper can cause socket interconnect reliability issues

❑ High-level typical process:

- Clean → Microetch → Flood OSP → Rinse

Immersion Tin

- Typical thickness:
  - 20-50 micro-inches
- Advantages:
  - Flat Surface
  - Lead-free
  - Easy to rework
  - 6-month shelf life



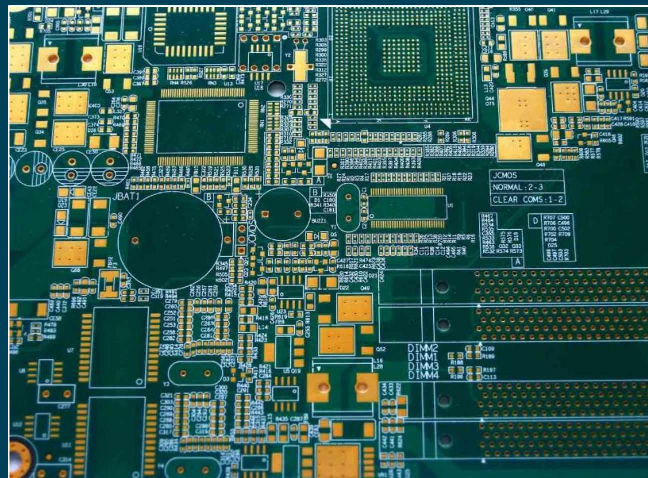
Immersion Tin (Cont'd.)

- Disadvantages:
  - High potential for damage during handling
  - Exposed tin can corrode – cause interconnect socket issues during direct socket connection
  - Tin whiskers

- High-level typical process:
  - Clean → Microetch → Predip → Apply Tin → Post dip →Rinse

Gold – ENIG

- Typical thickness:
  - Nickel: 100-200 micro-inches
  - Gold: 3-10 micro-inches



- Advantages:
  - Flat Surface
  - Lead-free
  - Approx. 12-month shelf life
  - Good for direct socket interconnection

Gold – ENIG (Cont’d.)

- Disadvantages:
  - Medium to high cost
  - Not reworkable
  - Complicated process

- High-level typical process
  - Clean → Microetch → Catalyst → Electroless Nickel →Rinse →Immersion Gold → Rinse

Gold – Hard Gold

- Typical thickness:
  - Nickel: 125-150 micro-inches
  - Gold: 25-30 micro-inches
- Advantages:
  - Durable surface
  - Lead-free
  - Excellent for direct socket interconnection
  - Long shelf life

Gold – Hard Gold (Cont'd.)

❑ Disadvantages:

- Very high cost
- Extra processing → labor intensive
- Plating / Bus bars

❑ High-level typical process:

- Apply Resist → Clean → Microetch → Electroless Nickel → Rinse → Electrolytic Gold → Rinse → Strip Resist → Clean

Immersion Silver

- **Typical thickness:**
  - 8-15 micro-inches of pure Silver
- **Advantages:**
  - Excellent Solderability
  - Good for direct socket interconnect
  - 6-12-months shelf life
- **Disadvantages:**
  - Sensitive to handling
  - Medium High cost
- **High-level typical process:**
  - Clean → Microetch → Electroless Nickel →Rinse → Immersion Silver → Rinse

Electroless Ni / Electroless Pd/ Immersion Au (ENEPIG)

- Finish/Thickness:
  - Nickel: 120-240 micro-inches
  - Palladium: 4-20 micro-inches
  - Immersion Gold : 3-10 micro-inches

- Advantages:
  - Forms better solder joints with SAC Alloys (Pb free)
  - Palladium eliminates potential corrosion
  - 12-months shelf life
  - Good for direct socket interconnection

Electroless Ni / Electroless Pd/ Immersion Au (ENEPIG) (Cont'd.)

❑ Disadvantages:

- Does not form good joints with Sn/Pb alloys
- High cost

❑ High-level typical process:

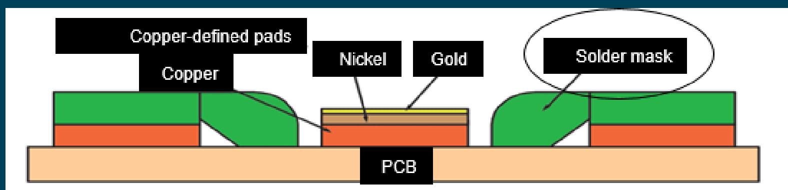
- Clean → Microetch → Electroless Nickel → Electroless Palladium →Immersion Au

Comparison of Surface Finishes

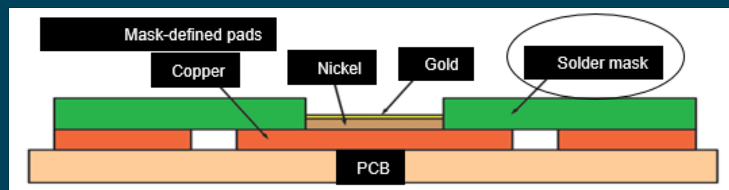
Type	Planarity	Solderability	Dual Compression Contact	Typical Cost
HASL	Poor	Good	Poor	Low
OSP	Good	Good	Poor	Low
Immersion Tin	Good	Good	Poor	Low
Immersion Ag	Good	Good	Good	Medium
Gold - ENIG	Good	Good	Very Good	Medium
Gold-Hard Gold	Good	Good	Excellent	Very High
ENEPIG	Good	Good	Excellent	High

Overview of PCB Solder-mask

- ❑ Primary purpose of solder-mask:
  - Prevent solder shorts under components
  - Prevent socket interconnect shorts
  - Prevent corrosion to underlying circuitry
  - Plating resist for surface finishes



Copper-defined Pads



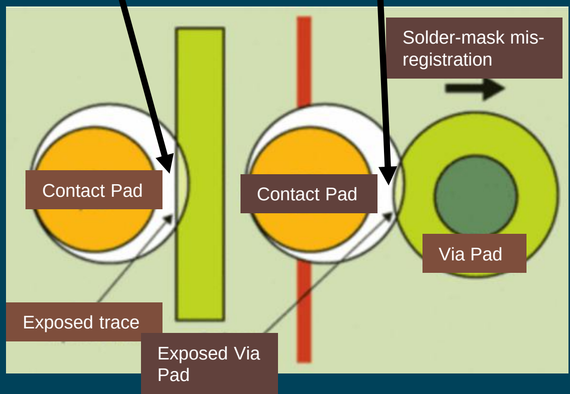
Mask-defined Pads

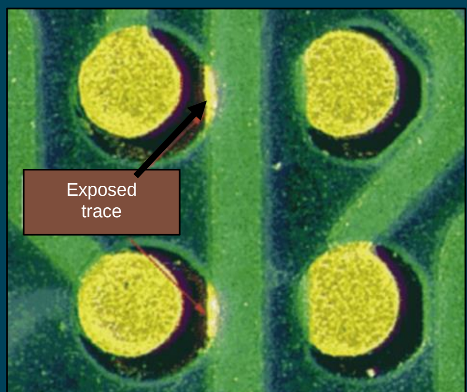
Solder-mask Considerations for Socket Connectivity

- Feature size of the solder-mask
- Registration of the solder-mask
- Tolerance on the feature size
- Thickness of the solder-mask

Importance of Solder-mask (SM) Registration

Potential Socket contact short in this area



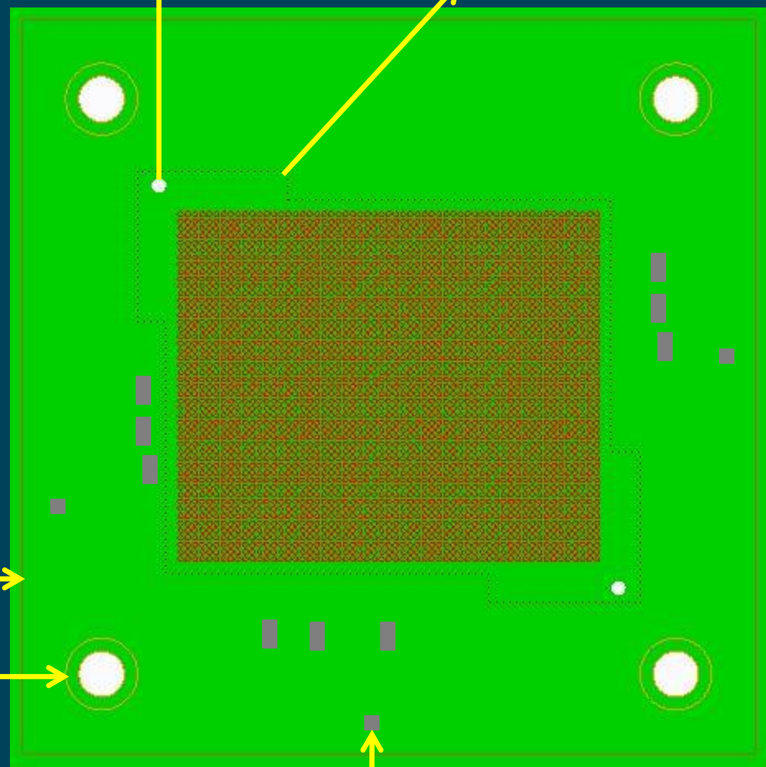


SM tolerance considerations
-- Size
-- Position
-- Thickness (primarily for sockets with short working range)

PCB Mechanical Keep-out for Socket

❑ Parameters to include in fab drawing

- Alignment hole location
- Socket body/frame
- Mounting hole location
- Surface mount components around the socket body/frame
- Pad diameter
- Surface Finish



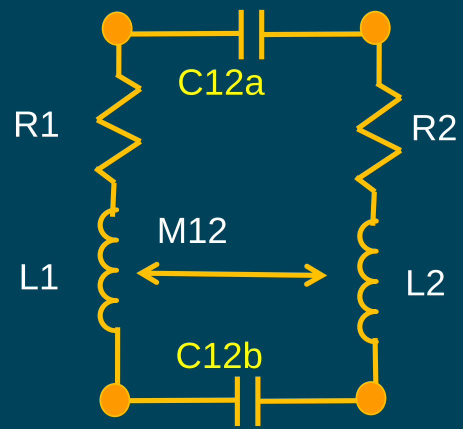
Section 6
Electrical Requirements

Impedance of the Socket

- In simple form, impedance (Zo) can be expressed in terms of inductance and capacitance
  - Zo = sqrt (L/C) (lossless impedance equation)
  - L (pin inductance) is a function of the pin geometry, socket pitch and pin length
  - C (pin capacitance) is a function of the pin geometry, socket pitch, pin length and dielectric material
- Impedance matching to system interconnect is essential in minimizing return loss for high-speed applications

Equivalent Circuit of the Socket

Example of BGA socket equivalent circuit
(2 pins are shown)



- To accurately model or calculate the impedance of one pin, the surrounding pins need to be accounted for

Notation:

C12a (BGA side): mutual capacitance between adjacent pins

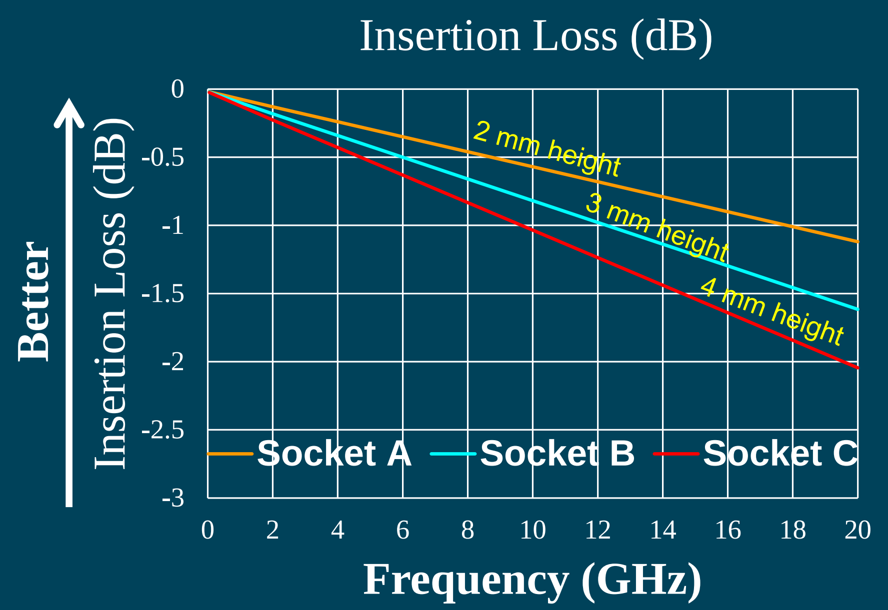
C12b (PCB side): mutual capacitance between adjacent pins

L1, L2: pin inductances

M12: mutual inductance

R1, R2: pin resistances

Socket Pin Insertion Loss

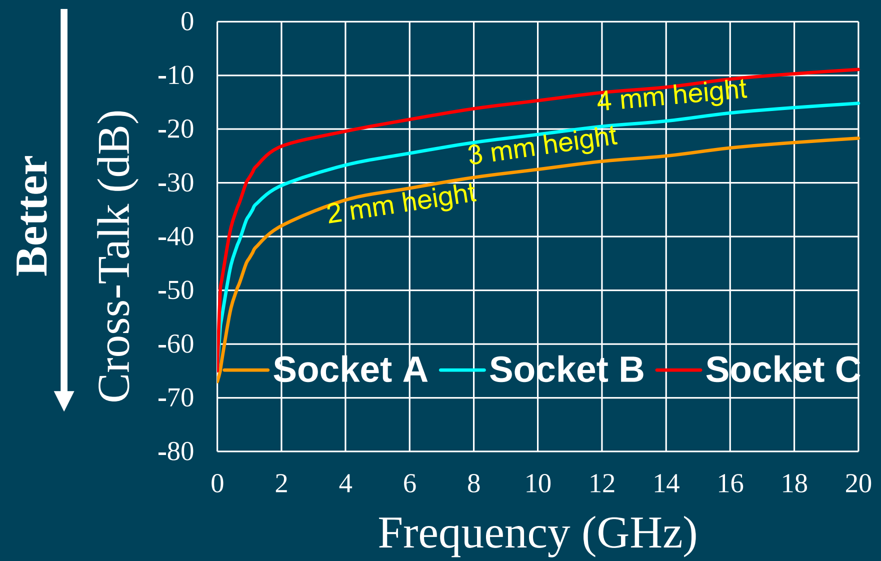


Socket Height: Socket A < Socket B < Socket C

- Insertion loss is proportional to socket pin length and contact resistance
- The longer the pin, the higher insertion loss for the same material
- The socket material also plays a role in insertion loss
- The lower loss material yields lower insertion loss

Low Insertion is preferred for signal integrity performance

Socket Pin-to-Pin Cross-Talk



Socket Height: Socket A < Socket B < Socket

- Cross-talk is proportional to the socket pin length
- The longer the pin length, the higher the cross-talk
- It is critical to have a low height socket for high-speed applications
- Socket signal pin-map also plays a critical role in reducing cross-talk
- The higher signal-to-gnd ratio, the lower the cross-talk

Minimal Cross-Talk is preferred for signal integrity performance

Current Carrying Capacity (CCC)

- Current carrying capacity is a very important electrical requirement of a socket. It must meet an application requirement for reliable operations
- The ability of socket pin contact to carry current is primarily limited by the maximum allowable operating temperature and the pin contact material and contact geometry

Section 7
Interconnect Socket and System Design

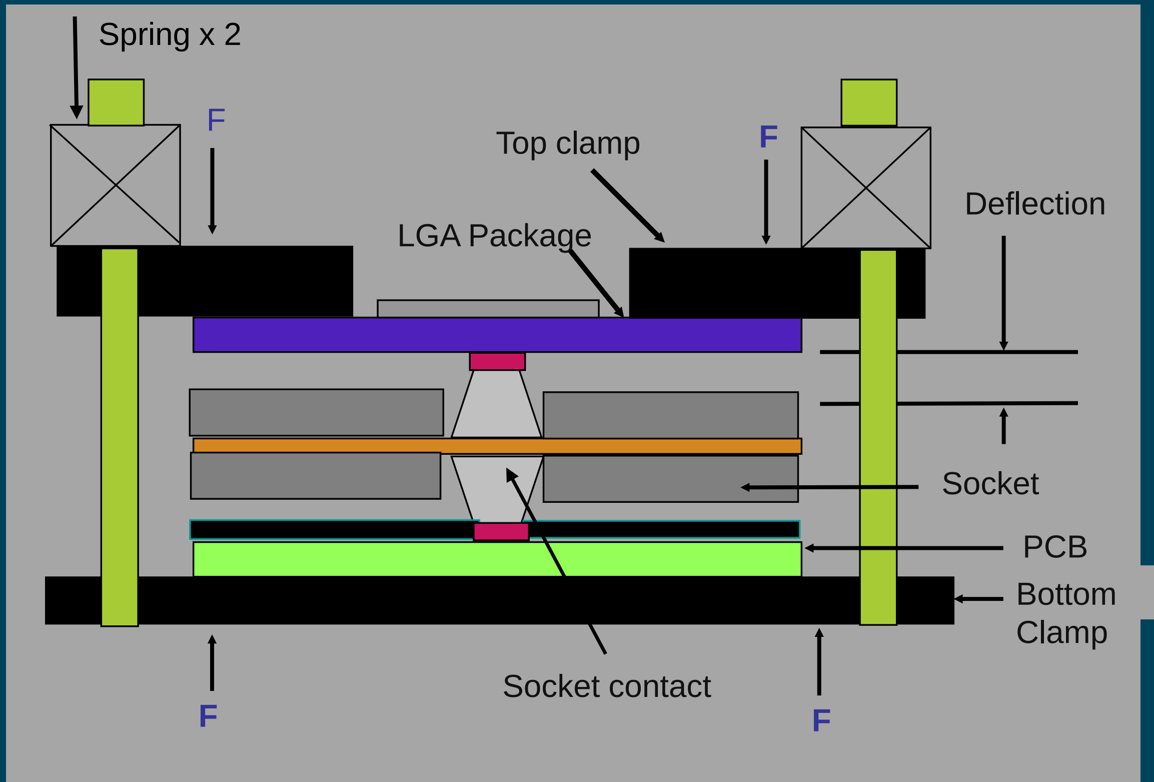
Types of Interconnect Systems

- Two types of interconnect systems

1. Load-based system
   - Required compression of the contact material is achieved by applying measured load using mechanical hardware system
   - Typically used where contacts have low working range

2. Deflection-based system
   - Required compression of the contact material is achieved by using a fixed mechanical stopper
   - Typically used where contacts have high working range

Load-based System



Schematic

Example:

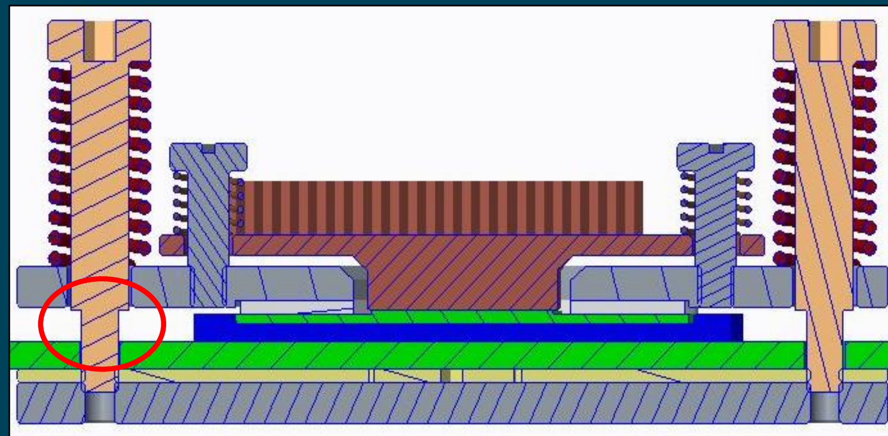
- Polymer socket contacts-- Typical working range < 0.005”

Load-based System (Cont'd.)

- ❑ Primary advantages:
  - Typically use spring screw retention system
  - Spring accounts for thickness variations in retention system, socket, and package

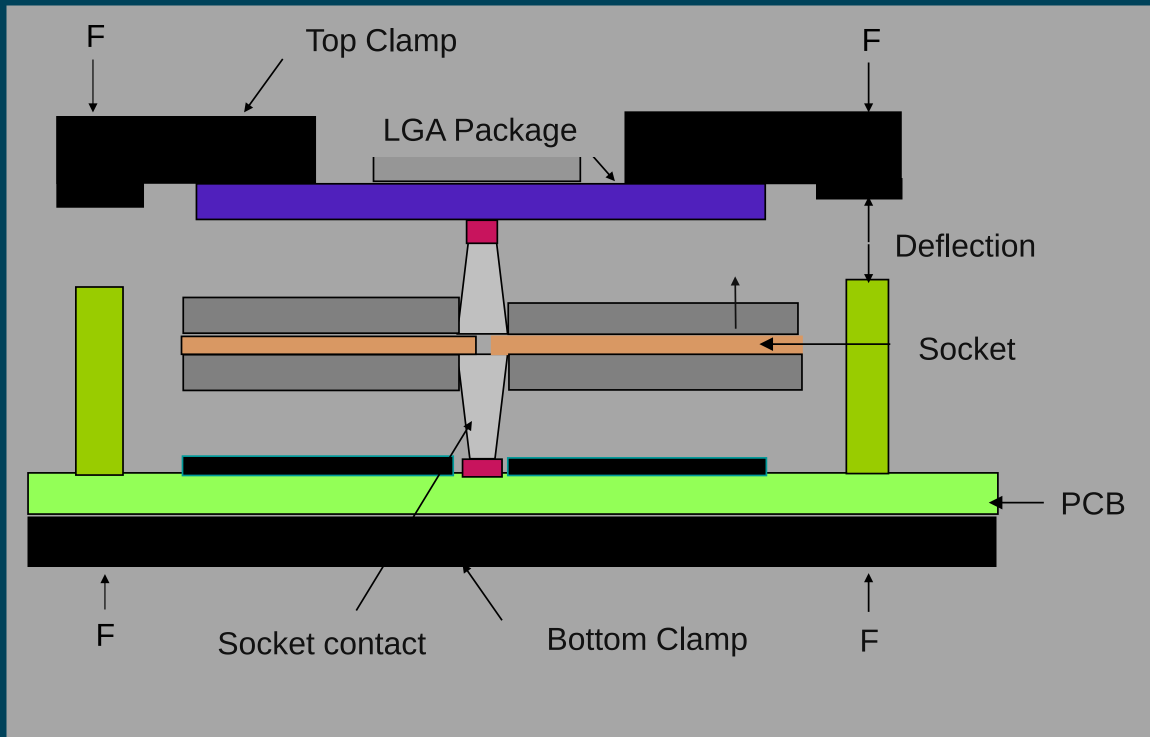
- ❑ Limitations:
  - High BOM cost
  - Typically used for sockets with low working range < 200um

Uncompressed



Compressed

Deflection-based System



Schematic

Example:
-- Pogo pins, stamped and formed contacts -- Typical working range = 0.010”-0.015”

Deflection-based System (Cont'd.)

❑ Primary advantages:

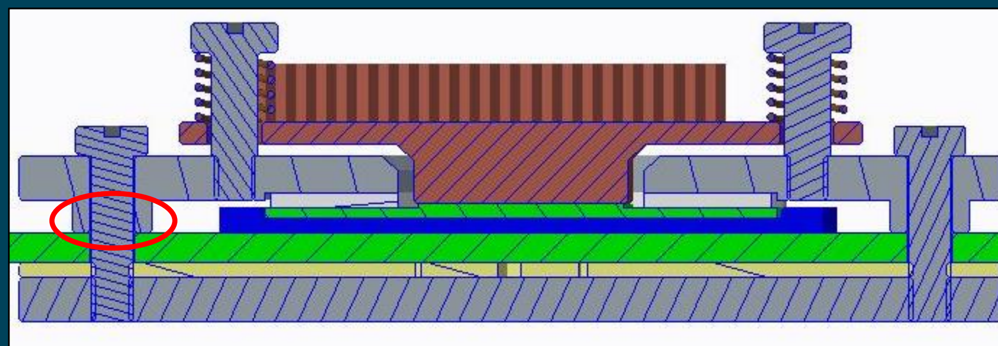
- Socket acts as compliant member accommodating thickness variation in retention parts
- Low BOM cost

❑ Limitations:

- Typically used for sockets with high working range >250um
- Typically use a pattern for tightening retention screws
- Require tight thickness and flatness control for retention hardware

Uncompressed

Compressed



Socket Design Parameters

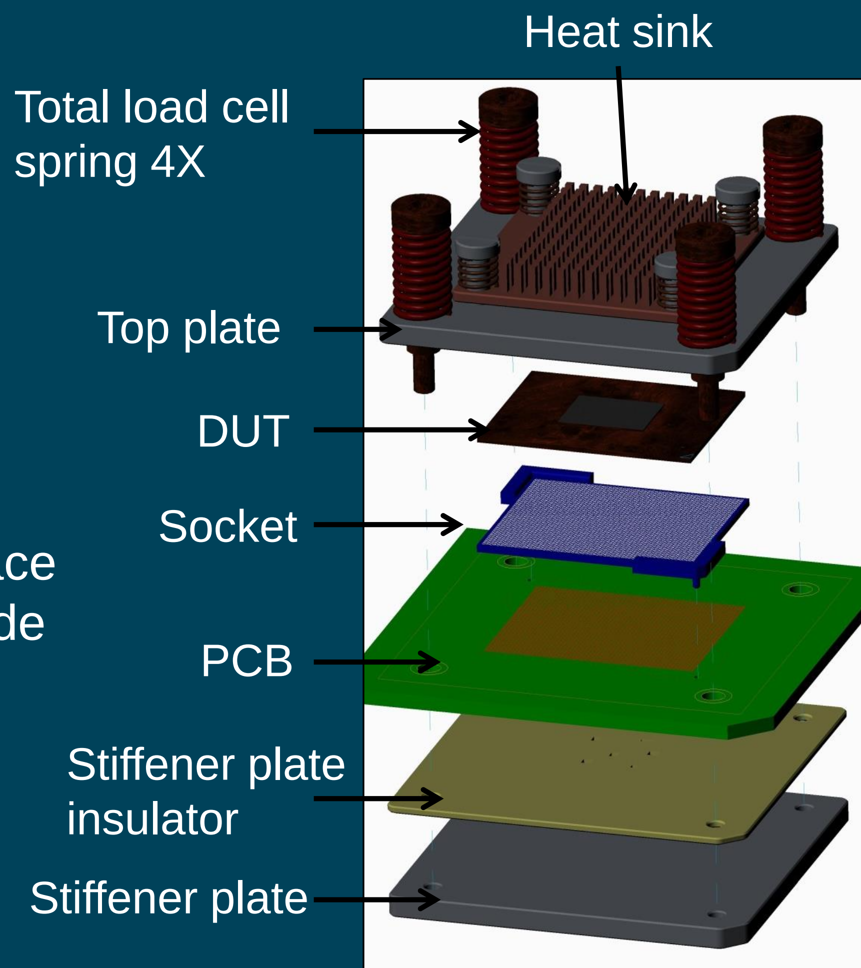
- Thermo-Mechanical
  - Compression and force
  - Cycle life / durability
  - Operating temperature
  - BGA vs LGA
  - Pitch
  - PCB keep-out and plating
  - Hard stops preventing pin over-compression

Socket Design Parameters (Cont'd.)

- ❑ Electrical
  - Impedance
  - Inductance
  - Current Carrying Capacity (CCC)
  - Contact resistance
- ❑ Cost
- ❑ Lead time

Mechanical Hardware Design

- ❑ Spring screw retention accommodate z-stack tolerances
- ❑ Split loading for bare die devices
  - Periphery loading
  - Heat sink loading
- ❑ Stiffener plate insulator openings accommodate surface mount components bottom side of PCB
- ❑ Top plate insulator openings accommodate surface mount components on DUT



Mechanical Tolerances

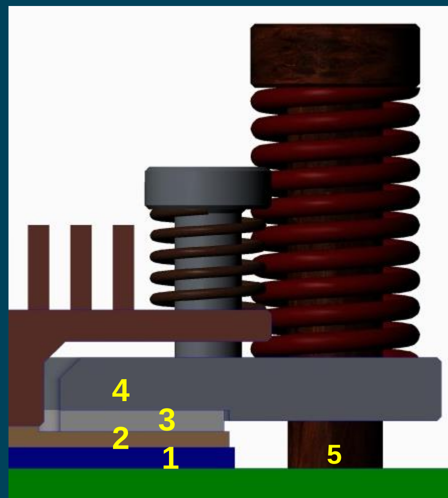
- Z-stack tolerance analysis:
  - Spring based loading: Spring compressed height variation
  - Displacement based loading: Interconnect compressed height variation
- XY tolerance analysis:
  - Alignment accuracy of interconnect pin to PCB pad
  - Alignment accuracy of interconnect pin to Device ball or pad
    - Monte Carlo based: David Shia, Intel Corporation; 2007 Burn-in and Test Socket Workshop
    - https://www.bitsworkshop.org/archive/archive2007/2007s6.pdf
  - For HVM test, alignment accuracy and repeatability of handler

Mechanical Z-Tolerance: Example

- Components for Z-stack tolerance analysis:

1. Compressed socket height
2. Package substrate
3. Insulator backing
4. Top plate
5. Spring compressed height

Sectional view

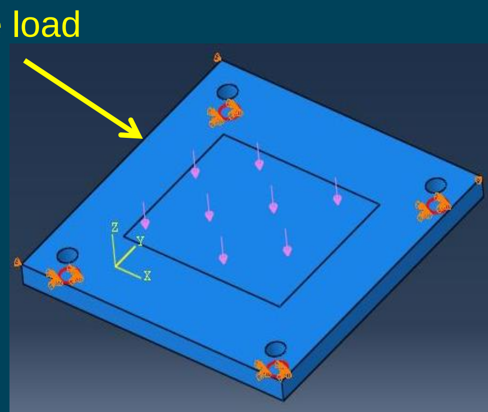


Force-Deflection Analysis

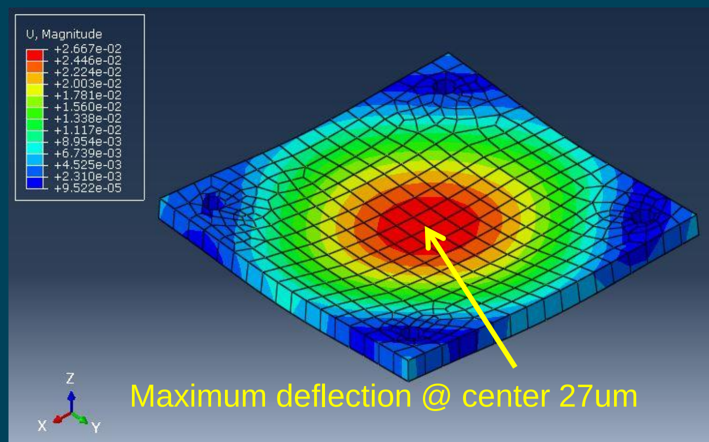
- ❑ Finite-Element-Analysis (FEA) is used for:
  - Optimization (thickness) of mechanical hardware components (stiffener plate, top plate, etc)
  - Interconnect array deflection distribution to ensure minimum deflection meets CRES criterion
  - Device warpage under mechanical load, thermal load, etc
- ❑ Commercially available tools:
  - ANSYS, Mechanica, Abaqus, etc.

Force-Deflection Analysis: Example

- First order approximation: individual components of the hardware analyzed for deflection



- Example: Stiffener plate
  - Material: Steel; E=200Gpa; v=0.3; Linear Elastic
  - Force: 400N
  - Deflection allowed: 30um max



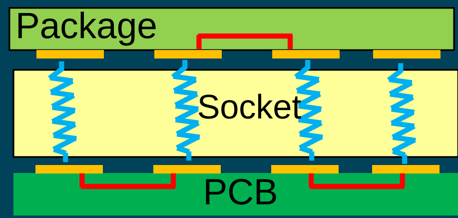
Section 8
Socket Interconnect System Testing

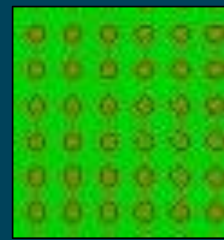
Socket Electrical Measurements

- ❑ Contact resistance measurement
- ❑ Signal integrity S-parameters measurements which contain the following data:
  - Impedance of the socket
  - Insertion loss, return Loss
  - pin-to-pin cross-talk

Contact Resistance Measurement

- Contact resistance board and package are designed to validate retention system and measure pin total resistance (bulk + contact)





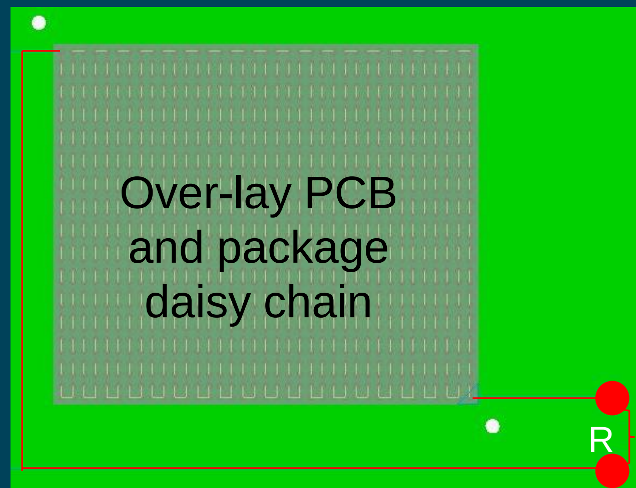
PCB daisy chain

- Contact resistance board can be designed with multiple loops
  - Helps in debugging areas which are electrically open
  - Electrical open indicates more PCB or package deflection. Insufficient stiffness of back plate and/or top plate

Package daisy chain

Contact Resistance Measurement (Cont'd.)

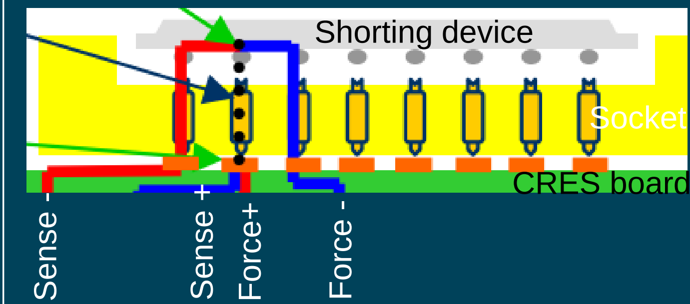
- ❑ Matching daisy-chain package needs to be designed
- ❑ Package is soldered down to daisy chain board. Measured resistance is $R_{soldered}$
- ❑ Total resistance per pin
  - $(R-R_{soldered})$/number of pins

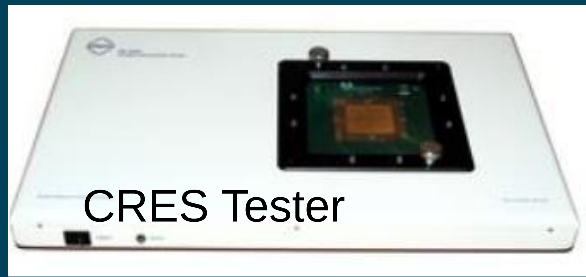


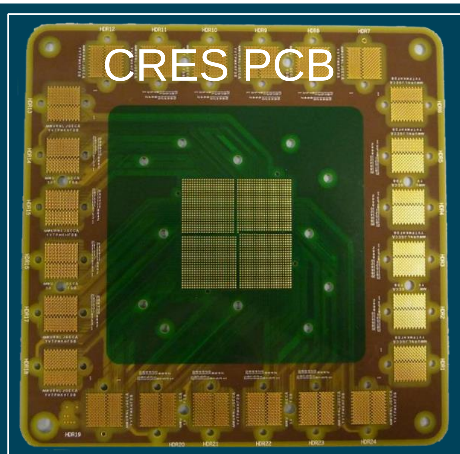
Contact Resistance Measurement (Cont'd.)

- Custom PCB is designed with 4-wire Kelvin measurement to measure single pin CRES in an array

Schematic of 4-wire measurement in an array





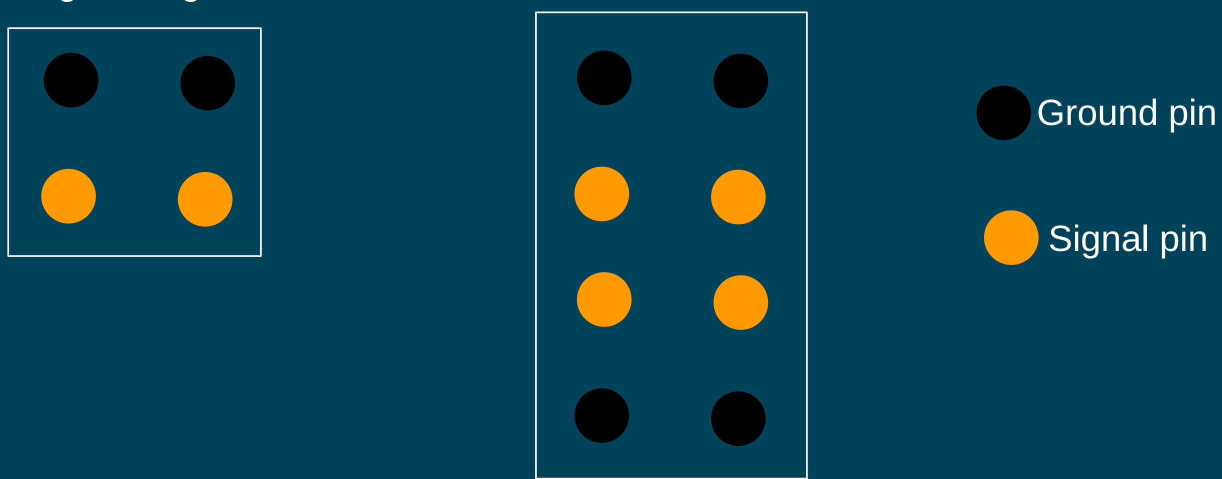


Signal Integrity Measurement

- Signal integrity S-parameter measurements characterize the electrical performance of the socket in terms of impedance, insertion loss, return loss and pin-to-pin cross-talk in frequency domain
- Identify a signal test pattern for testing. Examples below show 2-signal pin and 4-signal pins test patterns

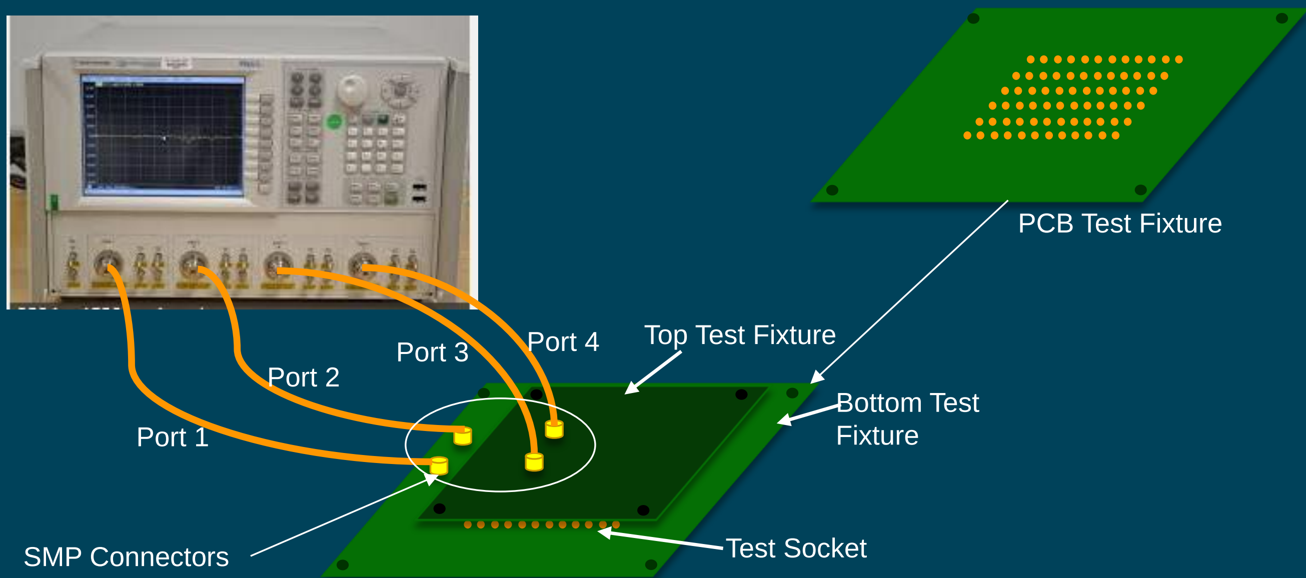
2-signal pin test pattern with 1:1 signal-to-gnd ratio

4-signal pin test pattern with 1:1 signal-to-gnd ratio



Signal Integrity Measurement (Cont'd.)

- Diagram below shows an example of connecting a VNA (Vector Network Analyzer) test equipment to test fixtures measuring the s-parameters of two socket pins through 4-port measurements

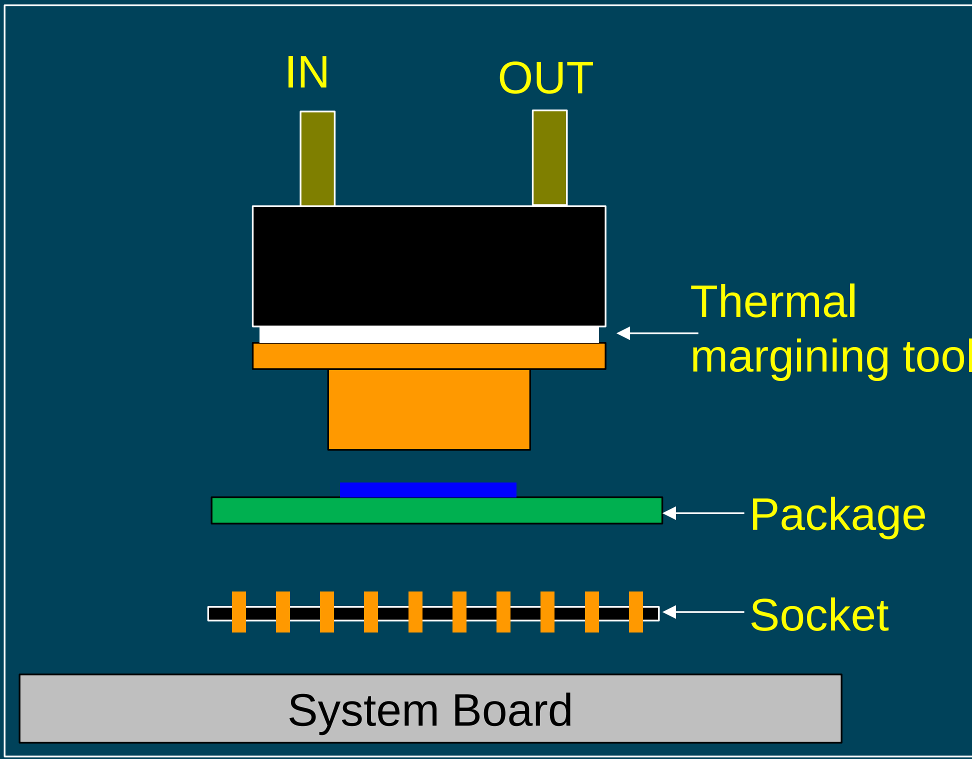


System Qualification

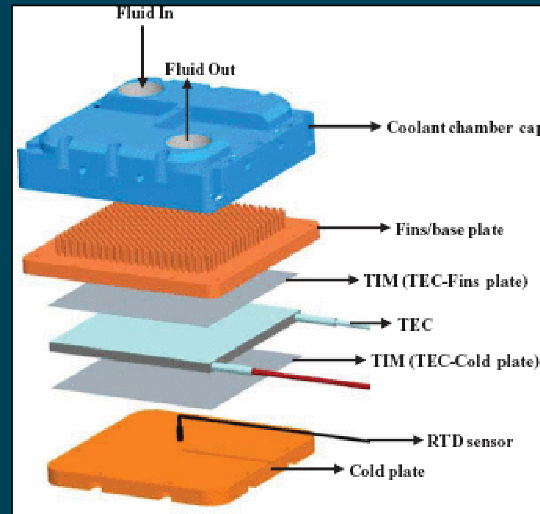
- System-level validation and testing
  - At normal operating conditions
    - Normal operating conditions; passive heat sink or active heat sink
    - Extreme operating conditions; Thermal margining tool
  - Long-term aging tests
    - Environmental chamber – system is subjected to environmental test conditions

Thermal margining tool for CPU

System Qualification (Cont'd.)



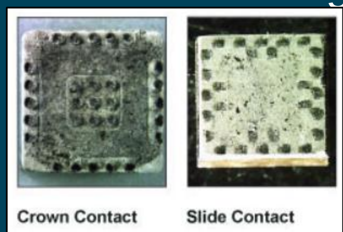
Schematic of system test



Exploded view of thermal margining tool

Maintenance: Repair & Cleaning

- Repair
  - Polymer sockets are harder to repair for damaged contacts
  - Dual compression pogo-pins can be replaced for bent pins caused by uneven loading
- Cleaning
  - Cleaning is essential for good CRES
  - Polymer socket contacts are cleaned using light brush and/or low pressure dry air
  - For HVM high volume test sockets, cleaning is done in-situ using cleaning coupons
  - For BGA devices there is solder migration from solder ball on to pin-tips



Section 9
Real World Example (Team Exercise) & Summary of Technologies

Team Exercise

- ❑ Divide into multiple teams (A, B, C & D)
- ❑ Each team has a set of requirements
- ❑ Discuss within the team and report out the socket choice meeting the requirements. Provide justification
- ❑ Make assumptions as needed.

Report Out

Report out must include the following:

- Socket contact element description and material
- Socket contact manufacturing process
- Socket contact plating finish
- PCB requirements (thickness, material, surface finish, plating, etc.)
- Socket to PCB attachment method
- Package to socket attachment method (include any mechanical attachment hardware and manufacturing process of attachment hardware)
- Any custom tooling required
- Any other requirements (Example: cleaning)

Team-A: Requirements

❑ Package parameters:

- ➢ Package size: 12 mm X 12 mm
- ➢ Die size: 5 mm X 7 mm
- ➢ Package pitch : 0.5 mm
- ➢ Package type: Ball-Grid-Array (BGA)

❑ Requirements:

- Cycle life: minimum 50 cycles (insertions)
- Operating temperature: 15ºC to 75ºC
- Electrical height: < 1.5 mm
- Socket attachment type: Surface-mount (solder or dual compression)
- Mechanical hardware: Standalone retention solution
- Prototype lead time: < 4 weeks
- Production cost: < $300/socket including hardware
- Production order quantity: 1K

Team-B: Requirements

❑ Package parameters:

- ➢ Package size: 12 mm X 12 mm
- ➢ Die size: 5 mm X 7 mm
- ➢ Package pitch: 0.5 mm
- ➢ Package type: Ball-Grid-Array (BGA)

❑ Requirements:

- Cycle life: >100K cycles (insertions)
- Operating temperature: -10°C to 100°C
- Electrical height: < 5 mm
- Socket attachment type: Surface-mount (solder or dual compression)
- Mechanical hardware: Handler compatible for cycling
- Prototype lead time: < 10 weeks
- Production order quantity: 100
- Production cost: <$5K/socket

Team-C: Requirements

❑ Package parameters:

- ➢ Package size: 12 mm X 12 mm
- ➢ Die size: 5 mm X 7 mm
- ➢ Package pitch: 0.65 mm
- ➢ Package type: LGA pads with ENIPEG plating

❑ Requirements:

- Cycle life: minimum 20 cycles (insertions)
- Operating temperature: -10°C to 100°C
- Electrical length: < 6 mm
- Socket attachment type: Surface-mount (solder or dual-compression)
- Mechanical hardware: Standalone retention
- Prototype lead time: < 24 weeks
- Production order quantity: 1million
- Production cost: <$10/socket

Team-D: Requirements

❑ Package parameters:

- Package size: 12 mm X 12 mm
- Die size: 5 mm X 7 mm
- Package pitch: 0.5 mm
- Package type: Ball-Grid-Array (BGA)

❑ Requirements:

- Cycle life: 10K cycles (insertions)
- Operating temperature: -10 °C to 100°C
- Electrical length: < 10 mm
- Socket attachment type: Through-hole
- Mechanical hardware: Handler compatible for cycling
- Prototype lead time: < 10 weeks
- Production cost: $100/socket
- Production order quantity: 5,000

Summary of Socket Key Technologies

	Relative Comparison of Three Technologies		
Factors	Polymer-based	Screw-Machine	Stamped-formed
Typical material	Silicon rubber filled with metal powder	Beryllium Copper	Beryllium Copper
Scalability <0.4mm pitch	Very Good	Good	Good
Electrical height	Low	Medium to High	Medium
Cost/pin	Medium	Medium to High	Low to medium
Wiping action	No	Yes	Yes
Compliance/working range	Low	High	High
Cycle life (insertion/removal)	Low	High	Medium to high
Solderability to PCB	Poor	Good	Very Good

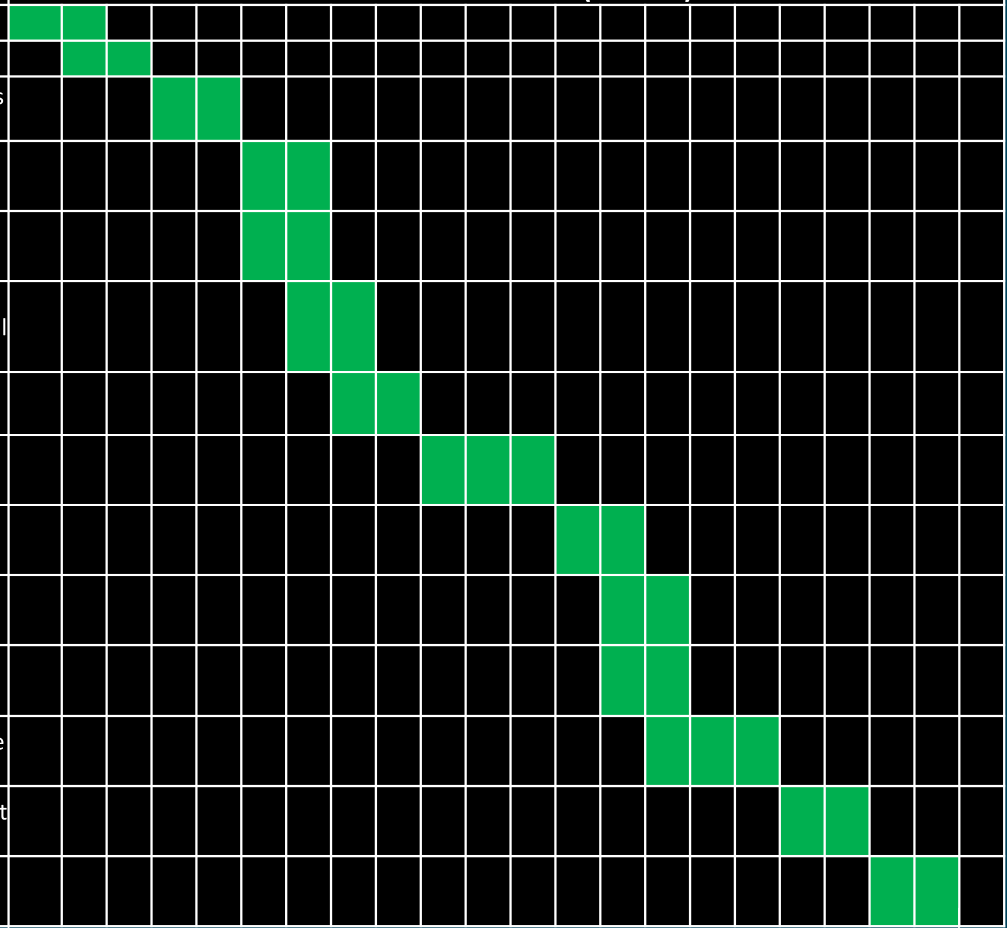
Summary of Socket Contact Key Technologies (Cont'd.)

	Relative Comparison of Three Technologies		
Factors	Polymer-based	Screw-Machine	Stamped-formed
Single Vs Dual compression	Dual only	Single and dual	Single and dual
Material compression set	Medium to high	None	Very low
Typical lead time	Short	Medium	Medium to long
Volume application	Low to Medium	Low	High
Tooling/NRE	Low	Medium	Medium to high
Real-world application	Validation	Test	Production/Burn-in
Cycle time to design	Short to medium	Short to medium	Long
Serviceability	Low (difficult)	High (easy)	Low(difficult) to medium

Section 10
Design to Production Activities
&
Check-list

Socket Design to Production Activity GANTT

#	ACTIVITY	RELATIVE TIMELINE (WEEKS)
1	Understand product requirement	
2	Create product requirement document	
3	Research and define type of socket contacts and select	
4	Design socket and mechanical hardware based on PRD -- Include FEA analysis	
5	Define PCB requirements and special mechanical tolerances, if any	
6	Design test boards for testing sockets for continuity, environmental conditions, signal integrity and contact resistance	
7	Create detailed mechanical drawings including tolerances	
8	Obtain quotes, order and receive parts – Socket, hardware, test boards, etc.	
9	Assemble and test socket assemblies for continuity using test boards	
10	Test for resistance stability with number of insertions	
11	Conduct signal integrity (SI) tests using SI test boards	
12	Conduct environmental tests – temperature and humidity cycling	
13	Revise socket and hardware designs per test results as required	
14	Finalize drawings and release design for production	



Time line depends on the complexity and number of design revisions

Process Steps and Check-list

No	Process Step	Check-List
1	Understand product requirement (PRD)	❑ Electrical and Signal Integrity (SI) ❑ Socket cycle life ❑ Socket and hardware cost ❑ Environmental
2	Create Product Requirement Document (PRD)	❑ Socket cycle life ❑ Socket cost ❑ Environmental test conditions ❑ SI requirements ❑ Keep-Out Volume requirements both for socket and hardware ❑ PCB requirements
3	Research and define type of socket contact to be used and select	❑ Review supplier socket specifications – cycle life, cost, signal integrity data ❑ Get preliminary quotes ❑ Select the best option based on PRD requirements
4	Design socket and mechanical hardware based on PRD	❑ Force-deflection analysis done to ensure robust and right material selected for hardware design ❑ SI analysis done to ensure socket meets electrical requirements ❑ Right amount of socket element deflection ❑ Right mechanical tolerances and ensure hardware is manufacturable

Process Steps and Check-list

No	Process Step	Check-List
5	Define PCB requirements and special mechanical tolerances, if any	❑ PCB surface finish ❑ PCB tolerances -- both absolute and positional ❑ Solder-mask requirements, if any ❑ PCB board material – dielectric constant (Dk), Dissipation factor (Df) ❑ Socket/hardware keep-out volume defined that meets PRD
6	Design test boards for testing sockets	❑ Daisy-chain test boards for contact resistance measurement ❑ Daisy-chain packages or test boards (simulating package) for contact resistance measurement ❑ SI measurement test boards
7	Create detailed mechanical drawings including tolerances	❑ Hardware material call-out (e.g. Al, Steel, etc.) ❑ Positional and absolute tolerances ❑ Surface finish/plating of the material
8	Obtain quotes, order and receive parts – socket, hardware, test boards	❑ Obtain quote for prototypes and production – sockets, hardware, test boards. ❑ Order both sockets, hardware and test boards

Process Steps and Check-list

No	Process Step	Check-List
9	Assemble and test socket assemblies for continuity using test boards	❑ Inspect all sockets and hardware parts to ensure they meet the specifications ❑ Inspect test boards for tolerances and surface finish
10	Check for resistance stability with number of insertions	❑ Record resistance/contact ❑ Disassemble and reassemble sockets and component/device ❑ Record resistance ❑ Repeat disassembly and reassembly and record resistance at every cycle ❑ Determine the socket life based on the PRD requirement of change in resistance from the initial resistance
11	Conduct Signal Integrity (SI) tests	❑ Socket Impedance ❑ Socket pin insertion loss ❑ Socket pin-to-pin cross talk ❑ Current carrying capacity/pin
12	Conduct environmental tests – temperature and humidity cycling	❑ Extreme high and low temperature testing depending on the application. Also, duration depends on application ❑ Thermal shock – temperatures depend on the application ❑ Humidity – typically 85%RH

Process Steps and Check-list

No	Process Step	Check-List
13	Revise socket and hardware designs per test results as required	❑ Changes made to the socket and socket hardware per test results ❑ Force-deflection analysis and SI analysis redone if required
14	Finalize drawings and release design for production	❑ Keep-out volume defined and made sure it meets PRD ❑ Positional and absolute tolerances defined both for PCB and mechanical hardware ❑ PCB surface finish/plating material defined ❑ Final check to ensure design meets product requirement document (PRD)

Section 11
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