# Military Applications of Flexible Circuits

## Design for Manufacturing

Bradford Saunders

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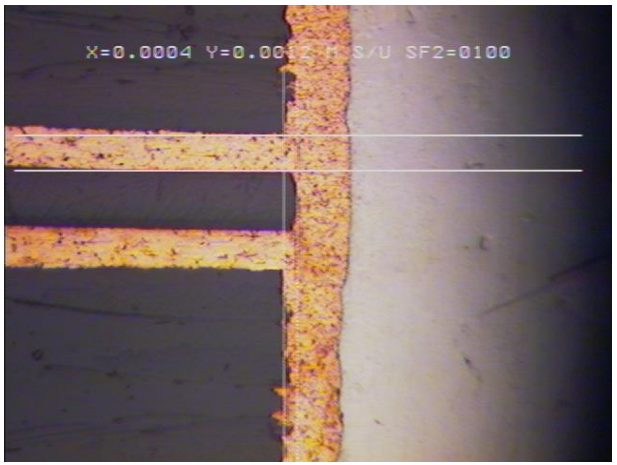
# Introduction




Three hour Seminar:

1. Conventional Flex
2. Basic Materials
3. Failure Modes
4. HDI Flex

*Please questions anytime*

Hard and soft copies may be minus images.

# Industry Specifications prevail

MIL-P-50884, MIL-PRF-31032

IPC (Association Connecting Electronics Industries)

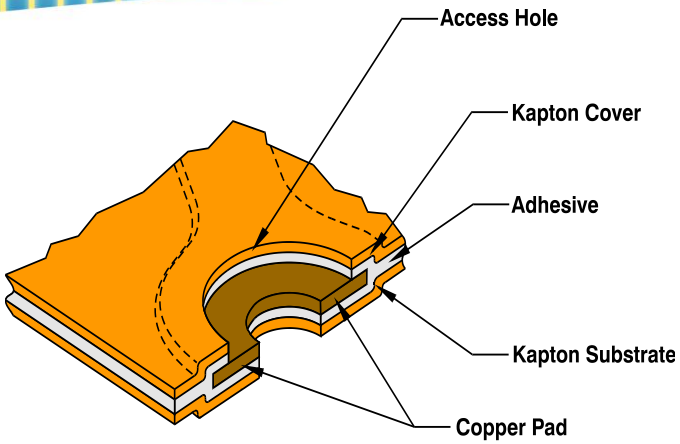
- Industry Specifications – Design, Material, Performance
  - **IPC 6013** - Qualification and Performance for Printed Flex Circuits
  - **IPC 2223** – Design Standard for Printed Flex Circuits
  - **IPC 4101** – Rigid board Material
  - **IPC 4202** – Flexible Dielectric Material
  - **IPC 4203** – Adhesive Coated Flexible Dielectric
  - **IPC 4204** – Metal Clad Flexible Dielectric
  - **IPC 600** – Inspection Bare Circuits
  - **IPC 610** – Inspection Assembled Circuits
  - **J-STD-001** – Soldered Assemblies

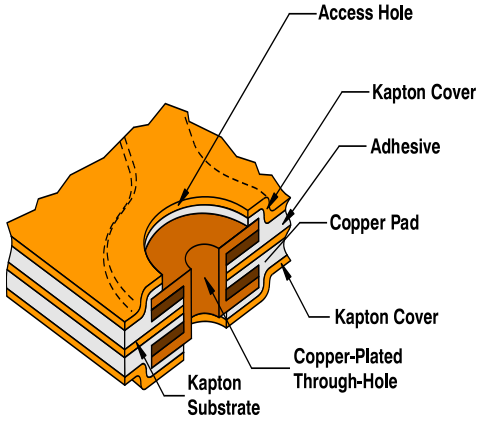
# Additional Industry Certifications

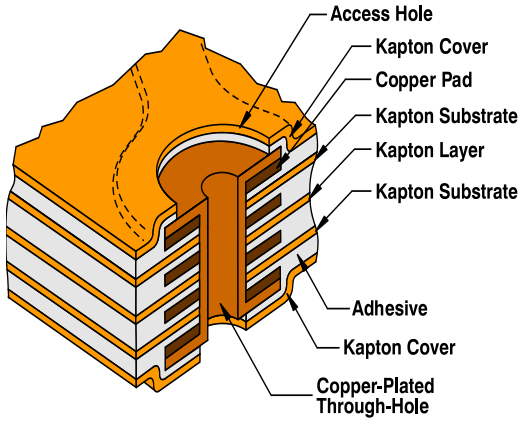
- ISO AS9100C certification
- Nadcap certification
- PCQR2
- HATS and IST used to validate reliability
  - HATS™ – Highly Accelerated Thermal Shock
    - Air-to-air thermal cycling
  - IST™ – Interconnect Stress Testing
    - Induced heat through current flow

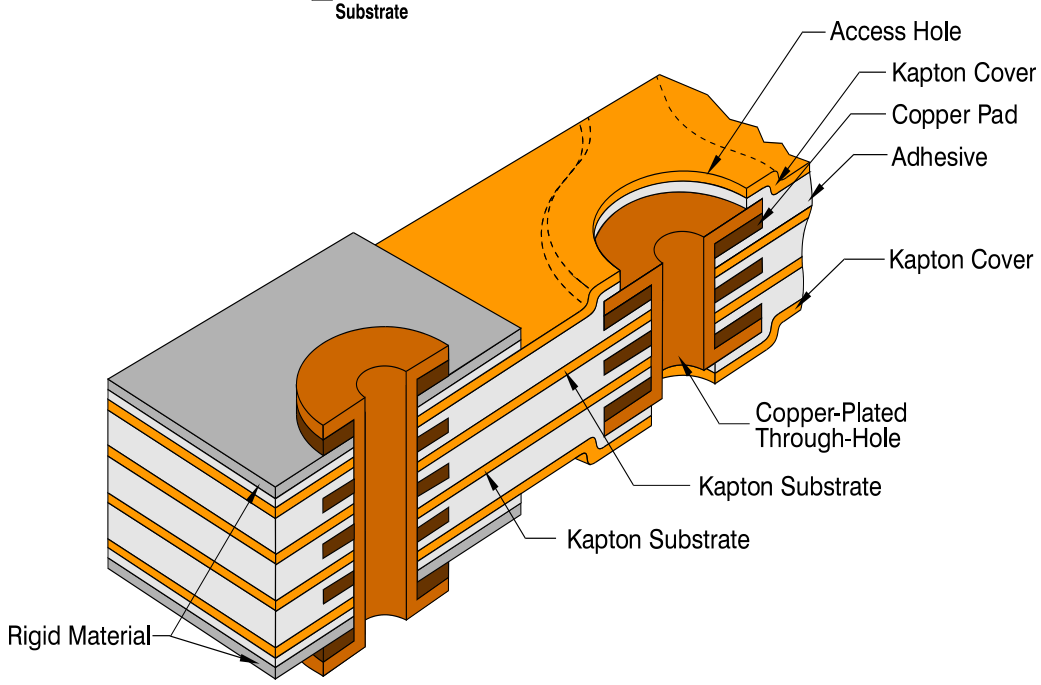
Lean Six Sigma

# IPC-6013, Type 1, 2, 3, 4



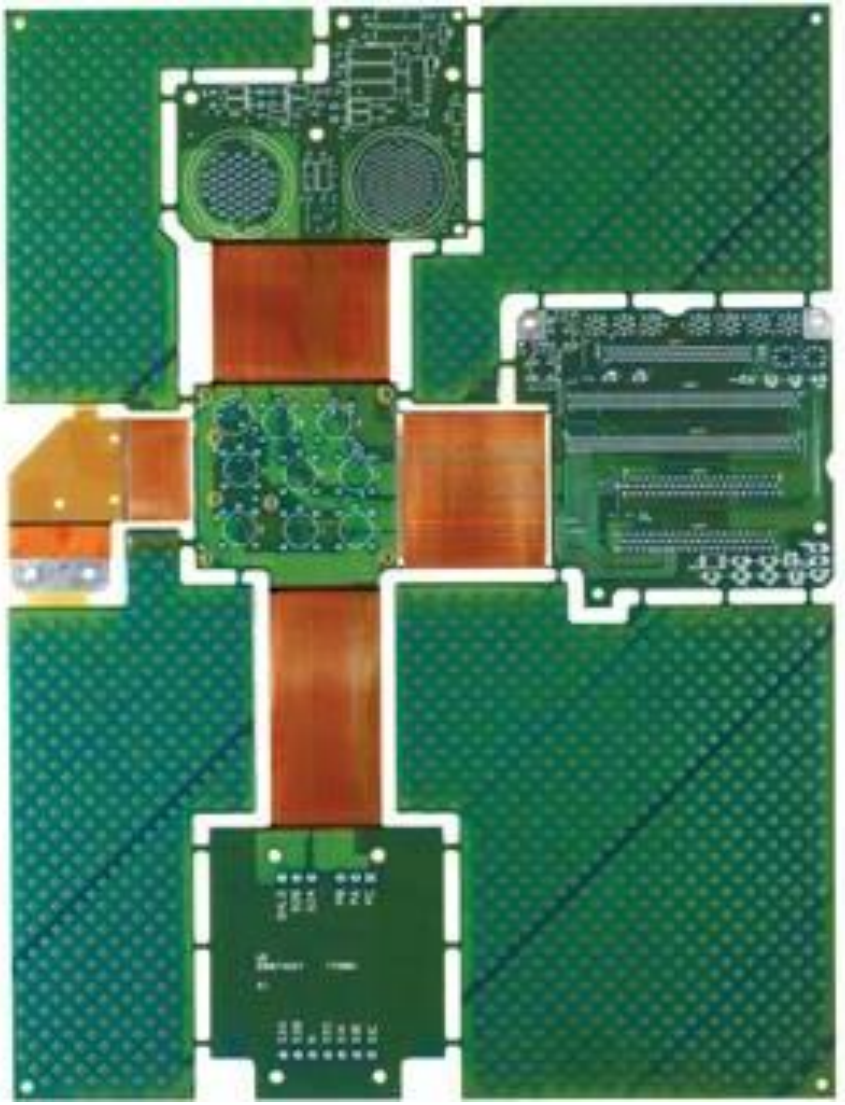



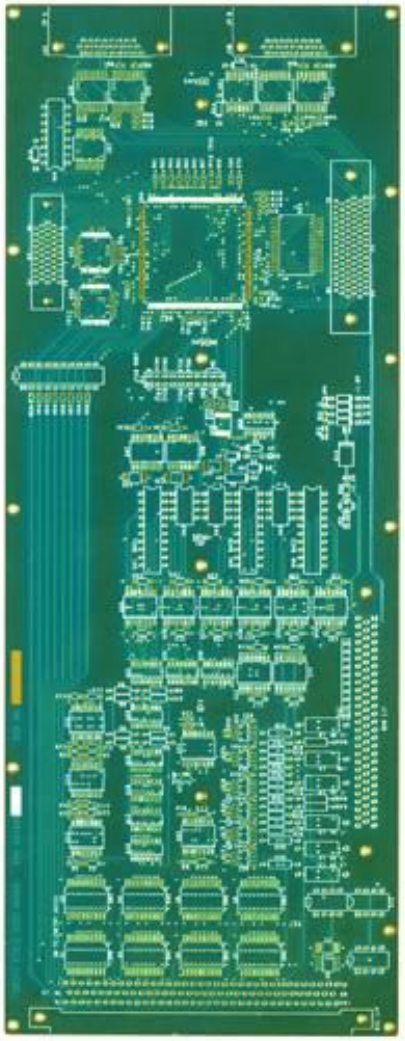

Conventional Flex Circuits

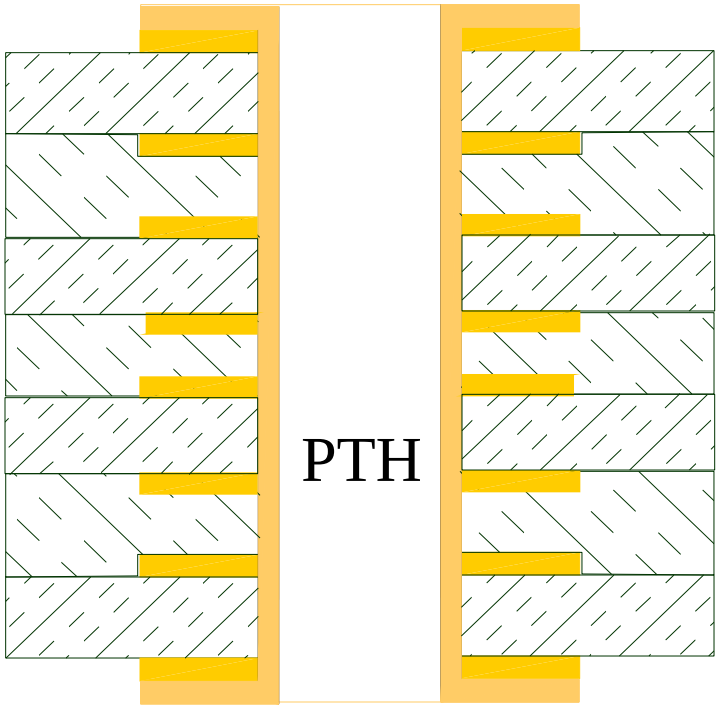
# Rigid-Flex Packaging

- Reliability
  - PTH
    - Adhesiveless
  - Heritage & Specifications
  - Less Parts (connectors)
  - Signal Integrity
- Ease of assembly
  - No Hand Wiring
  - No Daughter Cards
- Cost reduction
  - Real Estate Savings
  - Reduce Weight

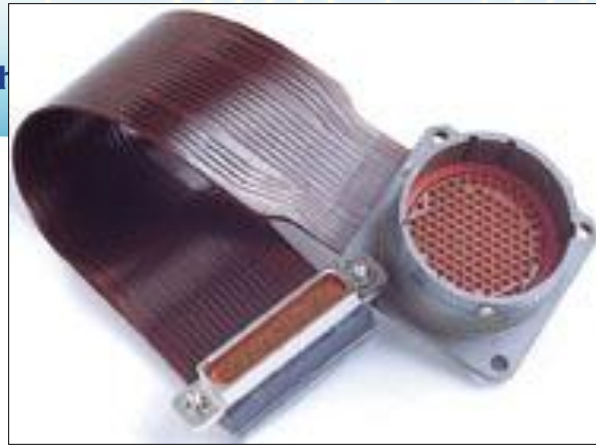


# Conventional Rigid Build





# Conventional Rigid-Flex Build



I/O Flex

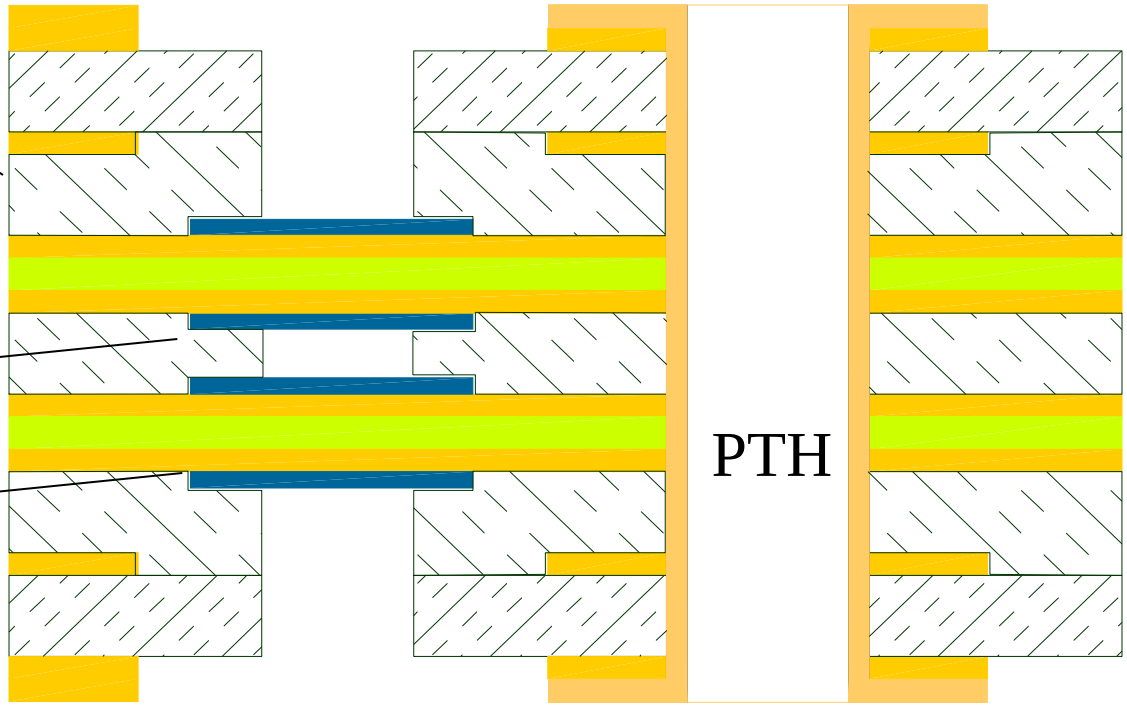
Rigid C-Stage

Rigid B-Stage

Flex

Cover Coat

Adhesive



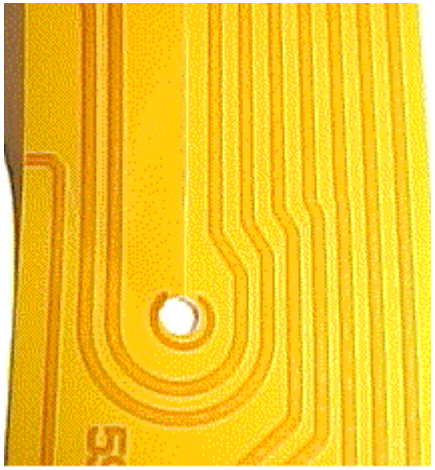
Plated Through Hole Z axis figures

# Material Selection

| Material | Glass Transition Temperature (Tg) | Coefficient of Thermal Expansion (Z ppm/°C) | Moisture Absorption (%) |
|---|---|---|---|
| **Polyimide (Flex)** | 210-260 °C | 125 | 0.8 |
| **Adhesive (Cover Lay)** | 33-39 °C | > 400 | 2.8 |
| **Epoxy (FR4 Rigid)** | 150-180°C | 80 | 0.18 |
| **Polyimide (Rigid)** | 220-260 °C | 120 | 0.5 |

# Type 1 & 2

- Single sided
  - Repeatable, Less hand touch (verses hand wiring)
  - Single sided, dual access available

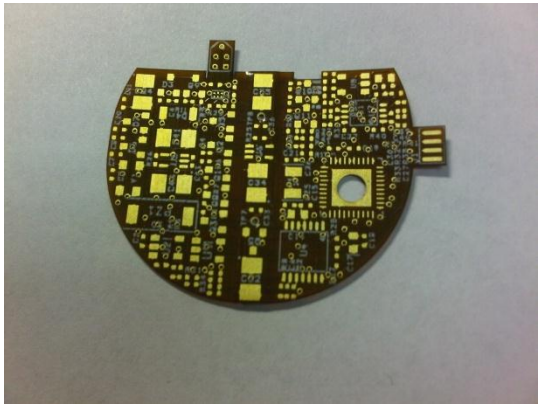


- Double sided
  - Differential and Single Ended Impedance
  - Smallest termination length (verses wire)

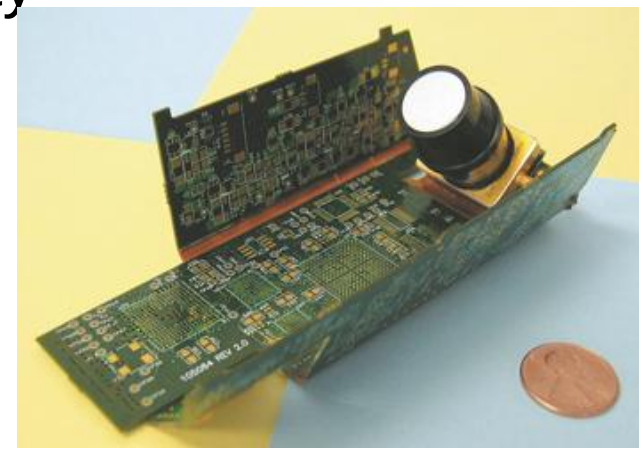
- Advantages
  - Lightweight inexpensive
  - Excellent usage in folded or tight radius
  - Shielding; Silver Ink, Conductive Film
  - External dielectric; LPI, Coverlay, Rogers
  - Stiffener lamination

| Perimeter Tolerance –*critical item* | | | |
|---|---|---|---|
| Tooling Method | SRD | Laser | Hard Tool |
| Hole to Edge | ±.010 | ±.0020 | ±.0020 |
| Outline | ±.005 | ±.0010 | ±.0012 |
| Trace to Edge | ±.010 | ±.0010 | ±.0011 |

# I/O + Daughter Card

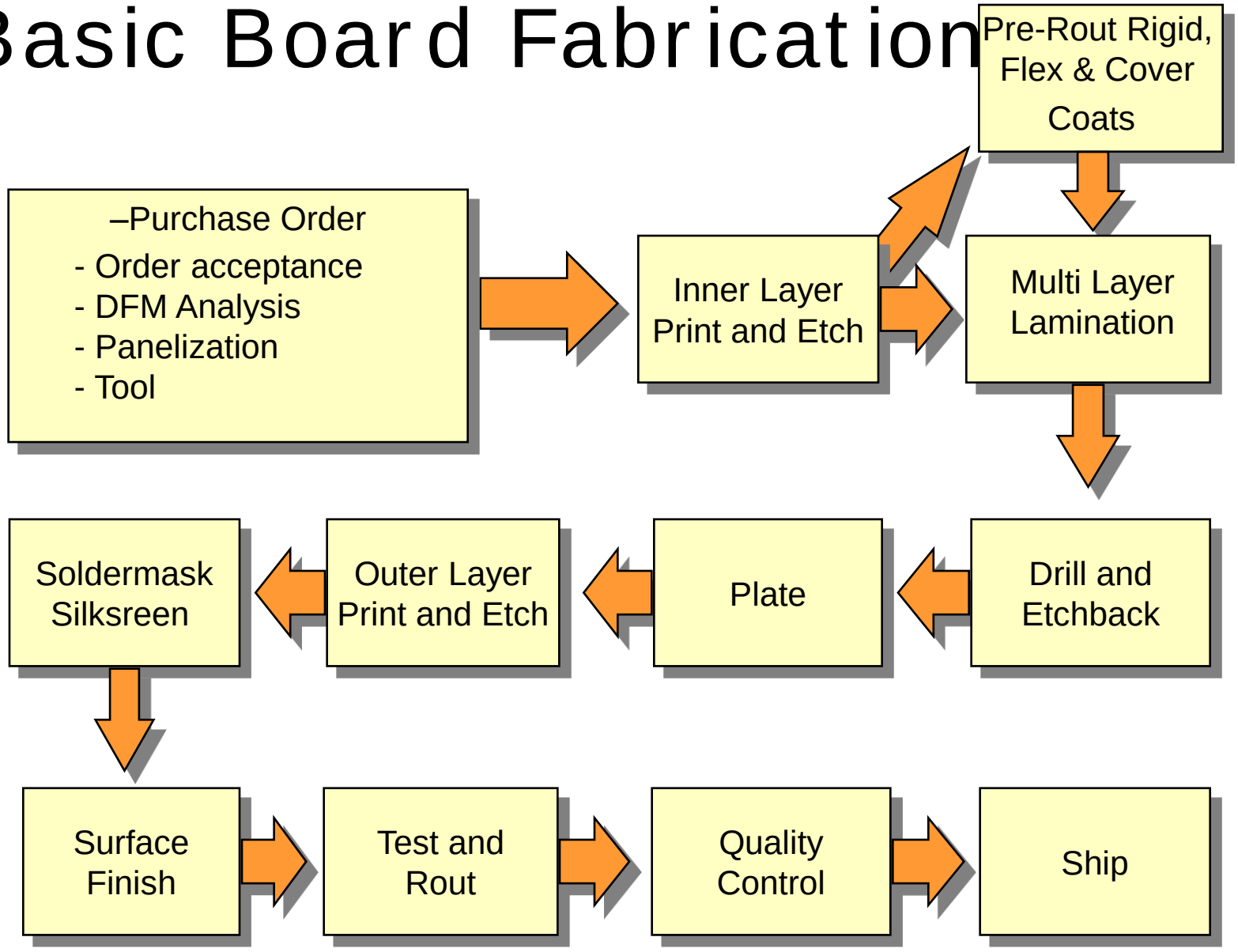


- Multilayer Flex  Type 3
  - Engineered adhesives
  - Turnkey Assembly; fully tested
  - Lower cost to Customer
    - Lowest aspect ratio increases yield
    - Higher piece count per panel
  - Material choices for Best flexibility
    - Shielding; Silver Ink, Conductive Film available
    - External dielectric; LPI, Coverlay, Rogers
    - Stiffener available

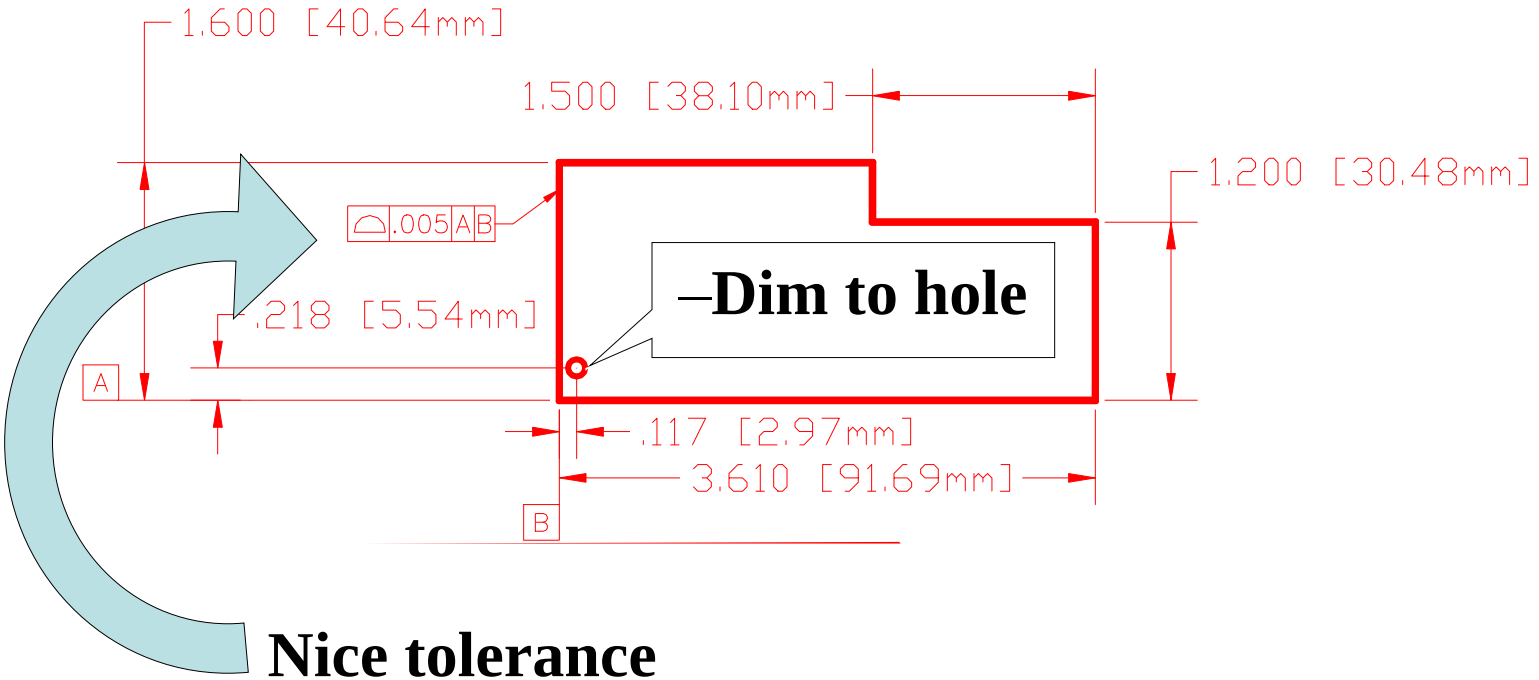


- Rigid Flex, Type 4
  - Rigid: epoxy, polyimide, others
  - Flex APLS (/11) or Adhesive (/1)
  - Sequential lamination & Customs

# Basic Board Fabrication



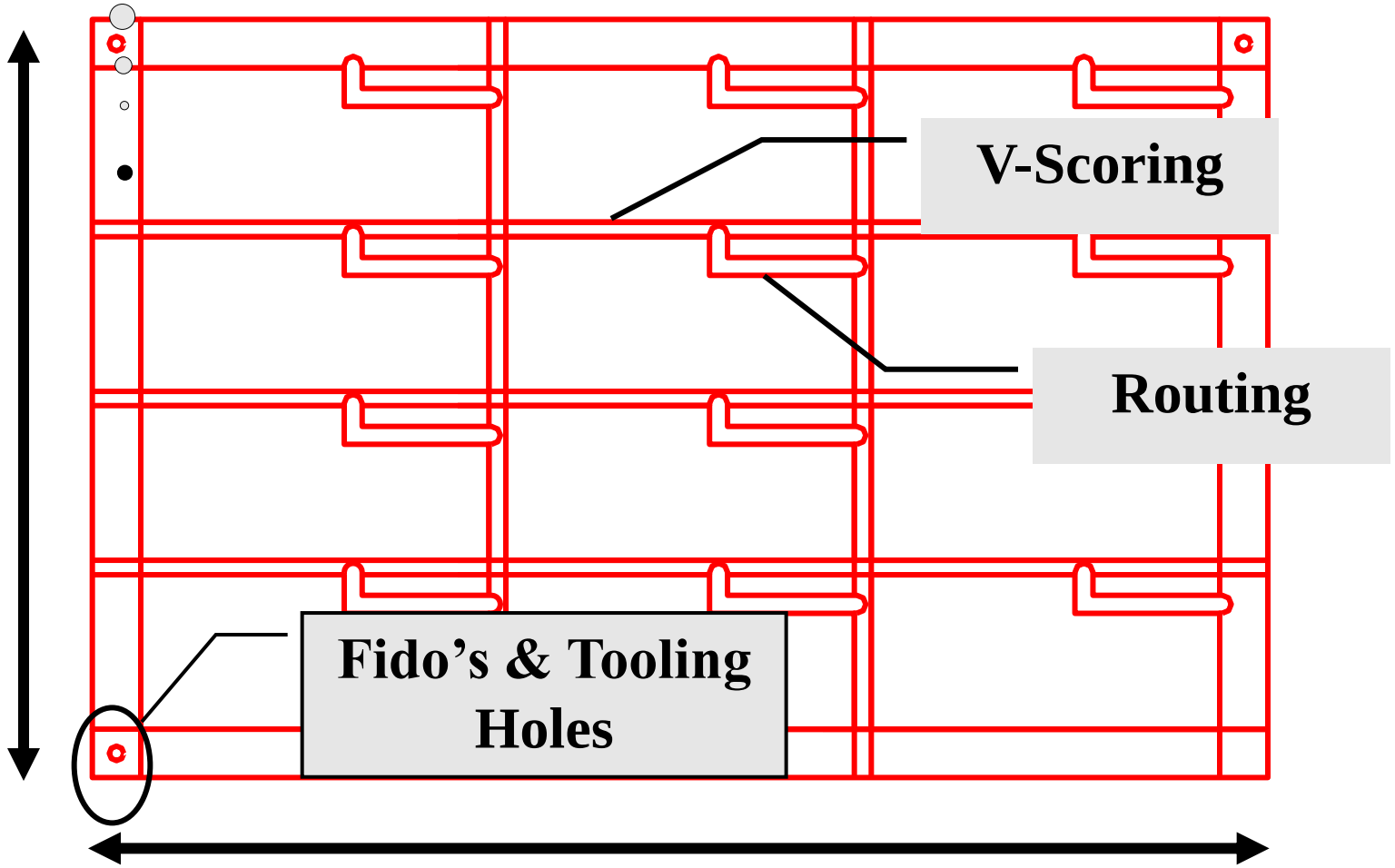
# The Board




**Nice tolerance**

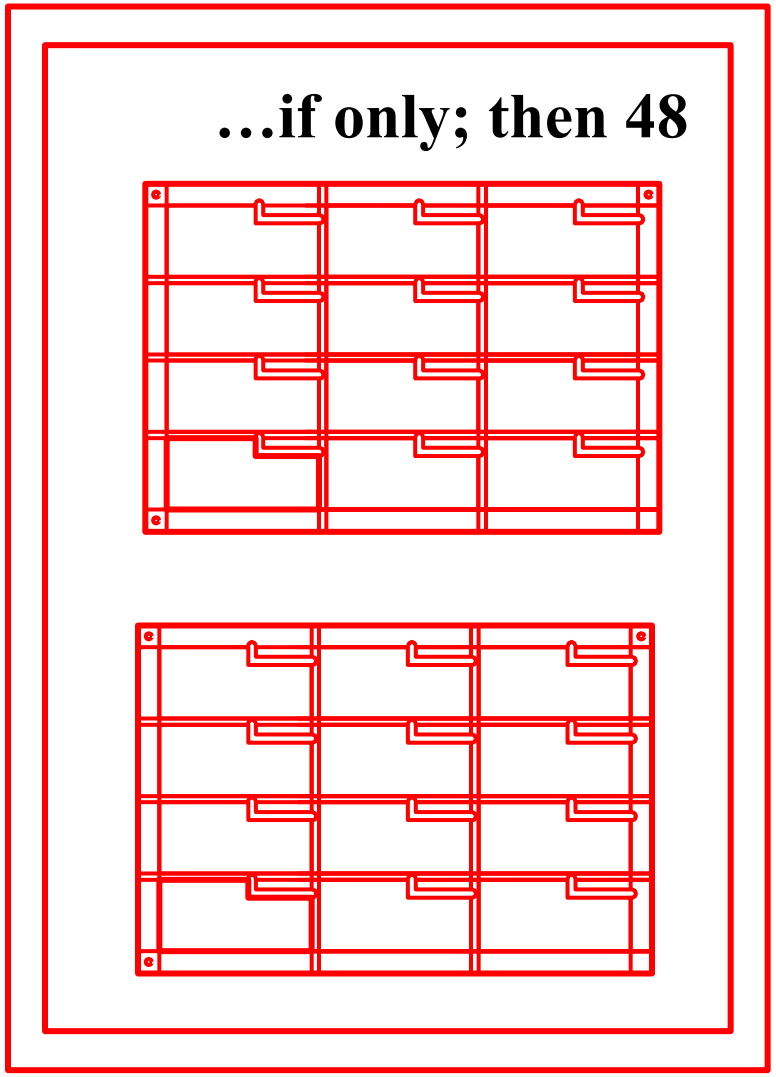
# Assembly Array

Needed?

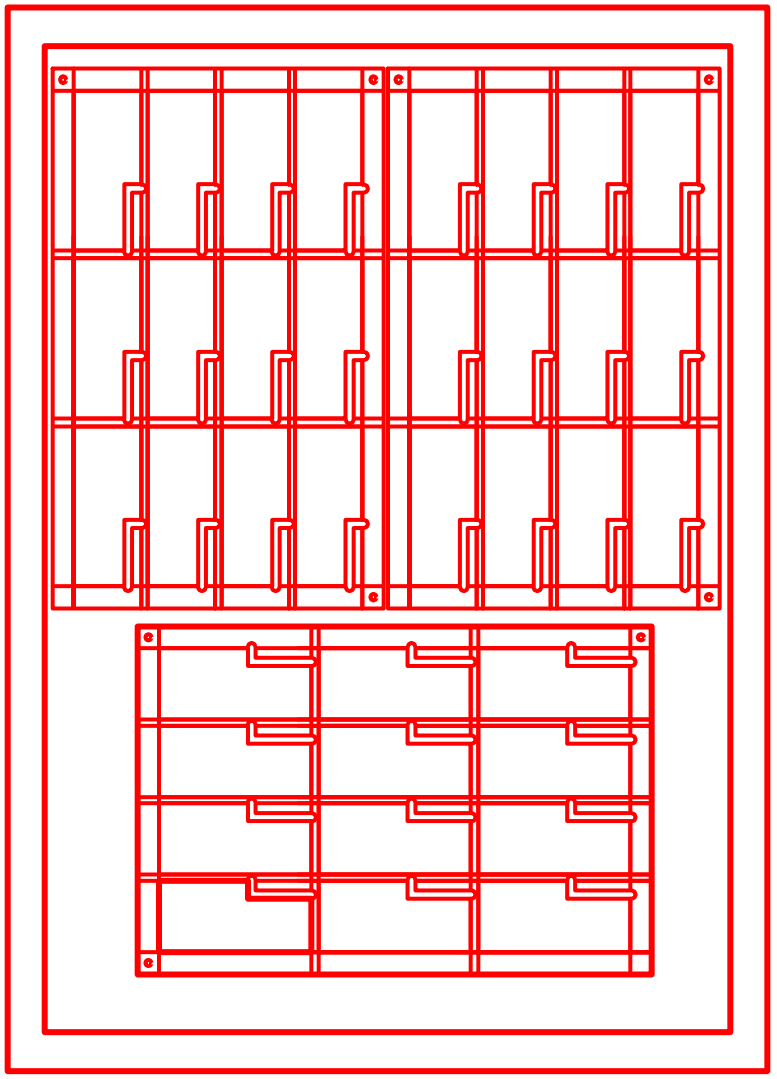


# Major Cost Driver - Panelization

## Production Panel

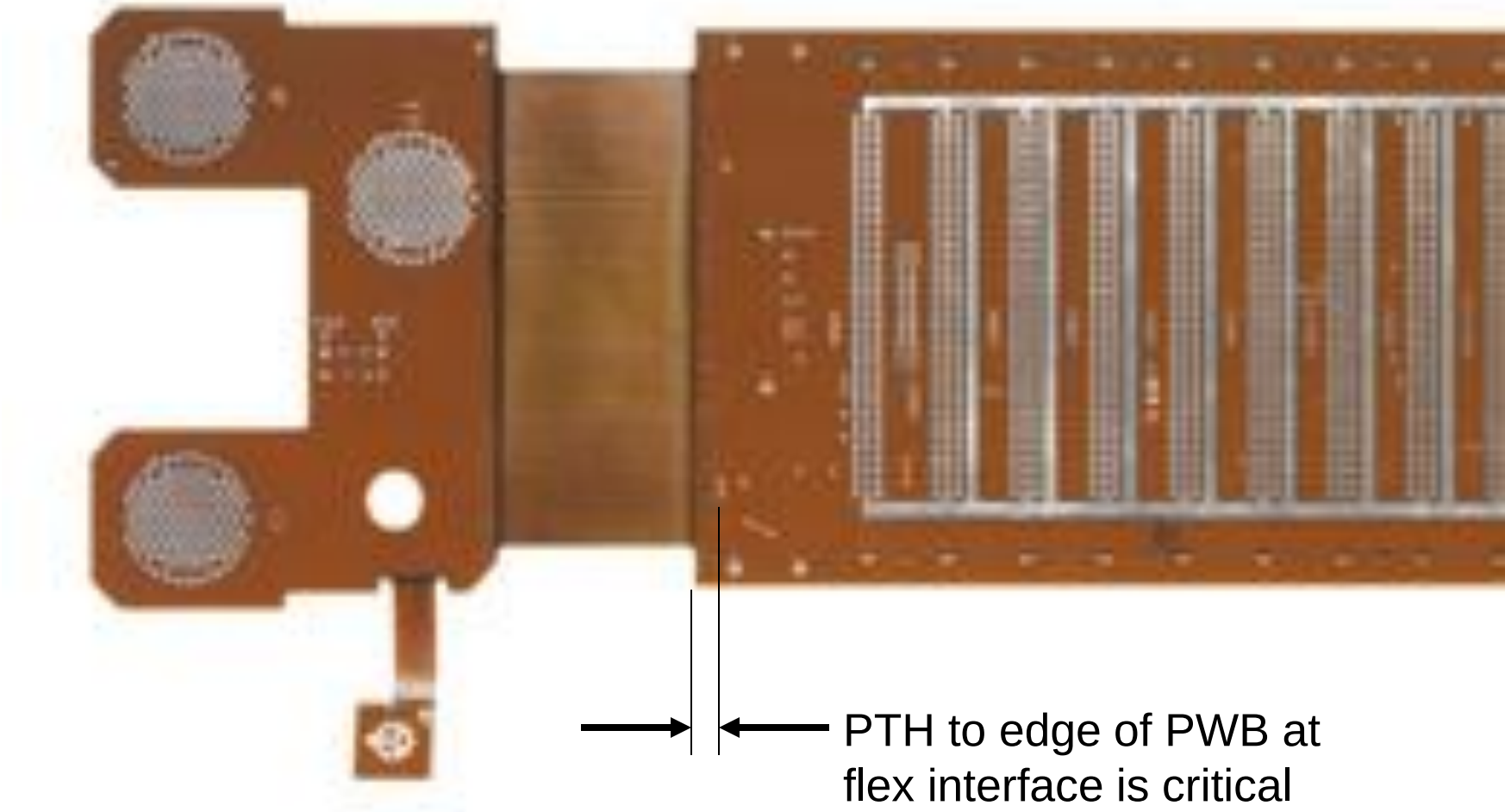



24 boards



36 boards

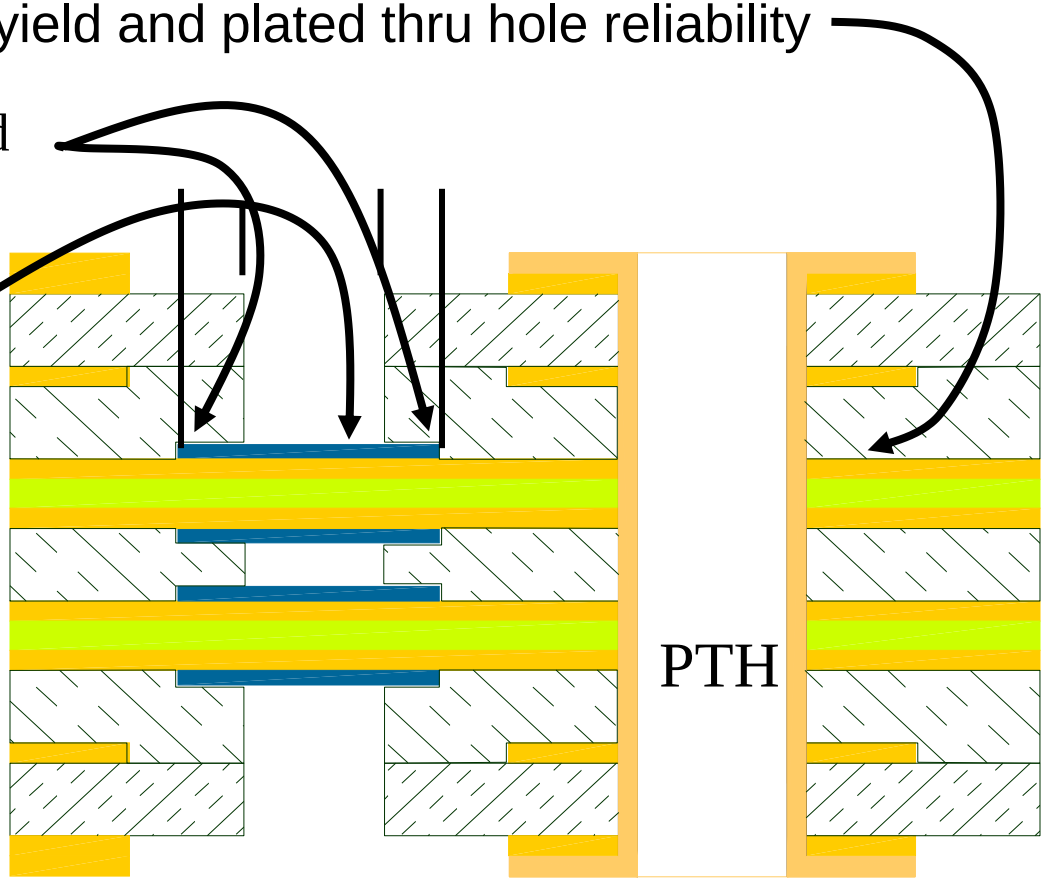
# The most critical item in Type 4 design



# critical item background

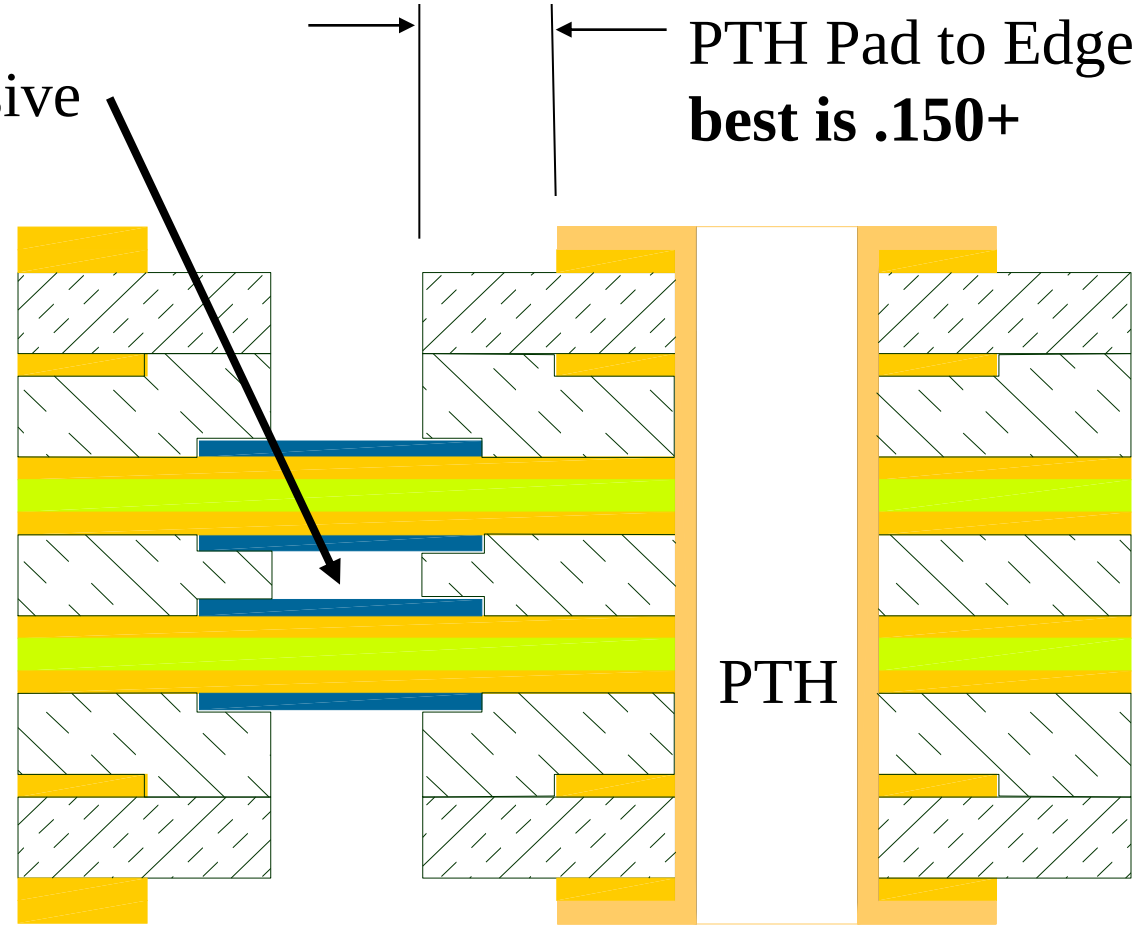
## Rigid Flex Fabrication “Pull Back” Method

- Adhesive removal results in yield and plated thru hole reliability
- “pull back” Coverlay from rigid
- .020 – .050 under rigid section
- Coverlay only in flex area



# Adhesiveless Build

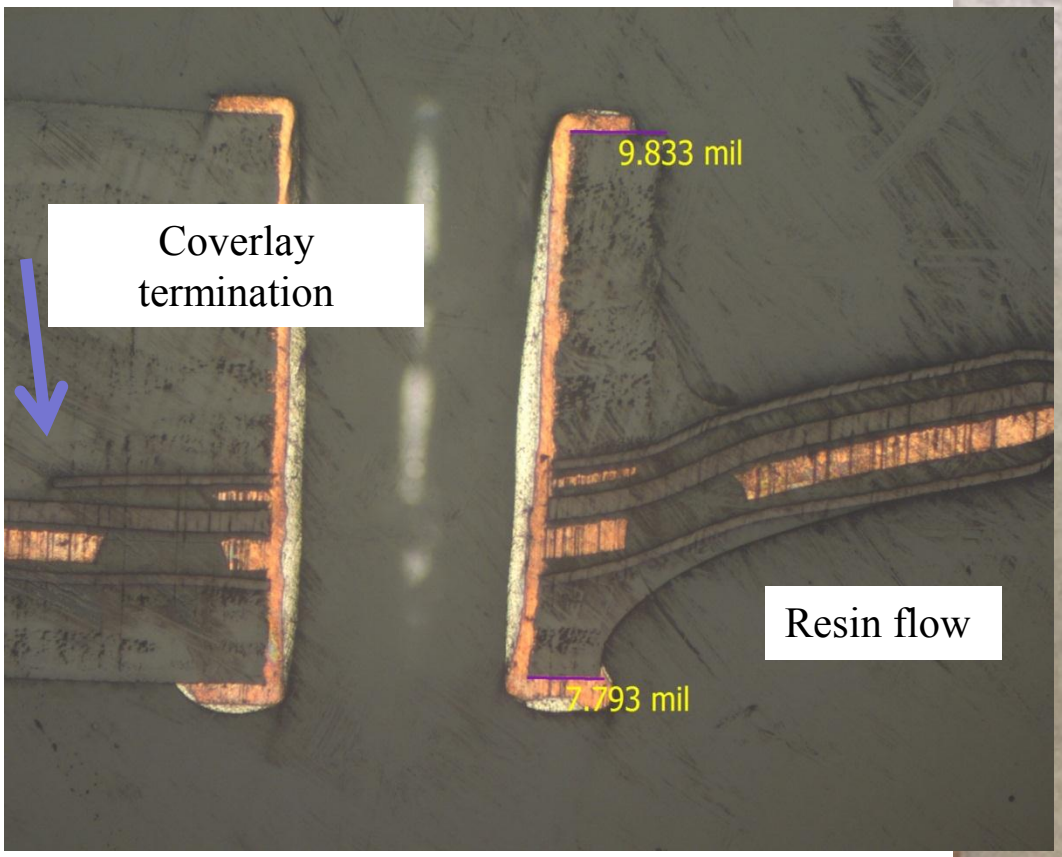
- Adhesive only within Cover Coat; not in PTH
  - No Adhesive

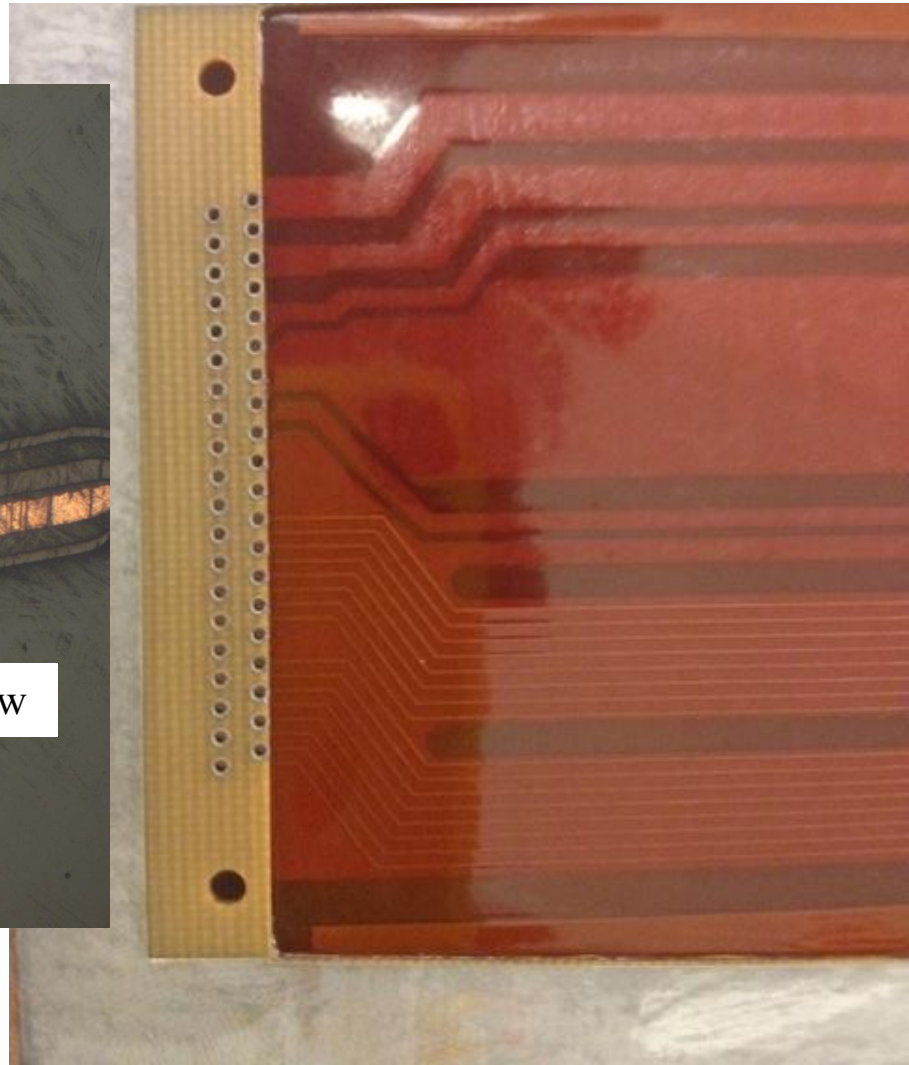



- **8 Layers**
- **4 Flex (APLS)**

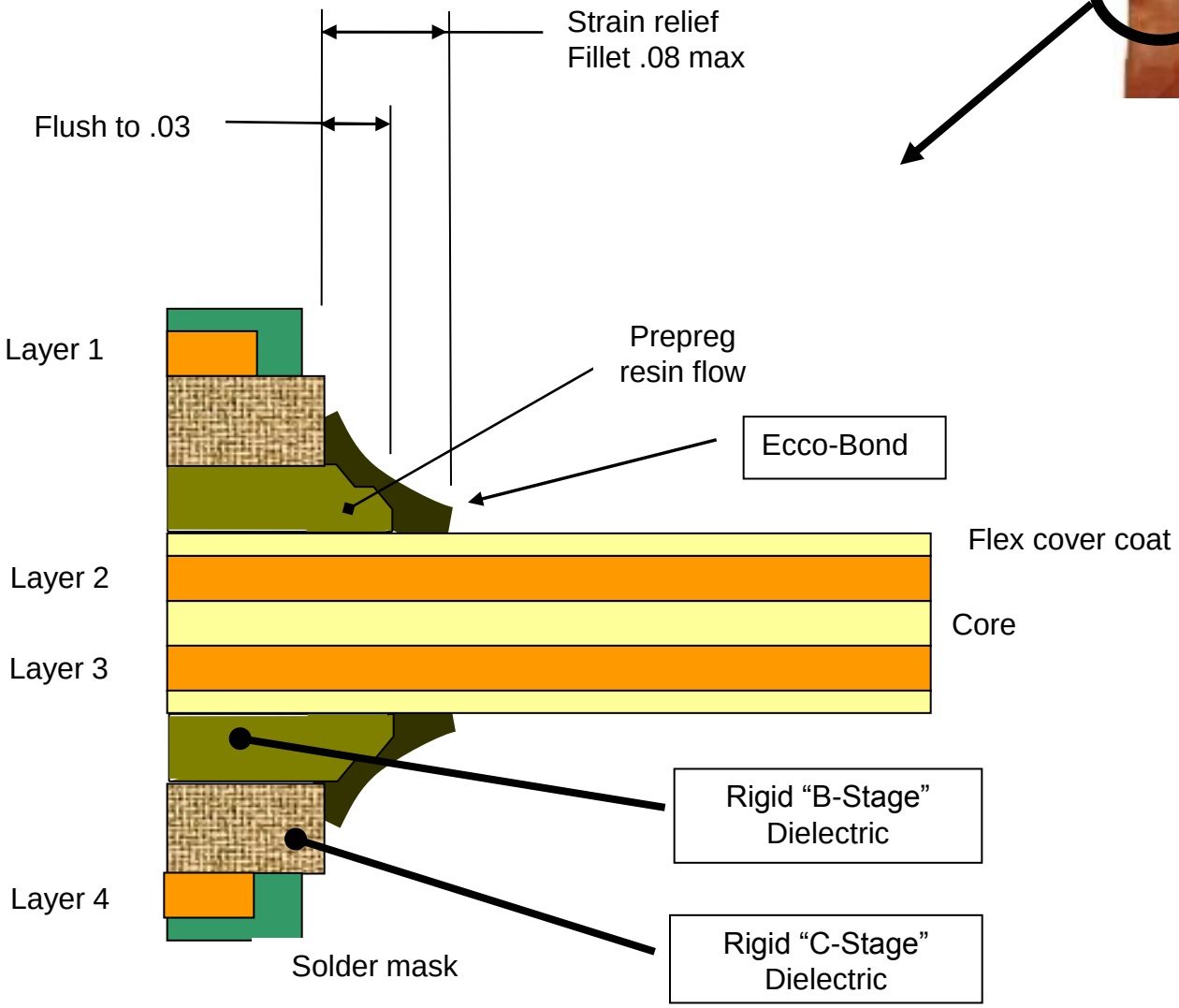
# Lessons learned

- Per print configuration had very high fallout
- Huge piece part price increase for future builds



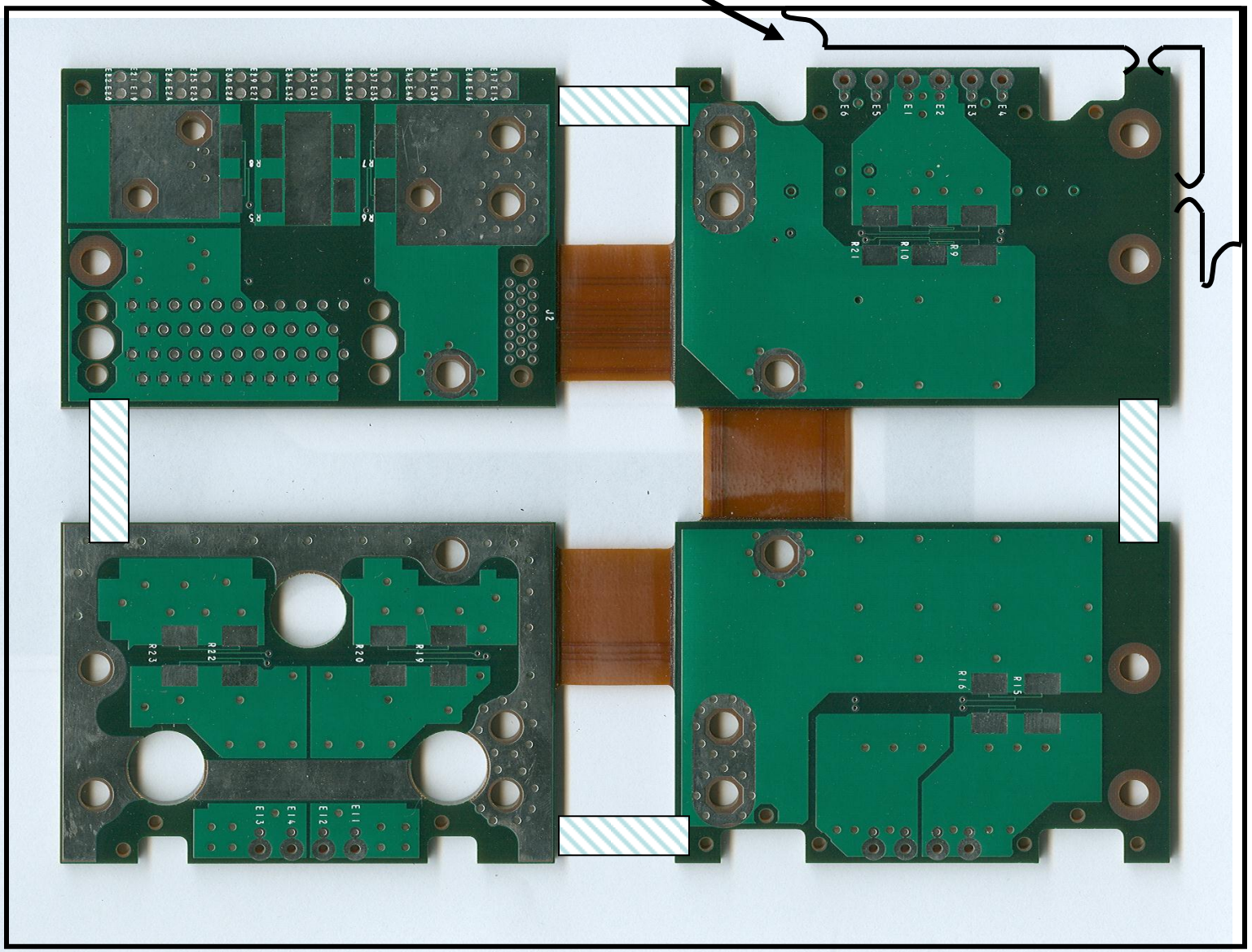



# Edge Consideration Transission line



# Heavy copper Flex

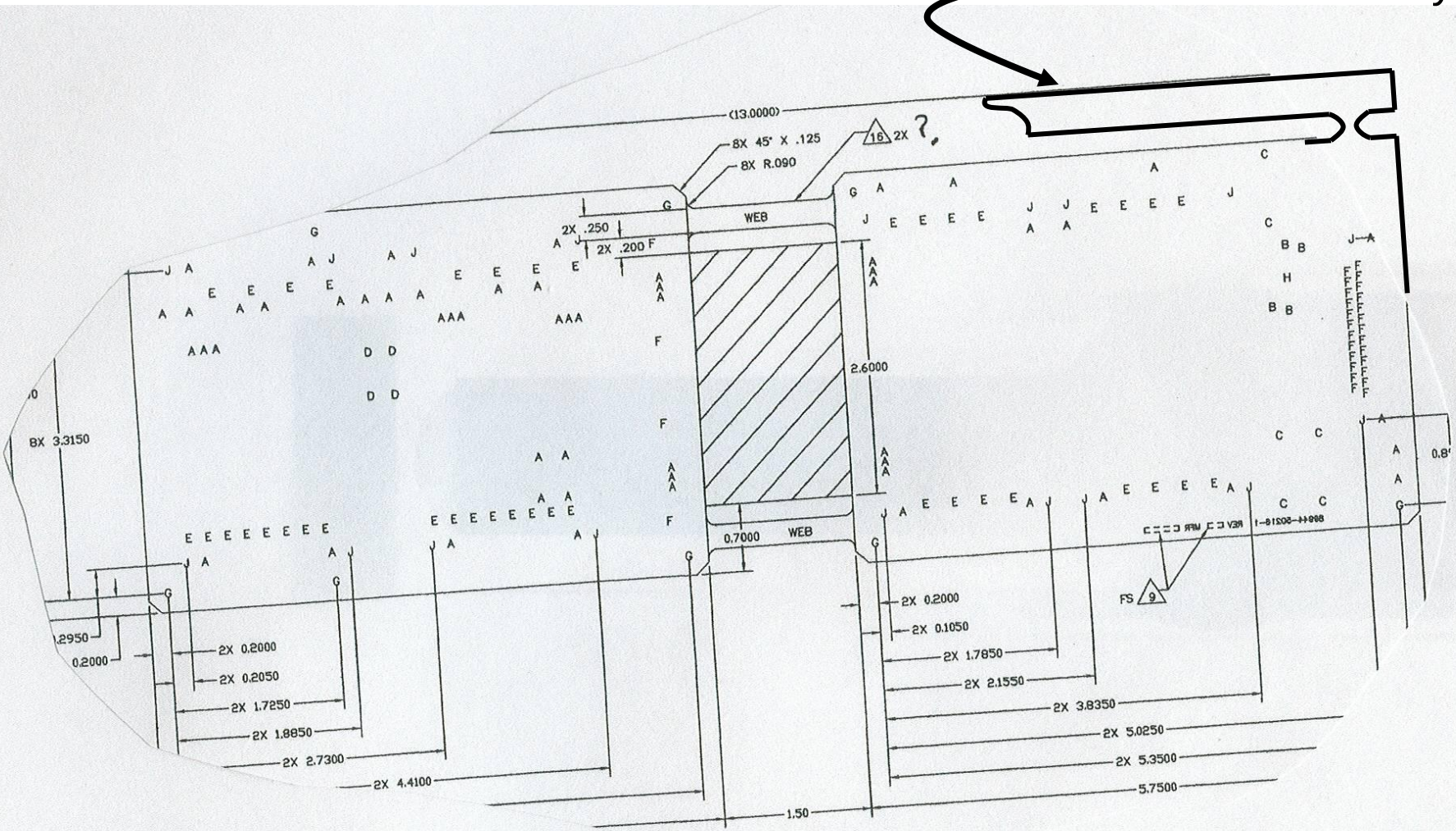
–Conventional Array



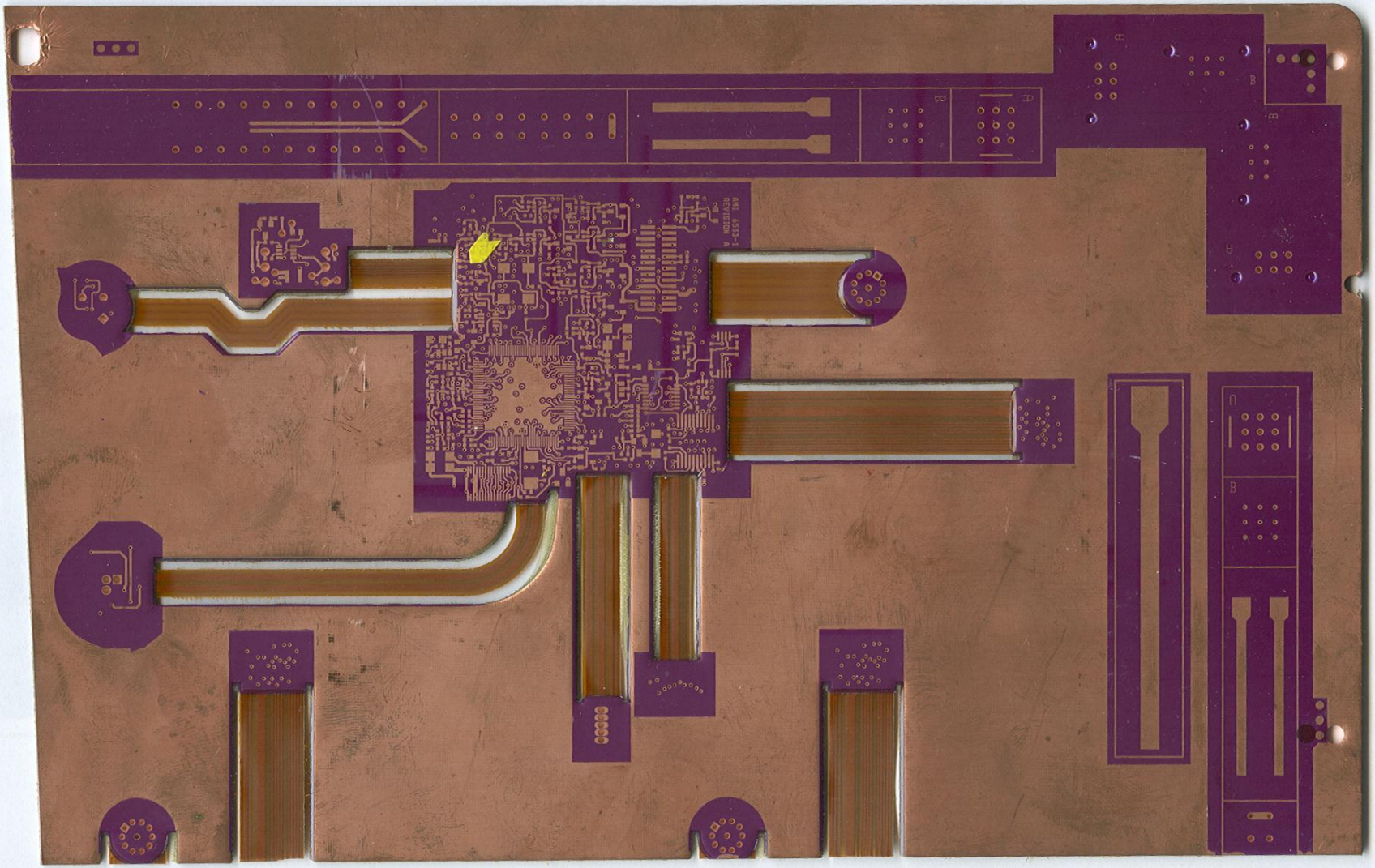
# Simple Array

Saves 1/3 of cost
Allows more up per panel

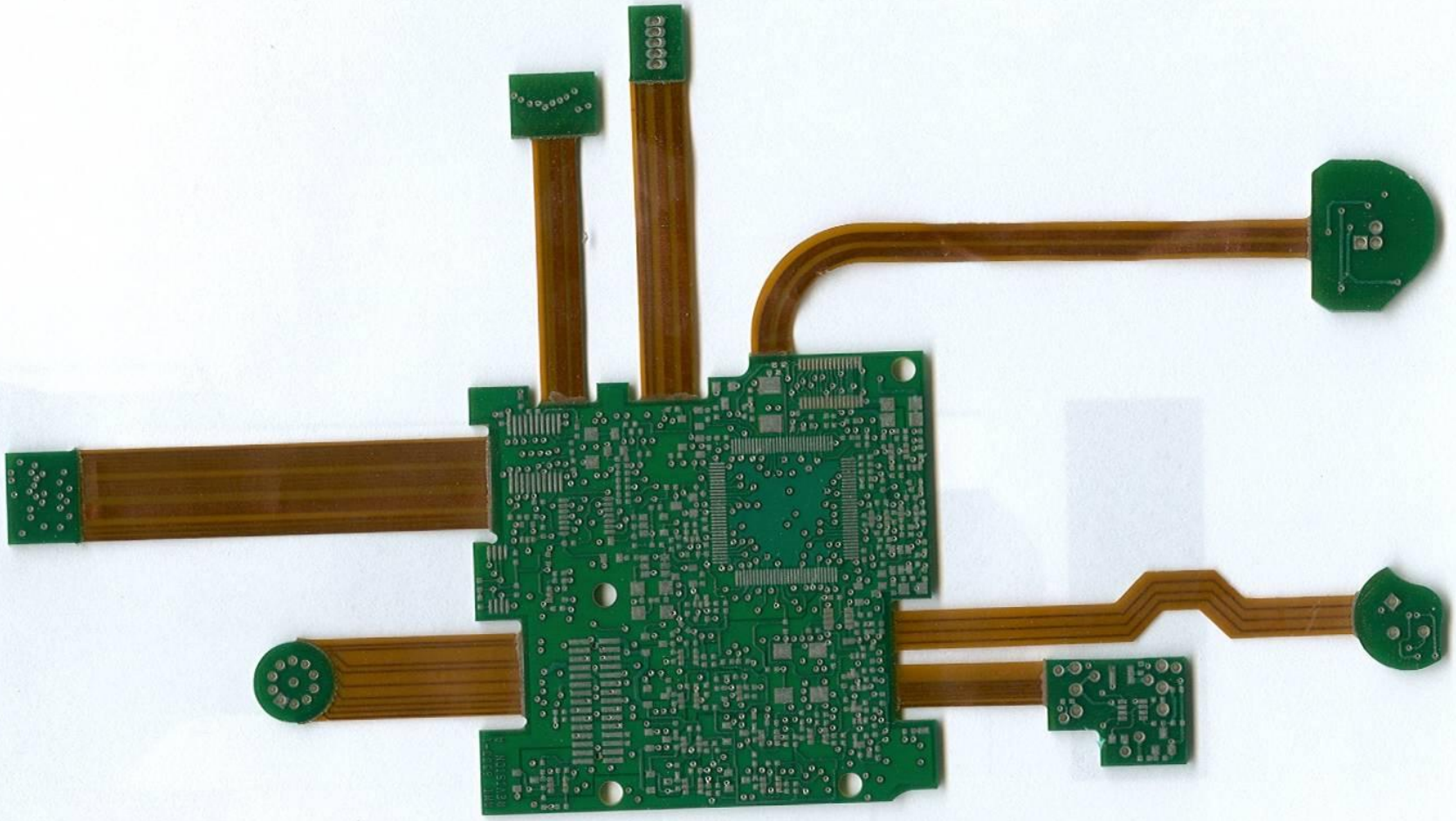
–Conventional Array



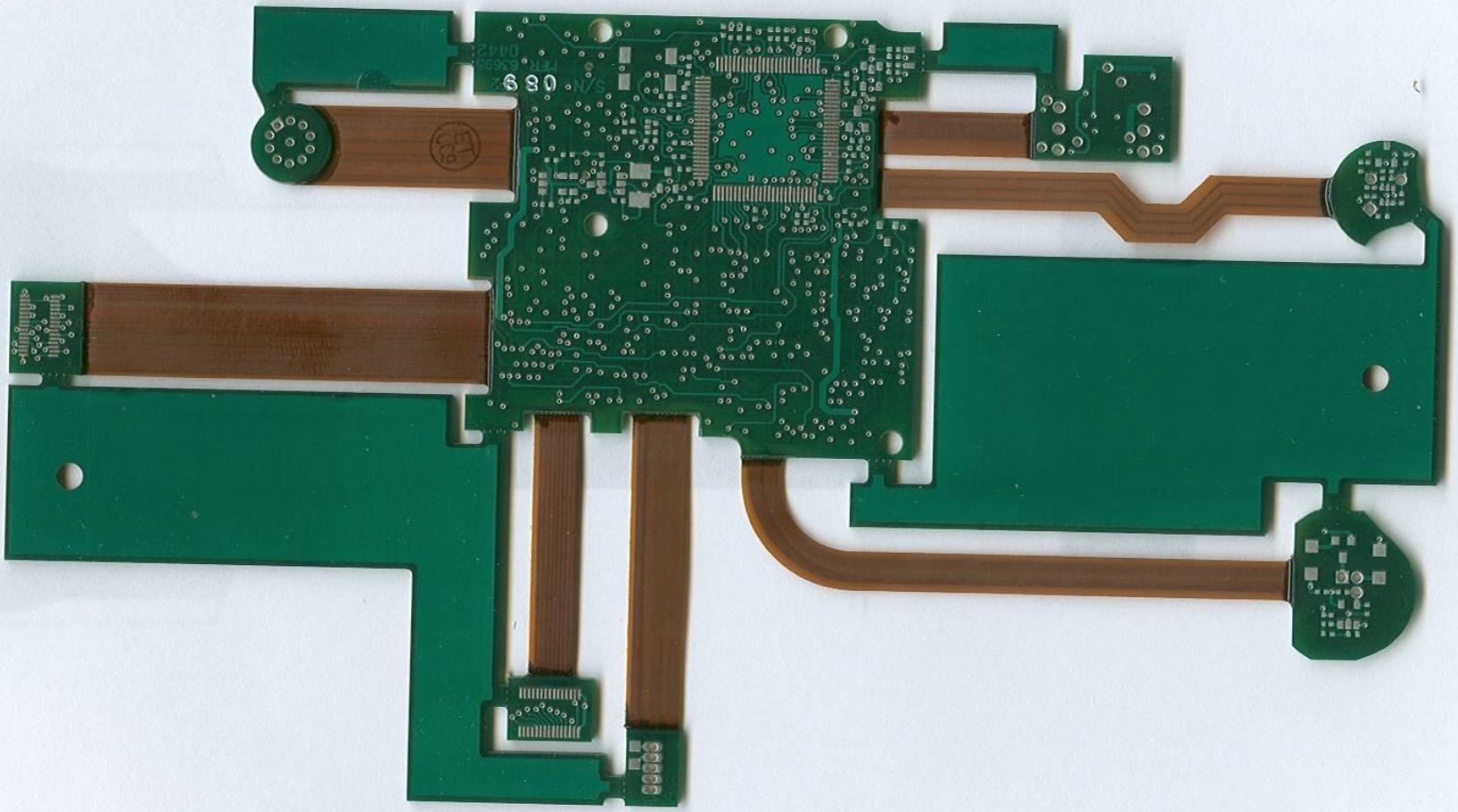
# View of Flex in Production Panel



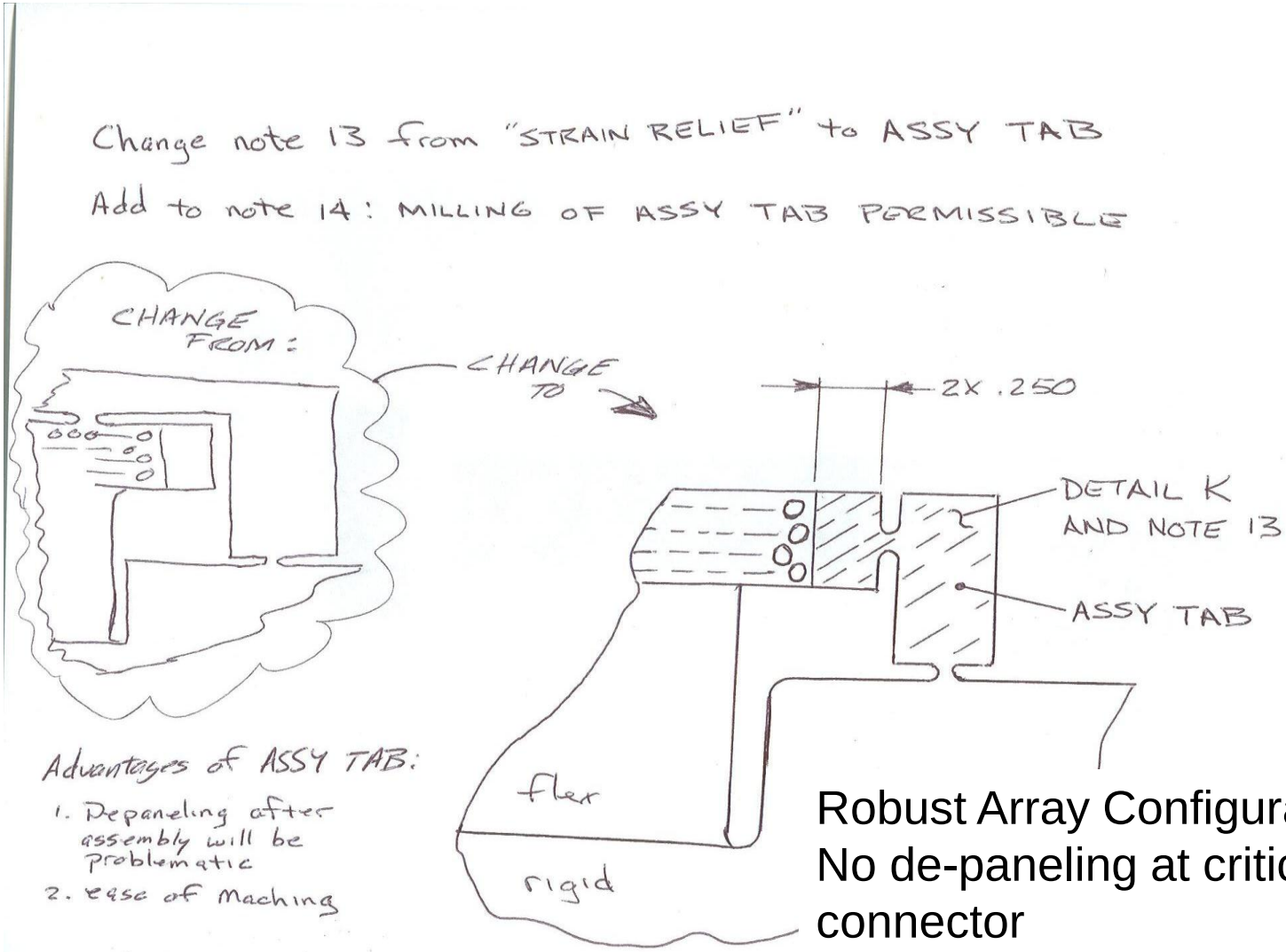
# Arrays for Flex



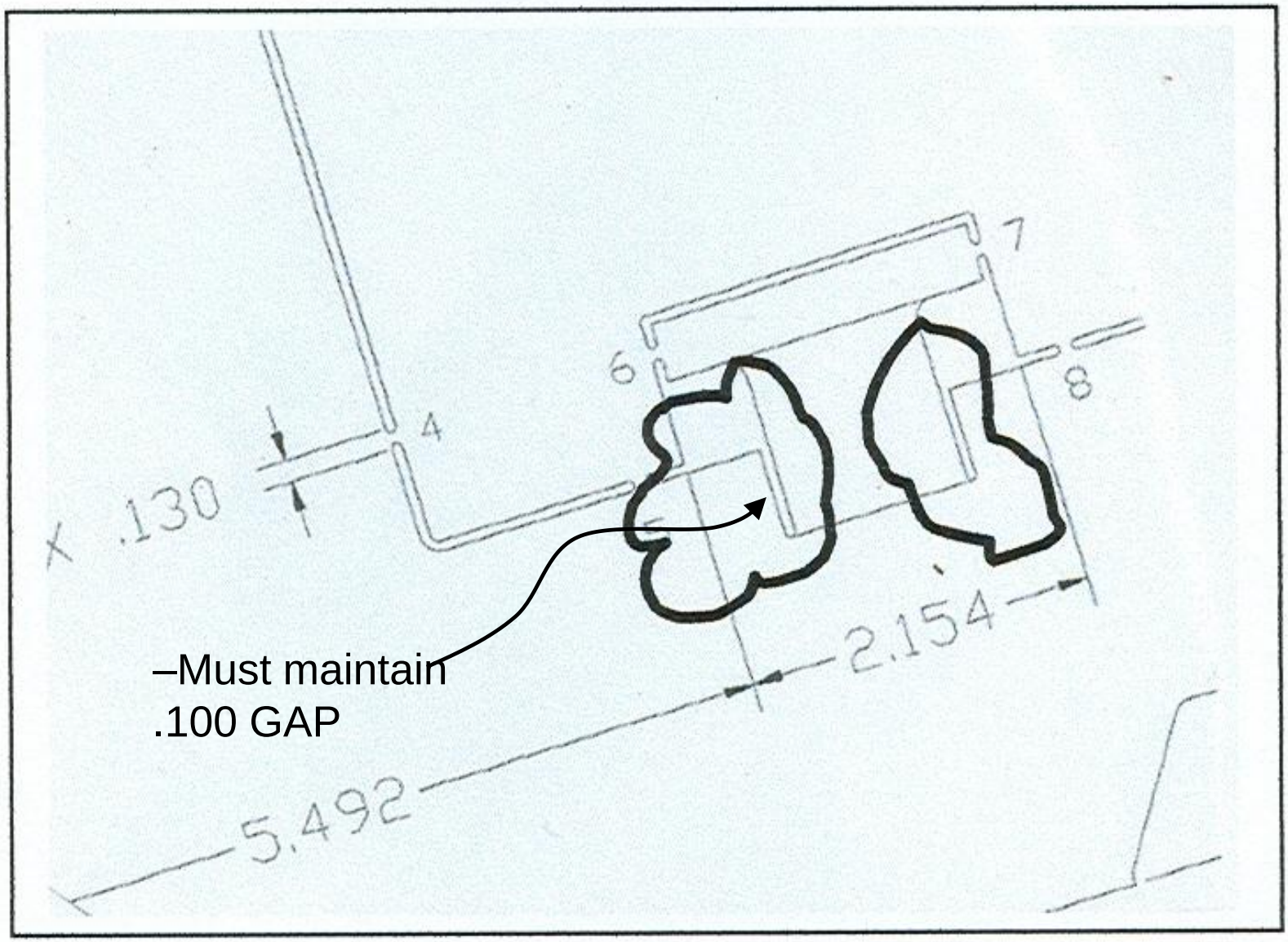
- Greatly increases assembly throughput
- Greatly increases fabrication yield



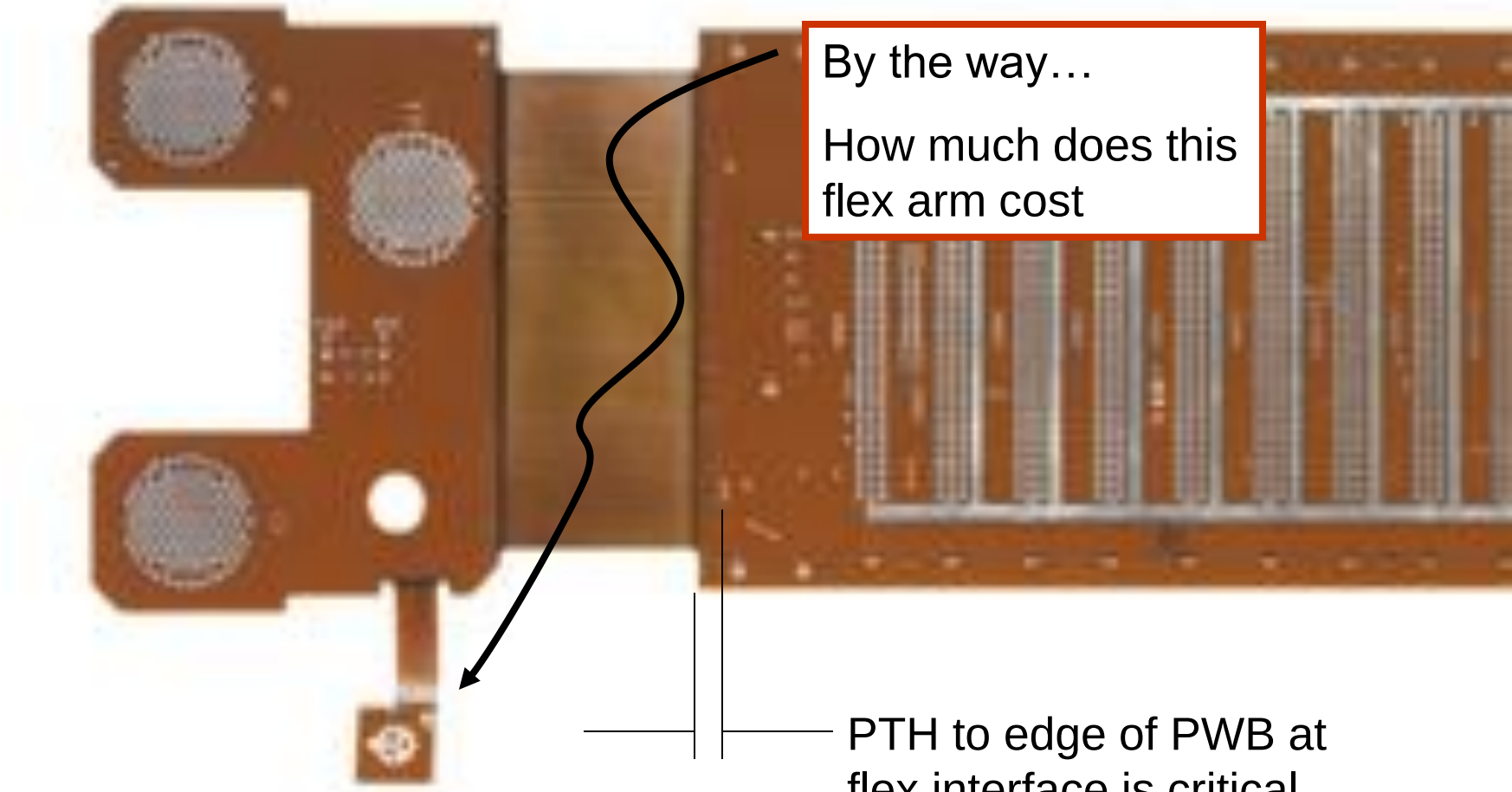
# Quick check during layout



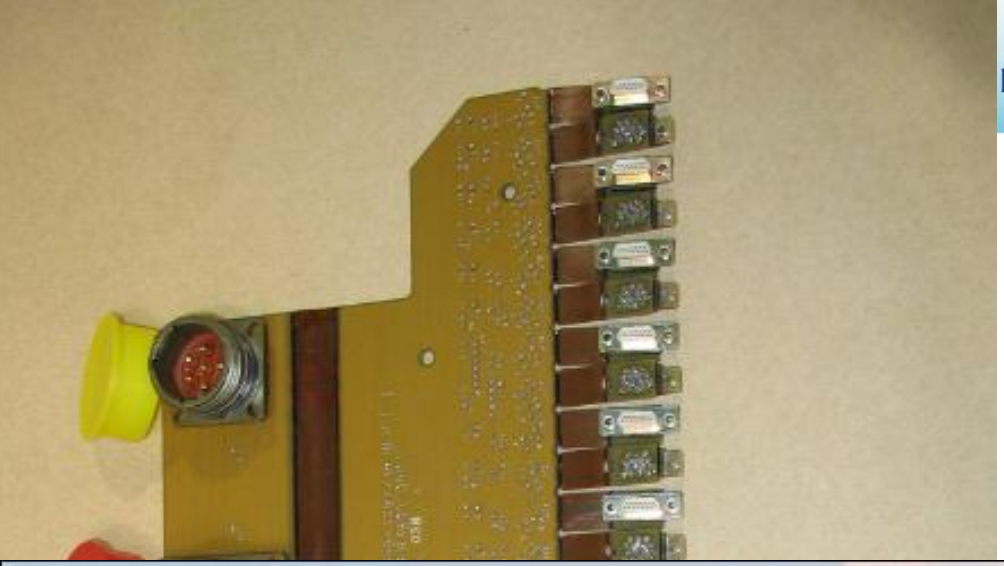

Robust Array Configuration
No de-paneling at critical connector


7
6
8
4
X .130
2.154
5.492
–Must maintain
.100 GAP

# How do you array?

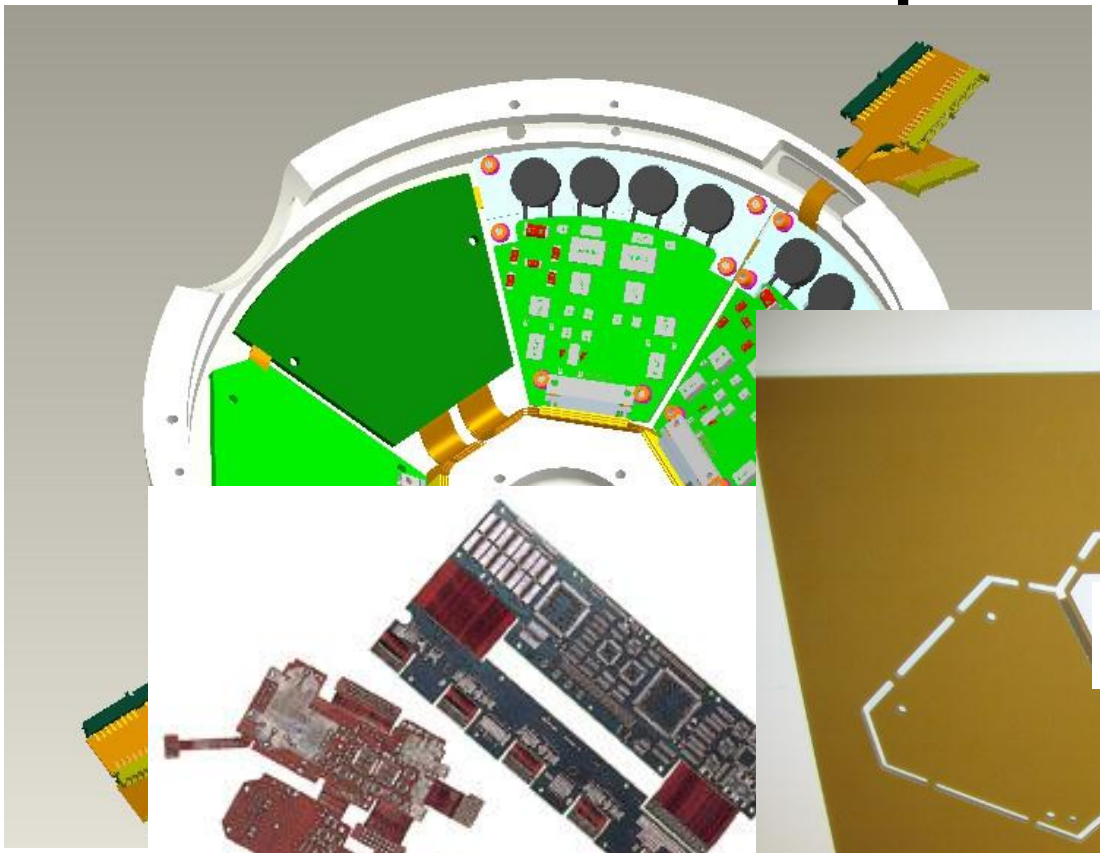


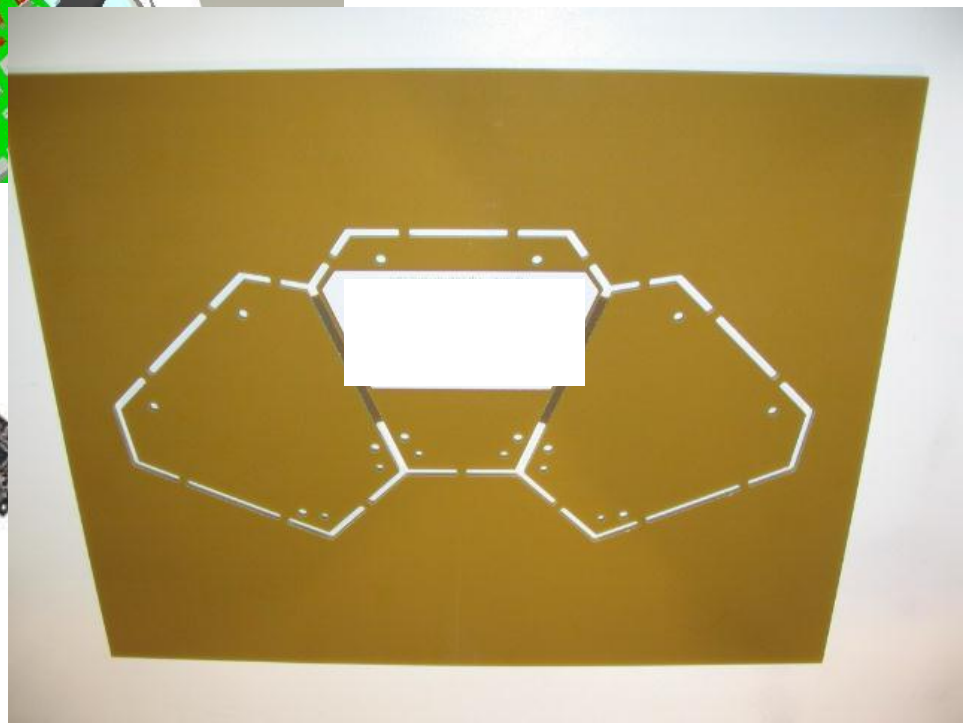
# Advanced Flex Configurations



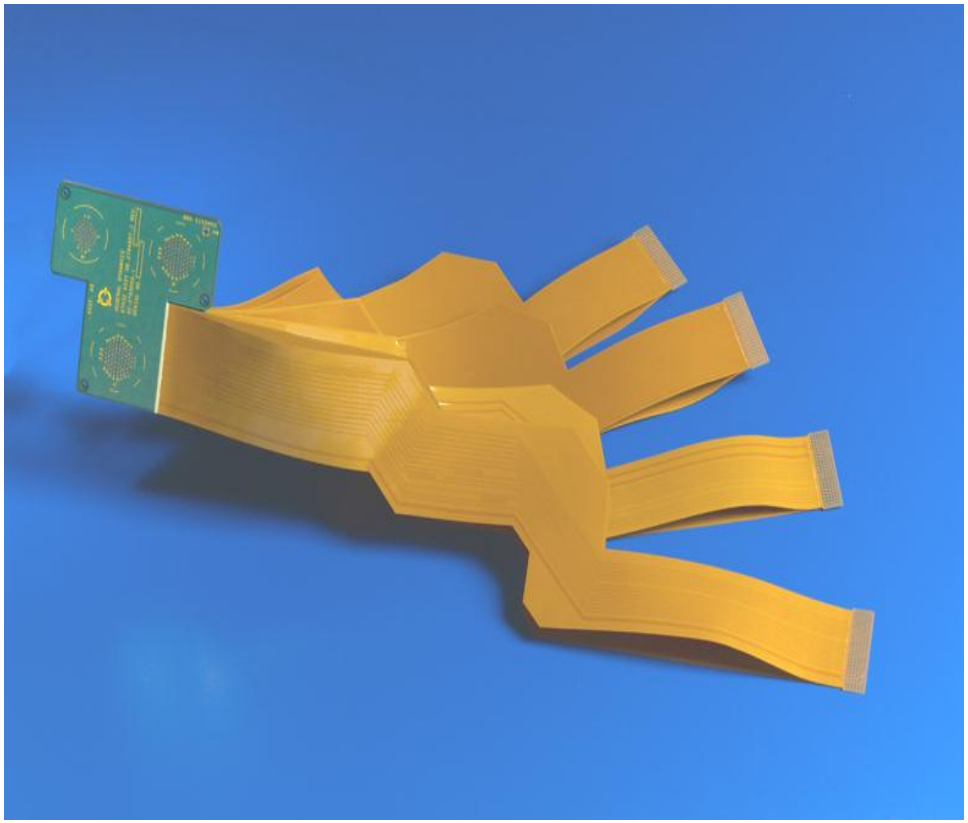

- Used extensively on Military Product
- Mission Critical
- Human Life Dependant
- Large scale systems to hand held

# Model and Mock up on new designs





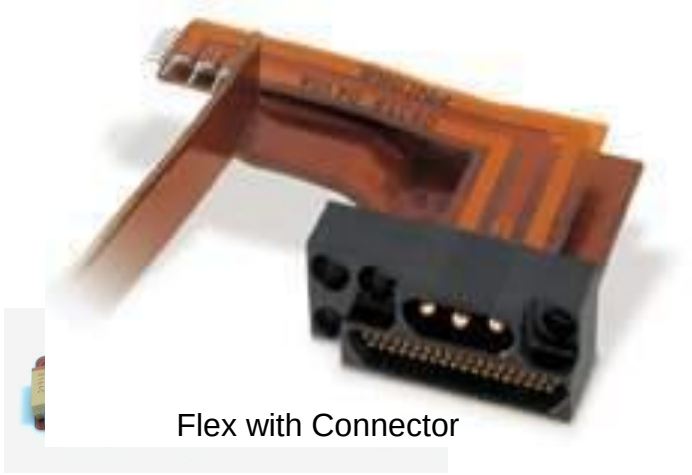
# Rigid Flex



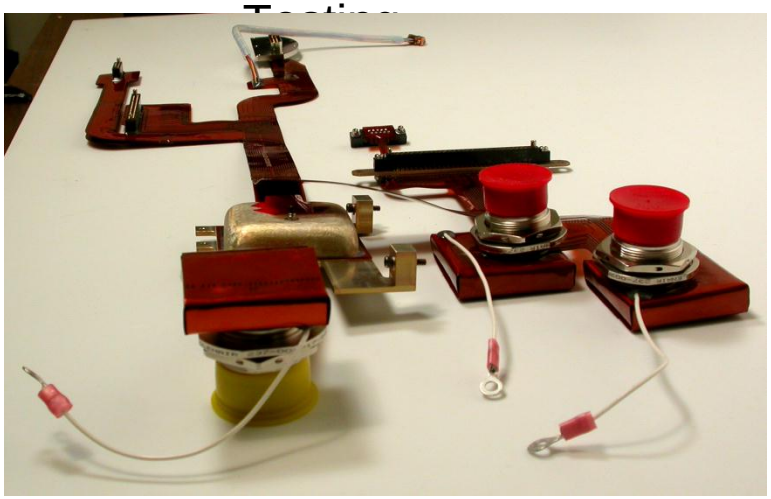
- Complex Designs
- Integrated Solutions:
  - SMT, BGA
  - Through hole, Press fit
- Packaging Solution
  - Electrical performance
  - Improves reliability
  - Reduces assembly costs

# Flex Circuit Assembly

- Assembly IPC-610, Class 3/J-STD-001
  - Mechanical stiffeners and metalwork
  - Connectors
  - SMT and Thru-hole Components
  - Testing

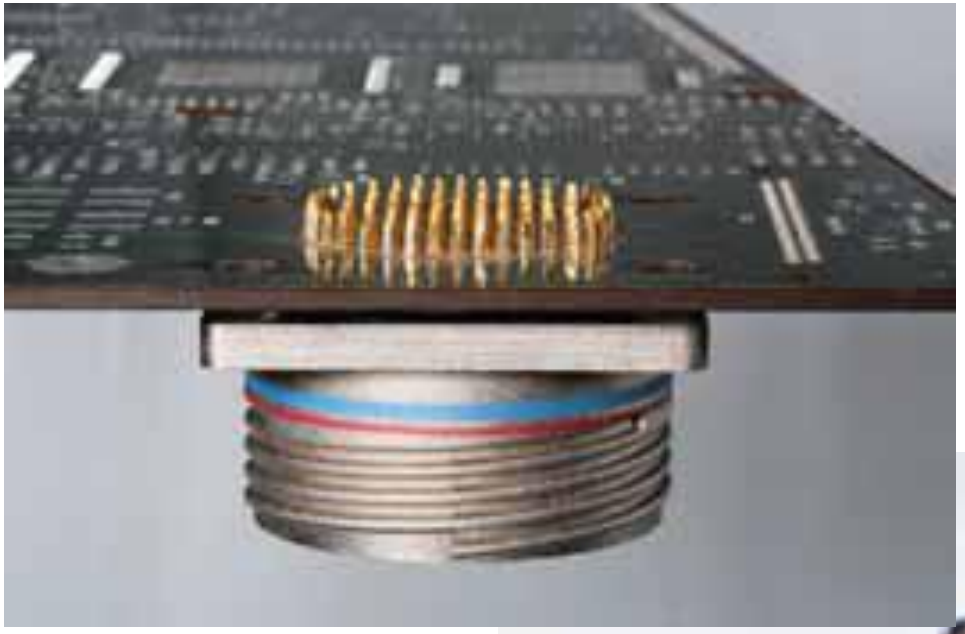


Flex with Connector

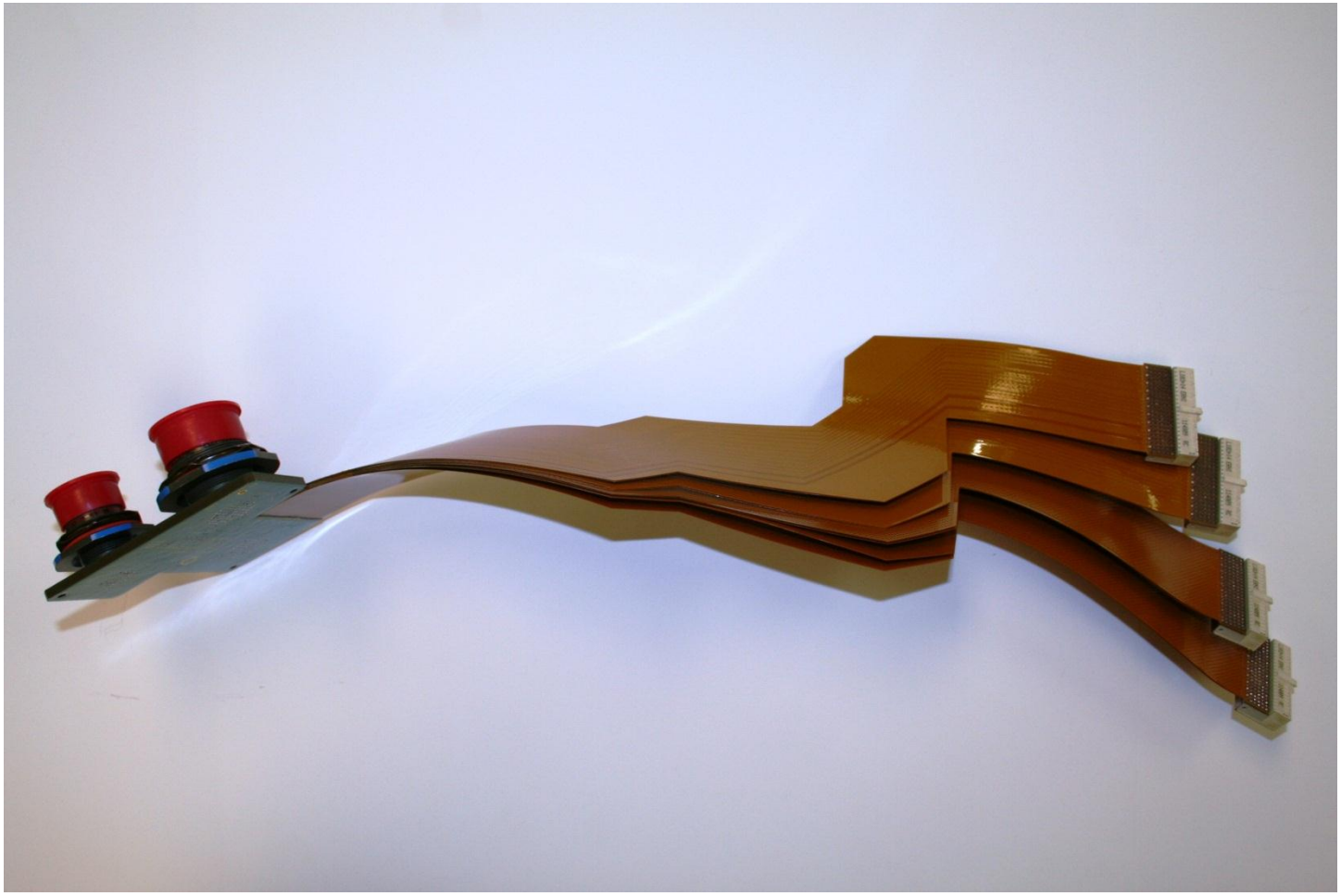


SMT Assembly

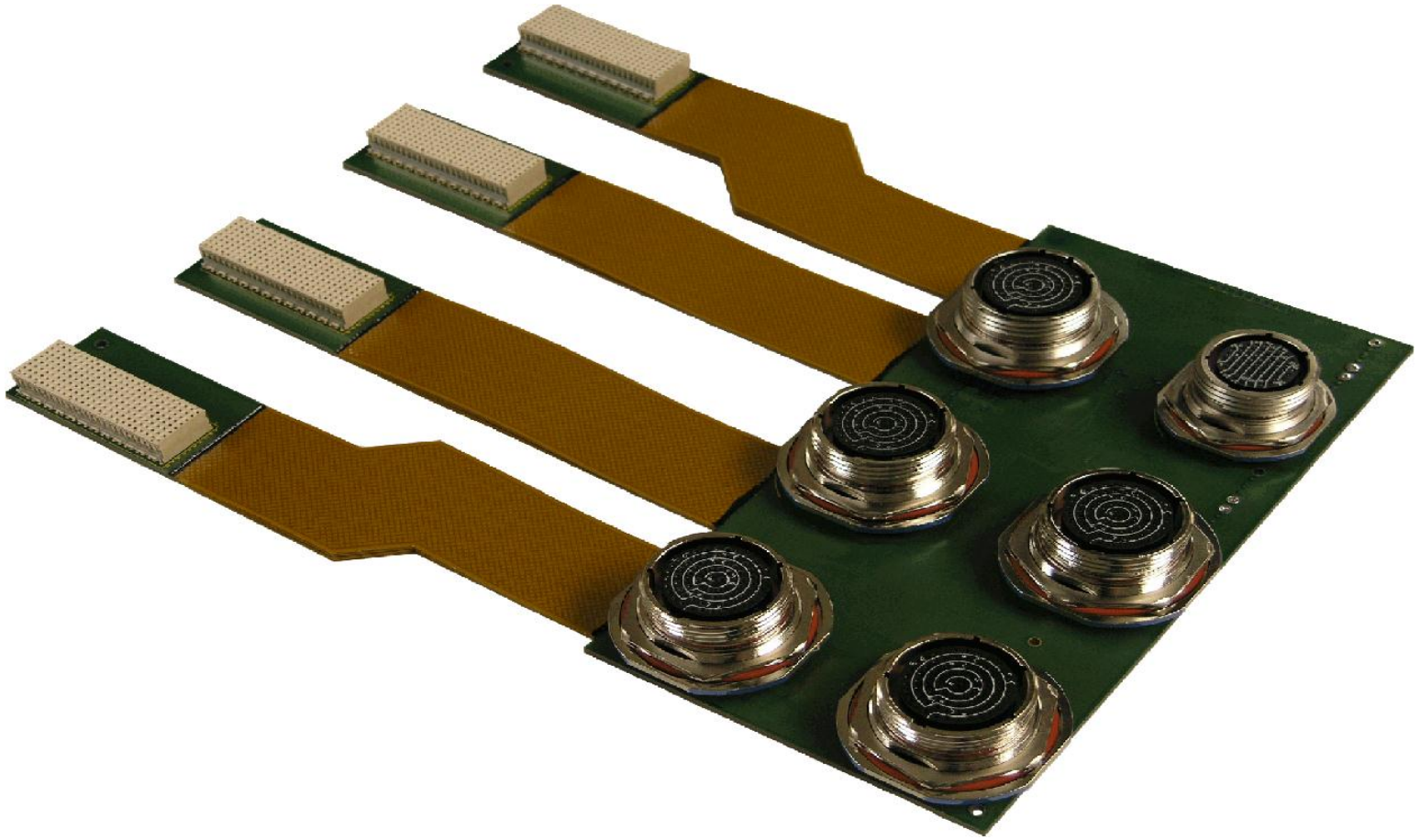
Mixed Thu/SMT Assembly



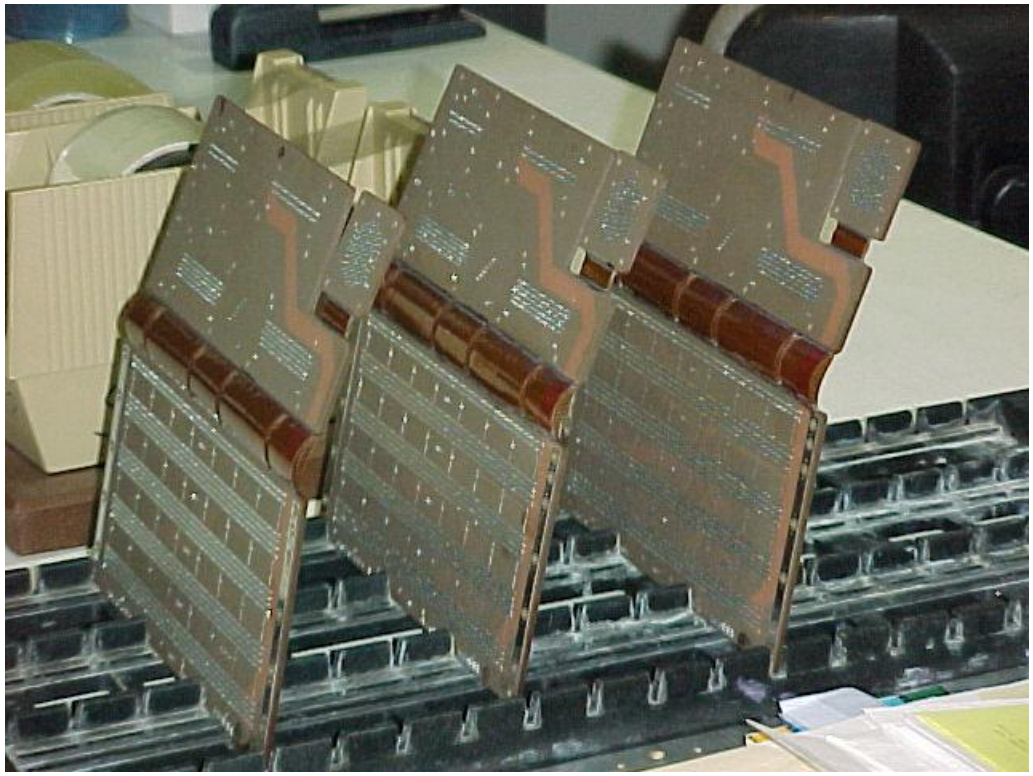
# Large panel size to 34” available

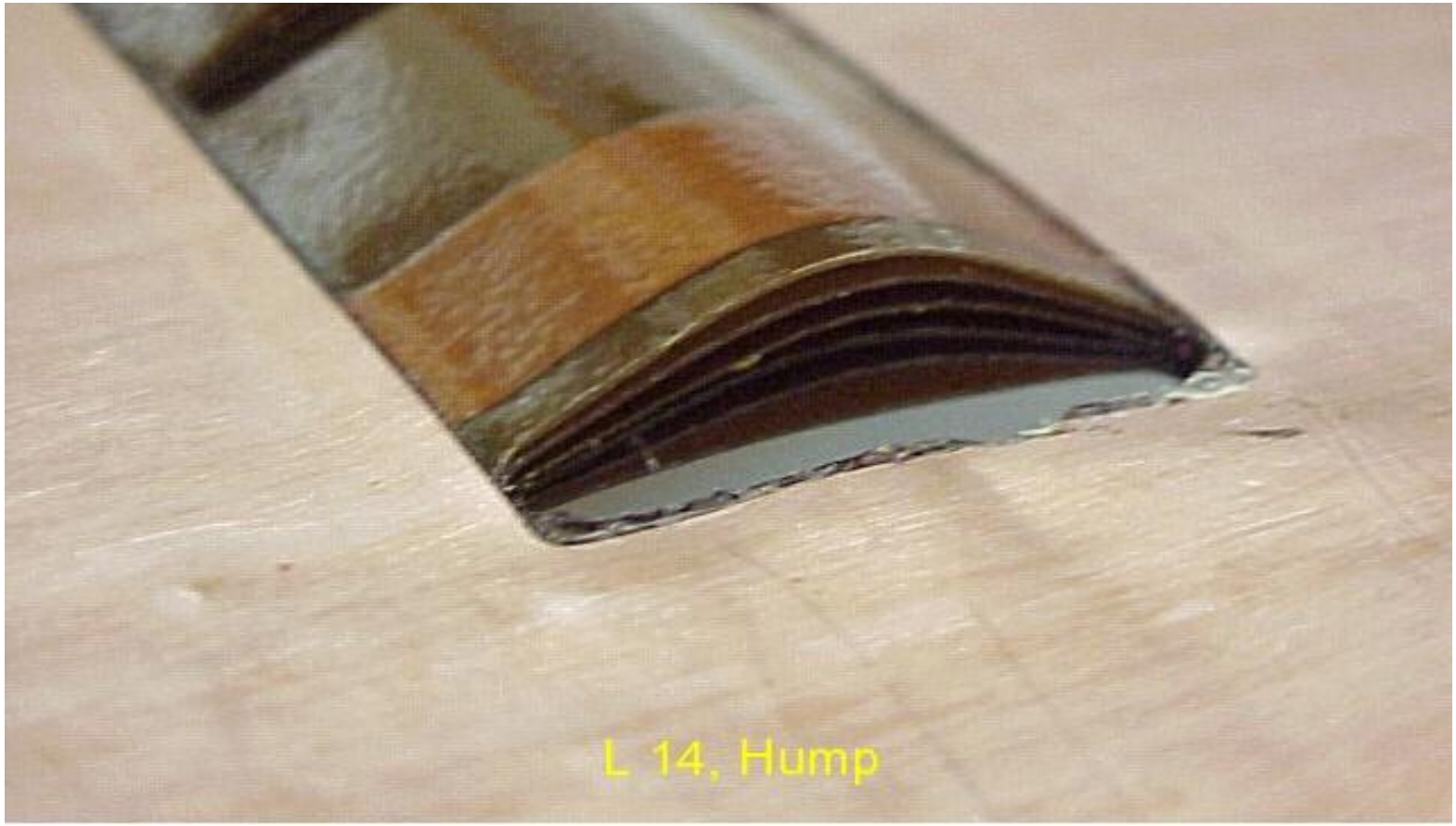


# 18 Layer Rigid-flex Circuit

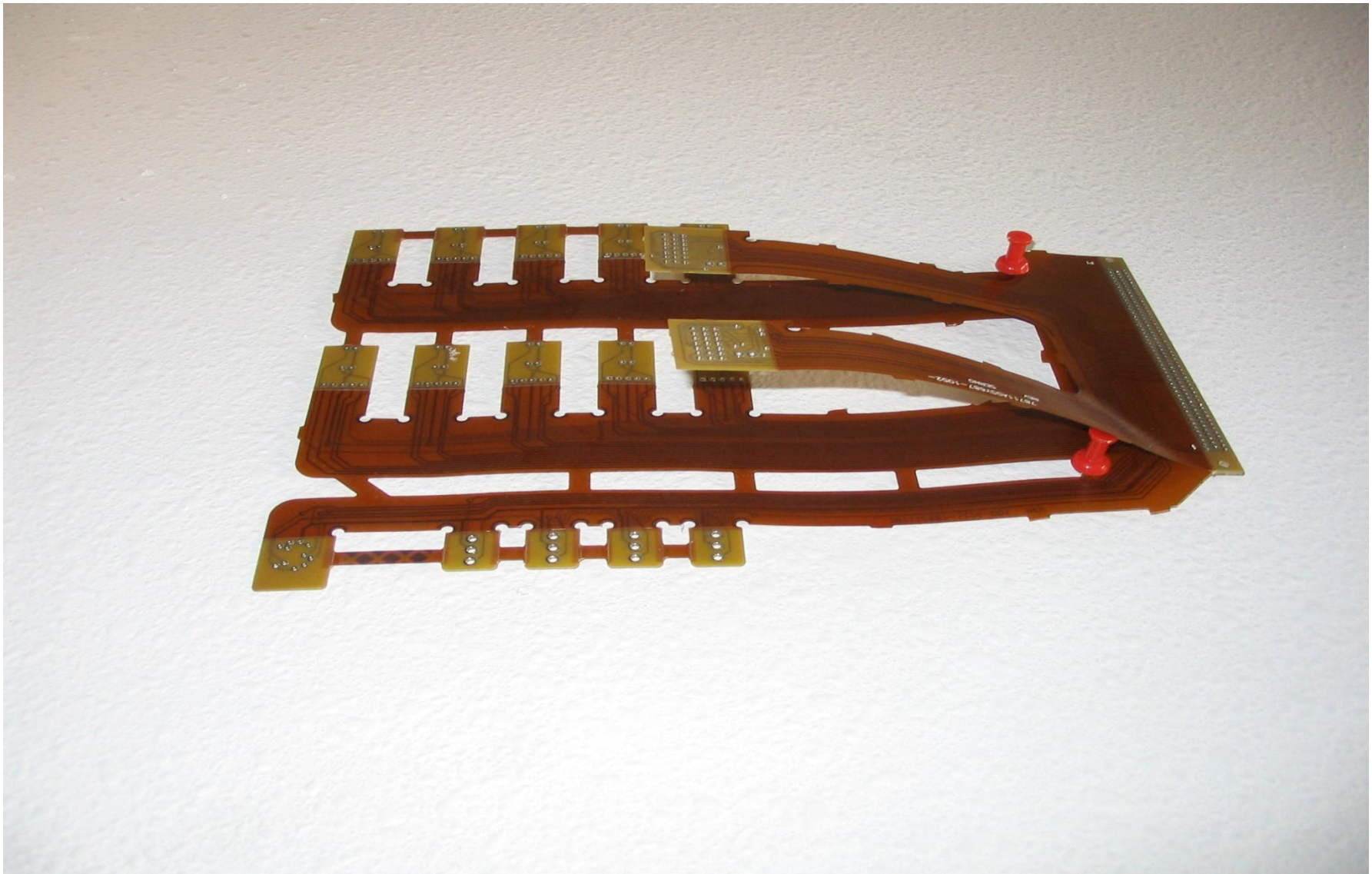


# Book Binder

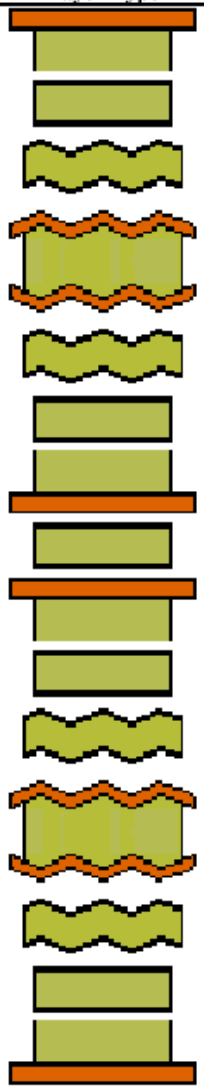



L 14, Hump

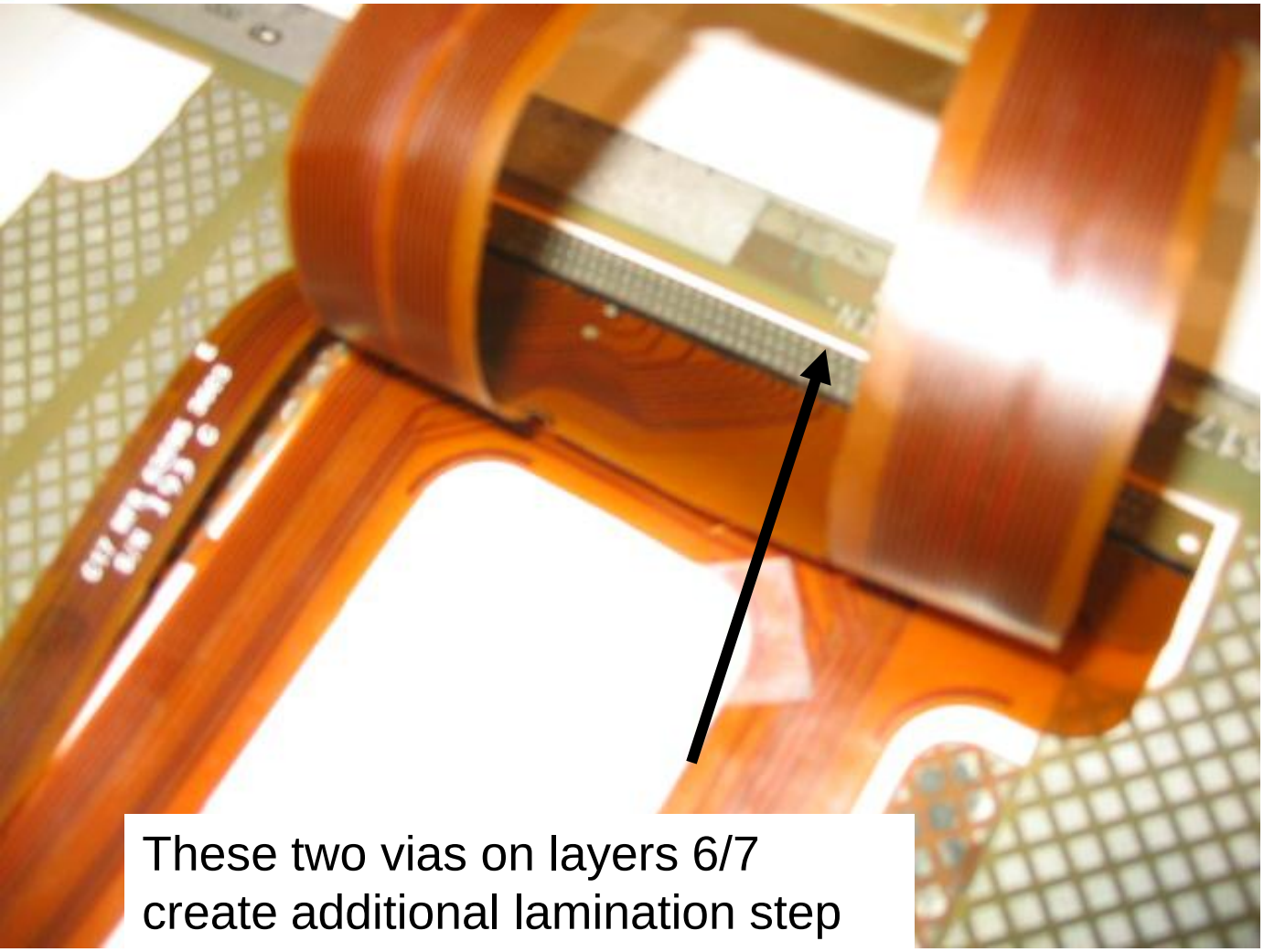
# Sequential Lamination Build Rigid-Flex



| Lyr | S-P | Layer Type | Thick | Weight | Foil Type | Qty | Core/PP | Material Description | Tolerance |
|---|---|---|---|---|---|---|---|---|---|
| 1 | s | | 0.0053 | 1.00 | HTE | | 0.0040 | GF/26-Tg 170 C Min | +0.0000 or -0.0000 |
| | | | 0.0050 | | | 2 | 1080NF | GF/26-Tg 170 C Min | +0.0000 or -0.0000 |
| | | | 0.0030 | | | 1 | LF0210 | Kapton Cover Layer | +0.0000 or -0.0000 |
| 2 | s | | 0.0033 | 0.50 | | | | | |
| 3 | s | | | 0.50 | | | | | |
| | | | 0.0030 | | | | | | |
| | | | 0.0050 | | | 2 | 1080NF | GF/26-Tg 170 C Min | +0.0000 or -0.0000 |
| 4 | s | | 0.0053 | 1.00 | HTE | | 0.0040 | GF/26-Tg 170 C Min | +0.0000 or -0.0000 |
| | | | 0.0075 | | | 3 | 1080NF | GF/26-Tg 170 C Min | +0.0000 or -0.0000 |
| 5 | s | | 0.0053 | 1.00 | HTE | | 0.0040 | GF/26-Tg 170 C Min | +0.0000 or -0.0000 |
| | | | 0.0050 | | | 2 | 1080NF | GF/26-Tg 170 C Min | +0.0000 or -0.0000 |
| | | | 0.0030 | | | 1 | LF0210 | Kapton Cover Layer | +0.0000 or -0.0000 |
| 6 | s | | 0.0033 | 0.50 | HTE | | 0.0020 | Adhesiveless Flex /11 | +0.0000 or -0.0000 |
| 7 | s | | | 0.50 | HTE | | | | +0.0000 or -0.0000 |
| | | | 0.0030 | | | 1 | LF0210 | Kapton Cover Layer | +0.0000 or -0.0000 |
| | | | 0.0050 | | | 2 | 1080NF | GF/26-Tg 170 C Min | +0.0000 or -0.0000 |
| 8 | s | | 0.0053 | 1.00 | HTE | | 0.0040 | GF/26-Tg 170 C Min | +0.0000 or -0.0000 |



**Sub assemblies:**
**L1-4 & L5-8**

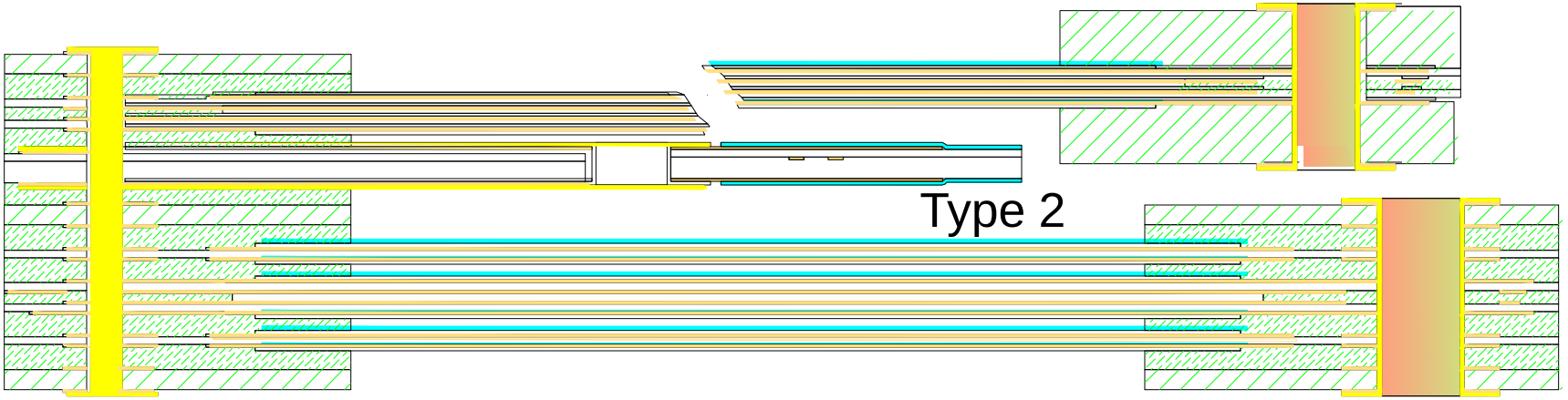


These two vias on layers 6/7 create additional lamination step

# Sequential Lamination

Technically a Type 4

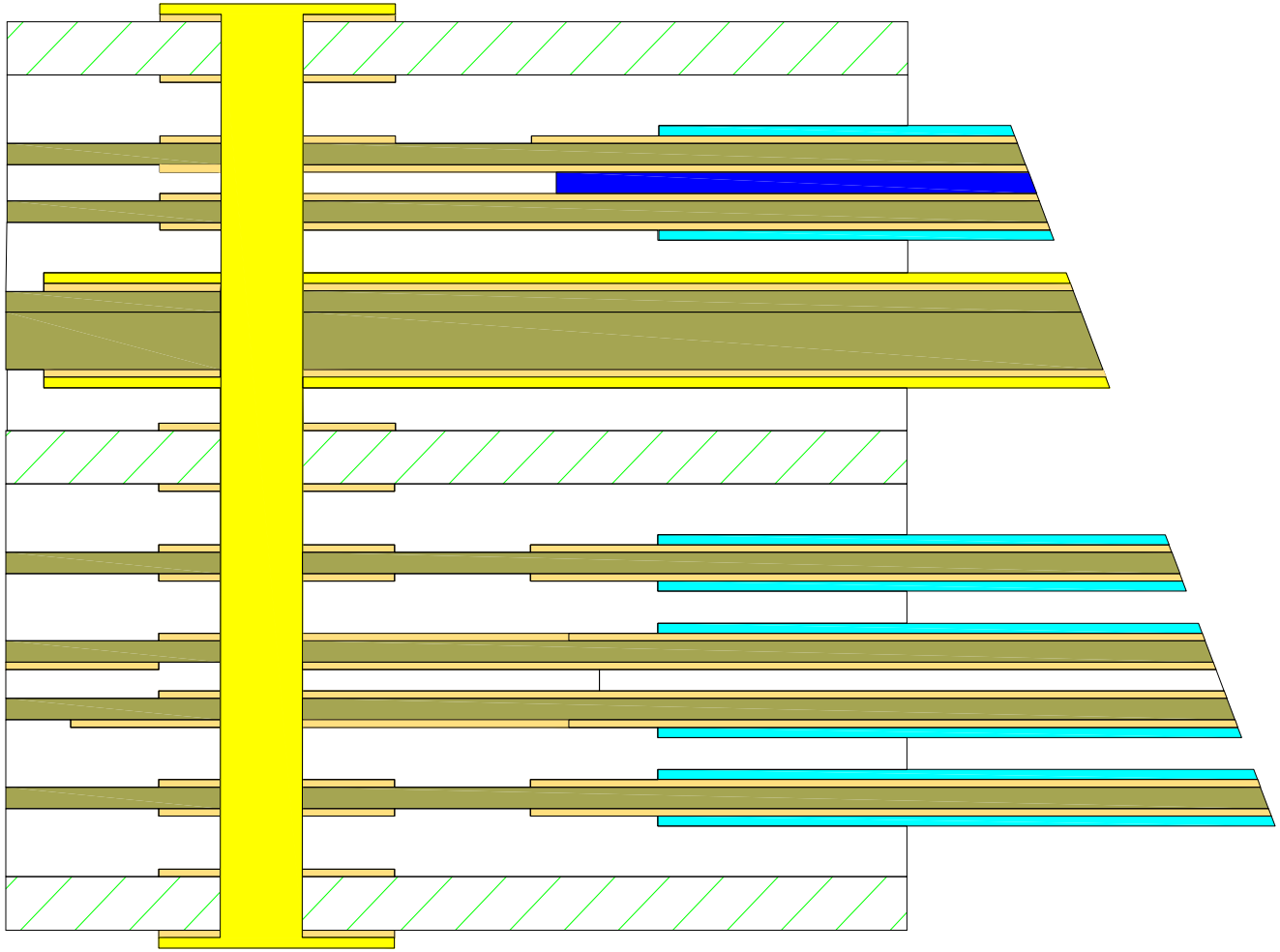
Could be a Type 3



Type 2

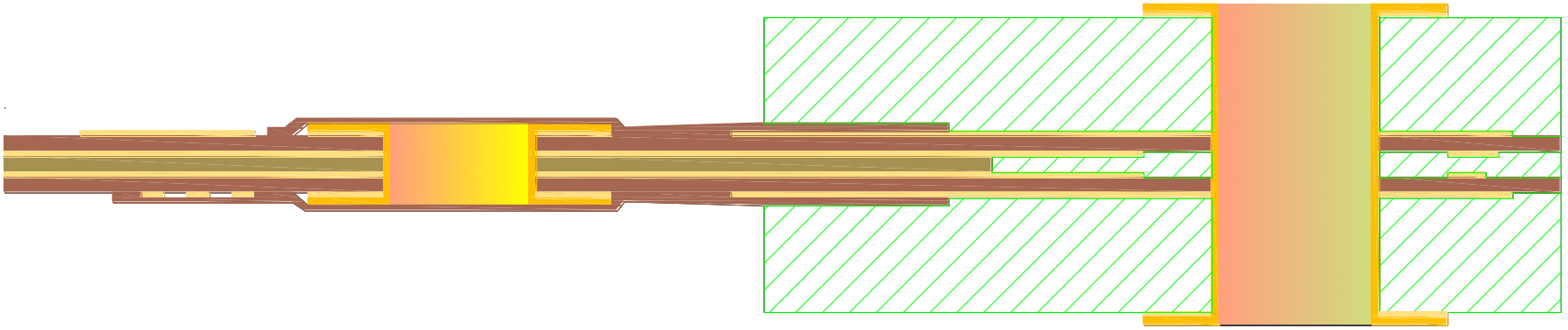
Type 4

# Sequential Stack up Detail



# Bondply Recess

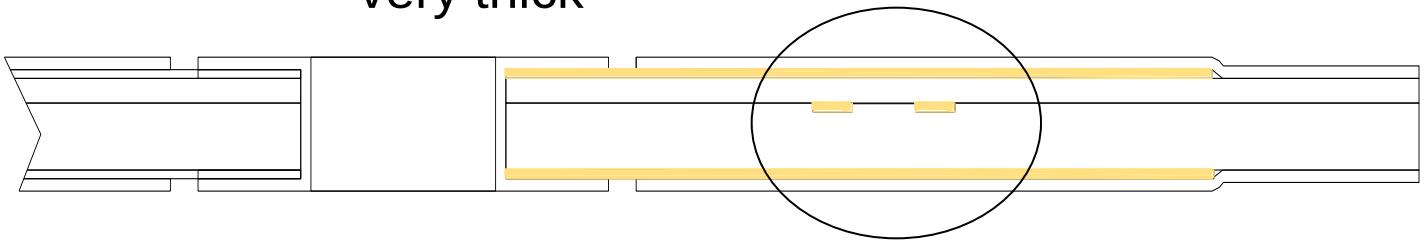
Type ?



Sequential Lamination and Plating
very popular in EMI

# Impedance

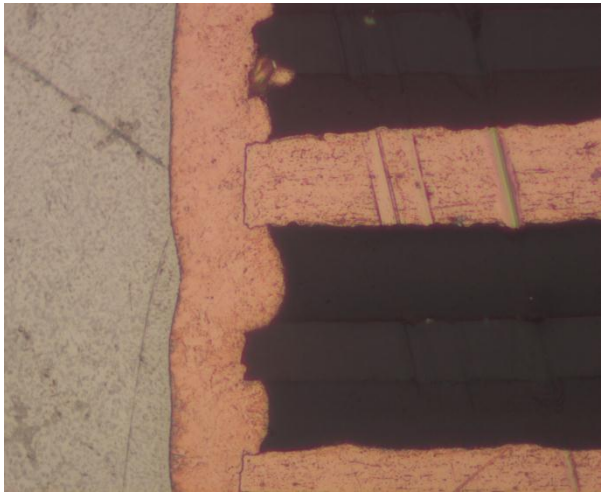
Type 3
very thick



Diff imped
4 or 5 core

# Materials

- **Dielectric**
- Polyimide/Acrylic
  - .0005” thru .012”
- Rigid materials
  - Polyimide or Epoxy
- Other;
  - LCP (Liquid Crystal Polymer)
  - FEP (Fluorocarbon)



- **Conductors Copper**
- Rolled Annealed (RA)
  - 1through 10 oz
- Electrodeposited (ED)
  - 5 through 17 micron & higher
- Other Metals
  - Beryllium copper
  - Cupro-Nickel
  - Other Heater foils used to manage resistance

Exotic Materials answering Electrical needs are available.

# Non Adhesive Build

- Adhesive removal greatly improves Reliability
  - Coverlay only in flexible segments
- Highly Accelerated Thermal Stress (HATS)
  - 2000+ cycles, Rigid-Flex AP showed no barrel cracking
  - Adhesive product failed in less than 100 cycles (not the /1)
  - IPC-4104/11 replacing the IPC-4104/1
- Excessive adhesives within the PTH do not stand up
  - Fail in both in high temp environment and assembly
  - Layer count is important
- Adhesiveless Rigid-flex closely tracks Rigid PWB PTH reliability

# Rigid-Flex: Rigid Materials

- **IPC 4101** –Copper Clad Rigid Material and Pre-preg
  - ***/24*** – Multi-functional Epoxy Tg=150˚C, Td=300˚C
  - ***/26*** – Multi-functional Epoxy Tg=170˚C, Td=300˚C
  - ***/124*** – Multi-functional Epoxy Tg=150˚C, Td=325˚C
  - ***/126*** – Multi-functional Epoxy Tg=170˚C, Td=340˚C
  - ***/40*** – Polyimide Tg=200˚C, Td=390˚C
  - ***/41*** – Polyimide Tg=250˚C, Td=390˚C
  - ***/42*** – Polyimide/epoxy blend Tg=200˚C , Td=310˚C
- /26 and /42 materials
  - Readily available sources for “No Flow” products to rigid-flex mfg’s
  - /42 material laminates at lower temperature and does not compromise flex cover materials in rigid-flex construction

# Rigid-Flex: Copper Clad Flex Materials

- **IPC 4204** –Copper Clad Flex Materials
  - ***/1*** – Copper clad polyimide with acrylic adhesive
  - ***/2*** – Copper clad polyimide with epoxy adhesive
  - ***/11*** – Copper clad adhesiveless polyimide
    - essential to providing high reliability
- /1 or /11 for 1 and 3 layer flex
  - /1 material is widely used in North America
  - /2 material is widely used in Europe and Asia

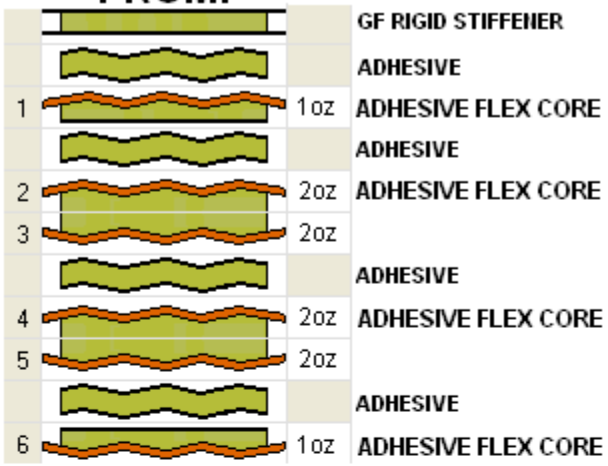
# Rigid-Flex: Flex Coverlay Materials

- **IPC 4202** –Adhesive coated Dielectric Film Materials
  - ***/1*** – Acrylic adhesive on polyimide
  - ***/2*** – Epoxy adhesive on polyimide
  - ***/18*** – Acrylic adhesive unsupported
  - ***/19*** – Epoxy adhesive unsupported
- /1 for coverlay on rigid-flex products
  - Epoxy is also an option, but not widely used
- /1 or /11 for 1 and 3 layer flex
  - /1 and /18 materials are widely used in North America
  - /2 and /19 materials are widely used in Europe and Asia

## Multilayer Flex with Stiffener

**Overall thickness .063 +/- .006**

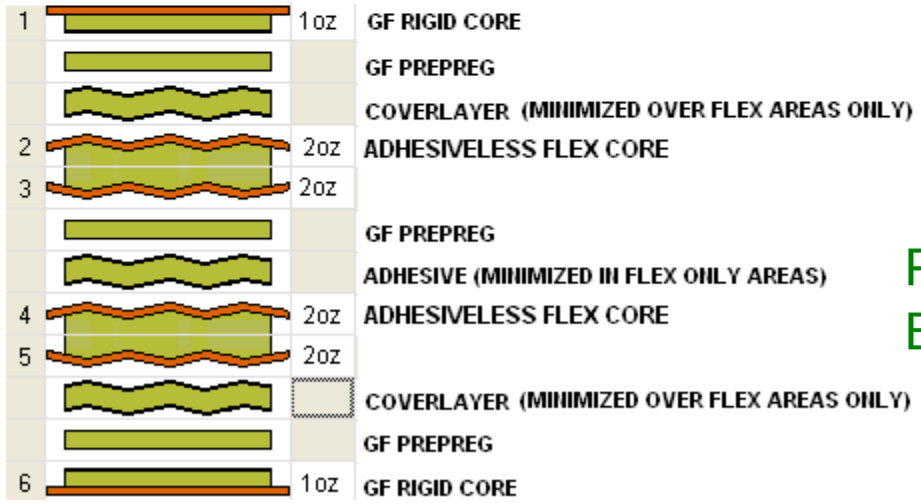
**FROM:**




## Multilayer Rigid-Flex

**Overall thickness .063 +/- .006**

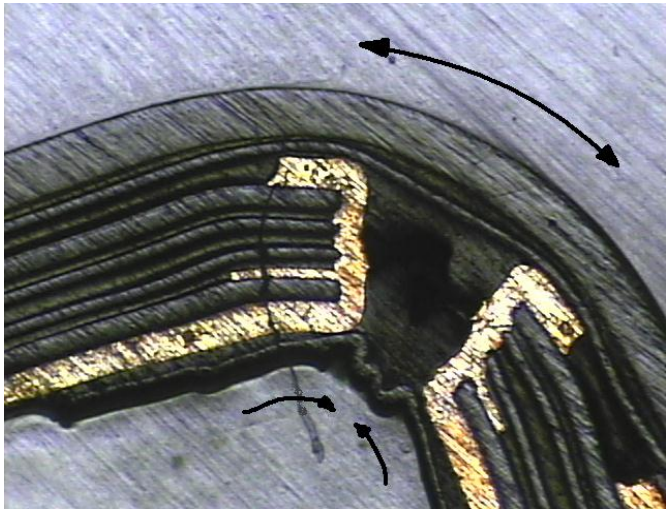
**TO:**




Fast Delivery
Best Reliability

# Basic truths

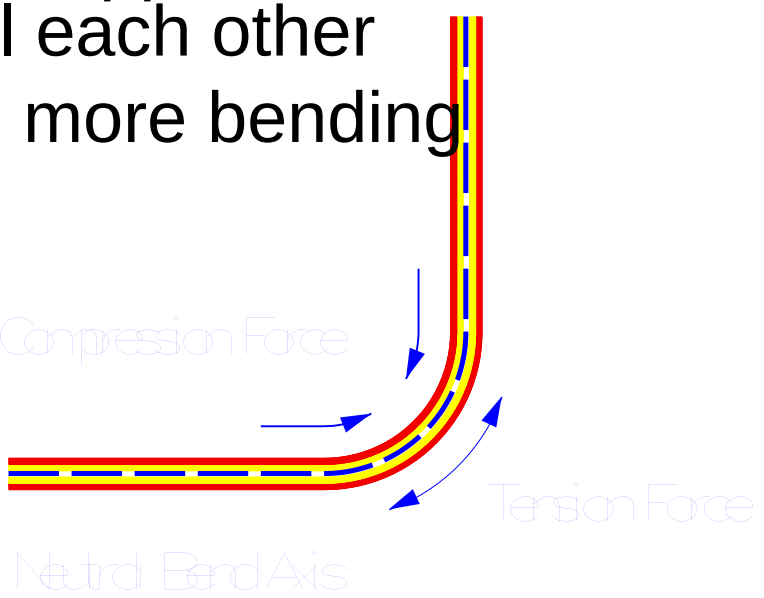
- High Current
  - Requires wider/thicker conductors, additional layers
  - Thicker foil demands a thicker adhesive
- Impedance
  - Requires thicker dielectric, additional layers
  - Lower width trace requires thinner copper
- Bend Ratio
  - 10:1 Single and Double Sided
  - 20:1 Multi-Layer



Keep PTH out of bend

# Properties Affecting Neutral Bend Axis Location

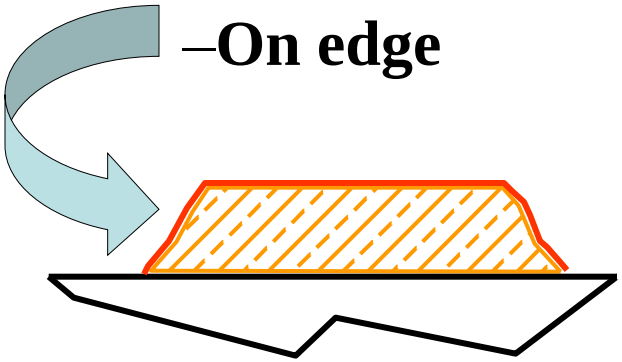
- Balanced construction keeps axis at center of stack
- Bend axis shifts towards
  - heavy copper or copper planes
  - thick polyimide dielectric >.003”
- Thick copper or polyimide on opposite sides of the neutral bend axis cancel each other
- Wider conductors withstand more bending
- Small conductors to inside
- Planes close to stack center

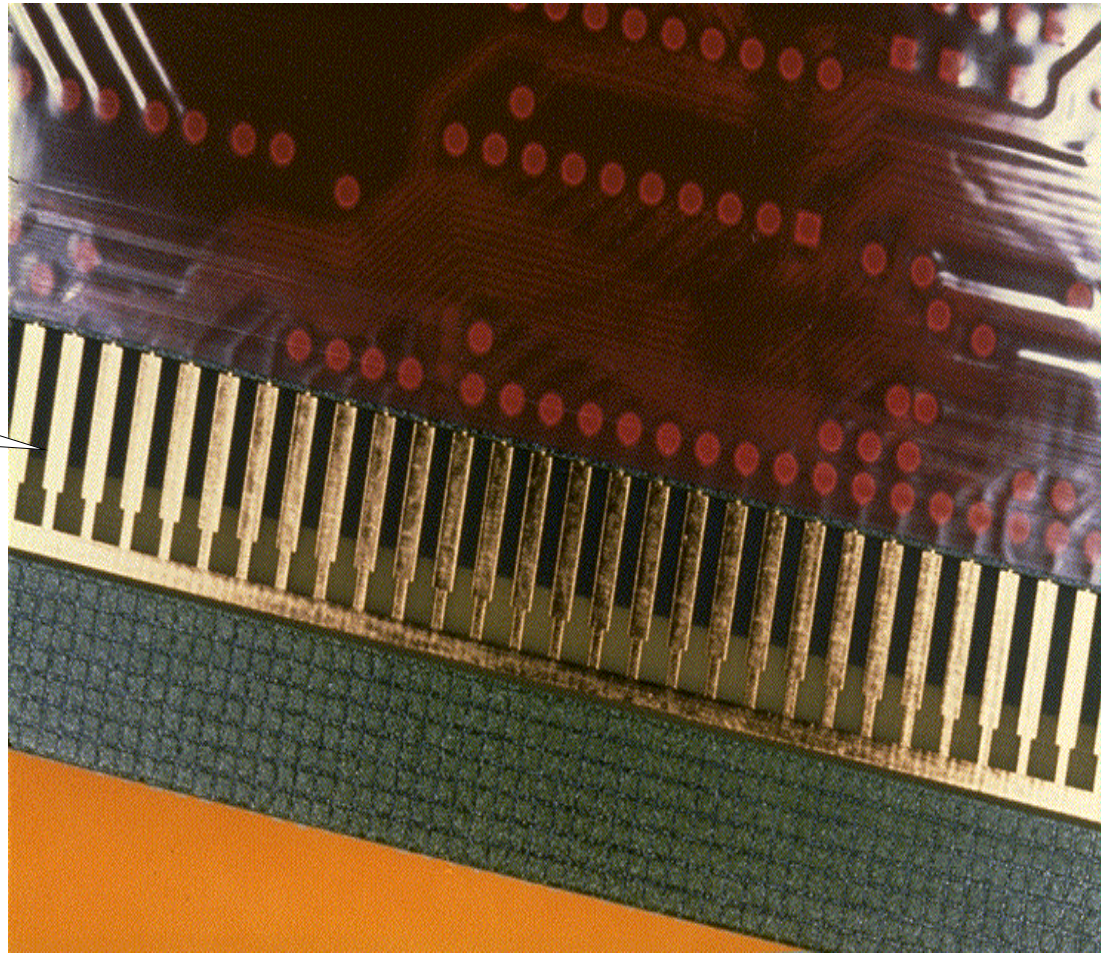


# Full Body Gold

Full Body Gold

–On edge

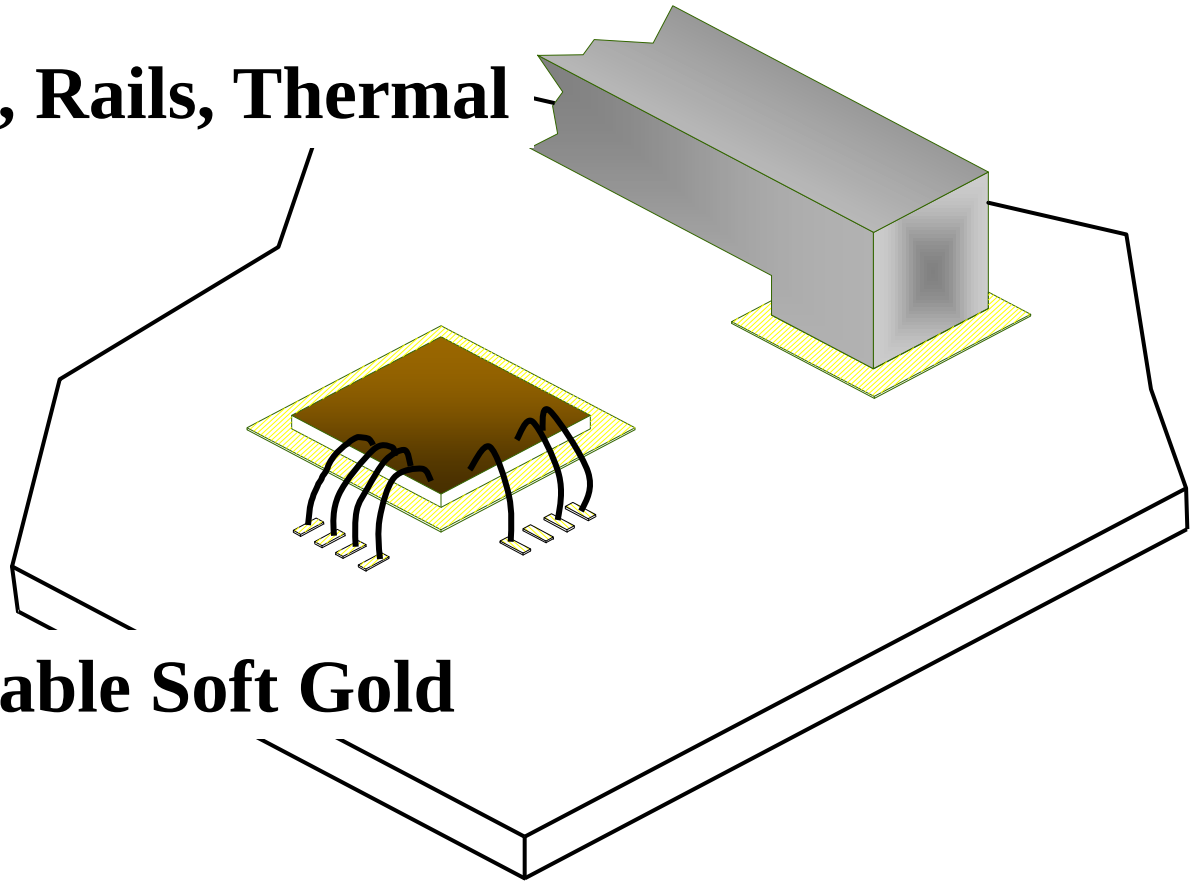




# Selective Gold

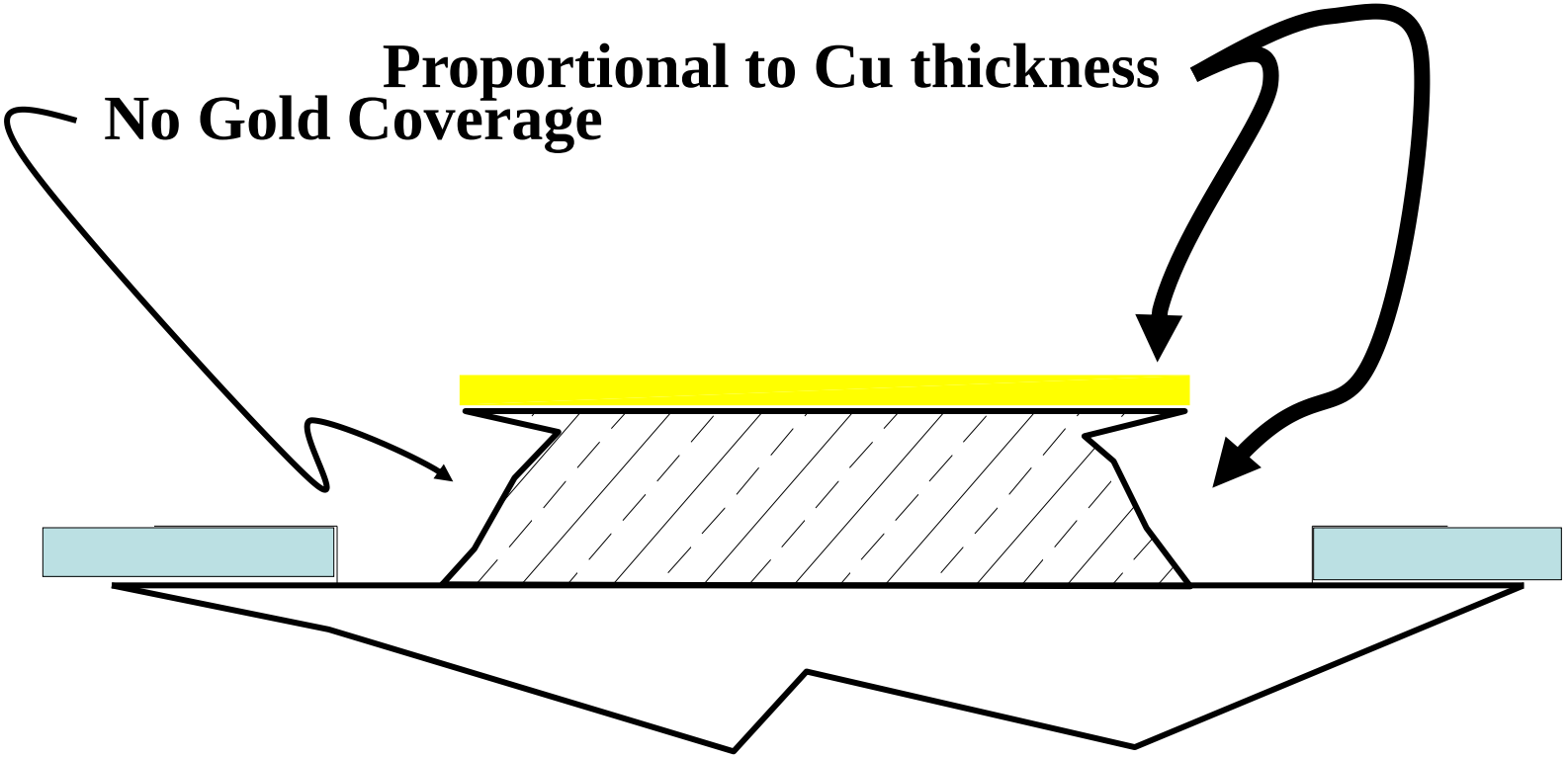
**Hard Gold for Flatness**

**Stiffeners, Rails, Thermal**



**Wire bondable Soft Gold**

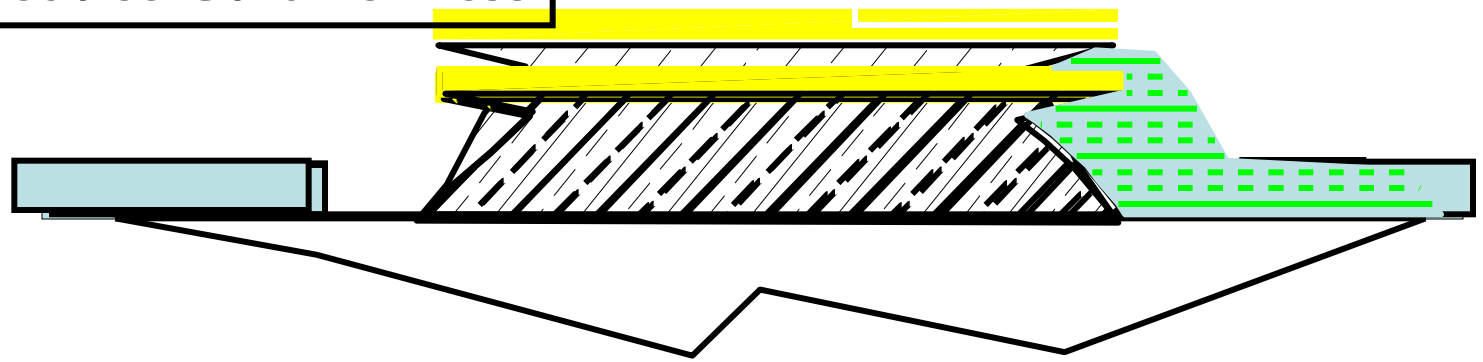
# Selective Gold Overhang



# Dealing with the Overhang

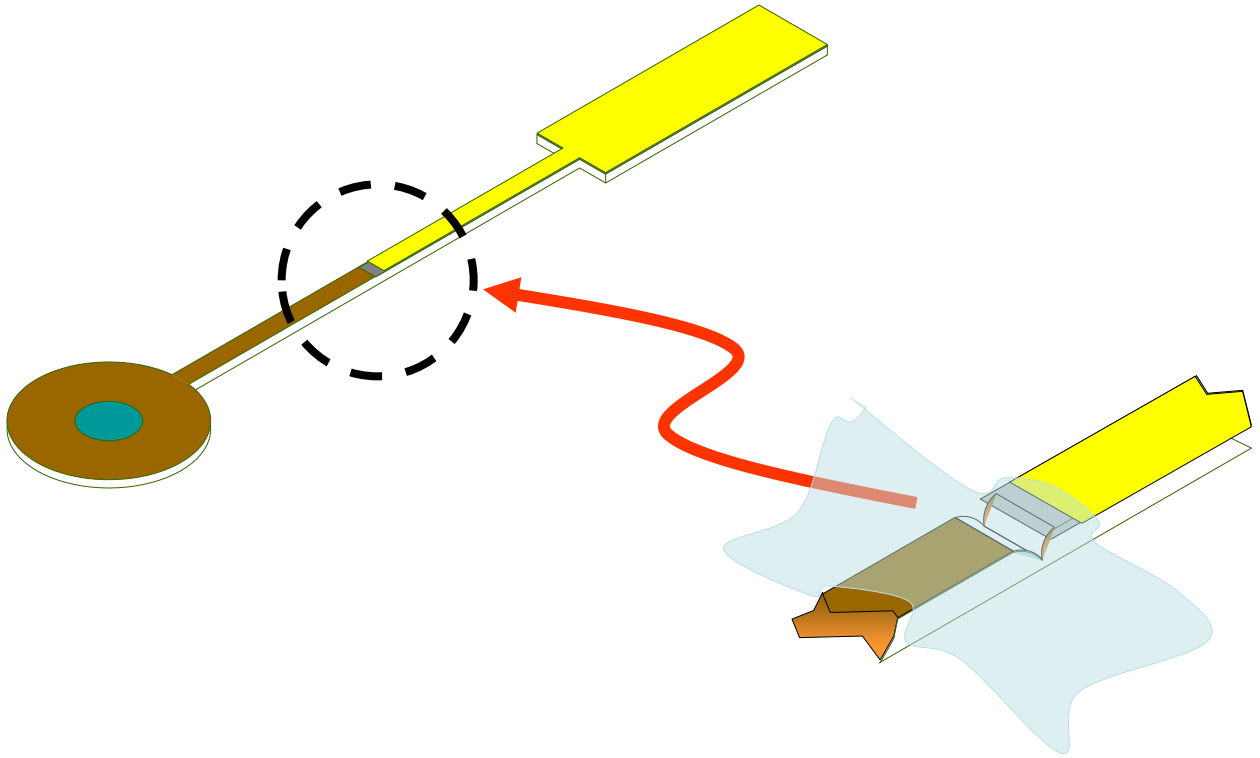
Reduce Cu thickness

Solder mask Encroachment
Onto Gold Lands



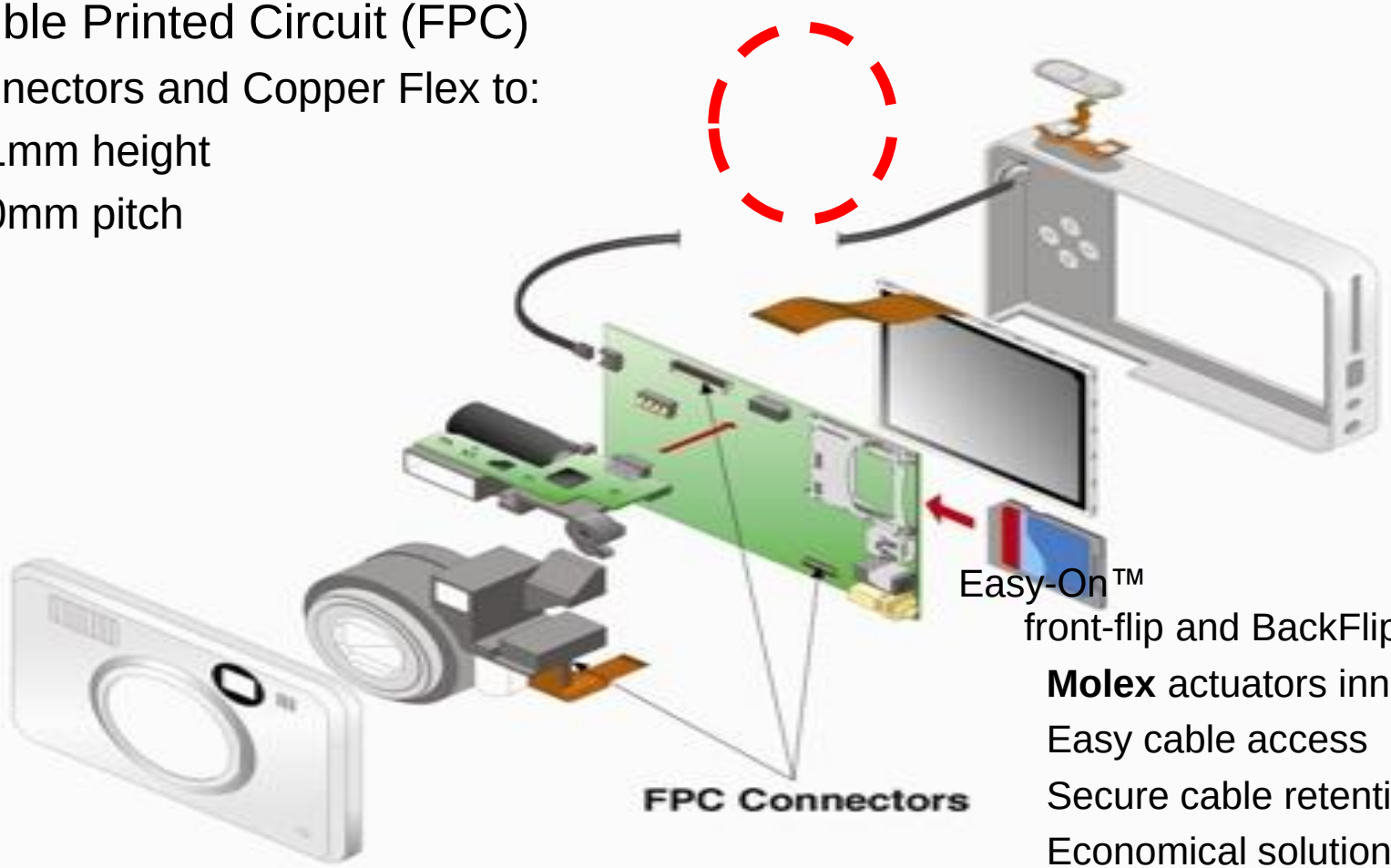
# Midas Touch

One part is Gold… then it's all Gold



# Digital Cameras drive FPC need

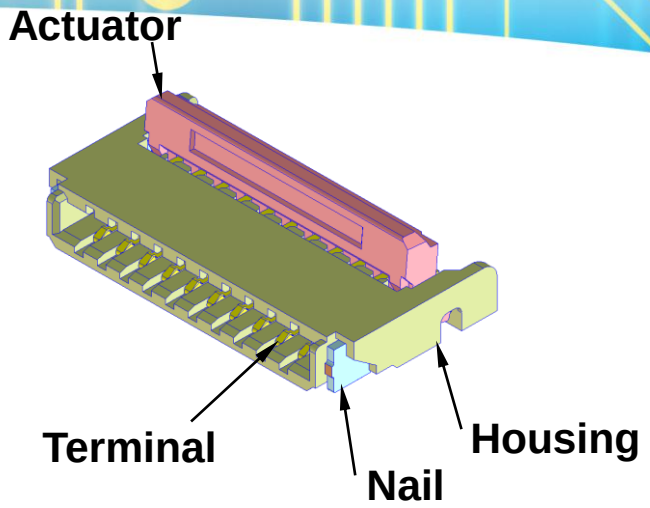
- Flexible Printed Circuit (FPC)
  - Connectors and Copper Flex to:
  - 1.11mm height
  - 0.30mm pitch

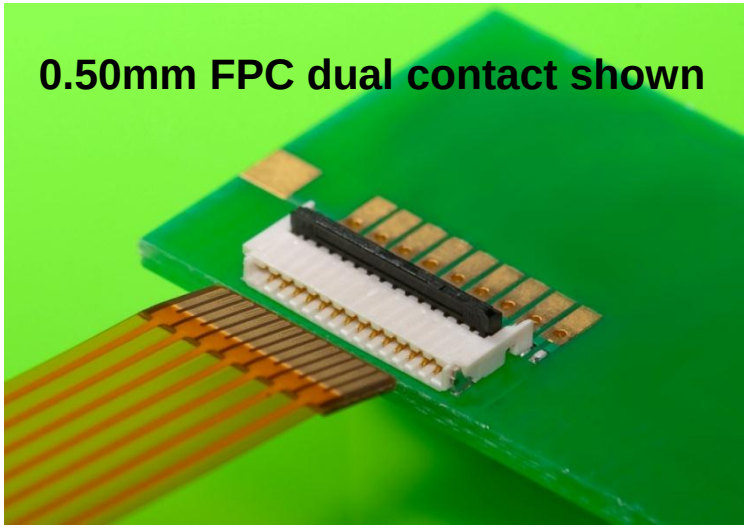


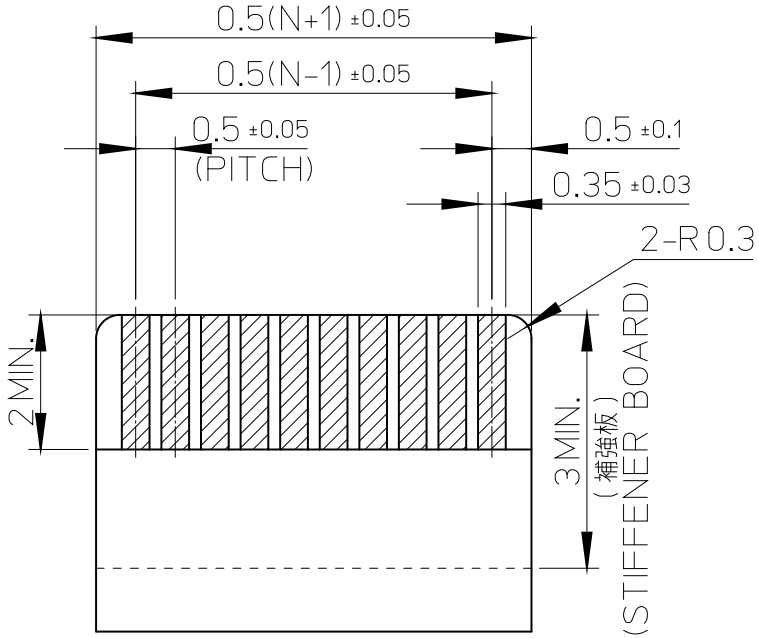

Easy-On™
front-flip and BackFlip™
- **Molex** actuators innovation
- Easy cable access
- Secure cable retention
- Economical solution

# FPC/ZIF

- Compact size, with Long wipe length
- Easy insertion and high pull force
- Trace routing ease



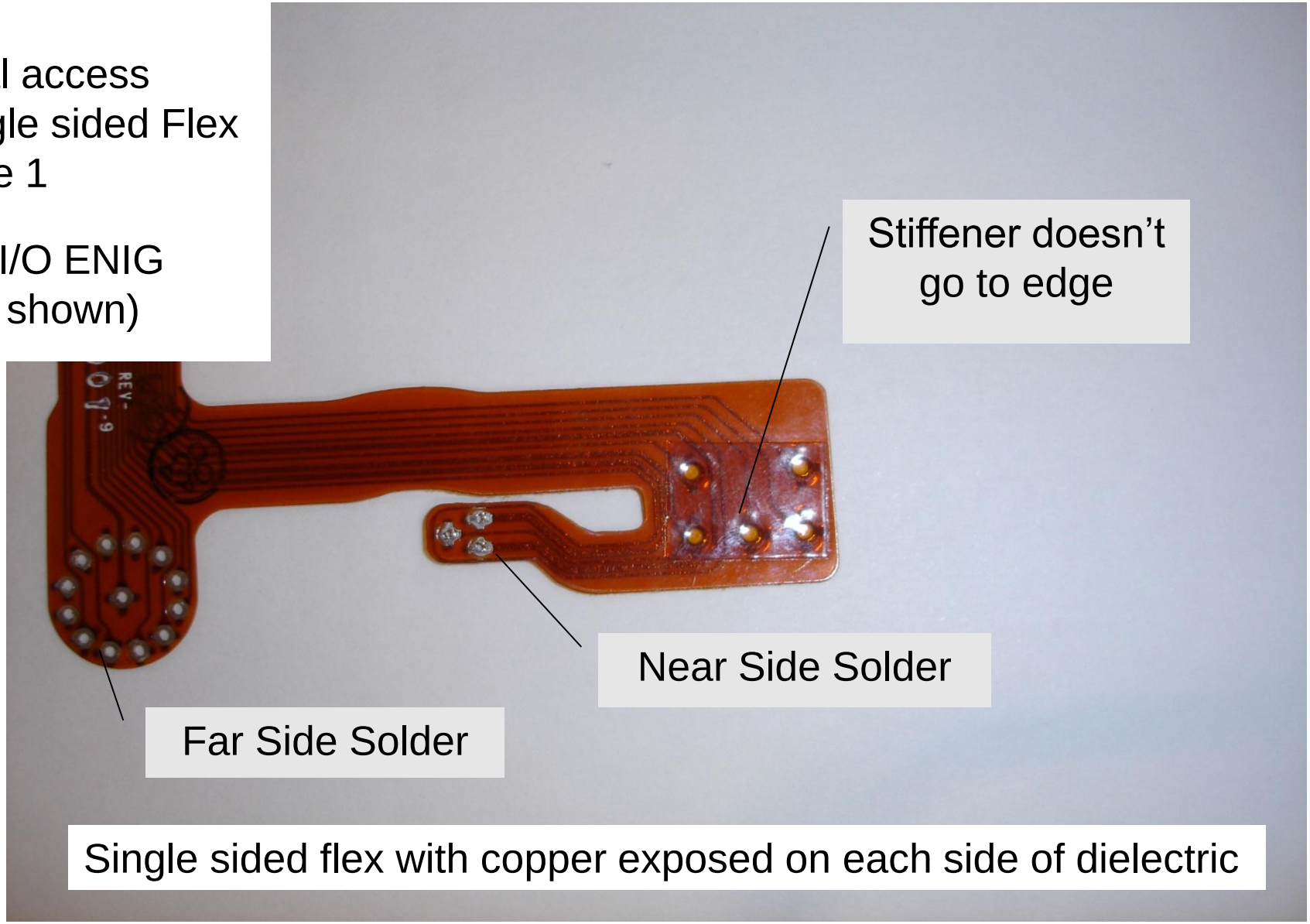
# Wiring harness to I/O Flex conversion

- Controlled Impedance is driving conversion to Flex due to length of wire prep termination
- Type 2 shown

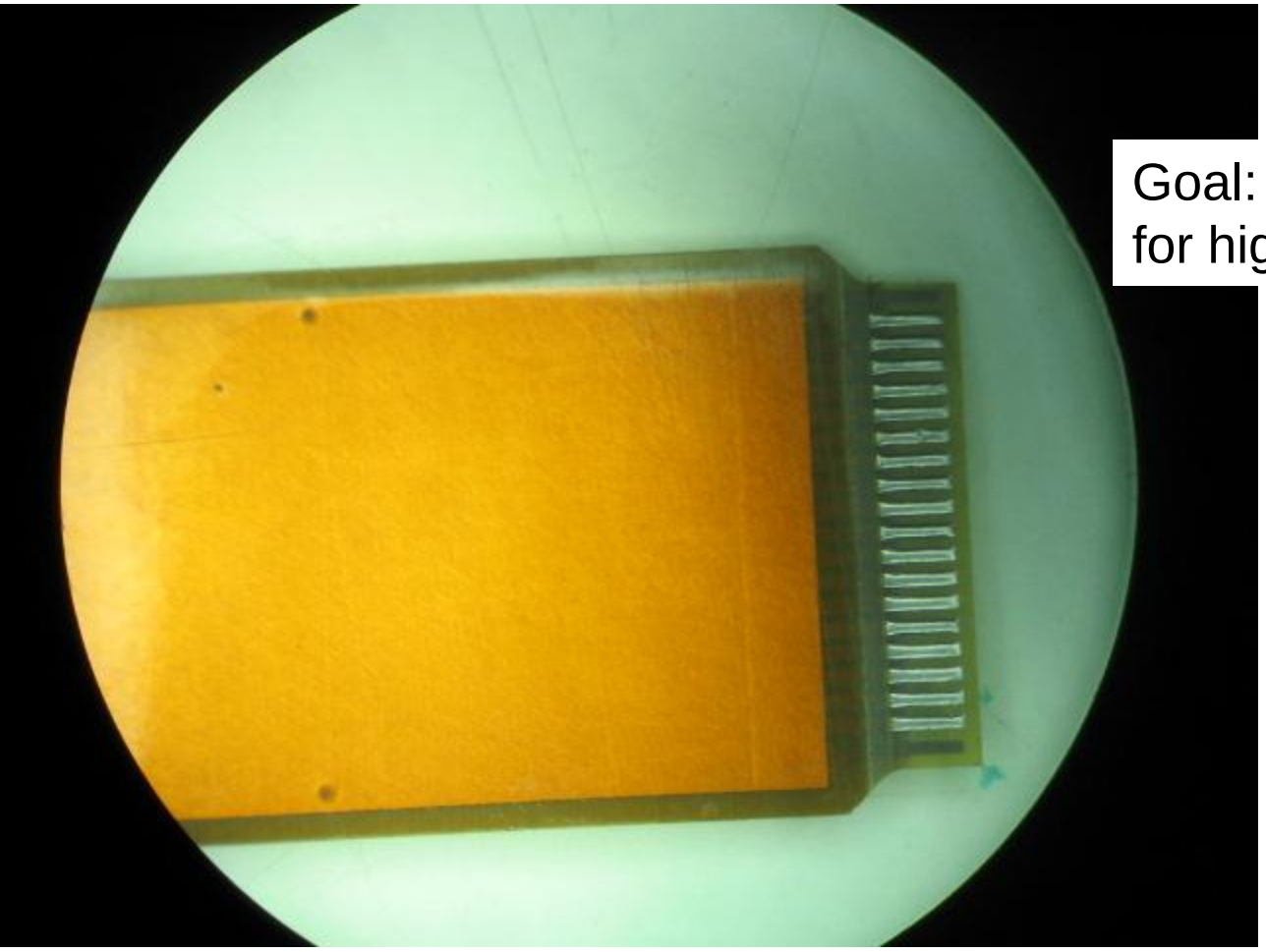
# Goal: Inexpensive single sided flex

Dual access
Single sided Flex
Type 1

ZIF I/O ENIG
(not shown)



# Harmless Flex Flex



Goal: Inexpensive Flex for high volume

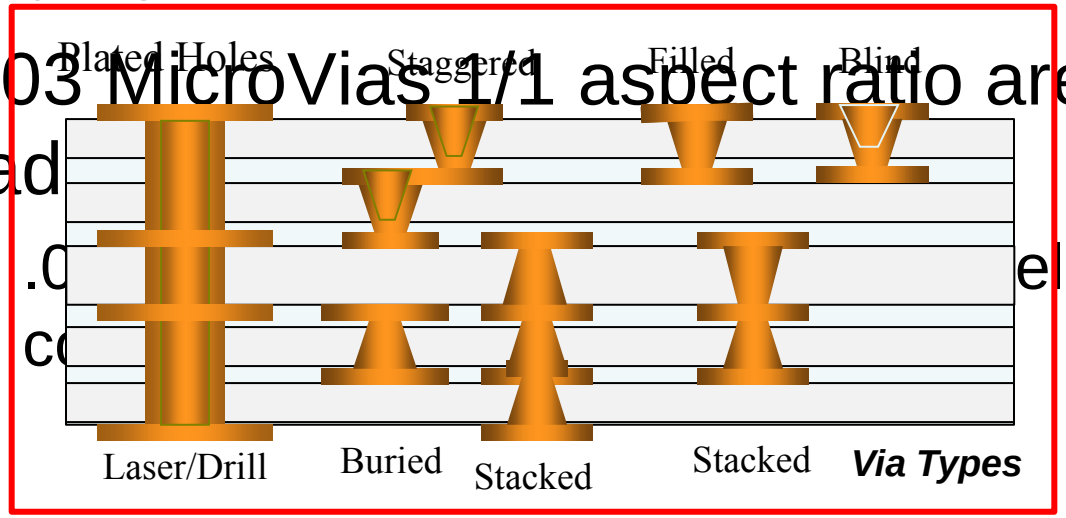
Use ENIG otherwise Connector may not make contact with fingers

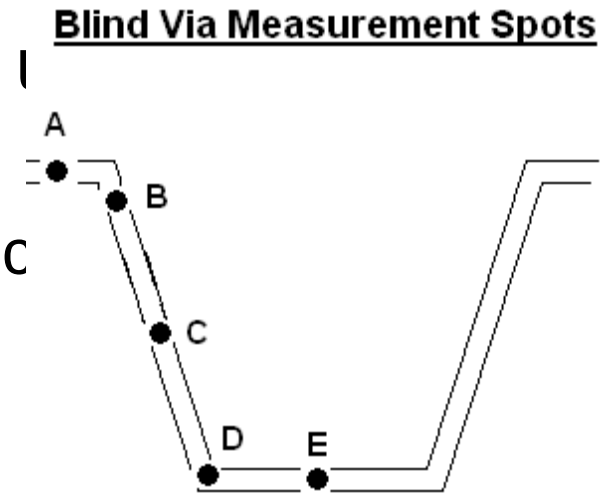
- due to the variation in solder

Poor yield

# HDI Flex IPC-6013, Type 3

- HDI Flex, pushes envelope of IPC-6013 description
  - Existing HDI specifications are Rigid based
- Sub 4/4 lines/spaces, 3/3 not uncommon, <2/2 used
  - Conventional Plated Through Hole not a technology driver
- .003 MicroVias 1/1 aspect ratio are
  pad
  - .0 elec
    co



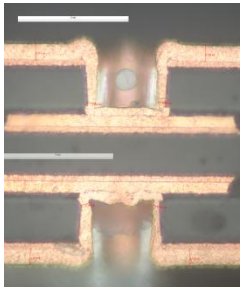



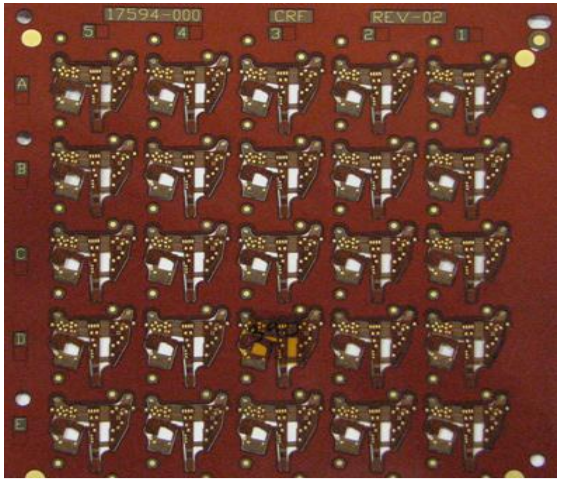
# IPC Flex Capability Roadmap

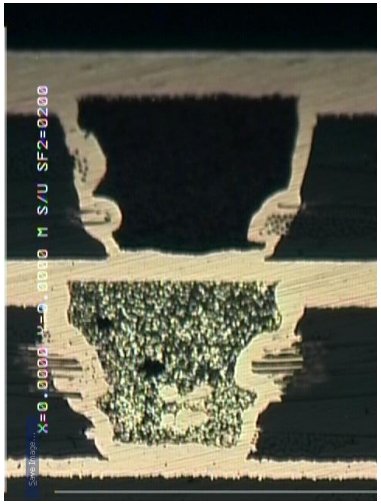
**Source: IPC International Technology Roadmap for Electronic Interconnects 2008-2009**

Table E2-1 – Design Feature Characteristics

| DESIGN FEATURES | CONVENTIONAL | LEADING EDGE | STATE-OF-THE-ART |
|---|---|---|---|
| Lines & Spaces (µm) | 100-250 | 50-75 | 10-25 |
| Via Diameter (µm; as drilled) | ≥275 | 100-250 | 50 |
| (Conductive) Layer Count | 1-2 | 2-12 | >12 |
| Dielectric Thickness (µm) | 25-100 | 12-25 | 12 |
| Conductor Thickness (µm) | 18-36 | 9 | 3-5 |
| Adhesive | Yes | Adhesiveless | Adhesiveless |
| Controlled Impedance | Not common | Possible | Yes |
| Minimum Annular Ring =(land diameter-hole diameter)x1/2 (µm) | 250 | 50 | None (landless via) |





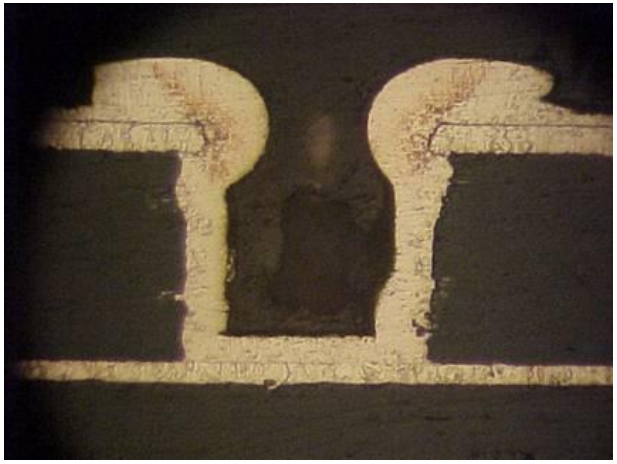



# What is HDI *High Density Interconnect*

IPC-2226 definition of microvia: A blind hole with a diameter (≤150 µm) having a pad diameter (≤350µm) formed by either laser or mechanically drilling.

*Based on rigid…*

- Drill or laser PTH mainly for connector I/O
- Thin Materials: .001 & .002 for impedance, ¼ oz Cu foil



| Feature | IPC-2226 | Units |
|---|---|---|
| Conductor Line/Space | 5 (125) | .002 mil (Micron) |
| Microvia Diameter | 6 (150) | .003 mil (Micron) |
| Thru Via Diameter | 10 (250) | mil (Micron) |
| Micro via Pad Diameter | 16 (400) | .009 mil (Micron) |
| Thru Aspect Ratio | 5 | Depth/Dia |
| Micro via Aspect Ratio | 0.5 | >1/1 Depth/Dia |

| Production Volume | High | Medium | Limited |
|---|---|---|---|
| Minimum Laser Via Formed Dia. | .004 | .003 | <.003 |
| Minimum Line and Spacing | .004/.004 | .002/.002 | <.002 |
| Minimum copper thickness | 9 micron copper on .001 core | 9 micron copper on <.001 core | <9 micron |
| Minimum pad size for thru-hole vias | Via diameter +.015 | Via diameter + .012 | Via diameter + .010 |
| Minimum pad size for micro vias | .004 + .008 | .003 + .006 | Via diameter + .005 |
| Thru hole plating aspect ratio | 4:1 | 6:1 | Note 1 |
| Blind micro via plating aspect ratio | 1:1 | 1.5:1 | >1.5:1 Note 2 |
| Panel Plating | Yes | Yes | Yes |
| Selective Plating or POP (Pads Only Plate) | *Maybe* | Yes | Yes |
| Number of layers | 2-6 | 6-8 | >8 |
| Profile Tolerance | .007 | .005 | .003 |
| Min. Conductor to Edge (For .005" encapsulation) | .015 | .010 | .007 |
| Via fill | Copper filled | Copper filled | Non conductive |

1. Thru hole aspect ratios do not typically exceed 4:1 in HDI products
2. Adjacent feature size can effect aspect ratio Cu plating

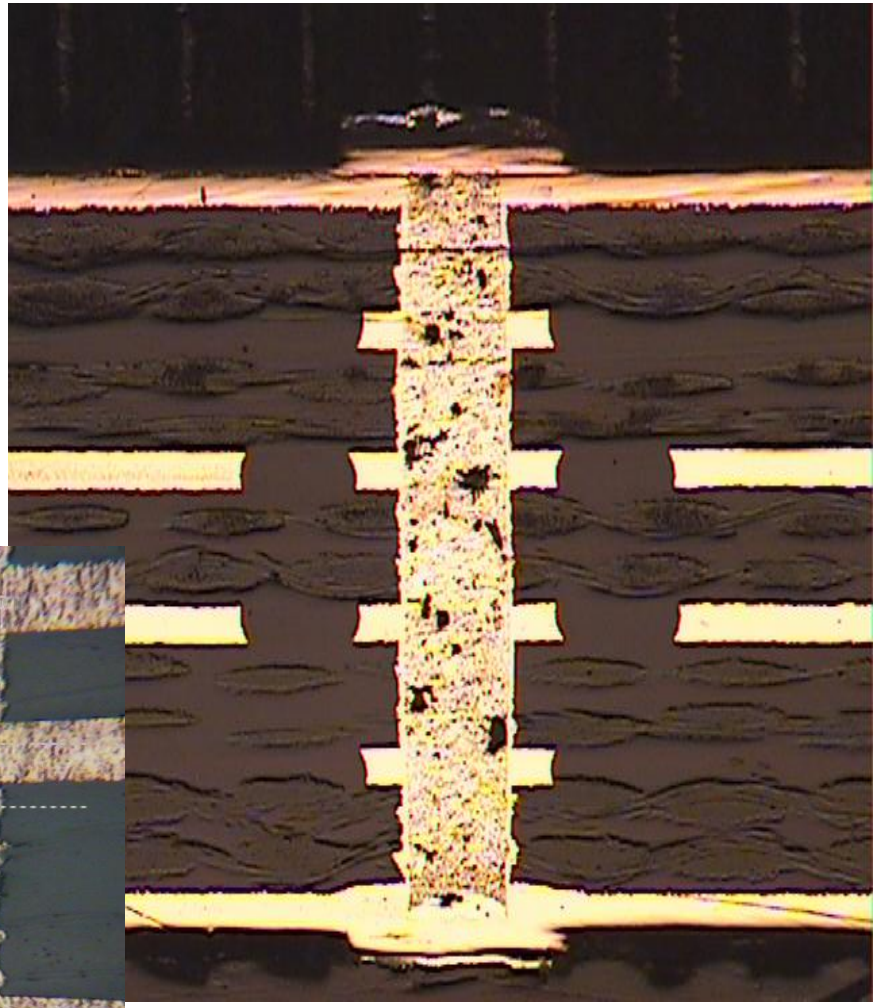
# Conductive Via Fill

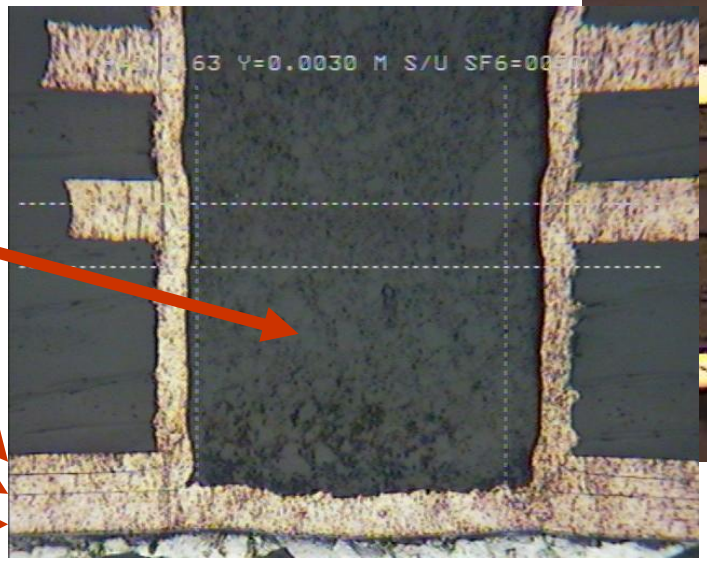
**Thickness (PWB)**: .008 to .085

**Drilled hole:** .008 to .018

**Aspect ratio:** 1:1 to 6:1

**Base material:** Hi Tg (cure 165ºC)





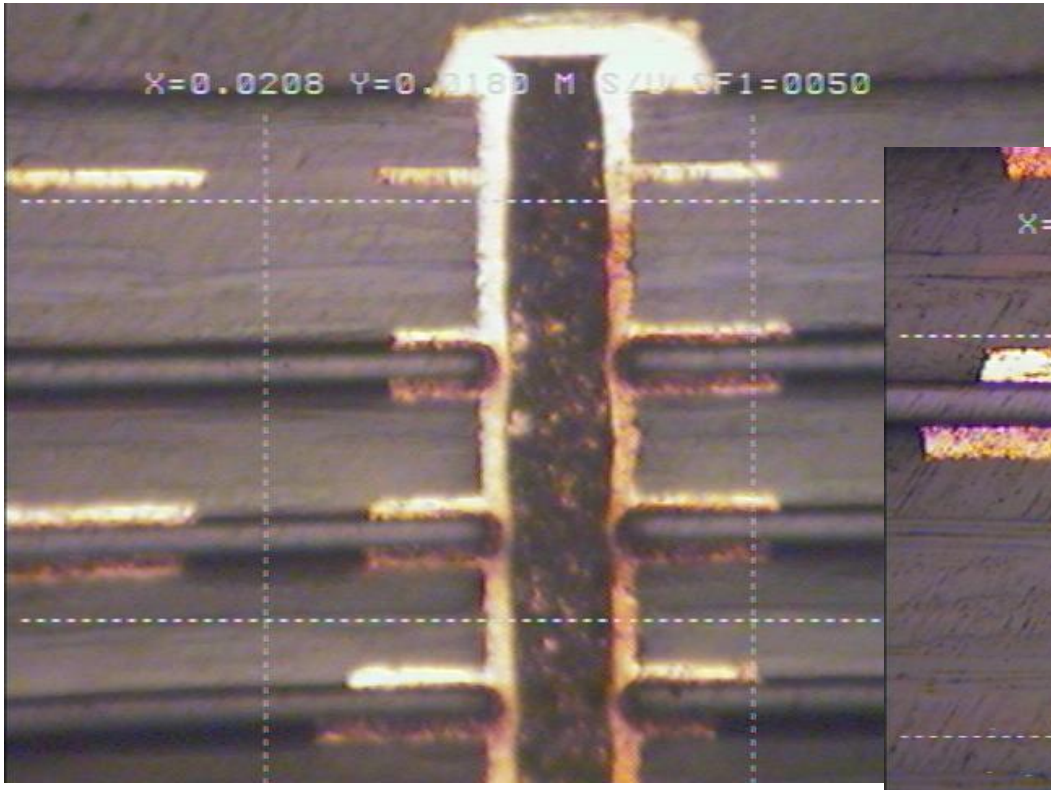

Fill

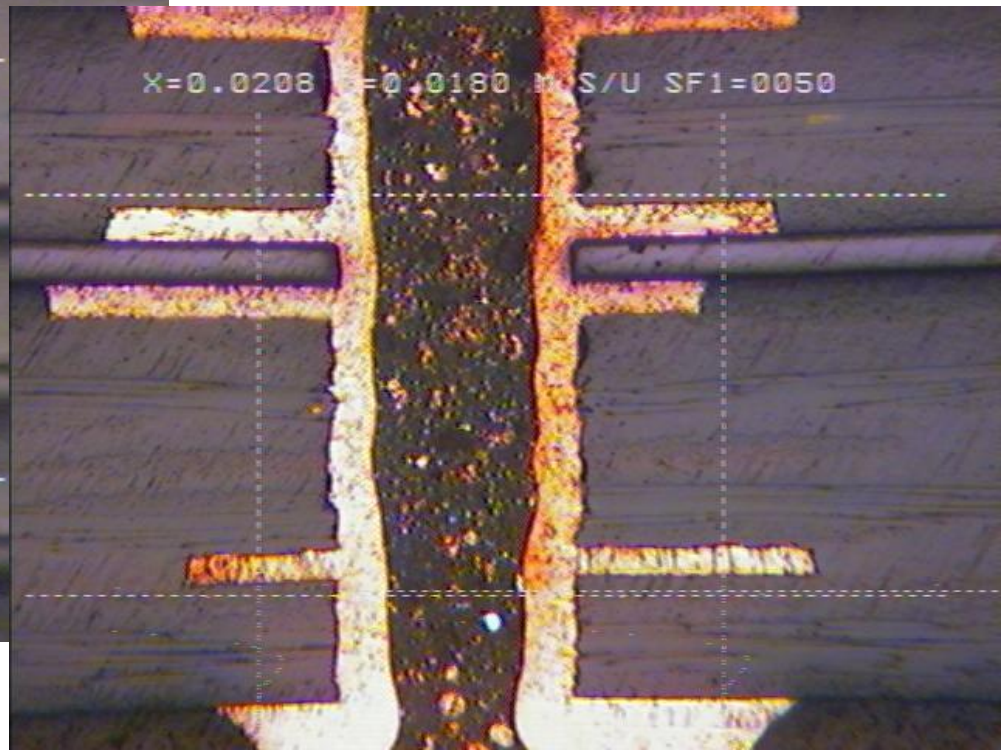
Foil

PTH

SEQ PTH

# Flex with Conductive Via Fill



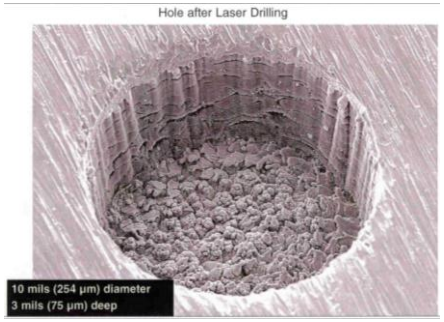
# High Density Interconnection

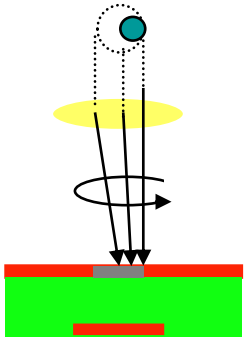
## Hybrid Laser

- UV laser cuts copper
- $CO^2$ laser cuts dielectrics

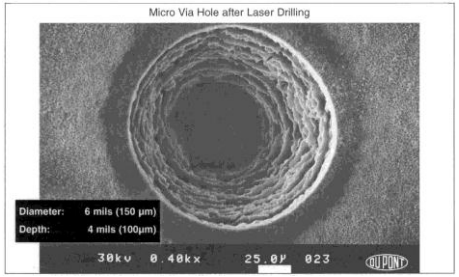
**Automated handling for thin foils**

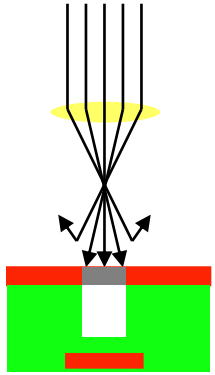
**4-point optical registration and compensation routines**

**U.V. drilling of l copper**



**$CO_2$ drilling of laminate dielectric**

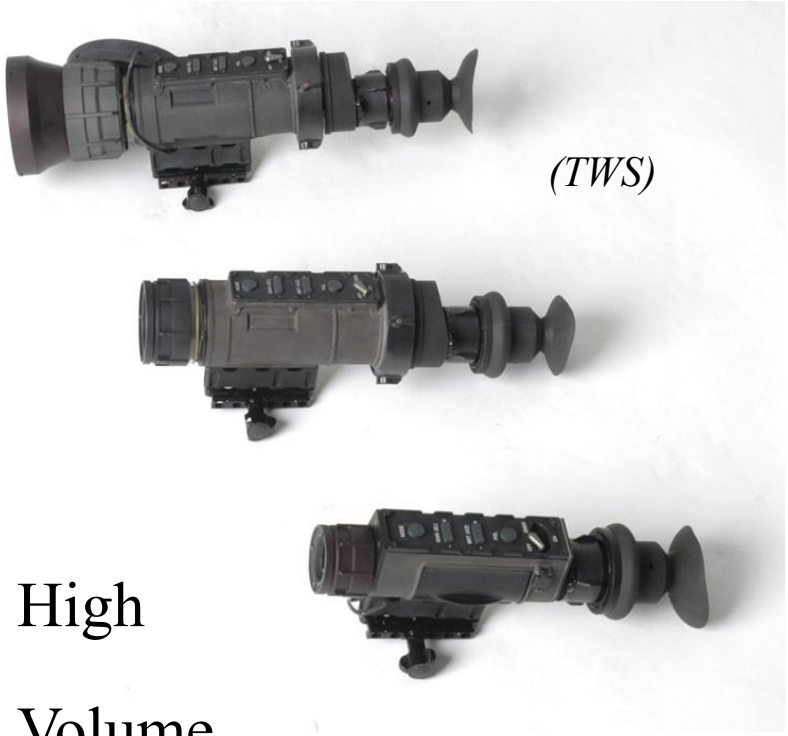
# Fail-Safe Flex Circuits in Small Places

## Sub .8mm BGA in high volume

Thermal Imaging "Night Vision"

*Images represent technology*

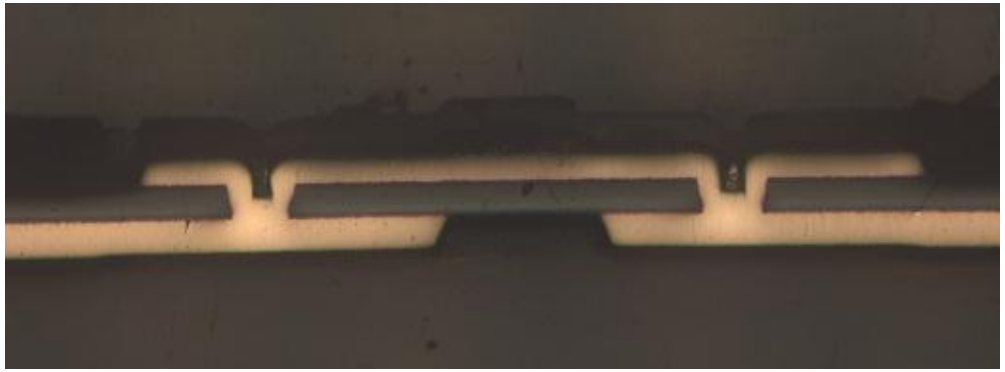
*not actual Customer product*



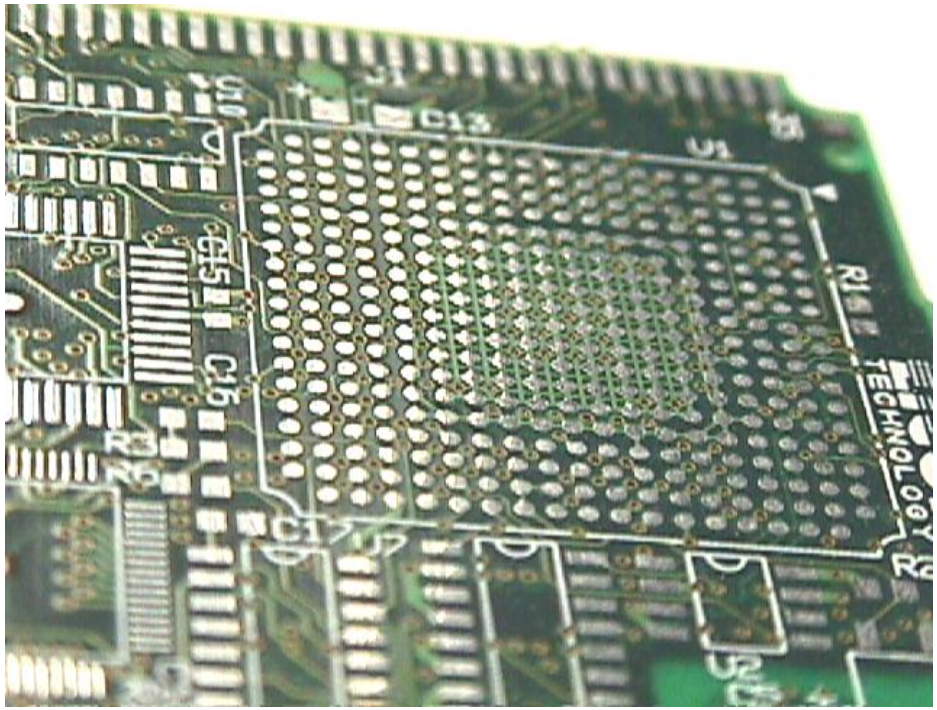

High

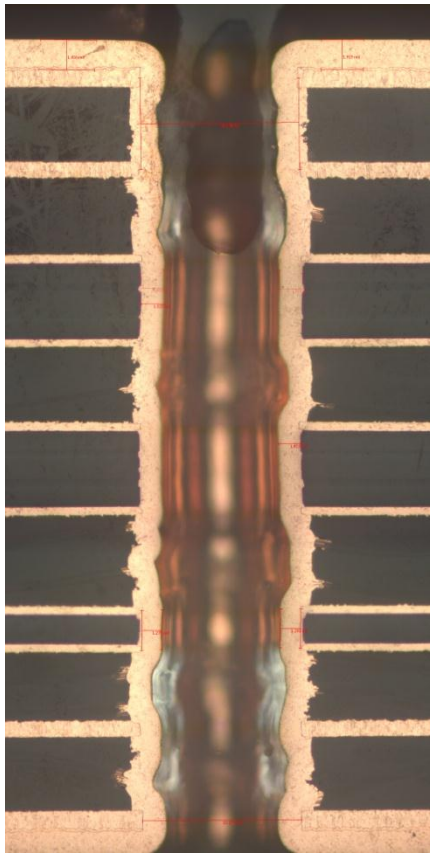
Volume

## HDI Type 3 Flex



# .8mm BGA, very nice

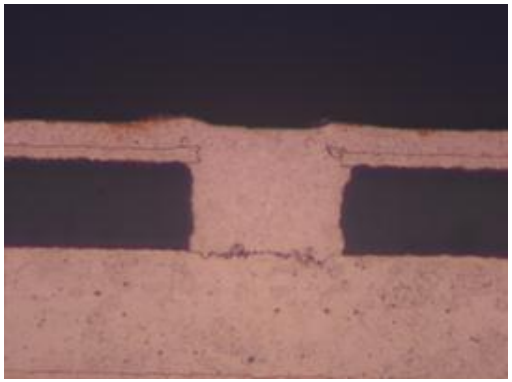


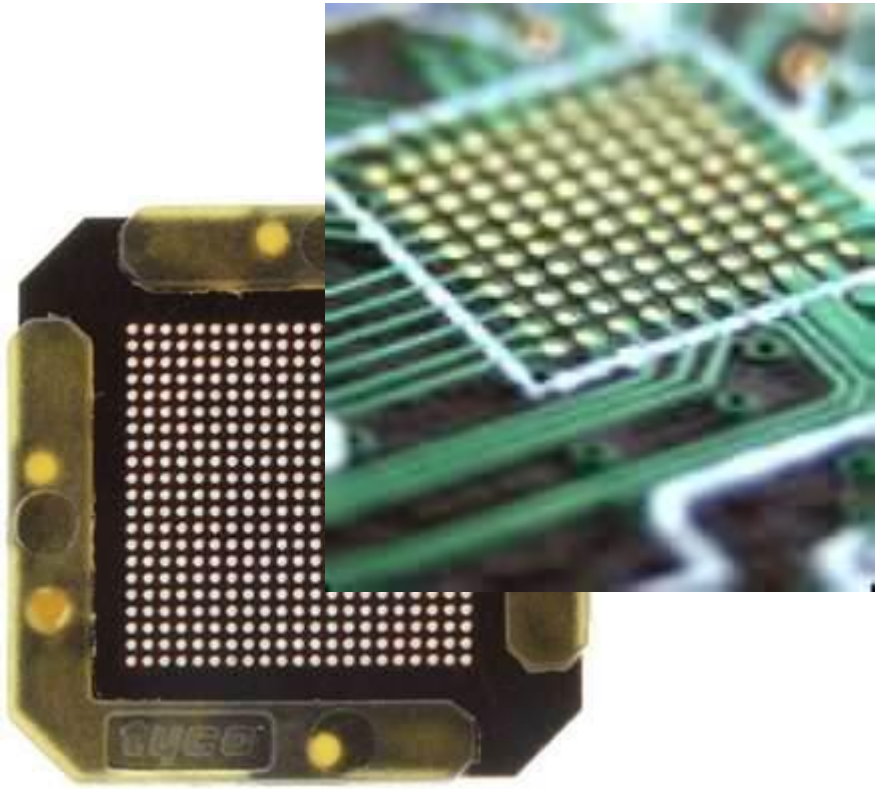


Dedicated pad for BGA and adjacent PTH via

.010-.0135 PTH

# <.8mm BGA requires Via In Pad



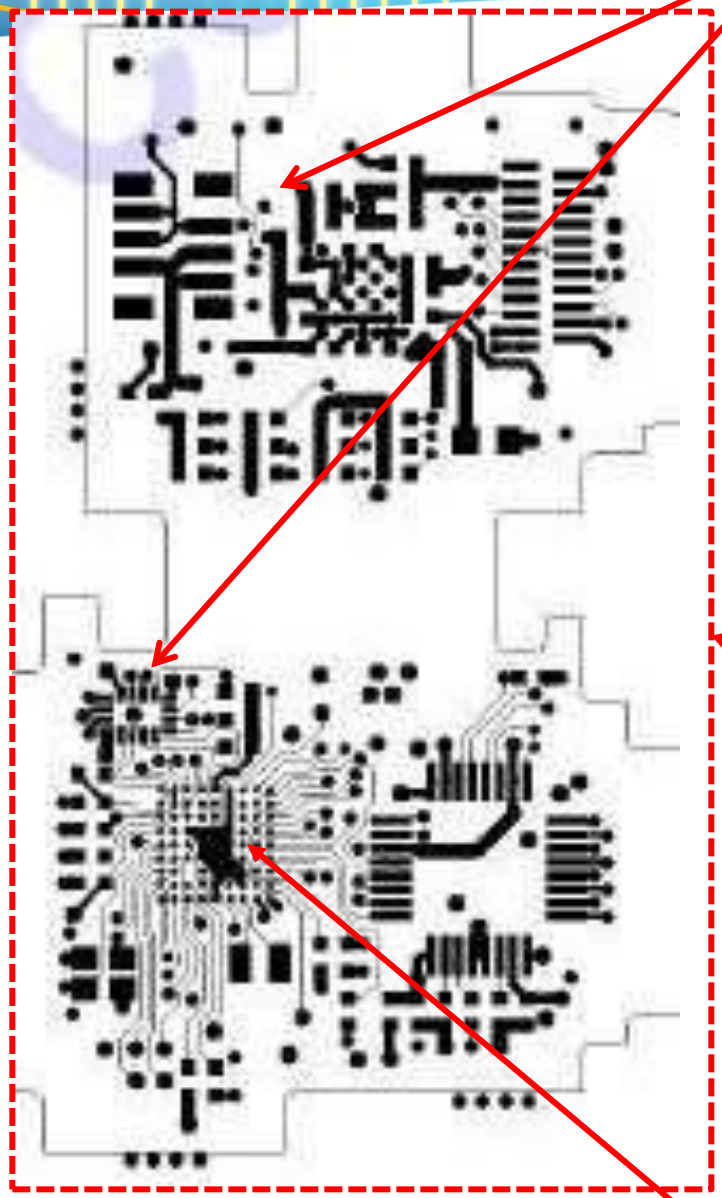


Copper filled via
.004 dia plated hole
.002 dielectric

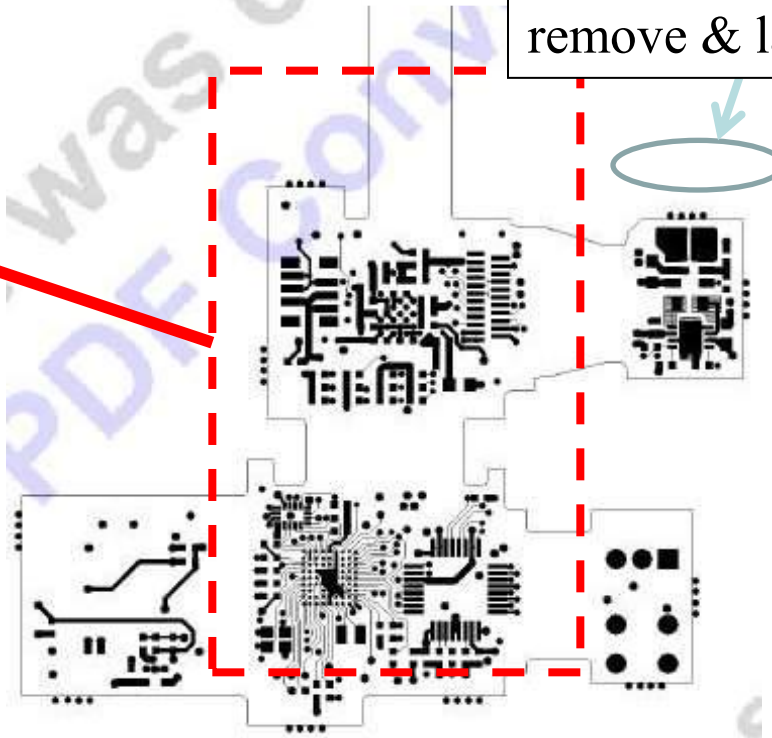
Advantages of solid copper via are huge (Minco Cu filled via)

other route layers

typical .017 pads being converted to micoVias



Customer prefers better de-panel configuration than “mouse bites”; remove & laser



.5mm BGA, NO Via In Pad (no VIP anywhere)

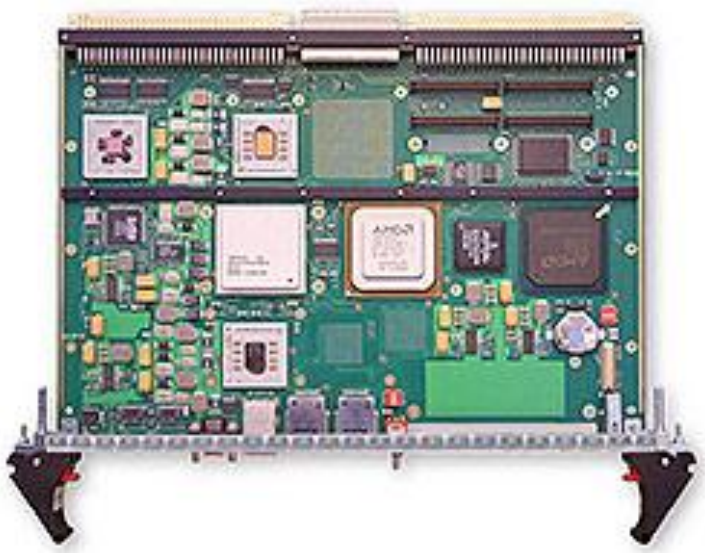
# Change From Conventional flex

- PO is greater than 1,000 pieces
  ...but less than a million

Customer Design for RFQ
  - Conventional Type 4 rigid flex
    - Layer 1/2  rigid, 3/4 flex, 5/6 rigid
    - .017 pad size with .006 PTH
  - Unable to meet budget
  - Unable to sustain quantity schedule

**IR Vision Electronics**

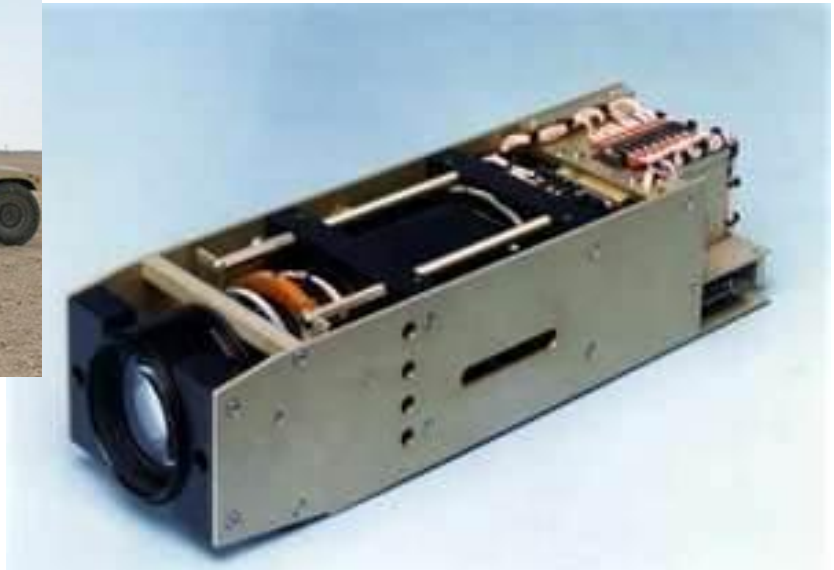
- The Package:
  - Double SMT
  - Envelope size of 3” x 2”
  - COTS components



# Change To HDI High Density Interconnect

- Same footprint of 3 x 2 inch
- Same component layout
- Program success

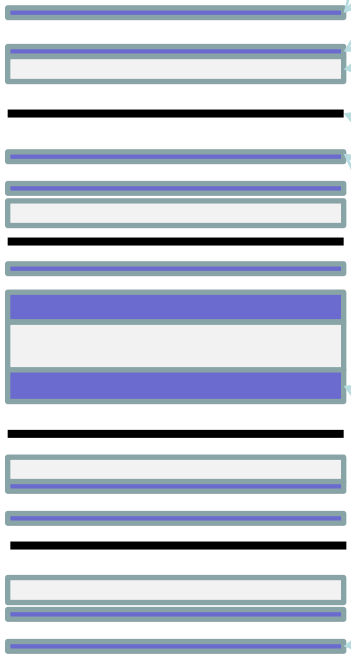
–Very small area for electronics



# 6 layer Diff Imped HDI



1/2 3rd plate
2/3 2nd plate
3/4 1st plate
5/4 2nd plate
6/5 3rd plate




.001

¼ oz .00035 (Layers 1,2,4,5)

4X .001 core with 1 side Cu ¼ oz

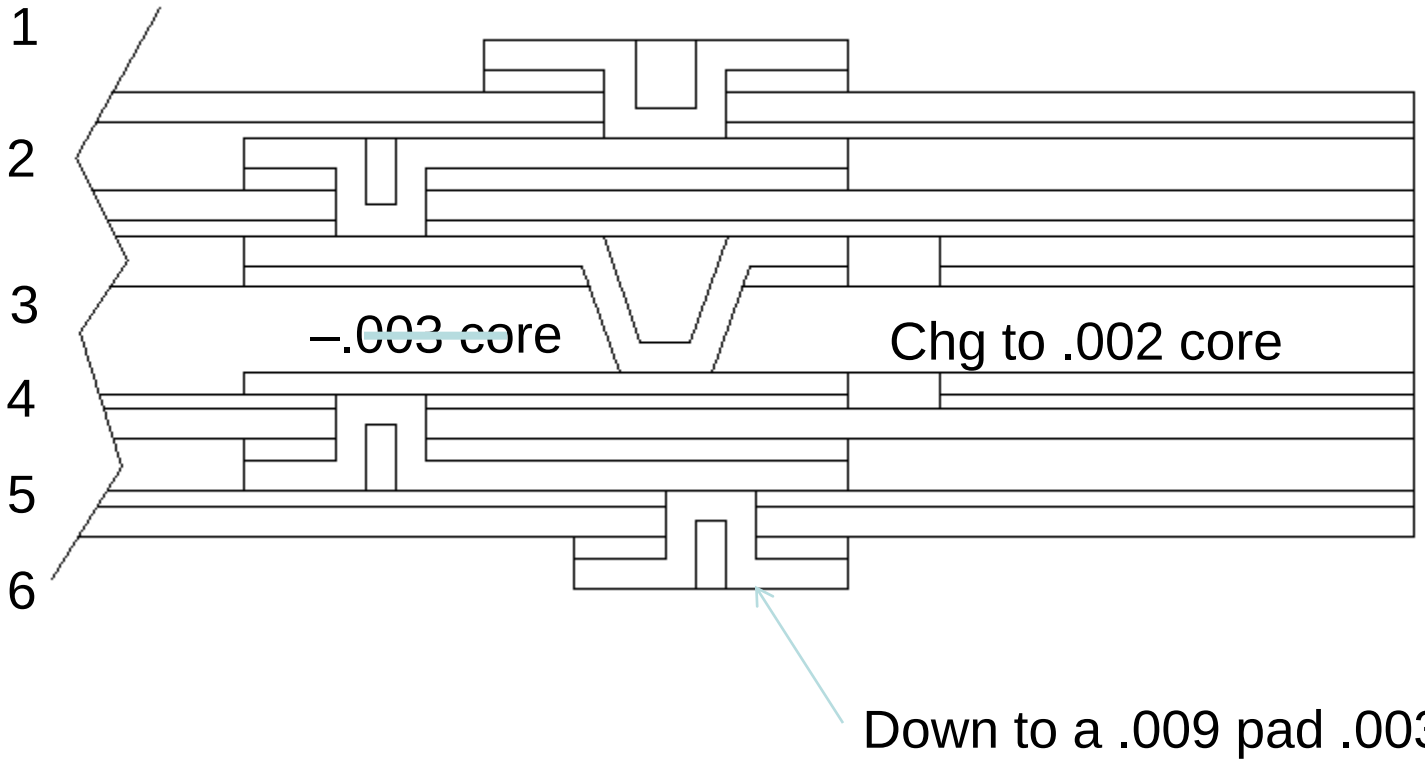
4X Adhesive .0003

3X .00085 internal plate up

No additional plating to layer 4
No vias 4 to 3

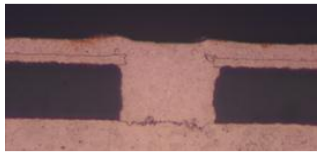
.001 plating (Layers 1 & 6)

# HDI stack up

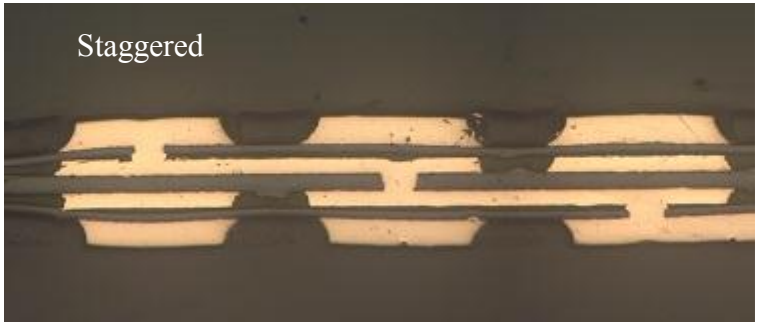


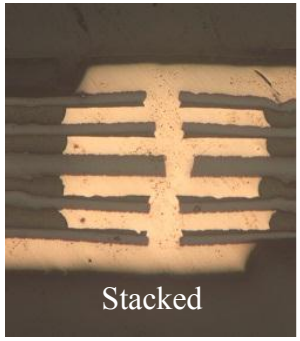
# Staggered vs. Stacked in Type 3 HDI

- Staggered μVias show significantly better results
  - Less Z axis effect
  - Less stress on flat surface
  - Copper Filled for Via In Pad
    - Maintains same design criteria
    - Eliminates planarization
- Stacked failure investigation
  - Copper Filled flatness specification required
  - Prefer Copper Filled without plannarizing



Copper Filled μVia




Standard μVia

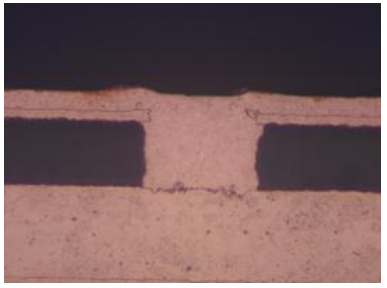
# Summary, *conventional builds*

## Cautions in Design

- Average or above Design Expertise Required
  - PTH to close to edge of part
  - Panelization hugely impacts cost reduction
  - Flex adhesive within PTH over 6 layers is a reliability concern
  - PTH create sequential lamination
  - Rigid-Flex arm length .25 inch MIN (2x .08) on conventional flex
  - Keep simple flex simple
  - RFQ early and often

# Quick tips and we're ready for production

- Center core plated hole equals material thickness + .001 (min)
  - prefer to start with full panel plate versus POP (Pads Only Plate)
- Subsequent layers are .002 dielectric or thinner; prefer .001
  - .004 vias on 12 mil pads (min via in .002 polyimide is .004)
  - .003 vias in 1 mil dielectric and ½ mil cores (plus adhesive)
  - Material + .001 for greater than .002 dielectric thickness, *but call first*
  - prefer staggered pads (staircase)



- External vias plated shut for VIP; no problem
- Conductor/spacing .003/.003 (less for higher dollars)
- Capture/Target pads .012 (.009 min)
- Maximum 6 layers (conductor topography transfer with > 6)
  - Other material options available if more than 6 layers ($$)

APEX EXPO 2013



# MILITARY APPLICATIONS OF FLEXIBLE CIRCUITS

Thank you,

**Brad Saunders**