High performance, low material transmission buses and cables

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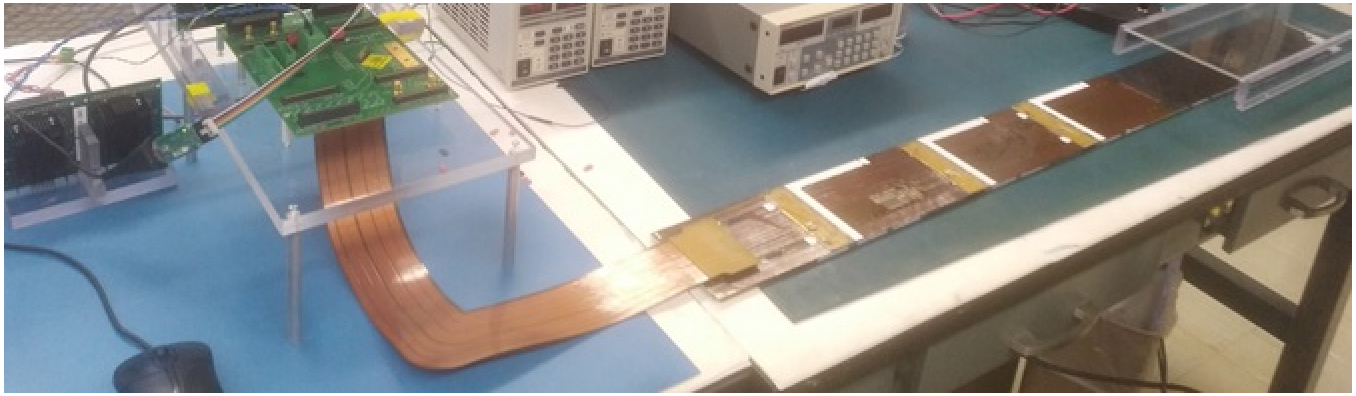
Flexible circuit technology

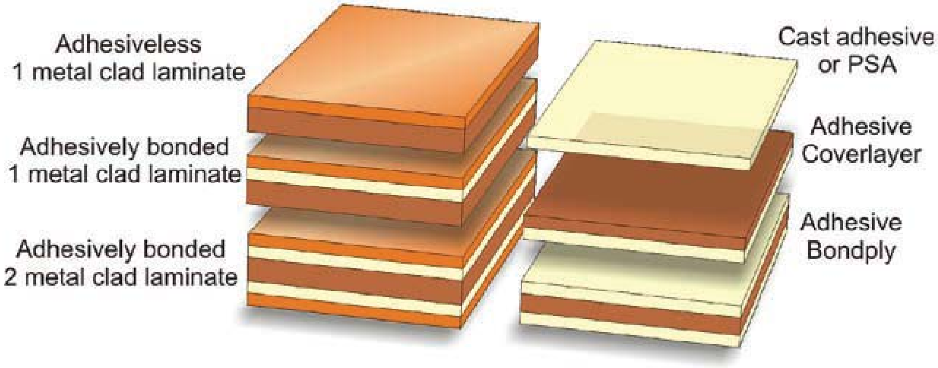


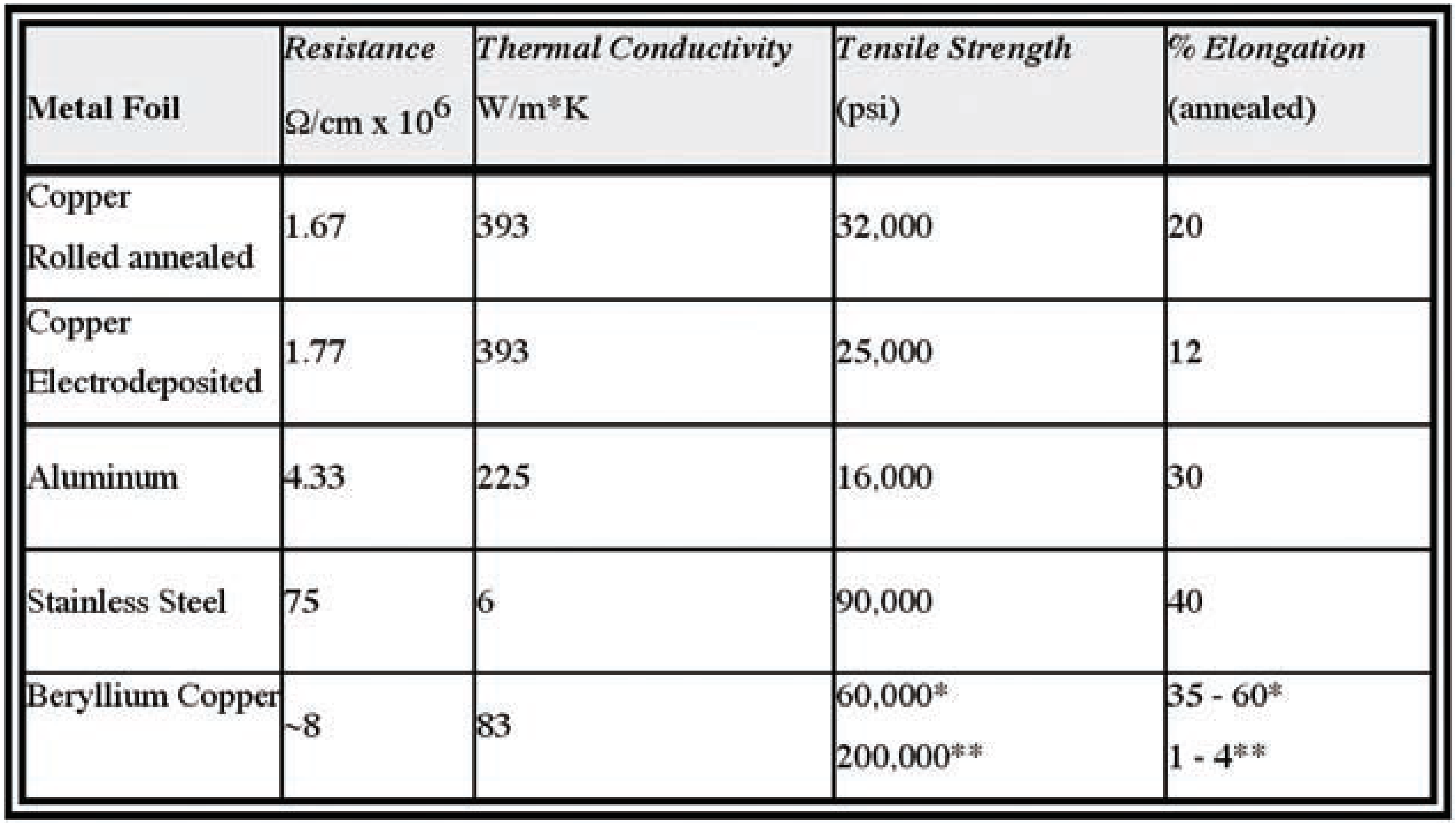
- Flex circuits are often use to connect detector element to the pheripheral electronics
- They substitute cables when
  - the number of connections is large
  - space is limited and «routing» must be tighly controlled
  - a «neat» organization is necessary
  - lenght is not «excessive», i.e. less than ~90 cm for each flexible element of the chain
- Traces transport
  - Signal (analogue, digital, differential, impedance controlled traces)
  - Power/ground
  - HV
  - Control signal (I2C, reset, temp sense, etc ….)

Flexible interconnection

- **The flex «interconnect» circuits aim for:**
  - **Narrow traces and gap when signal is involved (~ 100 um)**
  - **Thin layer of conductor (as low as reasonable achievable) to control the power dissipated in the system**
  - **Choice of thin insulating material with high dielectric strenght**
  - **2-4 layers stack-up**
  - **Low CTE dielectric material to reduce stresses on the system**
  - **Low dissipation factor for high frequency operation**
  - **Tolerant or resistant to radiation**

IN OUR FIELD:
Conductor choice: Copper or Aluminum
(RA or Electroplated/sputtered)
Dielectric: Polymide
(tipical trade names: Kapton, Apical, Upilex, Taiflex….)
Adhesiveless material are preferable
Adhesively bonded metal clad laminate must be tested against radiation
… Often we need to ignore IPC 223B standard …





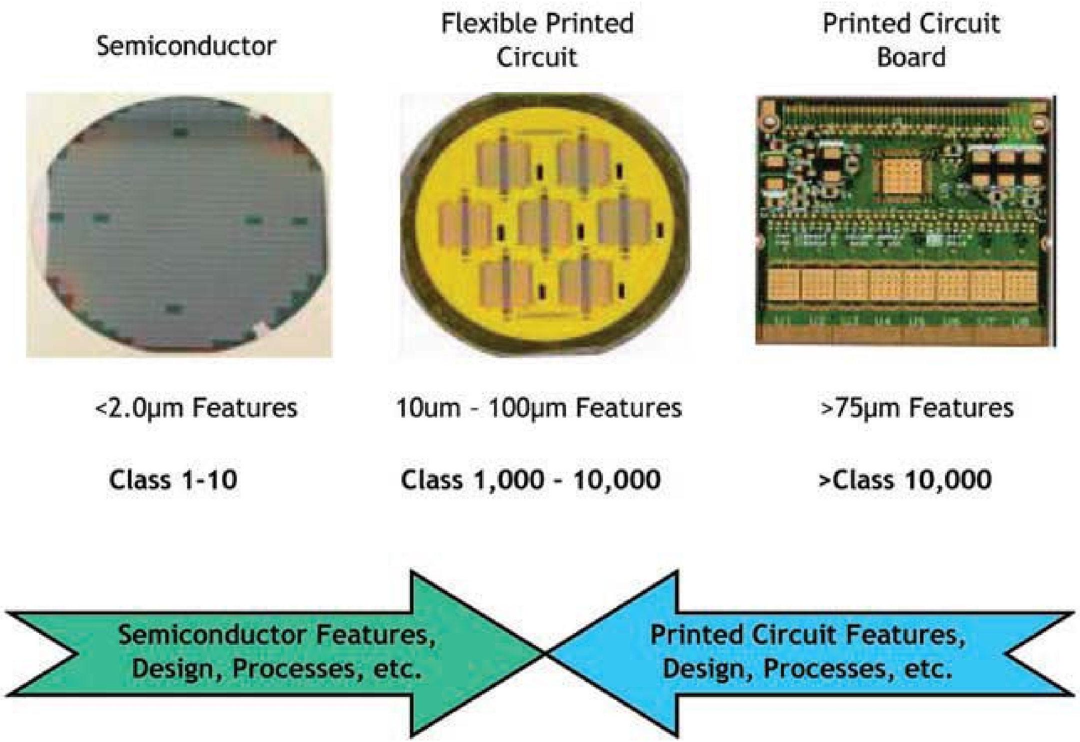
Metal Foil	*Resistance* Ω/cm x 10^6	*Thermal Conductivity* W/m*K	*Tensile Strength* (psi)	*% Elongation* (annealed)
Copper Rolled annealed	1.67	393	32,000	20
Copper Electrodeposited	1.77	393	25,000	12
Aluminum	4.33	225	16,000	30
Stainless Steel	75	6	90,000	40
Beryllium Copper	~8	83	60,000* 200,000**	35 - 60* 1 - 4**

* Annealed Dead Soft ** Heat Treated Full Hard

Needs for specialized facilities

The production of large-area, fine-pitch flexible interconnect is driven by a number of elements:

- Material selection
- Manufacturing processes
- Facilities, tooling, equipment
- Design and engineering support.



Semiconductor	Flexible Printed Circuit	Printed Circuit Board
<2.0µm Features	10um - 100µm Features	>75µm Features
Class 1-10	Class 1,000 - 10,000	>Class 10,000

Semiconductor Features, Design, Processes, etc.

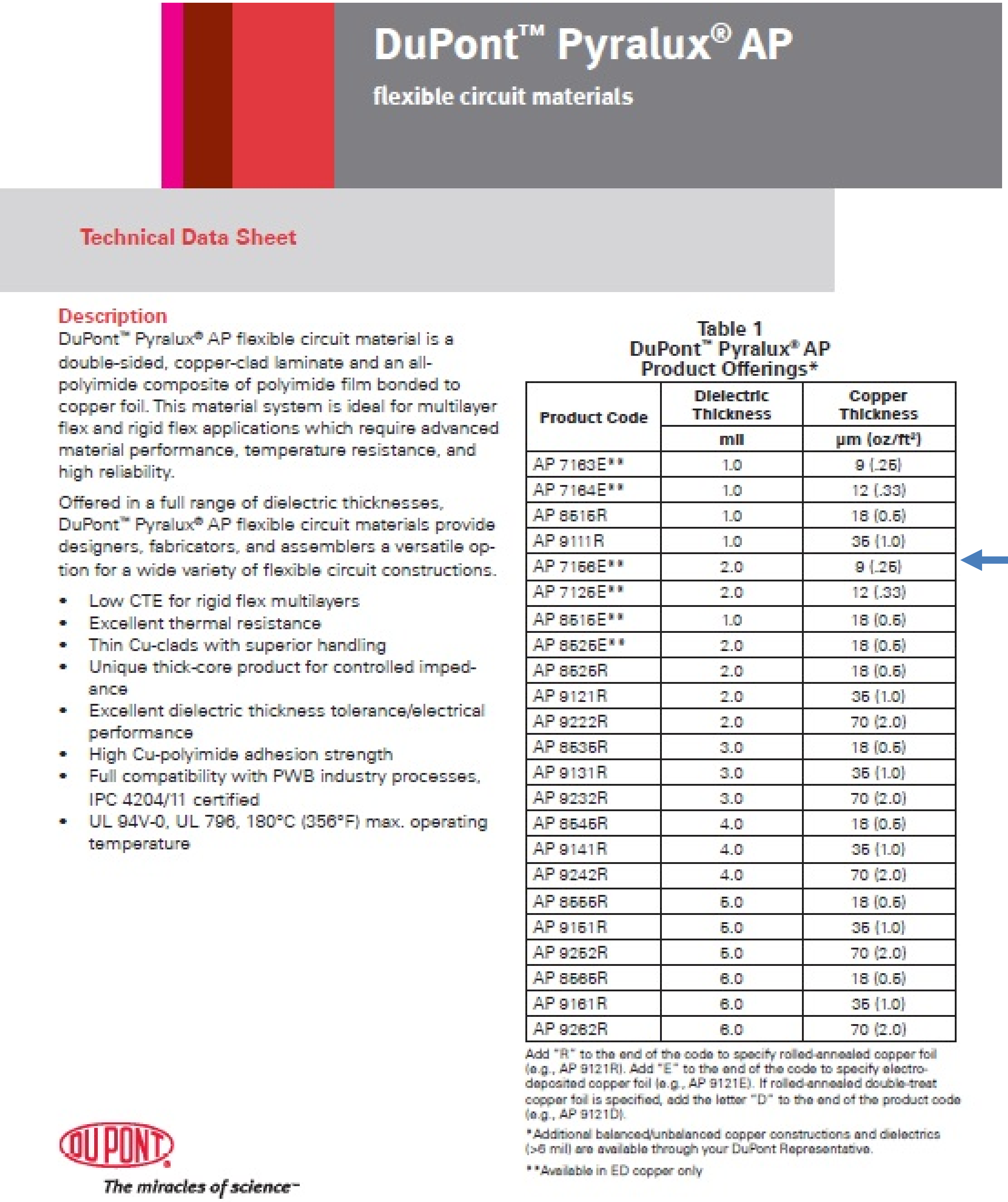
Printed Circuit Features, Design, Processes, etc.

The demand for thin, fine-pitch flexible interconnect requires unique considerations that are not possible with traditional printed circuit board (PCB) technologies.

Fine feature requirements, over large areas, must have clean process facilities and tooling.
Most PCB facilities have limited clean-room capabilities and are often restricted to Class 10,000 in the pattern transfer area.
Fine-pitch interconnect processing of structures with less than 100mm pitch requires clean process areas—i.e., Class 100-1,000–to be able to produce interconnect with acceptable yield, i.e. low-defect densities.

Typical material used in our applications

Novel materials should be compared against this data sheet



DuPont™ Pyralux® AP

flexible circuit materials

Technical Data Sheet

Description

DuPont™ Pyralux® AP flexible circuit material is a double-sided, copper-clad laminate and an all-polyimide composite of polyimide film bonded to copper foil. This material system is ideal for multilayer flex and rigid flex applications which require advanced material performance, temperature resistance, and high reliability.

Offered in a full range of dielectric thicknesses, DuPont™ Pyralux® AP flexible circuit materials provide designers, fabricators, and assemblers a versatile option for a wide variety of flexible circuit constructions.

- Low CTE for rigid flex multilayers
- Excellent thermal resistance
- Thin Cu-clads with superior handling
- Unique thick-core product for controlled impedance
- Excellent dielectric thickness tolerance/electrical performance
- High Cu-polyimide adhesion strength
- Full compatibility with PWB industry processes, IPC 4204/11 certified
- UL 94V-0, UL 796, 180°C (356°F) max. operating temperature

Table 1
DuPont™ Pyralux® AP
Product Offerings*

Product Code	Dielectric Thickness	Copper Thickness
	mil	µm (oz/ft²)
AP 7163E**	1.0	9 (.25)
AP 7164E**	1.0	12 (.33)
AP 8515R	1.0	18 (0.5)
AP 9111R	1.0	35 (1.0)
AP 7156E**	2.0	9 (.25)
AP 7125E**	2.0	12 (.33)
AP 8515E**	1.0	18 (0.5)
AP 8525E**	2.0	18 (0.5)
AP 8525R	2.0	18 (0.5)
AP 9121R	2.0	35 (1.0)
AP 9222R	2.0	70 (2.0)
AP 8535R	3.0	18 (0.5)
AP 9131R	3.0	35 (1.0)
AP 9232R	3.0	70 (2.0)
AP 8545R	4.0	18 (0.5)
AP 9141R	4.0	35 (1.0)
AP 9242R	4.0	70 (2.0)
AP 8555R	5.0	18 (0.5)
AP 9151R	5.0	35 (1.0)
AP 9252R	5.0	70 (2.0)
AP 8565R	6.0	18 (0.5)
AP 9161R	6.0	35 (1.0)
AP 9262R	6.0	70 (2.0)

Add "R" to the end of the code to specify rolled-annealed copper foil (e.g., AP 9121R). Add "E" to the end of the code to specify electro-deposited copper foil (e.g., AP 9121E). If rolled-annealed double-treat copper foil is specified, add the letter "D" to the end of the product code (e.g., AP 9121D).

*Additional balanced/unbalanced copper constructions and dielectrics (>6 mil) are available through your DuPont Representative.

**Available in ED copper only

The miracles of science™

Figure 6. Dielectric Constant vs. Frequency

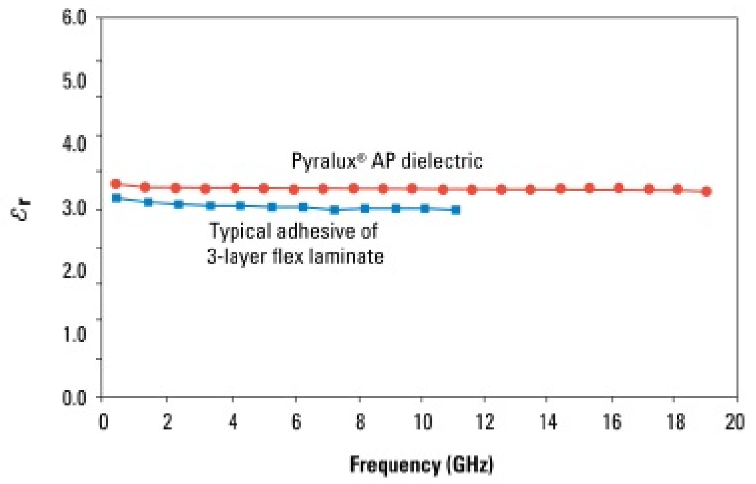
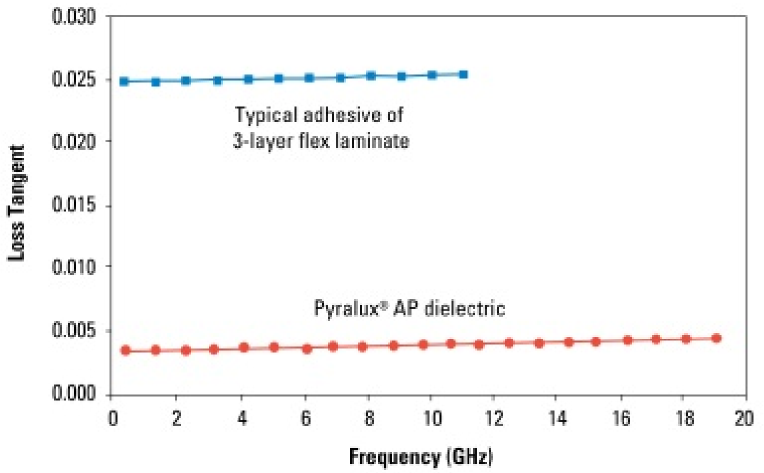


Figure 7. Loss Tangent vs. Frequency



Notes: The Typical Adhesive Value is for the adhesive alone. When the Adhesive is used in conjunction with Kapton® H film for typical 3-layer copper clads, the Loss Tangent will be measurably lower—typically about 0.020.

Earlier data suggests that the Typical Adhesive value drifts up noticeably after 12 GHz.

The Pyralux® AP dielectric values are typical for constructions 1 through 6 mils of dielectric. A new 3-mil bondply made specifically for use with AP has equivalent Loss Tangent Values.

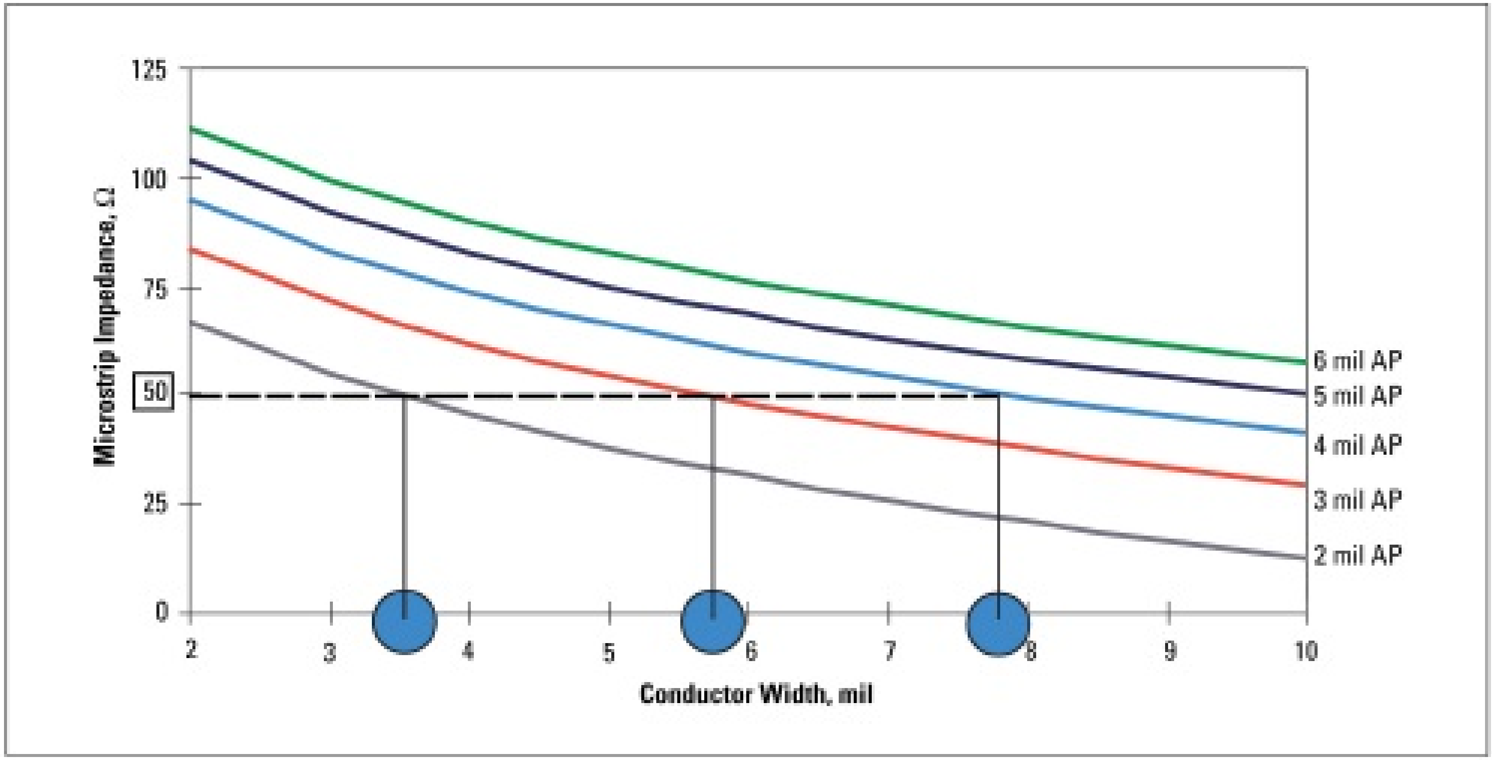


Figure illustrates the relation between conductor width and Impedance using different AP material

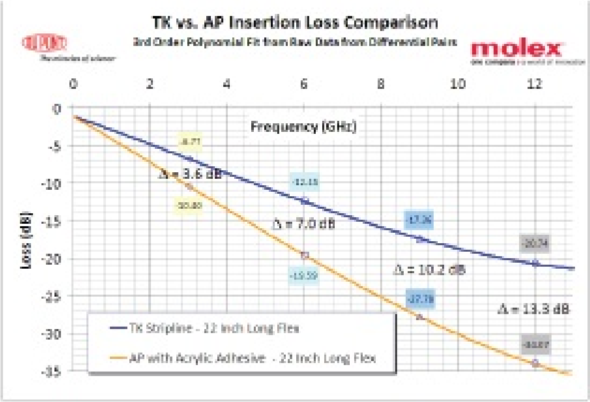
→ Presently a trace width of ~ 75 um can be used as standard with 18 um copper

→ Less than that, requires 9 um of less of copper

New dielectrics for high speed signal transmission: Pyralux TK

Pyralux TK is a material system that replaces the traditional higher loss acrylic adhesive with a Teflon® based material. The resulting structure has a dielectric loss up to an order of magnitude lower than traditional flex adhesives…. To be tested against radiation

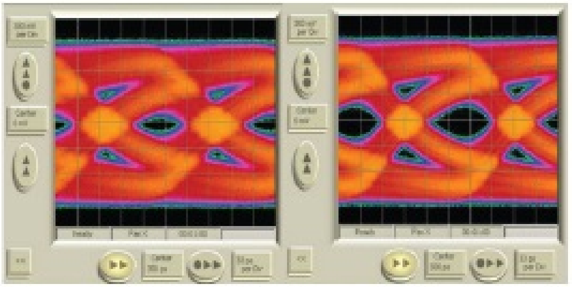
An interposer style connector attached to the flex circuit was used to connect the flex to the fixture board. The insertion loss of the flex plus the interposer was measured and the data shown in the following chart. This plot reflects the average of five differential pairs per material type.[1]



The reduction in insertion loss is quite significant and becomes greater as frequencies increase. This opens up more options to the interconnect designer. The reduced insertion loss can be applied to the loss budget or lengths of flex interconnect can be increased depending on system needs.

ANALYSIS OF EYE PATTERNS AT 6 GBITS/SECOND

The same test vehicles described above were subjected to a 31bit long Pseudo Random Bit Stream (PRBS-31) at 6 Gbits/second to evaluate performance in physical interconnects. The eye patterns data provided below is based on actual measured signals in differential pairs, not simulated from S-Parameters. The eye pattern test reveals there is a reduction in insertion loss with the TK material, as seen in the eye height improvement, and there is also an increase in the eye width.[1]



PYRALUX® AP **PYRALUX® TK**

AP		TK		
109.4	Jitter-PP (ps)	82.0	25% Improvement	Improved due to lower Dk of TK material. Signal travels faster through TK
59.4	Eye Width (ps)	82.7	48% Improvement	Improved due to lower Dk of TK material. Signal travels faster through TK
201	Eye Height (mV)	373	85% Improvement	Improved due to lower loss in TK
1.8	Digital SNR (db)	2.6	+0.8 dB Improvement	Eye height and width improvement combines to yield better system performance

ANALYSIS OF LOSS PER UNIT LENGTH – EXISTING VERSUS NEW FLEX MATERIALS

To determine the mechanism of the loss benefit, the same test structure was evaluated but with different lengths. Lengths of 22, 11 and 6 inch were evaluated. From this, the effect of the flex by itself can be determined by measuring loss of each structure. A valuable figure of merit, loss per unit length, can be determined by evaluating the difference in loss and dividing this by the difference in length. This eliminates the effect of the fixture and connector. Results of this analysis are shown below.[1]

Defects in fine pitch flex circuits

Defects found on flexible interconnect can include trapped fibers, hole in trace, and conductor-to-conductor shorts. These defects are the result of particles generated from process materials or the process environment, including tooling, operators, and the process facility.

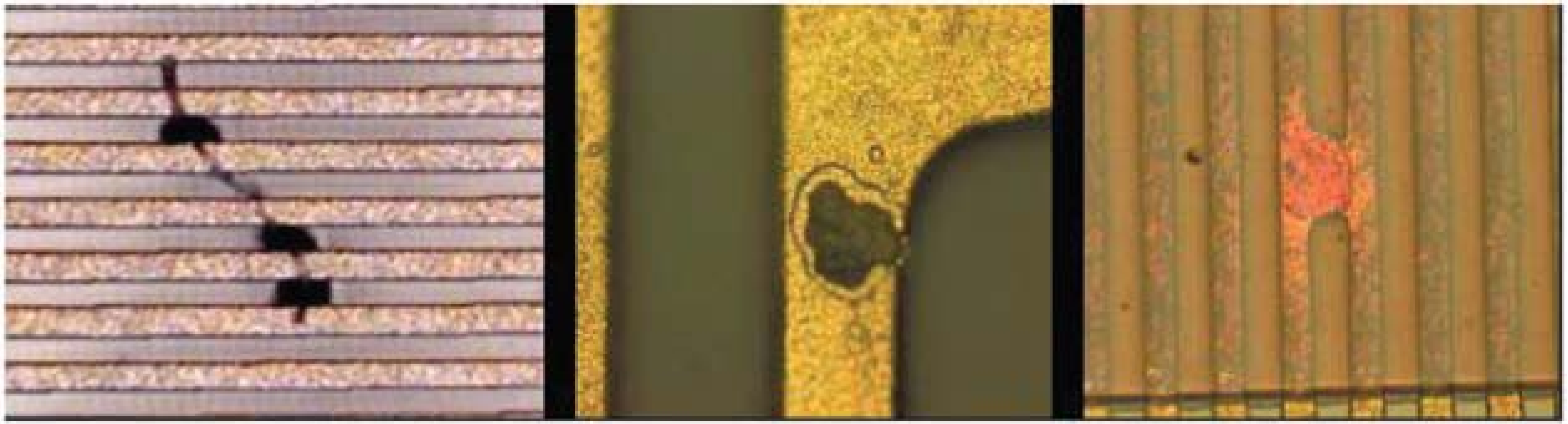
Many manufacturers have designed clean process tools that contain the work and protect it from an unclean facility (**for example CERN shop has such a facility**)

In addition to requiring clean space and controlled defect densities, fine-pitch interconnect involves thin dielectric materials (<50um) that are difficult to handle.

Traditional panel processing requires special handling to prevent material movement through processing.

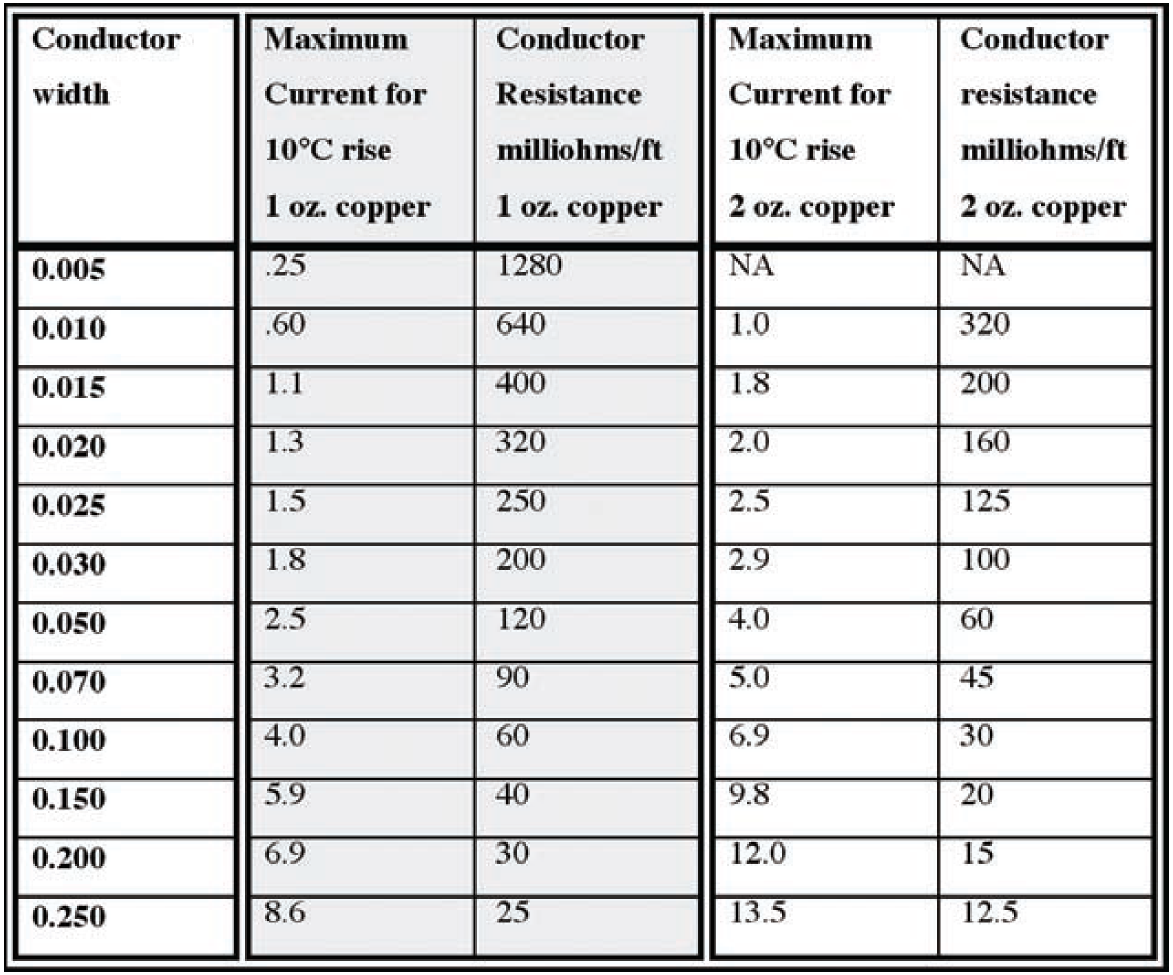
→ Opening in the coverlay can easily shift creating potential assembly problem

→ Especially difficult on **24”x36” (maximum commercially available size)** or 24”x28” panels



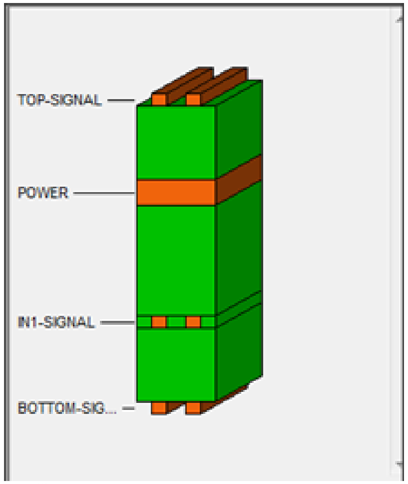
Current to be carried by the flex circuit is a limitation in the choice of the trace width

Conductor width and copper thickness have a direct impact on the current-carrying capacity of a flexible circuit. This table provides a means of determining the conductor width for a 10°C rise. This is for quick reference only. Please consult IPC-2152, Standard for Determining Current-Carrying Capacity in Printed Board Design, for more accurate design solutions.



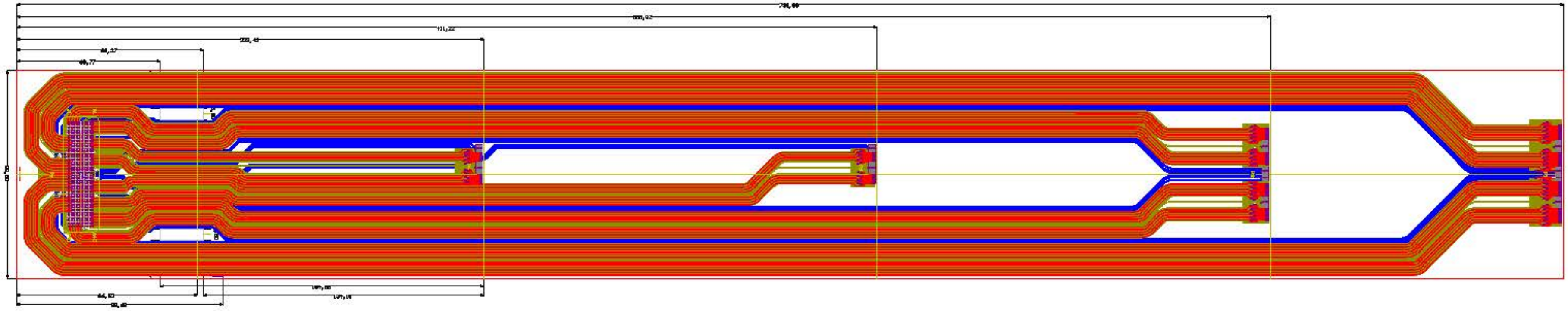
Conductor width	Maximum Current for 10°C rise 1 oz. copper	Conductor Resistance milliohms/ft 1 oz. copper	Maximum Current for 10°C rise 2 oz. copper	Conductor resistance milliohms/ft 2 oz. copper
0.005	.25	1280	NA	NA
0.010	.60	640	1.0	320
0.015	1.1	400	1.8	200
0.020	1.3	320	2.0	160
0.025	1.5	250	2.5	125
0.030	1.8	200	2.9	100
0.050	2.5	120	4.0	60
0.070	3.2	90	5.0	45
0.100	4.0	60	6.9	30
0.150	5.9	40	9.8	20
0.200	6.9	30	12.0	15
0.250	8.6	25	13.5	12.5

An example of long flex (four layers)

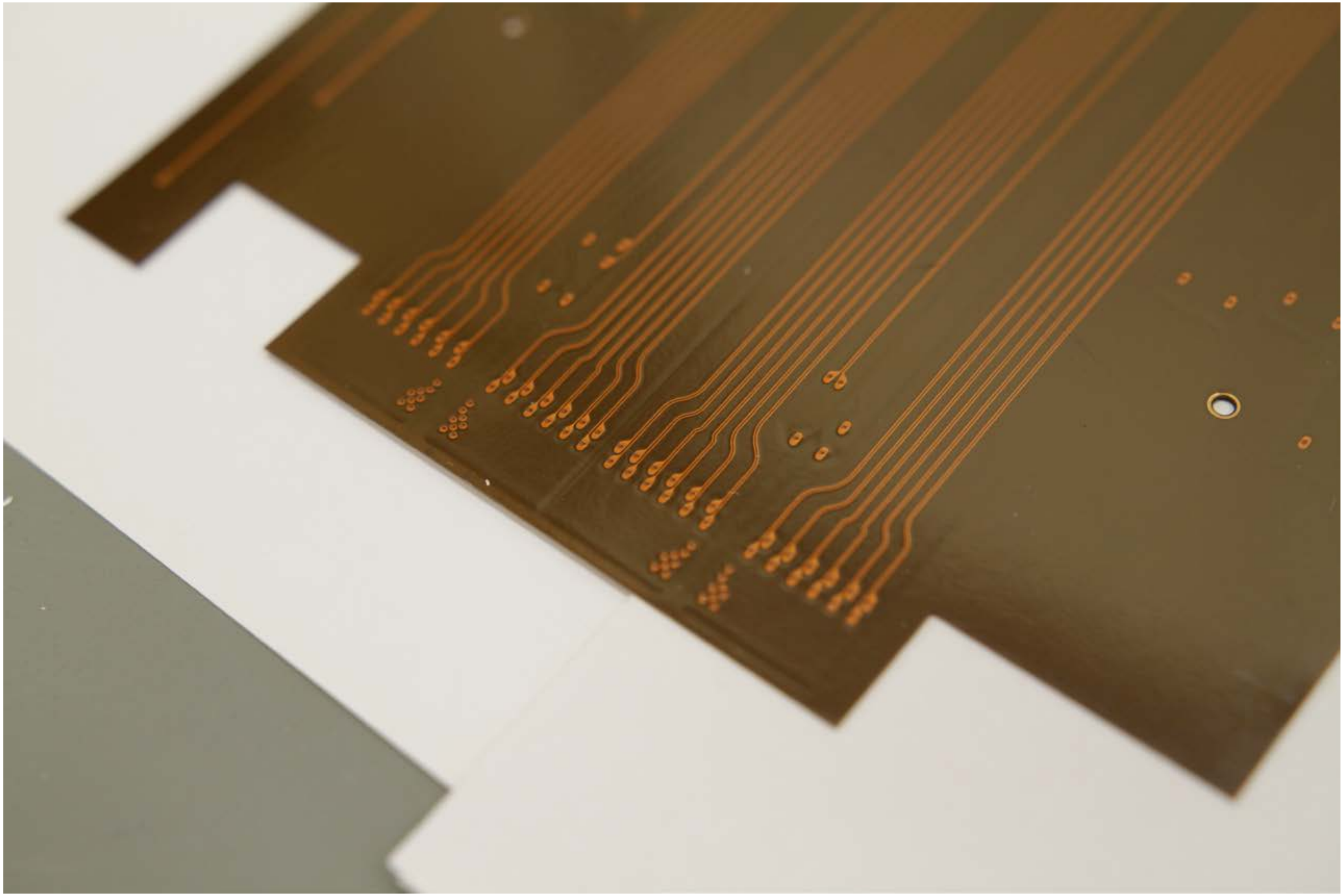


Technology: Full-flex + stiffener design in the connector area

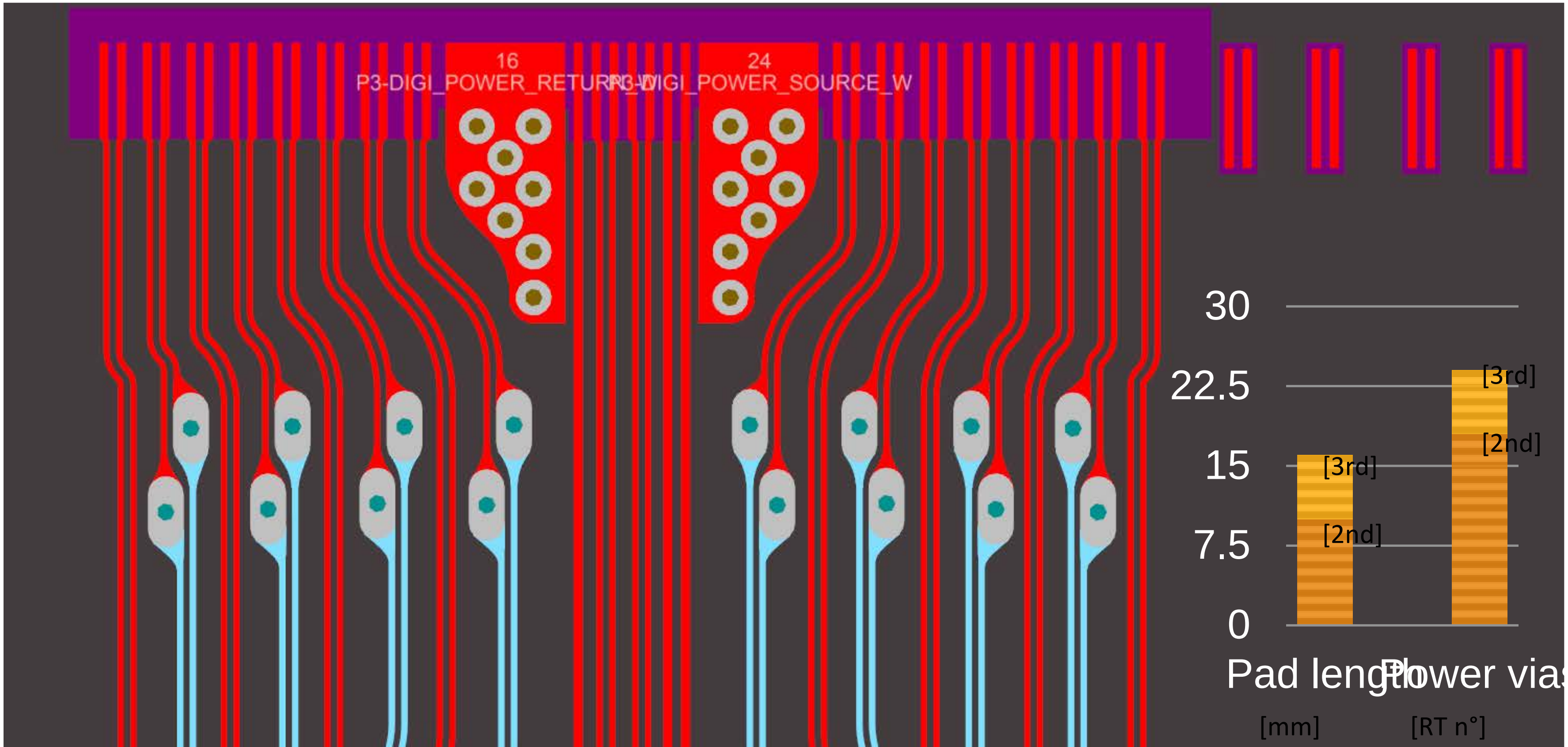
- Stack-up: Two double cores as in figure (18 um)
- Traces with/space adjusted in the inner layers to keep Zdiff ~ 100 Ohm
  - 115 um on top, 117 um in the inner layer
- Approximately 150 differential lines running along the flex.
- Power traces instead of planes: width increased accordingly to current and power dissipation need
- Drawback: the large area of the power traces reduce the flexibility of the circuit



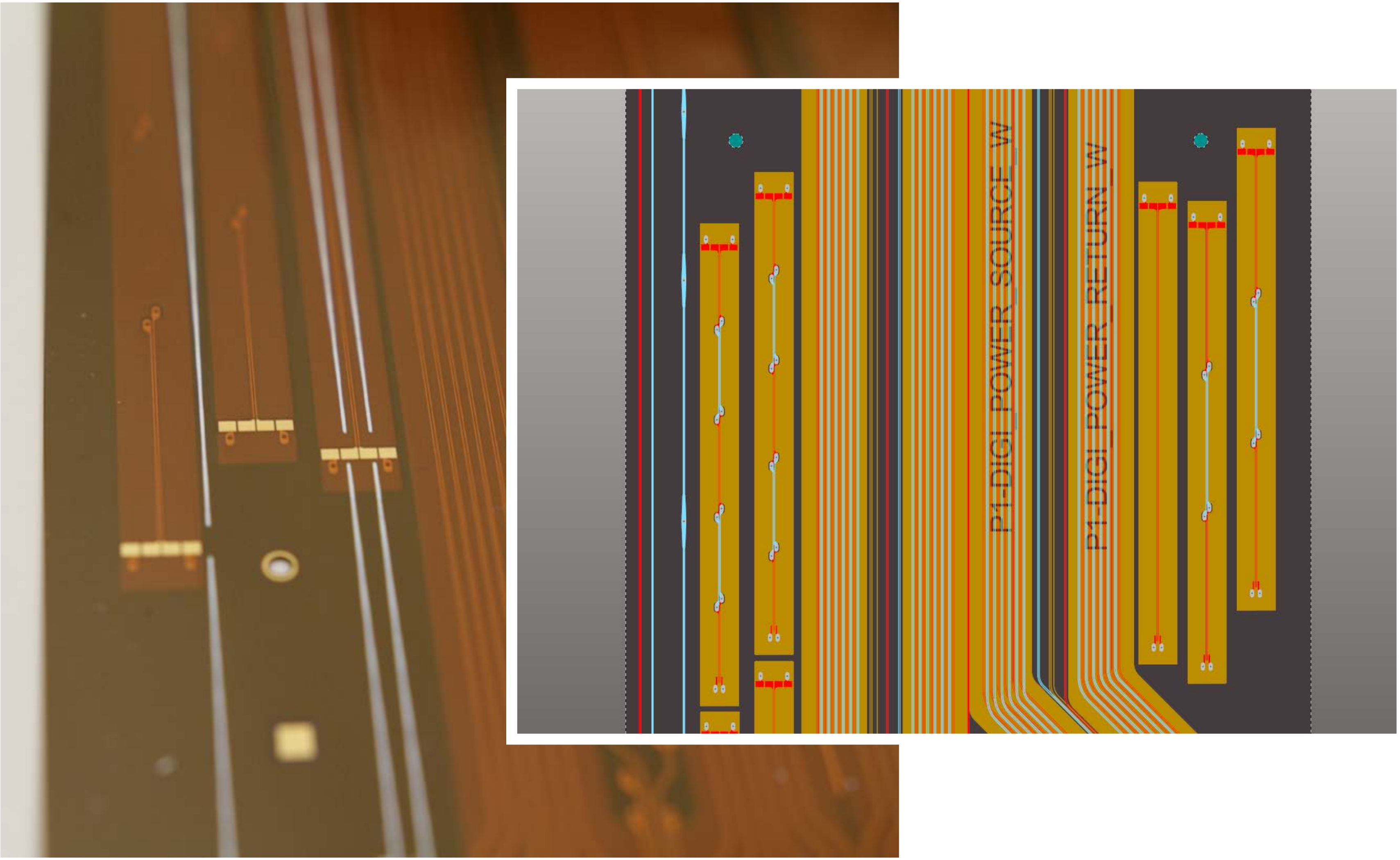
Traces near the edge



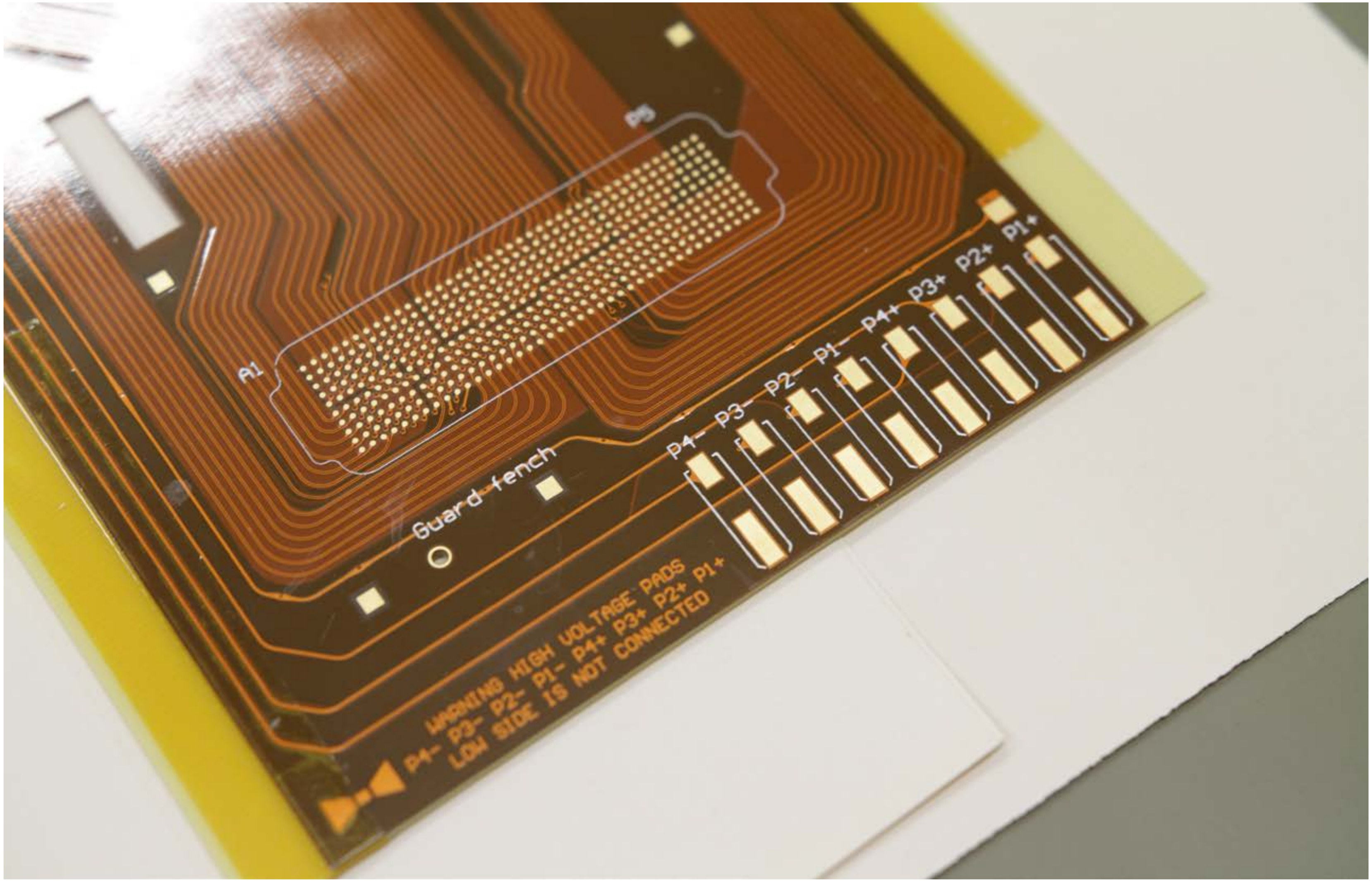
Tear Drop vias and details of differential lines terminated on pad for wire bonding to front-end hybrid



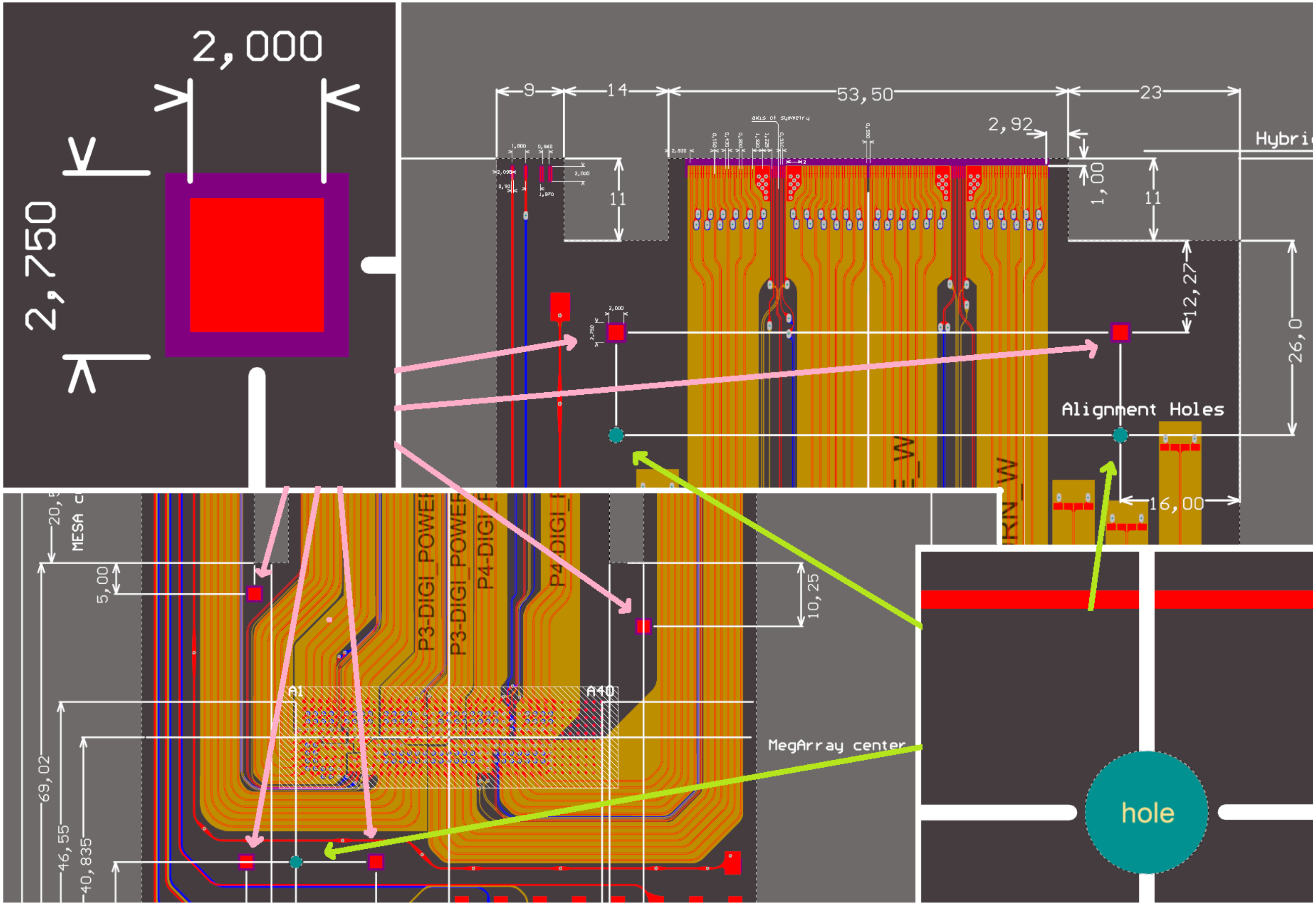
Via coupons for signal integrity & DC resistance testing



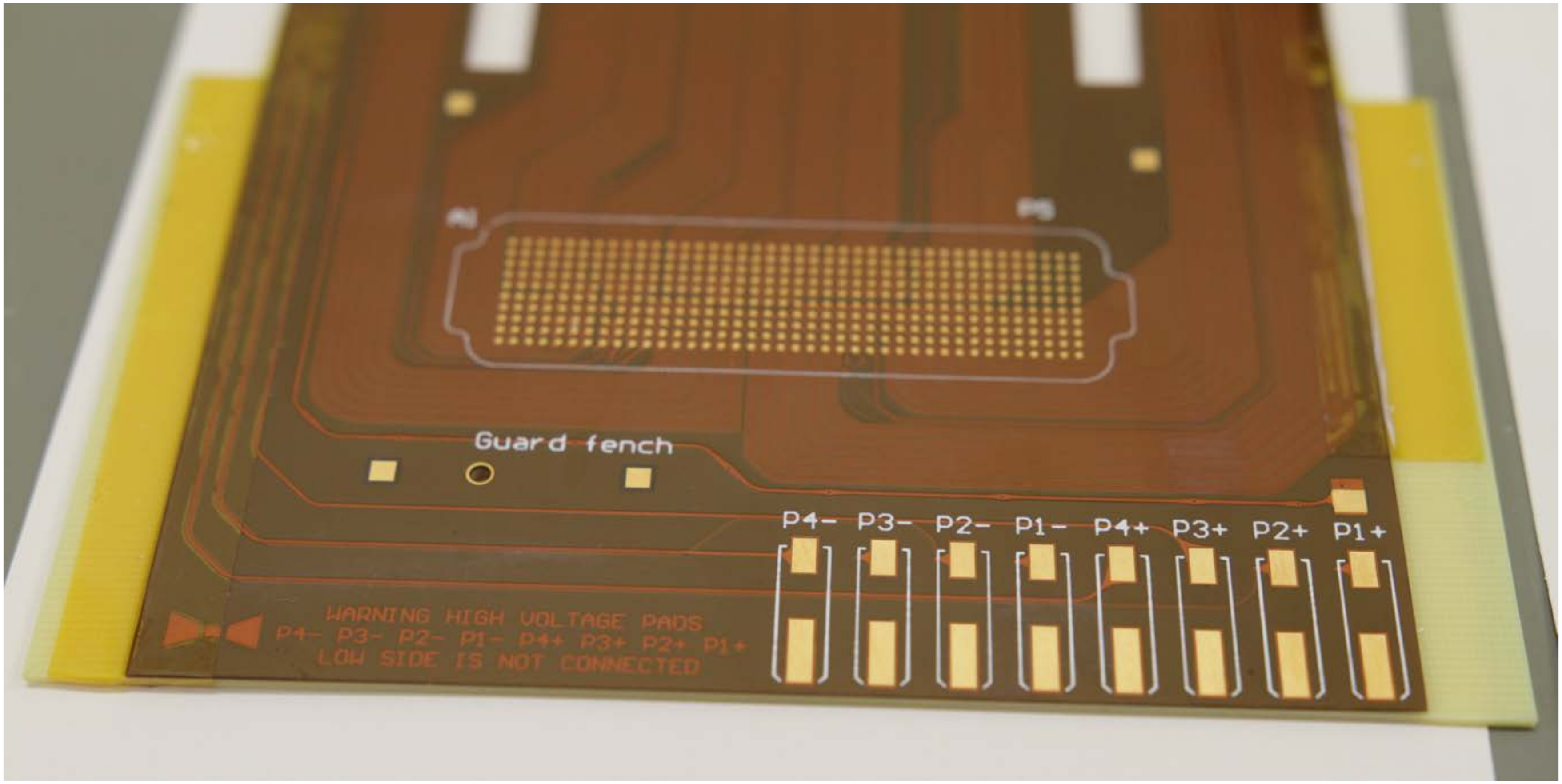
Alignment holes and optical targets



Alignment holes and optical targets

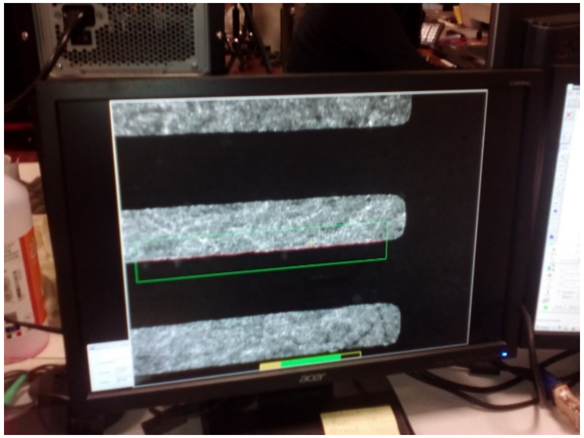


Consolidation of High Voltage connector pads



Wago 2060 / 2059 / Molex LiteTrap   SMD HV connectors

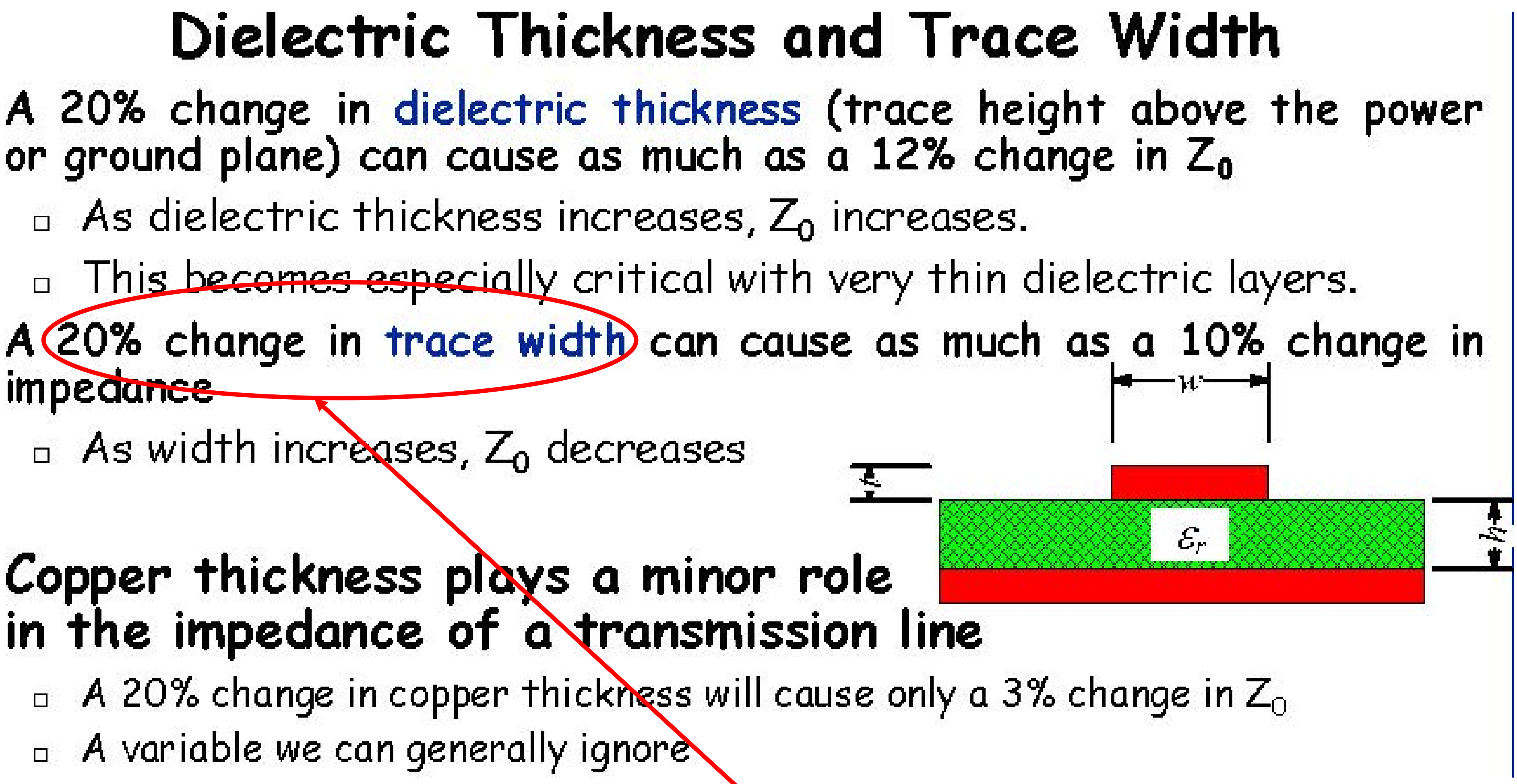
Optical inspection of the long differential traces



Very sharp edges and uniformity

- Indication of very good process
  - Unfortunately width is smaller than expected
- Average width ~ 96 um
- Obviously spaces between traces increases accordingly
- Impedance recalculated with new values → in agreement with measurements (within 5%)
- Design need to adjusted to correct this issue … not uncommon in the first set of prototypes
- Designer need to know the manufacturer process and adjust to it
- Thicknesses need to be measured after plating

2nd gen. Flex Results/Observation



Dielectric Thickness and Trace Width

A 20% change in dielectric thickness (trace height above the power or ground plane) can cause as much as a 12% change in Z_0

- As dielectric thickness increases, Z_0 increases.
- This becomes especially critical with very thin dielectric layers.

A 20% change in trace width can cause as much as a 10% change in impedance

- As width increases, Z_0 decreases

Copper thickness plays a minor role in the impedance of a transmission line

- A 20% change in copper thickness will cause only a 3% change in Z_0
- A variable we can generally ignore

Seems the dominant effect

Impedance of differential traces must be carefully tested

Example of TDR measurements on some traces:

- Two values of <impedance>ave: ~ 118 Ohm and 125 Ohm
- Slightly different propagation of the signal into the traces
- Extrapolated resistances: 10 Ohm and 8 Ohm respectively explain the slow rising

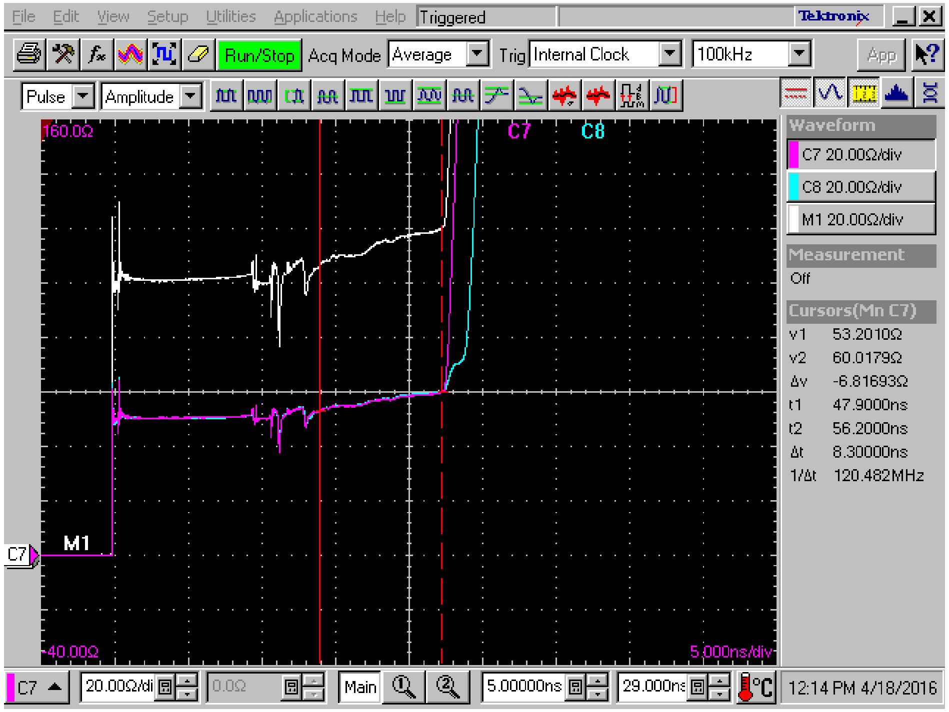
Acq Mode Average
Trig Internal Clock
100kHz

C7 20.00Ω/div
C8 20.00Ω/div
M1 20.00Ω/div

Cursors(Mn C7)
v1 53.9376Ω
v2 63.9396Ω
Δv -10.0020Ω
t1 47.4000ns
t2 56.2000ns
Δt 8.80000ns
1/Δt 113.636MHz

Measurement
Off

C7 20.00Ω/di 0.0Ω Main 5.00000ns 29.000ns 9:54 AM 4/18/2016



Acq Mode Average
Trig Internal Clock
100kHz

C7 20.00Ω/div
C8 20.00Ω/div
M1 20.00Ω/div

Measurement
Off

Cursors(Mn C7)
v1 53.2010Ω
v2 60.0179Ω
Δv -6.81693Ω
t1 47.9000ns
t2 56.2000ns
Δt 8.30000ns
1/Δt 120.482MHz

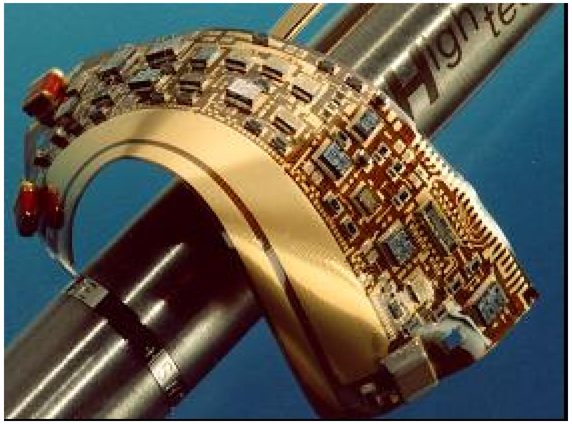
C7 20.00Ω/di 0.0Ω Main 5.00000ns 29.000ns 12:14 PM 4/18/2016

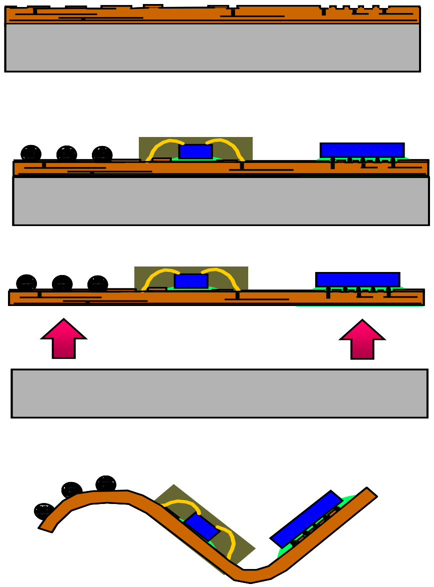
We are not always forced to have a stack-up made by foils ……

- **Few companies can build flex cables by "adding" layer (starting from a glass support to be removed at the end of the process)**
- **Thin and thick copper layer can be used in the same flex**
- **However this process allows blind vias and extremely narrow traces**
- **Prototype production: very long time and expensive**
  - About 6 months to have samples

- Glass substrates 24" x 24"
- Larger flex formats
- Equipment:
  - LDI for 15 µm line and space
  - Sputter Tool (vertical)
  - Electroplating Cu, Ni, Au
  - UV Laser

HiCoFlex® Technology



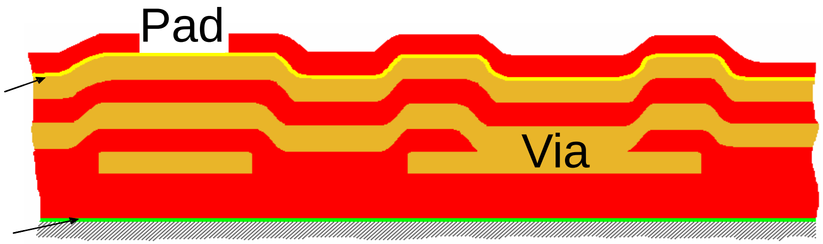


Fabrication of multilayer structure on rigid carrier substrate

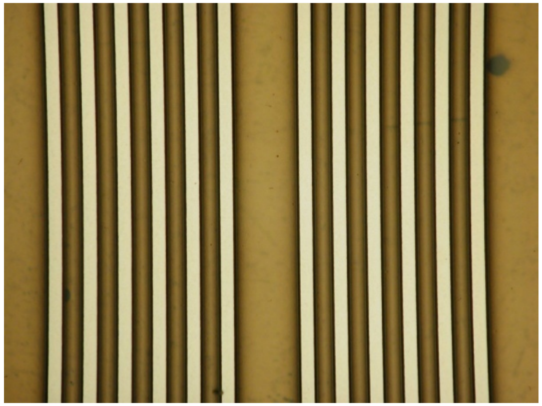
Assembling, Bonding Protection, Test

Separation of multilayer from rigid substrate

HiCoFlex®

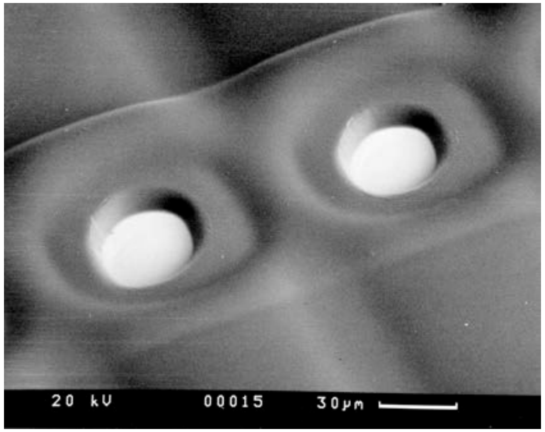


HiCoFlex® Technology

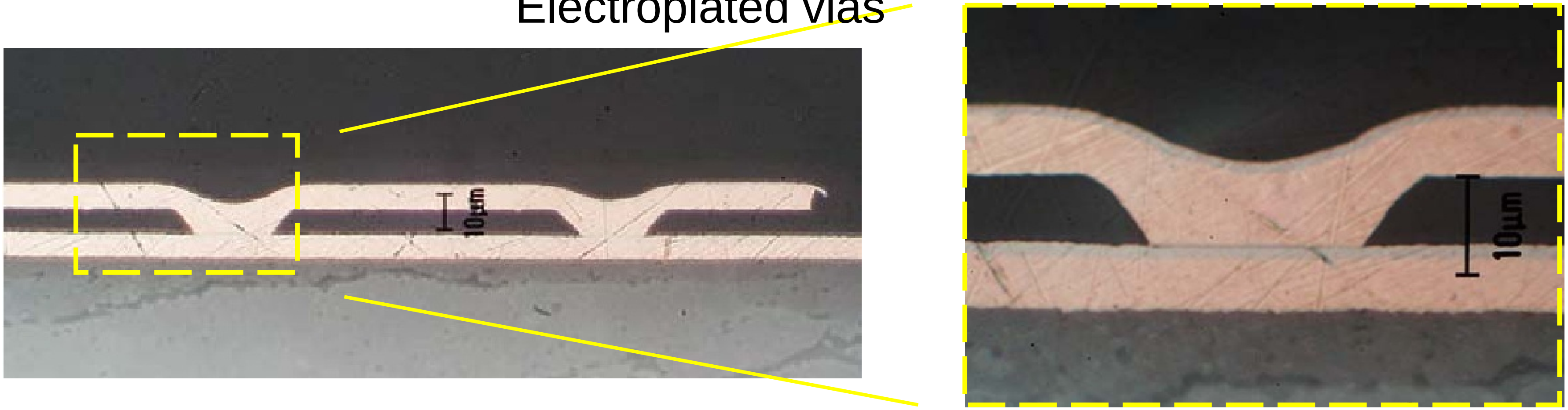


15 µm line/space conductors

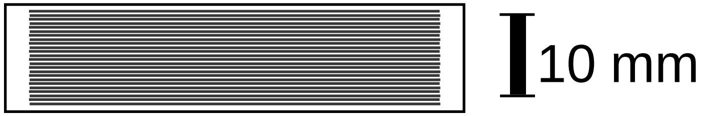
Laser cut vias
∅ 30 µm



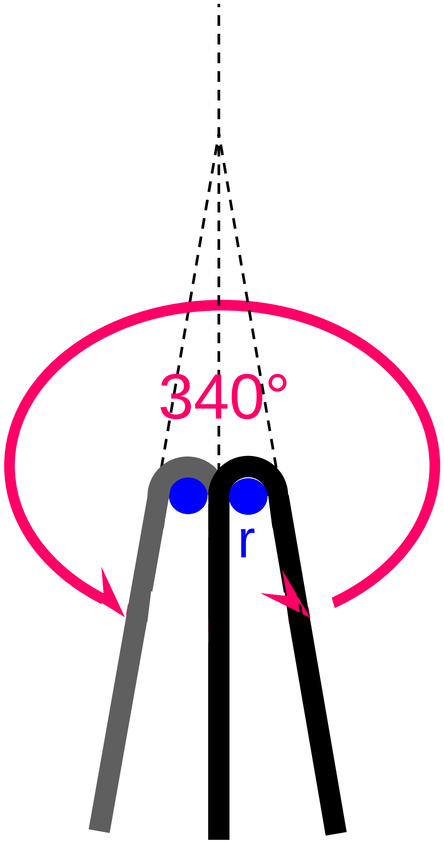
Electroplated vias



HiCoFlex® Technology



77 wires,
150 µm pitch,
25 µm total thickness



r = 1 mm

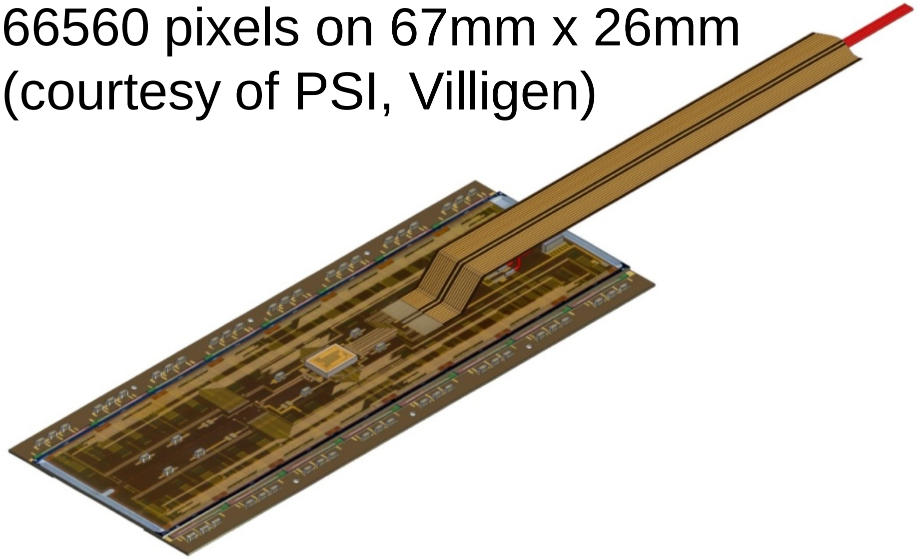
- no mechanical damage
- no change in electrical properties

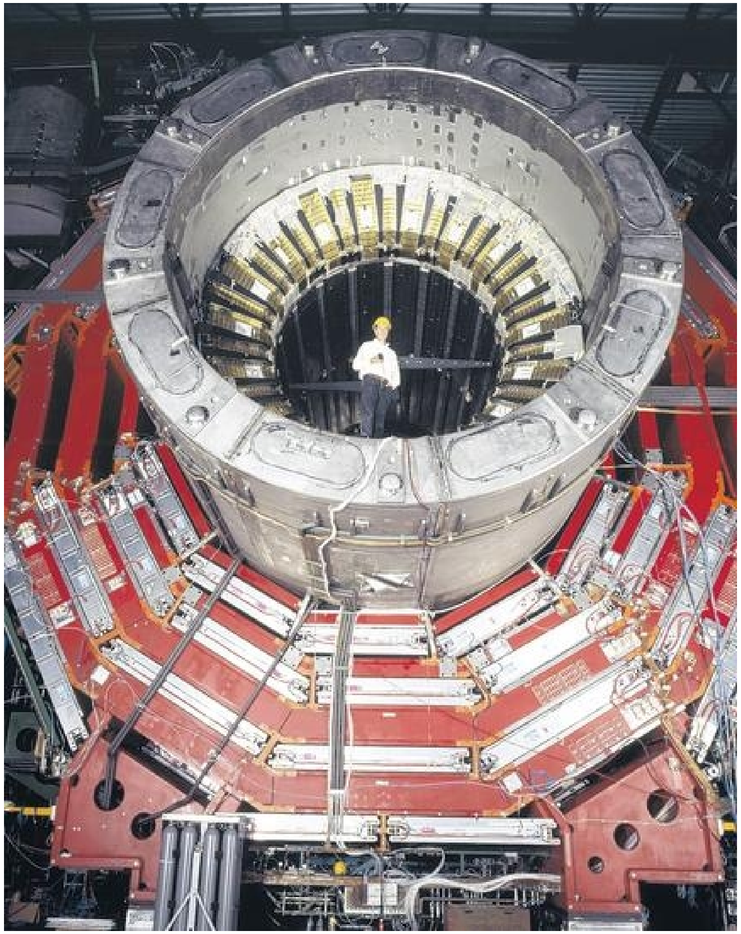
number of cycles > 10^7

HDI / VHDI

3-layer HDI flex
CMS experiment in the Large Hadron Collider (LHC) at CERN

Assembled barrel modul for
66560 pixels on 67mm x 26mm
(courtesy of PSI, Villigen)



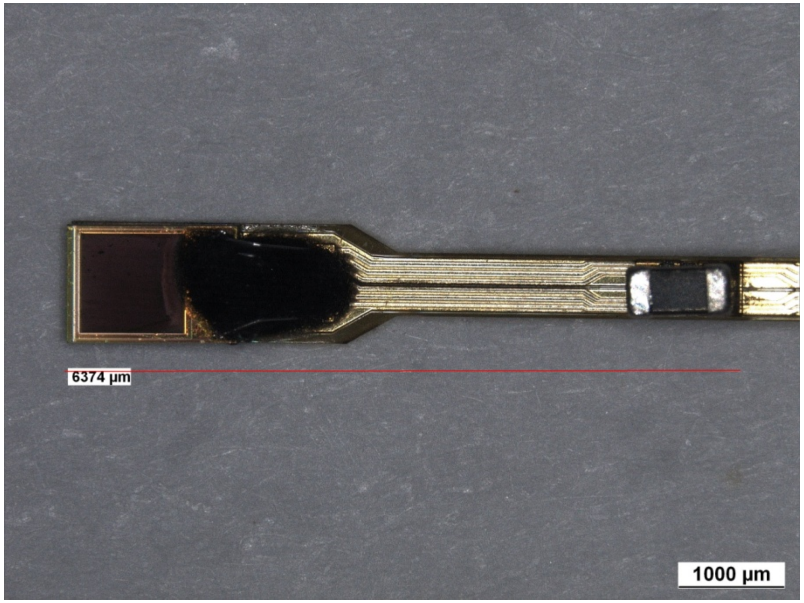


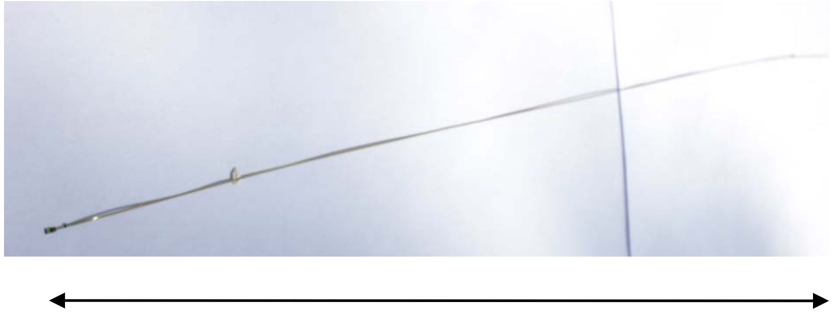
HiCoFlex Long Micro Cables

Medical application for catheder and endoscope connection

For example:

- Length typ. ≥ 0.5m
- Width ≤ 1 – 2 mm
- Number of layers: from 2 to 3





550mm