Materials for PCBs

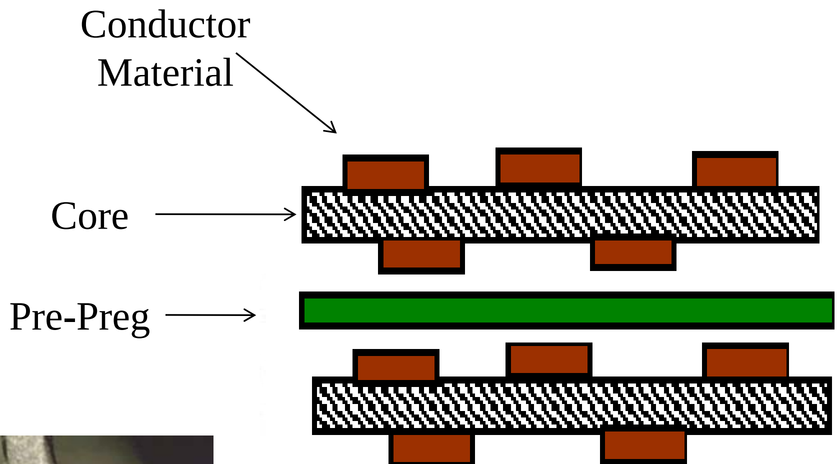
Rashad.M.Ramzan, Ph.D

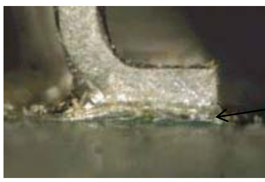
FAST-NU, Islamabad

Today's Topics

- PCB Materials
  - Conductor Coating Material
  - Laminate Material
    - Impact of PCB Laminate on Signal Integrity Types of PCB Laminates
      - Based on Materials used
      - Based on Application
    - Properties of PCB laminates
  - Soldering Materials
- Panel and Panelization

Terminology

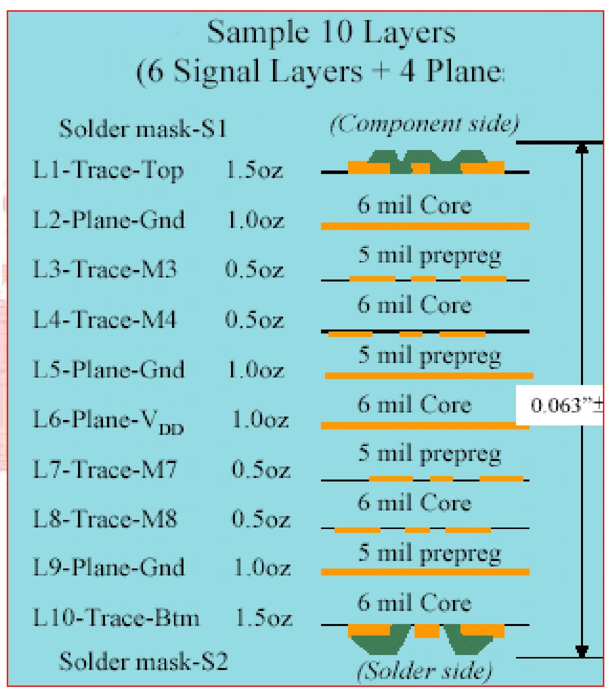




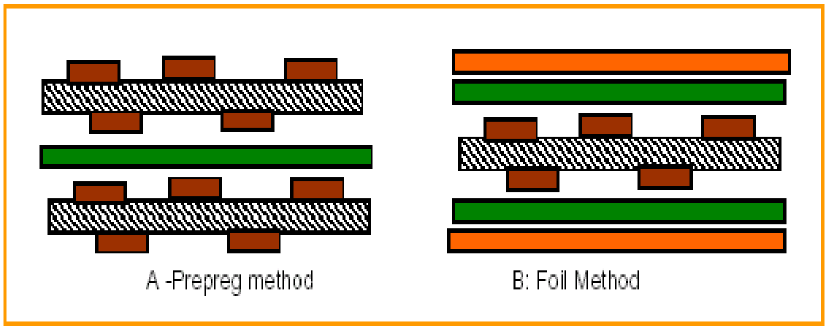
Solder Joint

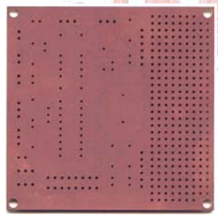
PCB Material

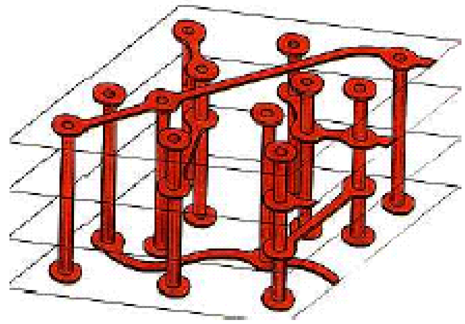
- Laminate Material
- Conductor Material
  - Al
  - CU



Conductor Material







Conductor Material Types

- One ounce of copper means one ounce (28.83 grams) of copper spread over one square foot of laminate.
- Many Types
  - Electro deposited, rolled, annealed, treated for stains proofing etc

One Ounce = 28.83 grams	
Weight in Oz/Sq.ft.	Foil thickness in microns (approximate)
1	35
0.5	18
0.25	10
0.125	5
2	70
3	100

Relative conductivity of some metals

Metal	Relative Conductivity
Gold	100
Copper	98
Aluminum	60
Nickel	27
Iron	17
Lead	15

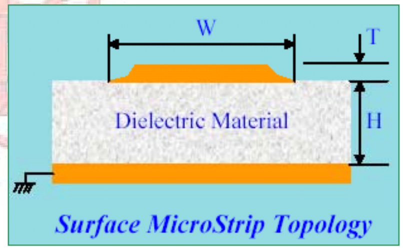
Impact of PCB Laminate

$$Z_o = \left(\frac{79}{\sqrt{\varepsilon_r + 1.41}}\right) \ln\left(\frac{5.98\,H}{0.8\,W + T}\right)\Omega \quad \text{Valid for } 5 < W < 15 \text{ mils}$$

$$C_O = \frac{0.67(\varepsilon_r + 1.41)}{\ln\left(\frac{5.98H}{0.8W + T}\right)} \quad \text{pf/in.}$$

$$t_{pd} = 1.017\sqrt{0.475\,\varepsilon_r + 0.67} \quad (\text{ns/ft})$$

$$l_{\max} = \frac{t_r}{2\,t'_{pd}}$$



Surface MicroStrip Topology

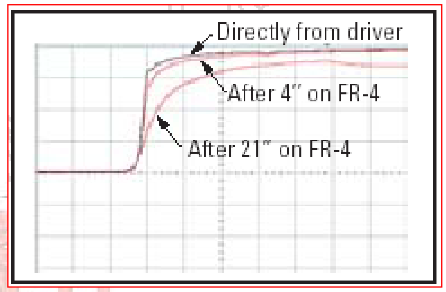
$$\text{Attenuation } \alpha \text{ (dB/inch)} = 2.3 * f * \tan\delta * (\varepsilon_{eff})^{1/2}$$

Impact of PCB Laminate

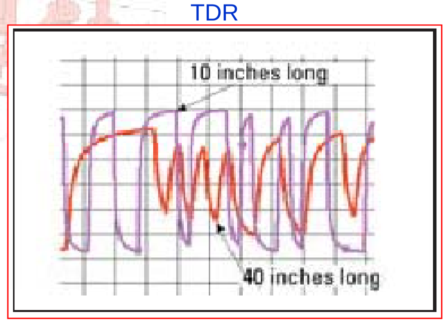
Medium	Delay (ps/in) ($1ps=10^{-12}s$)	Dielectric constant
Air (radio wave)	85	1.0
Coax cable	113	1.8
FR-4 PCB, outer	140	2.8
FR-4 PCB, inner	180	4.5
Aluminum PCB	240-270	8-10

Impact of PCB Laminate

- System Level Performance
  - Limits Rise Time
  - Long rise time limits clock speed
  - Results in tight noise budget
  - Signal Distortion beyond recovery in extreme cases
- Distance signal travels with Signal Integrity
  - Impact to signal Integrity is proportional to total net length and material on which trace runs.
- Rule of Thumb: 10ps degradation in Rise Time for every inch of FR4 trace.



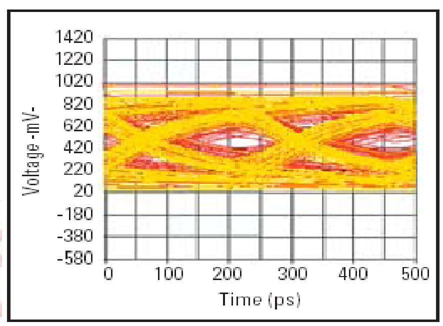
Initial Rise Time 50ps, Timescale is 200ps, measured using Agilent 86100 TDR



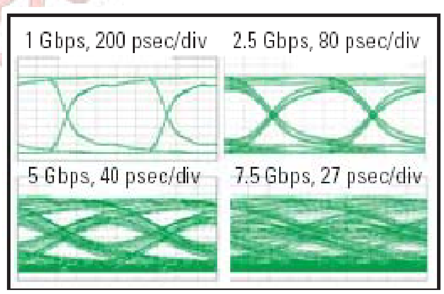
2.5Gbps bit stream, FR4 Material

Impact of PCB Laminate

- Feature Size and Control
  - Wider lines are fast and give better impedance control and lower resistance.
  - Differential Signaling helps but make IO pad design and routing a challenging job.



2.5Gbps bit stream with 4mil and 8mil Traces, FR4 Material

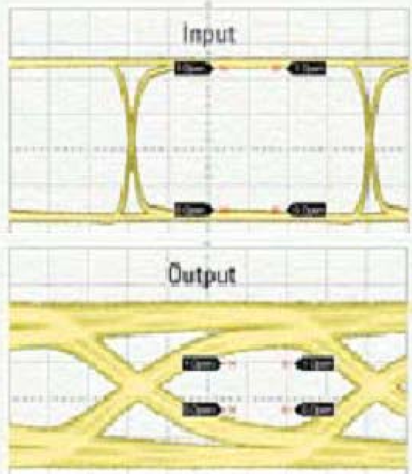


26 inches Back-plane Differential Line

Impact of PCB Laminate

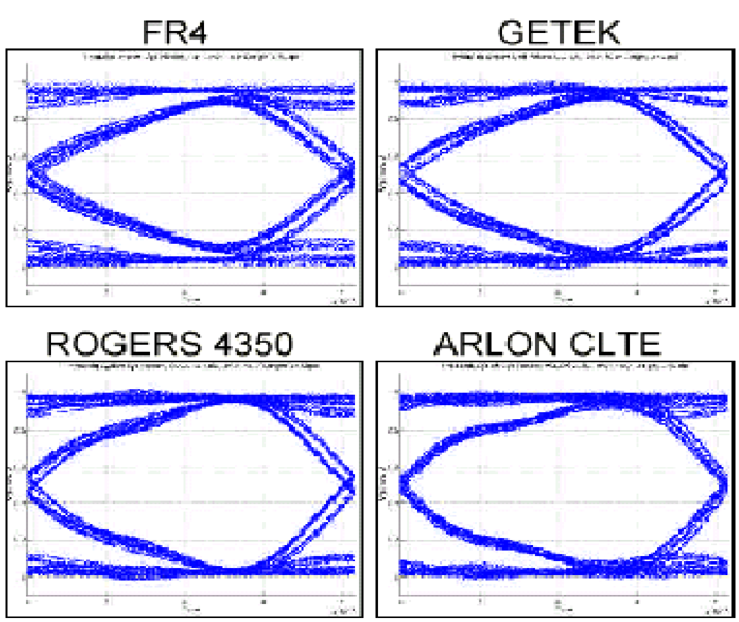
Board just run better on High Speed Materials

Eye Diagram of 2.5Gbps PRBS signal through 26 inches trace on FR4 through back-plane using Agilent 7162 Bit Error Rate Tester



Impact of PCB Laminate

SYSTEM EYE PATTERNS (2.4 Gbps)



FR-4:
Jitter = 0.11UI
Opening = 733 mV

GETEK:
Jitter = 0.09 UI
Opening = 790 mV

ROGERS 4350:
Jitter = 0.07 UI
Opening = 896 mV

ARLON CLTE:
Jitter = 0.05 UI
Opening = 820 mV

The output waveforms shown result from a 1 volt, 32 bit inverting K28.5 input bit pattern (2.4 Gbps, 60 pS edges) thatis applied to a system with two through holes, two AMP HS3 connectors, and a 12 mil, 50 ohm stripline trace that is approximately 18" long.

Courtesy AMP Circuits and Design

Laminate Impact on Signal Integrity

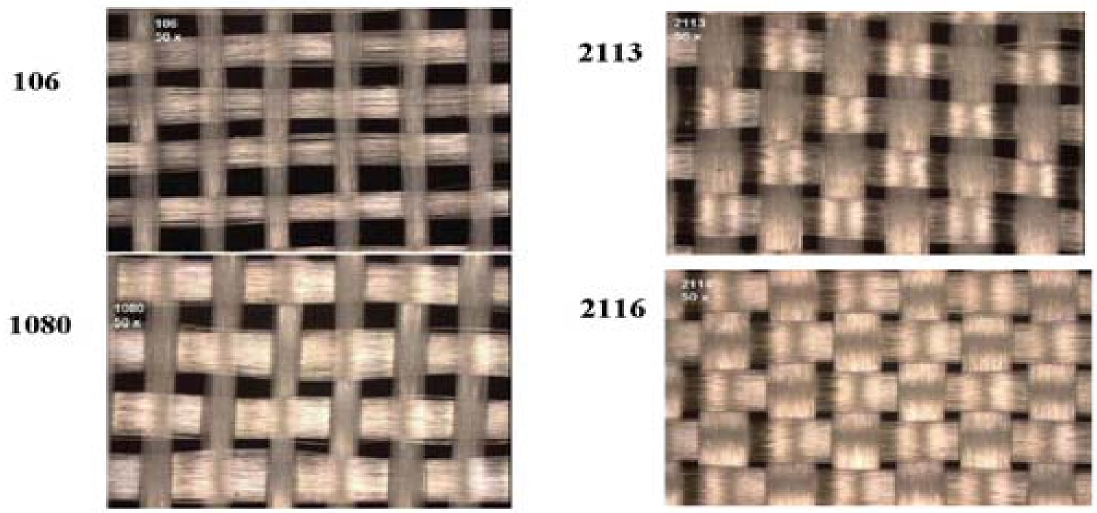
Attribute	Main Effect	Cause
Skew	Effects Timing	Unequal Dk on circuit
Rise/Fall time	Effects Waveforms Shape	Loss of high frequency harmonics
Noise,X-talk	Effects Waveforms Shape	Mutual Coupling(Dk)
Jitter	Effects Timing	Micro Dk Control
Attenuation	Effects Waveforms Shape	Loss of full signal Energy, High Df

Types of PCB Laminate

- All materials are basically composed of woven glass, plastic(resin) and copper. The mixing ratio enhanced the electrical properties.
- Three major Types
  - Enhanced Glass (Std Glass)
    - Dielectric Constant =6.6 Loss Tangent =.0012
  - Silicon glass (electrically enhanced)
    - Dielectric Constant = 4.4 Loss Tangent =.0006
  - Epoxy Resin
    - Dielectric Constant =3.7 Loss Tangent =.02

Types of PCB Laminate

Different Types of Fiber Weaves



Properties

- Electrical: Determines the speed and Signal Integrity Properties
  - **Dielectric constant**
  - **Loss tangent**
- Mechanical: Determines the reliability of board
  - **Glass Transition Temperature**
  - Thermal coefficient
  - Elasticity , brittleness, drilling qualities
- Manufacturability: Determines the yield and cost
  - Stacking qualities, yield, Moister absorption

Dielectric constant (Dk)

- Is measure of how much charge two conductors can hold at a certain fixed voltage. Low Dk hold less charge and high Dk more charge. Its also measure of the ratio of velocity in conductor and free space.
- Determines propagation velocity and amount of capacitances during coupling
- Low Dk leads to large feature size
- Low Dk material support better impedance control
- Dk of most material drops with frequency , flattens about 1.5 GHz

Loss tangent or Dissipation factor (Df)

$$\alpha = 2.3\, f\, \tan(\delta) \cdot \sqrt{\varepsilon eff}$$

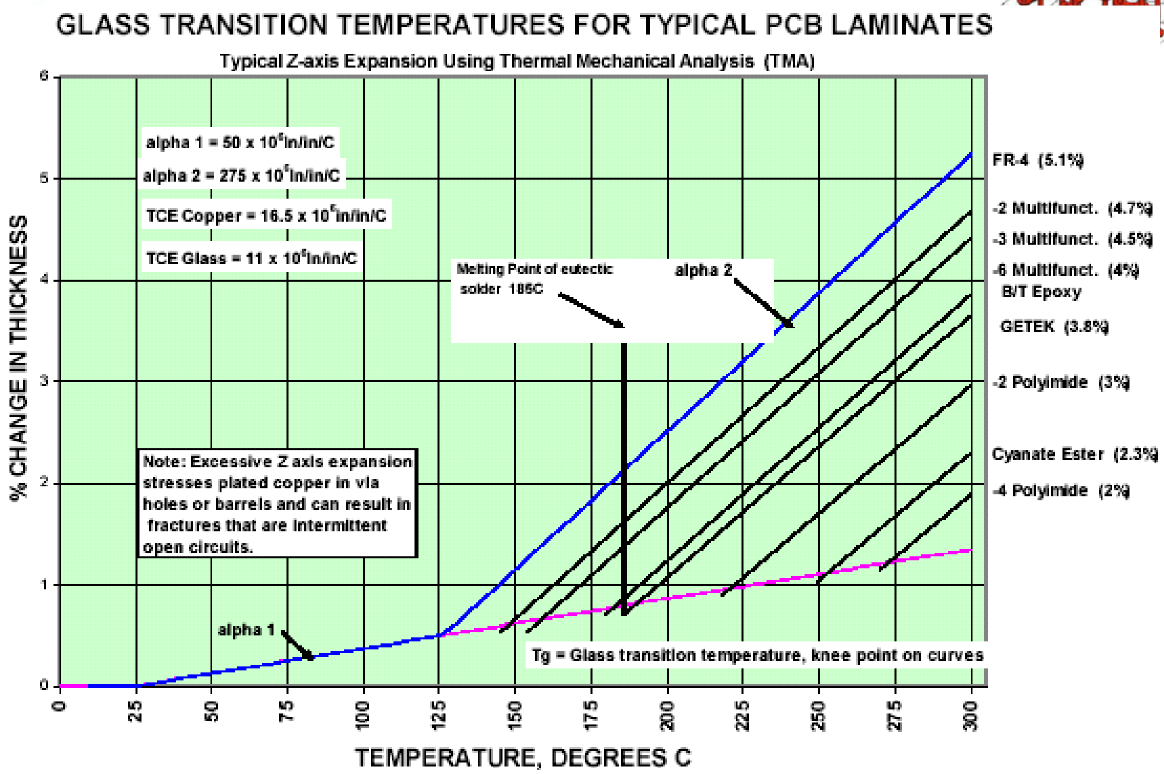
Where : α - Attenuation in dB / inch.

f - Frequency in GHz

$\tan(\delta)$ - Loss tangent of material

εeff - Effective relative Er of material

- Is measure of how much electromagnetic energy is absorbed by dielectric material. Like microwave oven, things that heat up quickly has high loss tangent. Glass and ceramic are low Df materials.
- Loss is frequency dependent, increases with frequency.
- Low loss improves signal integrity.
- Low loss allows more ringing from x-talk impedance mismatch.
- Low loss make more efficient wireless amplifier.



Analog vs. Digital Materials

f = .35 / Tr
Where: f - Frequency in GHz
Tr - Signal rise or fall time (Tf) in ns

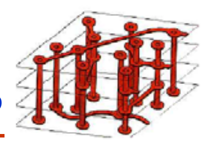
- Analog materials generally
  - Lower Er that is more stable over frequency and temperature.
  - Tighter tolerance on dielectric thickness.
  - Often offered with rolled or ED copper. Digital materials come with ED copper only.
- Few analog/RF materials are for multilayer applications.
- All digital materials are for multilayer applications.
- Loss tangent lower in analog materials, often by a factor of 10 or more.

Materials intended for digital applications

Material	Er (* at 1.0 MHz)	Thickness tolerance	Copper style	Multilayer compatible	Loss tangent
FR4	3.9 – 4.6*	+/- 1-2 mils	ED only	Yes	.02 - .03
FR408	3.4 – 4.1*	+/- 1-2 mils	ED only	Yes	.01 - .015
BT Epoxy	3.9 – 4.6*	+/- 1-2 mils	ED only	Yes	.015 - .02
Cyanate Ester	3.5 – 3.9*	+/- 1-2 mils	ED only	Yes	.009
Polyimide	4.0 – 4.5*	+/- 1-2 mils	ED only	Yes	.01
GETEK	3.5 – 4.2*	+/- 1-2 mils	ED only	Yes	.012
Nelco 4000-13	3.7 (1GHz)	+/- 1 mil	ED only	Yes	.01
Nelco 4000-13SI	3.5 (1GHz)	+/- 1 mil	ED only	Yes	.009
Nelco 6000	3.5 (1GHz)	+/- 1 mil	ED only	Yes	.008
Nelco 6000SI	3.2 (1GHz)	+/- 1 mil	ED only	Yes	.005
Speedboard N	3.0 *	+/- 1 mil	Prepreg	Yes	.02
Speedboard C	2.6 – 2.7*	+/- 1 mil	Prepreg	Yes	.004
Arlon 25 / Rogers 4003	3.4 (10GHz)	+/- 1 mil	ED only	Yes	.0027

ED = Electrically Deposited

Materials for Analog Applications



Materials for analog applications

Material	Er (10.0 GHz)	Thickness tolerance	Copper style	Multilayer compatible	Loss tangent
Rogers Ultralam 2000	2.4 – 2.6	+/- .5 mil	ED / rolled	No	.0019
Rogers 5870	2.3	+/- .5 mil	ED / rolled	No	.0012
Rogers 5880	2.2	+/- .5 mil	ED / rolled	No	.0009
Rogers 6002	2.94	+/- .5 mil	ED / rolled	Yes	.0012
Rogers 3003	3.0	+/- 1 mil	ED / rolled	Yes	.0013
Rogers 6006	6.15	+/- .5 mil	ED / rolled	No	.0019
Rogers 6010	10.2	+/- .5 mil	ED / rolled	No	.0023
Rogers 3006	6.15	+/- 1 mil	ED / rolled	Yes	.0025
Rogers 3010	10.2	+/- 1 mil	ED / rolled	Yes	.0035

Material Reference List

Material	Tg	e_r*	Tan (f)	DBV (V/mil)	WA, %
Standard FR-4 Epoxy Glass	125C	4.1	0.02	1100	0.14
Multifunctional FR-4	145C	4.1	0.022	1050	0.13
Tetra Functional FR-4	150C	4.1	0.022	1050	0.13
Nelco N4000-6	170C	4	0.012	1300	0.10
GETEK	180C	3.9	0.008	1100	0.12
BT Epoxy Glass	185C	4.1	0.023	1350	0.20
Cyanate Ester	245C	3.8	0.005	800	0.70
Polyimide Glass	285C	4.1	0.015	1200	0.43
Teflon	N/A	2.2	0.0002	450	0.01

* Measured with a TDR using velocity method.
Resin content 55%

Tg = glass transition temperature
e_r = relative dielectric constant
Tan (f) = loss tangent
DBV = dielectric breakdown voltage
WA = water absorption

All materials with woven glass reinforcement except teflon.

Note: Teflon is not a multilayer PCB material.

When to use high Frequency Laminate

- When trace is very long, signal attenuation becomes a major issue at high speed.
- Improved impedance control i.e RF PCB Design
- When future upgrades to higher speed are required, to avoid board swap.
- Back plane of giga bit communication system
- Space and military application, for more mechanical strength, temperature tolerances and fire resistant.
- Special application: Wireless base station amplifier and interface board, laser driver and serial driver board for optical communication

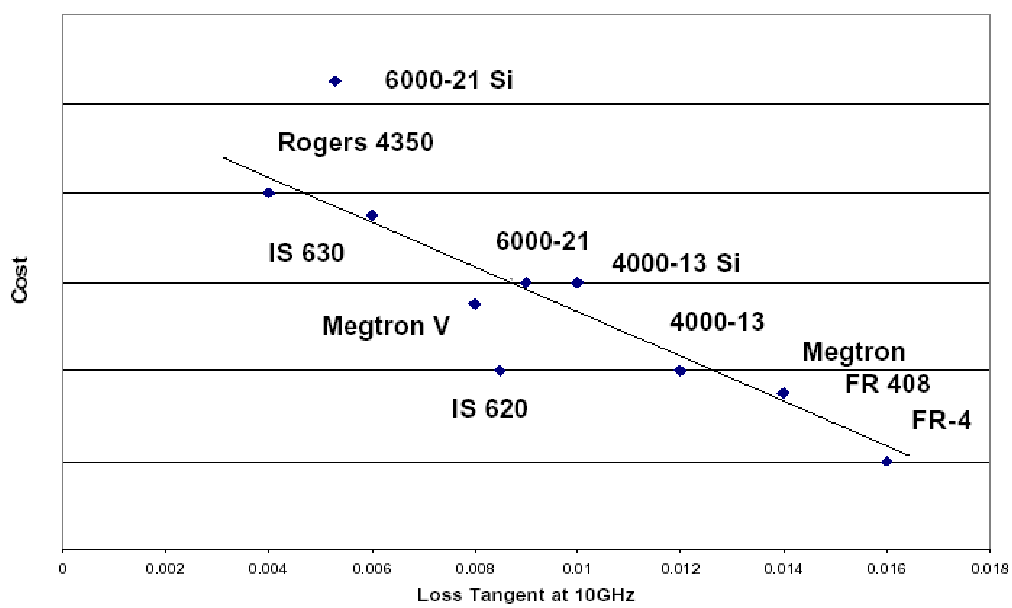
Application That Lead to High Frequency

- Optical networks
  - 10gbit/sec system are in market now.
  - This operates 0.6ghz to 3ghz on every channel.
  - Very fast compared to 125-600 GHz parallel bus.
- Parallel computing
  - Large parallel buses switching at same time
  - Still uses single ended circuitry compared to differential circuits, makes design much harder.

Serial ATA	1.25 Gbps
Hypertransport	1.6 Gbps
AGP8x	2.1 Gbps
Infiniband	2.5 Gbps
PCI Express	2.5 Gbps
Serial ATA II	2.5 Gbps
XAUI	3.125 Gbps
PCI Express II	5.0 Gbps
OC-192	9.953 Gbps
10 GbE	10 Gbps
OC-768	39.81 Gbps

Some current and next generation High Speed Buses are getting close to 100Gbps

Cost vs Material Type



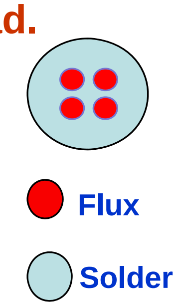
Moral of Story

- Most digital circuits today (0.2 to 2.0 ns rise and fall times) can use FR4 as a base material without concern of circuit malfunction.
- Always analyze analog circuits to compare the operating parameters of the material with the acceptable losses in the circuit.
- Then choose the material most suited to the application, looking at cost as only one of the driving factors.

Soldering Materials

- **Traditional Solder is an amalgam of Tin and Lead.**

%Tin	%Lead	Use
60	40	Good for all electrical and mechanical work
45	55	Very liquid used in plumbing



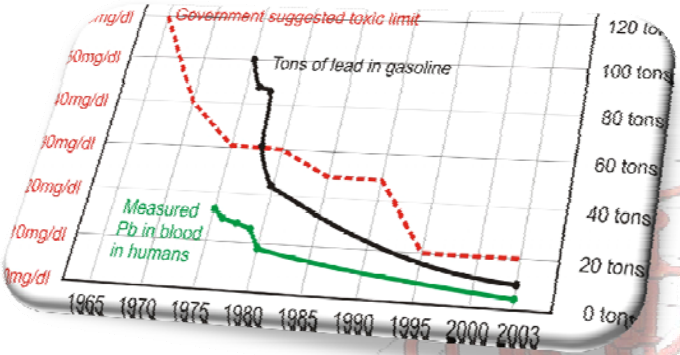
- **RoHS Directive (Reduction of Harzadous Substances) –bans Pb is Electronics Products**

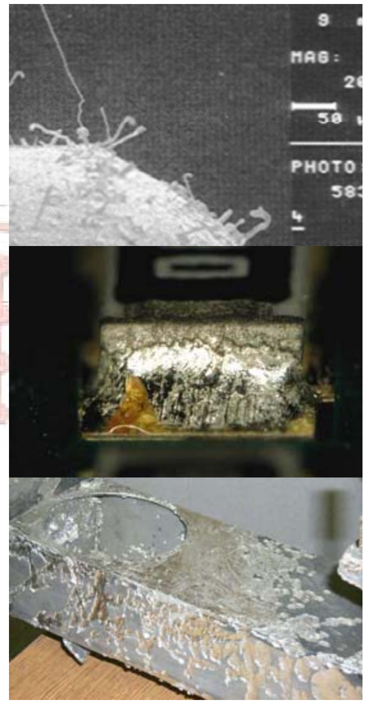
Lead Solders:
- SnPb37
- SnPb36Ag2

Lead-free solders:
- Sn93,5-Ag3,5-Bi3
- Sn95,5-Ag3,8-Cu0,7
- Sn91,9-Ag3,3-Bi4,8
- Sn96-Ag2,5-Cu0,5-Bi1
- Sn42-Bi58
- Sn96,5-Ag3,5
- Sn99,3-Cu0,7
- Sn89-Zn8-Bi3

Pro-Cons of Pb-Free Solders

USA population, Source: American Scientist





- Pros: Health Safety
- Cons: Sn whiskers, High temp soldering, At high temp low mechanical strength, low reflow soldering window (20C-40C), patent issues, Corrosion in unmodified wave soldering equipment

Solder Joints and Reliability

Reliability				
Mechanical	**Electrical**	**Thermal**	**Radiation**	**Altitude**
Cause	**Cause**	**Cause**	**Cause**	**Cause**
Mechanical shock vibration, drop, twist	High humidity, voltage, current, contamination, power cycling	High temperature storage, thermal cycling & shock, high operating temperature	Alpha particles, beta or gamma Ultra violet	Pressure, temperature, condensation
Effect	**Effect**	**Effect**	**Effect**	**Effect**
Solder joint failure, interface degradation, physical damage	Corrosion, electromigration, Degraded interfaces	Intermetallic growth, solder joint fatigue, popcorning	Data loss, embrittlement, discoloration	Deformation, embrittlement, corrosion

Panel and Penelization

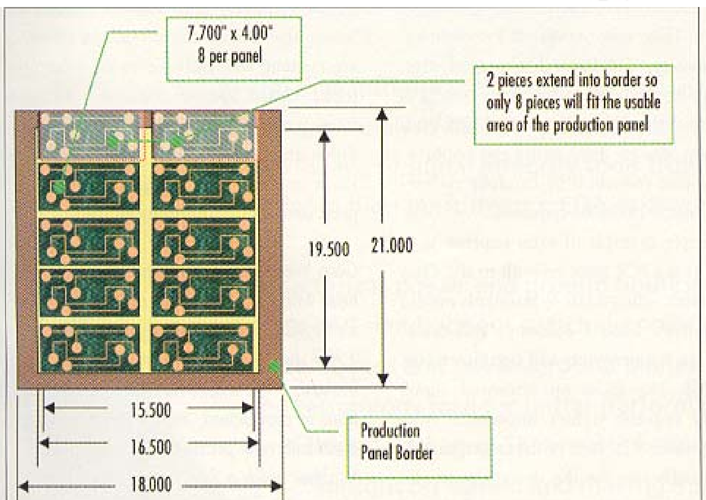
- **Panel**
  - The raw size of laminate known as core come in standard sizes called panels.
- **Panelize**
  - To lay up more than one (usually identical) printed circuits on a panels is called penalization The modules can then be separated after assembly into discrete printed circuits.

Image area in X dimension/(board size in X + spacing) * Image area in Y dimension/(board size in Y + spacing).

Panel size	Image area
12” x 12”	10” x 10”
12” x 18”	10” x 16”
16” x 18”	14” x 16”
18” x 24”	16” x 22”
24” x 36”	22” x 34”

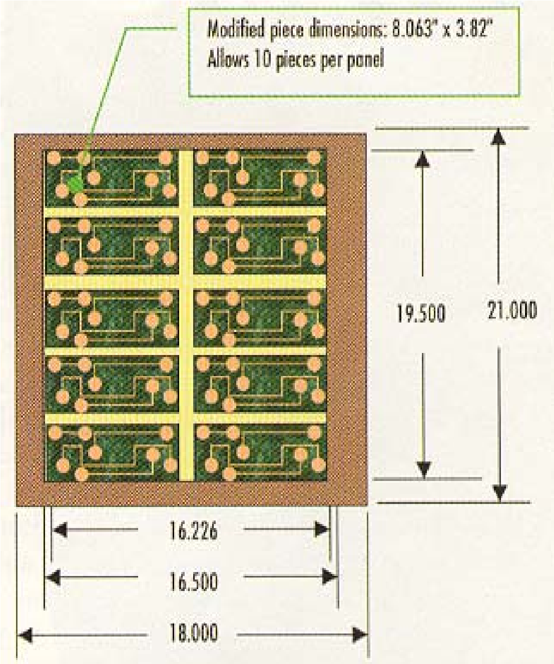
Importance of Penelization

- Margins are required to hold the board during fabrication (plating, drilling..)
- To facilitate automated soldering and assembly process
- To reduce the cost in high volume production
- Better to size the board in advance so that multiple boards fits on one with appropriate margins and inter board spacing.



Given: An 18" X 21" production panel. The PCB fabricator requires a 0.75" border for tooling and coupons.
Find: The usable area of the panel.
Solution: The 0.75" border requirement reduces the production panel by 1.5" in both the X and Y dimensions.
Result: The usable panel size is 16.5" X 19.5".

Penelization Example

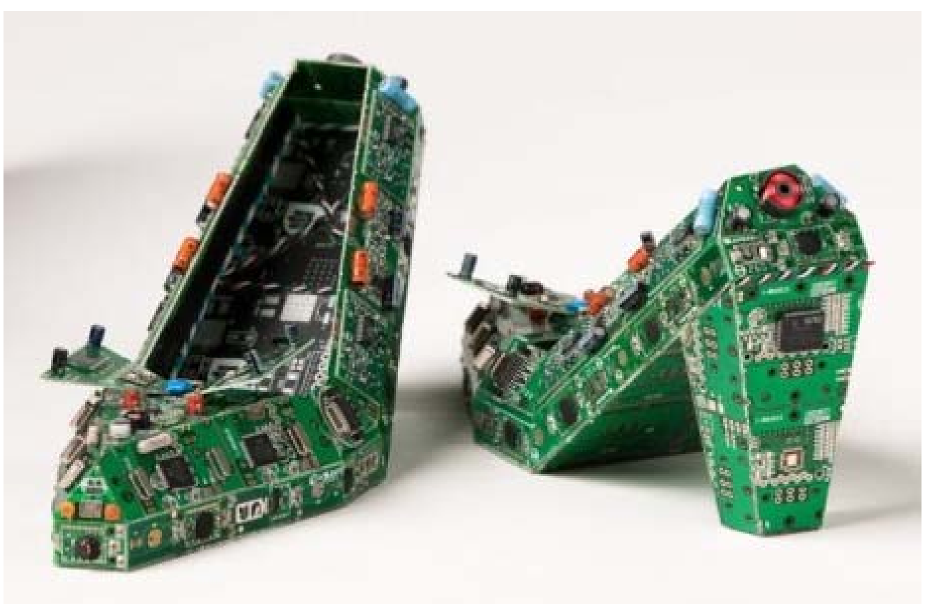


Given: Initial PCB with dimensions 7.700" X 4.000" to be supplied as individual pieces. NC route lane required between pieces for "singulation" into separate boards = 0.100". Usable panel area: 16.5" x 19.5", currently at 8 pieces per panel. See Figure 1.

Change: PCB's Y dimension by –0.180". This will allow exactly 5 pieces on the Y axis. Change the X dimension by +0.363". This still allows 2 pieces on the X axis. (Assumes the same 0.100" NC route lane for singulation)

Result: 10 pieces per panel, a 20% improvement. The original route area per piece of 30.8 in2 is still available.

Summary &….



Summary

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    - Impact of PCB Laminate on Signal Integrity Types of PCB Laminates
      - Based on Materials used
      - Based on Application
    - Properties of PCB laminates
  - Soldering Materials
- Panel and Panelization

Wakeup Please lets have Some Food....