Introduction to PCB Design
and
Basics of High Speed Switching

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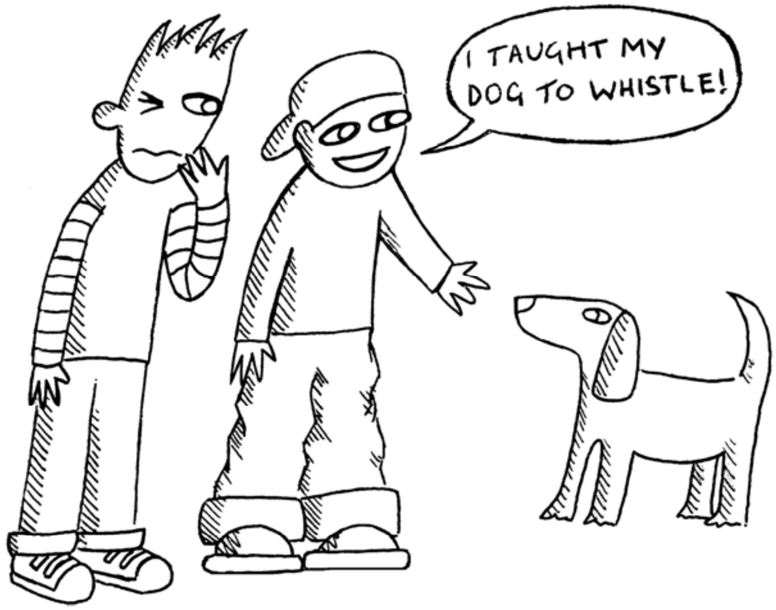
FAST-NU, Islamabad

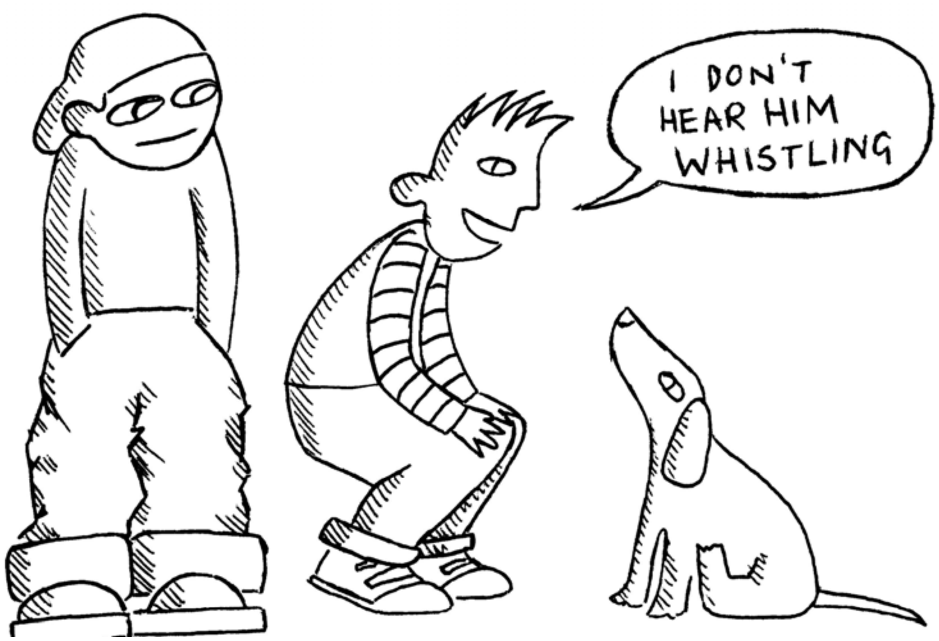
Today's Topics

- Package Contents
- Who is Who? and Where to seek help?
- PCB Today and Near..Far Future Vs. Our Position
- PCB Manufacturing
  - Single Layer and Double layer (Cost, Quick Prototyping)
  - Multi-layer (Density , Size, and Weight)
- Basic of High Speed Switching
  - Basic Anomalies in Signal
  - Time and Freq Domain Concepts
  - When its High Speed?
  - 3 dB frequency

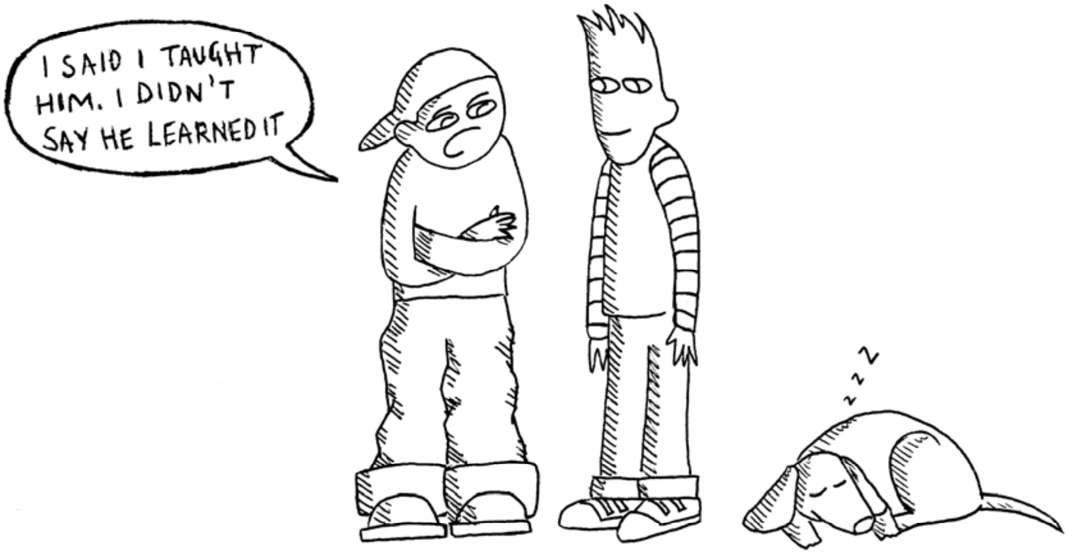
Learning & Motivation



Learning & Motivation



Learning & Motivation



Learning & Motivation: Student Perspective

"I'm planning to follow in your footsteps. That is, unless it turns out to be really boring."

What You have in Package..

- File Folder
  - Lecture Slides
  - Reference Material
  - Tutorials Guides for Practical Sessions
- CD
  - Protel 99SE and Service Pack-6
  - Altium PCB Designer
  - Application Notes
- Writing Pad, Pencil, and Eraser etc

Introduction of Instructor

- Education
  - BSc Electronics Engineering, UET Lahore 1994 (Merit Starship Holder)
  - Masters, SoC Design (CGPA 3.9)
    - Ohio State University, USA;
    - Royal Institute of Technology Stockholm, Sweden
    - Masters Thesis: Fraunhofer Institute of Integrated Circuits Germany
  - Ph.D in Radio Frequency Circuit Design and SDR
    - Linkoping University, Sweden
- Experience
  - Analog IC Design
  - Digital IC design
  - RF IC design
  - PCB Design: Designed and got manufactured more than 10 High Speed Multilayer PCB
  - SMPS , Analog and Digital System Design Military and Commercial
  - Google "Rashad Ramzan" for Details

This Course on PCB Design…..

- Why?
  - Very complex PCB design is not that Complex
  - To stop sourcing out PCB Design Work.
  - To start sourcing in?
  - This area has much potential: Any thing which is hand crafted,
    - Analog & RF IC
    - Digital Library Cell Design,
    - PCB Design..it's the easiest to start
  - Manufacturing & Assembly facility should be in Pakistan.
    - It will generate the economical activity.
    - And real technical know how.

Please join: http://groups.yahoo.com/group/FAST_PCB_2010

This Course on PCB Design…..

- How?
  - Interactive, Sharing of Knowledge.
- What is the Hurdle in High PCB Speed Design?
  - Signal Integrity
    - Tools? What the tools DO?
      - Expensive
      - Same as Stethoscope to Doctor? Tell some thing is wrong before manufacturing?
    - My experience: Strong theoretical background will help you more than any thing else.

A skilled carpenter can frame a chair better and faster with a hammer and hand saw than can an inexperienced person with a radial arm saw and a stable full of power tools. ***IT AIN'T THE TOOLS, IT'S THE OPERATOR!***

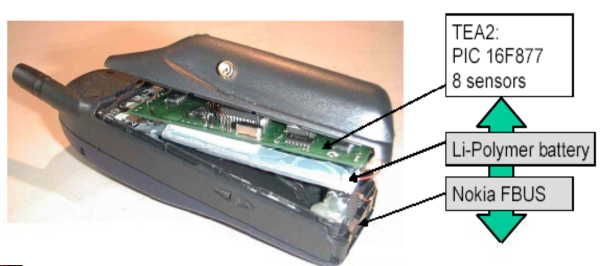
We will put lot of emphasis on theory!!! If you bear with me.

Fast Changing Electronics Industry

During this lecture

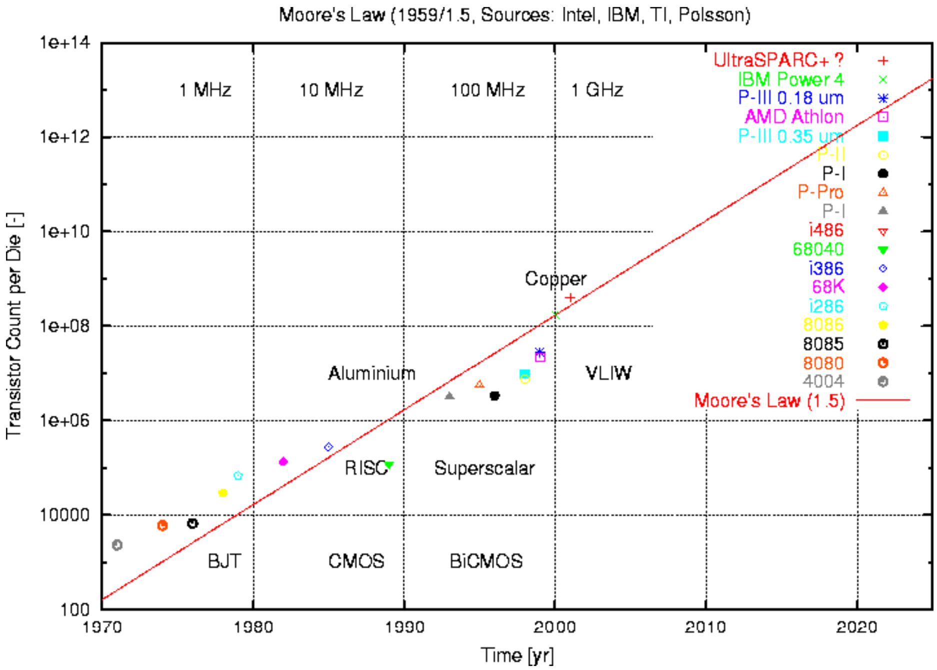
- 10K people logged to internet for the first time
- 12K new customers signed-up for cellural phone service
- 100 million emails were sent
- **12 trillion transistors were build, each costing less than 1/15th of office stable**

Today's Electronics Products

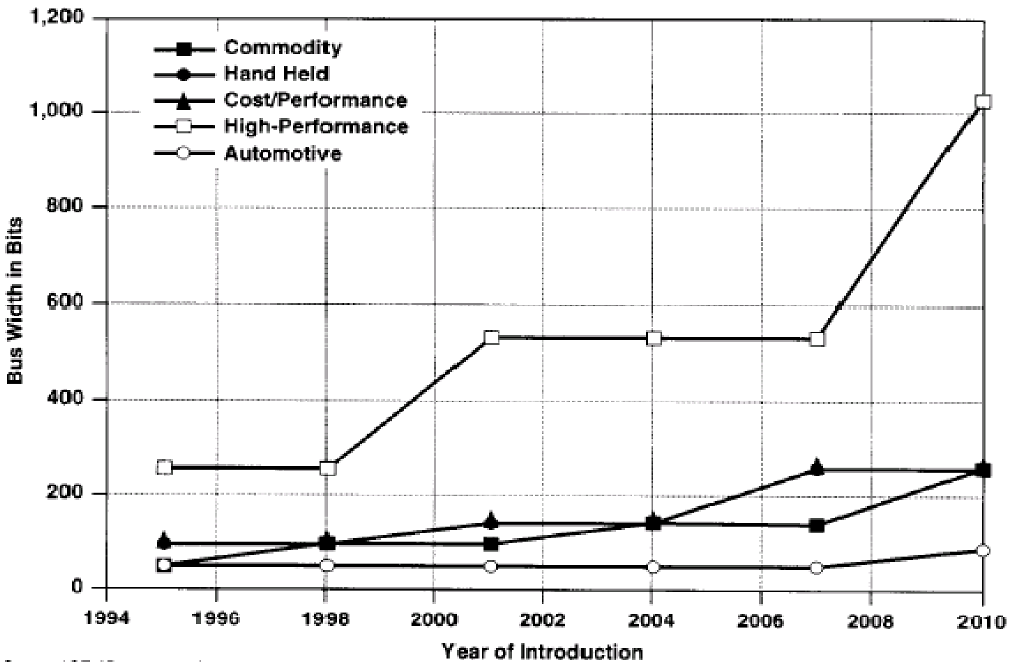


- Every electronics device having more than one components has PCB inside it.
- The technology and expertise required to design and manufacture these PCBs is increasing at same pace as speed of electronics it self. i.e. **Moore Law**
- Future electronics is interconnect limited not device limited.

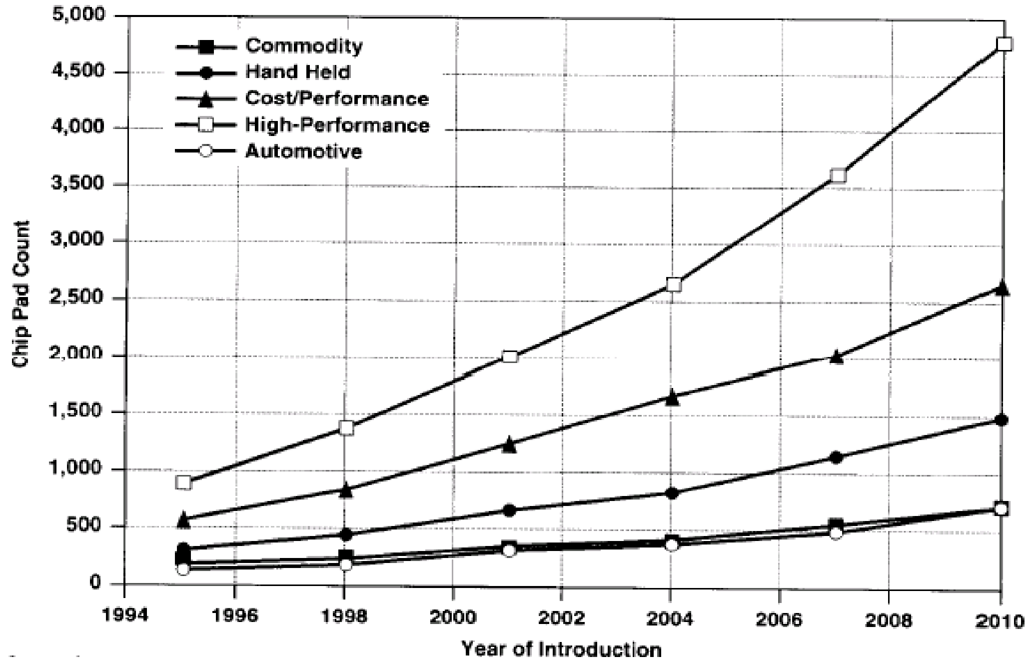
Moore 's Law: Doubles Every 18 Months



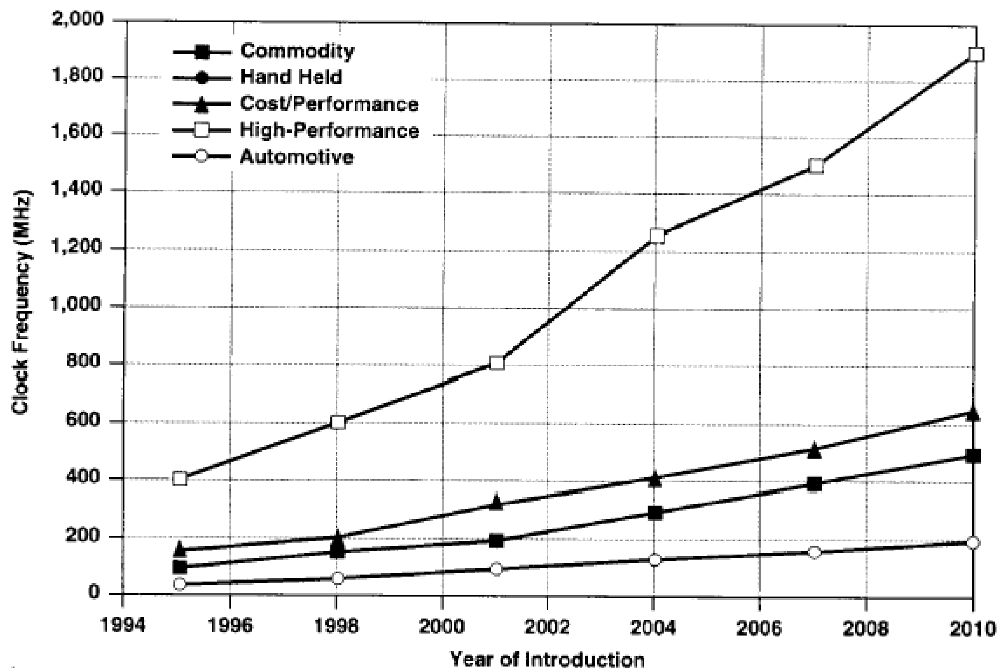
SIA IC roadmap: bus width in bits



SIA IC roadmap: I/O Pads on Chip

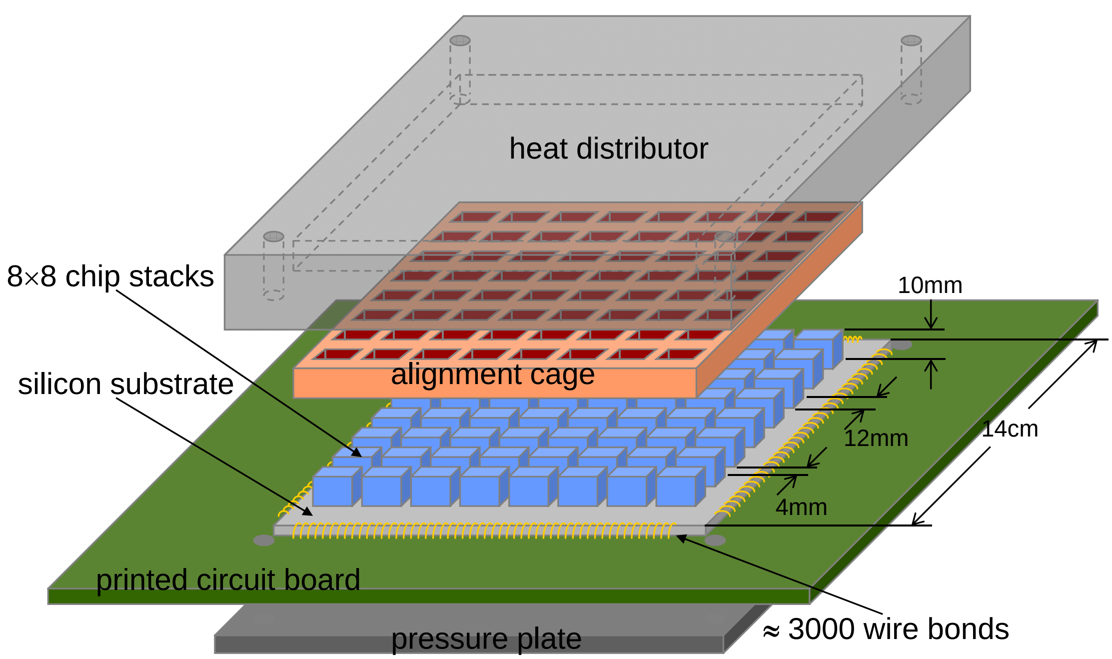


SIA IC roadmap: On-Chip Clock Frequency

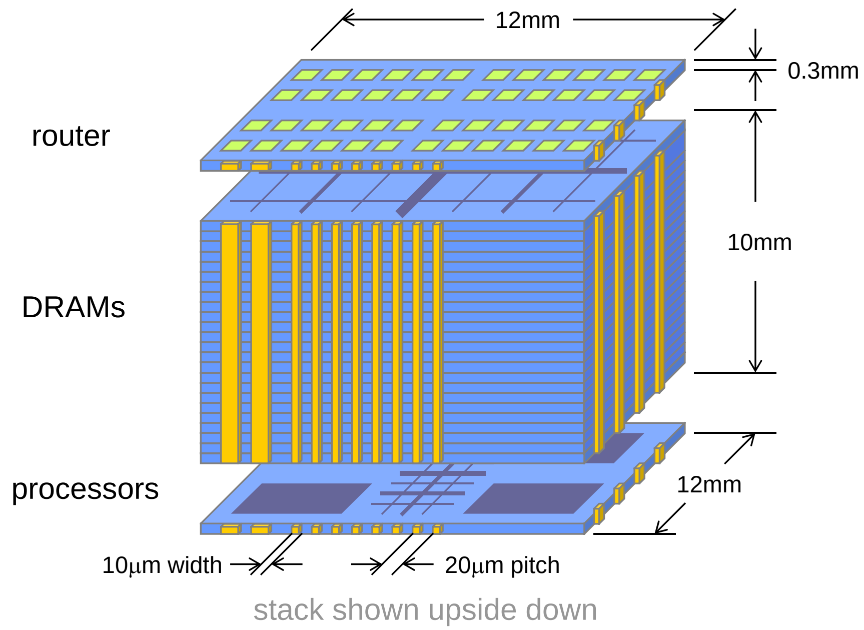


Today's……PCBs

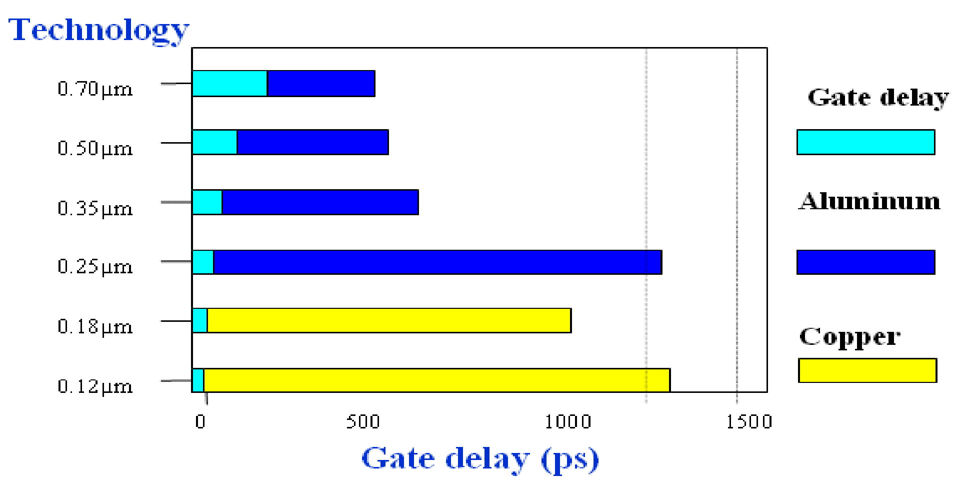
Today: Multi-chip Modules



Tomorrow: 3D Ball Structure



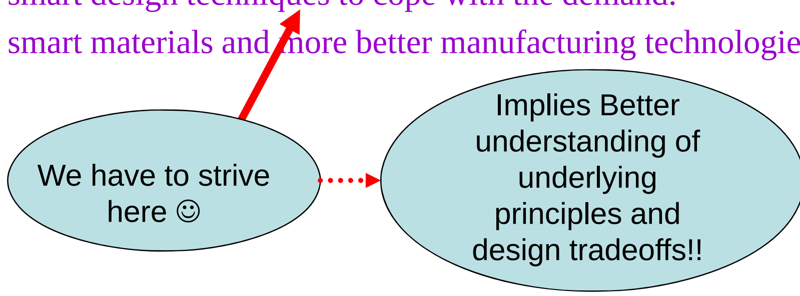
Conclusion-1: Interconnect Design



- The future electronics is interconnect limited not device limited.
- Solution: More smart design techniques to cope with the demanding Interconnect design and new material and technologies.
- IC Interconnect techniques, Models and software are applicable to High-end PCBs now.
- **High-end PCBs are shifting into MCMs, Hybrids, SoCs and buried passive in PCBs**

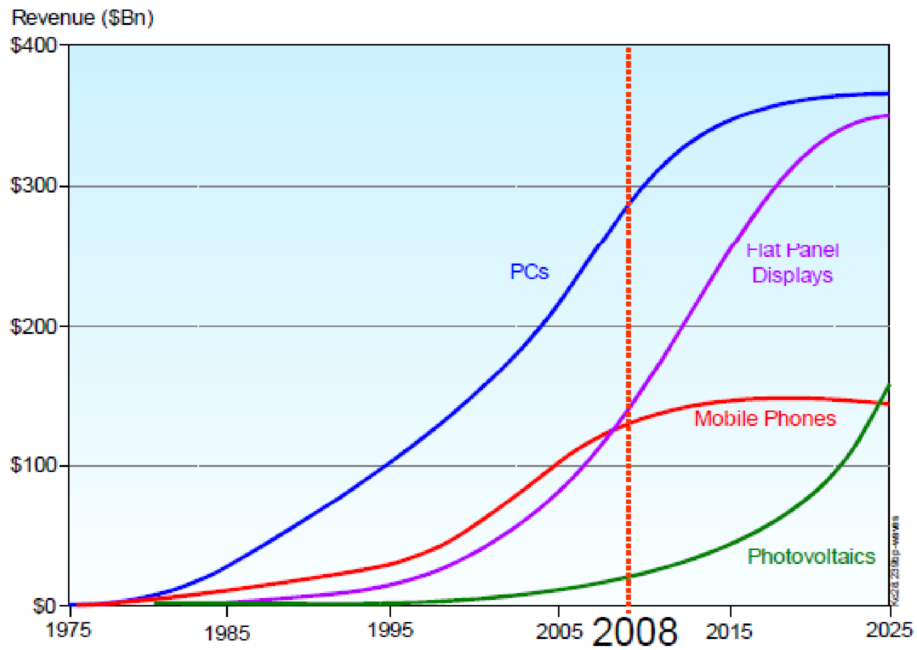
Conclusion-2: PCB Design

- New chips with high bus speed demand faster interconnect on the board at same time with larger IO count and hence larger board size.
- Larger board size → Large Interconnect Delays
- Solution:
  - More smart design techniques to cope with the demand.
  - More smart materials and more better manufacturing technologies.



Economical Aspects & Manufacturing Trends

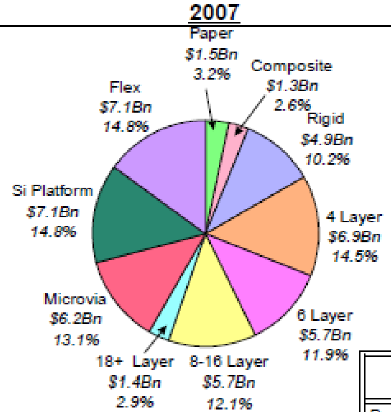
Growth in Electronic Industry



Source courtesy of PRISMARK

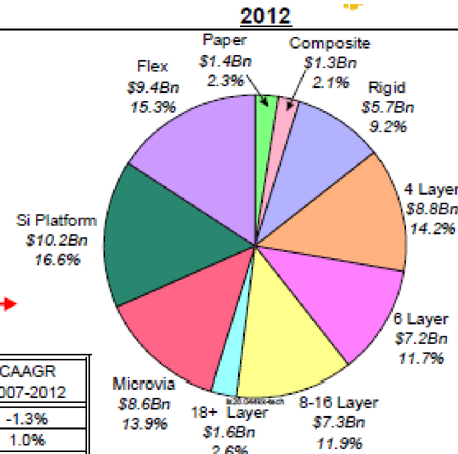
Global PCB Production vs. Technology

2007 Value **2012**



Total: $47.7Bn

CAAGR 5.2%



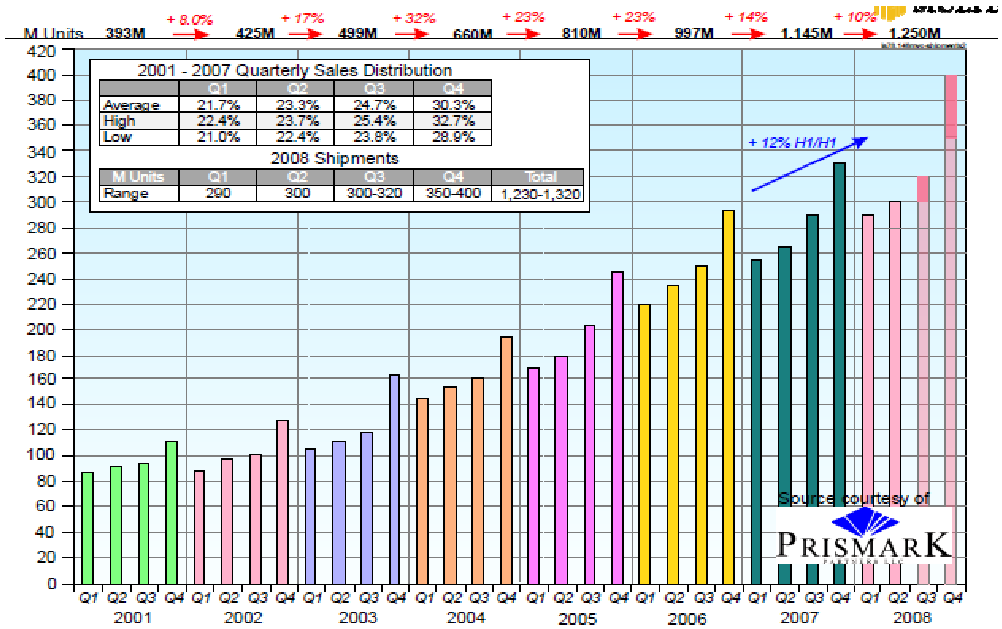
Total: $61.6Bn

Technology	CAAGR 2007-2012
Paper	-1.3%
Composite	1.0%
Rigid	3.1%
4 Layers	5.0%
6 Layers	4.9%
8 to 16 Layers	5.0%
18+ Layers	3.3%
Microvia	6.6%
Si Platform	7.6%
Flex	6.0%
Total	5.2%

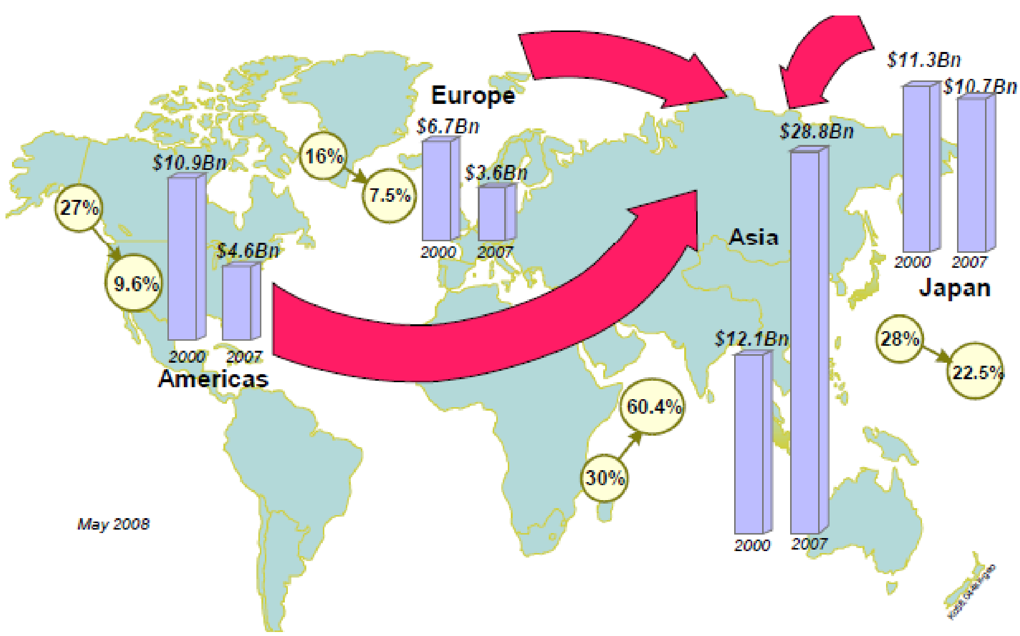
May 2008

Source courtesy of PRISMARK

RF PCB Design: 1.2 Million/Day



PCB manufacturing: 2000 and 2007



Source courtesy of PRISMARK

Leading PCB Manufacturers

	Sales (US$M)	Headquarters	2000	2005	2006	2007E	Business Focus and Direction
1	Ibiden	Japan	1,080	1,410	1,700	1,820	75+% sales from substrates; expansion in China and Philippines
2	UMTC (Unimicron)	Taiwan	360	910	1,250	1,550	Grew by acquisition, IC substrates, HDI boards , China expansion
3	Nippon Mektron	Japan	905	1350	1,450	1,530	Geographically diversified, sales including assembly value 20+%
4	SEMCO	Korea	380	960	1,200	1,270	Strong growth supported by aggressive IC substrates and HDI expansion, 80+% of sales
5	Nan Ya	Taiwan	440	770	1,150	1,240	80% sales from IC substrates; expansion in China
6	CMK	Japan	1,100	1,060	1,080	1,165	Maintain competitiveness by expansion in low cost regions
7	Kingboard (E&E)	China/HK	320	675	850	900	Grew by acquisition ; benefited by vertical integration
8	Tripod	Taiwan	105	460	625	830	Strong growth driven by memory modules and display boards
9	Fujikura	Japan	268	725	870	825	Leading FPC supplier with low cost competitiveness
10	Shinko	Japan	500	670	850	795	Advanced IC substrate supplier
11	Flextronics-Multek	US	600	560	670	780	Majority of the production moved to China already.
12	Young Poong (Inc. KCC, and Interflex)	Korea	350	700	625	715	Leading FPC supplier group in Korea ; FPC accounts for 65+% of group's total revenues
13	AT&S	Europe			580	675	Leading HDI supplier and has operations worldwi de
14	LG Electronics	Korea			560	660	Balanced PCB suppliers covering a wide range of products
15	Compeq	Taiwan	800	590	699	640	Leading HDI producers and developing rigid/flex business
16	Daeduck Group	Korea	480	640	650	620	Diversified product offerings; emerging IC substrate supplier
17	Gold Circuit	Taiwan				615	Focused NB PC motherboard producer
18	TTM (Tyco)	US	1,160	570	625	580	Leading US quick -turn PCB supplier; growth by acquisition
19	HannStar	Taiwan/China				570	Focused NB PC motherboard producer
20	WUS PCB Group	Taiwan				558	Strong growth from China operation

Source courtesy of PRISMARK

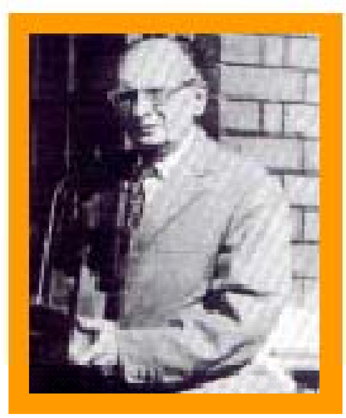
What we can do?

- Where is our share in this transition trend ..??
- Entrepreneurship
  - Lecture Slides
  - Reference Material
  - Tutorials Guides for Practical Sessions
- Formation of Small Companies
  - In coordination with manufacturing facilities
- Marketing
  - News papers ??? Are people there..No
  - Where are they?
  - On Net….Google…Facebook….etc

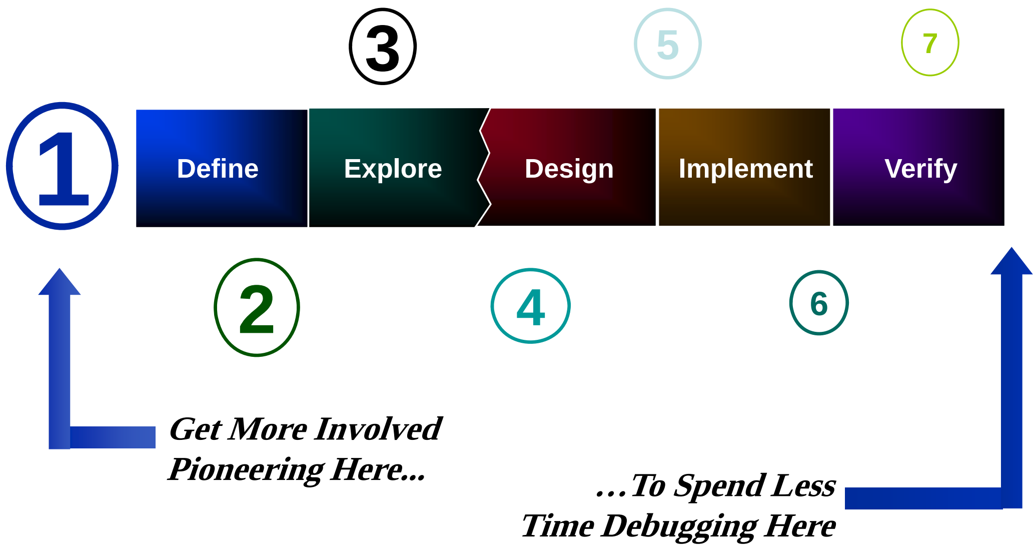
Basic Technology of PCB Design

History

- In 1943 , Paul Ester of Germany invented Printed Wiring Board.
- PCB annual business (2000) was $45, 250 Million and with the growth rate of 11%.



Our Job: Step by Step Design



Types of PCB

Single Layer PCB

- Apply solder to pads by immersing into tank of solder. Hot air level the solder when removed from the tank.

Double Layer PCB

- Apply solder to pads by immersing into tank of solder. Hot air level the solder when removed from the tank.

Multilayer Layer PCB

- Apply solder to pads by immersing into tank of solder. Hot air level the solder when removed from the tank.

Flex PCBs

- Apply solder to pads by immersing into tank of solder. Hot air level the solder when removed from the tank.

New Generations

  - Micro Chip Modules(MCM)
  - Hybrids
  - 3-D Structure (Future)

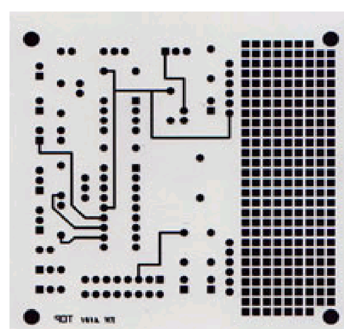
PCB Manufacturing

- Double Layer
  - Laminate Shearing
  - Drilling
  - Plating through Holes
  - Dry Film Imaging
  - Copper and Tin Plating
  - Etching
  - Stripping
  - Solder fusing
- Multilayer
  - Core Selection
  - Print and etch on both sides
  - Pressing with pre-preg and cu-foil
  - Drilling
  - Plate through Holes
  - Dry Film Imaging
  - Copper and Tin plating
  - Etching
  - Stripping
  - Solder Fusing

PCB Manufacturing- Step 1&2

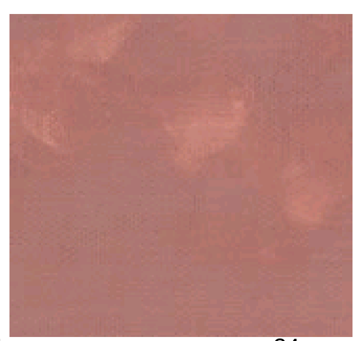
CAD File processing

- The PCB CAD files (Gerber files and Drill files) are sent to the manufacturer.
- The PCB manufacturer has their own pre-production inspection of the files at which they add drill list and identification.
- The CAD files are rasterised and photo plotted to make film artwork



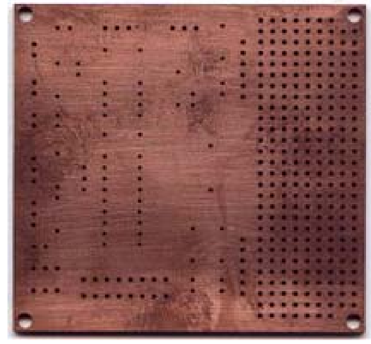
Shear Raw Material:

- Industry standard 0.059"(for double sided boards) thick, copper clad, two sides. Panels will be sheared to accommodate many boards.



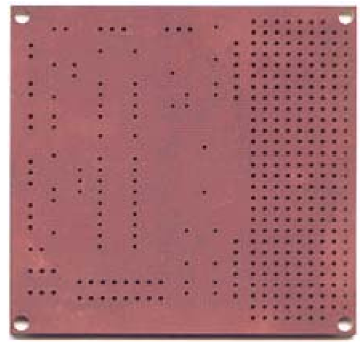
PCB Manufacturing- Step 3&4

Drilling The Holes



- The laminates, (with copper on both sides, but no pattern yet) are drilled with holes using NC machines and carbide drills. For reasons of economy, the laminates are larger panels that often contain several PCBs.

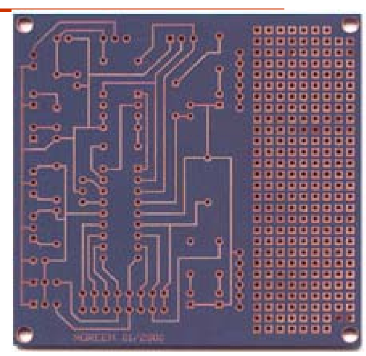
Electro-less Copper



- The drilled laminates are coated in a chemical to enhance electroplating of holes.

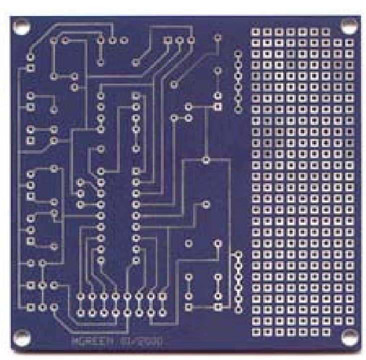
PCB Manufacturing- Step 5&6

Pattern Generation



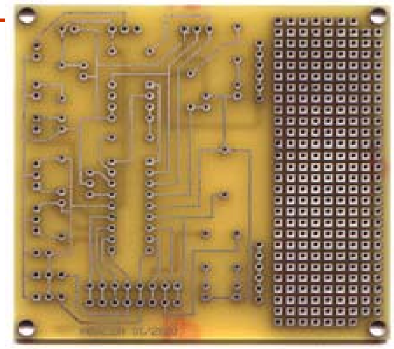
- The laminates are coated with a UV-sensitive photo-resist The track pattern is imaged onto each side of each PCB, using the photo plots and UV light The photo-resist is developed, leaving photo resist only where required.
- The laminates are put in acid for etching **forming the track pattern**

Electroplating:



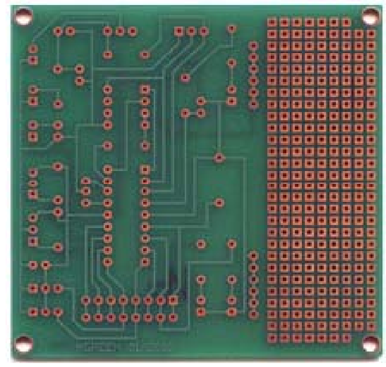
- Electrochemical process to build copper in the holes and on the trace area. Tin is applied on the surface.

PCB Manufacturing- Step 7&8



Strip and Etch

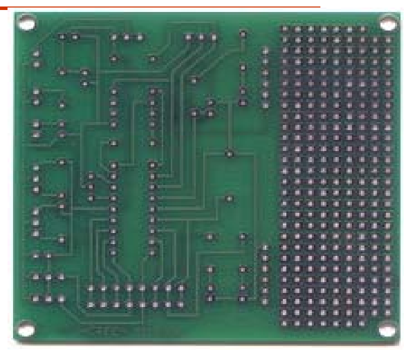
- Remove dry film, then etch exposed copper. The tin protects the copper circuitry from being etched.
- Only required track and PADS are left on the laminate, with plated through holes



Solder Mask

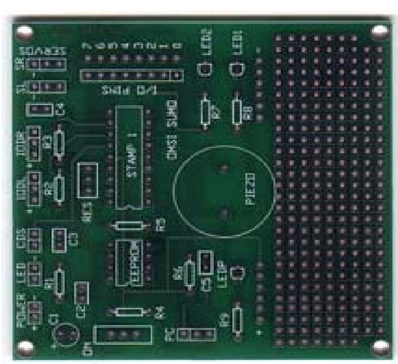
- Before applying solder mask, tin/lead is also removed. Solder mask is applied on the copper track.
- Solder mask (usually Green) is applied to all the PCB area except the PADS.

PCB Manufacturing- Step 9&10



Solder Coat

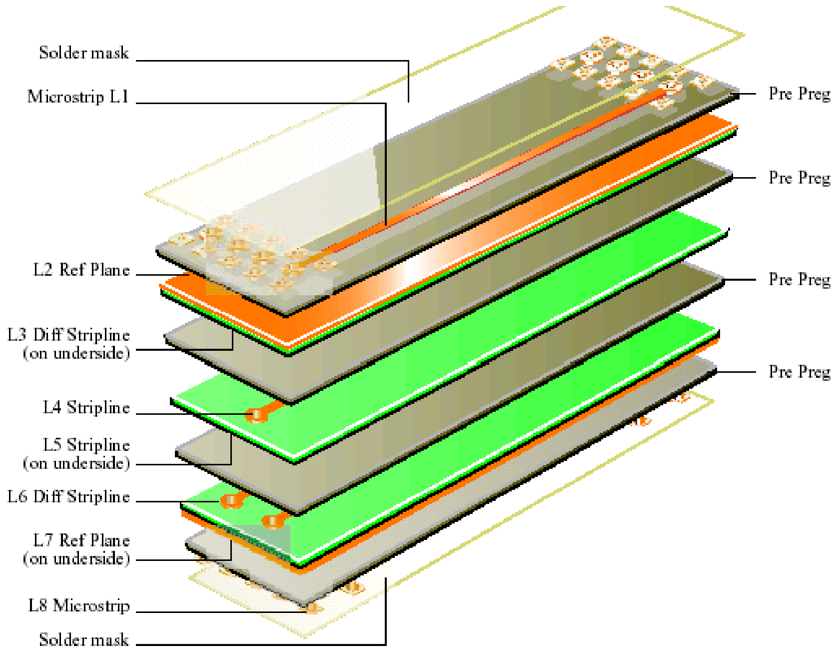
- Apply solder to pads by immersing into tank of solder. Hot air level the solder and open the holes when removed from the tank.



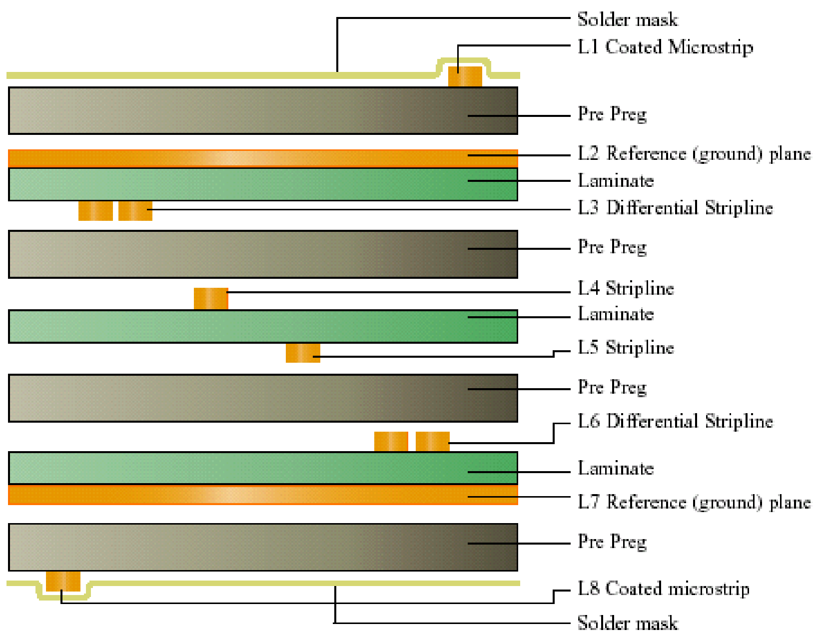
Final Stages

- The PCB is **silk-screened** with component Identification lettering (usually white)
- The silkscreen legend is dried.
- Any final drilling is done of holes that are not to be plated through,
- Laminate is **cut into individual printed circuit boards**

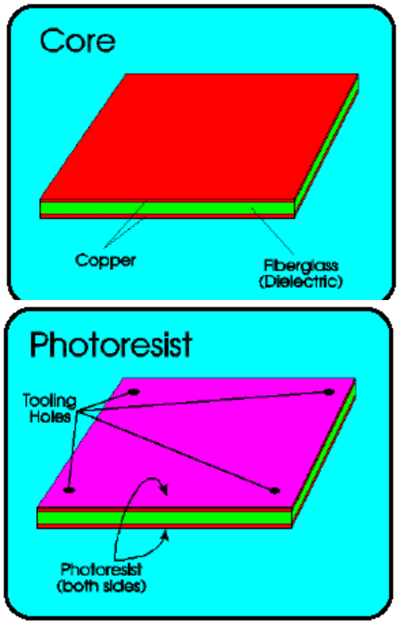
PCB Manufacturing-Multilayer

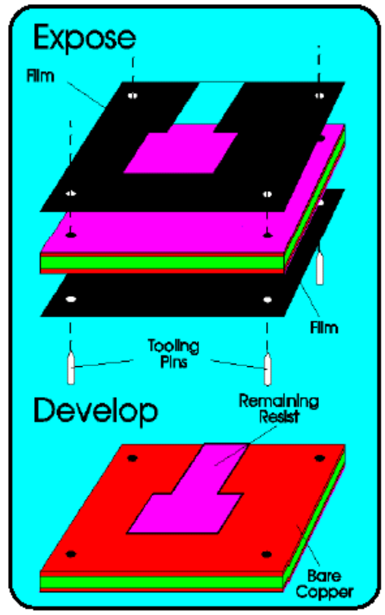


PCB Manufacturing-Multilayer

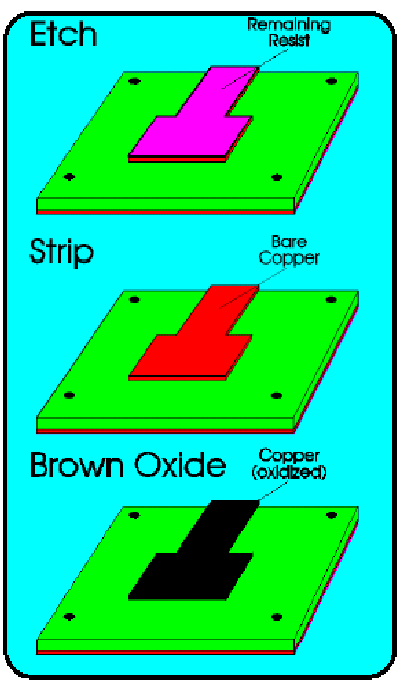


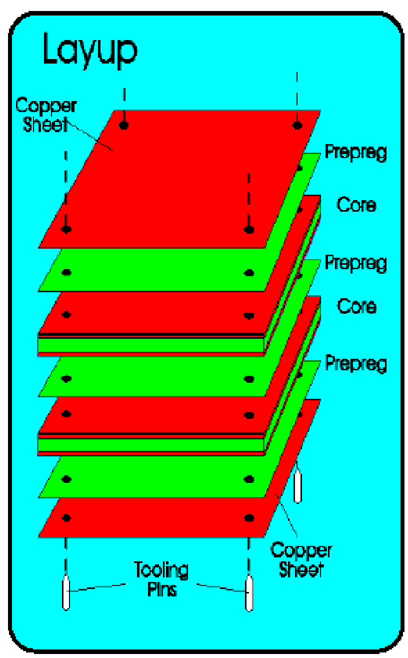
PCB Manufacturing-Multilayer



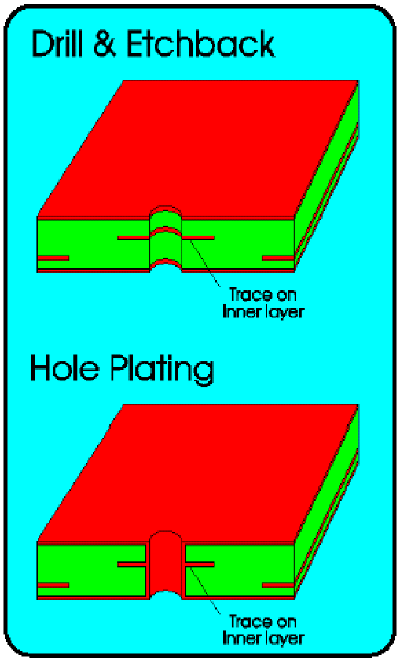


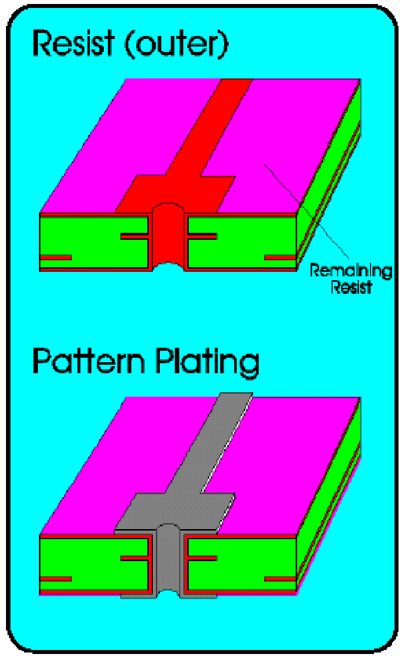
PCB Manufacturing-Multilayer



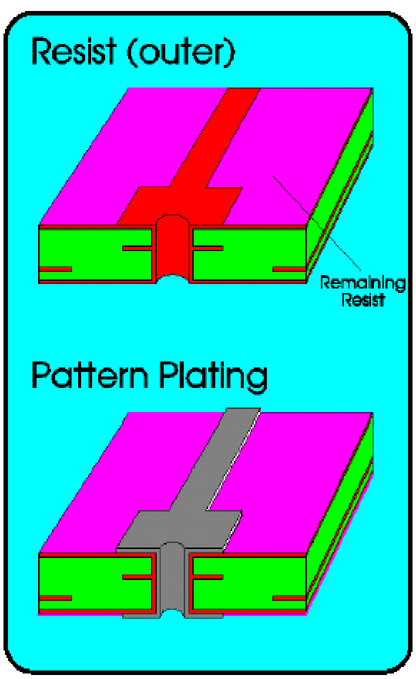


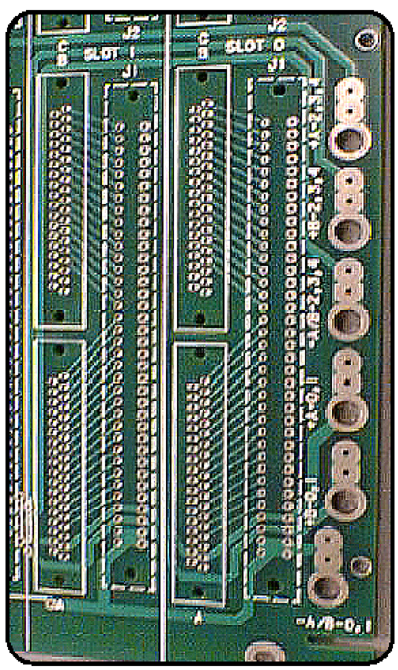
PCB Manufacturing-Multilayer





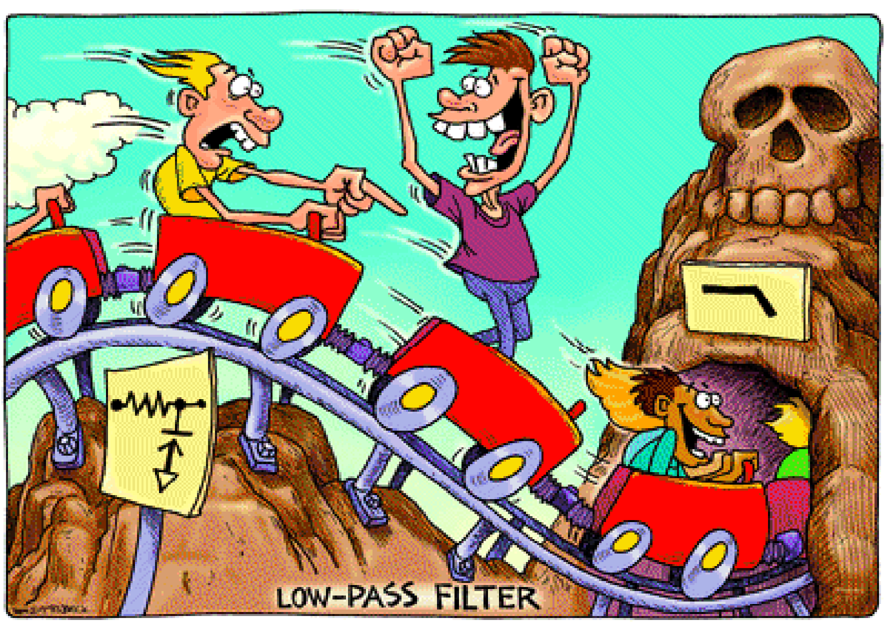
PCB Manufacturing-Multilayer





Basics of High Speed Switching

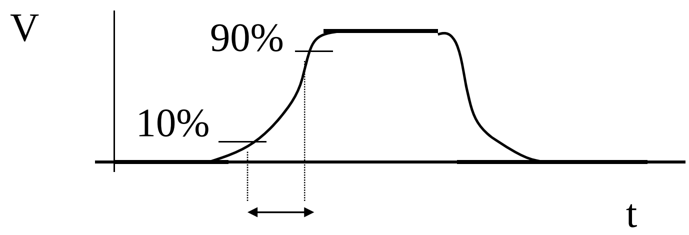
Channel Characteristics



Basics of High Speed

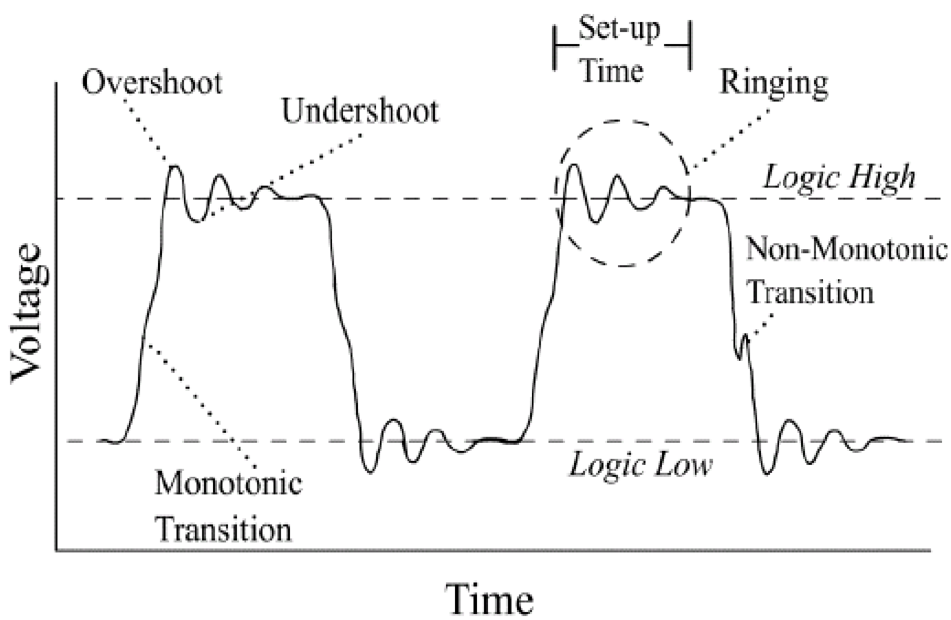
You are all well familiar with

- Rise Time
- Fall Time
- Delay Time

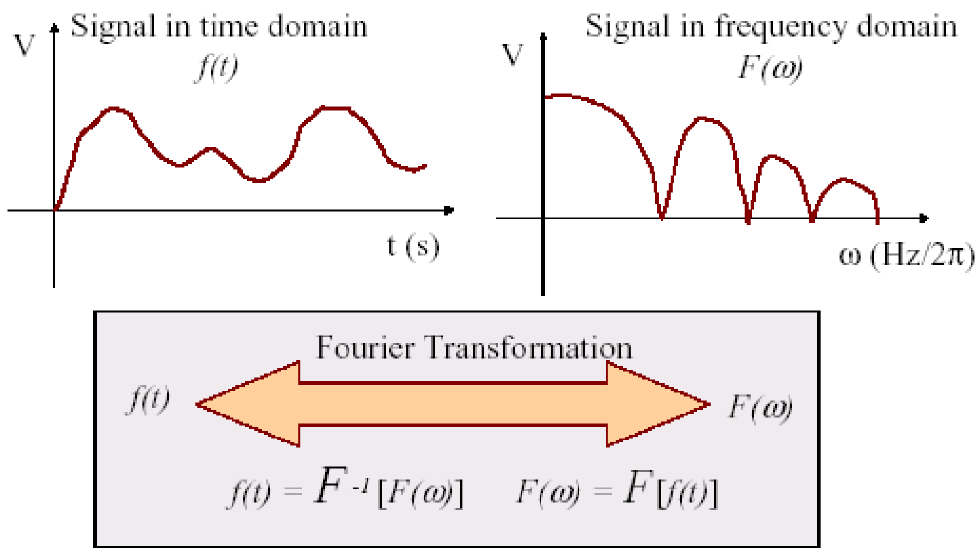


- GaAs, used in optical communication circuits has tr of 100-picoseconds.
- This is 30 to 50 times faster than some CMOS components.
- For sine wave rise time is 30% of the period of sine

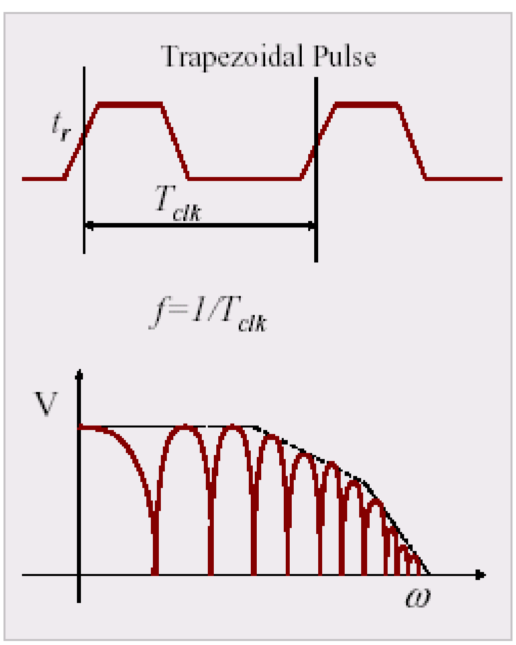
Basics of High Speed

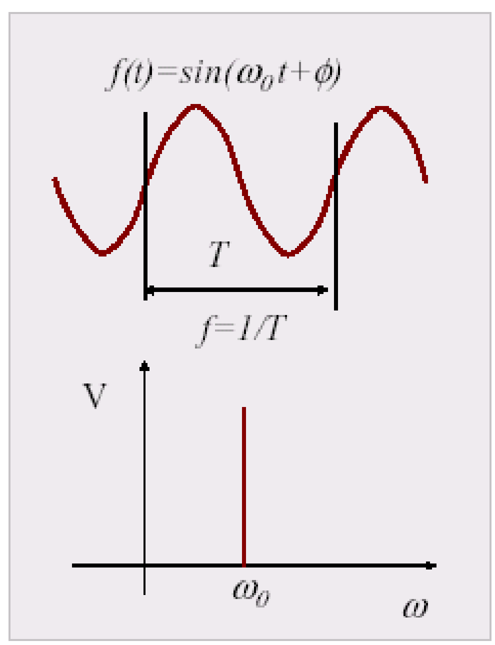


Signal Analysis in Time and Frequency Domain

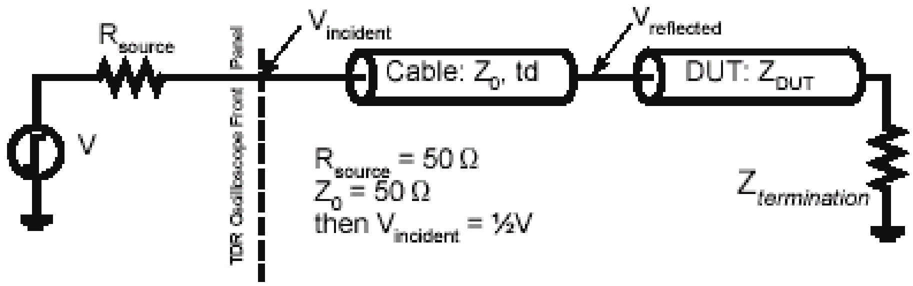


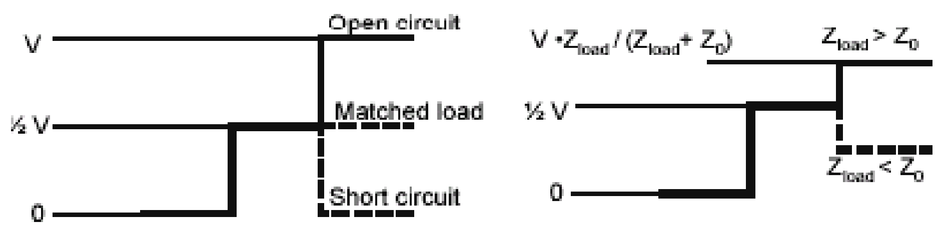
Digital Frequency vs. Analog Frequency



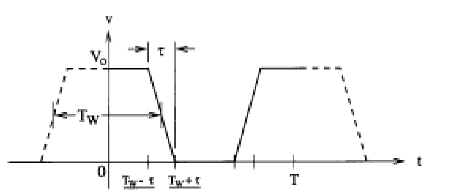


Time Domain Reflectometry (TDR)



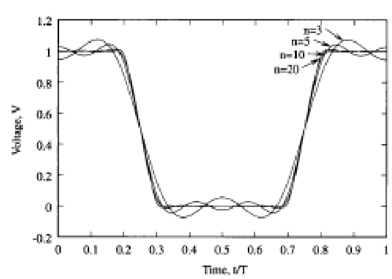


Signal BW- Trapezoidal Pulse Train

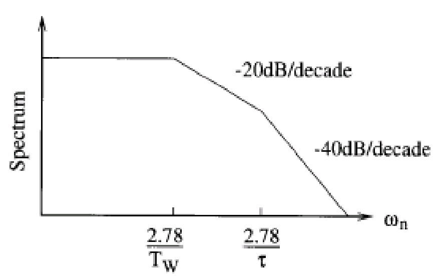


$$v(t) = V_o \frac{T_W}{T}\left(1 + 2\sum_{n=1}^{\infty} \frac{\sin(n\pi T_W/T)}{n\pi T_W/T}\frac{\sin(n\pi\tau/T)}{n\pi\tau/T}\cos\left(\frac{2\pi n}{T}t\right)\right)$$

Pulse train with trapezoidal edges set up for even symmetry



Trapezoidal pulse train with $T_W = 0.5T$ and $T/\tau = 10$ reconstructed from its Fourier series with the number of harmonics varying from 3 to 20.



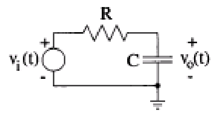
Envelope of the spectrum for the trapezoidal pulse train

$$f_{BW} \approx \frac{0.885}{t_r} \quad or \quad \left(\omega_{\min} = \frac{5.56}{t_r}\right)$$

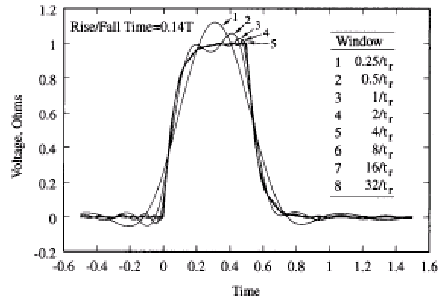
Bandwidth Needed for Modeling usually take

$$f_{BW} \approx \frac{1}{t_r}$$

Signal BW- Exponential Pulse



Simple RC circuit for estimation of bandwidth in interconnects.



Reconstruction of a pulse after rectangular windowing of its spectru shows that frequency components above $4/t_r$ are not needed Acceptable accuracy can be achieved with as little bandwidth as $1/t_r$.

$$|H(\omega)|^2 = \frac{1}{1+(\omega RC)^2}.$$

$|H(\omega)|^2 = 1$ while $(\omega RC)^2 \ll 1$ but drops to 1/2, the -3dB half-power point, at the corner frequency defined by $(\omega_{3dB}RC)^2 = 1$. RC can be eliminated using the 10% to 90% rise time to obtain

$$\omega_{3dB} = \frac{2.197}{t_r},$$

which in terms of frequency is

$$f_{3dB} = \frac{0.35}{t_r}.$$

Basic frequency components

$$f_{-3dB} \approx \frac{0.35}{t_r}$$

Bandwidth Needed for Modeling

$$f_{BW} \approx \frac{1.4}{t_r}$$

Example: BW Calculation

Question:

Estimate signal bandwidth for packaging modeling of a 500MHz clock signal.

Answer:

We assume the clock signal is in exponential pulse shape, with a rise time 10% of clock cycle, so $T_{clk}=1/f = 2\text{ns}$, $t_r = 10\% T_{clk} = 200\text{ps}$.

Basic frequency components

$$f_{-3dB} \approx \frac{0.35}{t_r} = 1.75\text{GHz}$$

Bandwidth Needed for Modeling

$$f_{BW} \approx \frac{1.4}{t_r} = 7\text{ GHz}$$

Speed of Light……

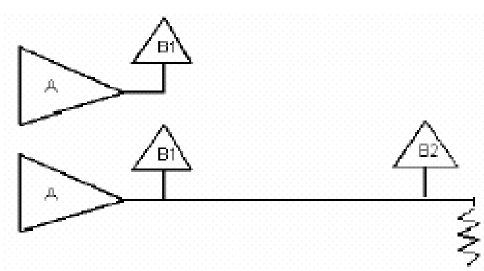
- Speed of Light 186,280 miles/sec in free Space
  - Its **11.8 in/ nsec** or 1ft/nsec
- In Other Materials

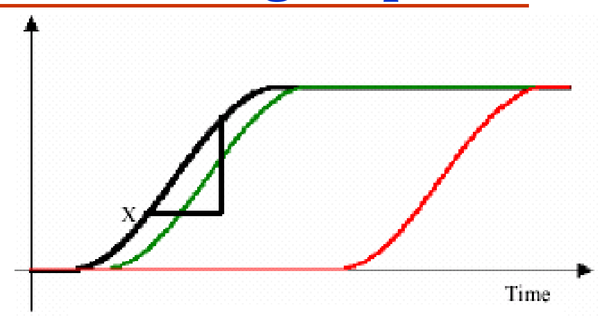
$$\frac{11.8}{\sqrt{\varepsilon_r}} in / n \sec$$
$$For \quad FR\,4 \; material \quad \varepsilon_r = 4$$
$$\Rightarrow \; Speed \approx 6 \; in / n \sec$$

–Its **6 in/ nsec** in FR4 PCB surface trace

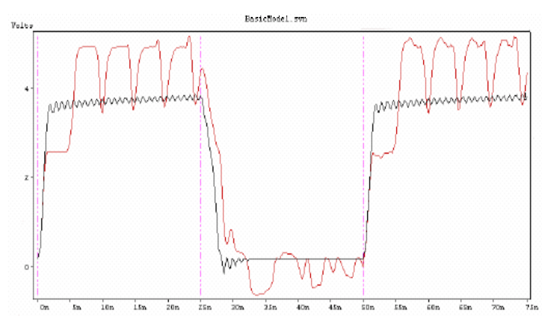
–Its even more slow in embedded traces.

Critical Length, When Its High Speed?





When traces are *long*, reflections return to the driver after the driver's output has settled.



- Black curve signal being driven by A.
- The green and red at B1 and B2.
- Rise time is 1 nanosecond.
- Propagation speed is 6”/ns.
- Distance from A to B1 is 2 inches(.3 nsec) and from A to B2 12 inches (2nsec)
- What's critical Length then ??

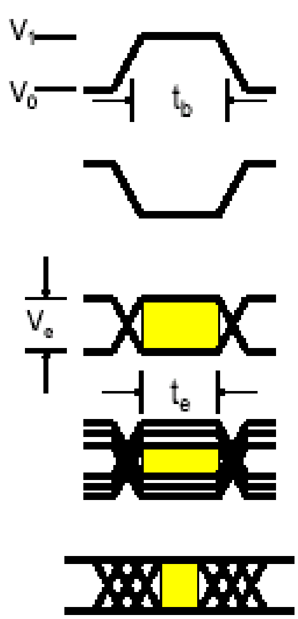
Critical Length, When Its High Speed?

- When the propagation time for the signal to reach the end of the trace and return (the round trip length) is equal to the rise time.
- For a 1 ns rise time signal and a propagation time of 6"/ns, one-way length to the end of the trace would be half that, or 3 inches.
- So the critical length in FR4 is often defined as 3 inches times the rise time in nanoseconds.

$$t_{of} \approx> 0.5\, t_r$$

$$t_{of} = Time \quad of \quad Flight \qquad t_r = Rise \quad Time$$

Quality of Received Signal



This is a "1"

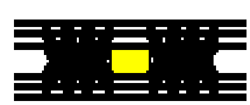
This is a "0"

Eye - space between 1 and 0

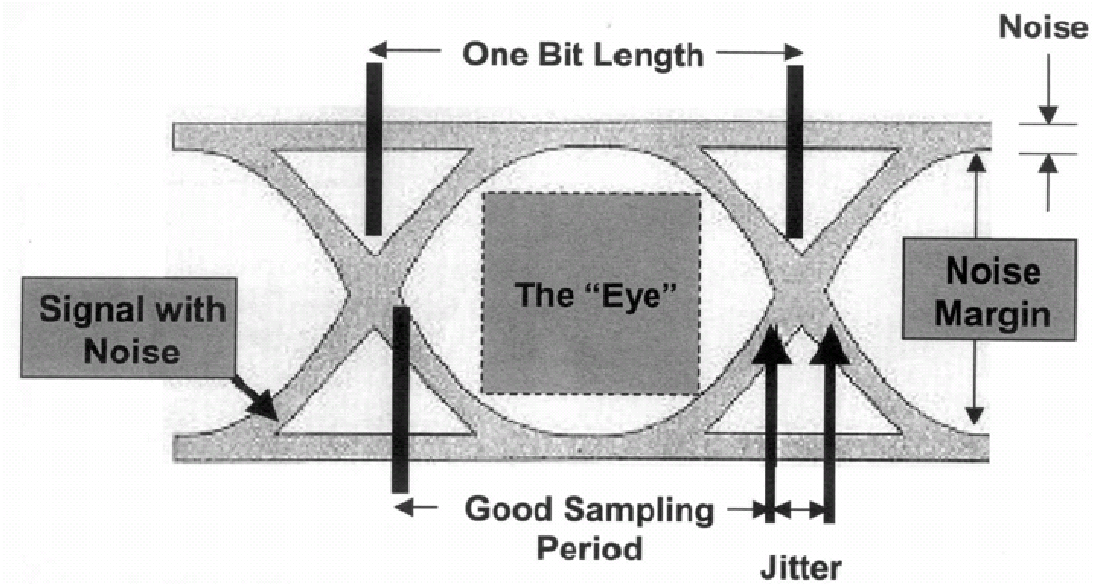
With voltage noise

With timing noise

With Both!



Quality of Received Signal



Eye Diagram: A view of noise , signal and Timing

Example: Memory Bus

Shared memory subsystem

- 20 small CPUs any of which may access an 8-bit wide RAM
- Bus traces are have 50 ohm impedance traces and are 10 inches long.
- Bus propagation length is much shorter than the rise time of a 74HCT640 gate.
- No terminators are used at either end of the bus.
- Bus driver should be able to drive 20 other circuits.
- With 9 ns maximum propagation delay of each transceiver, we plan to operate the bus on a 30-ns cycle (33 MHz)

Example: Solution

I/O load capacitance / driver = 10pF.

20 loads and C_{load} 200pF of load

2pf/in load of the backplane traces

C_{load} = 20 x 10 + 2 x 10 = 220 pF

Output resistance of 74HCT640

VCC = 4.5 V; VOH = 3.84; I_{out} = 6.0 mA

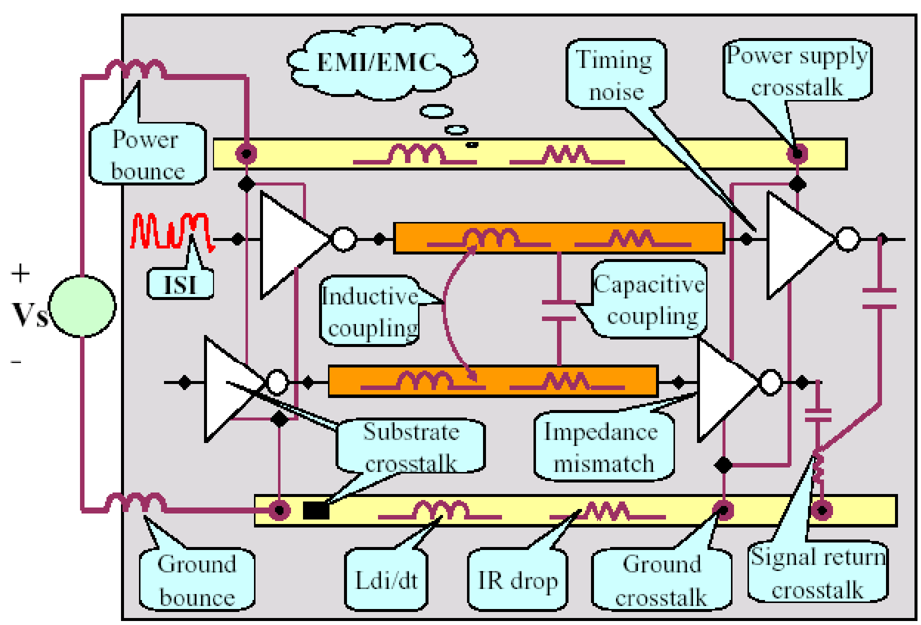
The high-side drive resistance = (VCC - VOH)/I_{out} = **110 Ω**

Charging time constant **T_{RC} = 110 x 220 x 10-12 = 24 ns**

The rise time **T_r = 2.2T_{RC} = 53 ns**

The data bus can not be run at 33 MHz (30.3nsec) with this rise time

Signal Integrity: Cumulative Overview



A Typical Product
PCB Overview

A Case Study: UMTS Stick

- Take off cap
- Take out wireless card
- Wireless Card

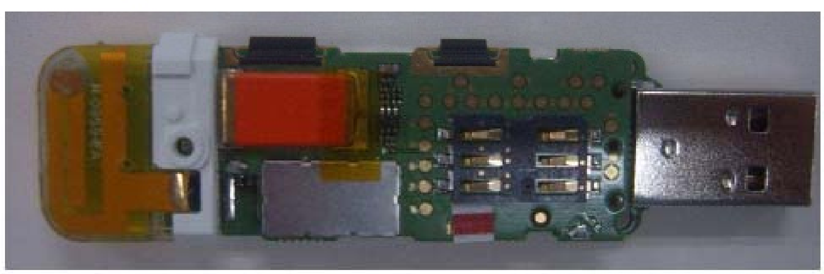
A Case Study: UMTS Stick

- Cover
- Cap
- Wireless Card & Main body

- Main Body

Disassembly of UMTS Stick

- Main board and card supporter – front, back



UMTS Stick: Multilayer PCBs

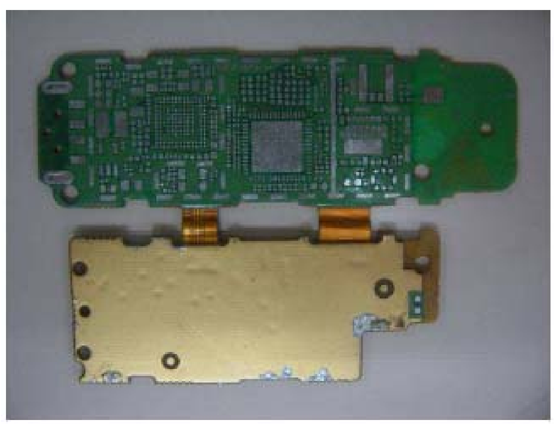
- RFPC with Component: Front Side

- RFPC with Component: Back Side

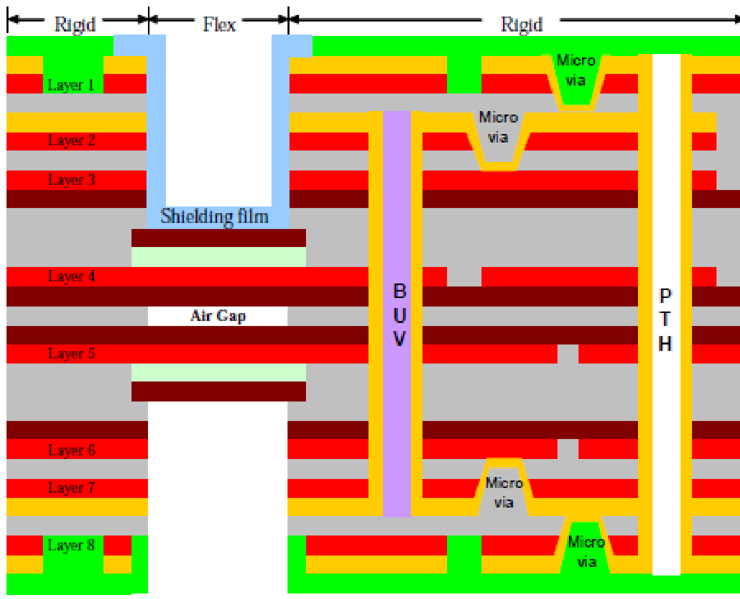
UMTS Stick: Multilayer PCBs

Top Side

Bottom Side



Inside UMTS Stick PCBs

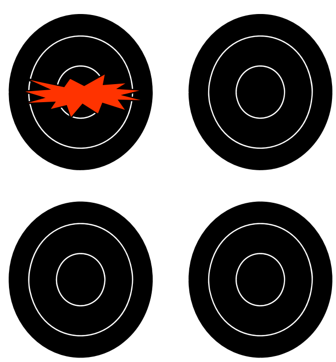


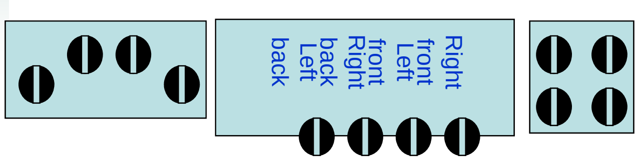
Thickness	Description
20 µm	Solder mask
20 µm	Plated Copper
18 µm	Copper foil
75 µm	Normal prepreg
20 µm	Plated Copper
18 µm	Copper foil
75 µm	No flow prepreg
12 µm	Base Copper of FCCL
20 µm	PI of FCCL
75 µm	No flow prepreg
13 µm	PI of coverlay
25 µm	Adhesive of coverlay
12 µm	Base Copper of FCCL
20 µm	PI of FCCL
75 µm	No flow prepreg
20 µm	PI of FCCL
12 µm	Base Copper of FCCL
25 µm	Adhesive of coverlay
13 µm	PI of coverlay
75 µm	No flow prepreg
20 µm	PI of FCCL
12 µm	Base Copper of FCCL
75 µm	No flow prepreg
18 µm	Copper foil
20 µm	Plated Copper
75 µm	No flow prepreg
18 µm	Copper foil
20 µm	Plated Copper
20 µm	Solder mask

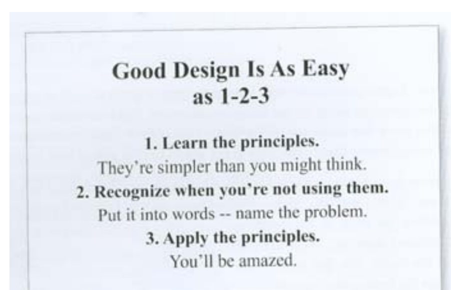
Feature: 1)Air gap; 2)Staggered µvia; 3)Buried via with epoxy fill

Rigid thickness 845 µm
Flex thickness 140 µm

Good PCB Design…is … in most cases a technical common sense

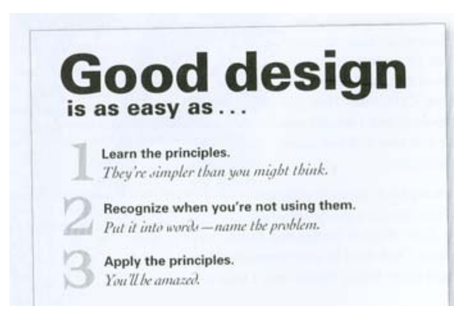






Good Design Is As Easy as 1-2-3

1. Learn the principles.
They're simpler than you might think.
2. Recognize when you're not using them.
Put it into words -- name the problem.
3. Apply the principles.
You'll be amazed.



Good design is as easy as . . .

1 Learn the principles.
They're simpler than you might think.

2 Recognize when you're not using them.
Put it into words — name the problem.

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Rules of the Game

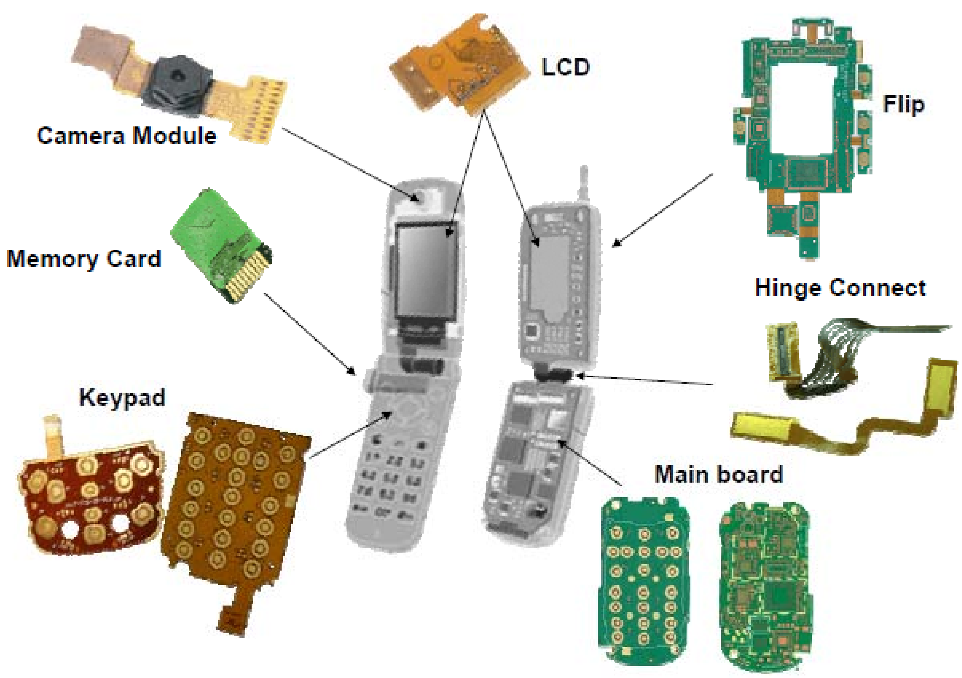
If we fall short of your expectation….or you already know what we plan to teach and discuss

Then

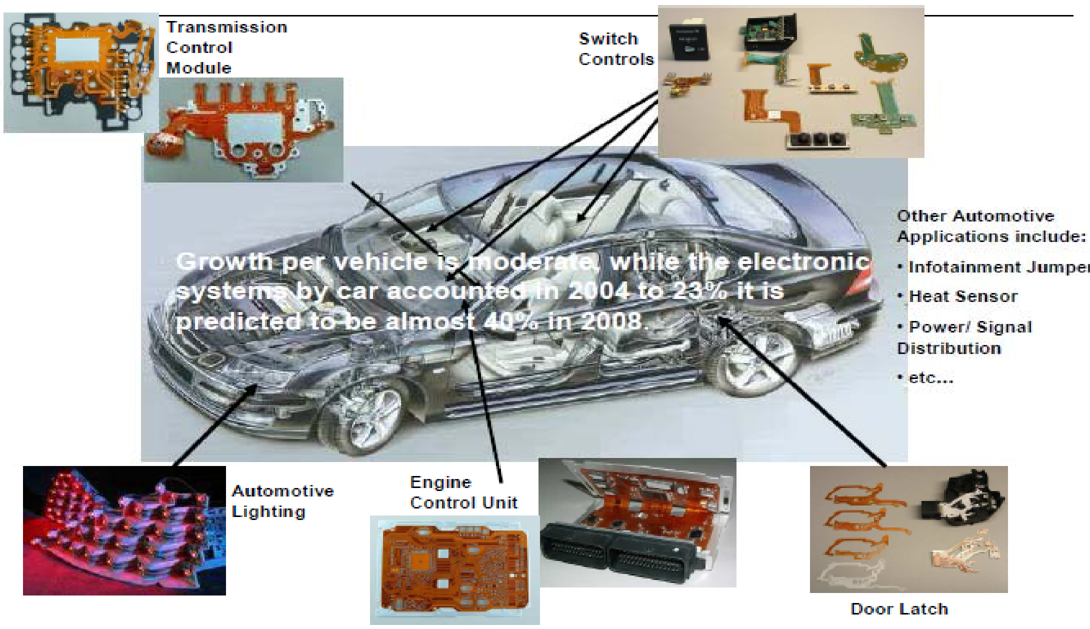
You can leave the course any time within first two days with full refund.

'You can't retire. You know too much.

Mobile Phone: PCB Types

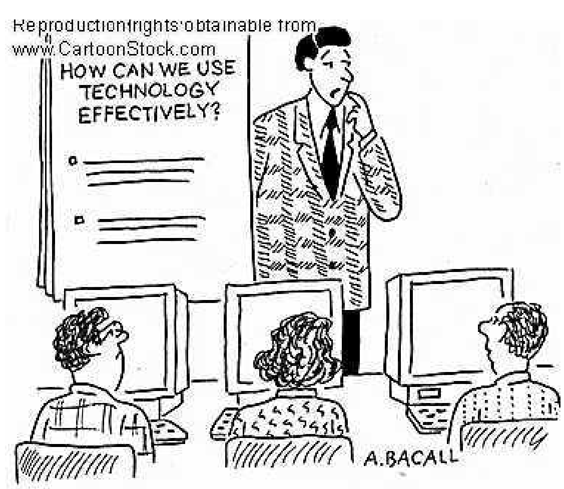


Modern Car: PCB Types



What can happen with U: Two things

"My class is so large and my seat is so far back, I feel like I'm taking a distance-learning course."



"I'm going to switch to plan 'B'. Our computers are down."

Wakeup Please lets have Some Food....