

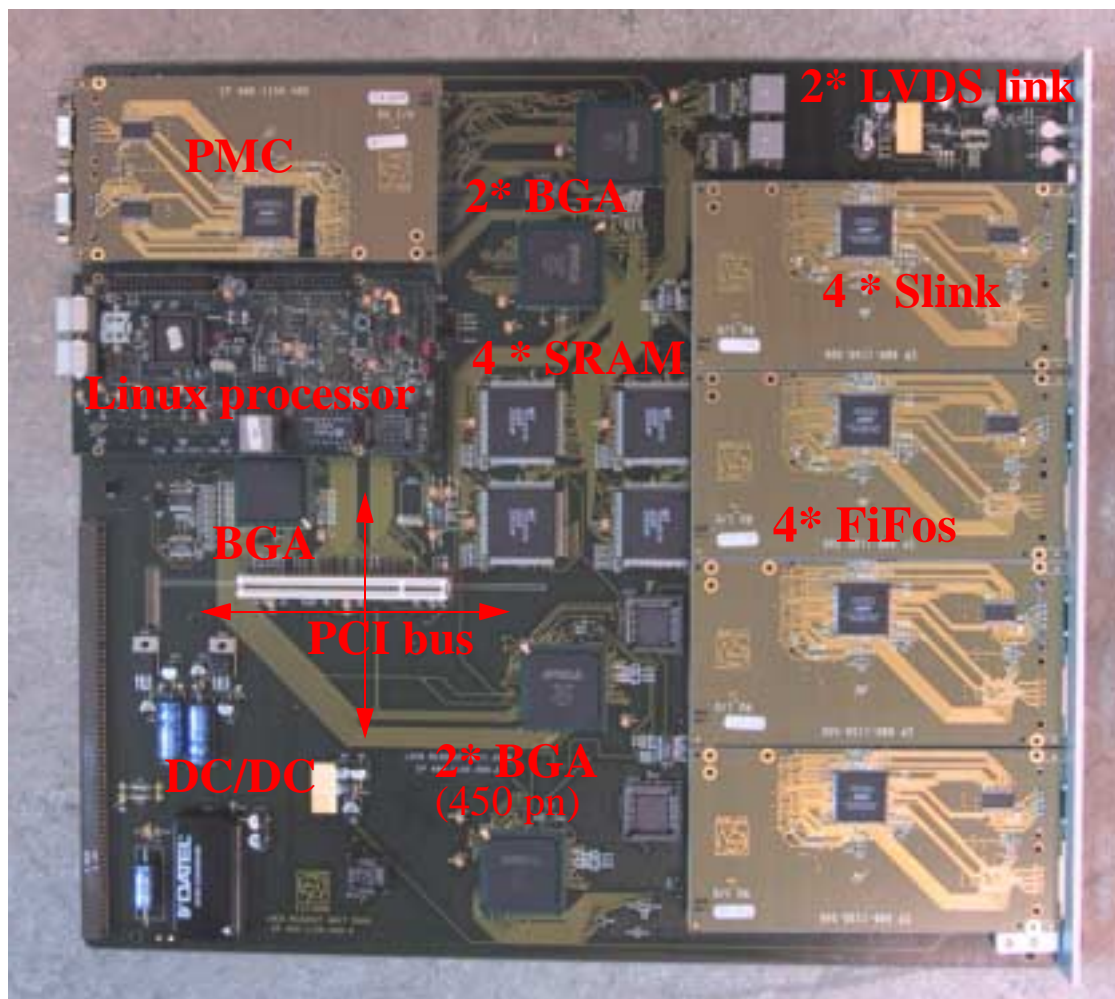
# First experience with a halogene-free PCB

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# LHCb Readout Unit ( 2000-2002 )



- 9U-size
- 366.7x400 mm
- 2.2 mm-thick
- 8-layer board
- 6 mezzanine cards
- 64 bit PCI bus
- 450 pin BGAs ( 4 \* )
- embedded 486 system

standard version:

FR4

Halogene free version:  
New laminate Matsushita  
R1566 and R1551

# board electrical details (EP 680-1150-400-A)

8 layers

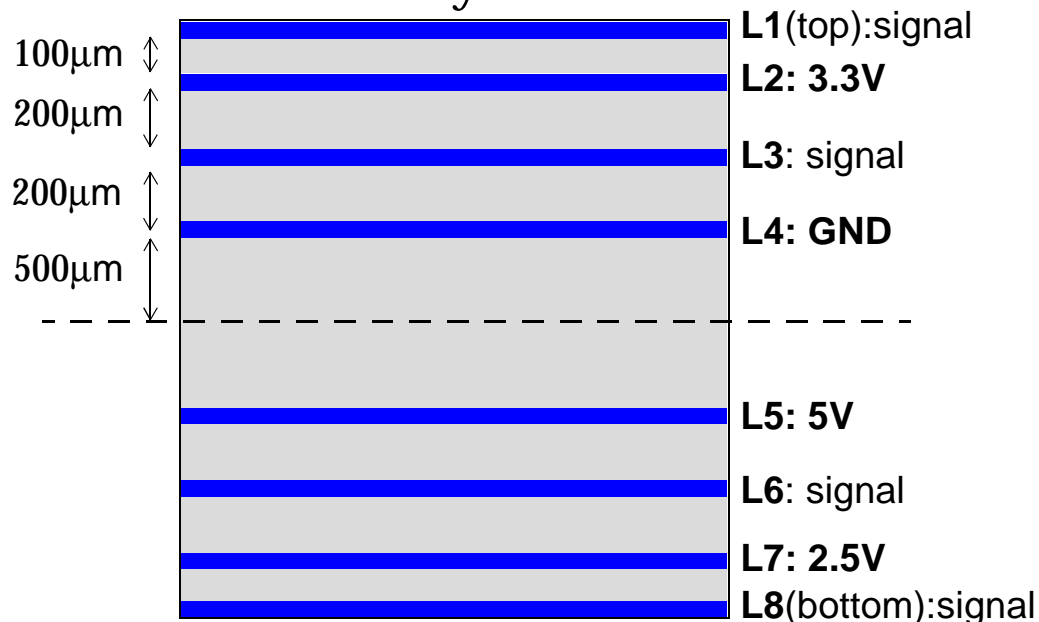
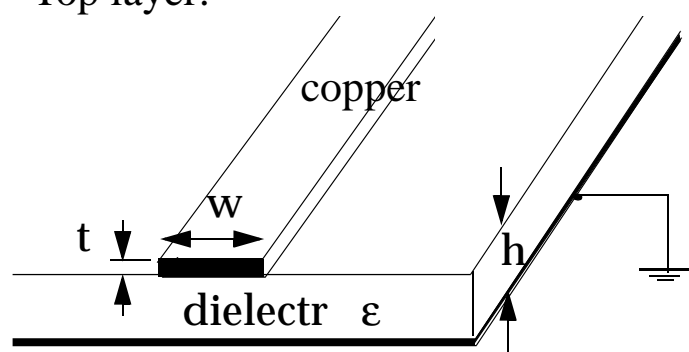


Figure 1 RU board stack-up

With  $\epsilon_r = 4.7$  for FR4 material, the top and bottom layer impedance is  $58.3 \Omega$  whilst inner layer impedance is  $55 \Omega$  ( These values correspond to unloaded lines). Propagation delays are  $59.5 \text{ ps/cm}$  for top and bottom layers and  $68.3 \text{ ps/cm}$  for inner layers.

Top layer:



$$h = w = 100 \text{ u}, t = 35 \text{ u}$$

$$Z_0(\text{FR4}) = 58.0 \Omega$$

$$Z_0(\text{H-free}) = 55.7 \Omega$$

strip line impedance:

$$Z_0 = \frac{87}{\sqrt{\epsilon + 1.41}} \ln \left( \frac{5.98 * h}{0.8 * w + t} \right)$$

$$\epsilon_{\text{FR4}}(1 \text{ MHz}) = 4.7 \longrightarrow \epsilon_{\text{Hfree}}(1 \text{ MHz}) = 5.2$$

4% less in  $Z_0$  can be compensated  $h=100 \rightarrow 107 \text{ u}$

# Standards and Directives for PCB

1.) EU Directives on Electrical and Electronic Equipment: **Phase-out by 2008** hazardous substances: Lead, Cadmium, **PBB, PBDE ( brominated flame retardants)**

## 2.) Flammability standards

### USA & Japan

**UL94-V0** ..... **Underwriters Laboratories Inc.**

<http://ulstandardsinfonet.ul.com>

<http://www.boedeker.com/bpi-il94.htm>

### Europe

#### **previous ISO ISO 1210:1992**

Plastics -- Determination of the burning behaviour of horizontal and vertical specimens in contact with a small-flame ignition source  
Withdrawn: 1999-03-01 Technical committee / subcommittee : [TC 61](#)

Replaced by: [IEC 60695-11-10:1999](#)

Fire hazard testing -- Part 11-10: Test flames -- 50 W horizontal and vertical flame test methods (**price 128.- CHF**)

[http://http://www.iso.ch/iso/en/Standards\\_Search.StandardsQueryForm](http://http://www.iso.ch/iso/en/Standards_Search.StandardsQueryForm)

# UL 94 Flammability compliance

**5VA** Surface Burn Burning stops within 60 seconds after five applications of five seconds each of a flame (larger than that used in Vertical Burn testing) to a test bar. Test specimens MAY NOT have a burn-through (no hole).

**This is the highest (most flame retardant) UL94 rating.**

**5VB** Surface Burn Burning stops within 60 seconds after five applications of five seconds each of a flame (larger than that used in Vertical Burn testing) to a test bar. Test specimens MAY HAVE a burn-through (a hole).

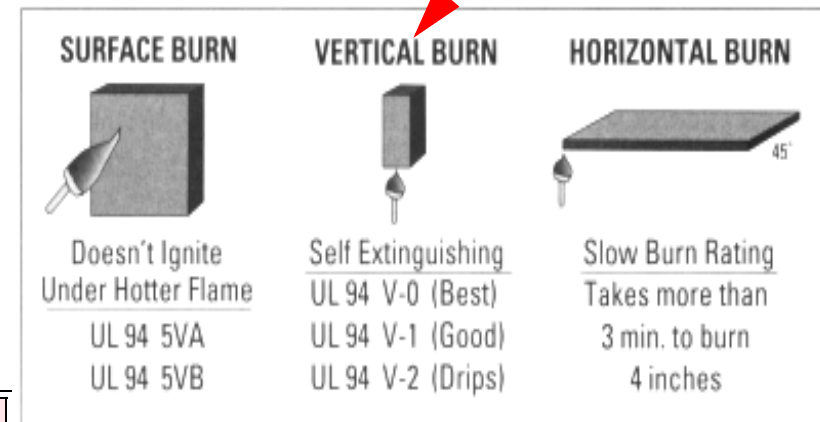
**V-0** Vertical Burn **Burning stops within 10 seconds after two applications of ten seconds each of a flame to a test bar. NO flaming drips are allowed.**

**V-1** Vertical Burn Burning stops within 60 seconds after two applications of ten seconds each of a flame to a test bar. NO flaming drips are allowed.

**V-2** Vertical Burn Burning stops within 60 seconds after two applications of ten seconds each of a flame to a test bar. Flaming drips ARE allowed.

**H-B** Horizontal Burn Slow horizontal burning on a 3mm thick specimen with a burning rate is less than 3"/min or stops burning before the 5" mark. H-B rated materials are considered "self-extinguishing".  
**This is the lowest (least flame retardant) UL94 rating.**

electronic modules



## UL 94 Flammability Ratings Summary

**UL94-VO rating used for PCB both FR4 and all new materials**

## Matsushita non-halogenated FR-4 (laminates R1566 and R1551 )

- Employs new ( phosphor-series ) flame retardants
- Satisfies UL94-V0 without using halogens or antimony
- General properties equivalent to FR-4
- Reliability is equivalent to FR-4

### Properties:

- Insulation :  $1 \times 10^{14}$
- Dielectric Const. 1 MHz:  $\epsilon = 5.2$
- Dissipation factor 0.01
- Trackresistance CTI 500V

Test	Halo-free	conventional FR-4
Br content	0.01 % or less	8 %
Cl content	0.037 %	0.044 %
Antimony Content	not detectable	-
Flammability	1.5 sec average 2 seconds max ( UL94V0)	1.3 seconds 2 seconds max ( UL94V0)

Equivalent FR4 in:

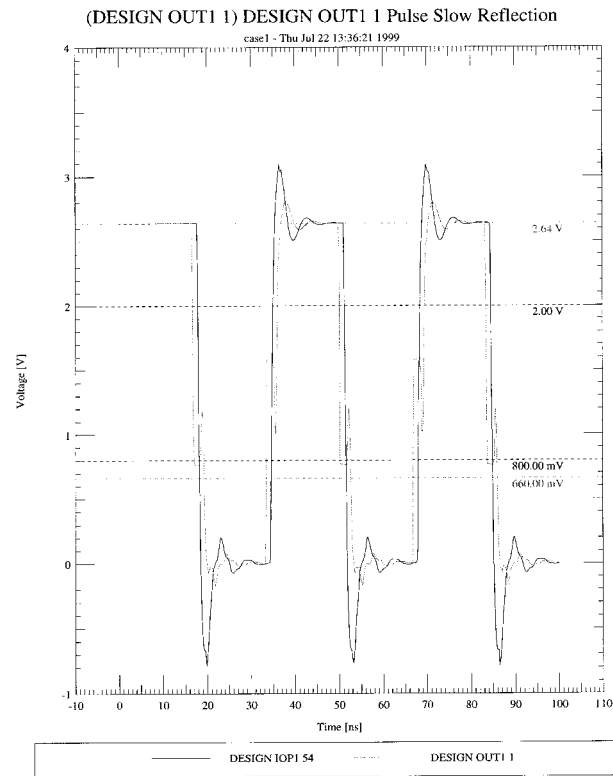
*process stability*

Twice better in:

*through-hole reliability*

Indust. Applications: green Laptops (Toshiba), portables (Ericson)

# Signal integrity simulation prior to Allegro layout

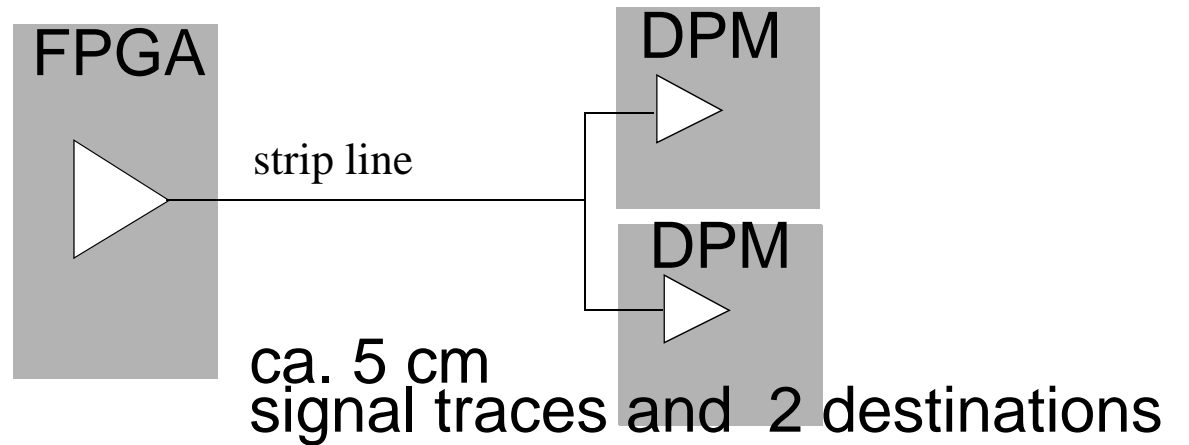


30 MHz signal simulation

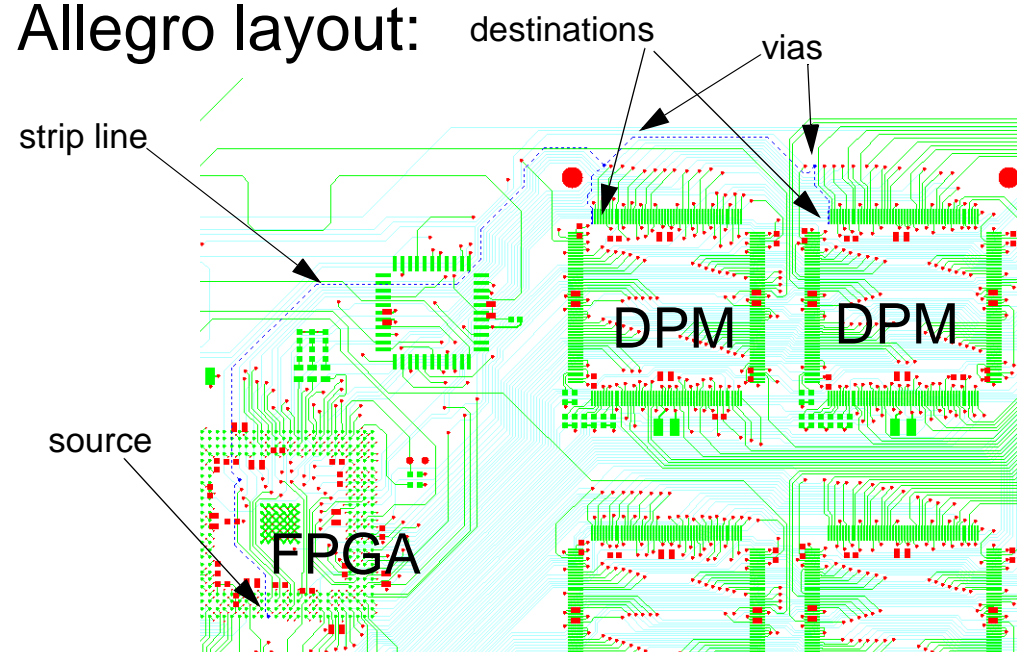
Spectraquest result with analog IBIS models for driver / receiver

(CMOS threshold L=0.8 H=2.0 Volt)

$t_f=1.8$  ns, 0.8-0.3-0.1 Volt reflective under/overshoot on high impedance ends



## Allegro layout:



# Signal measuring equipment

## Measurement equipment

Technical characteristics

### Tektronix Digital scope TDS784D

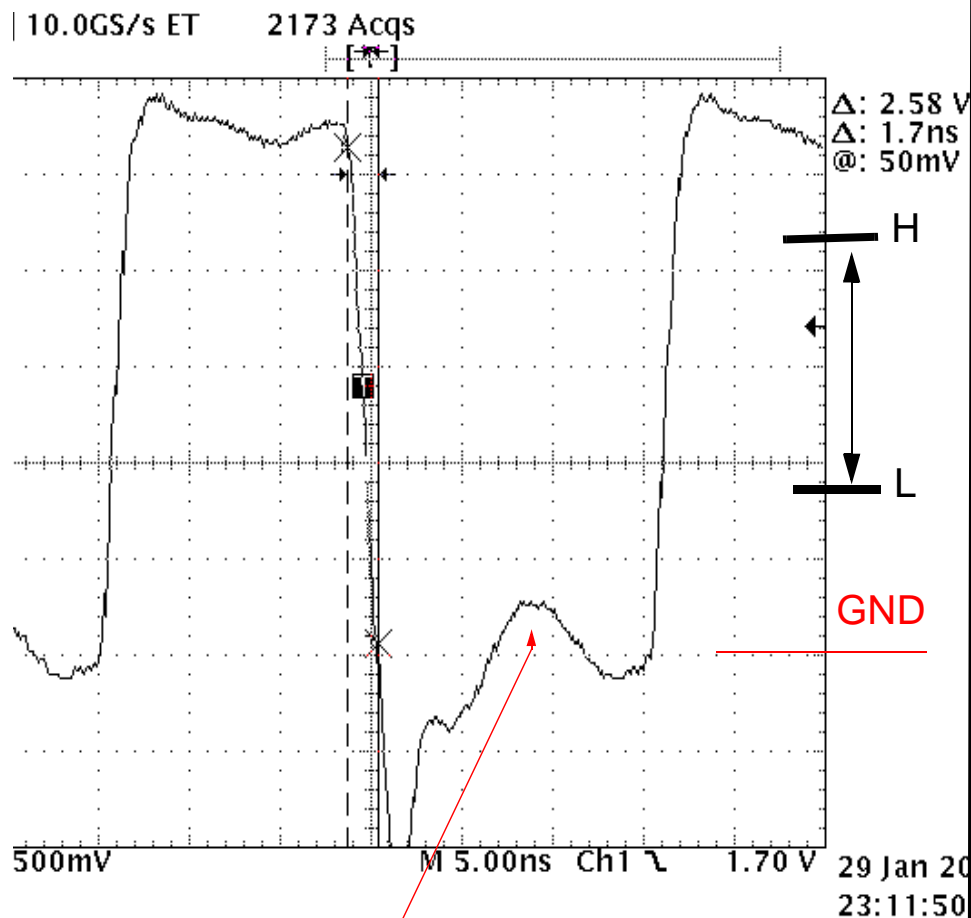
X	Max. Digitizing rate	4 GS/s
	Analog bandwidth	1 GHz
	Trigger jitter	7 ps
	Sensitivity	1 mV/div
	DC gain accuracy	$\pm 1.0\%$
	Effective bits	5.5 (1 GHz @ 4 GS/s)
	Vertical resolution	8 bits

### Tektronix active probe 5X 4GHz P6249

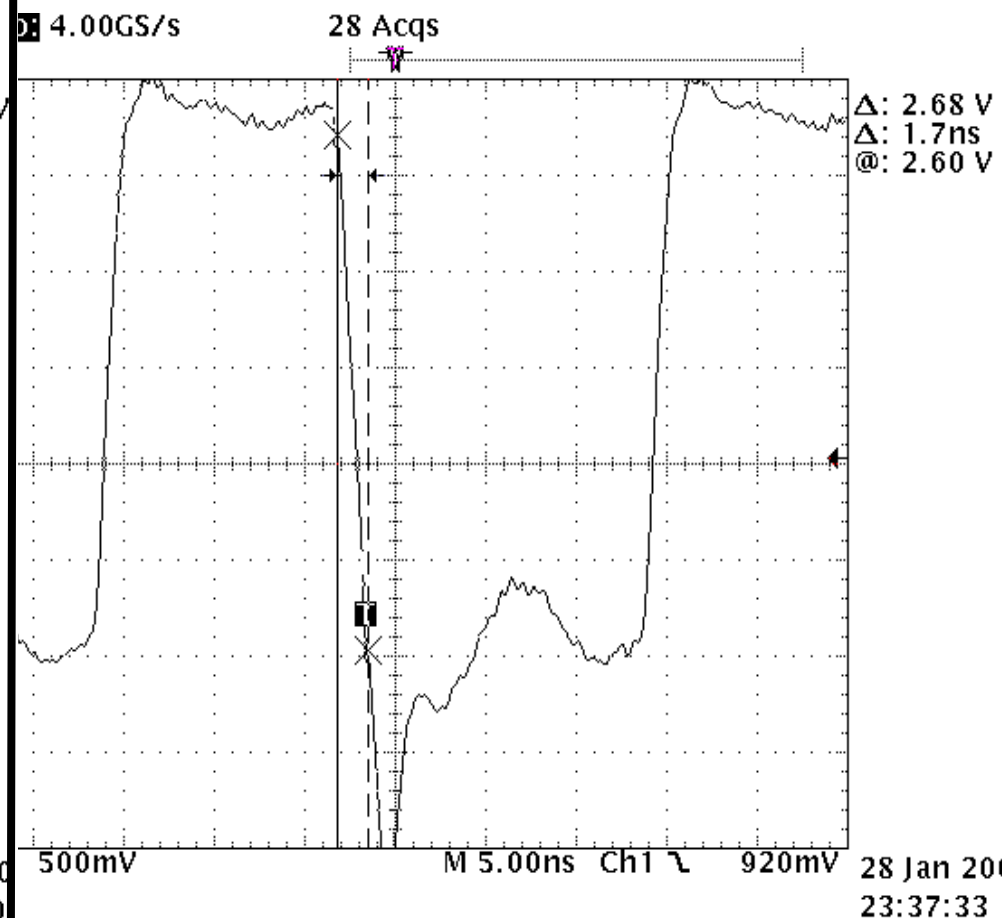
X	Bandwidth	4 GHz
	Linear input dynamic range	$\pm 1.75$ V
	Linearity	$\pm 4\%$ or less of dynamic range
	Input resistance	20 k $\Omega$ at DC
	Input capacitance	1 pF
	Offset range	$\pm 3.5$ V
	DC Offset drift	150 $\mu$ V/ $^{\circ}$ C
	System noise	300 $\mu$ V
	Delay time	5.05 ns $\pm 2$ ns
	DC attenuation	5:1 $\pm 2\%$
X	Rise time	$\leq 120$ ps
	Maximum offset voltage	$\pm 3.5$ V
	50 $\Omega$ termination	

# Measured 33 MHz signal shape on FR4 and Halogene free ( no mentionable difference )

## FR4



## Halo-free

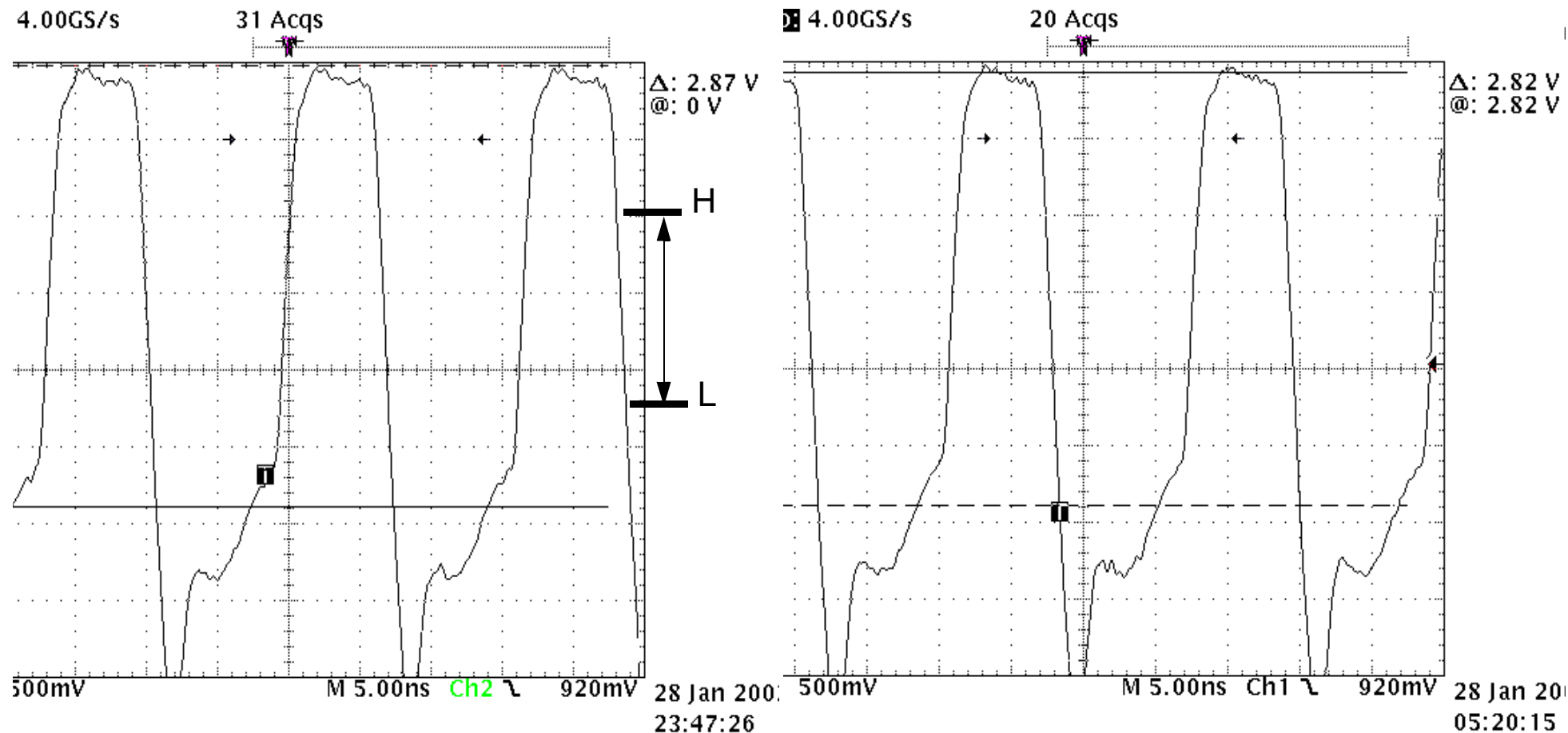


$t_f=1.7$  ns, 1.1 Volt reflective undershoot, 0.3 Volt overshoot, unsymmetric driver 6mA/3mA explains difference for less overshoot. Ground "bump" after ca 8 ns **not** related to transmission properties, inductive ground bouncing of driver ?

# Measured 66 MHz signal shape on FR4 and Halogene-free ( no mentionable difference )

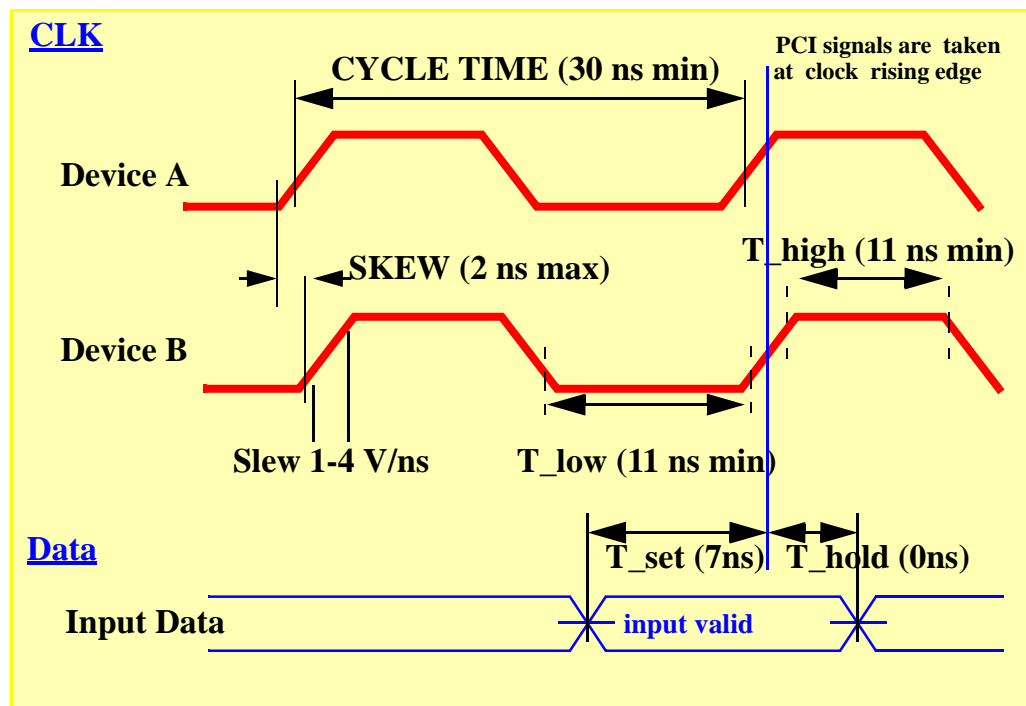
## FR4

## Halo-free



Ca 1 Volt undershoot. Non symmetric behaviour due to unsymmetric 6 mA / 3 mA output driver.  
Reflections do not affect however High / Low thresholds for 66 MHz operation

# PCI: a delicate CMOS bus



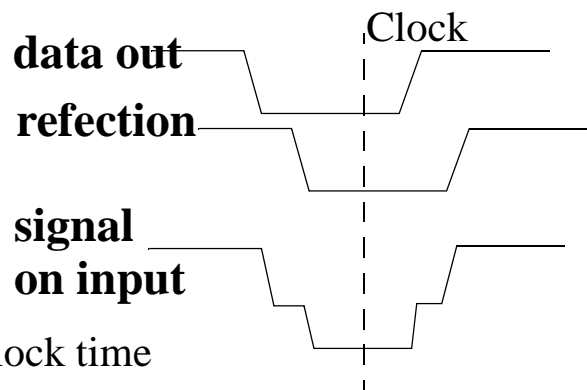
## Reflected Voltage wave technology

- .. Weak Voltage drivers & unterminated lines:
- .. No DC current due to termination resistors
- .. hence less spike/decoupling problems
- .. high imped. PCB 64 OHM +/- 10% (thin traces far from GND)
- .. low capacitance packages (plastic)
- ...80-100 OHM drive (6 mA)
- .. Slew rate 1..4 Volt/ns

## Limitation:

- .. limited total signal traces (~10 cm)

## Idealized principle:



better noise margin at clock time

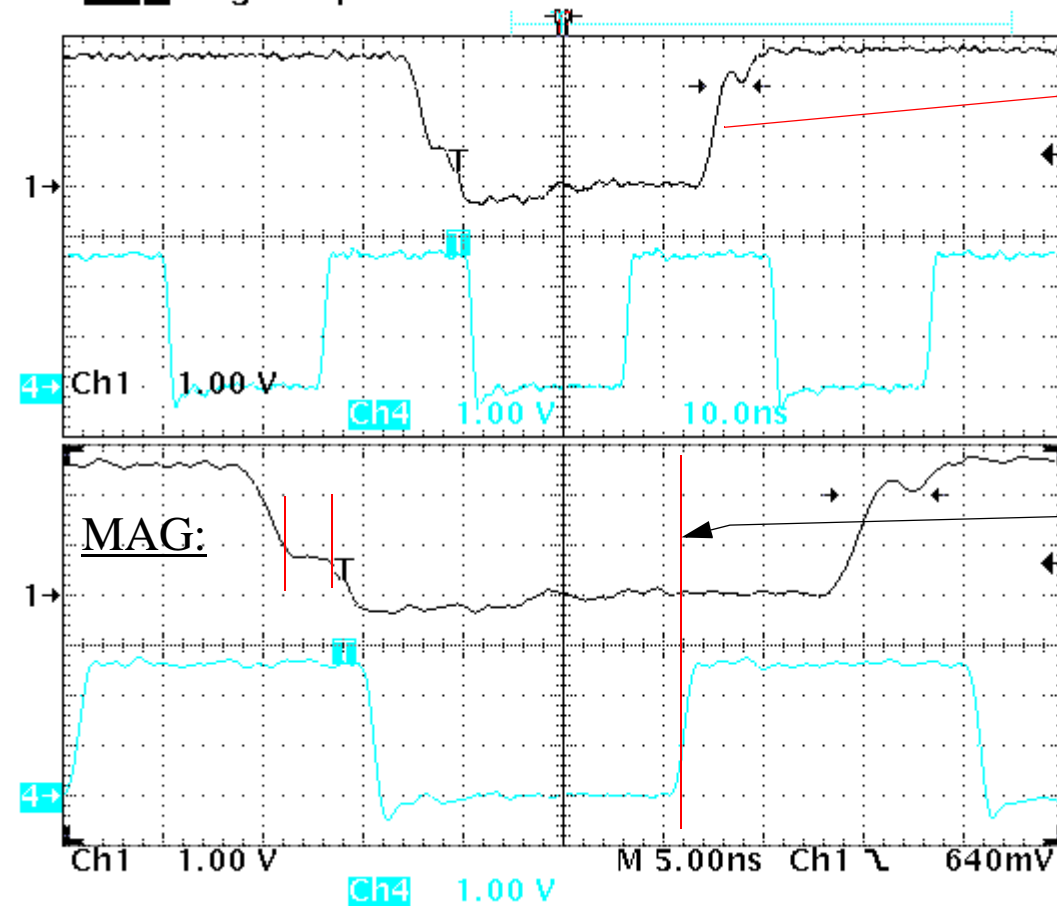
## PCI Clock signals:

- ...NOT: reflected wave (of course)
- ...if possible: point-point
- ...clock signal to be delayed by 0.8 ns (13 cm)
- ...Maximum 0.8 ns skew for diff. PCI chips
- ...data required stable 7 ns before rising clock

# PCI measurements on Halogene free RU

## Under test: PCI frame signal relative to PCI clock

Tek Stop: Single Seq 2.00GS/s



Slew rate  
ca 2 V/ns

33 MHz

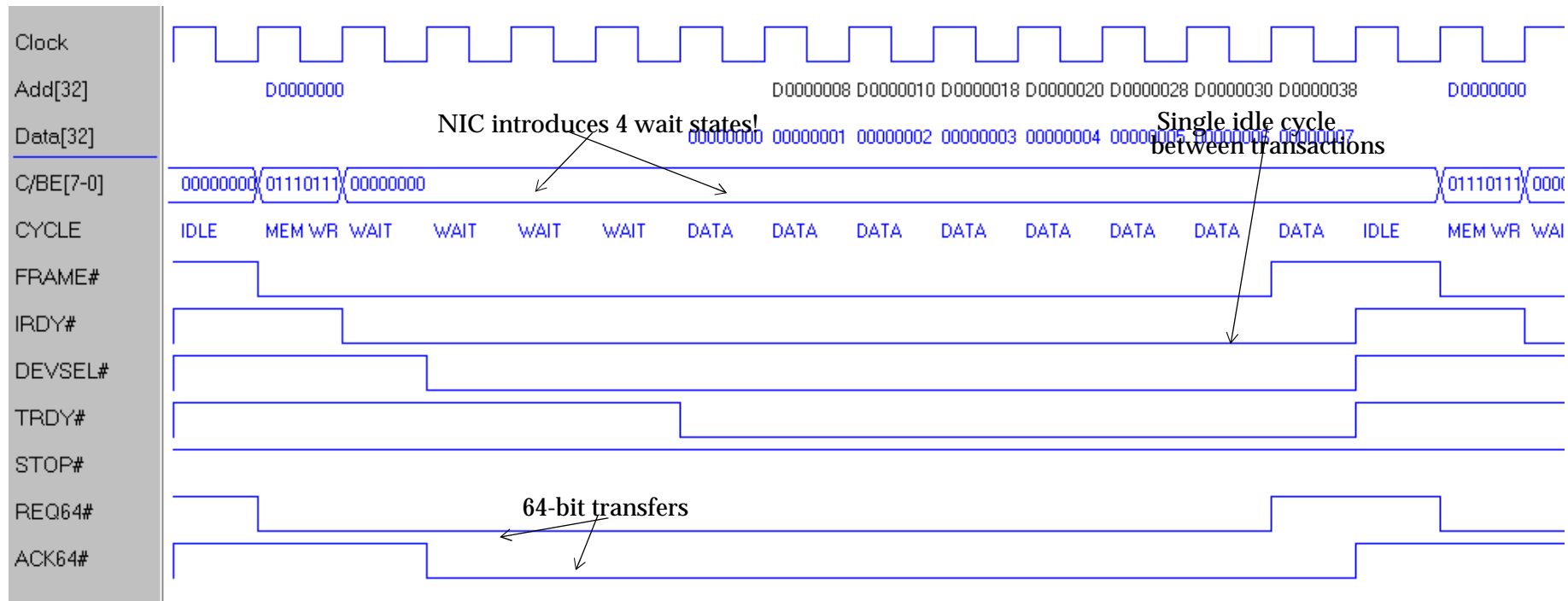
Data to be  
stable 7 ns  
prior to  
this line

### Perfect signals:

- reflected wave visible
- Slew rate OK
- $1/2 * (2.5 \text{ ns}) =$  reflection length  
 $1250/60 = 20 \text{ cm}$   
corresponds to  
(artificially) long  
20 cm signal path
- Clock signal  
 $T_r = T_f < 1 \text{ ns}$

# All-inclusive test: 64 bit PCI operation to PMC card

Figure 1 64-byte burst write to a Dolphin SCI NIC (LC4000 and L5B9350 chips)



## Implies that

- processor card ( Linux ) has done PCI chip initialization via 2 levels of PCI bus
- all read write transaction ( 64 bit bus ) work

# PCB & halogene-free Laminate suppliers

## Tendering June 2001

- .. many negative replies ( mostly no definite reply)
- .. **Cistelair Italy** “materiale molto particolare” cannot provide it for small quantities
- .. **Elektrotryck Sweden**: 4 weeks delivery 5 cards at factor 2 price payed previously for same cards in FR4

## Tendering PCI FLIC cards January 2002

- .. **Elektrotryck Sweden**: Offer for halogenen free

Article	Qty	Price/Pc [CHF]	Delivery
EP-680-11780-050	50	112	15-20 days
“ “	100	84.7	“ “
“ “	200	74.7	3..5 weeks

factor 2 to same card in FR4

## PCB Suppliers:

- AC-Plus, France
- Astron, UK
- Kamtronics, UK
- CISTELAIR, It
- KAPI, Be
- MULTEK, Ge
- PPC Electronivcs, CH
- SIEMENS CH
- **Elektrotryck, S** <-----used by us

## Laminate Suppliers

- ISOLA, Ge
- ISOVOLTA, Au
- POLYCLAD, Fr
- TOSHIBA, Jp
- **Matsushita, Jp** < ---used by us

# Relative cost of halogene-free PCB to full card cost

**Table 1** Electronic cards designed and manufactured in ED -DTb 2001-2002, prices in CHF

Card Name	Allegro layout	films + tooling	Mounting mask & Tool	PCB (FR4)	Components	Component Mounting	Frontpanel + mechanic s etc	Material + repro	User Repro cost per card	Relative increase per user for Double price H-free PCB
Readout Unit <sup>a b</sup> (8 layer 9U)	13300	2185	1900	425 (6 pc)	2820	1200 (155 for 100+)	200	4770	5000	<b>8.5 %</b>
Slink I/O <sup>c</sup> (4 layer PMC)	1850	900	1000	100 (15 pc)	160	100	-50	410	450	<b>4.5 %</b>
Slink testgenerator <sup>d</sup> (PMC)	945			100 (5 pc)	180	100	-50	430	450	<b>4.5 %</b>
MCU card <sup>e f</sup> (12 layer PMC)	5900	1460	1480	130 (10 pc)	530	350 100 for 100+)	-50	1060	1100	<b>12 %</b>
Quad MUX <sup>g</sup> Slink (8 layer PMC)	3500	915		71.50 (20 pc)	320	165		560	600	<b>12 %</b>
PCI-FLIC <sup>h</sup>	5777	1400	1870	70 (50 pc)	550	400	20	1040	1100	<b>0.3 %</b>

a.RU Card reference at CERN EP 680 1150 400

b.RU printed circuit: ML8;C15;FR4 24/10;Cu35µm;CMS2;Ni-Au;366.7 x 400mm (9U Fastbus)

c.Slink I/O card reference at CERN: EP-680-1150-500

d.Testcard Reference EP-680-1150-250

e.MCU Card Reference at CERN EP 680 1150 450

f.MCU printed circuit: ML8;C65;FR4 16/10;Cu35µm;CMS2;Ni-Au; 149 x 74 mm (PMC)

g.Quad Mux card EP 680 1150 510, ML4;C14;FR4 16/10;Cu35µm;SLDM2;SLK2;Ni-Au; 149.7 x 74mm Panelised

**PCB factor 2**

**Development cost not accounted**

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# Summary

- Halo-free PCB manufacturing possible (but basically single company so far)
- Factor 2 in PCB price ( expected to come down )
- Ca 5% increase in cost of our cards
- No electrical problems
- Impedance might have to be compensated by slight increase of layer thickness
- Obviously no manufacturing problems
- Stability expected as good as FR4

## Refernces

- *Development of Non-halogenated FR4*, T.Sagara et al., Matsushita Electric works
-