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Front-End electronics for Future Linear Collider W-Si calorimeter physics prototype

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<http://www.lal.in2p3.fr/technique/se/flc>

Introduction : FLC challenges for electronics

■ CALICE = W-Si Calorimeter

- Precision measurements : $\sim 10\%/vE$
 - good linearity (‰ level)
 - Good inter-calibration ($\%$ level)
 - Low crosstalk (‰ level)
- Large dynamic range
 - $0.1 \text{ MIP} \rightarrow 2500 \text{ MIPS} = 15 \text{ bits}$
- Low noise
 - Auto-trigger on MIP ($40,000 e^-$)
- Hermeticity : no room for electronics !
 - High level of integration : « SoC »
 - Ultra-low power : ($\ll \text{mW/ch}$)
- 30 Mchannels

■ « Tracker electronics with calorimetric performance »

FLC 128ch 30*20mm 1 W ?

ATLAS LAr FEB 128ch 400*500mm 100 W

Physics prototype overview

■ Multi-layer (30) W-Si prototype

- Active area : $18 \times 18 \text{ cm}^2$, depth : $24 X_0$
- 30 detector slabs slid into alveolar structure
- *See talk by J.C Brient*

Silicon wafer description

[JC Vanel LLR lab]

■ Matrix of 6x6 pixels of 1 cm²

- Low cost => simple process
- 2 manufacturers :
 - INP Moscow
 - Institute of Physics Prague
- AC coupling on PCB

4" High resistive wafer : 5 K Ω cm

Thickness : 525 microns $\pm$ 3 %

Tile side : $62.0^{+0}_{-0.1}$ mm

Guard ring

In Silicone $\sim$ 80 e-h pairs / micron

$\Rightarrow$ 42000 e⁻ /MiP

Capacitance : $\sim$ 25 pF

Leakage current : 1 – 5 nA

Full depletion bias : $\sim$ 150 V

Nominal operating bias : 200 V

Front-end board

6 active wafers

Made of 36 silicon PIN diodes
216 channels per board
Each diode is a 1cm^2 square

2 calibration switches chips

6 calibration channels per chip
18 diodes per calibration channel
See talk on ATLAS calibration

12 FLCPHY3 front-end chip

18 channels per chip
13 bit dynamic range

Line buffers

To DAQ part
Differential

14 layers
2.1 mm thick
Made in korea

Front-end electronics synoptic

- PIN diode
- 10mm cells

- Variable gain
- High dyn. Range
- Low noise

- dual gain
- 200 ns peaking time
- high linearity

FLCPHY3

- BiCMOS 0.8 μ m
- 18 channels
- Area : 6 mm²
- $V_{SS} = -5V$
- $P_d = 250$ mW
- TQFP64 packg

FLCPHY chip architecture

Chip architecture

- Variable gain preamp ($C_f = 0.2 \rightarrow 3 \text{ pF}$) adapt to several detectors
- Dual gain shaper (G1-G10) -> possible studies with larger (16bit) dynamic range
- Differential shaper and Track&Hold => better pedestal stability and dispersion
- Multiplexed output : 5 MHz

Preamplifier performance : noise

Charge preamp

- Folded cascode, negative output
- « mirror multiplied » feedback resistor, equivalent to 25 MO
- 3000/0.8 μ m PMOS input transistor
- $I_D = 600 \mu$ A bias current, 4mW total
- ENC = 1000e⁻ + 40 e⁻/pF @ $t_p = 200$ ns

ENC measurement of the FLCPHY3 preamp

Noise

- Series : $e_n = 1.6$ nV/√Hz
- $g_m = 8$ mA/V
- $C_{PA} = 10$ pF + 15 pF test board
- 1/f noise : 25e⁻/pF
- Parallel : $i_n = 40$ fA/√Hz

Signal uniformity (G1)

■ Signal (Gain 1, $C_f=1.6\text{pF}$)

- Amplitude = $696 \text{ mV/pC} \pm 18 \text{ mV}$
= $4.66 \text{ mV/ MIP} \pm 2.5\% \text{ rms}$
- Peaking time = $189 \text{ ns} \pm 2 \text{ ns rms}$
- Pedestals = $-3.7 \text{ V} \pm 4.8 \text{ mV rms}$

■ Noise

- $C_d = 0 \text{ pF}$: $V_n = 200 \text{ } \mu\text{V}$
- $C_d = 68 \text{ pF}$: $V_n = 410 \text{ } \mu\text{V}$

■ Crosstalk : < 0.1%

Signal uniformity (G10)

■ Signal (Gain 10, Cf=1.6pF)

- Amplitude = 3147 mV/pC $\pm$ 94
- Peaking time = 174 ns $\pm$ 2 ns
- Pedestals = -3.74 V $\pm$ 8.3 mV rms

■ Noise

- Cd = 0 pF : Vn = 500 μ V
- Cd = 68pF : Vn = 1.6 mV

■ Crosstalk

- < 0.2%

Linearity

■ Measured on all preamp gains

- $C_f = 0.2, 0.4, 0.8, 1.6, 3 \text{ pF}$
- Well within $\pm 0.2 \%$

■ Dynamic range ($G1, C_f=1.6\text{pF}$)

- Max output : 3 V
- linear (0.1%) range : 2.5V
= **500 MIPS @ $C_f = 1.6 \text{ pF}$**
- Noise :
 - 200 μV ($C_d = 0$)
 - 410 μV ($C_d = 68\text{pF}$)
 - = **0.1 MIP @ $C_d = 68 \text{ pF}$**
- Dynamic range : **> 12 bits**
 - 13 000 (14 bits) @ $C_d = 0$
 - 6500 (12 bits) @ $C_d = 68 \text{ pF}$
- Can be easily extended by using the bi-gain outputs

Results with detector

■ Cosmic test bench at LLR

- 1 MIP injected in channel 9
- Calculation : 4.97 mV
- Measurement : 5.05 mV
- Well visible above the noise

■ MIP signal with ^{90}Sr source

- *See talk by J.C. Brient*

■ Readout boards

- Developed by UK group
[P. Dauncey Imperial college]

Next steps

R&D on technological prototype

- Larger dynamic range : 3000 MIPS (16 bits)
- Lower power : $\sim 100 \mu\text{W}/\text{ch}$, Autotrigger mode
- See also talk by D. Strom et al.

Next steps : technological prototype

Pending questions

- What **technology** to target for 2010-2020?
- What about **signal integrity** on a 16bit mixed-signal chip ?
- When to digitize ? Can we have **1 ADC /channel** ?
- What **(low) power** level can be reached ?

Evolution of technology feature size

Embedded readout ASIC

Signal integrity on mixed-signal ASICs

Conclusion

■ FLCPHY3 chip fulfills FLC Wsi testbeam prototype

- Low Noise : $4000e^- = 0.1 \text{ MIP}$
- Maximum signal : 600 MIPs
- Linearity : 0.1%, crosstalk 0.1%
- Low pedestal dispersion : 4.8mV rms = 1 MIP
- Can fit other detectors (variable gain 0.2-3pF, bi-gain G1-G10 shaper)

■ 1000 chips have been produced for 2004-2005 testbeam

■ Next steps

- Low power developments for technological prototype
- New chip in SiGe $0.35\mu\text{m}$ with Idle mode
- Trying to integrate the ADC...