Analog Signal Processing on ASIC: Noise Analysis

Calorimeter Meeting, September 2009

Outline

- I. Signal shape
- II. Preamp
 - (i) Current mode
 - (ii) Voltage mode
- III. Integrator
 - (i) Delay line and integrator
 - (ii) Gated integrator
- IV. Pedestal subtraction
- V. Conclusions

Introduction: Specifications

- Luminosity increase
 ⇒ Avoid PMT ageing
 ⇒ PMT decreased by a factor 4-5
- ⇒Main implication: preamp input equivalent noise must be decreased.

	Value	Comments	
Energy range	0-10 GeV/c (ECAL) Transverse energy	1-3 Kphe / GeV Total energy	
Calibration	4 fC /2.5 MeV / ADC cnt	4 fC input of FE card: assuming 25 Ω clipping at PMT base 12 fC / ADC count if no clipping	
Dynamic range	4096-256=3840 cnts :12 bit	Enough? New physic req.? Pedestal variation? Should be enough	
Noise	<»1 ADC cnt or ENC < 5 -6 fC	< 1 nV/öHz ?	
Termination	50 ± 5 Ω	Passive vs. active	
AC coupling	Needed	Low freq. (pick-up) noise	
Baseline shift Prevention	Dynamic pedestal subtraction (also needed for LF pick- up)	How to compute baseline? Number of samples needed?	
Max. peak current	4-5 mA over 25 Ω	50 pC in charge	
Spill-over correction	Clipping	Residue level: 2 % \pm 1 % ?	
Spill-over noise	« ADC cnt	Relevant after clipping?	
Linearity	< 1%		
Crosstalk	< 0.5 %		
Timing	Individual (per channel)	PMT dependent	

- Skin effect:
 - As the frequency of AC current is higher, its current density over a cable is higher on the surface and lower in the core: $f\uparrow \rightarrow R\uparrow$
 - Skin effect losses introduce a long tail in the step response of the cable so part of the signal is delayed and does not contribute the shaped output signal
 - As resistance increases so does the noise
- The skin noise effect is computed using a lumped resistor approximation at the central frequency of the signal (shaping time).
 - Valid provided that shaping time is much shorter that propagation delay in the cables.
 - Exact computations of the noise should be performed to validate this approximation.

For long cables and high frequency $|Z| \approx Z_o$ del cable



I. Signal shape

- Digitized by hand (using TDR figure)
- In simulations: double exponential aprox



 $t_1 = t_2$ $\tau_1 = 5ns$ $\tau_1 = 10ns$

 $V(t) = K \left(1 - e^{\frac{t - t_1}{\tau_1}} \right) - \left(1 - e^{\frac{t - t_2}{\tau_2}} \right)$

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II. Preamplifier

- Cable coupled amplifier (ATLAS LAr style)
- Common gate with double feedback
 - Inner loop to reduce input impedance preserving linearity and with low noise
 - Outer loop to control the input impedance accurately
- Transimpedance gain is given by RC1

$$Z_i(j\omega) \approx \frac{\frac{1}{g_{m1}}}{G} + R_{C1} \frac{R_1}{R_1 + R_2}$$

- Noise is < 0.5 nV/ JHz
 - Small value for R_1 and R_2
 - Large g_{m1} and g_{m2}



II. Preamplifier

For detailed calculations, see David's <u>talk</u> (Calorimeter Electronics Upgrade Meeting 2/6/2009).

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- Current mode: - PSD of input referred mode: $i_{ni}^{2} = i_{ni}^{2}\Big|_{e_{i,Re}} + i_{ni}^{2}\Big|_{e_{n}} + i_{ni}^{2}\Big|_{i_{n}} + \operatorname{cov} \dots$ - Assumption: cable seen as Z_{0} from the preamplifier side HF - $i_{ni}\approx15pA/JHz$ ($R_{c}=25\Omega$, $R_{s}=25\Omega$, $e_{n}=0.9nV/JHz$, and $i_{n}=10pA/JHz$) - PSD at the output $e_{no}\approx7nV/JHz$ • Transimpedance gain $Z_{T}=500\Omega$
 - Voltage mode: - PSD of input referred mode: $e_{ni}^2 = e_{ni}^2 \Big|_{e_{tRc}} + e_{ni}^2 \Big|_{e_{tRT}} + e_{ni}^2 \Big|_{e_n} + e_{ni}^2 \Big|_{e_n} + e_{ni}^2 \Big|_{e_n} + e_{ni}^2 \Big|_{e_n}$
 - e_{ni}≈1.2nV/√Hz
 - PSD at the output e_{no} ≈12nV/JHz
 - Gain G=10, equivalent to transimpedance gain $Z_T = 500\Omega$ since $Z_T/Z_i = G$

II. Preamplifier

• Noise in current preamplifier is 50 to 100% smaller...



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III. Integration: Delay Line Integrator and Switch



III. Integrator: Comparison



- It is a correlated sampling method
- For white noise, T> Δ T, T<<T_f and Δ T<<T_f

$$\sigma_{noT}^2 = \left(\frac{1}{\tau_i}\right)^2 e_{ni}^2 \Delta T$$

- => Independent of the correlated sampling time T (if T>∆T)
- Comparing with integrated noise before CDS:

$$\sigma_{no DLInt}^{2} = \frac{1}{2} \left(\frac{1}{\tau_{i}}\right)^{2} e_{ni}^{2} \Delta T$$

=> CDS increases noise by factor √2

- Reduces LF noise (correlated for t>>T)
- BUT increases uncorrelated noise!



Conclusions

- Select the current over the voltage amplifier; noise is about a factor 1.5-2 higher
- Numbers my present a 10-20% error
 - Effect of lumped resistor modelling skin effect
 - Systematic for all (comparison does not have this error)

	Integrated noise [uV rms] (10 Hz to 1 GHz)	Noise in ADC counts
Switch INT (Calc)	210	0.5
Switch INT (Tran Sim)	200	0.63
DL INT (SIM)	210	0.5
DL INT with R _g noise (Sim)	1100	3
CDS + Switched Int (Calc)	300	0.75
CDS + Switched Int (Tran Sim)	300	0.75
CDS + DL Int (Sim)	300	0.75
CDS + DL Int With R _g noise (Sim)	330	0.82

- Delay line integrators are equivalent:
 - Although delay line presents extra noise due LF noise after delay line subtraction and before integration.
 - Only adds 10 %-20% after pedestal subtraction
- Pedestal subtraction is essential
 - It attenuates LF noise
- However correlated sampling increases uncorrelated noise
 - Intrinsic resolution is degraded by a factor v2
 - Multiple correlated sampling is often used to avoid this
 - Cannot oversample (ADC and digital get too complicated)
 - Discrete processing through switched capacitor circuits?
- So far we have discussed mainly intrinsic resolution:
 - Pedestal subtraction is crucial to remove LF pick up noise
 - Differential circuitry might be needed:
 - Aiming for low noise
 - Card with (a lot!) of digital electronicse

Plans

Baseline solutions

- Pursue two different (and complementary) schemes for the moment:
 - Optimize discrete solution made with Op Amps (Carlos)
 - Clipping in the FE card
 - Robust and relatively short development time
 - Study an integrated solution aiming for lowest noise possible
 - Current mode input
 - Fully differential circuitry
 - Clipping in the PM base is assumed

Further refinements

- Although clipping in the PM base is assumed for ASIC
 - Uncertainties on average current and PM ageing still high
 - Thinking about a method to perform integrated clipping could be useful
 - Gaussian shaping? (see backup slides)
 - Integrated delay line (all pass filters)?
- A method to implement a correlated sampling without uncorrelated noise increase would help

- Sampled (switch capacitor) system?