LAUROC1
Liquid Argon Upgrade Read Out Chip
LAUROC or l’AUROCH?

- **LAUROC**: liquid Argon Upgrade Read Out Chip
- **Aurochs** [ˈɔːrɒks]: extinct species of Wild Ox
- Strong and bullish
- [Astérix en Hispanie]
- Suggested by Claude Colledani!
New design to speed up the digitization up to 40MHz and remove analog memories and obsolete components

Replace preamps and shapers (and ADCs, SCAs, Glink…)

Hybrid preamps used (0T configuration) → precise input impedance

- Very low noise (~0.4 nV/√Hz)
- Large supplies -6 +12 V
- Some precision components and uF capacitors

Shapers used AMS 1.2um BiCMOS
Preamplifier requirements

- Precise input impedance: $Z_{in} = 50 \, \Omega$ (Front) or $25 \, \Omega$ (Middle/Back) to terminate the cables from the detector

- Low noise < 10 $\, \Omega$, with $C_d = 400$ pF (Front) or 1.5 nF (Middle/Back)

- Current sensitive configuration (large $C_d$, long duration signal) $t_p = 50$ ns
  - $\text{ENI}^2 = \alpha \frac{e_n^2 C_d^2}{t_p^3(\Delta)} + \beta \frac{i_n^2}{t_p(\Delta)}$ where $\Delta$ is a triangle
  - 0T50 400pF: ENI@50ns=55nA, 0T25 1.5nF: ENI@50ns=150nA
  - Spec : < 120 nA for 50 $\, \Omega$ and ENI < 300 nA for 25 $\, \Omega$ (pileup dominating at HL LHC)

- Dynamic range:
  - Front 50 $\, \Omega$ : from 50 nA noise up to 2 mA = 40 000 or 15.5 bits
  - Middle and back 25 $\, \Omega$ : from up 200 mA to 10 mA = 50 000 or 16 bits

- Radiation resistance : $\sim 1$ Mrad

$\rightarrow$ “Universal” preamplifier with selectable dynamic range and input impedance (25/50 Ohm)
LAUROC0 overview

- Integrates 8 channels with variants of preamp: PA 25 and 50 Ohms as well as a preamp 25-50 for which Zin can be selected by SC

- Preamp Input impedance
  - Super Common Gate: low input impedance
  - Fine tuning of Zin (±5%) possible with C2

- Noise:
  - Amplifier = low noise voltage sensitive
  - “Electronically cooled” resistor

- HG and LG outputs available:
  - Discriminator at the output of the LG PA used to short $R_f$ and to avoid saturation of the HG

  ⇒ This system generates some non linearity
  ⇒ Lauroc1 built around this preamp “PA_25_50” but wo the discri system (= wo the HG output)
- Input transistor = 1V NMOS transistor, 3000 μm/ 0.25 μm
- Cascode trans: 2.5V NMOS transistor
- Dynamic range adjustable by R0
- Input impedance adjustment by Cf (8 bits)
- Possibilty to tune the current that flows in the input preamp
  - ibo_pa can be set to 2.5 mA or 5 mA using SC parameter
  - R_bleed: can add 6 mA using SC parameter
LAUROC1 overview

- 4 channels using the preamp_25_50 of Lauroc0 (Zin tuneable by SC)
  - Channel 1, 2 and 3: LG preamp followed by one CRRC2 HG shaper and one CRRC2 LG shaper
  - Channel 4: conservative channel using the discriminator and HG and LG PA for comparison

- Preamps followed by CRRC2 shapers built around an amplifier: designed by Mietek Dabrowski @BNL
  - \( T_o \) tuneable between 1.25 ns and 20 ns
Impedance flat from 10 kHz to 100 MHz < 1 Ω variation versus current due to Super Common base Zin variation

\[ Z_{in} = R_0 + Z_{in \, SCB} \]

\[ G = \frac{C_1}{C_2} = -3, \quad R_0 = 100\Omega \]

\[ Z_{in \, SCB} = \frac{g_{m1}}{140} = \frac{270@10\mu A}{140} = 2\Omega @200\mu A \]

\[ \Delta Z_{in} = 2\Omega/4 = 0.5\,\Omega \]
HG 25 Ω PA: Equivalent Output Noise

Gain at the output of the preamp = $1K/25=40$

⇒ Input Noise:
18.4 nV/40 = 0.46 nV/√Hz or 13 Ω

series noise 18.4 nV/√Hz

$\frac{4kT R_0}{(1+|G|)^2}$ with $G=-3$

$R_0=100 \ Ω \Rightarrow$ Equ. Noise: 0.32 nV/√Hz or 6.25Ω

// noise dominated by
$R_I=1K \ (51\%)$
$R_{deg}=15K \ (26\%)$

Series noise:
$R_0=100 \ (43\%)$
NMOS ampli (24%)
NMOS SCB amp (8%)

$\Rightarrow$ Gain at the output of the preamp = $1K/25=40$

$\Rightarrow$ Input Noise:
18.4 nV/40 = 0.46 nV/√Hz or 13 Ω
2 setups:
Omega testboard (characterization)
LAL/BNL setup= Injection board (Toy cal. board)+ external Pulser (Large Pulse) + DUT + ADC

Measurements performed on scope and using the full chain (with ADC)

The chip size is 2.8 mm x 2.5 mm.
Packaged in a LQFP 100 14*14 package.
LAUROC1 measurements: Zin vs C2 uniformity and vs freq.

Specification: Zin tunable, 25 ± 2.5 Ω and 50 Ω ± 5 Ω up to 20 MHz

Zin vs C2 (9 bits, LSB = 31.6 fF) for 3 channels
Specifications

Linearity

INL < ±0.2% on High Gain output
INL < ±0.5% on 80% of Low Gain dynamic range
INL < ±3% on the full dynamic range

HG

HG/LG ratio = 24

LG

INL < ±0.1 %
LAUROC1 50 Ω 2 mA config: Linearity measurements

Specifications
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Linearity
INL < ±0.5% on 80% of Low Gain dynamic range
INL < ±3% on the full dynamic range

HG
Linearity channel 1hg

HG/LG ratio = 23

LG
Linearity channel 1lg

Specifications
HG/LG ratio = 23

INL [%]

Pct 5%-100% [%]

injected current [mA]

gain = 20739.16 mV/mA

gain = 898.84 mV/mA

CdLT LAUROC TWEPP 2019
XTk (differential) between channels : 25 Ω 10 mA config

Injection of 400 µA in ch1, Xtk in Ch 2 and Ch3. Cd= 1.5 nF on all channels

Ch1: HG diff output @ 400 µA

Ch2: Differential signal (HG)

Ch3: Differential Xtk (HG)

Xtk < 0.2 %

Specification:
Cross-talk < 0.5%

Ch1: HG diff output @ 400 µA

Ch1: Differential LG signal

Ch2: Differential Xtk (LG)

Ch3: Differential Xtk (LG)

Xtk < 0.07 %
ENI vs tp 5-100% (injection of LArg pulses)

Specification:
< 300 nA @ tp 5-100% = 50 ns, Cd=1.5 nF for 25 Ω config
< 120 nA @ tp 5-100% = 50 ns, Cd= 330 pF for 50 Ω config

LAUROC1 noise: below specification but larger than expected by 20%
Series noise as expected : $e_n = 0.45 \, \text{nV}/\sqrt{\text{Hz}}$  
$C_{tot}=36 \, \text{pF}$ and parallel noise negligible, even with leakage current

But large 1/f noise (400 e-)
Attributed to dielectric noise in input $C_1=30 \, \text{pF}$ MIM capacitor (goes as $4kT\omega \tan\delta$): $\tan\delta$ of SiO2= 0,002 => 278 e-

Special channel added in LAuroc2 with external capacitor for $C_1$ to prove it definitively
Series noise input transistor

3000/0.25 µm transistor at $I_D=4\ mA$
Measurement = $2 \times $ theory
Simulation < theory !

New layout with minimized bulk contribution
Measured noise now at 0.36 nV/√Hz
close to calculations = 0.3nV (0.56nV before)
Difference corresponds to 0.2 nV/√Hz ~ 2 Ω
• LAUROC1: Low noise input preamp measured alone as charge preamp followed by external variable CRRC$^2$ shaper. $C_f = 1$ pF
  – All current sources switched off: preamp biased externally by external RL
  – Noise expected: $\text{ENC} = 174 \frac{e_n C_{\text{tot}}}{\sqrt{t_p}} (\delta) \oplus 166 i_n \sqrt{t_p} (\delta)$
  – Parallel noise due to $R_f = 5$ M and leakage current, measured $I_G = 10$ nA
PAC ENC measurement @ Id=4mA

- Good agreement for series noise: $e_n = 0.45 \text{nV}/\sqrt{\text{Hz}}$, $C_{tot}=36 \text{ pF}$
- Parallel noise negligible, even with leakage current
- But large unexpected 1/f noise (400 e-)
- At ATLAS shaping ($t_p = 30 \text{ ns}$) 1/f increases noise by ~20%

![Graph showing ENC vs. shaping time]

ENC = $174 e_n C_{tot}/\sqrt{t_p (\delta)} \oplus 166 i_n \sqrt{t_p (\delta)}$
1/f noise origin

- 1/f can originate from the 2 transistors or the MIM cap
- Negligible 1/f measured on input transistor
- 1/f at the same level on CH4 which does not have 2.5V cascode
  \[ \Rightarrow \text{remains dielectric noise in the MIM input capacitor} \]

- Confirmed by measurement at small and large currents which shows 1/f unchanged
  - At 1 mA series noise plotted \( e_n = 0.6 \text{ nV/√Hz} \)
  - At 8 mA \( e_n = 0.35 \text{ nV/√Hz} \)
- ENC CH4 (1 V cascode)
- Input transistor alone (from previous run)
- Dielectric noise is parallel noise going as $4kT \omega C \tan \delta$
- $\tan \delta$ of SiO2= 0,002 => 278 e-, not far from the 320 e- given by the fit
Noise summary

- Noise measurements on preamp alone show good agreement with theoretical noise

- Series noise:
  - \(e_n = 0.6 \text{ nV/}\sqrt{\text{Hz}}\) @ 1 mA
  - \(e_n = 0.45 \text{ nV/}\sqrt{\text{Hz}}\) @ \(I_d = 4 \text{ mA}\)
  - \(e_n = 0.35 \text{ nV/}\sqrt{\text{Hz}}\) @ \(I_d = 8 \text{ mA}\)
  - Total capacitance 36 pF: 10% parasitics in MIM + input transistor

- Parallel noise:
  - \(i_n = 0.09 \text{ pA/}\sqrt{\text{Hz}}\) due to \(R_f = 5 \text{M}\) and 10 nA gate leakage current
  - Larger than expected but still negligible

- But large 1/f contribution
  - Independent of drain current or cascode type
  - Not seen on input transistor alone
  - Attributed to dielectric noise in input 30 pF MIM capacitor (goes as \(4kT\omega\text{Ctan}\delta\)): \(\tan\delta\) of \(\text{SiO}_2 = 0.002\) => 278 e-, not far from the 320 e- given by the fit

  - Increases series noise by \(~20\%\)
  - Would need a special channel with external capacitor to prove it definitively
LAUROC conclusion

• Good performance for impedance matching and linearity
• Noise models were wrong for large transistors and large current: go back to BSIM3 model [J. Kaplon]
• Non negligible 1/f noise attributed to MIM caps
• Interesting design lower noise at BNL with fully differential amplifier [ALFE M. Dabrovski et al.]
• Final versions of LAUROC and ALFE submitted in sept.

• ATLAS at USC:
Waveforms

Lauroc1 status 3 October 2018

Low gain PA
HG shaper outputs
LG shaper outputs
LG_Preamplifier_25_50, followed by a low noise amplifier with a gain=20 for the HG path
=> Shaper noise negligible

**Dynamic range of the 25 Ω preamp tuneable by SC: 5 mA or 10 mA**

- Cload ADC= 20 pF
- Simulations @ T=15 ns
- Ratio HG/LG ≈ 25

- **LG_preamplifier 25 Ω with a dynamic range of 5 mA (tuned by SC), Cd=1.5 nF**
  - HG path: 250 μA give ± 983 mV, tp= 46.5 ns and ENI= 167 nA
  - LG path: 5 mA give ± 988 mV, tp=46 ns

- **LG_preamplifier 25 Ω with a dynamic range of 10 mA (tuned by SC), Cd=1.5 nF**
  - HG path: 500 μA give ± 930 mV, tp= 46 ns and ENI= 220 nA
  - LG path: 10 mA give ± 920 mV, tp= 46 ns

- **LG_preamplifier 50 Ω with a dynamic range of 2 mA, Cd=400 pF**
  - HG path: 75 μA give ± 945 mV, tp= 48 ns and ENI= 53 nA
  - LG path: 2 mA give ± 923 mV , tp= 46 ns
2 power domains well separated: \( vdd_{\text{pa}} = 2.5V \) (total= 100 mA) and \( vdd_{\text{sh}} = 1.2V \) (total=125 mA)

- QFN or QFP 128 pins
- Same pinout for HEC, ALFE and LAUROC ASICs
- Pad ring of Lauroc available on LARg SOS server
- Final ASIC: should be in BGA package
• Input impedance \( R_{in} = R/(N+1) \)
• Resistor noise \( 4kT/R << 4kT/R_{in} \)
• Very stable termination \((R, N \text{ indep. of signal current and active components})\)
• Fully-differential output