A New Floating Point Readout Chip for CMS Calorimeters

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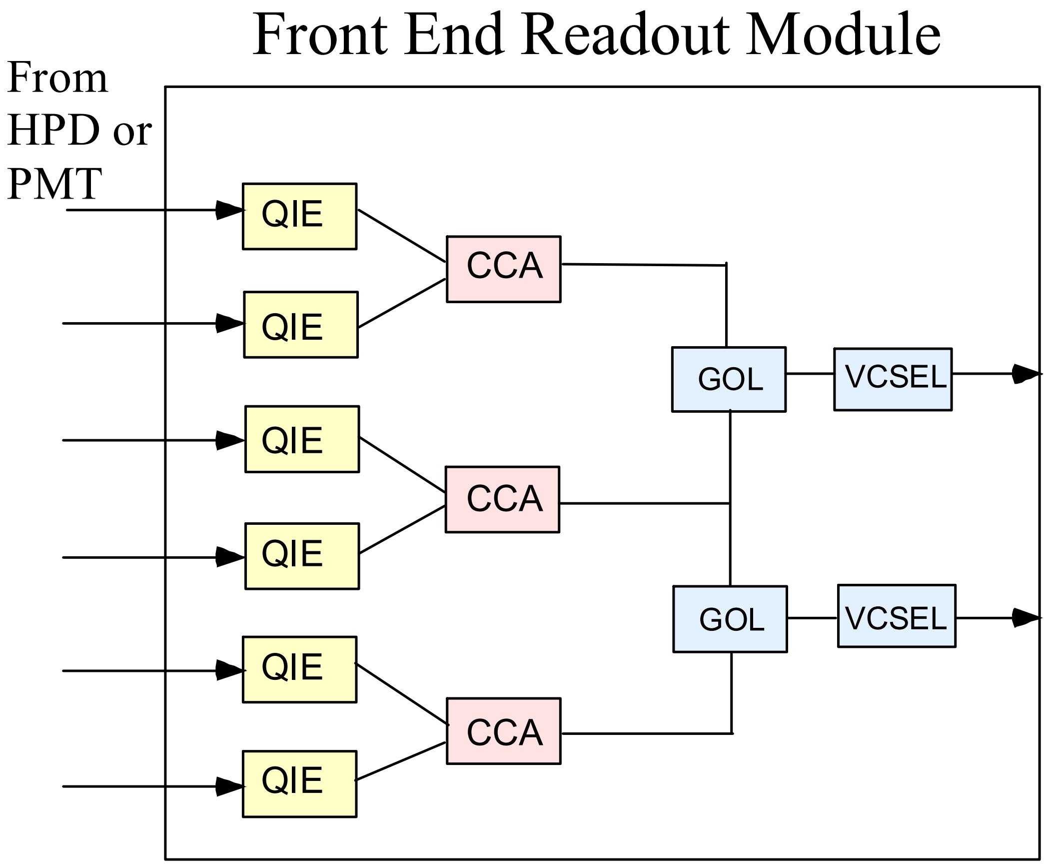
Introduction

- The Floating Point Readout Chip for CMS Hadron Calorimeters is the latest in a series of QIE chips designed at Fermilab for processing signals. It is called QIE8.
- QIE stands for Charge (Q) Integrator and Encoder.
- A QIE is a custom integrated circuit that accepts a signal from a source such as a PMT or HPD and digitizes the signal.

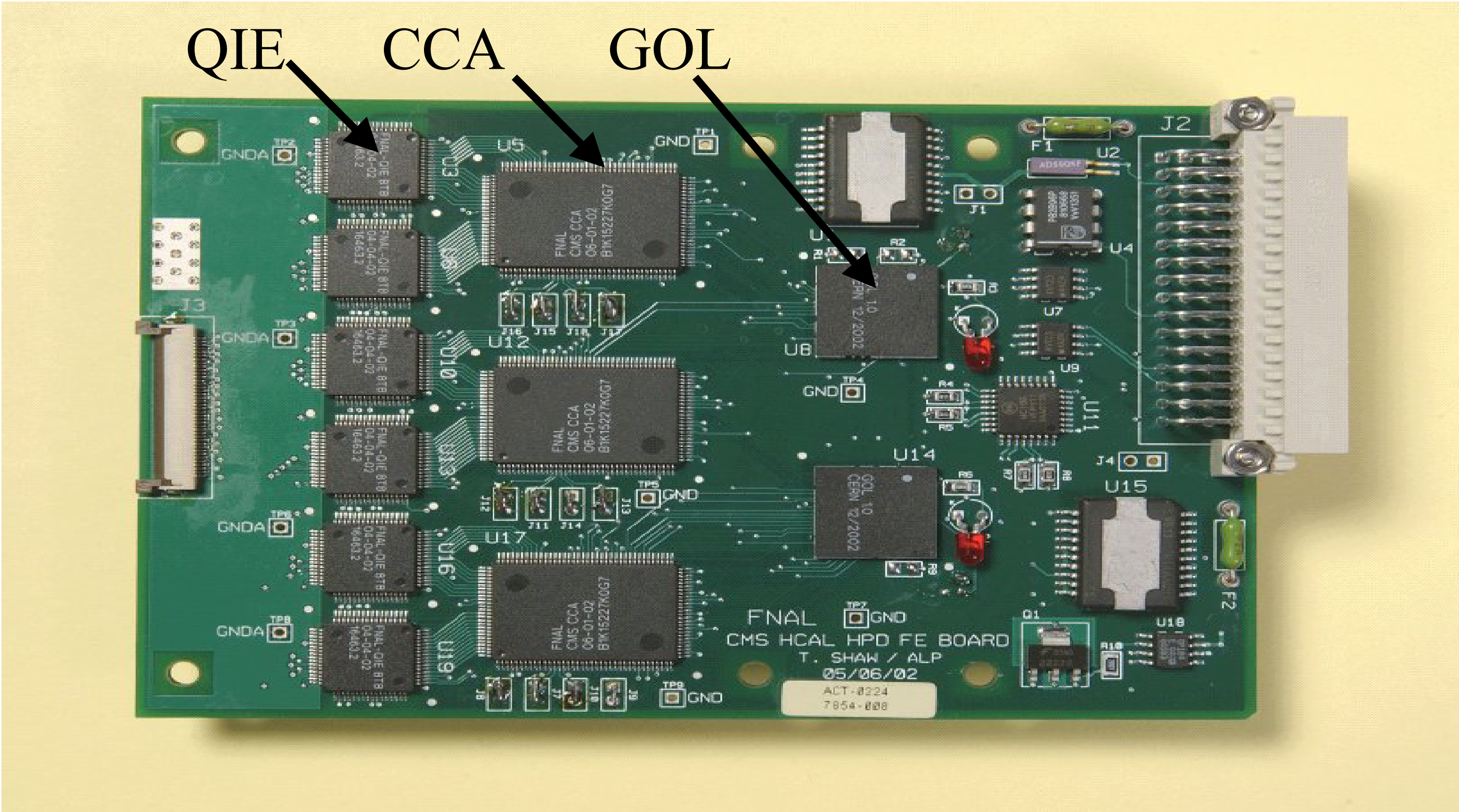
CMS Hadron Calorimeter Front End Readout Module

- Two QIE8 chips interface to each CCA (channel control ASIC) chip

  (See LHC 2002)
- The CCA sends control signals to the QIE8 and accepts data from the QIE8.
- 3 CCAs feed data to 2 GOLs



Hadron Calorimeter Front End Module

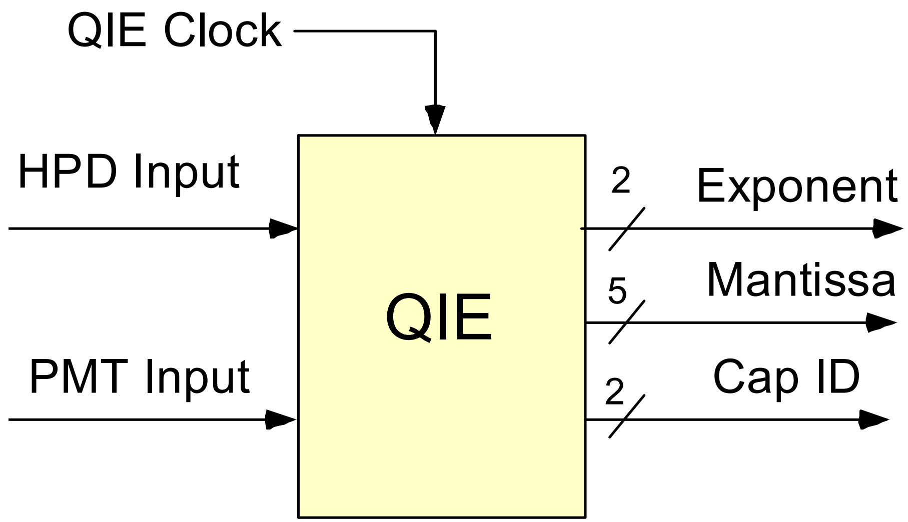


QIE8 Chip Development

- QIE8 designed in AMS 0.8 μm BiCMOS process.
- First version of chip had a major problem in that operation at 40 MHz was marginal at best.
- Problem traced to poor model of P-channel devices.
- AMS later acknowledged problem and provided new models.
- Second version of the chip was redesigned for different PMOS models and included significant layout changes needed to achieve desired performance.
- The second version was the production order!!

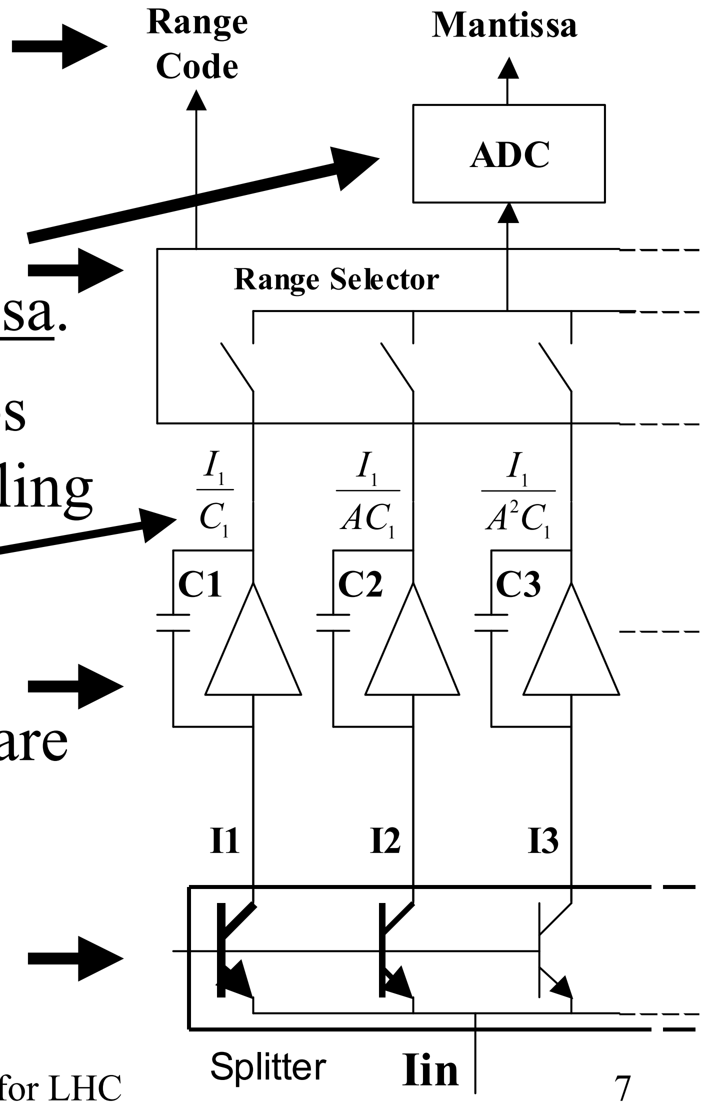
QIE8 Basics

- **QIE8 can be programmed to accept either positive (PMT) or negative (HPD) input charge by powering the appropriate input.**
- **QIE8 operates in a 4 step pipeline mode.**
- **QIE8 digitizes input signal over a wide dynamic range and provides the necessary resolution for CMS.**
- **The QIE8 has an embedded non-linear 5 bit FADC.**
- **The data is output as a 2 bit exponent and 5 bit mantissa along with the time slice information, which is referred to as Cap ID.**



The QIE in a Nutshell

- 5) The range code forms the exponent.
- 4) For a given input charge, one appropriate range output is selected and digitized by an ADC, forming the mantissa.
- 3) Splitter ratios and integration C ratios are chosen to achieve range-to-range scaling of the transfer gain (I/C) by factor ***A***.
- 2) Each splitter range output feeds a charge integrator. The current fractions are integrated simultaneously on all ranges.
- 1) Input current pulses are divided into weighted fractions by a current splitter



QIE8 Specifications

Resolution = 2%
Q_{MAX}/Q_{LSB} = 10,000 (>13 bits)
Beam crossing time = 25 nsec
ADC DNL (small signals) <0.05 LSB

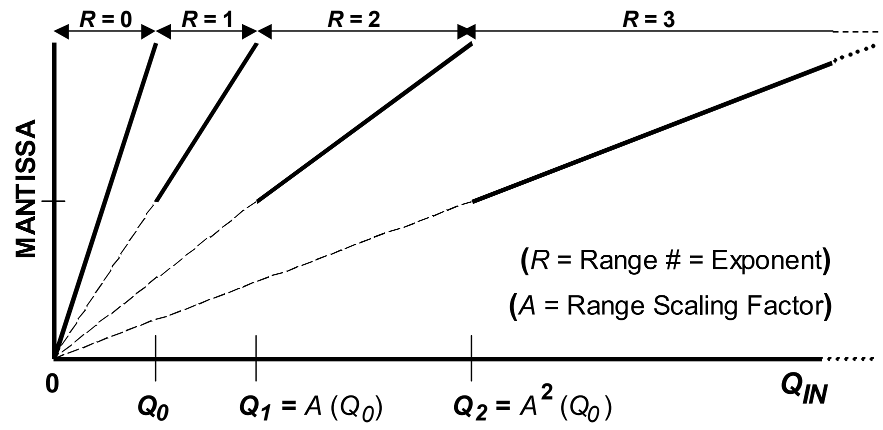
- HPD (positive) input
  - Q_{LSB} = 1 fC (normal mode)
  - Q_{LSB} = 0.33 fC (cal. Mode)
  - Input impedance < 40 Ω
  - Input analog BW > 20 MHz
  - ENC (C_{in} = 30 pF) <0.5 fC
- PMT (negative) input
  - Q_{LSB} = 2.7 fC (norm mode)
  - Q_{LSB} = 0.9 fC (cal. mode)
  - Input impedance = 50/93 Ω
  - Input BW > 40 MHz
  - ENC (5m, 50 Ω cable), 2fC

Design Challenges

- Custom FADC with very low DNL
- Mixed mode analog/digital design
- Must respond to positive and negative inputs.
- Single power supply for easy operation
- Controlled impedance inputs
- High sensitivity inputs (1 fC/LSB for HPD)
- Very high sensitivity calibration mode (1/3 fC/LSB to track detector response shifts from radioactive source (200 e).

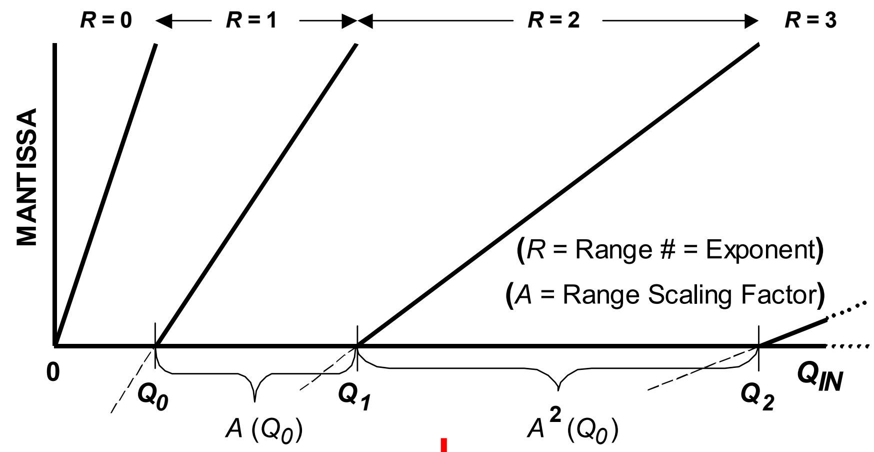
QIE8 Uses A Modified Floating Point Design

If range integrators **not** offset:
all ranges intersect at the origin



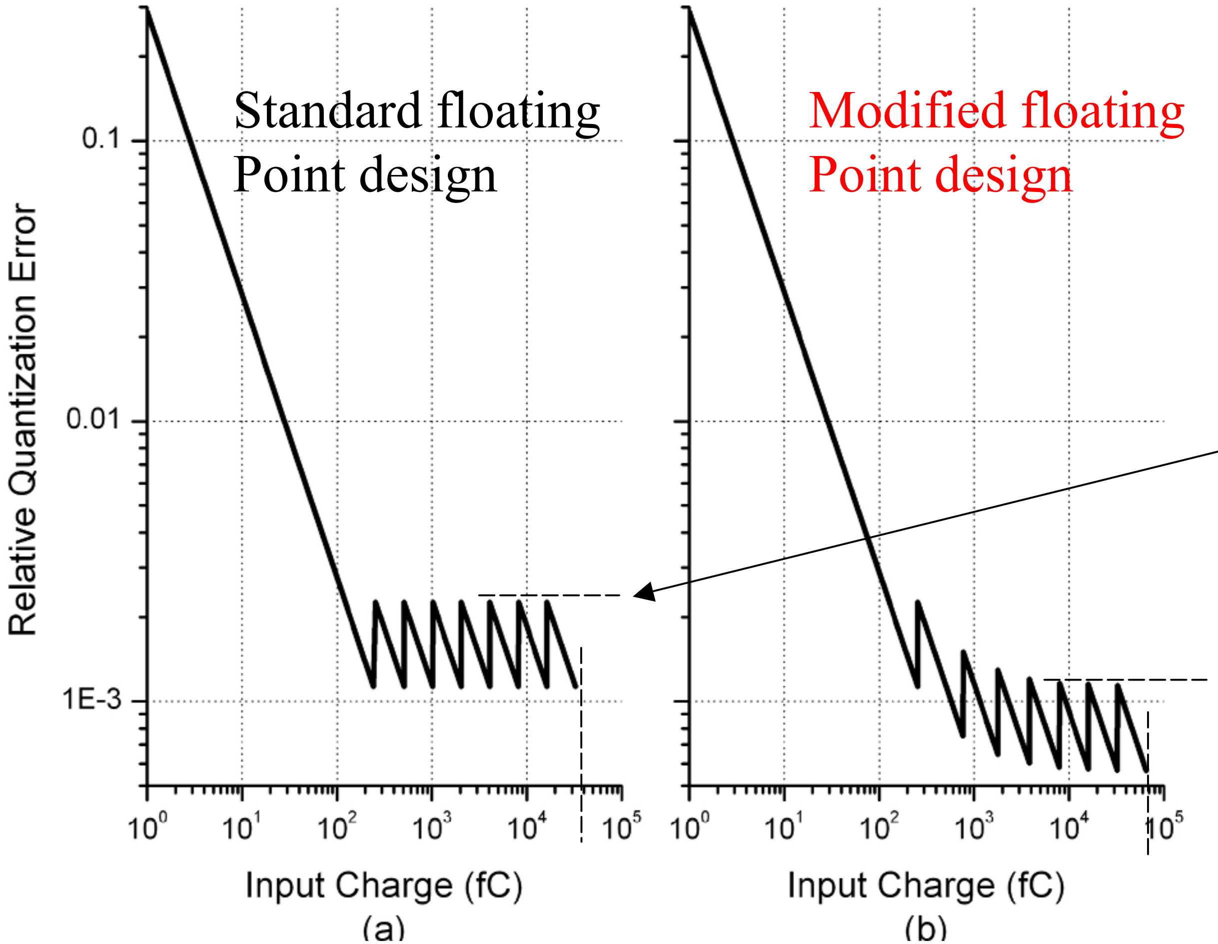
A = 2: standard floating point
(All ranges except the lowest use half the ADC span)

QIE scheme:
Range integrators are offset



"**Modified**" floating point format
More efficient: each range uses the full ADC span)

Resolution (Relative Quantization Error)



Example:

$A = 2$

$N = 8$ bits

$Q_{LSB} = 1\text{fC}$

8 ranges

$$e_{qr\max} \approx \frac{1}{(\sqrt{12})2^{N-1}}$$

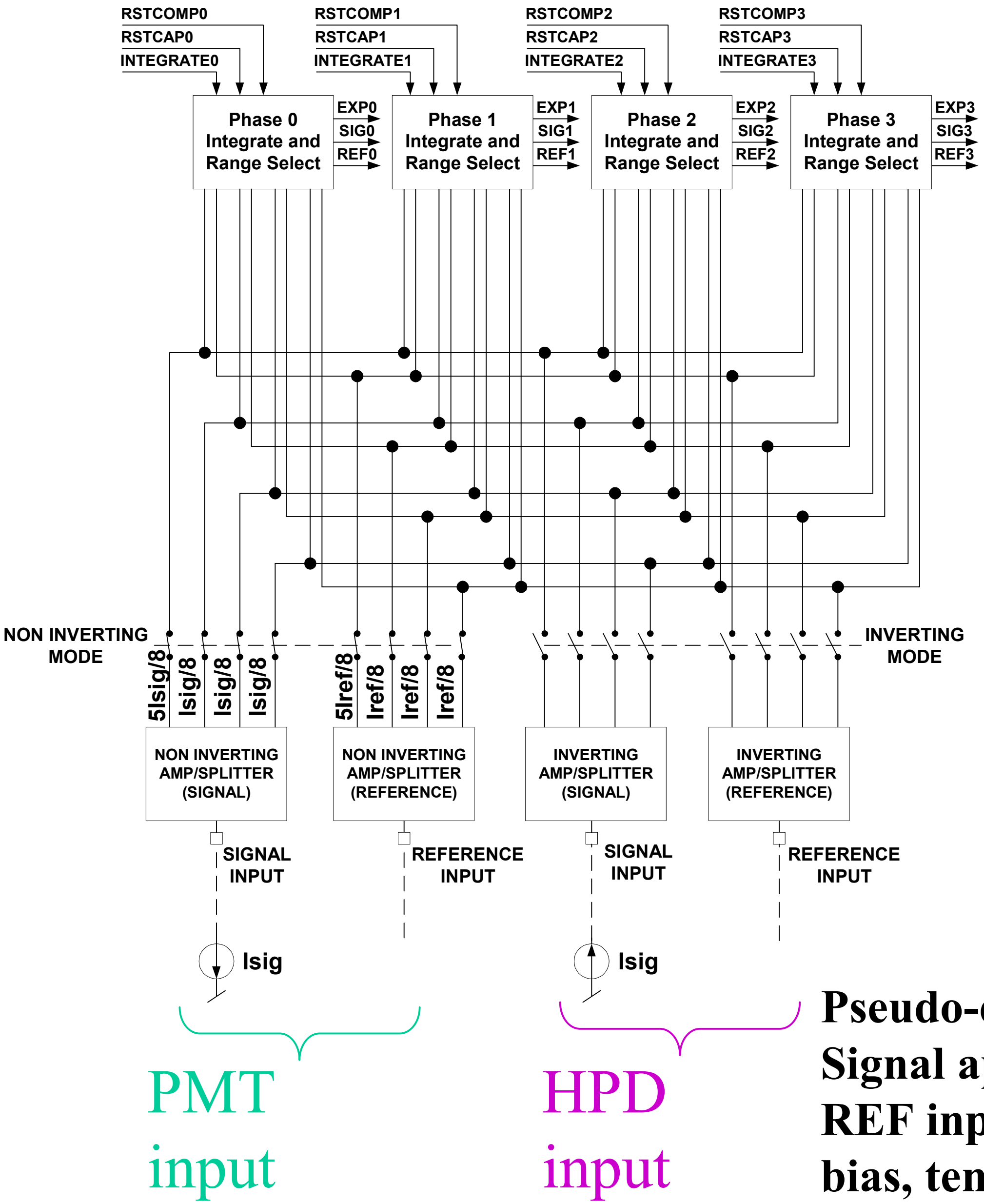
$$e_{qr\max} \approx \frac{1}{(\sqrt{12})2^{N}}$$

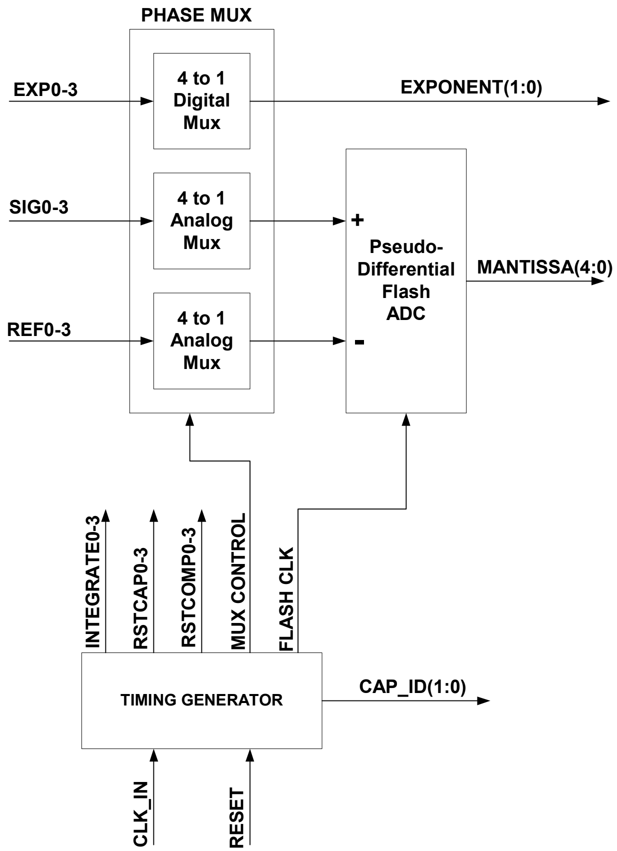
Modified floating point with $A = 2$: 2x smaller error, 2x more range!

Design Strategy

- In order to have a sensitive and fast input, the number of transistors in the input splitter needs to be minimized.
  - To reduce the number of transistors, use fewer ranges (which requires a larger range scaling factor, A)
  - Choose 4 ranges (5:1:1:1 splitter ratio) and range scaling A = 5
  - Perform range scaling mostly with integration capacitor ratios instead of current splitter ratios.
- Number of ADC bits
  - Uniform ADC requires 6 bits to meet resolution requirement
  - A non-uniform ADC can achieve same resolution with only 5 bits
  - Use 5 bit non-uniform ADC
    - To reduce bits in data output.
    - To simplify ADC design (fewer comparators)

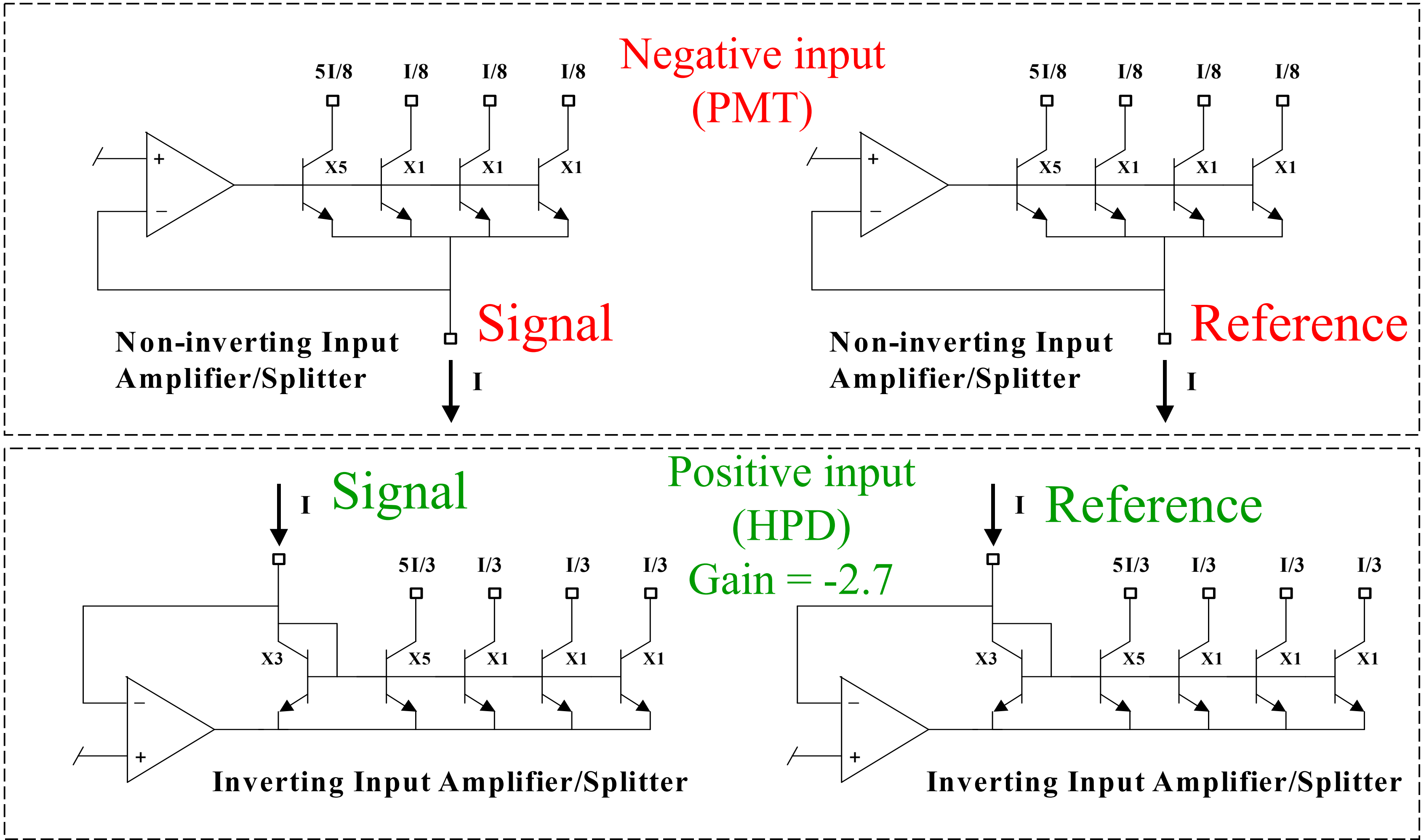
Block Diagram





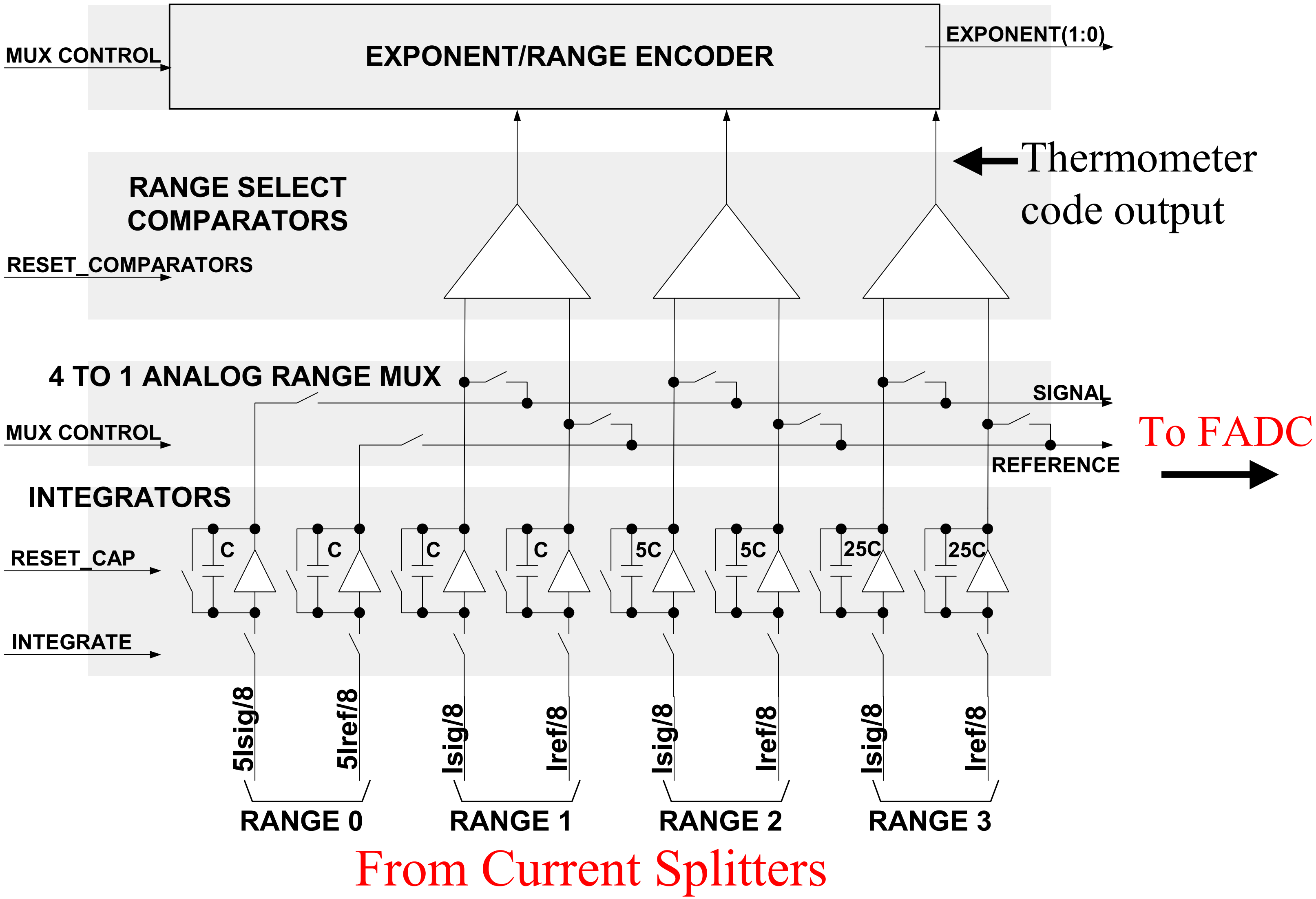
Pseudo-differential QIE configuration: Signal applied between SIG input and ground, REF input is "dummy." QIE insensitive to bias, temp, supply V, common mode noise

Different Input Amps for PMT and HPD

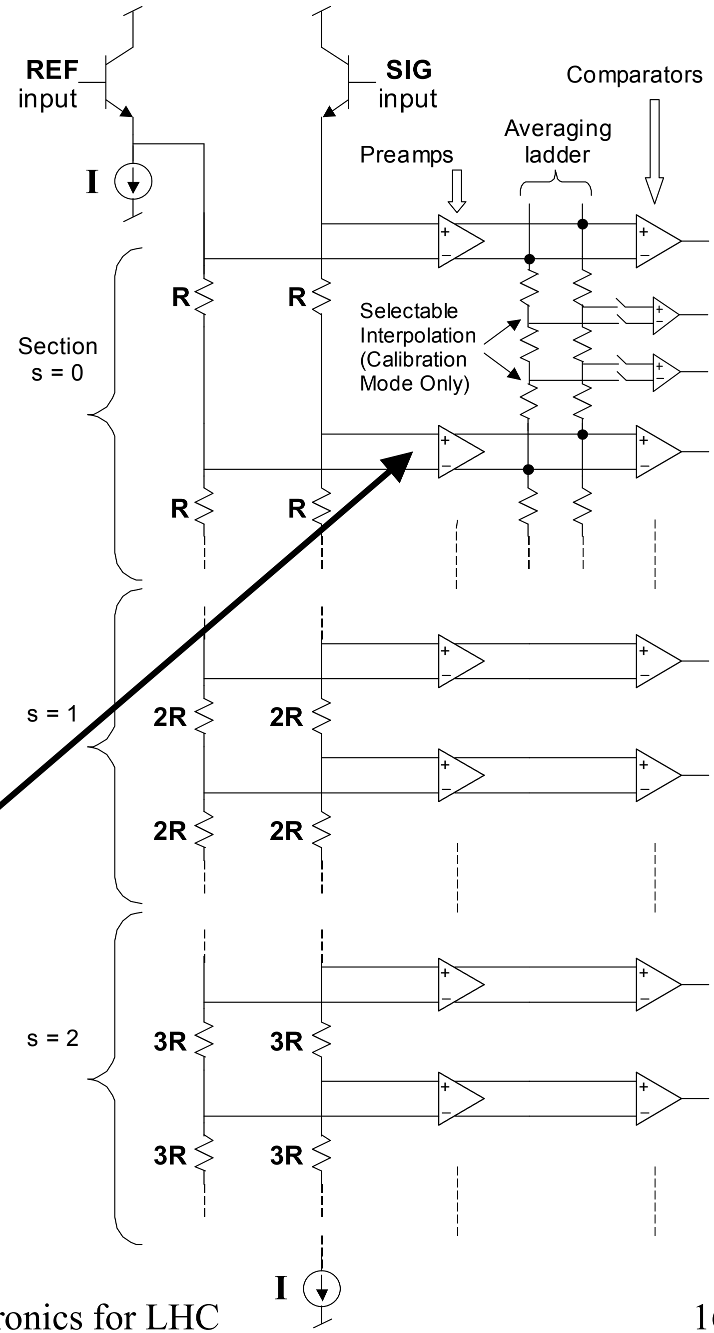


Note: a 4 range (5:1:1:1) splitter uses only 8 transistors

Integrators and Range Select Circuits



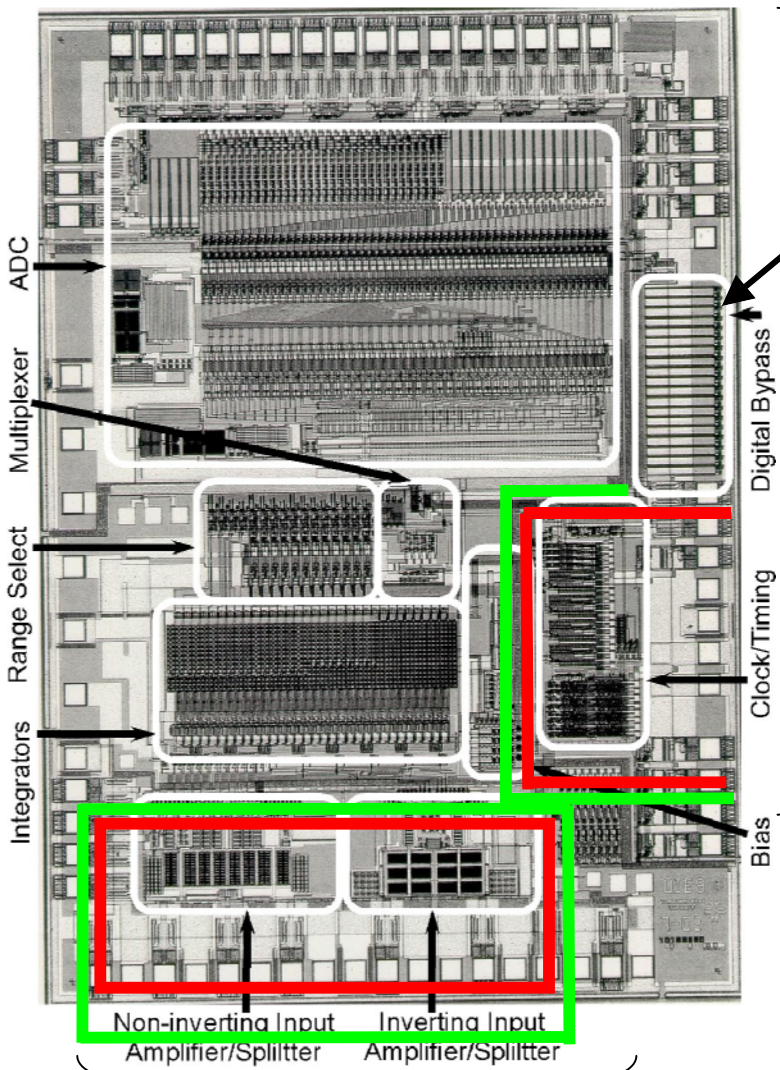
Custom Pseudo Differential, Non-uniform ADC



Preamps with output averaging for low DNL

Digital outputs (low level differential)

Analog power, bias



Digital bypass caps (650 pF total)

Digital power, control inputs

Analog/digital substrate isolation technique:

N collector implant (connect to +5V)

Substrate contact (dedicated gnd pin)

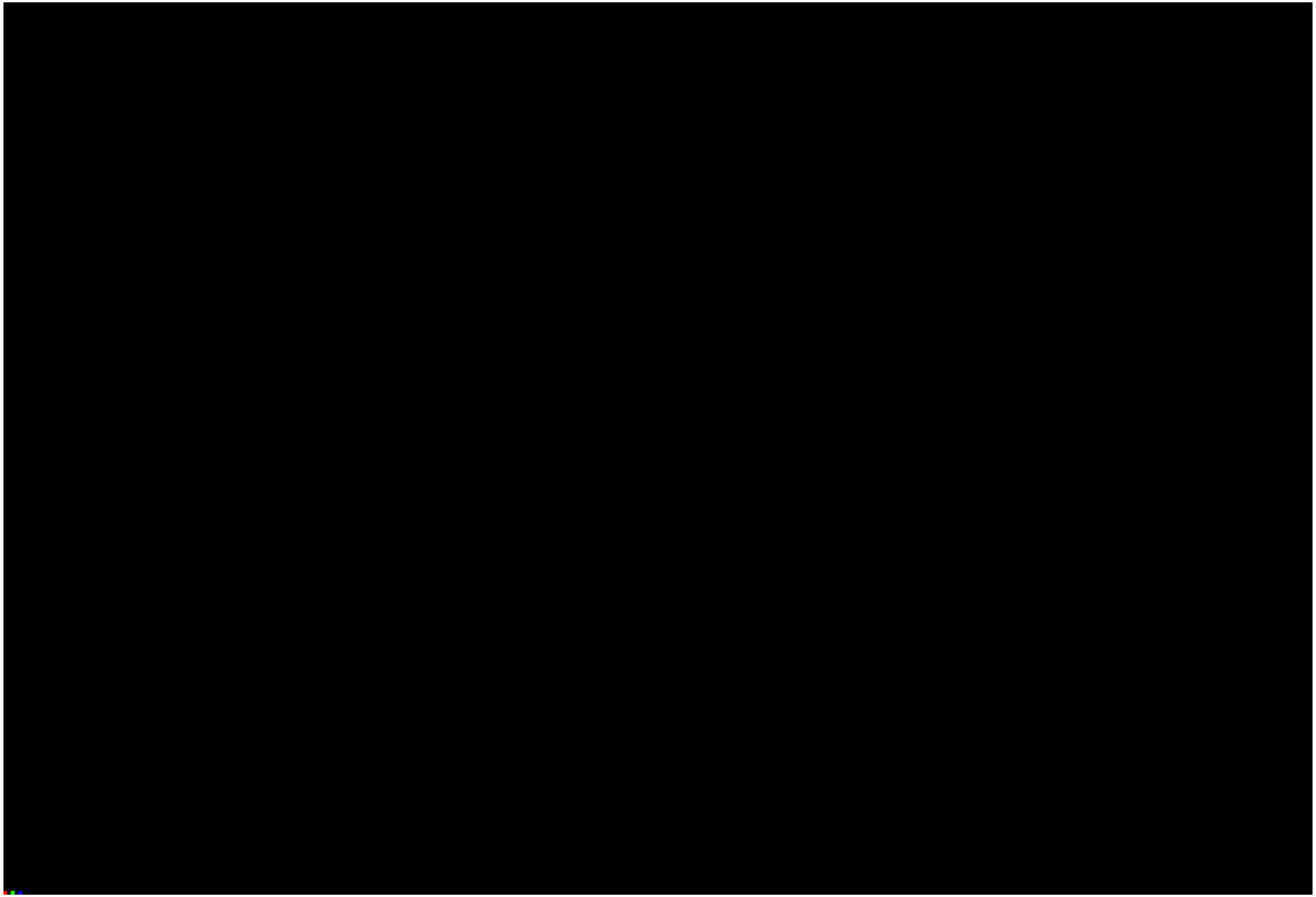
Die size: 3.0 x 4.3 mm

Analog inputs (pseudo-diff.)

Production Testing

- Received 25,079 packaged parts
- Built robot chip tester (4 months) to handle parts
  - Eliminates Post Doc burn out
  - Insures bad parts are sorted properly
  - Minimizes damage to pins due to handling
  - Tester holds 7 trays with 160 QIE8s per tray
- Tests all QIE8 functions
  - 18 major tests
  - Each test test may include hundreds of measurements

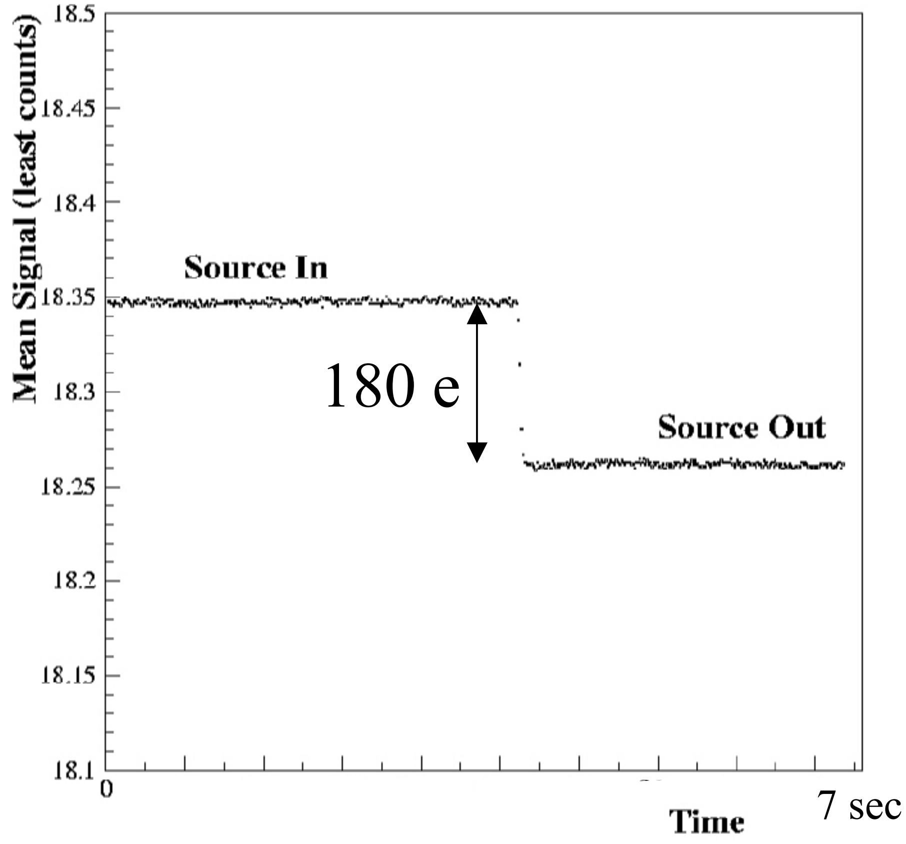
QIE8 Chip Tester



Test results

- Meets all specifications
- Runs at > 70 MHz
- Low DNL (< 0.05 LSB in normal mode)
- Power = 330 mw from single 5.0 V supply.
- Stable against shifts in bias, temp, clock, Vdd, etc.
- No digital coupling to inputs if board is laid out properly (tricky).
- Need 8200 +1800 parts for HPDs and PMTs. Expect 19,500 good parts. (Yield=78%)

Radioactive source calibration test: each point is 500,000 acquisitions (14 ms) averaged.



Summary

- Production quantity of QIE8 chips has been received.
- All chips have been packaged.
- Testing with newly developed robot is proceeding.
- The robot has been so successful that a second robot is being built.
- QIE8 parts meet specifications.
- Yield is good.