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Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT) Calorimeter

PEM Electrical Test Equipment Specification

DOCUMENT APPROVAL

Prepared by:

James Ampe
CAL Electrical Subsystem Lead

Date

Bob Kraeuter
CAL System Engineer

Date

Approved by:

Gunther Haller
LAT Electronics Manager

Date

W. Neil Johnson
CAL Subsystem Manager

Date

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1 INTRODUCTION

1.1 PURPOSE

This document details the design of the Calorimeter Pre-Electronics Module (PEM) Electrical GSE implementation, an electrical readout system designed to test the PEM assembly. Calorimeter PEM testing is performed after CDEs are inserted into the PEM mechanical structure, and before proceeding to the next level of assembly where the Analog Front End Electronics (AFEE) boards are integrated onto the PEM assembly to form the Calorimeter module.

1.2 APPLICABLE DOCUMENTS

Documents and drawings that are relevant to the development of the PEM EGSE and its requirements include the following:

NASA-STD-8739.7	Electrostatic Discharge Control
LAT-SS-00115	LAT Mechanical Systems – Level III Specification
LAT-MD-00408	LAT Program Instrument Performance Verification Plan
LAT-SS-00210	LAT-CAL Subsystem Level IV Specification
LAT-SS-00222	Calorimeter Module Assembly, Test, and Calibration Requirements
LAT-SS-00262	Calorimeter Module Assembly and Test Plan
LAT-SS-01xxx	Calorimeter Functional Test Procedure

1.3 DEFINITIONS AND ACRONYMS

1.3.1 Acronyms

AFEE	Analog Front End Electronics of the Calorimeter
CAL	Calorimeter Subsystem of the LAT
CDE	Crystal Detector Element of the PEM
DAS	Data Acquisition System
ESD	Electrostatic Discharge
GCFE	Glast Calorimeter Front-end Electronics
GCRC	Glast Calorimeter Readout Control electronics
GLAST	Gamma-Ray Large Area Space Telescope
LAT	Large Area Telescope
PEM	Pre-Electronics Module of the CAL
TBD	To Be Determined
TBR	To Be Resolved
TEM	Tower Electronics Module

1.3.2 Definitions

cm	centimeter
Dead time	Time during which the instrument does not sense and/or record gamma ray events during normal operations
MeV	Million Electron Volts, 10^6 eV
nsec	nanoseconds (10^{-9} second)
usec	microseconds (10^{-6} second)

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2 INTRODUCTION

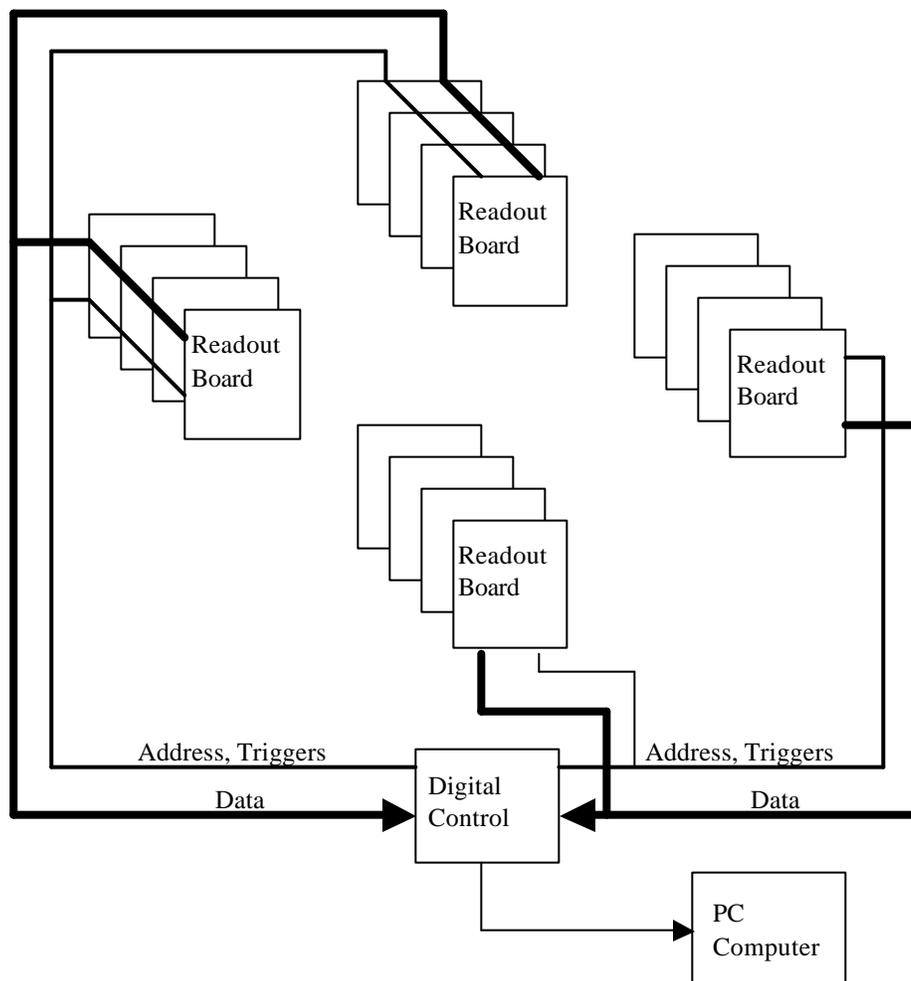
The Glast calorimeter PEM readout system is designed to test the calorimeter structure assembled with crystals. The crystals have PIN diodes mounted with lead attached lead wires. The structure will be tested with the PEM Readout electronics continuously for a few days with muons as a signal source, prior to full flight assembly.

2.1 Circuit Description

The goal of the readout circuits is to clearly see the muon signals out of both log-end diodes. With the expected muon peak to be about 12 MeV per log end, the readout circuits have a designed dynamic range of 0 to 120 MeV per log end. The small PIN diode (large energy diode) has 1/6 the area of the large PIN diode (low energy diode). Therefore, the high energy signal path is given more gain to compensate for the difference in light collection.

The circuits are arranged as four Readout boards per calorimeter side, one board per calorimeter row. A digital controller board collects the Analog to Digital Converter (ADC) data and passes it to a PC computer using a National Instruments card. Data is gathered and passed to the PC in a format similar to that of the flight Tower Electronics Module (TEM). Common software then can be used to display and process the software.

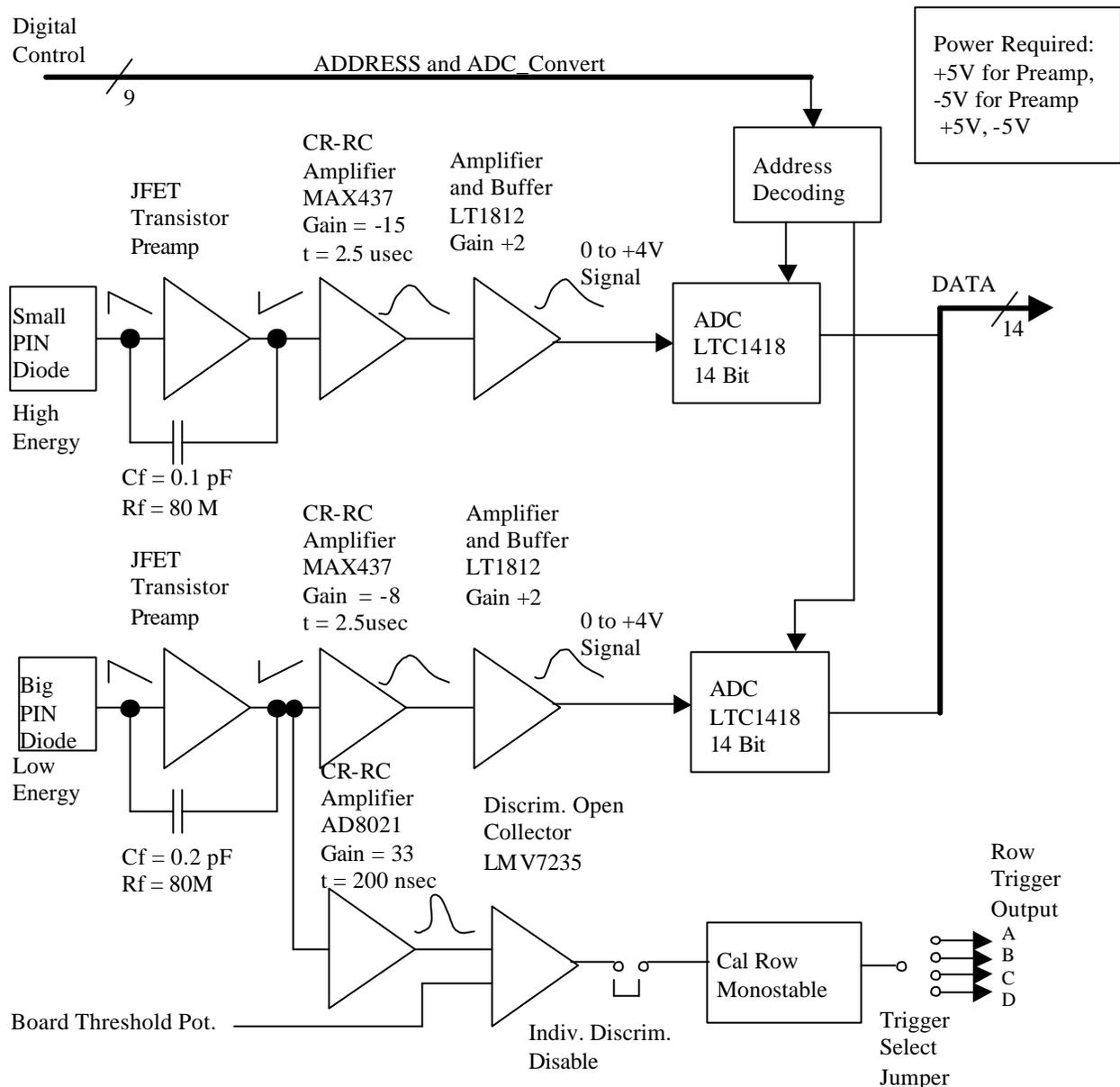
Figure 2-1 - Cal PEM Readout Electronics Block Diagram



2.2 Readout front-end electronics Circuit Description

The front-end electronics is designed to have a similar configuration as the calorimeter AFEE front-end board and GCFE front-end ASIC. Each pin diode has a preamp, followed by a CR-RC shaper. The time constant of the shaper is 2.5 usec, as in the GCFE ASIC. The shaped signal is fed directly into a sampling ADC for conversion. A fast shaper is used off the low-energy diode for a timing signal. The fast shaped signal is fed to an open collector discriminator. The open collector discriminators enables simple logical 'OR'ing of the row's triggers. The Readout Controller Board generates the ADC_Convert signal from the trigger signals. The front-end electronics diagram is shown in Figure 2-2.

Figure 2-2 - Readout Board Block Diagram.



2.3 Readout Board Connections:

Table 2-1 - Readout Board Power Connector, 15 Pin Male D-Sub.

Signal	Connector Pin	Description
+5V	1,9	Opamp and ADC power
-5V	2,10	Opamp and ADC power
Gnd	3,6,11,14,15	
+5V_Preamplifier	4,12	Preamplifier power
-5V_Preamplifier	5,13	Preamplifier power

Table 2-2 - Readout Board ADC Data Connector, 16 Pin IDC Connector.

Signal	Connector Pin	Signal	Connector Pin
Data0	2	Data8	10
Data1	3	Data9	11
Data2	4	Data10	12
Data3	5	Data11	13
Data4	6	Data12	14
Data5	7	Data13	15
Data6	8	Gnd	1,16
Data7	9		

Table 2-3 - Readout Board Address and Control Connector, 20 Pin IDC Connector.

Signal	Connector Pin	Description
Addr_LE\	2	Readout Addressed Low Energy Diode
Addr0	3	Row Log end address, LSB
Addr1	4	Row Log end address bit
Addr2	5	Row Log end address bit
Addr3	6	Row Log end address, MSB
Addr_Row0	7	Row Address, LSB
Addr_Row1	8	Row Address, MSB
Addr_Side0	9	Cal Side Address, LSB
Addr_Side1	10	Cal Side Address, MSB
Row_Diode_Sel	12	Not Used
ADC_Convert\	13	High to Low Transition starts conversion.
Row_ADC_CS\	14	Logic low selects the ADCs.

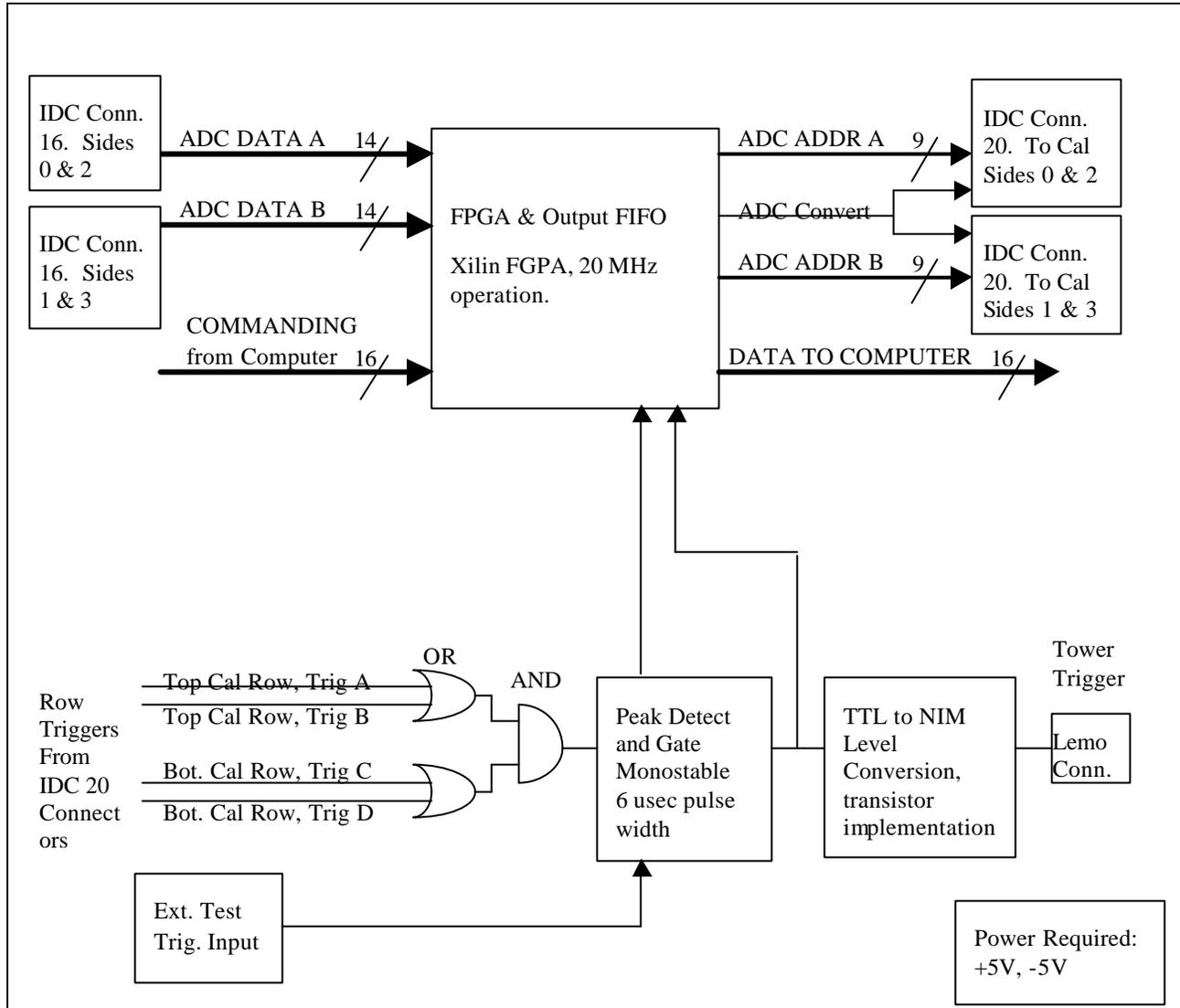
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Row_ADC_Shdn\	15	Logic Low holds ADCs in shutdown mode.
Trigger_A	16	One Top Row board is jumpered to output trigger on Trig_A line.
Trigger_B	17	One Top Row board is jumpered to output trigger on Trig_B line.
Trigger_C	18	One Bottom Row board is jumpered to output trigger on Trig_C line.
Trigger_D	19	One Bottom Row board is jumpered to output trigger on Trig_D line.
Gnd	1,11,20	

2.4 Readout Controller Circuit Description

The function of the Readout Controller board is to generate the ADC_Convert signal from trigger inputs, and to send the resulting ADC data to the PC computer. The controller board has discrete logic to form a coincidence trigger from the top and bottom layers of the calorimeter. The controller board also employs two separate address and data paths to speed up the data collection time. The two paths enable one ADC to be read while another ADC is being addressed. Data is transferred to the PC computer at a 20 MHz rate. Monostables are used on the board to add extra dead time following data readout. The block diagram of the Readout control board is shown in Figure 2-3.

Figure 2-3 - Readout Control Board Diagram.



The calculated minimum deadtime is computed below:

- Time to peak = 4usec. ADC Conversion time = 3.5 usec.
- Data readout time (100 nsec per 2 ADCs) = $48 * 2 * 4 * 50\text{nsec} = 38.4 \text{ usec}$.
- Readout deadtime = $38.4\text{us} + 3.5\text{us} + 4\text{us} = 45.9 \text{ usec min}$.

2.5 Geometric Orientation:

Figure 2-4 - Reprinted Coordinate System of Flight Calorimeter. From Cal ICD Document.

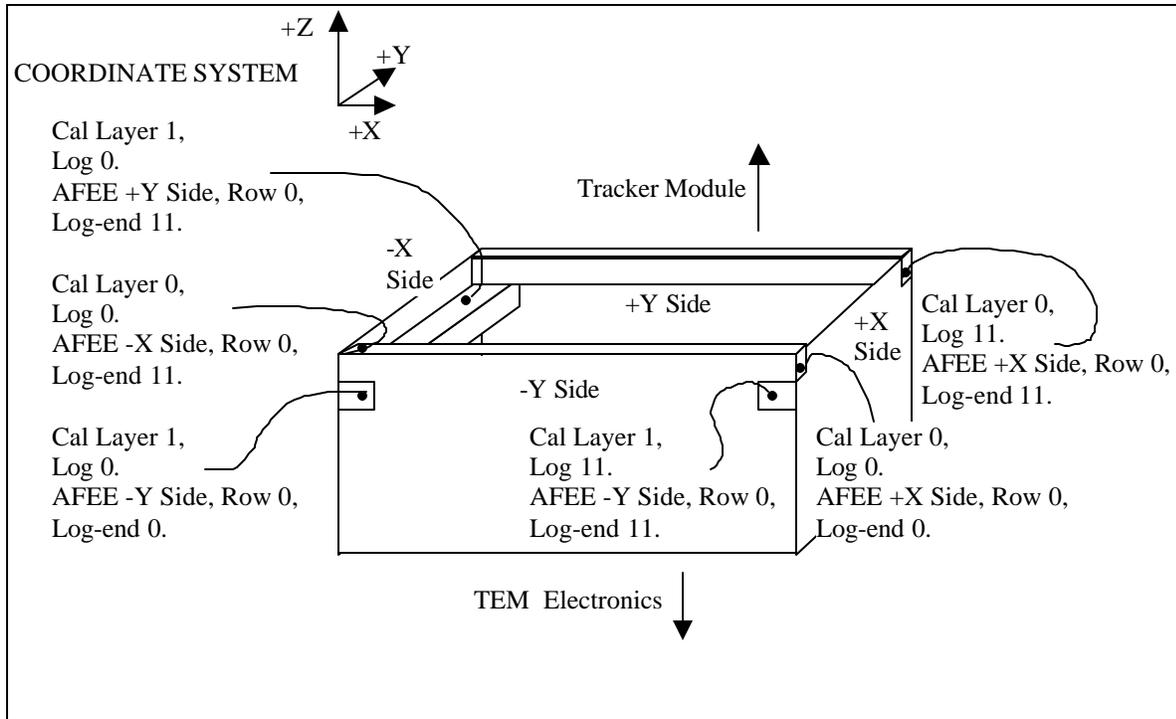
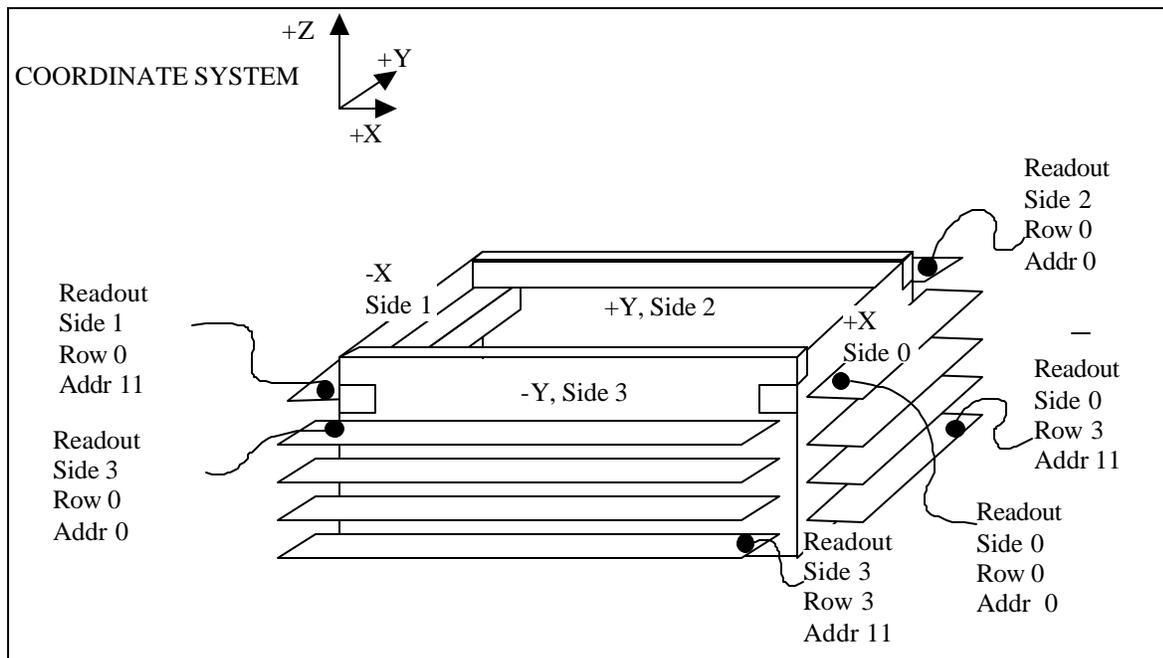


Figure 2-5 - Calorimeter With 16 PEM Readout Electronic Boards.



2.6 Data Transmission Format

Table 2-4 - Data Order to PC Computer

Long Word Count	Bits 31–30 Address Bits 2 & 1	Bits 29 – 16 ADC Bits, Bit 29 MSB, Side -	Bit 15 Bit 0 (LSB) Addr.	Bit 14 Energy Level	Bits 13 – 0 ADC Bits, Bit 13 MSB, Side +
0	00	Side 1, Row 0, Addr 11	0	'0' Low Energy	Side 0, Row 0, Addr 0
1	00	Side 1, Row 0, Addr 10	1	'0' Low Energy	Side 0, Row 0, Addr 1
				...	
12	00	Side 1, Row 1, Addr 11	0	'0' Low Energy	Side 0, Row 1, Addr 0
13	00	Side 1, Row 1, Addr 10	1	'0' Low Energy	Side 0, Row 1, Addr 1
				...	
24	00	Side 1, Row 0, Addr 11	0	'1' High Energy	Side 0, Row 0, Addr 0
25	00	Side 1, Row 0, Addr 10	1	'1' High Energy	Side 0, Row 0, Addr 1
				...	
36	00	Side 1, Row 1, Addr 11	0	'1' High Energy	Side 0, Row 1, Addr 0
37	00	Side 1, Row 1, Addr 10	1	'1' High Energy	Side 0, Row 1, Addr 1
				...	
48	00	Side 1, Row 2, Addr 11	0	'0' Low Energy	Side 0, Row 2, Addr 0
49	00	Side 1, Row 2, Addr 10	1	'0' Low Energy	Side 0, Row 2, Addr 1
				...	
60	00	Side 1, Row 3, Addr 11	0	'0' Low Energy	Side 0, Row 3, Addr 0
61	00	Side 1, Row 3, Addr 10	1	'0' Low Energy	Side 0, Row 3, Addr 1
				...	
72	00	Side 1, Row 2, Addr 11	0	'1' High Energy	Side 0, Row 2, Addr 0
73	00	Side 1, Row 2, Addr 10	1	'1' High Energy	Side 0, Row 2, Addr 1
				...	
84	00	Side 1, Row 3, Addr 11	0	'1' High Energy	Side 0, Row 3, Addr 0
85	00	Side 1, Row 3, Addr 10	1	'1' High Energy	Side 0, Row 3, Addr 1
				...	
96	00	Side 2, Row 0, Addr 11	0	'0' Low Energy	Side 3, Row 0, Addr 0
97	00	Side 2, Row 0, Addr 10	1	'0' Low Energy	Side 3, Row 0, Addr 1
				...	
108	00	Side 2, Row 1, Addr 11	0	'0' Low Energy	Side 3, Row 1, Addr 0
109	00	Side 2, Row 1, Addr 10	1	'0' Low Energy	Side 3, Row 1, Addr 1

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				...	
120	00	Side 2, Row 0, Addr 11	0	'1' High Energy	Side 3, Row 0, Addr 0
121	00	Side 2, Row 0, Addr 10	1	'1' High Energy	Side 3, Row 0, Addr 1
				...	
132	00	Side 2, Row 1, Addr 11	0	'1' High Energy	Side 3, Row 1, Addr 0
133	00	Side 2, Row 1, Addr 10	1	'1' High Energy	Side 3, Row 1, Addr 1
				...	
144	00	Side 2, Row 2, Addr 11	0	'0' Low Energy	Side 3, Row 2, Addr 0
145	00	Side 2, Row 2, Addr 10	1	'0' Low Energy	Side 3, Row 2, Addr 1
				...	
156	00	Side 2, Row 3, Addr 11	0	'0' Low Energy	Side 3, Row 3, Addr 0
157	00	Side 2, Row 3, Addr 10	1	'0' Low Energy	Side 3, Row 3, Addr 1
				...	
168	00	Side 2, Row 2, Addr 11	0	'1' High Energy	Side 3, Row 2, Addr 0
169	00	Side 2, Row 2, Addr 10	1	'1' High Energy	Side 3, Row 2, Addr 1
				...	
180	00	Side 2, Row 3, Addr 11	0	'1' High Energy	Side 3, Row 3, Addr 0
181	00	Side 2, Row 3, Addr 10	1	'1' High Energy	Side 3, Row 3, Addr 1
				...	
191	01	Side 2, Row 3, Addr 0	1	'1' High Energy	Side 3, Row 3, Addr 11

3 MEASURED PERFORMANCE:

3.1 Noise Measurements:

Low Energy Noise Measurement:

Figure 3-1 - Signal peak histogram from Am-241 source.

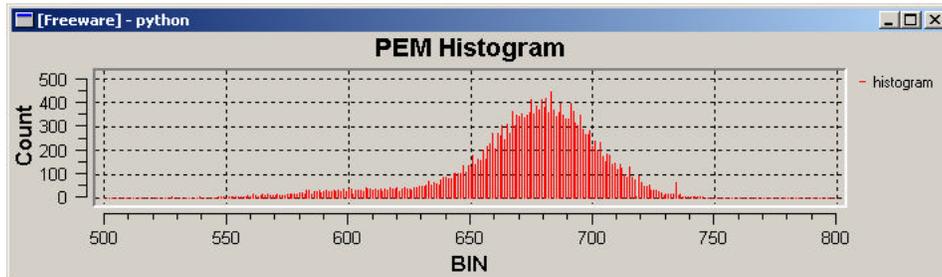
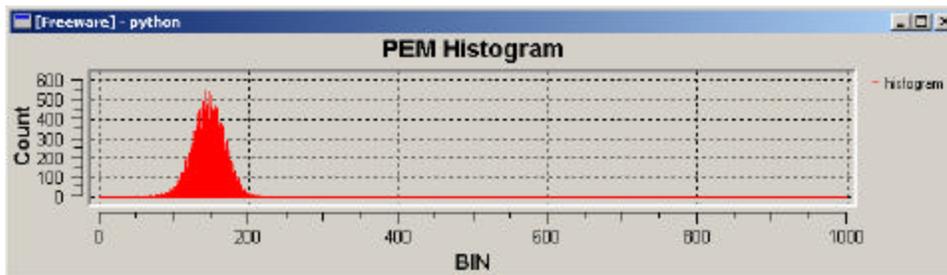


Figure 3-2 - Low Energy Baseline plot



FWHM = 45 bins, Peak 680, Baseline 150 16,500 electrons/photon in silicon .

Noise sigma = (45 FWHM / 2.35 FWHM/sigma) * (16,500 e- / (680-150)) = 596 electrons.

High Energy Noise Measurement:

Figure 3-3 - Signal Peak Histogram from Am-241 source.

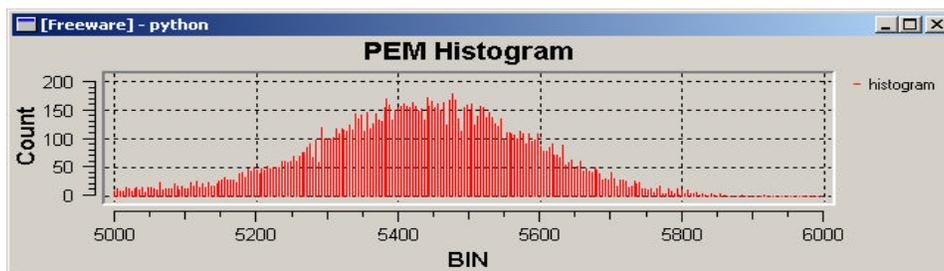
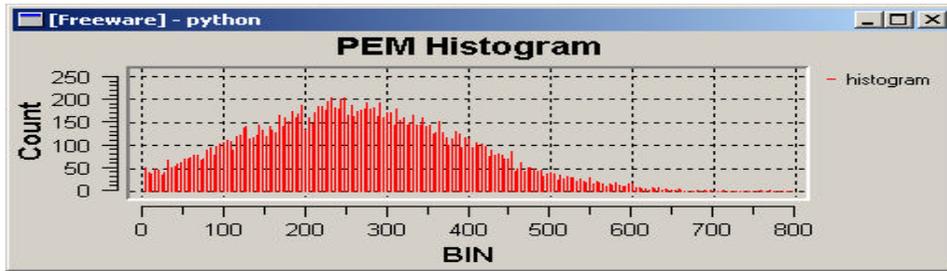


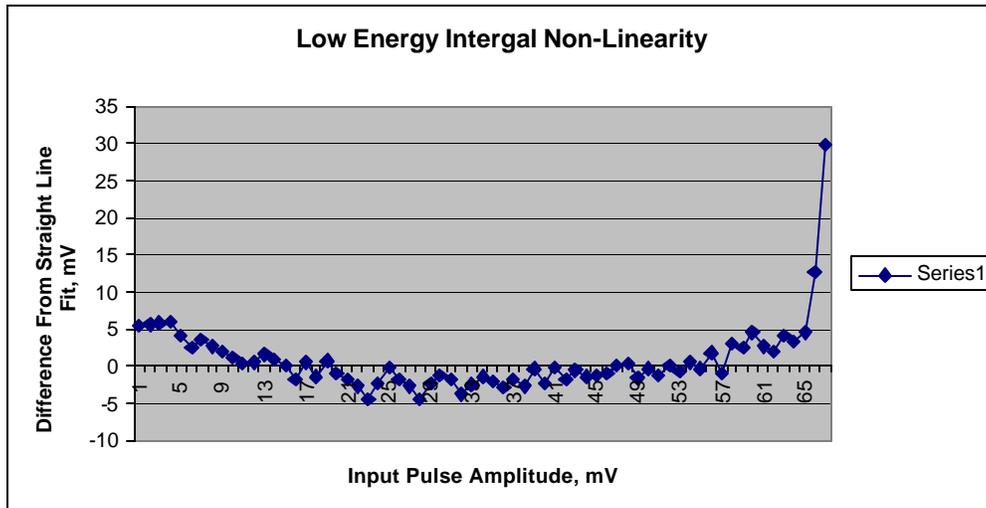
Figure 3-4 - HE Signal Baseline



FWHM = (5600-5280) = 320 bins, Peak 5450, Baseline 250, 16,500 electrons/photon in silicon .
 Noise sigma = (320 FWHM / 2.35 FWHM/sigma) * (16,500 e- / (5450-250)) = 432 electrons.

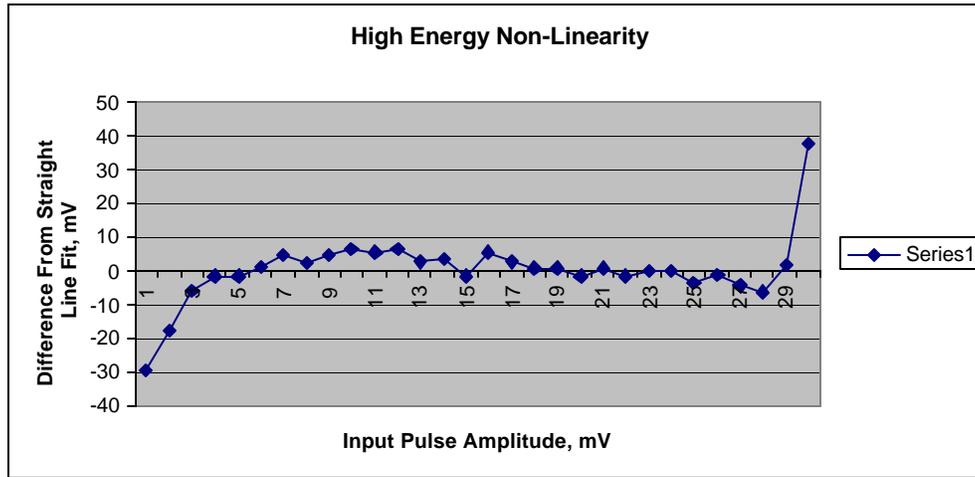
3.2 Intergal Linearity Measurements:

Figure 3-5 - Low Energy linearity measurement, using external pulser.



Computed standard deviation, not including end points = 2.5 mV, 0.06% of full scale, for low energy range.

Figure 3-6 - High Energy linearity measurement, using external pulser.



Computed standard deviation, not including end points = 4.9 mV, 0.12% of full scale, for high energy range.

3.3 Power Measurements:

Table 3-1 - Measured Power Consumption of Readout Board

	Current per Readout Board	Current for all 16 Readout Boards
+5V Preamp	0.145 A	2.32 A
-5V Preamp	0.044 A	0.70 A
+5V	0.285 A	4.56 A
-5V	0.215 A	3.44 A
Bias, +70V	negligible	negligible

Table 3-2 - Measured Power Consumption of Controller Board

	Current per Readout Board
+5V	0.091 A
-5V	Not Used

The PEM Readout board does warm up with 3.5 Watts dissipated per board. Cooling of the boards by radiation and convection is sufficient. Measured temperature of single Readout board operating in enclosed aluminum box.

Table 3-3 - Measured temperatures of single PEM Readout Board in enclosed box.

	Temperature, deg. C
Outside Air Temp	22.5
Aluminum box outside surface temperature	25.6
Inside box air temperature	28.4
PEM Readout Board temp	Estimated 30

4 PEM READOUT BOARD COMPONENT LIST

Front-end transistor:

Phillips BF862, standard product jfet transistor. \$0.25 each. Yfs transfer admittance 38mS at 10mA bias, input capacitance 10pF, noise voltage 0.8nV/root Hz. typical at 100 kHz data sheet values.

Op-Amp. Low Noise Lower Bias Current:

MAX437CSA Maxim (LT1037CS8 Linear Technology \$2.15, OP37GS \$2.68 Analog Devices, OPA37 Texas Instruments). Single low noise OP-Amp, Stable Gains>5, Noise 2.5 nV/root Hz typ., GBW = 60 MHz, 15 V/usec Slew, Supply Current 2.4 mA, Max supply voltage 22 volts, Spec'd for +/-15V operation. \$2.45 ea qty 100+ from Maxim.

Op-Amp Low Noise, High Slew:

AD8021AR Analog Devices. Single Low Noise Op-Amp, Noise 2.1 nV/root Hz, GBW = 500 MHz., Slew 100 V/usec, Supply current 7 mA, Max supply 22 volts. \$2.20 each from Future Electronics.

Comparator, Open Collector:

LMV7235M5 National Semi. Single comparator, open collector output, 45 nsec max, 6 mV input offset max. supply current 0.1 mA, 5.5V max supply voltage. SOT-23 Pkg, reel of 1000, Pioneer electronics \$0.63 ea for 1K reel, stock.

Buffer Driver.

LT1812CS5 Linear Technology Op-Amp, +/-5V supply, 3.6 mA max supply current per amp, GBW 100 MHz., Slew 750 V/usec, Cap Loads OK, Noise 8 nV/root Hz., 1.5 mV max input offset, 4.1 V swing into 500 ohm load. SOT-23 pkg, \$1.35 for qty 100+ from Digikey.

Address Decoding Logic:

74AC521 Fairchild, 8 bit digital comparator, 20 lead chip, 10 nsec propagation delay.

75HC154 Fairchild 4 to 16 decoder, 24 lead chip.

Analog to Digital Converter, Parallel Output:

LTC1418 Linear Technology, \$8.65 ea from Digikey qty 100+, 14 bit ADC, 200 ksps, +5V operation, 3 mA current, 0 to 4.096 input range, Acquisition time 0.3us typ., 1 usec maximum acq time, 14 tristatable data lines.

4.1 Cost and Power Consumption (per channel)

Preamp: Power 7mA from +/- 5V, 70 mW power. Parts cost \$5.00

Shapers: Qty 2 MAX437s, Qty 1 AD8021. Power 2.5mA * 2 from +/-5V, + 7mA from +/- 5V. 120 mW power. Cost 2*\$2.50 for Max437s, + \$2.20 for AD8021, + \$5.00 for passive parts. \$12.20 shapers parts cost.

Discriminator/Triggers: Qty 1 LMV235 + monostables, passives. Cost \$4.00 each, power 5 mW.

Amp Buffer, ADC and switch: LTC1812 qty 2, LTC1418 qty 2.. Cost 2*\$1.40 + 2*\$9.00 + \$3.00 Passives. Cost \$23.80. Power 2*36 mW + 2*15 mW power = 102mW power.

Additional items, regulators, control, passives 10 mW, \$3.00 per channel.

Total Cost: \$5.00 + \$12.20 + \$4.00 + \$26.20 + \$3.00 = \$50.4 per channel cost.

Total Power: 70 mW + 120 mW + 5 mW + 102mW + 10 mW = 307 mW per channel.

4.2 Cost and Power Consumption (per tower)

Tower Cost Estimates per Tower: $\$51 * 48 * 4 = \9.8k parts + \$3k for boards +\$1k slush +\$2k assembly = \$15.8k electronics cost.

Tower Power Estimates per Tower: $0.310\text{W} * 48 * 4 = 60$ Watts, (6.0 Amps from +/-5V supplies)