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Precision Calibration of Calorimeter Electronics in the D0 Liquid Argon/Uranium Particle Detector

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Precision Calibration of Calorimeter Electronics in the D0 Liquid Argon/Uranium Particle Detector

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Abstract

The ability to cross calibrate thousands of channels of detector electronics is of prime importance. This paper will describe the system used to deliver and distribute a 300 nanosecond pulse across 50,000 channels of electronics with better than 0.25% difference between channels from a location more than 200 feet away. The system is used for both cross calibration and functionality checking, (i.e. missing channels).

Design of a fixed width pulse generator of high stability is presented as a key ingredient in the system's overall performance. In addition, the design of a controlled impedance distribution system is discussed.

I. Overview

The D0 Calorimeter detector is made up of many cells sandwiched between uranium plates. This sandwich is immersed in liquid argon and has an electric field applied that causes any free ions to be collected on the cell. These cells are connected in towers that extend away from the interaction point.

As particles pass through the detector, they liberate ions that collect on detector cells. The charge on these cells is integrated by Charge Sensitive Preamplifiers, producing a proportional voltage. The output of each preamp is shaped, digitized and stored if a trigger occured. The mapped cell information is used to reconstruct particle paths and energy deposits.

The calorimeter itself is divided into three main sections, the central calorimeter and the north and south end-cap calorimeters. Each section contains four Preamp Boxes and each box contains 4608 preamps. There is a calibration system associated with each Preamp Box for a total of 12 systems. During a calibration run, the signal from each system is directed to one of the 32 positions in the Preamp Box stimulating 144 preamp channels. The position is incremented until all preamps have been stimulated.

II. Physical Description

The Calibration system is comprised of three units (figure 1).

A. PULSER
attenuator
filter
transformer

B. DISTRIBUTION
switch box
transmission lines

C. FANOUT/CONVERSION
fanout board
preamp board

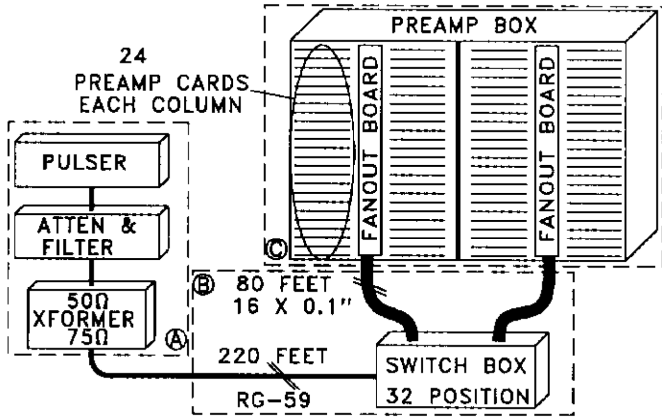

Fig. 1 Typical Calibration System.

Calibration is accomplished by injecting charge into the front end of each preamp hybrid. A timed high voltage pulse is converted to a current source by a 500KΩ resistor at the preamp input. An often used method of injecting charge is to connect a capacitor, which is charged to some known voltage, to the input of the preamp. The accuracy, precision and long term stability of resistors are far superior to capacitors. (Consider matching 50,000 capacitors in the 10pF range to 0.1% tolerance.)

The preamp output voltage can swing to 5 volts and the integrating capacitor is 5 picofarad. The calibration signal, therefore, must supply a charge of 25 picocoulombs for full scale output signal.

$$q = CV = (5\times10^{-12})\cdot 5 = 25 \text{ picocoulombs}$$

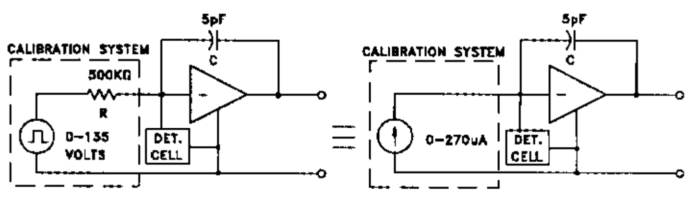

Fig.2 Calibration Signal Injection

1 Work supported by the U.S. Department of Energy under contract No. DE-AC02-76CHO3000.

The amount of charge deposited is the integral of the current during the injection time. If a simple rectangular pulse 300 nanoseconds wide and 50 volts in amplitude is integrated, this becomes 100μamperes, it will provide more than enough drive.

$$q = \int_{t_0}^{t_1} \frac{v(t)}{R} dt = \int_{t_0}^{t_1} i(t)dt$$

$$VC = \int_{0}^{3E\text{-}7} 100E\text{-}6dt = 300E\text{-}13 = 30 \text{ picocoulombs}$$

$$\text{for } C = 5pF \quad V = \frac{q}{C} = \frac{30E\text{-}12}{5E\text{-}12} = 6 \text{ volts}$$

Since the voltage amplitude, duration and resistors tolerance can be carefully controlled, a very stable, well defined charge can be delivered.

The charge pulse must cover the entire dynamic range of the system (effectively 15 bits). An attenuator provides the coarse adjustment for this range while the DAC[2] power supply is used for fine adjustments.

A. Pulser

The pulse is formed by charging a transmission line[3] to a predetermined voltage (figure 3). A DAC power supply is connected to the line through a limiting resistor RLIMIT and a BLOCKING diode.

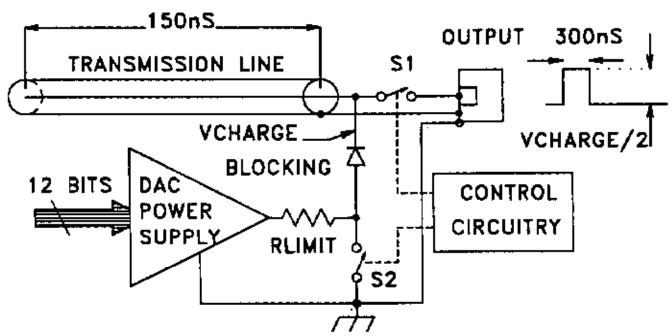

Fig. 3 Pulser block diagram.

The switches S1 and S2 are opened and the cable charges to the DAC voltage setting. When the Pulser is triggered the CONTROL CIRCUITRY immediately closes S1 and S2. The switch S1 connects the output of the pulser to the distribution system. Switch S2 removes the charging voltage so the SCRs[4] will turn off. The result is a well defined pulse of fixed width with variable amplitude controlled by a 12 bit DAC.

After an appropriate time the control circuitry returns the switches to their open state and the transmission line begins to recharge. All triggers that might occur during the recharge cycle are ignored until the transmission line is fully charged.

The actual switch S1 is comprised of three nanosecond SCRs stacked in series to handle the high voltage. The gate of each SCR is isolated with a small pulse transformer. The switch S2 is a single MOSFET[5] rated at 350 volts. A single MOSFET can be used for switch S1, however, it was found that the SCRs required less gate drive. The gate drive ultimately ends up as part of the output signal.

The output signal at full DAC setting is 135 volts in amplitude and 300 nanoseconds in width into a 50Ω load. The Pulser can be run at a rate of 1000 hertz.

Attenuator

The amplitude of the Pulser's output is coarsely controlled by a 0-120 db attenuator. The attenuation factor can be remotely set in 10 db increments allowing coverage of the entire dynamic range of the electronics. This unit takes 100 milliseconds to configure a new setting but is not changed often. The attenuator is a commercial unit made by Hewlett-Packard, model 355F, DC to 1000MHz 0-120 db.

Filter

The output of the Pulser is a rectangular pulse with rise and fall times in the 10ns range. Due to physical constraints in the distribution of the pulse, the final lines that feed the preamps, (4 cards; 6 hybrids/card), cannot be terminated into the characteristic impedance. Therefore some frequency limits are imposed to help control reflections. The final lines, which are not terminated, are short compared to wavelength.

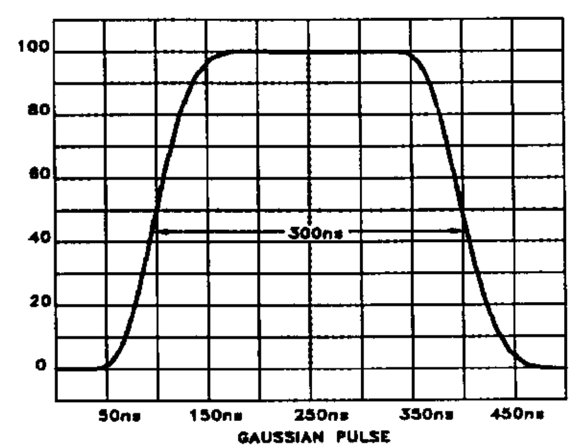

Fig. 4 Filtered Pulser output

2 Digital to Analog Converter

3 Standard RG-58 coax

4 Silicon Controlled Rectifier [type GA201A] manufactored by Unitrode

5 Metal Oxide Semicondutor Field Effect Transistor [type IRF721]

An 8-pole low pass gaussian filter has been chosen to limit frequencies of the pulse to about 5 MHz. This type of filter exhibits no overshoot or ringing and has a minimum time delay.

The filtered pulse (figure 4) has a smooth gaussian shape that is much easier to distribute while maintaining most of the original area of the pulse. The gaussian step response has no ringing or overshoot.

Transformer

The transformer provides three functions.

It inverts the polarity of the signal sent to the preamp hybrids. The initial design of the Pulser was for preamps that required a positive signal. During development it was established that the opposite polarity preamp (that is a negative voltage pulse) should be used. Since Pulser construction was completed with a positive voltage pulse, it was decided that a transformer could provide the inversion with no other rework of the system. (It should be noted, however, that inverting transformers are more difficult to make and should be avoided if possible.)

The transformer provides DC isolation between the Preamp Box ground, which is mounted on the detector, and the Moving Counting House ground, 150 feet away.

Finally, it matches the output impedance of the Pulser/Attenuator/Filter (50Ω) with the distribution system and fanout (75Ω).

B. DISTRIBUTION

Care was taken to ensure that each transmission path is electrically equal. All cables are matched for length and attenuation and each path in the fanout board is made to be of equal length.

Delivering the calibration signal to the preamps requires a low loss system. Initially a 50Ω system was developed but it was found there was excessive signal degradation. A shift was made to use a 75Ω system with the largest cable physically possible. The longest single run of cable is between the Pulser and the Switch Box measuring about 220 feet. Low-loss Fluoroform RG-59 cable was selected for this run. Attenuation is 1.9db/100feet at 55MHz.

The second longest run is from the Switch Box to the Fanout boards. This run is approximately 80 feet long but is restricted to a small cross sectional area. A special assembly of 20 (four spare) 75Ω low loss 0.1" diameter cables is used on the outputs of each Switch Box. Attenuation is 3db/100feet at 30MHz.

The final signal path uses 8" jumpers from the fanout board to the preamp back plane. Here again a low loss 0.1" diameter 75Ω cable is used (3db/100' @ 30MHz).

Switch

The pulse must be distributed to all of the electronic channels in the system. Each Preamp Box has 32 distinct paths that the pulse can be channeled to (16 in each half of the Preamp Box). The Switch Box is simply a 32 position coaxial switch. The unselected channels are back terminated to ground providing more crosstalk rejection.

Mercury wetted reed relays are used to provide the switching to the particular path. They provide a very repeatable and reliable connection to each position selected.

A relay was chosen that has contact resistance less than 50 milliohms and can handle two amperes of current at 500 volts. This ensures reliability and maintains fractional changes, due to contact resistance, in the 75Ω system.

The switches require approximately 5 milliseconds to change states and therefore require a small wait between selections.

These reed type relays must be located away from magnetic fields to ensure proper operation. We experienced a malfunction when the Switch Box was operated in a 100 gauss field.

C. FANOUT

The purpose of the fanout is to distribute the pulsed lines, which emanate from the Switch Box, over the entire Preamp Box. It is also where the signal is terminated into its characteristic impedance (75Ω).

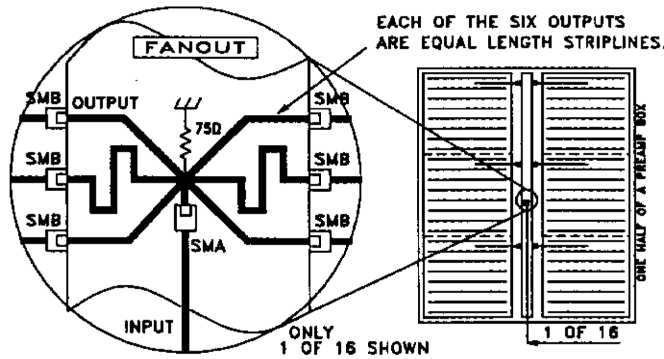

Fig 5. Fanout detail shown for half a Preamp Box.

Each Switch Box drives two fanout boards that reside in each half of the Preamp Box between two columns of preamp cards as seen in Fig 1. The Fanout boards are 8-layer printed circuits that map outputs to particular preamp boards. The lines are terminated with 75Ω and have six outputs. The lengths of all the outputs (96 total) are equal. Striplines are used in printed circuit boards to route each output to its corresponding connector on the preamp backplanes (figure 5). The Fanout boards measure 2.5" x 31" x 0.062".

The final path of the pulse signal is via short cables connecting the fanout board to the preamp board. One pulse position (1 of 32) will cause six areas of the preamp box electronics to be 'hit' simultaneously. A total of 144 channels of electronics are pulsed at any one position.

The final conversion of the pulse from a voltage to a current signal is carried out on the preamp card. The input of each preamp has the high value resistor (500KΩ) that converts the voltage signal into a current signal.

III. CONCLUSIONS

The calibration system built for the D0 experiment has been shown to provide the necessary stability and uniformity across the entire Calorimeter. However, during its engineering evolution, many compromises have been made, such as the inverting transformer and the 50Ω pulser, filter and attenuator. Data results confirm the designed goal of 0.25% across channels.

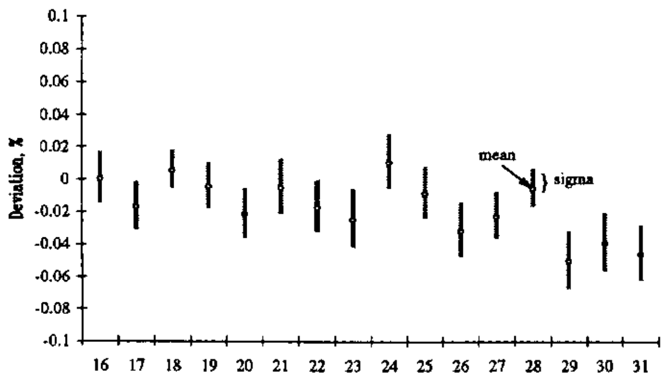

Fig. 6 Pulser deviation and uniformity.

The empirical measure of performance is shown in figure 6. The data demonstrates the uniformity of sixteen different channels of the calibration system when normalized to one channel, in this instance channel sixteen. The data was obtained by connecting, one at a time, each of the sixteen cables to the same fanout connector. Measurements, therefore, use the same Preamp/BLS/ADC acquisition channels. The stability of the pulse is given in the sigma. A minimum of 100 pulses were acquired at each position. This scheme tests the conformity of all parts of the system up to the fanout board.

The timing and shape of the calibration pulse is very critical. The average area of the calibration signal must equal the detector signal within the same time frame. A 50 nanosecond delay of the pulser signal is equivalent to a systematic error of 0.5%/nanofarad when compared to the detector signal.

IV. ACKNOWLEDGMENTS

I thank everyone involved with the D0 calorimetery electronics. A special thanks to Lars Rasmussen for getting some last minute data.

V. REFERENCES

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