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A system to control the Hamamatsu H5783 PMT module and condition signals for TDC readout

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We describe design and testing of a prototype system to control the Hamamatsu H5783 miniature PMT and Cockcroft-Walton high voltage generator used on 800 scintillation counters in the CDF-II muon upgrade. Mounted on each counter is a PMT Amplifier and Discriminator (PAD) circuit (5 x 5 cm^2) that controls the H5783 gain, amplifies the mV level signals and generates ECL outputs for signals above an adjustable threshold. A category-5 (ethernet) cable carries power, digital control and discriminated output signals between a PAD and Control and Concentrator Units (CCU). Each CCU supervises the operation of up to 48 counters with an interface to the CDF slow controls system, and concentrates ECL signals onto twisted-pair cables for readout by a TDC.

Introduction

This note describes the design and tests of a prototype circuit to control Hamamatsu H5783 photomultiplier tube (PMT) modules that will be used on 800 scintillation counters in the CDF-II muon upgrade. The H5783 modules contain a miniature (8 mm diameter) PMT and an adjustable HV generator, in a sealed package (2 x 2 x 5 cm^3), suitable for use with the waveshifting fiber readout of these counters. Modules require 12 volt power, and a variable voltage, 0 to 1 volt, to adjust the PMT gain.

A PMT Amplifier and Discriminator (PAD) circuit board (5 x 5 cm^2) mounts on or near each counter to control the H5783 PMT gain, amplify the PMT signal and discriminate against noise with an adjustable threshold. Each PAD communicates with a Control and Concentrator Unit (CCU) via an eight-wire, category 5 (ethernet) cable.

Phototube Amplifier and Discriminator

The prototype PAD circuit schematic is shown in Fig. 1. PMT signals are amplified by a commercial amplifier chip (Analog Devices, AD8015) that has a 240 Mhz bandwidth, 1.5 ns rise time, differential gain of 200 for inputs less than 2 mV, and a differential output saturation of 1.1 V. The amplifier is capacitively coupled and impedance matched to the 50 ohm signal cable of the PMT. The differential discriminator (AD96685) has a 2 ns rise time, and a time-over-threshold output width. Data for control of PAD functions is received via an RS232 interface (DS14C89). One section of a digital control, dual potentiometer (AD8402) adjusts the voltage for the PMT gain, while a second section injects a small DC current into the amplifier input to generate a differential threshold voltage at the discriminator input. Referenced to the input voltage, the discriminator threshold can be adjusted from 0.2 to 3.5 mV. Potentiometers are used in the voltage divider mode, the mode least sensitive to temperature or component variations, shifting the burden of control function stability to voltage regulation. To insure clean DC power for each voltage, noise is bypassed to ground with two capacitors.

The system schematic is shown in Fig. 2. Each H5783 PMT module is connected to a PAD by an RF signal cable (RG174) and by four wires for the power, ground, a reference voltage (1.2 V, generated by the module), and a PMT gain adjustment voltage. Each PAD is connected to a CCU via a category 5 cable, using three wires for power (15 mA @ –5 V, 40 mA @ +12 V), three for serial data adjusting gain and threshold potentiometers, and a twisted pair of wires for the ECL output signals. The power distribution from the CCU to each PAD will be current limited or fused. In a CCU, ECL signals from up to 48 counters are concentrated onto twisted pair cables for TDC readout.

A CCU prototype does not exist at this time. To test the PAD prototype, a simple program generated the PAD control signals on a PC parallel port.

Test results

A schematic of the system used to test the PAD prototype is shown in Fig. 3. A small scintillator, placed in front of the phototube module, is illuminated by a radioactive source. The PMT output signal is split (and impedance matched) to the PAD input and to the oscilloscope Channel A (upper traces). In all tests described below, the oscilloscope is triggered on the discriminator output, Channel B (lower traces). The results are not sensitive to control cable length from 3 ft, to the 40 ft length typically used in CDF.

The PAD threshold settings are either 0.21 mV (low), or 2.0 mV (high), while HV settings for the PMT are 600 V (low gain) and 800 V (high gain). Low gain PMT signals are shown on a 2 mV/division scale in the top two pictures of Figure 4. High gain PMT signals are shown in the middle two pictures on a sensitive scale (2 mV/division). Since a large fraction of those signals extend below the visible area of the screen, we include the bottom two pictures with the high gain signals shown on a less sensitive scale (20 mV/division). In each case, the picture on the left is with the low threshold setting while the picture on the right shows the result with the high threshold. The low threshold signals are typical of PMT pulses while the high threshold setting yields 2 mV minimum pulse heights, as expected. The PAD outputs are similar for both thresholds, though the rate is lower with the high threshold.

Discussion

PAD circuit gain and threshold control functions work as designed. Thresholds on input pulses can be set in the range 0.21mV to 3.5 mV. For the gain and threshold settings in the typical working environment used here, background counting rates were less than 1 Hz. In general, circuit oscillations are absent over the full range of threshold. To limit any tendency for the circuit to oscillate at low threshold settings, it is important to avoid unshielded leads on the amplifier input. An RF shielded container has been designed for the PAD; however an unshielded circuit was used for these tests. By using Velcro, the shield box, just slightly larger than the current PAD circuit board, can be mounted on the cover of a counter, close to the PMT, with the control cable secured to the counter by a strain relief.

With low thresholds, the activity of the source generated >1 MHz of PMT signals, without noticeable PAD threshold or gain changes. This rate capability is suitable for use in a coincidence with the muon drift chambers. The pulses have a < 2ns rise time and a 5 ns fall time, much faster than the decay time (about 10 ns) of the wave shifting fibers used in the counters. When spaced more than 5ns apart, signals for individual photoelectron arrival times will generate multiple PAD output pulses. If desired, multiple signals can be coalesced in the CCU before transmission to the TDC. With the PMT operating at 800V (1000 V maximum) single photoelectrons typically will produce signals of 2 mV, safely above the PAD circuit's lowest threshold, 0.21 mV.

Using short (< 20 cm) cables from the PMT to the RF shielded PAD, will minimize ambient noise pickup at the amplifier input. In a room with PCs and other electronic equipment running nearby ambient noise in our tests has always been below the 0.21 mV minimum threshold.

Post prototype features

We hope to include additional features in the next version of the PAD. For timing calibration and system testing, a short pulse suitable to fire an LED can be implemented with no additional control cable lines. During normal data downloads, LED pulses are inconsequential, therefore, a clock pulse formed in the control station by an external trigger can instruct a PAD to generate a pulse. The pulse will be carried by shielded cable from a small 2-pin connector on the PAD to an LED on the counter. We will also add a test point on the PAD circuit board, allowing the PAD input to be viewed with an amplified scope probe.

The CCU will be designed to sense if power to a PAD is interrupted during installation or debugging. On restoration of the current, the CCU will download the gain and threshold settings.

Cost Estimate

PAD units, assembled and tested, will cost $42/channel, including the LED driver and test features. The cost breakdown, given in Table 1, is based on the prototype and quotes for components for 800 counters. For the CCU, the cost breakdown, also given in Table 1, is based on inquiries, catalog prices, or past experience. The category 5 cable costs (40', terminated, non-plenum, @ $5 unshielded or $10 shielded), and connectors on the PMT leads are not included in the cost estimate.

Labor costs are based on using students for assembly and testing of PAD and CCU units. For 800 PAD channels (+64 spares) and 24 CCU (+2 spare cards), the total cost of the system is $59,616 ($68.3/channel).

Table 1: Per Channel and Total Cost Summary

PMT Amplifier and Discriminator (PAD)	$42	
Amplifier ($6)		Voltage regulator and passive parts ($1)
Connectors ($8)		Board/Etching ($3)
Discriminator ($2)		HV and threshold control ($6)
Stuff and solder ($3)		Digital interface ($4)
LED pulser and control ($5)		RF shield case ($2)
Labor to assemble and test ($2)		
Control and Concentrator Unit		
for 24 channels	$19	
SBComputer ($200/24 = $8)		PS ($100/24 = $4)
Case, AC, hardware ($100/24 =$4)		Wiring and Connectors ($25/24 = $1)
Labor to assemble and test ($50/24=$2)		
for 48 channels	$12	
SBComputer ($200/48 = $4)		PS ($150/48 = $3)
Case, AC, hardware ($100/48 =$2)		Wiring and Connectors ($50/48 = $1)
Labor to assemble and test ($100/48=$2)		
Control Unit Cards (24 channels/card)	$12	
Connectors ($50/24 = $2)		Board/Etching ($80/24 = $3)
Stuff and Solder ($80/24 = $3)		Digital interfacing ($80/24 = 3$)
Labor to assemble and test ($20/24=$1)		

Cost Summary

864 PAD ($42/channel)	36,288
12 Control Units 24-ch. ($456)	5,472
12 Control Units 48-ch. ($576)	6,912
38 CCU cards ($288/24-ch.)	10,944
Total	$59,616

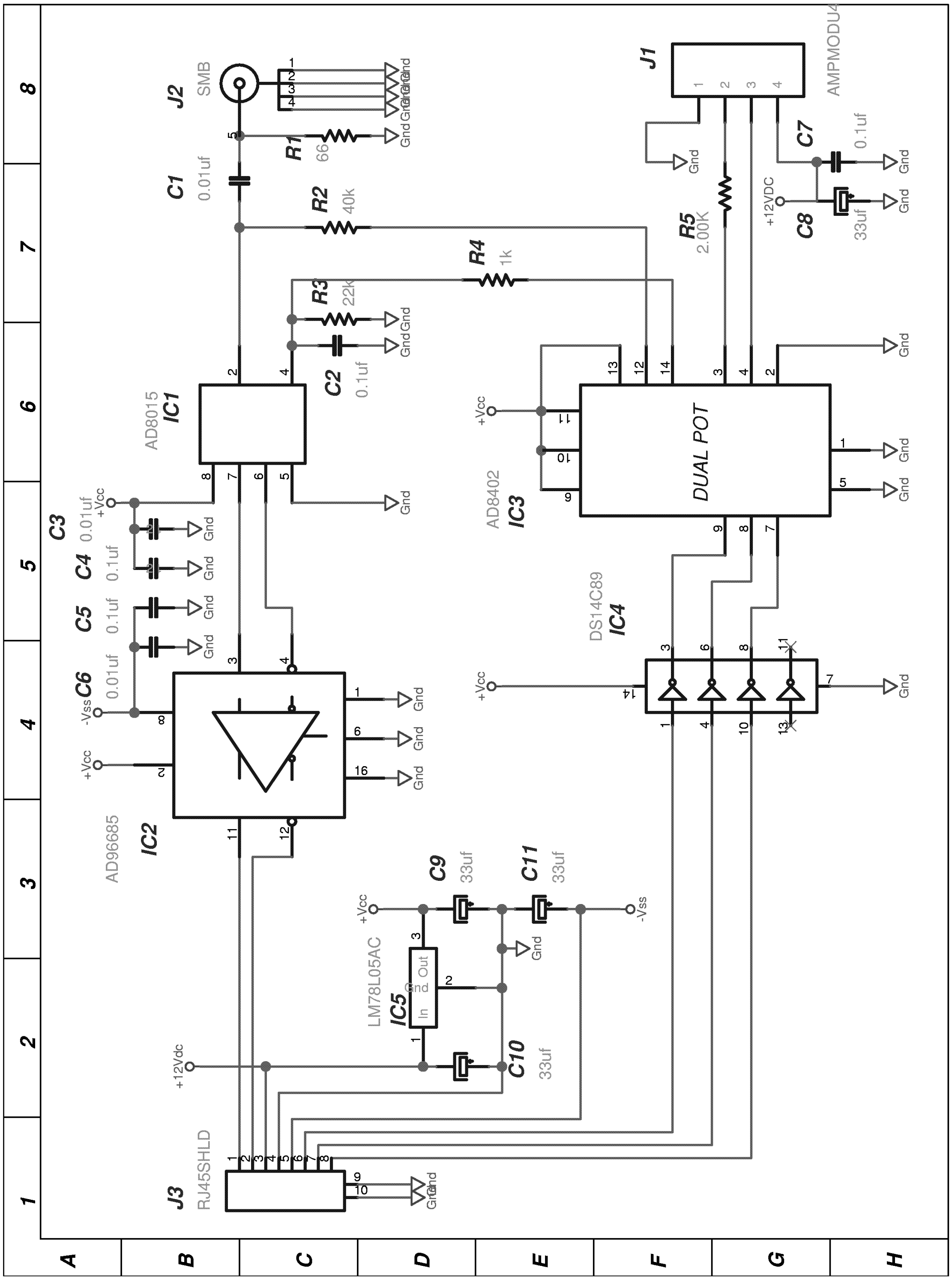
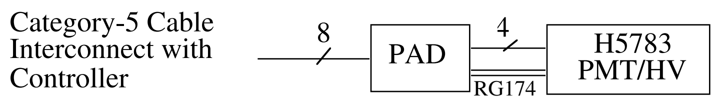


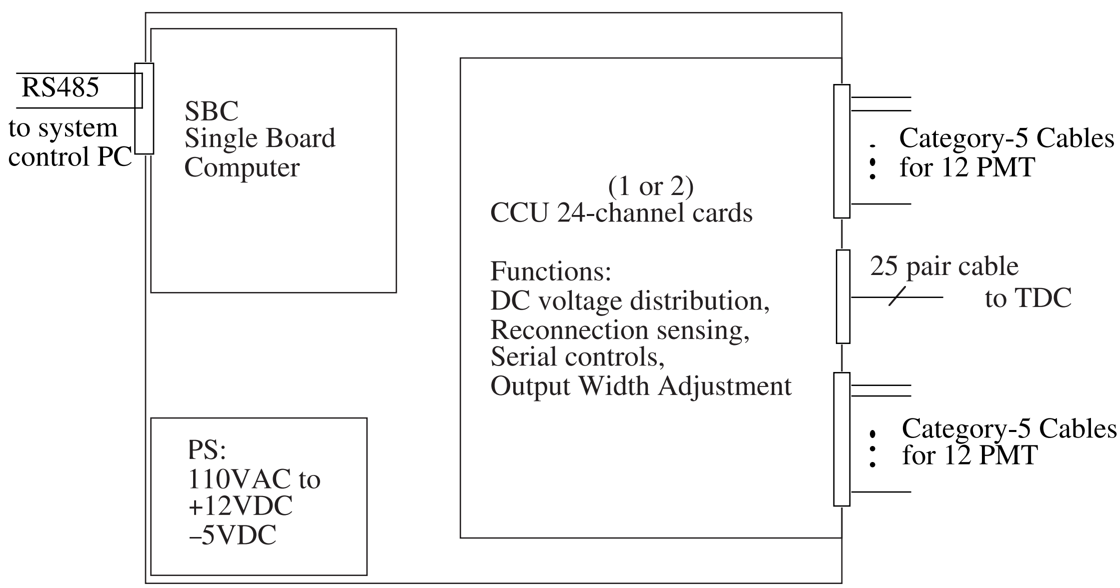
Figure 1: Phototube Amplifier and Discriminator Schematic

System Components
for H5783 PMT Module Readout

H5783 PMT Module and PMT Amplifier - Discriminator (PAD)



Control and Concentrator Unit (CCU)



Interface to CDF-II Slow Controls

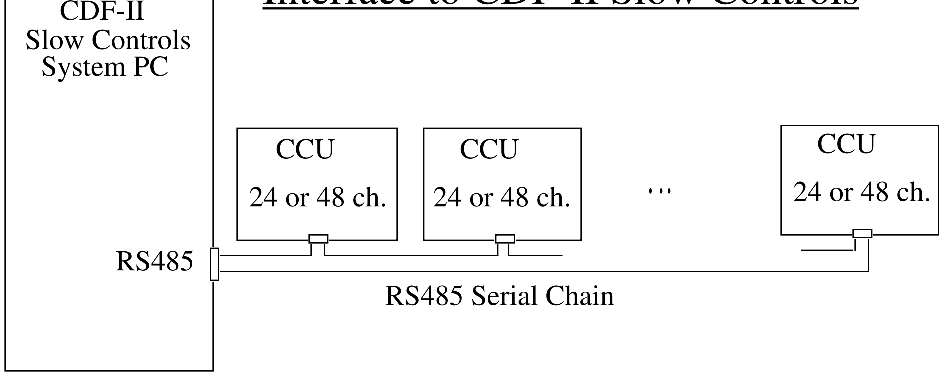


Figure 2: System schematic for control of Hamamatsu H5783 PMT

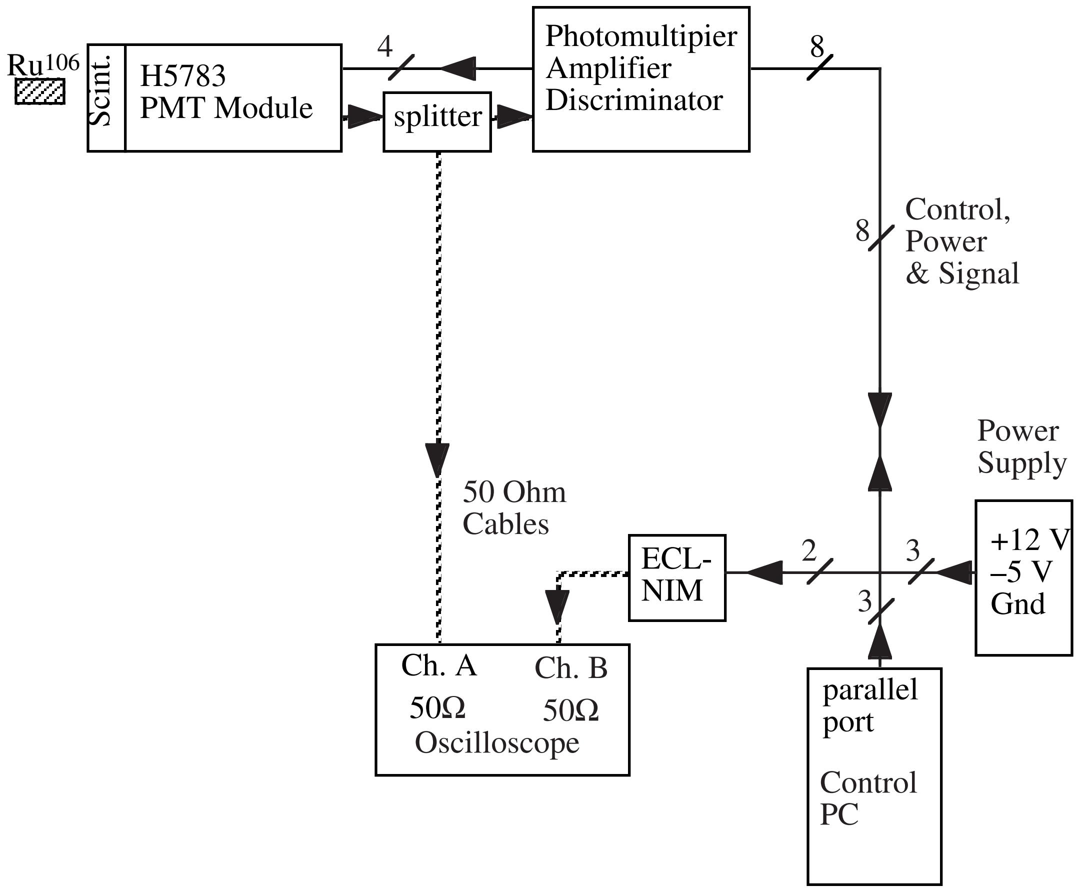


Figure 3. Testing System for PAD

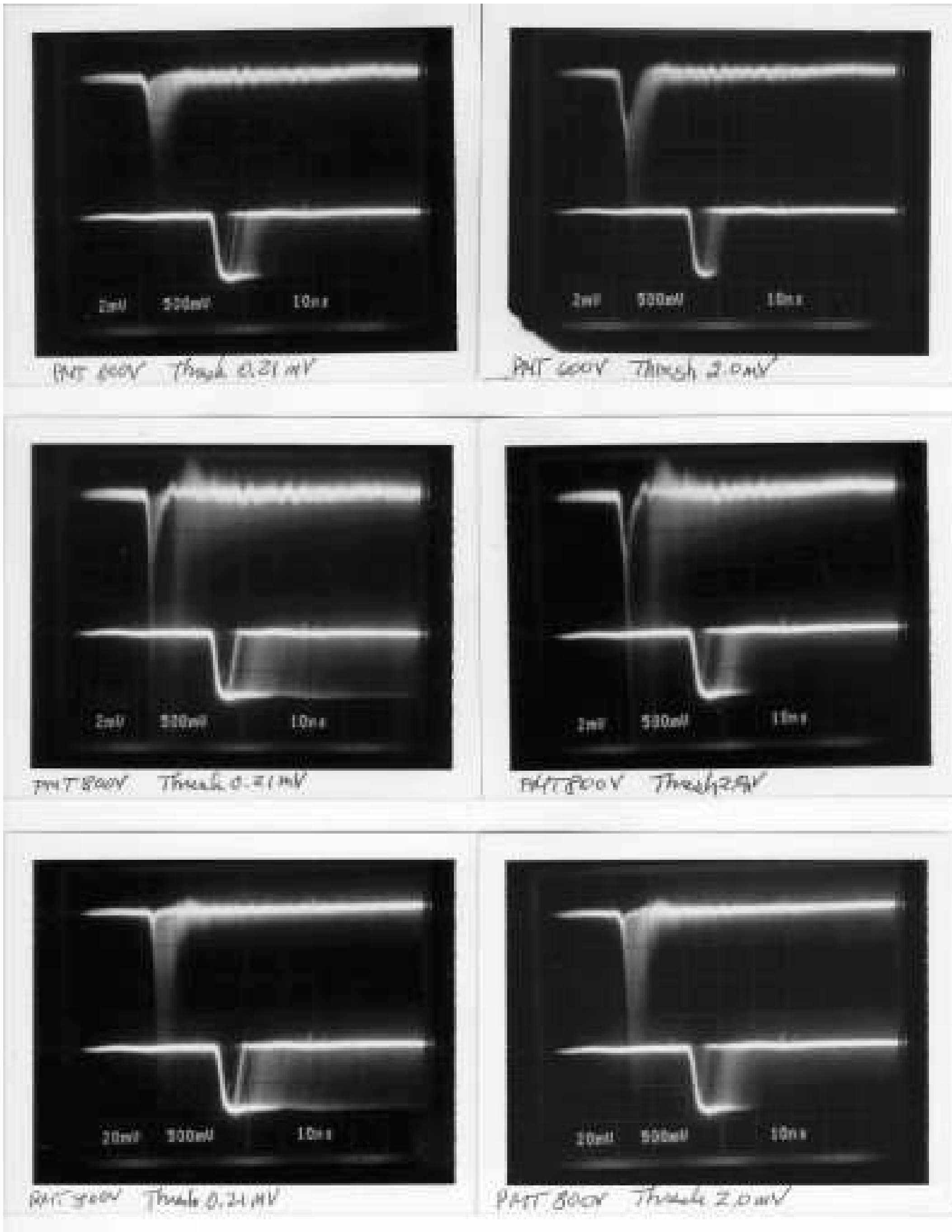


Figure 4. Pictures of PMT pulses (top traces) and PAD outputs (lower traces).
Scope trigger is on lower trace. Discriminator threshold: left, 0.21 mV; right, 2.0 mV.
PMT HV: top, 600 V; middle, 800 V; bottom, 800 V (note 20mV/div).