DEVELOPMENT OF AN ULTRA-FAST PHOTOMULTIPLIER TUBE FOR THE NEXT GENERATION OF GAMMA-RAY CHERENKOV DETECTORS FOR THE NATIONAL IGNITION FACILITY [PD-PMT]

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ABSTRACT

A new ultra fast photomultiplier tube and associated drivers has been developed for use in the next generation of Gamma-ray High Pressure Gas Cherenkov Detectors [GCD] for the National Ignition Facility (NIF). Pulse-dilation technology has been applied to a standard MCP-based photomultiplier tube (PMT) to improve the temporal response time by about 10X. The tube has been packaged suitably for deployment on the NIF and remote electronics has been designed to deliver the required non-linear waveforms to the pulse dilation electrode. This is achieved with an avalanche pulse generator system capable of generating fast arbitrary waveforms over the useful parameter space. The pulse is delivered via fast impedance-matching transformers and isolators, allowing the cathode to be ramped very quickly between two high voltages in a controlled non-linear manner. This results in near linear pulse dilation over several ns. The device has a built in fiducial system that allows easy calibration and testing with fibre optic [FO] laser sources. Results will be presented demonstrating the greatly improved response time and other parameters of the device. Fuller results of further testing will be presented by others.

1 INTRODUCTION TO PULSE DILATION FOR A PMT

Currently Photomultiplier tubes [PMTs] with an impulse response function of ~ 100ps are used in GCDs to investigate the properties of gamma rays emitted in ICF experiments on the NIF [1]. The Pulse Dilation Photo Multiplier Tube [PD-PMT] is based on one of these standard fast Photo Multiplier Tubes manufactured by Photek and is able to deliver an impulse response nearer 12ps for a limited record length of ~10 ns. The standard PMT consists of a photocathode, MCP, mesh and anode in an ultra high vacuum envelope. Conventionally, electrons are accelerated from the photocathode onto the MCP. The MCP provides signal gain and the exiting electrons are accelerated through the mesh and onto the anode, where the signal to be recorded is produced. The mesh is grounded and is a reference for the accelerating potential at the MCP exit. The mesh

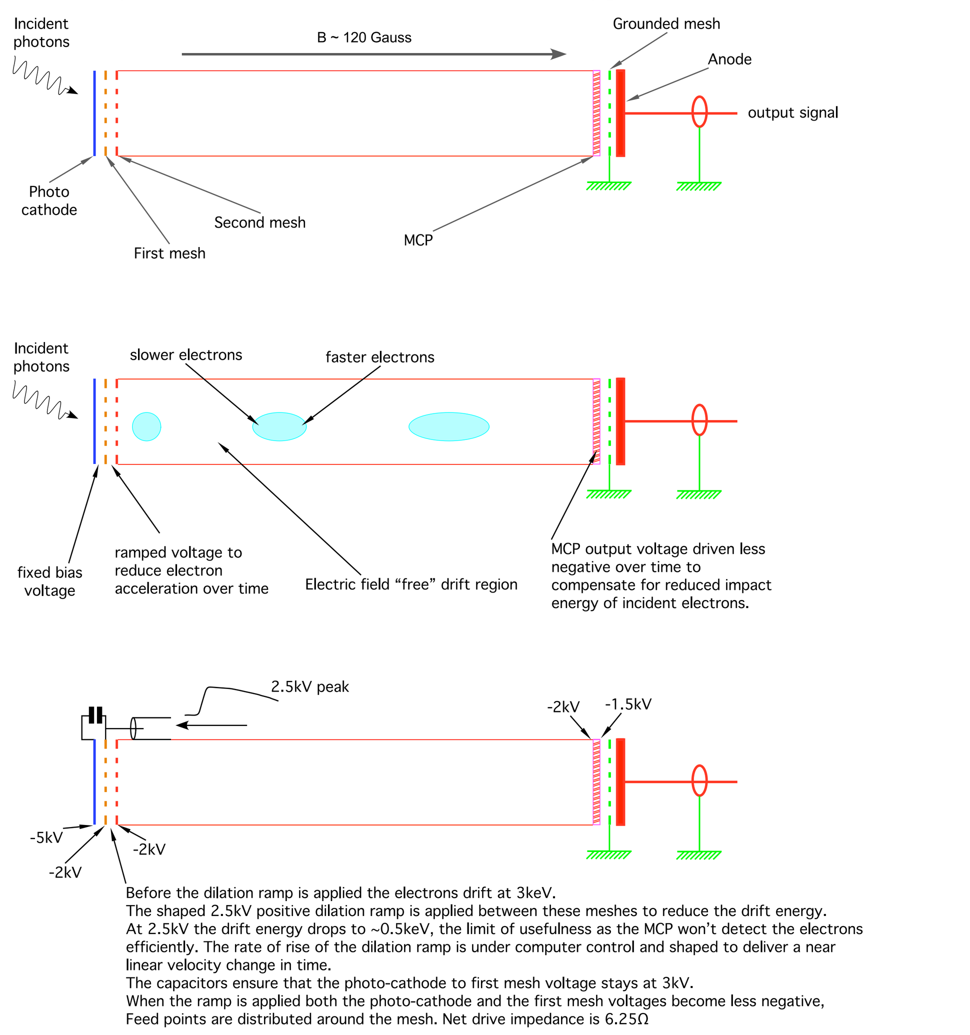


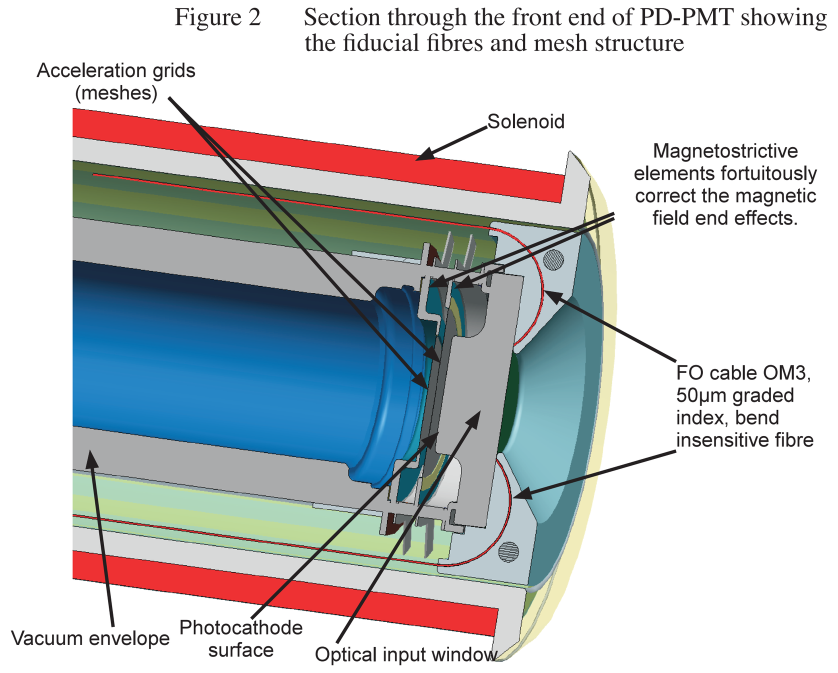
Figure 1 Pulse dilation scheme

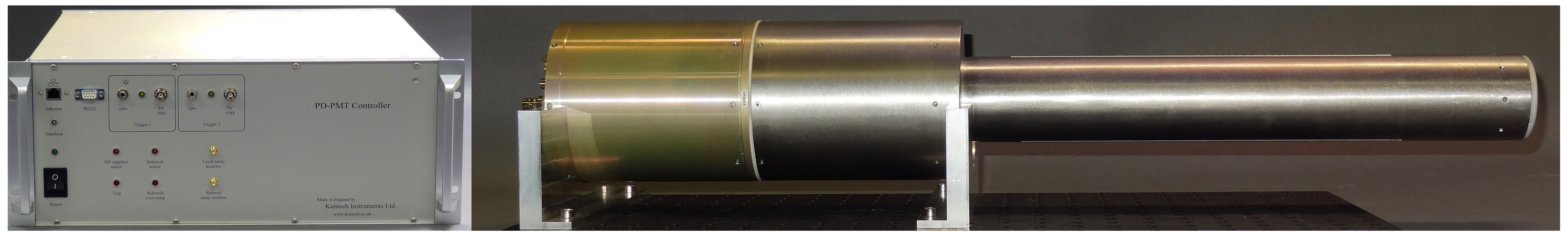
also stops the "mirror" charge effects that would otherwise give rise to a precursor signal in the anode. The basic tube has a response time of around 100ps. This is a bit fast for propagation to a recording device (typically 50m away on the NIF). To overcome this, the signal is used to drive a fibre optic modulator and to modulate an optical signal that is easily transported over long distances to a high bandwidth optical recording system.

The objective of developing the PD-PMT is effectively to increase the system bandwidth for a short time. This has several advantages:

1. The time history of the signal under investigation can be more highly resolved.
2. The impulse response function [IRF] of the PMT no longer affects the recorded signal.
3. The recording device does not need such a high bandwidth.
4. It may be possible to do away with the FO modulator and carry the signal to a recorder in coaxial cable.

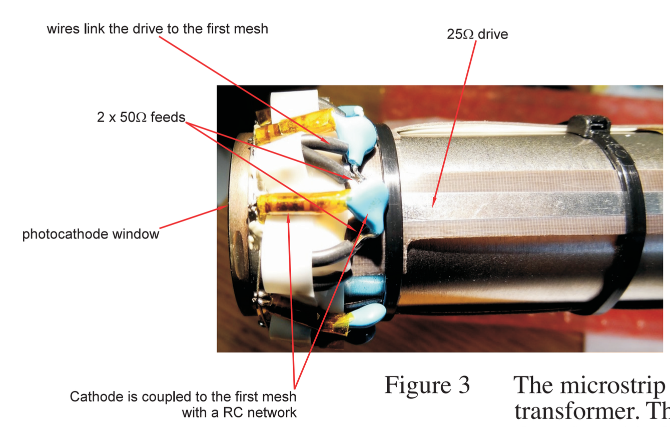
Figure 2 Section through the front end of PD-PMT showing the fiducial fibres and mesh structure





The pulse dilation converts a short-lived temporal history to a longer timescale for a limited time. The technology has been in use on the NIF for x-ray imaging in devices such as DIXI[2, 3] and SLOS[4].

For pulse dilation the standard PMT is modified by increasing the distance from the cathode to MCP input face from a sub mm gap to hundreds of mm as shown in Figure 1. In order to make sure the photo-electrons go from the cathode onto the MCP an axial magnetic field is applied. The field is larger at the rear end, near the MCP, to ensure that electrons from near the edge of the photo-cathode do arrive at the MCP in spite of the Larmor radius being ~ 0.25mm. The bunch of electrons from a 9mm cathode can be up to ~ 10mm in diameter for a 130 gauss field and 1eV photo electrons.



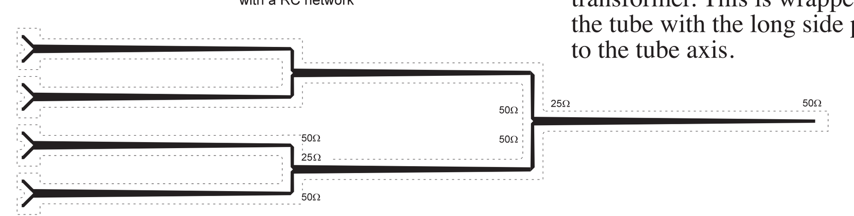


Figure 3 The microstrip impedance matching transformer. This is wrapped around the tube with the long side parallel to the tube axis.

In addition two meshes are added to the tube just after the photo-cathode. These permit the manipulation of the electron energies as they leave the photo-cathode region by changing the voltages on them. Effectively the tube has energy modulation.

Dilation works by reducing the electric field between these two meshes in time during the event under investigation. This results in later liberated photo-electrons being accelerated towards the MCP less and having a lower velocity as they leave the second mesh. The resulting bunch of electrons produced from the event then has differential velocities encoded on it. By allowing the bunch to drift, the slower electrons lag further behind the early faster ones and the time history encoded in the bunch is stretched (dilated) as it passes down the tube. This idea was first proposed and tried by Prosser [5] in oscilloscopes.

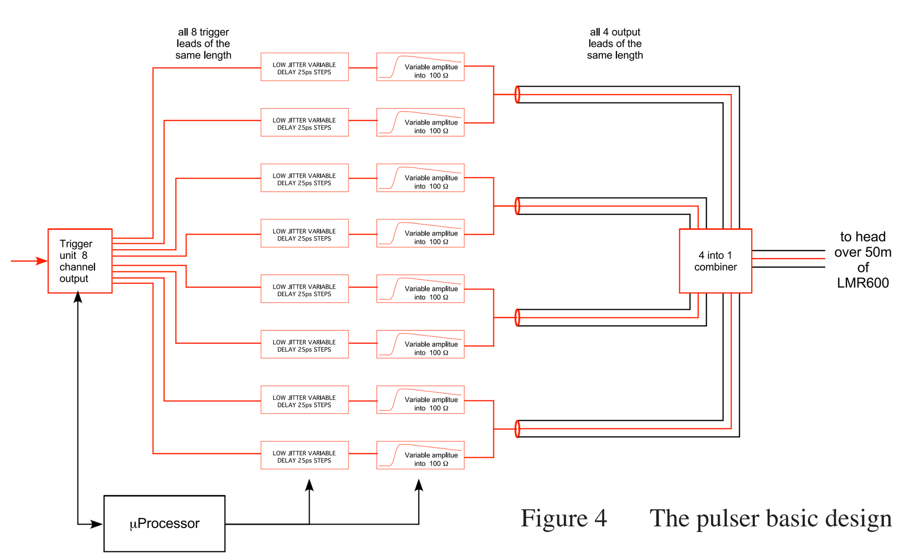


Figure 4 The pulser basic design

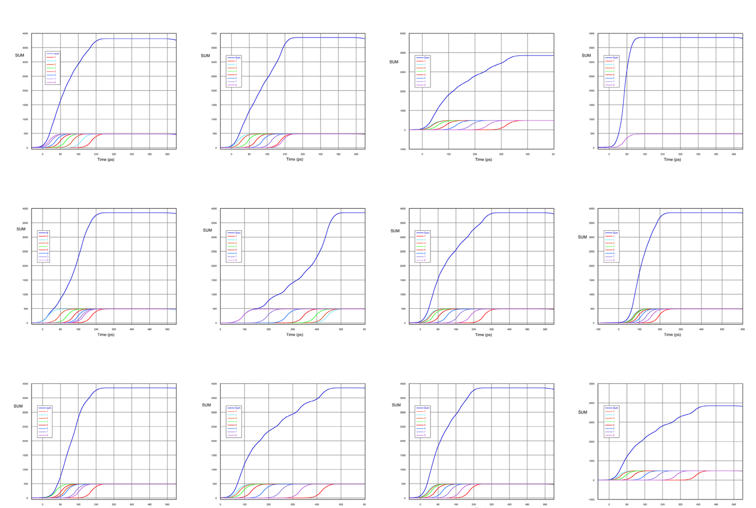


Figure 5 Simulated arbitrary waveforms for the photo-cathode mesh drive. The required waveform is a parabola at the photocathode, but it is also necessary to compensate for the losses in the 50m of cabling (which has an IRF like an error function). The actual shapes used were obtained optically by empirically tweaking the various delays to make the dilation as linear as possible, see Figure 13.

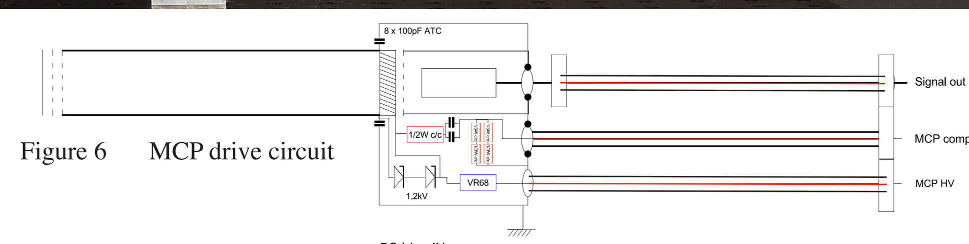


Figure 6 MCP drive circuit

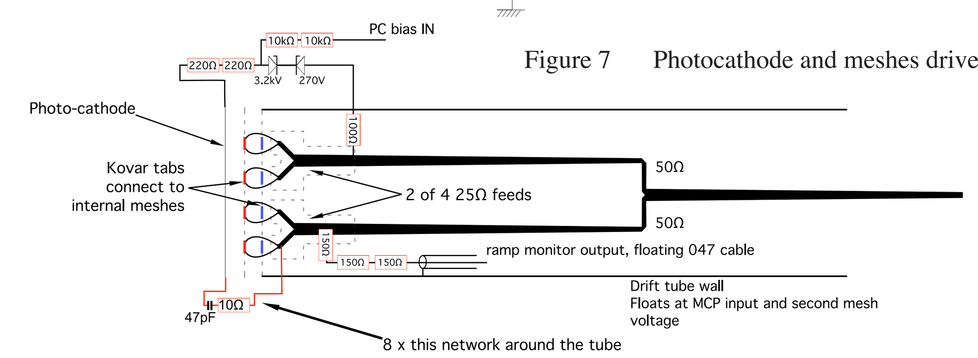
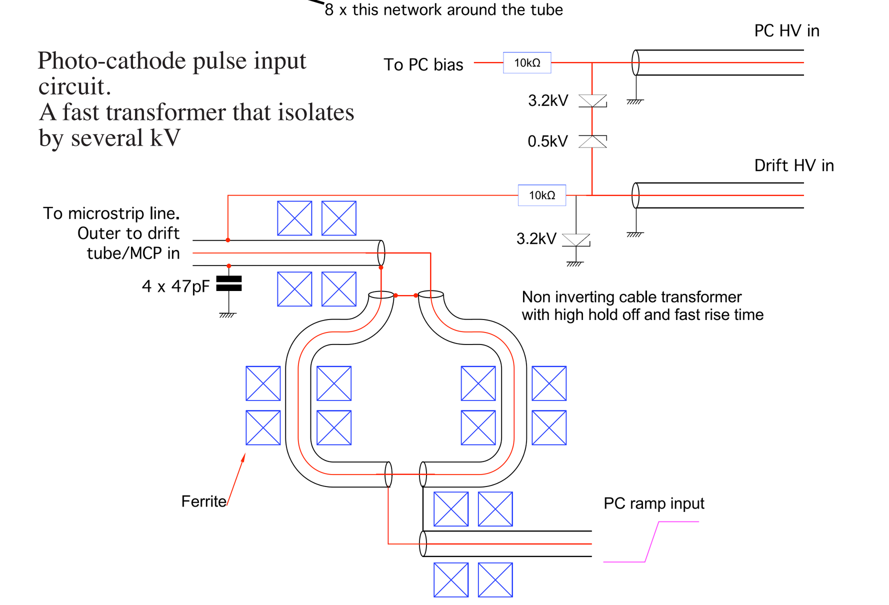


Figure 7 Photocathode and meshes drive

Figure 8 Photo-cathode pulse input circuit. A fast transformer that isolates by several kV



In order that the dilated bunch of electrons has a linear temporal transformation to real time it is necessary that the modulation of the electron velocity as a function of time at the cathode region is linear. This implies that the voltage change must be non linear as the voltage affects the energy. Consequently a shaped voltage waveform has to be applied between the two meshes. The shaping of high voltage pulses on a sub nanosecond timescale is done with a sophisticated avalanche pulse generator developed for this.

2 DILATION PULSER

The avalanche pulse generator used for the dilation drive is based upon 8 individual pulse generators. Each of these pulser drives 100Ω. They have variable amplitude and precision low jitter variable timing, both of which are under computer control. The eight pulses are added together. The avalanche pulses have a fast leading edge but decay quite slowly. This allows many varied shapes of pulse to be applied to the dilation meshes. See Figure 4 for the pulser layout and Figure 5 for some simulated results. In order to apply the dilation pulse to the meshes near the cathode the drive impedance has to be reduced to 6.25Ω. In addition the voltage is applied across two meshes and they start at the MCP input voltage of ~-2kV. I.e. the pulse drive cable is floating at -2kV.

These requirements are achieved with two transformers. Initially a cable transformer provides the floating drive with very fast rise time capable of holding off >5kV. The second transformer

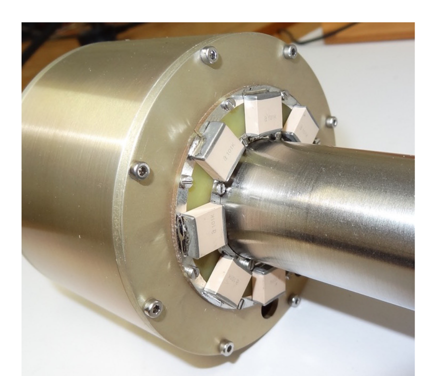
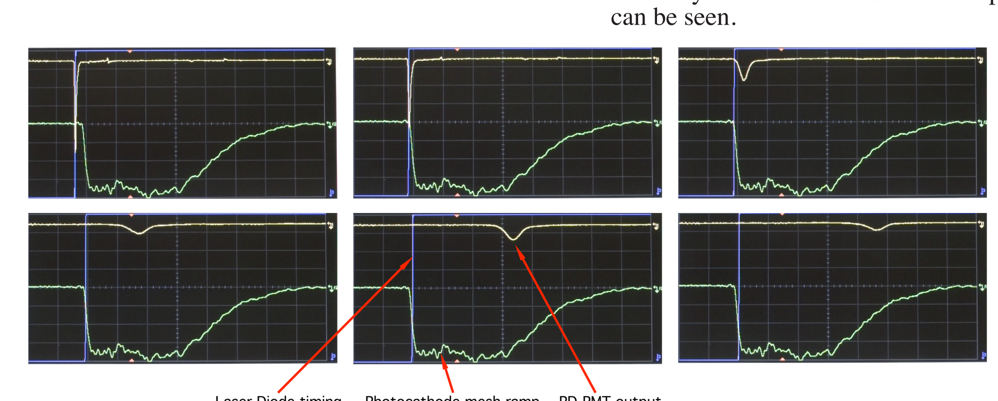


Figure 9 [Left] The drift tube and MCP input are at the same potential and decoupled from ground with 8 fast capacitors. The can around the rear end of the tube stops RF noise from the ramp getting onto the MCP and upsetting the gain.

Figure 10 [Below] Oscilloscope traces showing the PD-PMT output (top), the negative going ramp (bottom) and the timing of the laser diode w.r.t. the ramp (vertical blue line). The laser diode is moved successively through the ramp edge and the delayed and dilated PD-PMT output can be seen.



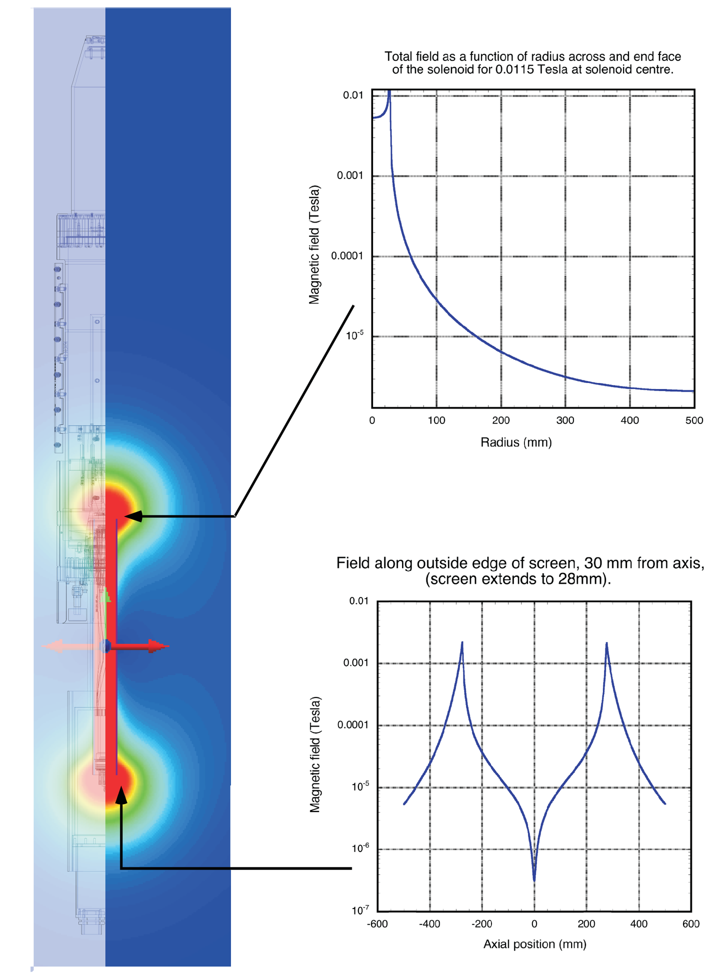


Figure 11 Estimates of stray fields outside solenoid of PD-PMT using a simplified geometry. Central field 0.0115 Tesla (approx. 1000 turns at 5 amps). No correction for magnetic materials in tube or external parts of the detector. Includes a 1 mm thick mu metal screen (which does not saturate) the full length of the solenoid. No end plate screening.

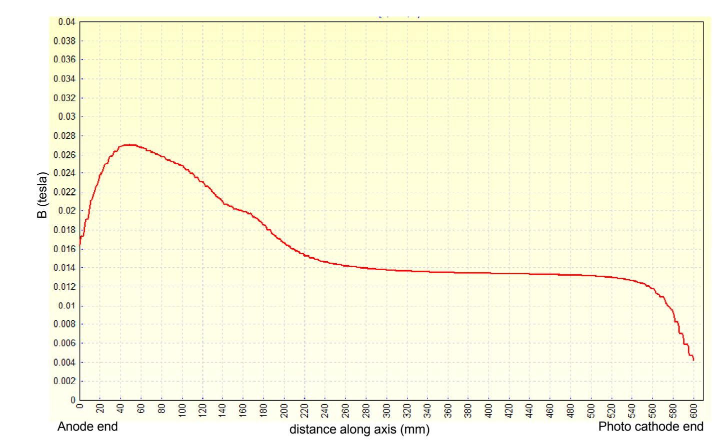


Figure 12 Calculated field with rear end demagnification section

is a microstrip line with a PTFE dielectric that progressively splits the 50Ω input into eight 50Ω outputs which are mounted around the tube and end near the meshes.

3 MAGNETIC FIELD CALCULATIONS

As this is a non imaging device the field constraints are considerably reduced from previous dilation tubes the authors have been involved with. The main criterion is that the field gradient is not so steep that electrons are reflected and that electrons emitted at the photo-cathode will find their way to the MCP, all in the same time for the same exit velocity from the cathode region. Consequently, the field around the rear end of the tube is stronger than at the input, see Figure 12. This makes an insignificant change in the axial velocity. Concern about the effects of the magnetostrictive vacuum envelope elements near the input end of the tube proved unfounded as the simulations showed that they could act like a compensating coil if the position of the cathode in the end of the solenoid was suitably chosen.

In order to reduce the stray fields from the solenoid, a mu metal screen was used. Simulations showed that provided this did not saturate it reduced the field to acceptable levels, see Figure 11. As this is not an imaging device the field requirements are modest. The Larmor diameter of the photo electrons must just be a lot smaller than the cathode and MCP diameters. This was achieved by around a factor of 9 for the UV photons that are expected. If we assume that the work function is ~ energy of the lowest energy photon the photo-cathode will detect and then look at the surplus energy that the UV photons have, the Larmor radius is ~ 0.5 mm for the 13mT field at the photo-cathode.

Simple calculations were performed to establish that the solenoid would operate with ~ 50 volts and the winding would weigh ~ 4kg.

4 FIDUCIAL SYSTEM

The nature of a dilated tube makes timing crucial. The device has to be triggered so that the event occurs at the correct part in the ramp applied to the cathode region.

PD-PMT has an electrical monitor (decoupled from the high DC voltages) on the electrical signal at the cathode and has two fibre optic fiducial inputs. The fibre has to take a signal from the rear bulkhead of the assembly to the photo-cathode and inject the light. A multi-mode fibre (Clearcurve® OM_2) with a graded index (for good bandwidth) and good resistance to being bent through tight radii was chosen. The lengths of the two fibre were matched mechanically. The fibres point at the cathode without obscuring the optical access to the cathode required for the detector, see Figure 1.

5 MCP GAIN COMPENSATION

When the electrons impact the MCP they generate secondary electrons in the MCP channels. The number generated per impact event depends upon the incident energy. Consequently the electrons later in the dilated bunch produce fewer secondary electrons

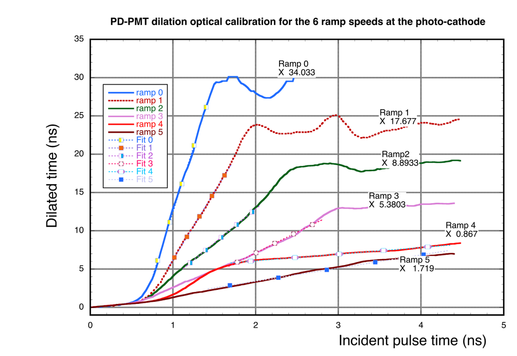


Figure 13 Examples of dilation ramps measured optically. These are the six with the unit as supplied.

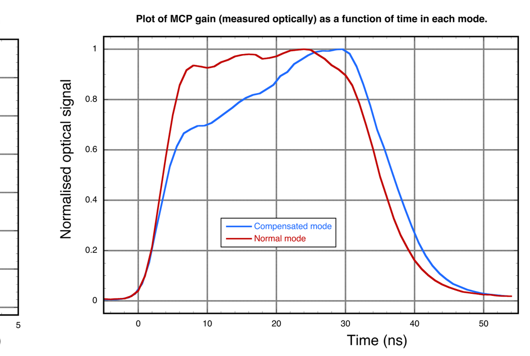


Figure 14 The MCP gain as a function of time with and without compensation turned on. The slope of the compensated gain profile can be adjusted.

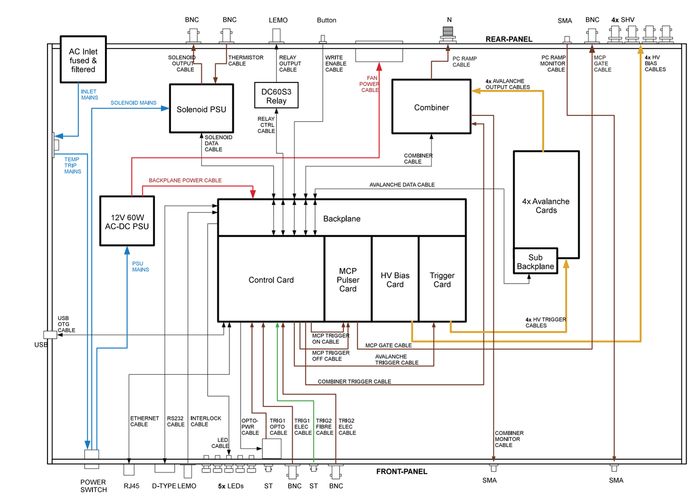


Figure 15 The control box, block diagram, indicating the various electronic modules.

than do earlier electrons. This appears as a fall in the gain of the tube as a function of time. In PD-PMT this can be compensated for by increasing the MCP gain during the time that the electron bunch arrives at the MCP. A small increase in the MCP voltage can compensate for the gain. This compensation is on the dilated timescale, not the un-dilated time, so it is a modest rate of rise of voltage on the MCP. An alternative but untried method would be to use another mesh in front of the MCP to accelerate the electrons. This acceleration could be increased in time; again on the dilated timescale. Note that the transmission of the meshes is typically ~ 70%, so more meshes has problems with reducing the sensitivity of the tube, however, the process has the potential to be more linear.

The electronics package has the ability to increase the gain approximately linearly during the dilated event. The slope of the gain adjustment is nominally linear but the slope can be changed. Two modes are shown in Figure 14.

A FET based pulse generator is used to generate the pulse to drive the gain compensation of the MCP.

6 PRELIMINARY RESULTS

Other papers will deal with the testing of this device using short pulse lasers. In addition to that, the device was tested with a ~30ps laser diode injected into the fiducial system. Some of the results obtained are shown here.

A 630nm 30ps laser diode was injected into a single mode fibre, this was then connected to a fiducial input to the PD-PMT. The laser diode sync. output was displayed on an oscilloscope along with the monitor of the ramp which is derived from the first photo-cathode mesh and the output signal of the PD-PMT. The timings of the three signals were skewed so that the display represented the part of the ramp where the laser diode pulse arrived at the photo-cathode. The relative timing between the laser diode and the ramp was adjusted with the scope triggering from the ramp signal, so that it appears stationary in subsequent pictures of the scope output. The relative timing was adjusted using a Highland P400 delay unit driven by a computer. This allowed the laser diode timing to be swept through the ramp and gave a very visual picture of dilation, especially when shown as a video. Some snap shots from the video are shown in Figure 10.

The scope traces clearly show the effects of dilation and that the IRF no longer affects the recorded data. For shorter incident pulses this may return.

7 REFERENCES

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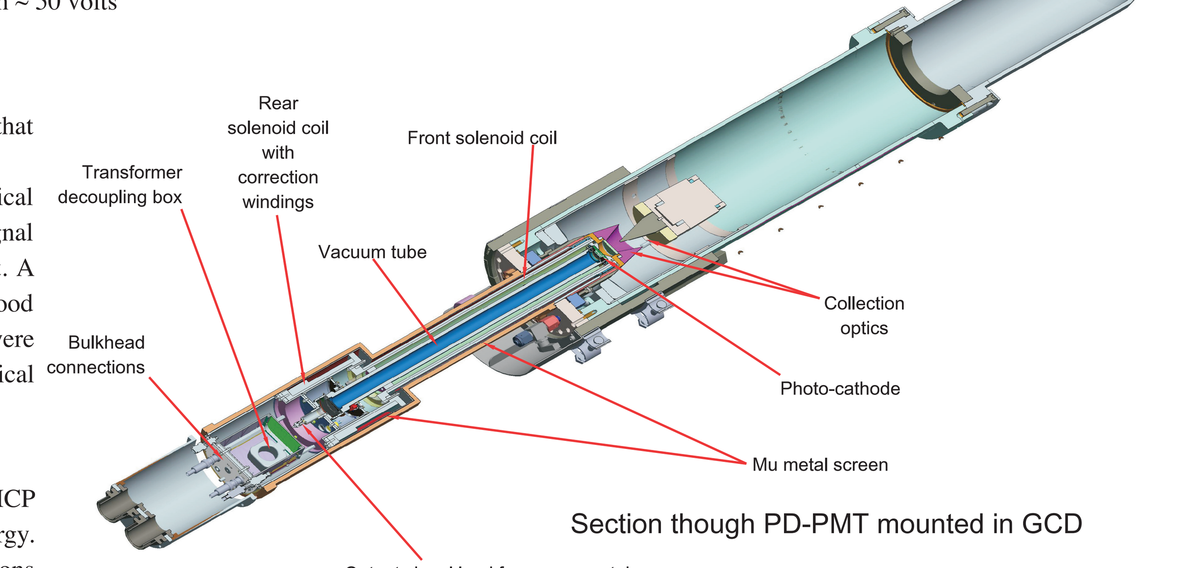

Section though PD-PMT mounted in GCD