Transmission-Line Readout with Good Time and Space Resolutions for Planacon MCP-PMTs

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Abstract

With commercially-available multi-anode microchannel plate photomultiplier tubes (MCP-PMT) and electronics, resolutions significantly better than 10 psec have been achieved in small systems with a few readout channels[1,2]. For large-scale time-of-flight systems used in particle physics, which may cover tens of square meters, a solution must be found with a manageable number of electronics channels and low total power consumption on the readout electronics without degrading the system timing resolution. We present here the design of a transmission-line readout for a Photonis Planacon MCP-PMT that has these characteristics. The tube, which is 5 cm square, is characterized by signal pulse rise times in the order of 200 psec and transit time spreads (TTS) in the order of 25 psec[1, 2]. The model 85011-011 MCP has 1024 anode pads laid out in an array of 32 by 32 on the back of the tube. The proposed readout is implemented on a Rogers 4350B printed circuit board with 32 parallel 50-ohm transmission lines on 1.6 mm centers, each traversing one row of 32 pads. The board is connected with conductive epoxy to the 1024 anodes of the tube, each transmission line being read out on each end.

We have simulated the electrical properties of the transmission-line readout board with Hyperlynx and Spice simulators. The simulations predict that the readout transmission-lines can achieve a signal bandwidth of 3.5 GHz, which should not significantly degrade the time and spatial resolutions intrinsic to the MCP-PMT signals.

I. INTRODUCTION

The typical timing resolution in large time-of-flight detector systems in high energy physics experiments has plateaued at approximately 100 psec [3, 4]. This is set by the characteristic difference in light collection paths in the system, which in turn is set by the transverse size of the detectors, characteristically in the order of one inch (100 psec). To do significantly better requires building detectors covering tens to hundreds of square meters with variations in the length of signal path appreciably less than 1 mm, and electronics systems to read them out with long-term stability [5, 6]. Commercially developed MCP-PMT tubes with micro-channel diameter size (pore size) of 2 micron to 25 microns, which achieve an output pulse with rise time in the order of 200 psec and transit time spread in the order of 25 psec, could offer a possible solution,using Cherenkov light generated at the MCP face as a relativistic particle traverses the detector.

Recent measurements have achieved time resolutions on the order of 6 psec using commercial tubes [3,4]. However, the output signals of commercial tubes are collected by a large number of discrete anode pins or pads, typically from 64 to 1024. For instance, the Burle/Photonics model X85011 tube, which is 2 x 2 inches overall, has 32 x 32 anode pads. If we readout each anode pad individually, we require 1024-channels of readout electronics. The challenge is not only to find a solution that retains the tube's intrinsic fast-timing performance, on the order of a few picoseconds, in large scale detectors, but also to have a manageable number of readout channels and low power consumption.
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II. TRANSMISSION-LINE READOUT BOARD

Achieving a very fast rise time signal in MCP-PMT outputs is essential for good timing performance. With commercial tubes, pore size, anode pad size, and the number of anodes have been defined by the manufacturers. However if one buys tubes with bare anode pads, one can design ones own readout boards to reconfigure the outputs to meet the application requirements.

As shown in Figure 1, Burle/Photonics' custom X85011 tube has 32 x 32 anode pads on the back. Each pad is 1.1 x 1.1mm, with a pitch of 1.6mm. Our goal is to design a readout board using fewer channels of electronics to readout all 1024 anodes of the tube without significant degradation of tube's fast timing performance.

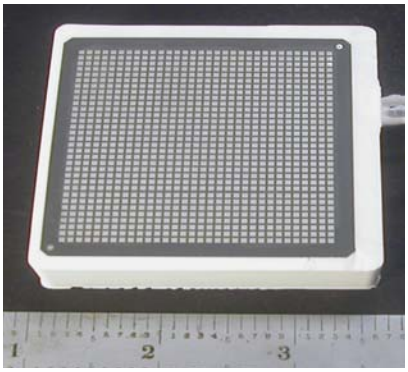

Figure 1: View of 32 x 32 anodes on the back of Burle/Photonics' tube X85011.

Figure 4 shows a prototype of transmission-line readout board designed to adapt for Burle/Photonis tube X85011.

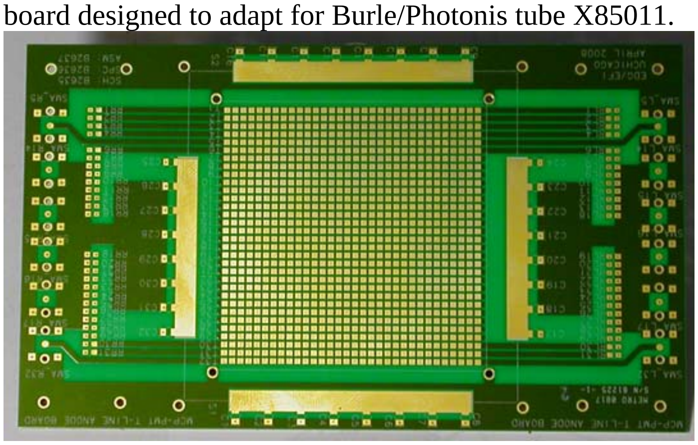

Figure 4. The transmission-line readout board which ties 32 anodes pads in a row, the signals being readout at both ends of the line.

The transmission-line readout board is implemented on a Rogers 4350B printed circuit board with 32 parallel 50-ohm transmission lines on 1.6 mm centers, each traversing one row of anode pads on the back of the tube. Each transmission line is being readout on each end. With this transmission-line readout board, one 1024-anode tube only needs 64-channel readout electronics.

III. MODELING AND SIMULATION OF TRANSMISSION-LINE READOUT

The transmission-line readout board can present excellent analog bandwidth to incorporate with the fast signals from the tube. Figure 5 shows interconnections between the transmission-line and 32 stub-loaded anodes pads.

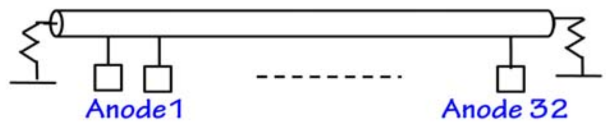

Figure 5: 32 anodes on the back of the tube are stub-tied evenly in a row within 2-inches in the middle of 4-inch transmission-line on the readout printed circuit board

Each anode pad contributes a ~100fF capacitance to the line. The lossy transmission-line model in the simulation was extracted from a layout of the printed circuit board by Hyperlynx.

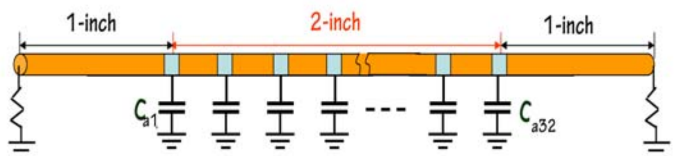

Figure 6: Equivalent schematic of simulation on signal integrity for transmission-line readout board.

The simulation of signal integrity was setup with the equivalent schematic shown in Figure 6. The input signal can be applied on any of the 32 anodes in the simulation.

Figure 7 shows the simulation result of signal integrity. A input force with 100 psec rise time is applied to pad #16. The green is the input pulse on pad #16; the red is the output pulse at the left end; the blue is the output pulse at the right end. The expected 9.6ps time delay was observed over a 1.6mm length difference between left and right with the velocity of ~0.55c on the PCB. The simulation shows that the transmission-line presents an analog bandwidth of 3.5GHz, well-matched to the signal bandwidth from a tube with a rise-time of 100 psec. The observed reflecting ringing on the output pulses are caused by impedance discontinuities over the transmission line. Because the 32 stub-loaded capacitance in the middle of the line results in a slightly lower impedance than 50-ohm.

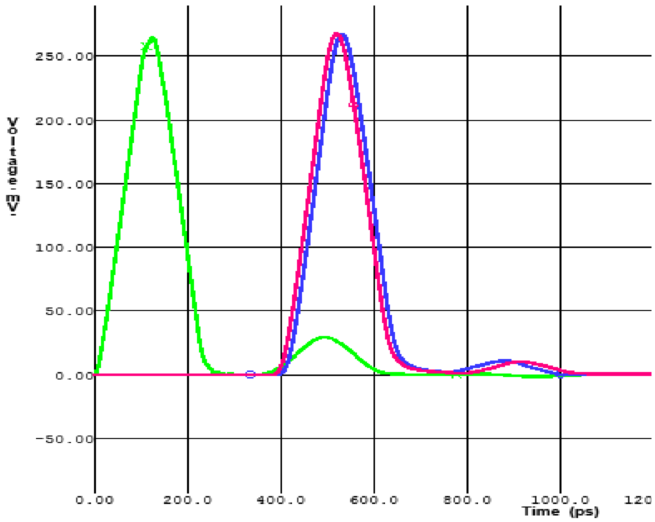

Figure 7: Simulation result of signal integrity on the transmission line with 32 stub-tied anodes. The input force with 100ps rise time is applied to pad #16. The green is the input force; the red is output waveform at the left end of the line; the blue is the output waveform at the right end of the line. The line is designed with 50-ohms and terminated at each end.

In order to avoid stub capacitance over the transmission-line, we propose to design a transmission-line anodes being directly incorporated to the tube in the future. Since there is no more stub capacitance coupled onto the transmission line, the problem of impedance discontinuity can be solved.

Figure 8 shows the simulation result of transmission-line anodes without stub-tied anode pads, the output signals on each end can be well-terminated. No reflection has been found on either side of the line in the simulation.

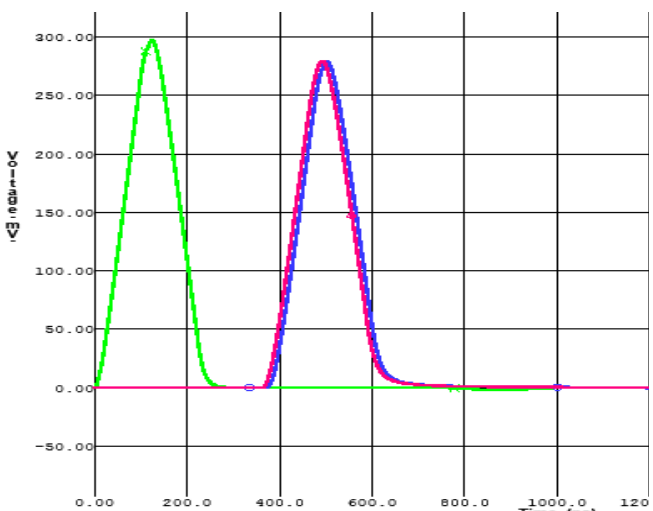

Figure 8: Simulation result of transmission-line without stub-tied anodes. The input force with 100ps rise time applied to pad #16. The green is the input force; the red is output waveform at the left end of the line; the blue is the output waveform at the right end of the line. The line is designed with 50-ohms and terminated at each end.

IV. TRANSMISSION-LINE READOUT ELECTRONCIS

Depending on the system requirements, the transmission-line anodes can be readout in a number of different methods. Figure 9 shows a system aimed to achieve a one to few psec timing resolution.

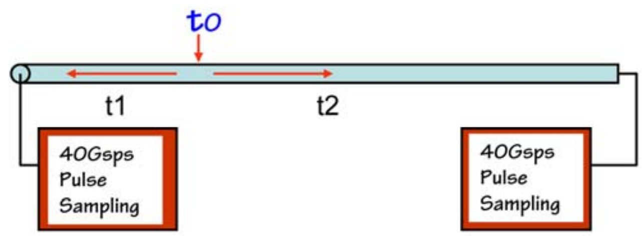

Figure 9: A diagram of transmission-line readout system using fast sampling circuits, aimed to achieve a one to few picoseconds timing resolution.

The readout system described above is based on fast sampling techniques. Comparing to the widely used timing measurement electronics in high energy physics experiments such as leading edge discriminator and time-to-digital converter (TDC); multi-threshold discriminator and TDC; constant-fraction discriminator and time-to-amplitude and ADC; the fast sampling system up to 40GS/s can achieve better timing resolution [7]. With pulse sampling system, a 40GS/s custom designed sampling circuit can be employed to record pulses from both ends of the transmission lines. An additional precision system reference clock may be used as timing calibration.

Transmission-line readout can give timing, spatial and energy information with the same data recorded by sampling circuits. For instance, a photon causes an electron avalanche in the tube; this group of electrons is collected at the time t0 at a point of the transmission line. The collected charge induces a corresponding electric pulse which propagates to both ends in a delay time of t1 and t2 respectively. The voltage waveforms on each end can be recorded by the fast pulse sampling chips. We can process the recorded pulses to precisely find t1 and t2. The "mean-time", which presents the particle striking time t0 can be calculated by summing t1 and t2 then divide by 2; the location hit by the particle can be obtained by taking a difference between t1 and t2. In addition, the integration of total charge collected on both ends represents the energy.

V. CONCLUSION

The ultimate goal in the front-end electronics is to develop a custom ASIC that incorporates fast sampling of the MCP pulses for transmission-line readout. This design is in progress. As an intermediate step, we will test the transmission-line architecture using a 40GS/s digital oscilloscope as well as Ortec NIM module constant-fraction discriminators and time-to-digital converters having approximately 3 psec resolution. The system will first be tested using the Argonne laser test stand.

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