TECHNICAL ARTICLE

DETAILED PERFORMANCE CHARACTERISTICS OF A NEW DISCRETE DYNODE TOF DETECTOR

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Presented at The 47th ASMS Conference on Mass Spectroscopy and Allied Topics
June 13-17, 1999, Dallas, Texas

Why use a discrete dynode detector for TOF?

The basic performance features inherent in the technology are so outstanding that they will bring dramatic improvements to applications, which previously used MCP detectors.

Why Use Discrete Dynode Technology?

- *Large linear pulse output: > 1 volt into 50 ohms*
- *Fast recovery time (large pulses): <2ns pulse width*
- *High linear output current: >30μA, continuous*
- *Very low noise: <3 ions/minute*
- *High performance immediately after pump-down*
- *High pressure operation*
- *Robust mechanical construction*

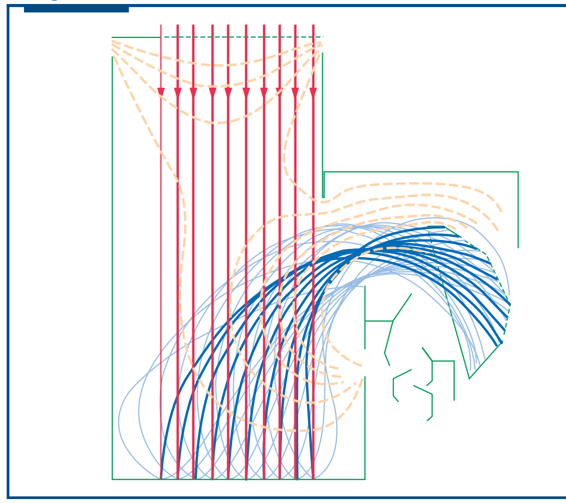
The first three areas listed all relate to dynamic range. That is the ability of the detector to deliver linear response to:

- a very large, sustained ion flux, or
- a very large ion burst, or
- ion signals immediately after a large ion burst

We have reported on the details on these characteristics earlier and they are still quite remarkable when compared to MCP detector. We are continuing to make improvements in these areas.

Clearly, the noise figure of 3 ions per minute will remain difficult to approach using other technologies.

Figure 1



In **Figure 1**, the ion input optics of our new TOF detector showing:

- the basic electrode structure,
- incoming ions with arrow indicators,
- electrons sweeping from 1st to 2nd dynode (left to right),
- and equipotentials as dashed lines.

Only 4 dynodes of the multiplying structure are shown, but dynode chain actually continues to include 25 dynodes.

This is a very efficient structure (>90%).

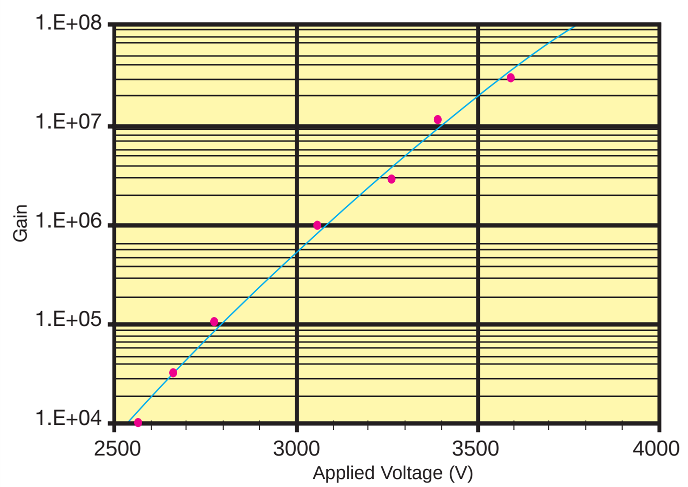
There are three important areas influenced by the multiplier's input optics:

- Ion collection efficiency;
- Time dispersion between all possible electron trajectories must be minimised to maintain a narrow pulse width;
- Sensitivity to unwanted ion and electron interactions must be minimised to eliminate artefacts in the output pulse.

An interesting detail is a voltage applied to the entry grid which eliminates artefacts in the signal caused by secondary emission particles resulting from input ions colliding with the grid.

In **Figure 2**, Gain curve of DM152 demonstrating another of the new concepts we are incorporating in our new TOF detectors. We have designed this detector to initially operate with an applied voltage of ~3kV, and with an upper limit, reached as the multiplier ages, of ~4.5kV. This increased voltage range enables significant improvements in both pulse width and multiplier aging characteristics. The choice of the upper limit was based on the voltage ratings of conventional vacuum feedthroughs.

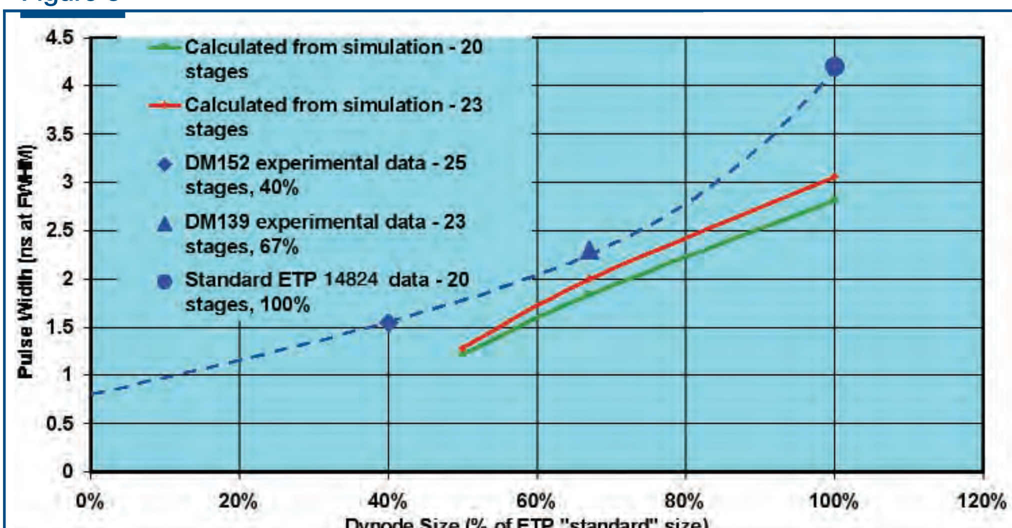
Figure 2



We have achieved the optimal initial operating voltage by selecting different active dynode materials for different parts of the multiplier dynode chain. The DM152 was designed to operate at a gain between 10^5 and 10^6. A design optimized for 10^7 operation would require a simple change in dynode materials. By changing the combination of materials we can design a multiplier to operate at any required gain and still maintain optimal initial voltage

Figure 3 shows the influence of dynode size on the detector's output pulse width including both calculated figures and data taken with 3 different multipliers. The pulse width at half maximum is plotted against dynode size. We have chosen the dynode size from one of our 'standard' TOF detectors, AF824, as the measurement unit for this data. The upper blue circle indicates the AF824 data.

Figure 3

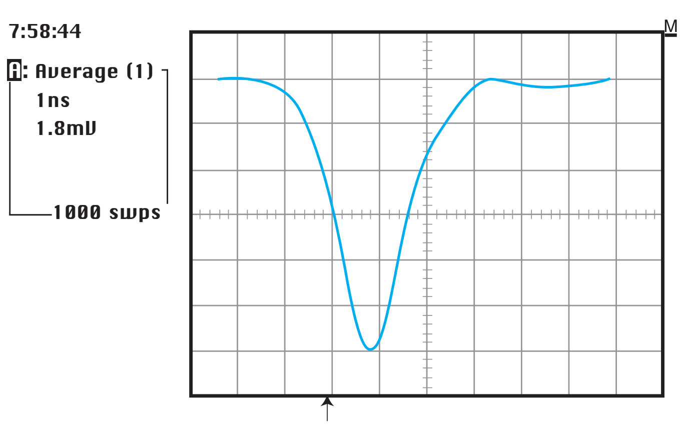


The data all indicates that to achieve a narrow pulse width the multiplier's dynode size should be as small as possible. We have chosen 40% of "the standard size" as a practical compromise between pulse width and manufacturing ease.

This '40% size' is not a fundamental size barrier. We expect to continue this shrinking process and further improve detector speed.

In **Figure 4**, typical pulse from the DM152. These pulse measurements have been made by averaging a large number of single ion events.

Figure 4



1250 sweeps:	average	low	high	signs
ampl(1)	89.8mV	79.5	120.1	6.5
width(1)	1.54ns	1.18	2.33	0.16
rise(1)	1.51ns	0.84	3.19	8.16
fall(1)	1.22ns	0.88	2.90	0.15
2ns area(1)	-464.154 pVs	-589.813	-413.500	19.765

Reducing the dynode size not only increases detector speed, it also enables designs with a small physical size. For the DM152 we have kept the 'footprint' small, 33 x 33mm, and the active area large, 10 x 25mm.

I should point out that within this active area the ion collection efficiency is ~90% verses the 50% or 60% of an MCP.

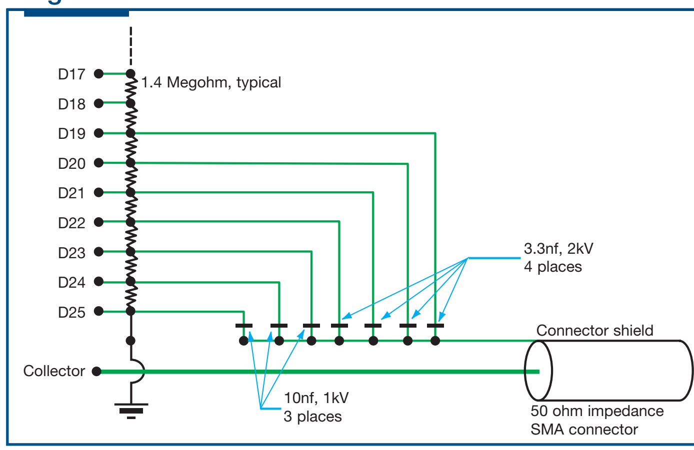
Electronics are mounted directly on the multiplier section and serve a couple of different functions:

- 1 - They support a zener diode chain along with associated capacitors which are part of the voltage distribution network for the dynodes.
- 2 - They also include a compensation network that helps to couple the signal to the output cable and minimize ringing.

As is well known, when the frequency components in a detector's output signal exceed 100 Mhz, impedance matching and ringing become a major issue. We found it is important to mount the compensation circuit and an impedance matched connector directly on the multiplier. It is also important to insure that all cables and connectors between the detector and detection electronics have appropriately matched impedance. Any break in the chain of matched components can cause a signal reflection and lead to ringing.

Figure 5 shows output circuit to minimise ringing. After trying a variety of 'text book solutions' we selected this circuit as the most effective in minimizing ringing. Essentially, capacitors are connected between each of the last several dynodes and the signal line's shield. For this to be effective a matched impedance signal line must extend up to the detector.

Figure 5



In **Figure 6**, output circuit to control two processes that can limit the level of the multiplier's output pulse:

- voltage droop during a large pulse and
- excessive space charge in the dynode area.

Figure 6

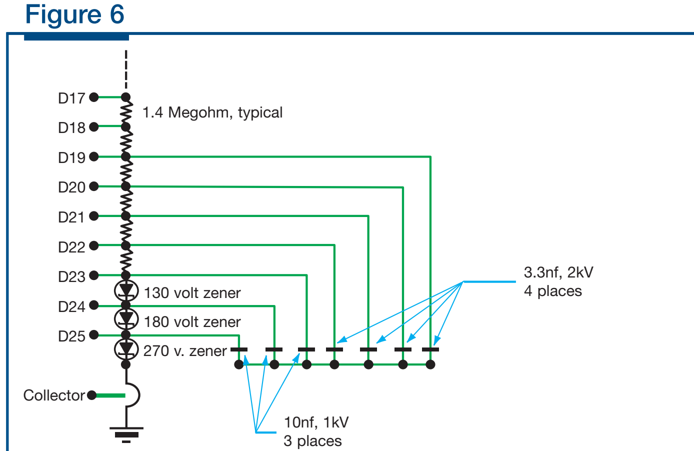
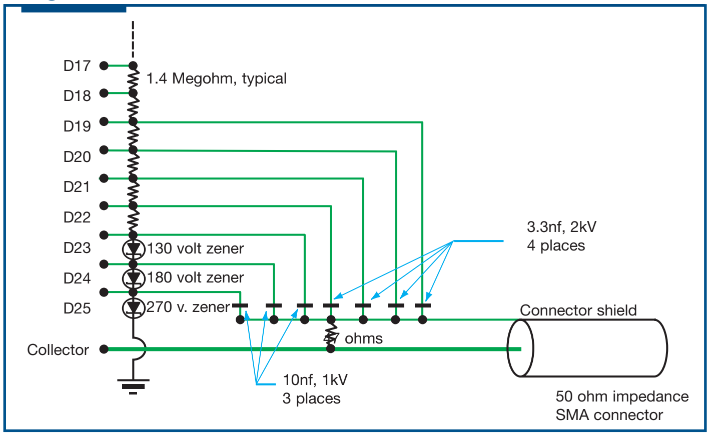


Figure 7



Above diagram shows the output circuit used on the DM152 TOF detector. It combines the concepts shown in **Figures 5 & 6** and is very effective in both controlling ringing and providing large linear pulses.

The capacitors, in this case, are used to supply the dynodes with the extra charge that is extracted from the multiplier during a large pulse, since the resistor chain is too slow to for this purpose. This ensures that the dynode's voltage level, and therefore its efficiency, is maintained during the pulse.

Excessive space charge will both limit the size of a pulse and increase its width. It is strongly dependant on the inter-dynode field strength, and therefore, controlling dynode voltages will also minimise space charge effects. The voltage on the last 3 dynodes is fixed to progressively increased voltages with zener diodes to further minimises effects from space charge.

Figure 8

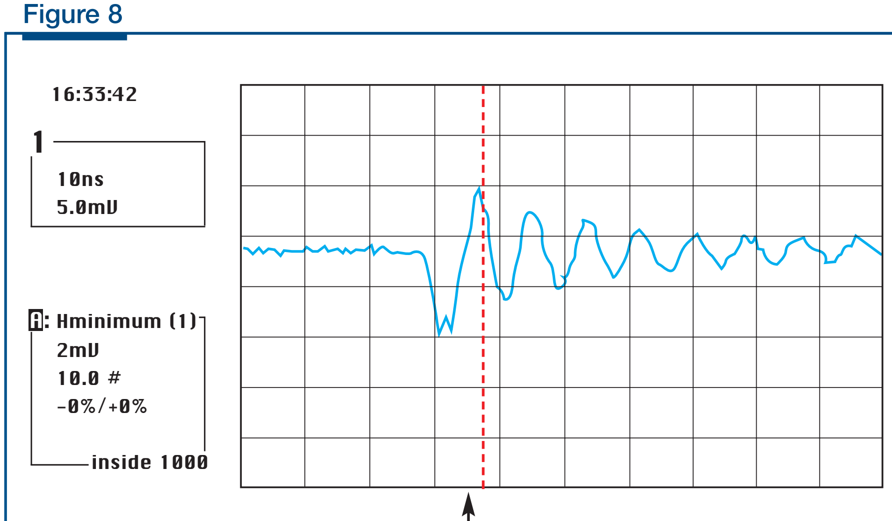
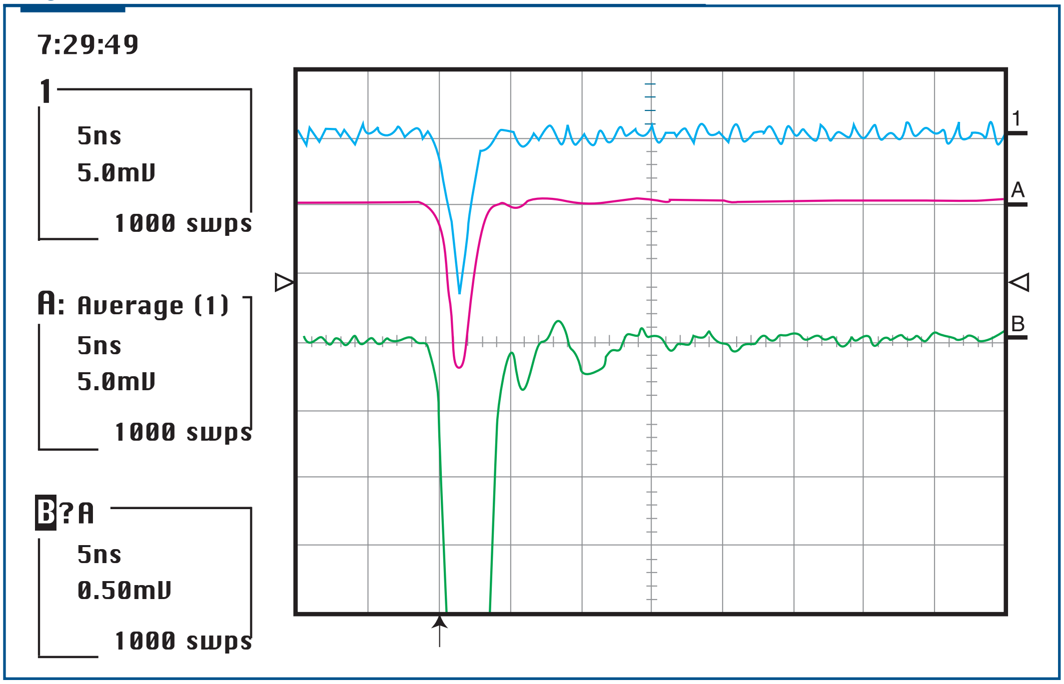


Figure 8 shows the pulse from a multiplier with no output circuit, showing near 100% ringing level.

In **Figure 9**, the pulse shape from the DM152 TOF detector which includes the output circuit. The top trace is a single pulse. The middle trace is the average of 1000 pulses, and the bottom curve has been expanded by 10X in the x scale so that we can see the residual ringing more clearly.

Figure 9



We very consistently measure ringing levels of ~2% of the signal peak with 1.5 Ghz bandwidth electronics as shown here. This wide bandwidth system provides a very severe test for this measurement. Another way of significantly minimising ringing is to reduce the bandwidth of the detection electronics. To achieve the optimal performance in a TOF system the instrument's bandwidth should be just wide enough to achieve the required time resolution.

We have looked at the details of several different areas in the design of the DM152 TOF Detector. We have achieved superior performance by focussing design and development effort into several distinct areas. The methods reviewed have contributed to the DM152's outstanding performance in the areas of:

- Operational life
- Pulse width
- Ringing
- Linearity

The unusual combination of superior performance characteristics for the DM152 will lead to its use in a wide variety of applications.

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