

Simultaneous Mode Electron Multiplier with Analog and Gated Pulse-Counting Outputs

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INTRODUCTION

In some applications of mass spectrometry it is desirable to analyze mass spectra containing peaks which range from less than 100 counts per second (cps) to in excess of 10^9 cps. This capability is especially desirable in isotope ratio applications where a very large elemental mass peak and a small isotope peak are separated by just one atomic mass unit.

Standard pulse counting discrete-dynode electron multipliers have a linear dynamic range extending from a few ions per seconds up to ion count rates of $\sim 5 \times 10^6$. By using an increased bleed current it is possible to increase this upper linear limit by one order to $\sim 5 \times 10^7$ cps. But to measure peaks in a mass spectrum which span up to 9 orders of magnitude, it is necessary to extend the dynamic range of a standard electron multiplier detector by around 3 orders of magnitude.

To achieve this extended dynamic range, it is necessary to use a multiplier in analog mode for peaks in the upper 3-4 orders (i.e. for equivalent ion count rates from $\sim 10^6$ cps to $>10^9$ cps), and use the multiplier in pulse-counting mode for ion count rates from 100 to 10^6 cps.

One approach to this problem is to switch the high voltage applied to a standard pulse-counting multiplier in order to switch between analog and pulse-counting modes of operation. The main problem with this approach is that after changing the applied HV when switching modes, the multiplier takes several seconds to settle. This settling delay can interfere with the efficient collection of data. Further, this arrangement can only operate in one of the two modes at any given time.

This article describes a new approach to increasing the effective dynamic range of an electron multiplier by dividing it into two functionally separate sections. The first section of the detector operates in analog mode and is always active, providing a continuous monitor of the ion signal. The second section of the multiplier provides additional gain to the signal and is used in the pulse-counting mode. The pulse-counting section can be rapidly gated off to protect it from very high intensity signal peaks.

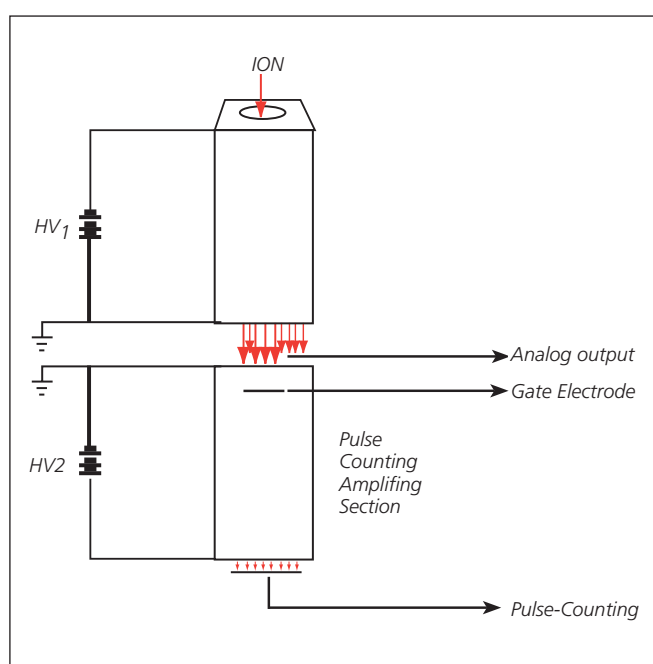


Figure 1. Schematic diagram showing the functional layout of a 14200 series active film Multiplier™.

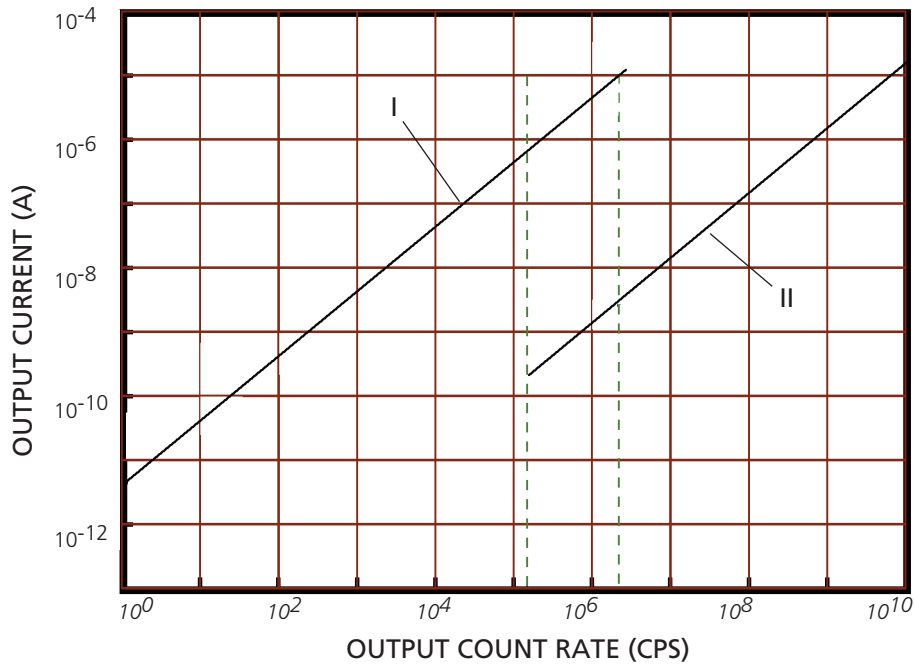


Figure 2. The current measured at I the pulse-counting output of the "simultaneous mode" multiplier operated with an overall gain of 3×10^7 , and II the analog output multiplier operated with an overall gain of 1×10^4 , plotted as a function of the input ion count rate.

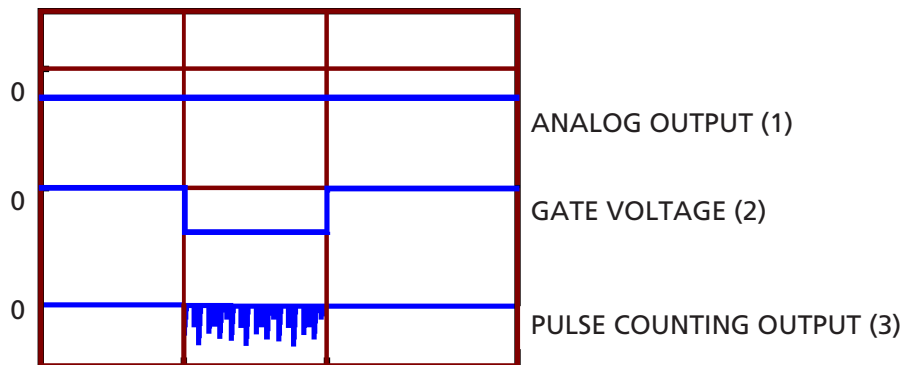


Figure 4. Oscilloscope trace of the voltage applied to the gate electrode and the corresponding output from the pulse-counting section of a 14200 series simultaneous Mode active film Multiplier™ (time base is $20 \mu\text{s}$ per division)

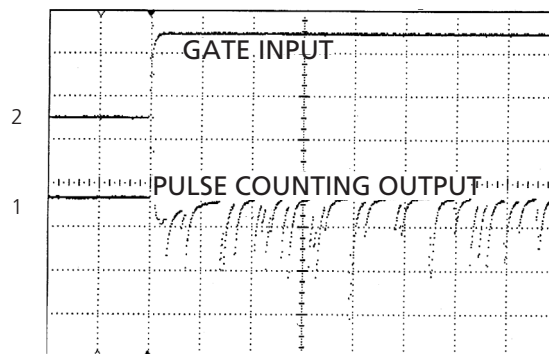


Figure 4. Oscilloscope trace of the voltage applied to the gate electrode and the corresponding output from the pulse-counting section of a 14200 series simultaneous Mode active film Multiplier™ (time base is $20 \mu\text{s}$ per division)

PRINCIPLES OF OPERATION

The 14200 series 'Simultaneous Mode' ACTIVE FILM Multiplier™ divides the detector up into two separate amplifying sections, shown schematically in figure 1. The first section of the multiplier operates in analog mode and is operated at a gain of $\sim 1 \times 10^4$. Following this analog section, a special 'beam-splitting' dynode extracts approximately 50% of the electron signal and directs it into a shielded Faraday Cup from which the analog output signal is taken. The remaining 50% of the electron signal continues on to the pulse-counting section of the multiplier to be further amplified to a level suitable for pulse-counting operation (by another 3×10^3 making $\sim 3 \times 10^7$ in total) before being collected by the pulse-counting output electrode.

For operation in analog mode, the gain of the first section of the multiplier is set to $\sim 1 \times 10^4$. At this gain the correlation between the analog output current and input ion count rate is represented by curve (I) in figure 2. As the maximum linear output current for a discrete-dynode electron multiplier is $\sim 15 \mu\text{A}$ ($\sim 15\%$ of the bleed current through the dynode resistor chain for a typical ACTIVE FILM Multiplier), then at 104 gain this limit corresponds to an equivalent input ion count rate of 5×10^9 cps.

For operation in pulse-counting mode the gain of second section of the multiplier is set so that the combined gain of both sections of the multiplier is $\sim 3 \times 10^7$. At this gain the maximum linear count rate of the multiplier (so that its output current is $< 15 \mu\text{A}$) is $\sim 4 \times 10^6$ cps. The correlation between output current and input ion count rate for the pulse-counting section of the multiplier is represented by curve (II) of figure 2.

From the two lines in figure 2 it can be readily seen that when the two modes of operation (analog and pulse-counting) are used in the one detector, the overall linear dynamic range of the detection system would extend from a few ions per second up to $> 10^9$ cps.

At the front end of the pulse-counting section of the multiplier, a special 'Gate' electrode is used to selectively protect the pulse-counting section from exposure to very large peaks.

Figure 3 shows the effect of the potential applied to the gate electrode on both the analog and pulse-counting outputs. When the gate voltage is set to VG (curve 1), the pulse-counting section is enabled and pulses from the input ions are seen from the pulse-counting output (curve 2). At the same time the analog output (curve 3) is also functioning. When the gate is set to ground (0 volts) the pulse-counting section is disabled and there is no output from the pulse-counting section. The operation of the analog output is unaffected by the gate. Consequently, it monitors the ion signal at all times and can be used to select when the lower detection limits of the pulse-counting mode part of the detector are required.

Figure 4 shows an actual oscilloscope trace of the voltage applied to the gate electrode and the corresponding output from the pulse-counting section of the multiplier. A voltage applied to the gate electrode can switch the pulse-counting section "on" or "off" in less than $20 \mu\text{s}$.

APPLICATION IN MASS SPECTROMETRY

Operation of the pulse-counting part of this detector does not affect the output of the analog section. Consequently the analog output can be used to continuously monitor the ion current from the analyzer. This allows the analog output of the 14200 series ACTIVE FILM Multiplier to be used to determine when the pulse-counting section is required and when it should be protected from very high intensity mass peaks.

When the pulse-counting section of the multiplier is activated by application of the appropriate voltage to the gate electrode, the pulse-counting and analog outputs simultaneously give a signal that is proportional to the input ion current and are both valid, provided the maximum count rate of the pulse-counting section is not exceeded.

This continuous monitoring function of the analog output combined with a gated pulse-counting output, makes the 14200 series ACTIVE FILM Multiplier ideal for application in fully automated extended dynamic range ion detection systems.

TECHNICAL SPECIFICATIONS

| Electrical Parameter | Typical Specification |
|--|---|
| Application | Quadrupole mass spectrometers |
| Input ion optics | Off-axis first dynode |
| Number of lead connections | 5 |
| Applied -HV on analog section for 10^4 gain | -1.8 kV |
| Applied +HV on pulse-counting section for 3×10^7 gain | +1.0 kV (assuming 10^4 gain on analog section) |
| Dark current from analog output (-2.5kV) | $< 1 \text{ pA}$ |
| Dark counts from pulse-counting output (+1.8kV/+1.5kV) | 0.05 cps |
| Gate electrode operating voltages | Gate Closed: 0 volts Gate Open: fixed %* of +HV (* varies with specific model) |

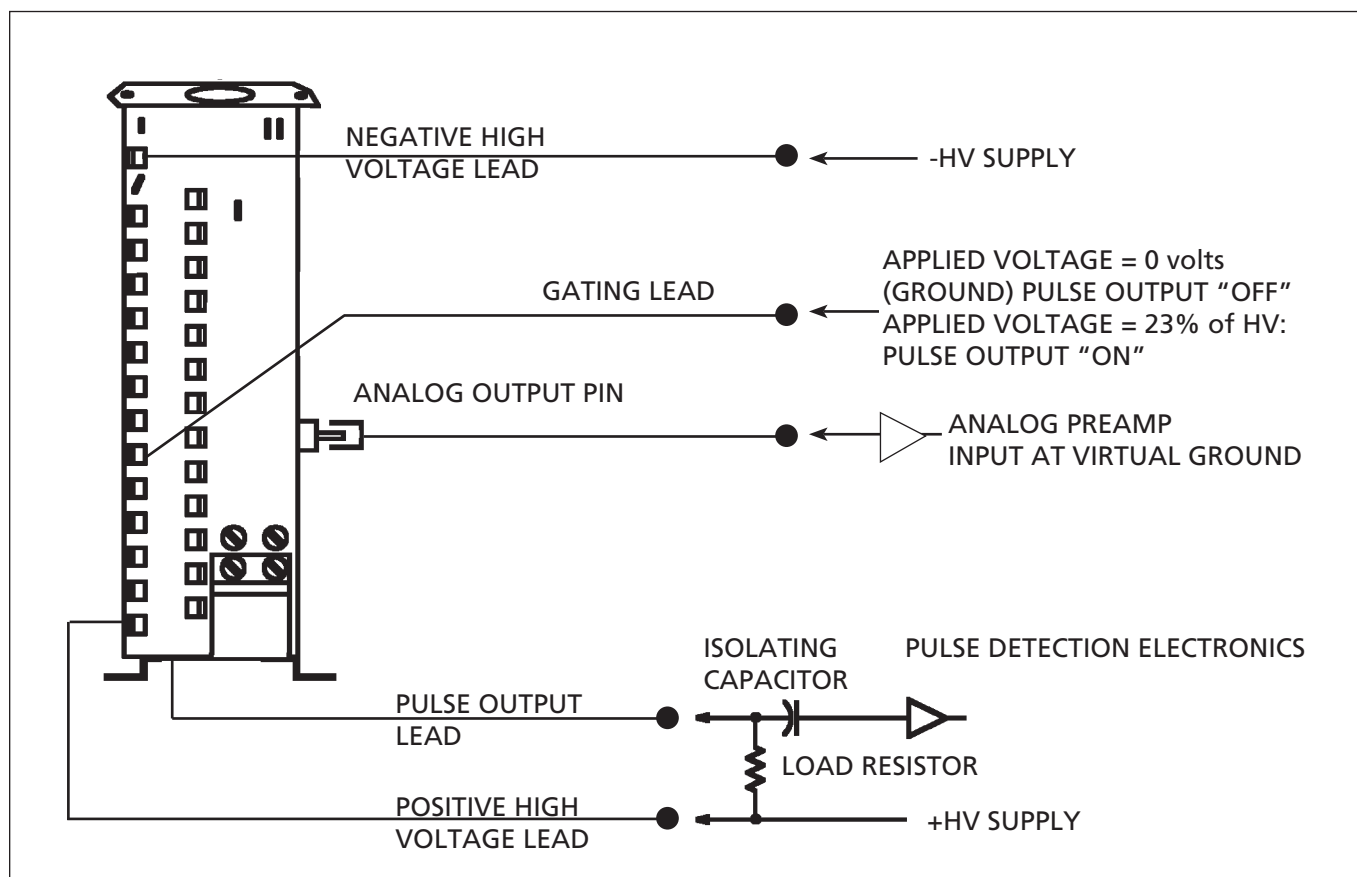


Figure 5. Wiring diagram for the 14200 series active film Multiplier.

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