Removing Dead Time Variations Due to Detector Pulse Width in Ion Counting Systems

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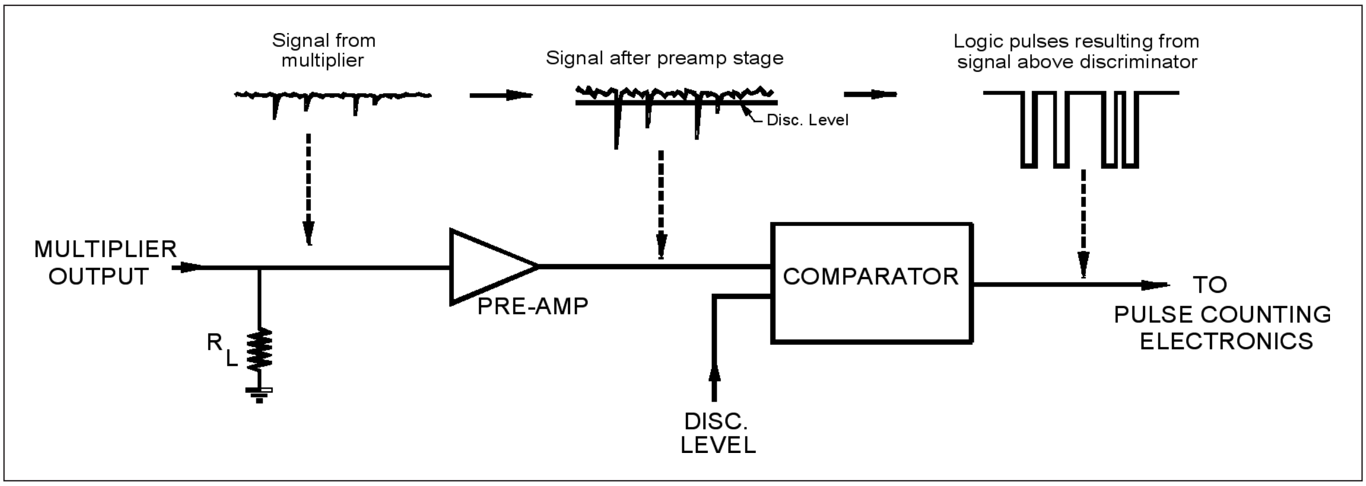

Figure 1. Schematic diagram of typical ion-counting electronics. This circuit shows pre-amplifier and comparator/discriminator to remove noise from multiplier signal pulses. Note RL can be a separate load resistor but is typically the 50Ω input impedance of the preamp.

INTRODUCTION

The maximum linear counting rate achievable by a pulse-counting detection system (Figure 1) depends on several parameters:

1. detector linear output current limit
2. detector gain
3. discriminator level, and
4. dead time.

Whereas linear output current and gain are parameters associated with the detector, the discriminator level and dead time are parameters of the supporting electronics.

To achieve the optimum performance from a pulse counting system, it is essential that the discriminator and dead time are appropriate for the characteristics of the detector pulses: If a system dead-time far exceeds the detector pulse width, the maximum linear counting rate can be unnecessarily limited by this dead-time. (Figure 2) On the other hand, if the pulse length exceeds the dead time, this can cause errors that can not be properly corrected using normal methods.

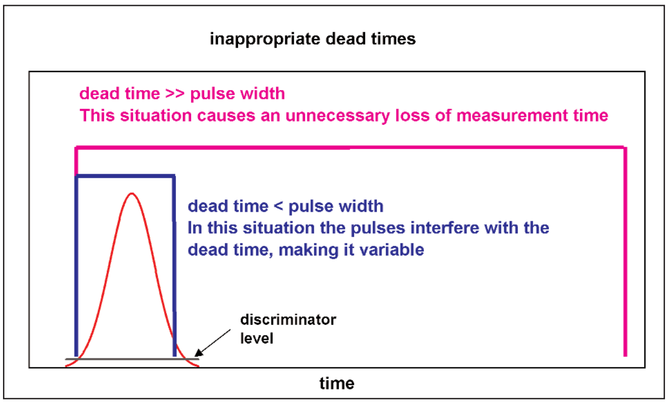

Figure 2. Two different dead times that are inappropriate for the pulse width illustrated.

This article addresses this second case, and presents a method for the conditioning of signal pulses from a detector to allow the use of shorter dead times, thereby increasing the maximum achievable counting rate of a system.

The Issue In an MS pulse counting system, count losses occur due to the dead time of the detection system's electronics. The losses that are incurred increase as a function of the rate of ions entering the detection system and the length of the electronic's dead time (Figure 3a). These losses are accounted for by making "dead time corrections" to the measured count rate. For a system with a fixed dead time (ie. a non-paralysable system) the expression relating the true count rate n to the measured count rate *m* is

$$n = \frac{m}{1 - m\tau} \quad \text{.................................} \ (1)$$

where τ is the dead time.

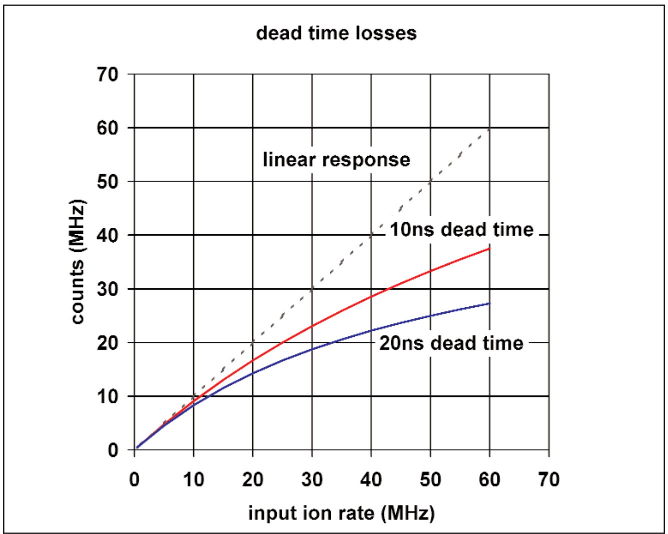

Figure 3a. The theoretically predicted count rates for detection systems with 10ns and 20ns dead-times. The differences between the predicted count rates and true count rate are due to dead time losses.

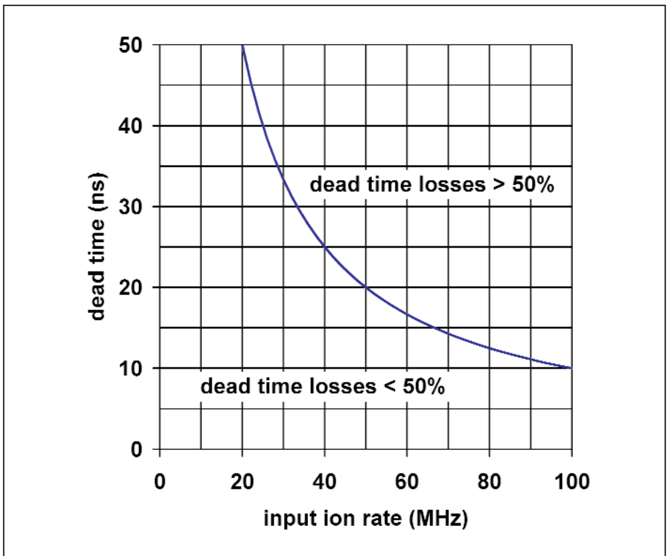

Figure 3b. The maximum dead time allowed to limit dead time losses to 50% at a given input ion rate.

To keep corrections accurate, dead time losses are typically limited to ~50%. The dead time required to measure a given true rate while maintaining less than 50% losses is shown in Figure 3b.

Equation 1 describes the correction that applies to a system that has a fixed dead time. To keep the dead time fixed in level-detecting systems (as typically used in MS), the width of the pulse at the discriminator level must be less than the dead time of the electronics.

If the dead time is shorter than the pulse width at the discriminator level, then the dead time can be variable, and Equation 1 is not strictly applicable.

While pulses from an electron multiplier can have a well defined full-width measured at half-height maximum (fwhm), variation in pulse heights can lead to a considerable variation in widths at the fixed level of the discriminator. (Figure 4a). So, it is insufficient that the dead time is longer than the pulse at fwhm, it must be ensured that the dead time is longer than the width of the largest pulses at the discriminator level. (Figure 4b). The output pulses from a standard ETP pulse-counting detector have full-widths at half maximum of ~5ns, but their widths could exceed 20ns at the 5% level.

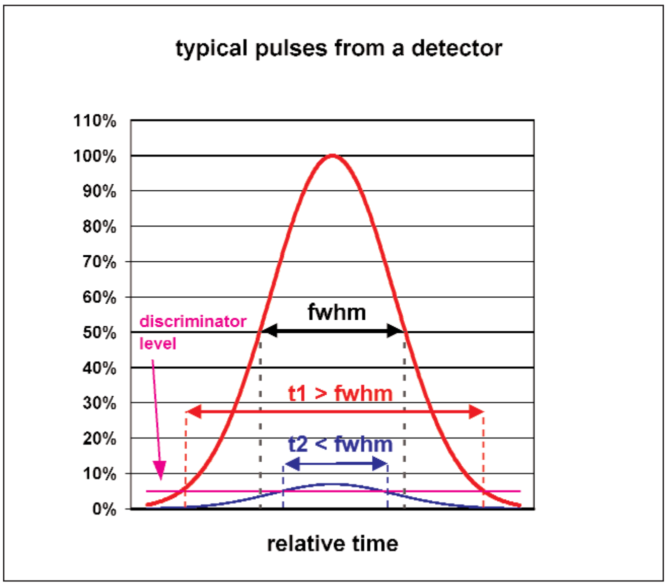

Figure 4a. Output pulses from a detector have a distribution of pulse heights. While the fwhm of the pulses may have only small variations, the width of the pulses at a fixed discriminator level can have large variations (t1 compared with t2).

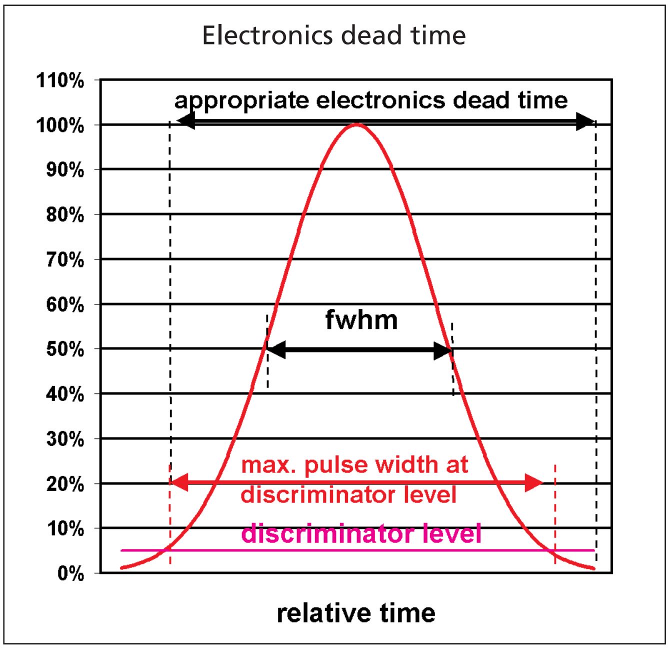

Figure 4b. The electronics dead time should be set to be longer than the widest pulse at the discriminator level.

It is worth noting that the dead time is due to the detection system electronics and not the detector - the detector continues to produce output pulses in response to input ions during this dead time, but these output pulses are not recognized by the counting system.

The pulse data shown in Figure 5a were recorded from a special high count rate ETP pulse-counting electron multiplier. Figure 5b shows a set of measurements made with this detector, using an ARI* amplifier/discriminator with an 18ns dead time. This figure also shows the results of applying equation 1 using two different dead times (18ns and 30ns).

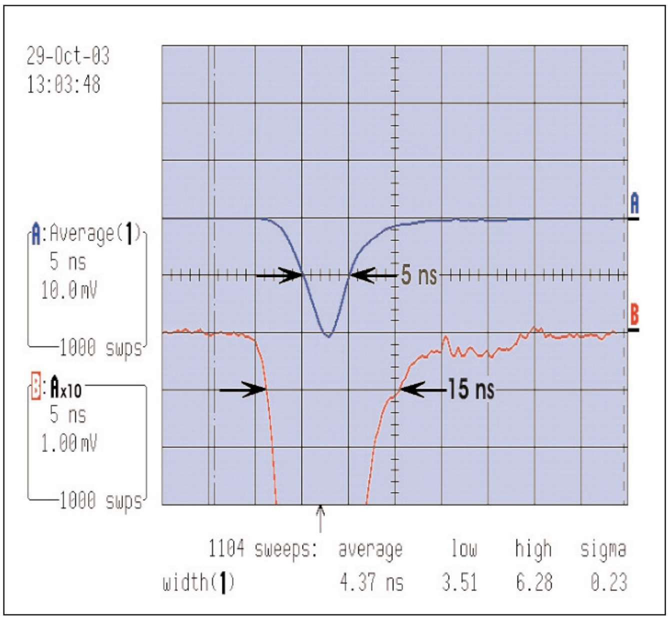

Figure 5a. Typical pulses from an ETP detector. The average width near the 10mV level (~half-maximum) is ~5ns. The average width near the 1mV level is ~15ns.

Using a dead time of 30ns gives a better linear correction at higher count rates than does 18ns. This indicates that the system is not behaving as one with a fixed dead time of 18ns, ie. the dead time of the electronics is being affected by the width (at the discriminator level) of the detector pulses.

The work of this project was to investigate if electron multiplier pulses could be processed to provide a narrower pulse width at the discriminator level so as to remove the interference of the pulses from the electronic's dead time.

**Note:- The amplifier-discriminator used in this work was a model F-100T from Advanced Research Instruments Corporation, 2434 30th Street, Boulder, Colorado. 80301.*

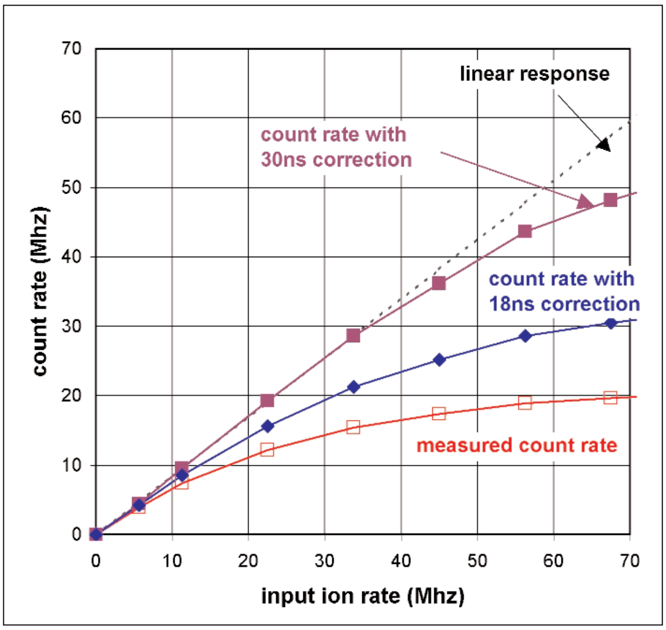

Figure 5b. Measured and corrected count rates obtained with pulses as shown in Figure 5a. An amplifier/ discriminator with an 18ns dead time was used.

THE APPROACH

Figure 6a shows an arrangement of a capacitor and resistor that has been introduced into the signal line between a detector and a pre-amp. In this arrangement, these components act as a differentiating circuit.

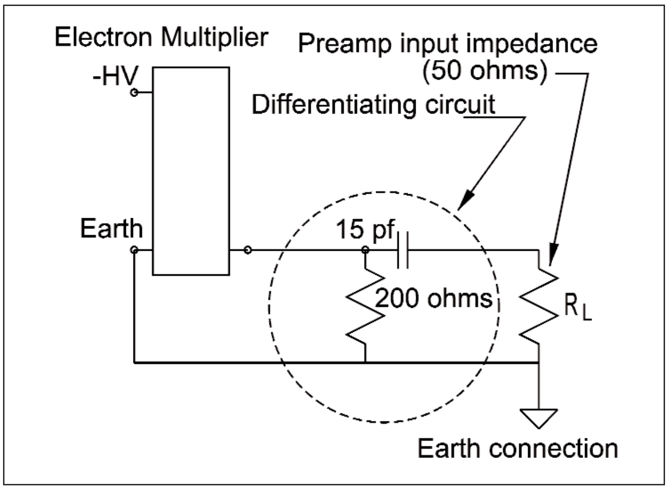

Figure 6a. An arrangement of a capacitor and resistor that has been introduced into the signal line between a detector and a pre-amp. In this arrangement, these components act as a differentiating circuit.

The results of a SPICE model of the signal at the pre-amp with and without the differentiating circuit are shown in Figure 6b. The differentiating circuit produces a bipolar pulse that has a rapid return to baseline after it's negative swing, permitting the use of shorter dead times. The differentiated pulse has a smaller negative amplitude than the non-differentiated pulse, requiring the use of a lower discriminator level. However, the differentiating circuit also behaves as a high-pass filter. Together with the low-pass character of the pre-amp input, it forms a notch filter that works to suppress system noise, resulting in an overall improvement of the signal-to-noise ratio.

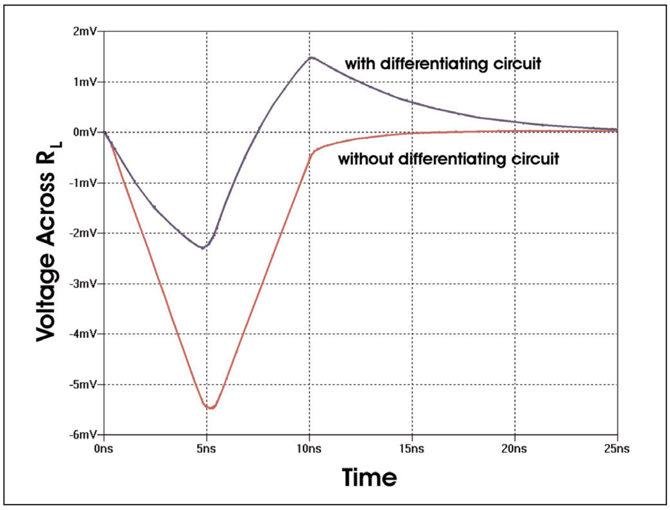

Figure 6b. The results of a SPICE model of the signal at the pre-amp (RL) with and without the differentiating circuit.

By adjusting the R and C values of the circuit, it is possible to tailor the time that the pulse takes to return to baseline from its positive upswing. Since the amplifier-discriminator used in testing had an 18ns dead time, the R and C values chosen were to allow the pulse's re-approach to baseline in this time. (Figure 6b). By choosing different R and C values, this re-approach time could be further reduced for better compatibility to shorter dead times.

Results Figure 7a shows pulse data recorded from a special high count rate ETP electron multiplier that has been configured to include the differentiating circuit of Figure 6a in its signal line. The pulse shape is seen to be in very good agreement with the SPICE model, with a width of ~ 8ns at the -1mV level, compared with ~15ns for the non-differentiated pulse.

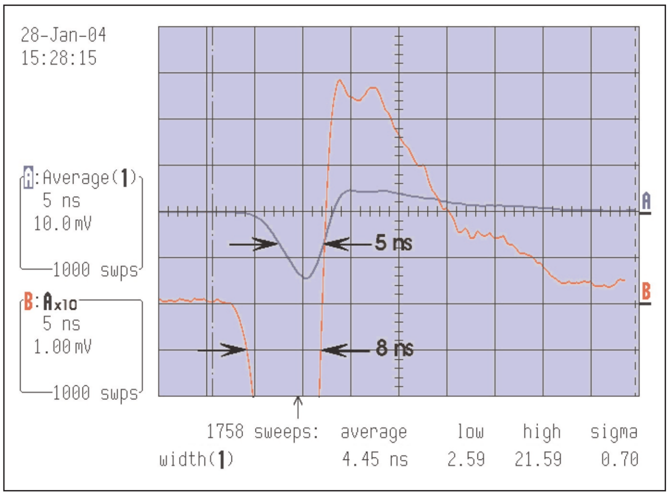

Figure 7a. Typical pulses resulting from a detector with a differentiating circuit. The average width near the 8mV level (~half-maximum) is ~5ns. The average width near the 1mV level is ~8ns.

A set of measurements made with this detector is shown in Figure 7b. Applying Equation 1, the correction with best linear fit was obtained by using a dead time of 18ns. In this case, the corrected data shows a linear response out to a count rate of > 50MHz.

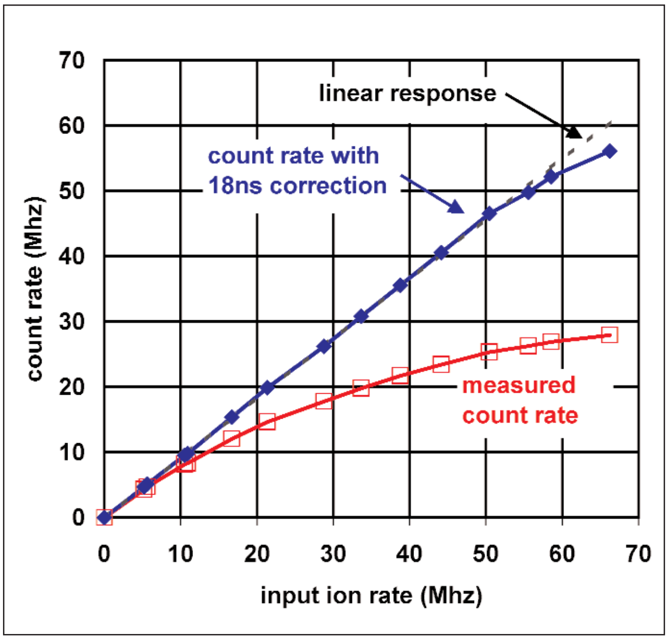

Figure 7b. Measured and corrected count rates obtained with pulses as shown in Figure 7a. An amplifier/discriminator with an 18ns pulse pair resolution was used.

This result indicates that the pulses from the detector are not compromising the 18ns dead time of the electronics, allowing a strictly correct use of equation 1. The result is also in agreement with the prediction of Figure 3b that a system with an 18ns dead time has losses of ~ 50% at ~53MHz.

The effect of the circuit on system noise was dramatic. The suppression allowed the discriminator level of the system with which the tests were performed to be set significantly lower than it had ever previously been used (0.5mV).

CONCLUSION

A method for improving the maximum linear count rate of a pulse counting detection system has been demonstrated. The method consists of the introduction of a differentiating circuit into the signal line of an electron multiplier so as to reduce the pulse widths at the discriminator level.

In tests performed, interference with the dead time of the electronics system from detector pulse width was eliminated. Without this interference, the correction that gave the best linear fit to measured data used a dead time that was due entirely to the system electronics, allowing accurate use of the normal dead time correction equation. In this way, corrected count rates were obtained that were linear beyond what has previously been achievable. (> 50MHz).

The differentiating circuit also strongly attenuates system noise, allowing the use of significantly lower discriminator levels and operating gain. Therefore, higher count rates will be achieved for a given detector linear output current, and detector life will be enhanced.

The circuit used in this work was tuned to provide the best results for a system with an 18ns dead time. By adjusting component values, the same circuit could be tuned to match systems with any other dead time.

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