

Response Time Measurements of the NIF DANTE XRD-31 X-ray Diodes

Donald Pellinen, Matthew Griffin, National Security Technologies, LLC (NSTec). Livermore Operations (LO)

Prepared for submission to the **Review of Scientific Instruments**

ABSTRACT

The XRD-31 is a fast, windowless X-ray vacuum photodiode developed by EG&G. It is currently the primary fast X-ray detector used to diagnose the X-rays on NIF and OMEGA on the multichannel DANTE spectrometer. The XRD-31 has a dynamic range of less than $1e-12$ amps to more than 10 amps. A technique is described to measure the impulse response of the diodes to a 150 fs pulse of 200 nm laser light and a method to calculate the “risetime” for a square pulse and compare it with the computed electron transit time from the photocathode to the anode. Measured response time for 5 XRD-31s assembled in early 2004 was 149.7 ps \pm 2.75 ps.

BACKGROUND

The XRD-31 was developed in the 1970s to measure X-rays in the sub kilovolt and kilovolt energy ranges. A summary of the response of the detector is in an EG&G TECHNICAL BULLETIN by Bret Davis in 1979 that shows some time response data but does not document how it was taken.¹ A letter from Thomas L. Harper of Lawrence Livermore Laboratory (now Lawrence Livermore National Laboratory (LLNL)) to Jim Martin and Ken Gilbert of Sandia Laboratories supplies several references.² An EG&G TECHNICAL BULLETIN, dated 12/16/82 ,shows dc calibrations vs. photon energy.³ Kornblum and Slivinsky described an XRD-30 with a gold cathode in 1978.⁴ Spielman and Anthes of Sandia Labs calculated and measured the saturation current of an XRD-31 in 1981.⁵ Campbell, Tirsell, and Laird described a new 50 ps detector and made comparisons with the XRD-31 in a presentation at the American Physical Society Plasma Physics meeting in 1981.⁶ Kornblum and Kauffman described the installation of the XRD-31 in Nova in The Review of Scientific Instruments (RSI) in 1986 but only described the energy response of the spectrometer and not the temporal response of the XRD-31.⁷ Currently the XRD-31s are used on the DANTE X-ray spectrometers used on the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory and the OMEGA facility at the University of Rochester. The Dante soft X-ray power diagnostic for NIF has recently been described by Dewald ET al.⁸ Campbell et al. describe the calibration procedures for the OMEGA DANTE at the National Synchrotron Light Source (NSLS).

PROGRAM

A program was set up to understand the physics of the XRD-31, including the temporal response as a function of operating conditions. This test program was expanded to document the temporal response and insure quality on each XRD-31 used on the NIF DANTE.

A cross sectional view of an XRD-31 is shown in Figure. 1.

Photons enter the detector from the left and pass through the Anode A, which is an etched nickel grid having about an 84 percent transmission, and interact with the Photocathode K. The two outer connectors connect to 50-ohm bias cables that maintain the positive bias voltage on the anode grid. Photons passing through the grid create photoelectrons at the photocathodes that are attracted to the anode, inducing an image charge on the anode as they move across the gap. A positive pulse is transmitted along the cathode stalk and propagates to the output cable.

A setup of the laser light path to measure the response is shown in Figure. 2A. The light passes into the vacuum chamber through a quartz window. Chamber pressure is maintained below $5e-5$ Torr.

The electrical setup configuration is shown in Figure 2B.

After the initial studies were made, these checks became routine quality control steps to measure the response characteristics of every XRD used on NIF DANTE. We use a 150-femtosecond pulse of 200 nm laser light from the Short Pulse Laser Lab at the LO of NSTec. Readout was with a Tektronics TDC 6604 transient recorder with a DC to 6 GHz frequency response.

MAXIMUM CURRENT VS VOLTAGE

The current limitations on electron flow through space were first described by Child¹⁰ and Langmuir.¹¹ The initial application was for the then new electron tubes. It also applied to high voltage diodes and to electron suppression on kiloampere faraday cup measurements. When an electron beam propagates in a space, a space charge barrier is formed as described by Pellinen and Staggs in 1973.¹² Spielman developed a similar analysis in 1981 and applied it to an XRD-31.⁵ We use Spielman's equation to calculate the saturation current for non relativistic electrons is:

$$I=2.34 \times 10^{-6} A * V^{3/2} / X^2 \quad (1)$$

Where I is the saturation current, A the area of the detector in cm², V is the applied voltage and X the anode to photocathode spacing in cm. Figure 3 is a plot of calculated saturation current vs. bias voltage across the gap. This actual instantaneous voltage across the AK gap is actually $V_{bias} - 75 * I$ due to the voltage drop from driving the 50-ohm cathode and the 25-ohm impedance of the two parallel bias cables.

The tests are done to determine if the XRD-31 follows the transit time vs. voltages equation for response and what the actual risetime is vs. bias voltage. Tests are usually begun at the lowest voltage so the current limitation will prevent overvolting and damaging the digitizer in the event excessive light is applied to the photocathode. If excessive light were incident, one would expect a waveform that was "clipped" by the space charge. If a "clipped" waveform is seen, the light intensity would be appropriately reduced to avoid damaging the digitizer on higher bias shots where the space charge limit is much higher.

RISETIME

There may be other limits on the risetime of the detector, but the fundamental limit is the transit time of the electrons across the space between the anode and cathode. In the event that this is true then

$$t = X \sqrt{\frac{2 * m}{q e * V}} \quad (2)$$

X is the spacing between the anode grid and photocathode, V is the applied voltage and qe and m the charge and mass of the electron and t the transit time.

Experiments

With the setup in figure 2 the voltage is varied and the waveforms recorded. Data is taken from +50 volt bias to +5000 volt bias in 1, 2 and 5 steps

Figures 4a, 4b, and 4c show the waveforms with their integrals for 50, 500, and 5000 volt biases, respectively. Risetimes shown on the traces are from 10 to 90 percent of amplitude at the first maxima without the addition from subsequent ringing. The width of impulse response is the full width at half maximum (FWHM).

The data taken in response to the impulse is an impulse followed by high frequency ringing.

Normally one is interested in the response to a rectangular voltage pulse of finite duration. By integrating the impulse response over time we generate logical equivalent of the pulse response. In

fact we sum the digitized results to get the “integral.” A summary of the data for XRD 049 is below with the plot in Figure 5. The transit time is calculated from equation 2.

Pulse Response, XRD-049

Grid	Calculated	Measured	Full Width
Volts	Transit time ps	Risetime ps	Half Max ps
50	1,480	1,220	1,235
100	1,050	780	801
200	740	560	562
500	468	369	370
1,000	331	264	271
2,000	234	196	197
5,000	148	148	150

A summary of the response of the XRDs assembled at Bechtel Nevada with chrome photocathodes in early 2004 and tested in August 2004 is below

Pulse Width of Chrome Cathode XRD-31s at 5 KV Bias

XRD #	Cathode Material	A-K Space mm	Width Ps
038	Cr	3.1	155
049	Cr	3.1	150
062	Cr	3.1	147
080	Cr	3.1	150
090	Cr	3.1	147
094	Cr	5.3	209

The mean pulse width of the 5 diodes with the 3.1 mm anode cathode spacing was 149.7 +/- 2.75 ps.

ANALYSIS OF DATA BY CAMPBELL ET AL.

The same analysis was applied to the waveforms shown by Campbell, Tirsell, and Laird in their paper.⁶ Using the Campbell et al. Figure 3 we get a pulse width of 160 ps, about 140 ps from their Figure 5 and 145 ps from Figure 7. It was not specified how they measured the response and if they were limited by the response of the readout device.

DISCUSSION OF RESULTS

The risetime of the detector appears to track the square root of the voltage over a factor of 100 in bias voltage. The readings with a 5 kV bias are becoming close to the risetime of the 6604 transient recorder so the actual response time is probably less than signal displayed. For a step function the response can be corrected with the formula

$$Tr^2 = Tr_{system}^2 - Tr_{device}^2 \quad 3$$

where Tr is the rise-time of the device under test, Tr_{system} is the response of the measured signal and Tr_{device} the risetime of the measuring instrument.¹³ That was for a step function pulse, not an impulse, so the technique is not directly usable. The slightly slower calculated transit time from the integral method and the FWHM measurement could be due to the fact that the calculation assumes complete electron transit and the measurements are from fractional levels on the waveforms.

Also note the oscillations about 340 ps after the main pulse on the higher bias traces. This time delay corresponds well with the down and back propagation time for the 108 mm distance from the cathode center to the electrical feedthroughs for the bias voltage. It probably is the reflection from the mismatch at the bias voltage feedthrough. Also, the time appears to be relatively constant with voltage. One would expect this time difference to decrease with increased voltage if it was caused by electron ballistic effects.

Acknowledgements

The authors would like to thank a number of people who have assisted or encouraged this project. Among them are Kelly Campbell, Dean Lee, Robert Turner and Franz Weber of Lawrence Livermore National Laboratory (LLNL) who were instrumental in formulating the program. We are especially grateful to Joe Smith formerly of LLNL for assembling the six chrome XRDs and teaching us the assembly techniques. Bechtel Nevada LO personnel assisting were Larry MacNeil, Oliver Sweningsen, and Mike Cardenas. Jerry Richter and Jerry Blair of NSTec were kind enough to offer very valuable suggestions.

This work was done and the manuscript has been authored by Bechtel Nevada under Contract No. DE-AC08-96NV11718 and by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the United States Department of Energy. The United States Government retains and the publisher, by accepting the article for publication acknowledges that the United States Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

- 1 B. Davis, XRD-31 X-RAY DETECTOR, EG&G TECHNICAL BULLETIN, April 23, 1979 unpublished.
- 2 Letter, T. Harper, Lawrence Livermore Laboratory, to J. Martin and K. Gilbert Sandia National Laboratory, April 20, 1983, Unpublished.
- 3 L. Singman, LLNL-EG&G CROSS CALIBRATION OF A WINDOWLESS XRD, EG&G TECHNICAL BULLETIN, December 16, 1982, unpublished.
- 4 H. N. Kornblum and V. W. Slivinsky, "Flat-response, subkiloelectronvolt x-ray detector with a subnanosecond time response," Rev. Sci Instrum. 49(8), August 1978, p 1204.
- 5 R. Spielman and J. Anthes, "A study of Bare X-ray Diode Saturation Due to a High Fluence X-ray Pulse," AIP Conference Proceedings #75, Low Energy X-ray Diagnostics, Monterey 1981.
- 6 Campbell, Tirsell, Laird, "Improved 50 ps Response X-ray Detector with Optical Applications," UCRL-86340, presented at APS Division of Plasma Physics Annual Meeting, New York, October 12-16, 1981.
- 7 H. N. Kornblum and R. L. Kauffman, Rev. Sci. Instrum. V 57 (8) August 1986, p 2179.

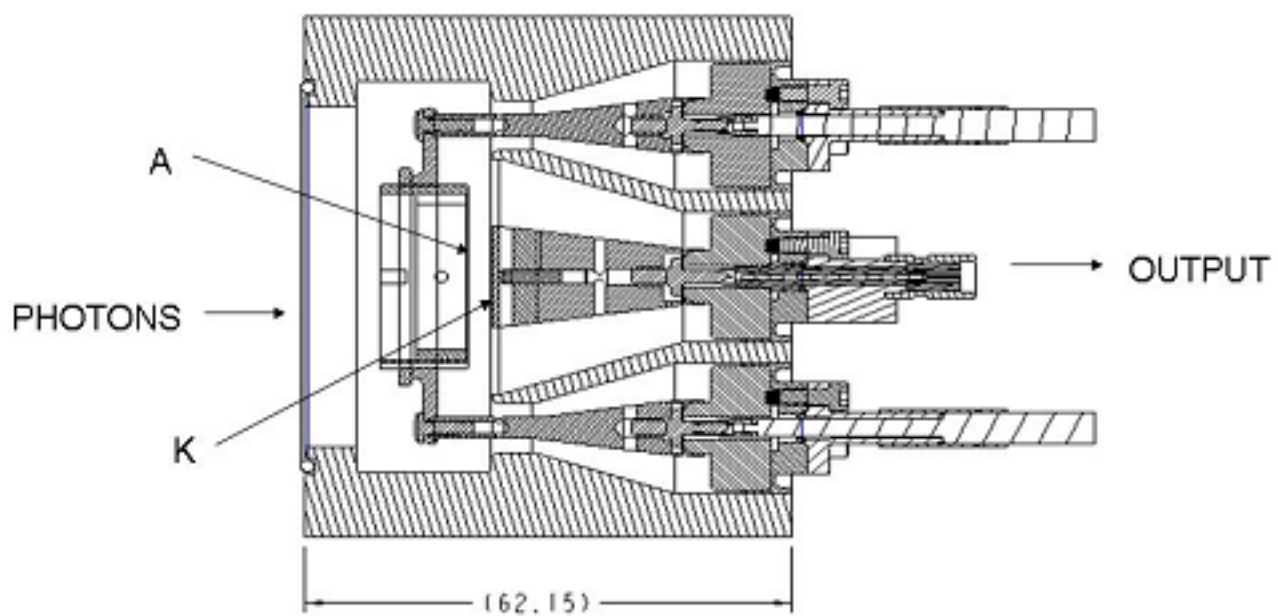
- 8 E. L. Dewald et al. "Dante soft x-ray diagnostic for National Ignition Facility," Rev. Sci. Instrum. 75(10) October 2004, p 3759.
- 9 K. M. Campbell et al., "Omega Dante soft x-ray power diagnostic component calibration at the National Synchrotron Light Source," Rev. Sci. Instrum. 75(10) October 2004, p 3768.
- 10 Child, D. C. "Discharge from Hot CaO," Phys. Rev. Vol. 32, pp 492-511 May 1911
- 11 Langmuir, I., "The effect of Space Charge and Residual Gases on Thermionic Currents in High Vacuum," Phys. Rev., Ser. 2 Vol. 2, pp. 450-486, December 1913.
- 12 D. Pellinen and V. Staggs, Rev. Sci. Instrum., Vol. 44, No. 1, January 1973.
- 13 D. Pellinen, Q. Johnson, and A. Mitchel, Rev. Sci. Instrum., Vol. 45, No. 7, July 1974 p 994.

List of Figures:

- Figure 1 Dante Diagnostic X-RD-31 Detector
- Figure 2B Electrical Setup for XRD-31 Risetime Measurements
- Figure 3 Calculated Saturation Current vs. Bias Voltage for XRD-31
- Figure 4A XRD-049 Response to 150 fs laser pulse with +50 Volt Bias
- Figure 4B XRD-049 Response to 150 fs laser pulse with +500 Volt Bias
- Figure 4C XRD-049 Response to 150 fs laser pulse with +5000 Volt Bias

Figure 5 Computed Transit Time and Measured Risetime Vs Bias Voltage, XRD-049

DANTE DIANOSTIC X-RD-31 DETECTOR



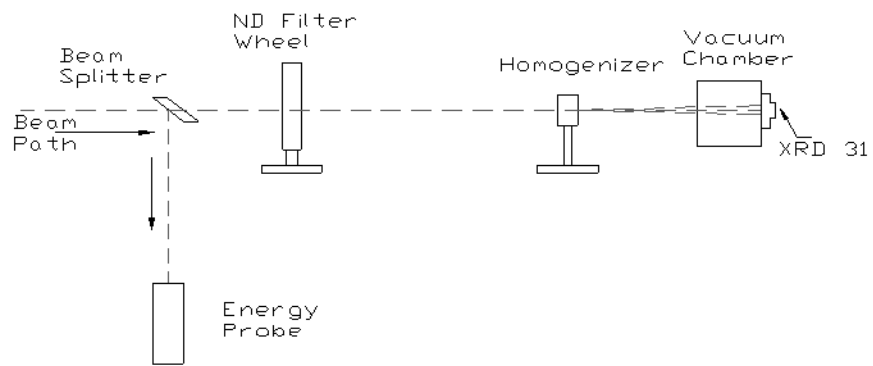


FIG 2a

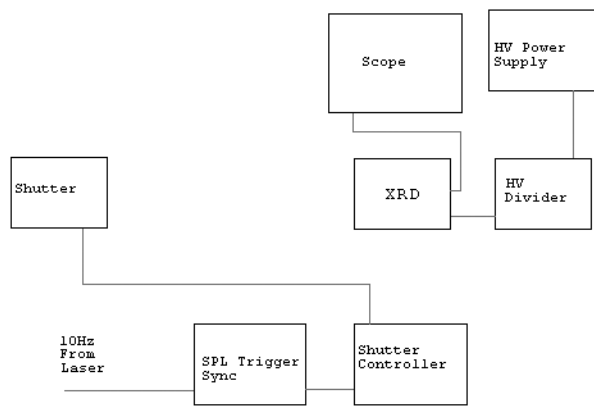
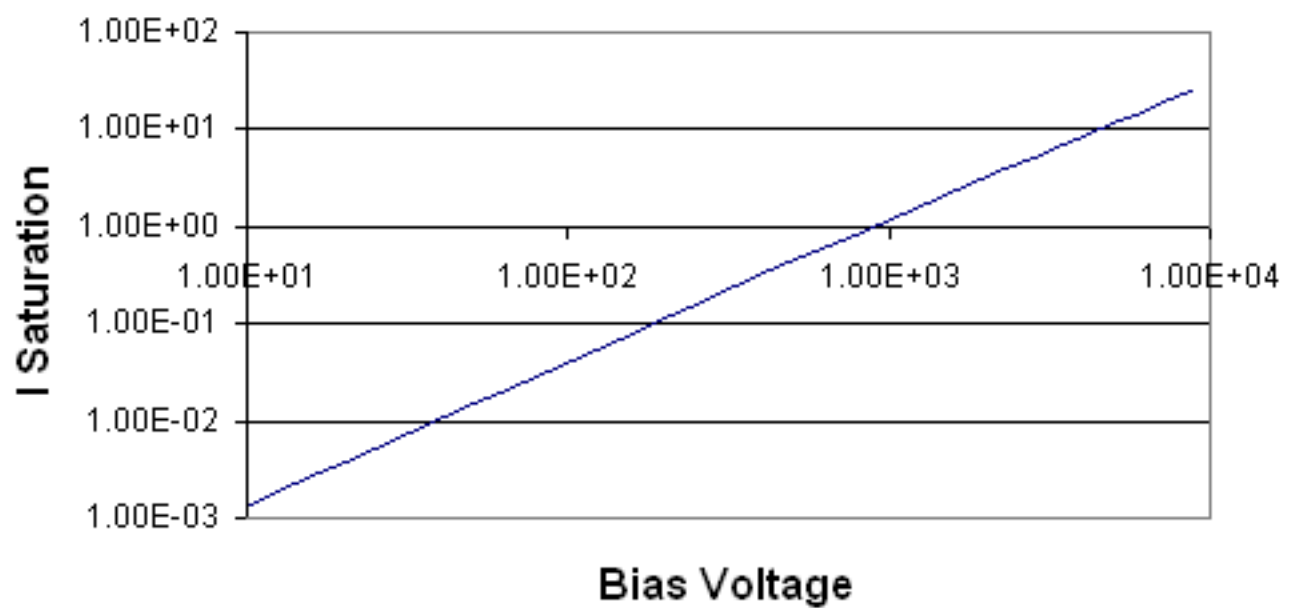


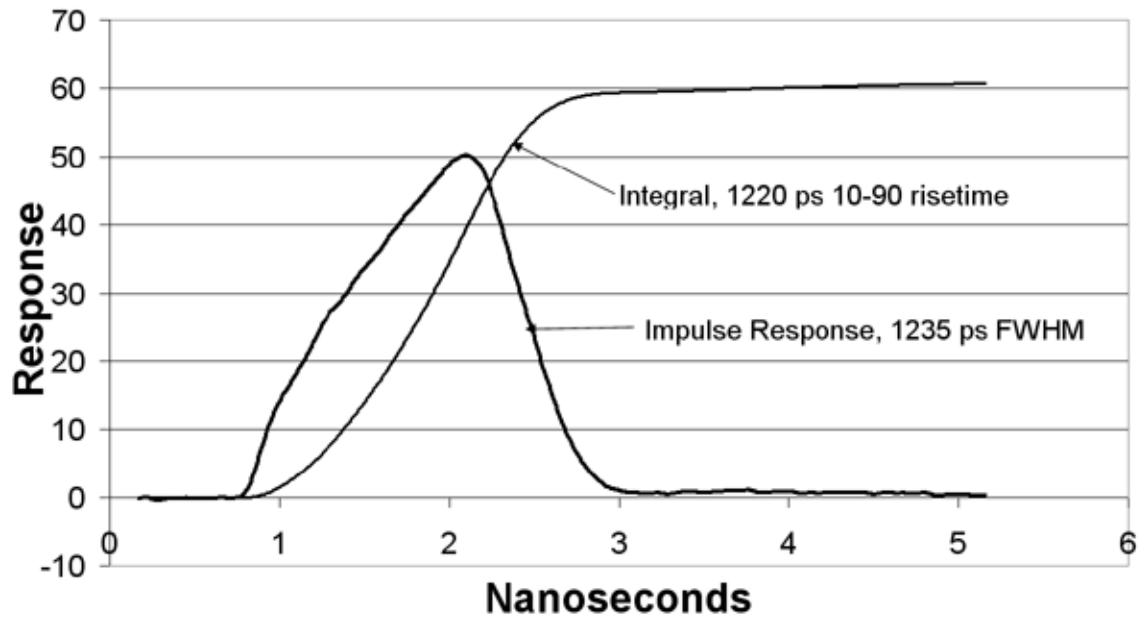
FIG 2b

Pellinen fig3

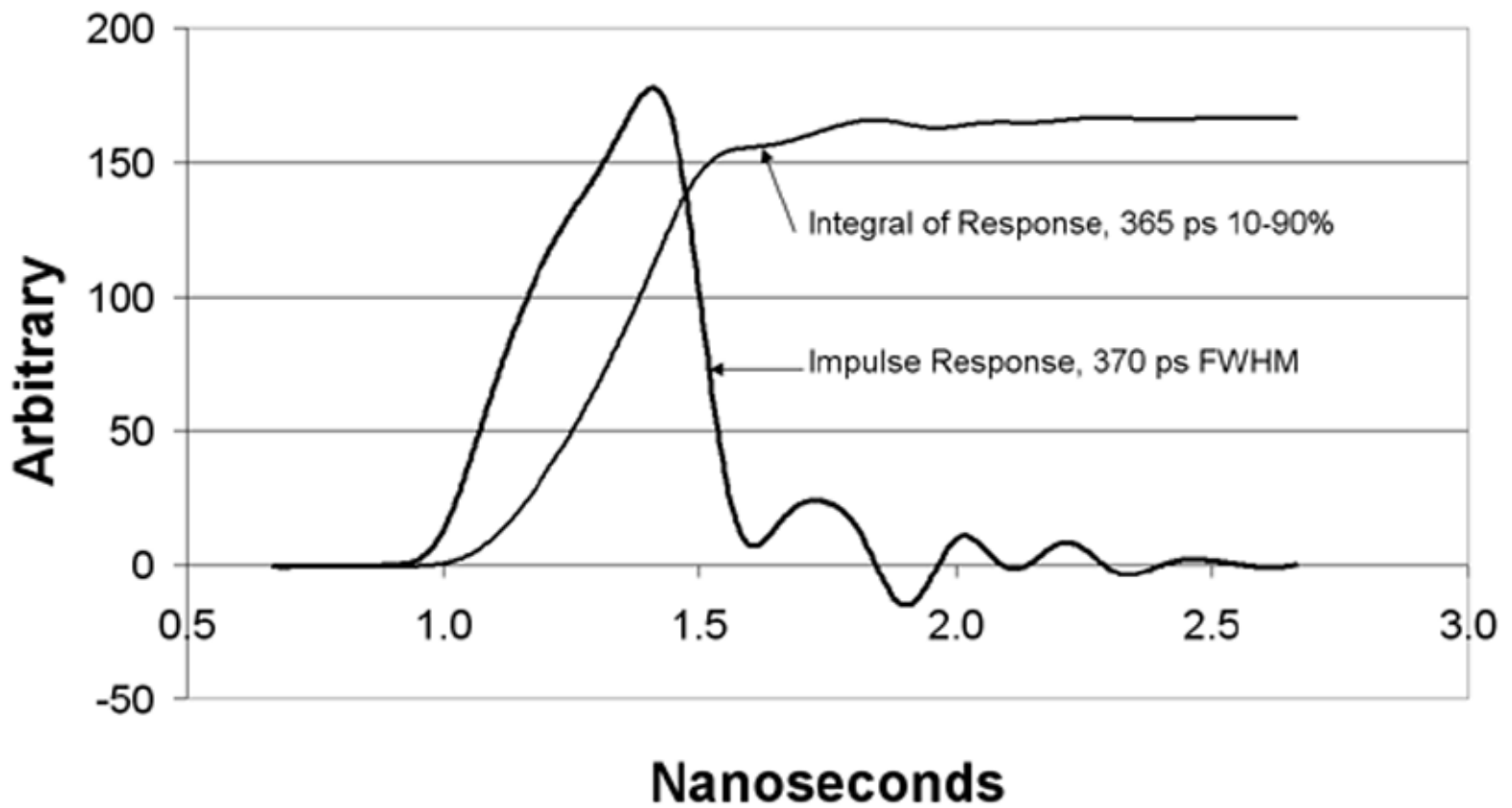
I saturation vs Bias Voltage 3.1 mm



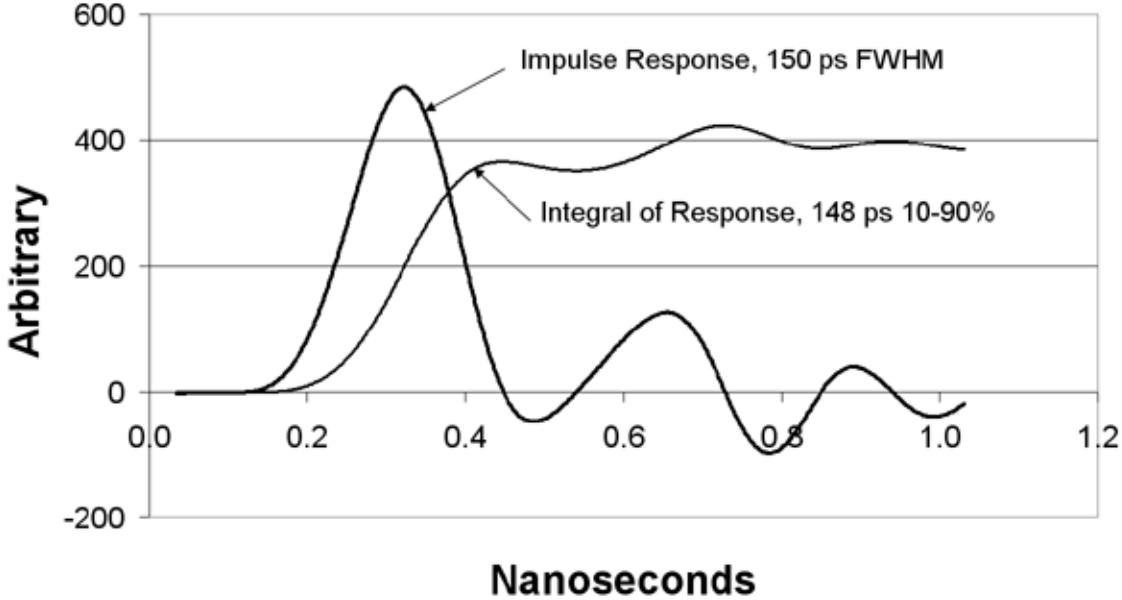
XRD-049 50 Volt Bias



XRD-049 500 Volt Bias



XRD-049 5000 volt bias



Computed Transit Time vs Measure Risetime

