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NDIA National Defense Industrial Association

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A Robust Methodology for Calculating MIL-DTL-23659 Fireset Compliance

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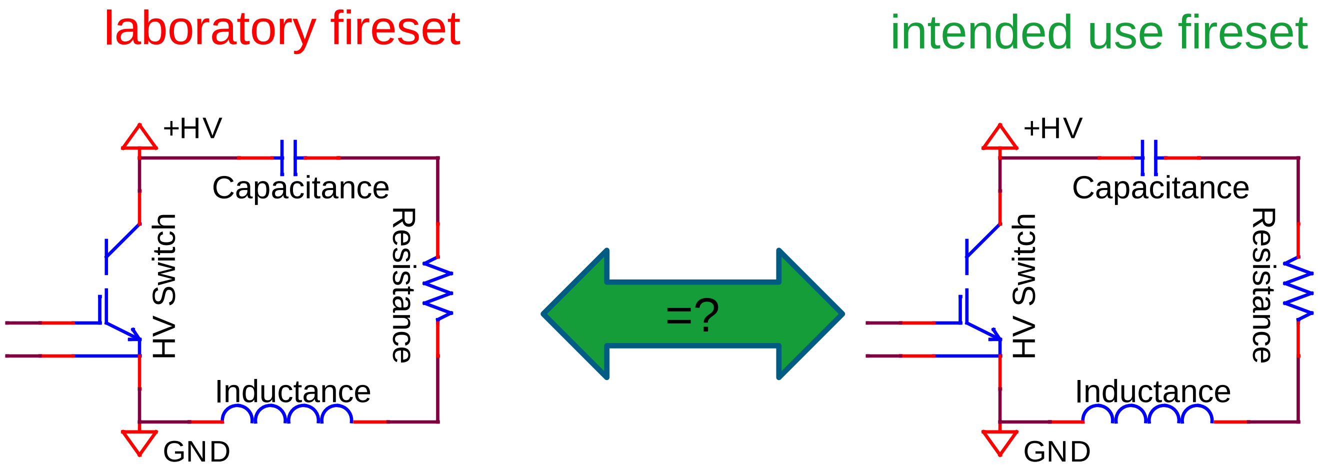
Introduction

- In order to qualify an initiator for a product, a laboratory fireset is required
- The laboratory fireset must be similar to the intended use fireset
- These conditions are set forth in MIL-DTL-23659
  - Differences are specifically stated in paragraph A.5.1 in Appendix A



MIL-DTL-23659F Requirements

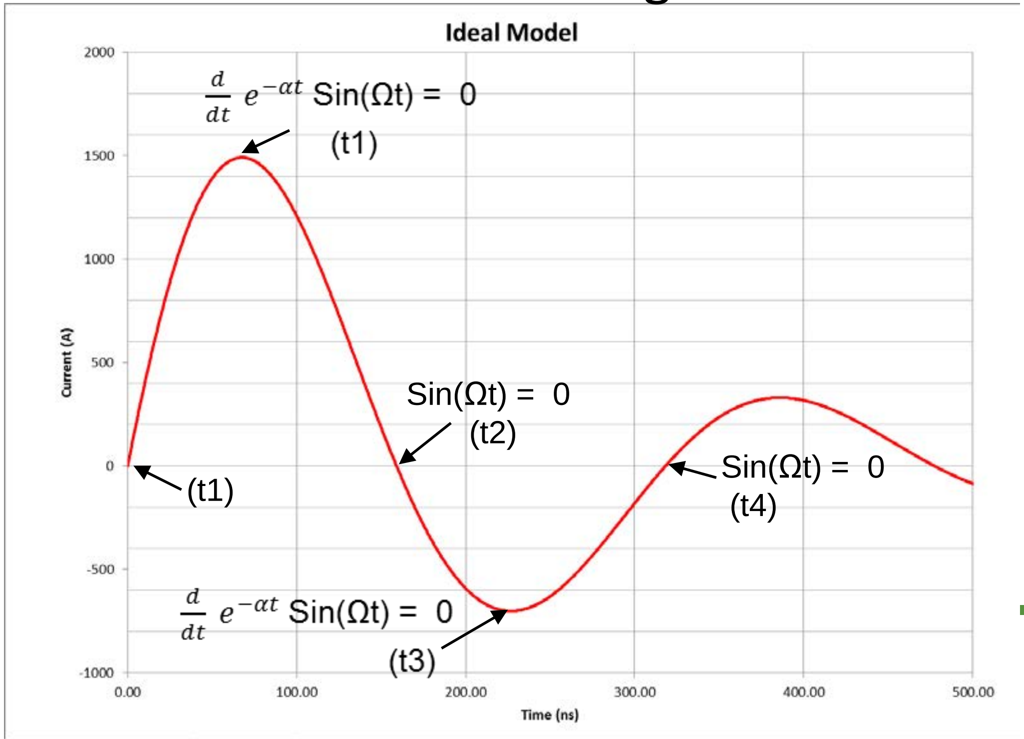
- Paragraph A.5.1 – Firing Properties Firing Unit
  - Firing unit for firing properties tests, hard fire, and all-fire tests
    - shall be as close as possible to intended-use firing unit configuration
  - Firing switches that do not operate in the same voltage range as the intended firing switch shall not be substituted
  - Test firing unit shall have transient firing properties within 25 percent of intended use firing properties
    - After modifications to measure the necessary data such as a CVR
    - Transient firing properties are a measure of discharge impedance and should be a measure of dynamic (steady state) resistance, inductance, and capacitance as determined through short circuit fireset discharge analysis at appropriate voltages (threshold and all-fire voltages)
  - MASS and MNFV safety requirements shall be met after scaling by a ratio of ratios method (new in 23659F)
    - First positive peak/second positive peak ratio

Ideal Wave Model

- The ideal equation for a damped sine wave
  - Closely approximates the ringdown of a fireset
  - $I(t) = \frac{V}{(L\Omega)} e^{-\alpha t} sin(\Omega t)$
  - $\Omega = \sqrt{\omega^2 - \alpha^2}$
  - $\alpha = \frac{R}{2L}$
  - $\omega = \frac{1}{\sqrt{1000LC}}$
  - Inductance (L) is expressed in nanohenries
  - Resistance (R) is expressed in Ohms
  - Capacitance (C) is expressed in microfarads
  - Time in nanoseconds

Derivation of single variable solution

- On the ideal waveform
  - Let t_0 be the beginning of the ideal waveform
  - Let t_1 be the time at the first positive peak
  - Let t_2 be the time at the first zero crossing
  - Let t_3 be the time at the first negative peak
  - Let t_4 be the time at the second zero crossing



Derivation of single variable solution (continued)

- At t1 (maxima), $\frac{d}{dt}\ e^{-\alpha t}$ Sin(Ωt) = 0
- At t2, Sin(Ωt) = 0
- At t3 (minima), $\frac{d}{dt}\ e^{-\alpha t}$ Sin(Ωt) = 0
- At t4, Sin(Ωt) = 0
- Half-cycle time (HCT) = $\frac{\pi}{\Omega}$
- HCT can be approximated by three different methods:
  - Estimate HCT by using t2-t0
    - Find t0 by extrapolating a line from the 10%-30% peak current to the y-axis zero crossing (Extrapolated Method)
  - Estimate HCT by using the two zero crossings (t4-t2)
  - Estimate HCT by using t3-t1 (first maxima and minima)

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Derivation of single variable solution (continued)

- At t1 (maxima) and t3 (minima):
  - $t_3 = t_1 + HCT$
  - $\left| {}^{I(t_1)}/_{I(t_3)} \right| = -\frac{P_1}{P_3} = \frac{\frac{V}{(L\Omega)} e^{-\alpha t_1 * sin(\Omega t_1)}}{-\frac{V}{(L\Omega)} e^{-\alpha t_3 * sin(\Omega(t_1 + HCT))}}$
  - The ratio of the peaks can be calculated by the following derivation
  - $= \frac{e^{-\alpha t_1}}{e^{-\alpha t_3}} = \frac{e^{-\frac{R}{2L} t_1}}{e^{-\frac{R}{2L}(t_1 + HCT)}} = e^{\frac{R}{2L}(HCT)}$
  - $ln\left(-\frac{P_1}{P_3}\right) = \frac{R}{2L}(HCT)$ Thus $R = \frac{2L ln\left(-\frac{P_1}{P_3}\right)}{(HCT)}$

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Derivation of single variable solution (continued)

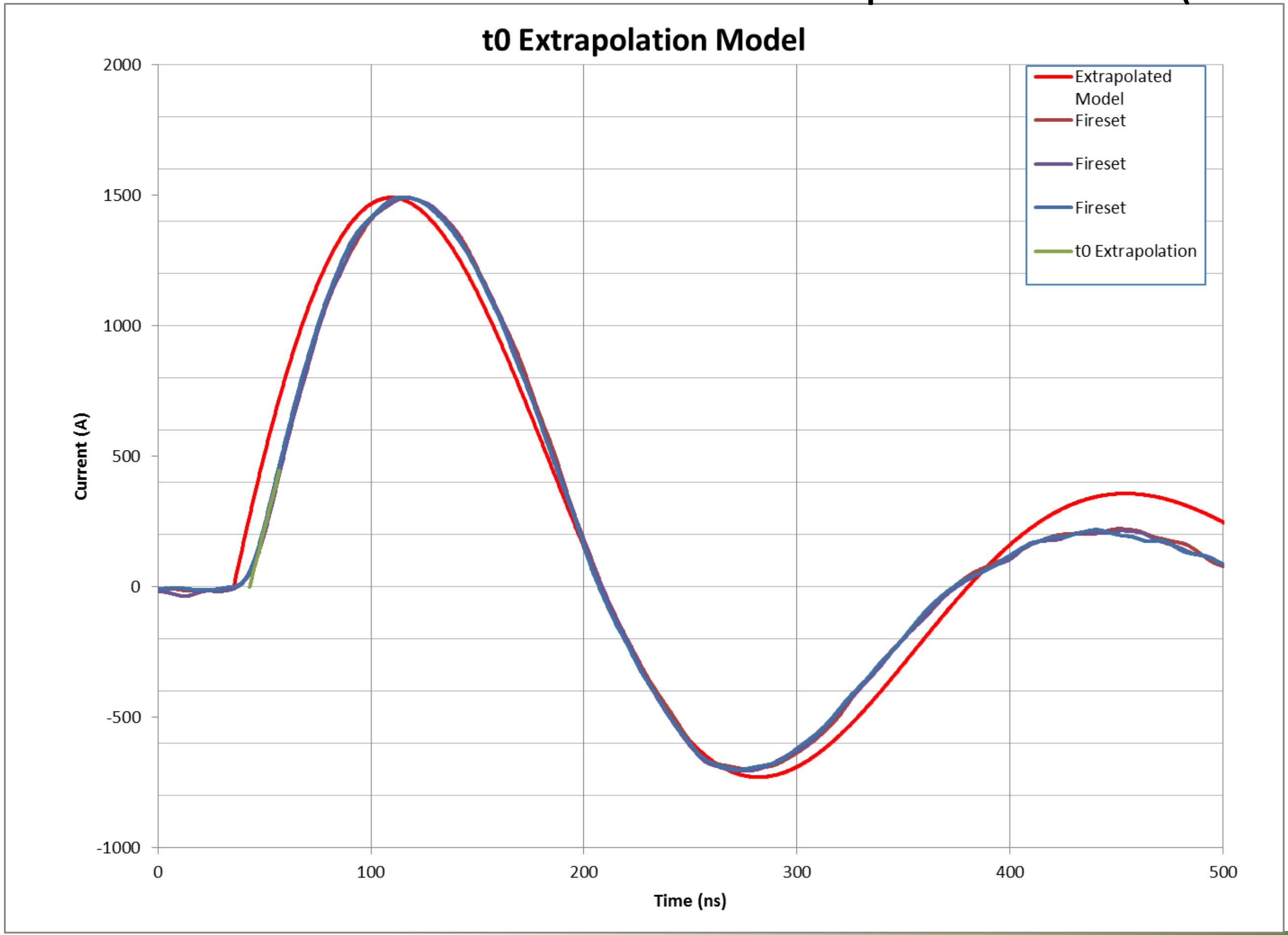
- At t_2, Sin(Ωt) = 0, thus $\Omega\ (HCT) = \pi$
- $\pi = \sqrt{\frac{1}{1000LC} - \left(\frac{R}{2L}\right)^2}\ (HCT)$
- Solve for C:
- $C = \frac{1}{1000L\left(\frac{R^2}{4L^2} + \frac{\pi^2}{(HCT)^2}\right)}$
- Substituting R into the equation above:
  - $C = \frac{1}{1000L\left(\frac{\left[\frac{2L\ln\left(-\frac{P_1}{P_3}\right)}{(HCT)}\right]^2}{4L^2} + \frac{\pi^2}{(HCT)^2}\right)}$

Derivation of single variable solution (continued)

- All variables can now be expressed by a relation of the empirical data to a single variable (inductance).
- Iterate inductance to fit the model curve to the empirical data
  - Iterate until peak current is matched
  - Equations will automatically adjust the resistance and capacitance based upon measured data points
  - Align t2 for the measured and ideal waveforms

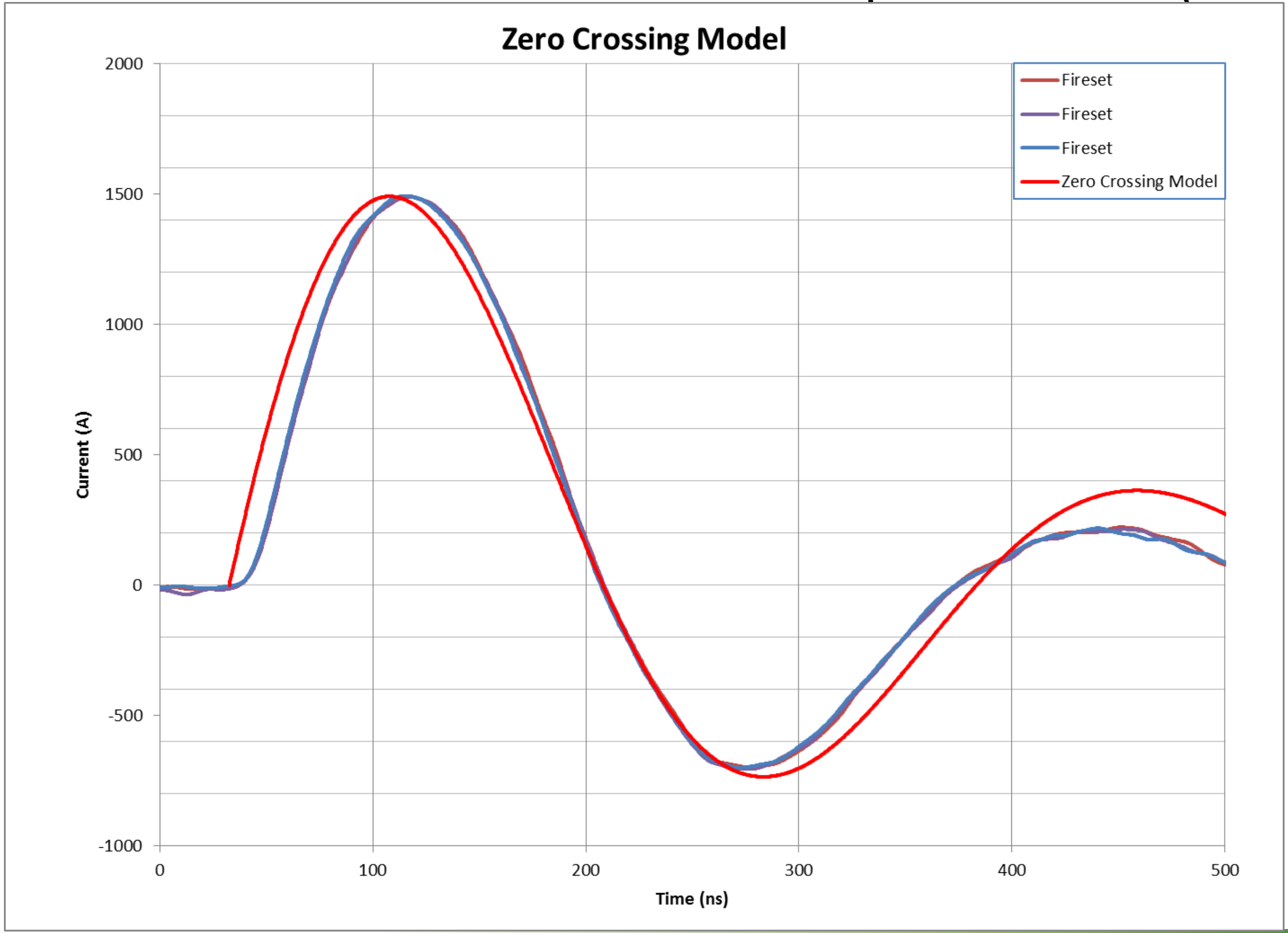
Calculation of Impedance Parameters – Extrapolated t_0 Model

- Using the measured data:
  - Inductance iterated to 24.74 nH to match peak current (1491 A)



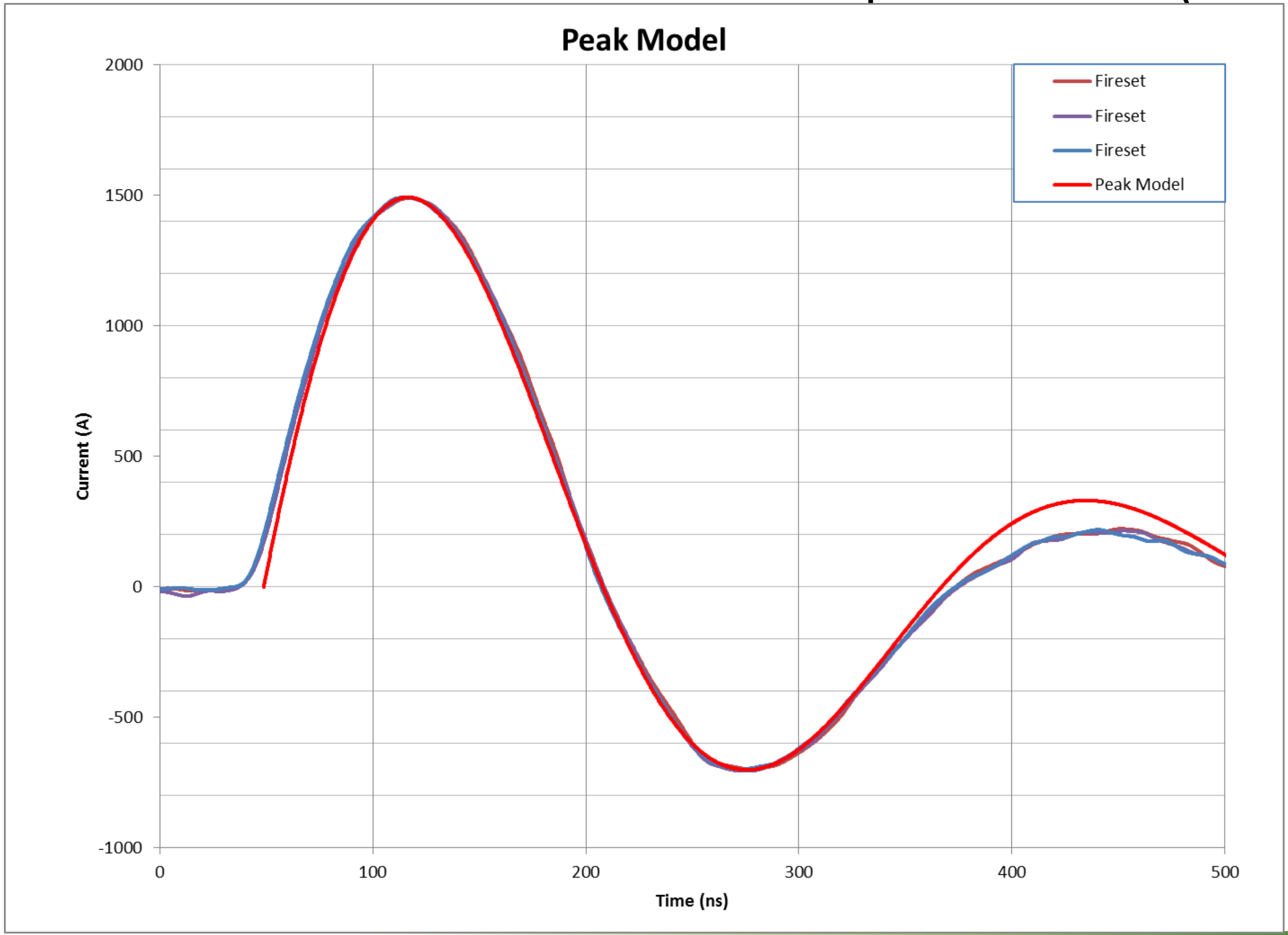
Calculation of Impedance Parameters – Zero Crossing t_4-t_2 Model

- Using the measured data:
  - Inductance iterated to 25.27 nH to match peak current (1491 A)



Calculation of Impedance Parameters – Peak (t_3-t_1) Model

- Using the measured data:
  - Inductance iterated to 22.45 nH to match peak current (1491 A)



Comparison to Empirical Data

- Neyer D-Optimal Threshold testing results
  - Two firesets characterized using this method on same product lot
  - Firesets were different by design to match different intended use firesets
  - Both firesets used to perform group A, B, C tests
- Impedances calculated by using the peak method for best fit
  - HCT = $t3 - t1$
  - Fireset differences compared by calculating impedance at the full cycle frequency (reactance & resistance) for both firesets:
    - $X_L = 2\pi f L$
    - $X_C = \frac{1}{2\pi f C}$

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Comparison to Empirical Data (continued)

- Differences in Impedance
  - Calculated

Firing Voltage	% Impedance Difference	Impedance Component	% Difference	Component Difference Sum
Max	-1.6%	L (nH)	15.4%	38.5%
		C (µF)	21.9%	
		R (Ω)	1.2%	
Mean	-3.9%	L (nH)	15.6%	36.3%
		C (µF)	16.6%	
		R (Ω)	4.0%	
Min	-6.4%	L (nH)	14.8%	46.6%
		C (µF)	26.3%	
		R (Ω)	5.5%	
	-4.0%	Average Impedance Difference		

  - Measured

	Group	% Change
Fireset 1 vs. Fireset 2 Difference in Mu	Group A	-4.34%
	Group B	-4.45%
	Group C	-4.36%

  - Impedance difference matches threshold differences much closer than the sum of the relative differences in impedance components
  - Difference in peak currents (15%) and "ratio of ratios" defined in MIL-DTL-23659F, A.5.1 (17%) much higher than the threshold difference in data

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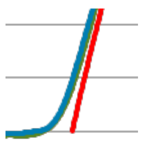
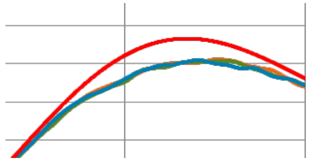
Pitfalls using an ideal wave model

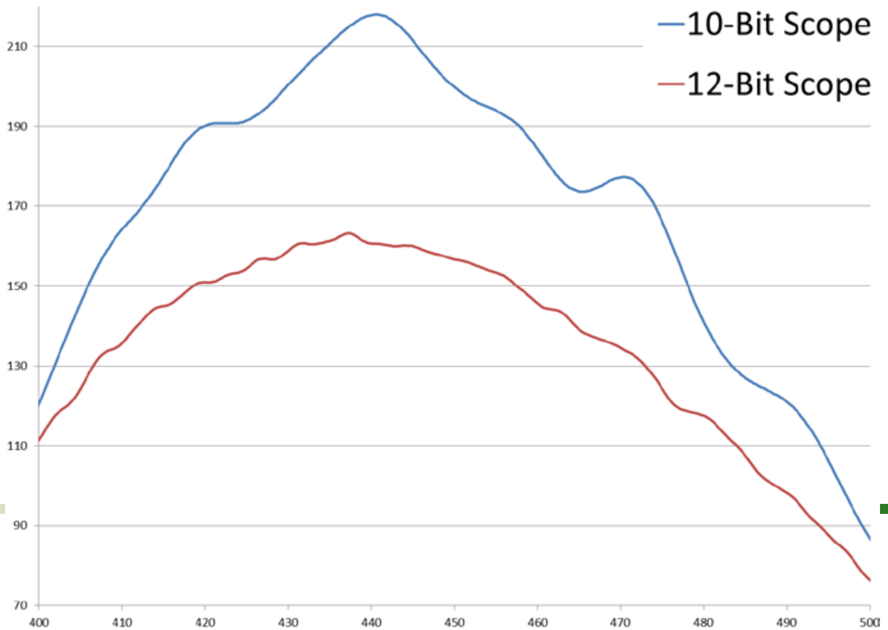
- Nonlinearities of solid state switch
  - At low voltages, switch used performs in a nonlinear fashion
  - At turn on



At the second peak



- Fidelity of Measurements
  - An 8-10 bit oscilloscope is insufficient to properly bin the voltage output of the CVR.
  - A 12-bit scope resolves this problem



Conclusion

- Presented a robust model to calculate impedance parameters based upon empirical CVR measurements
- Predictions are consistent with results during threshold testing
- Must match t_0 once the solid state switch exits nonlinear region of operation
- High precision oscilloscopes help accuracy of prediction greatly

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