The Effect of Out-Of-Band Energy on the Measurement and Analysis of Pyroshock Data

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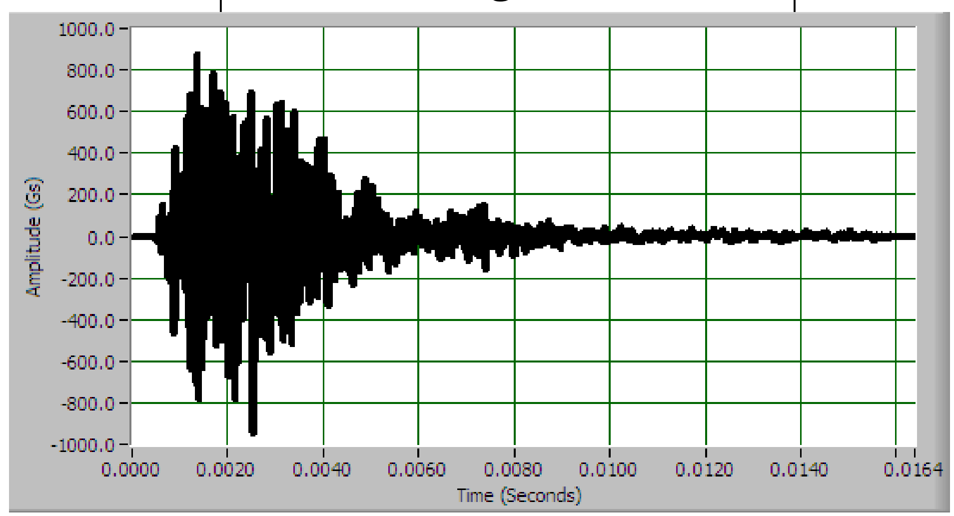
What is Out-of-band Energy?

The best way to describe it is with an Example:

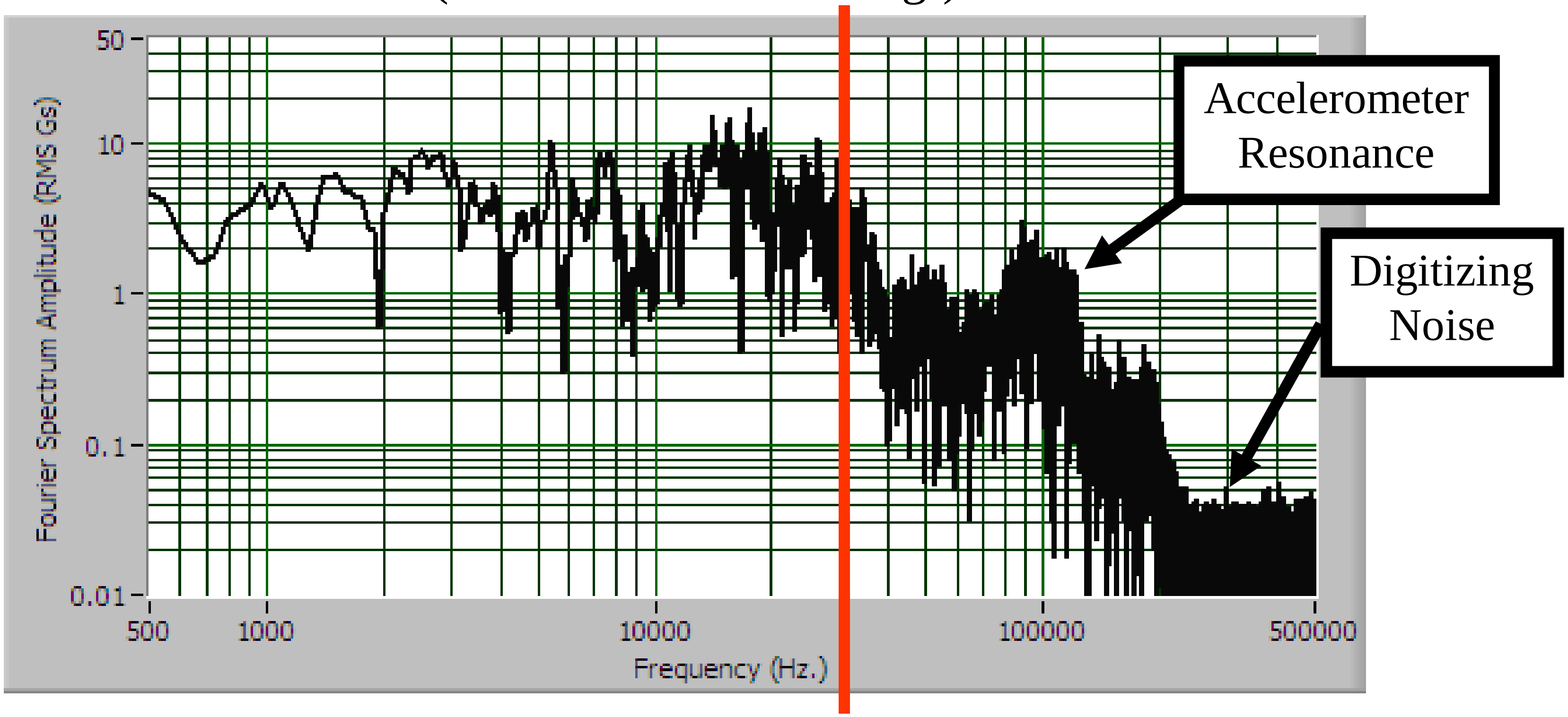
Suppose We Put an Accelerometer on the “Wing” of our Starfighter to Measure the Response to the Explosion

If We Acquired the Data at 1 Million Samples/Second The Response Might Be Something Like This



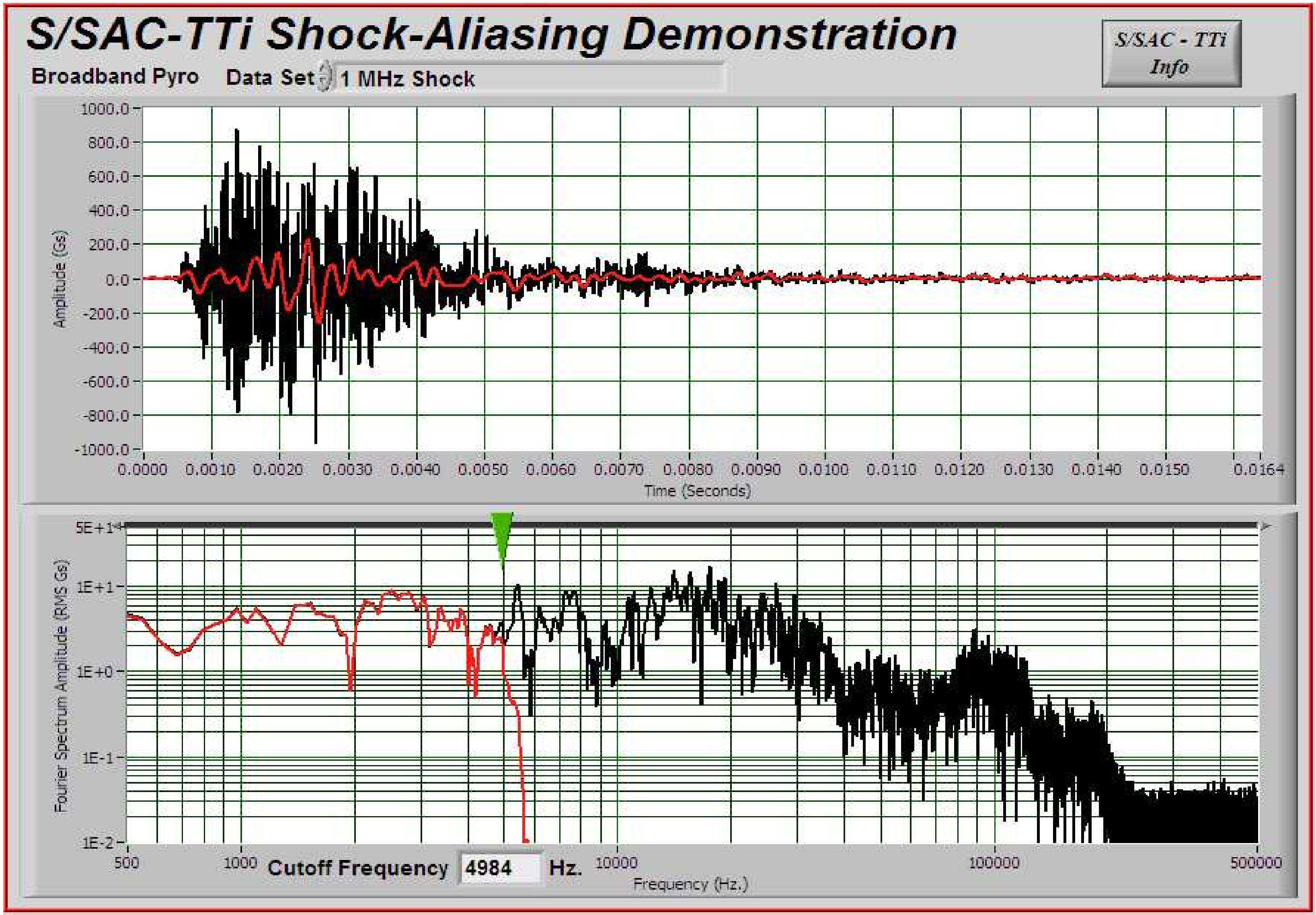
To See What's Really Going On
We Calculate the Spectrum

We see that the Response Includes a Lot of High-Frequency Energy
(And a lot of it is Wrong!)



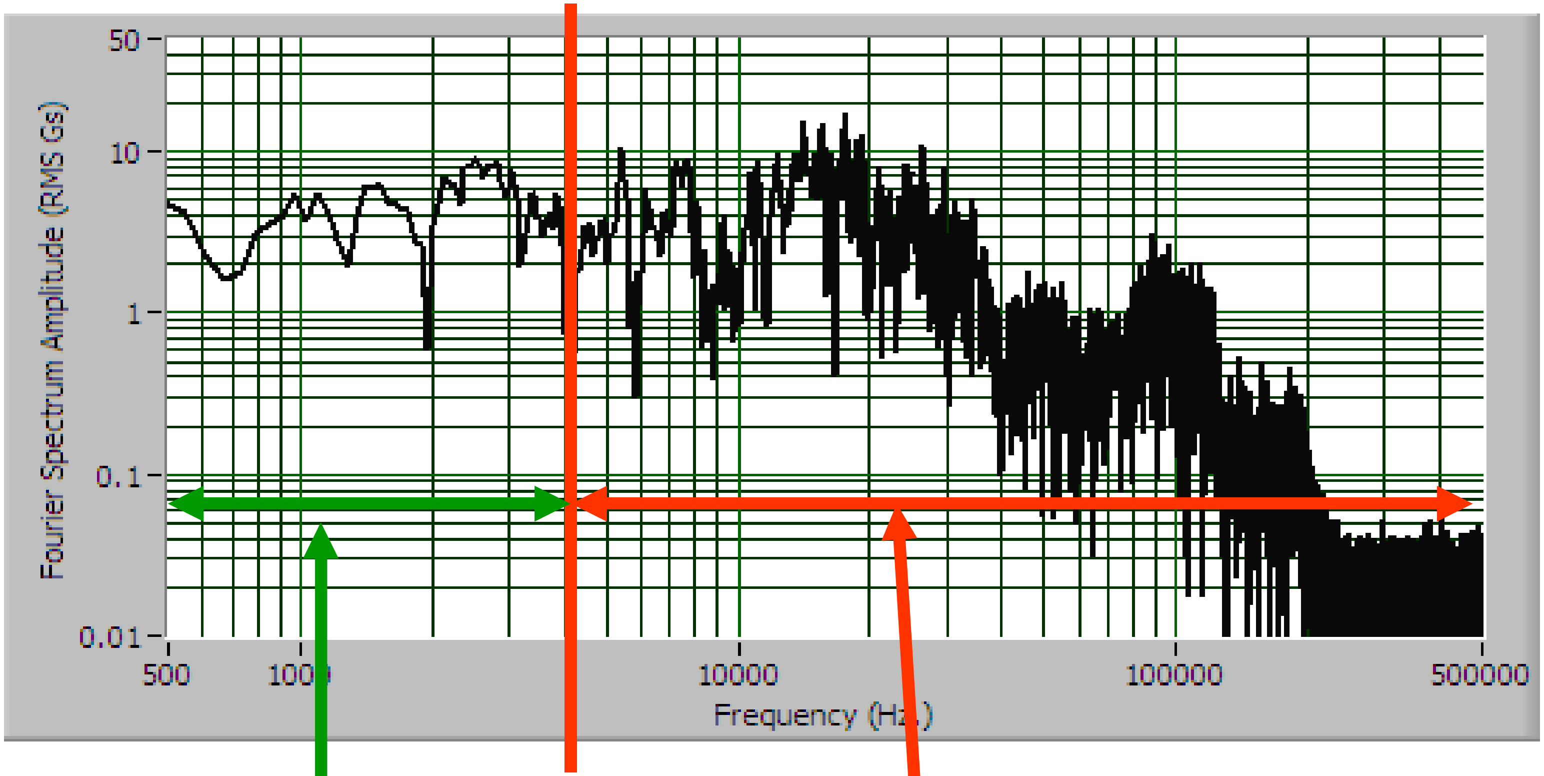
And, We Don't Care About a Lot of the High-Frequency Energy
Because it Does Not Cause Damage.

Lowering the Measurement Bandwidth



Out -of-Band Energy

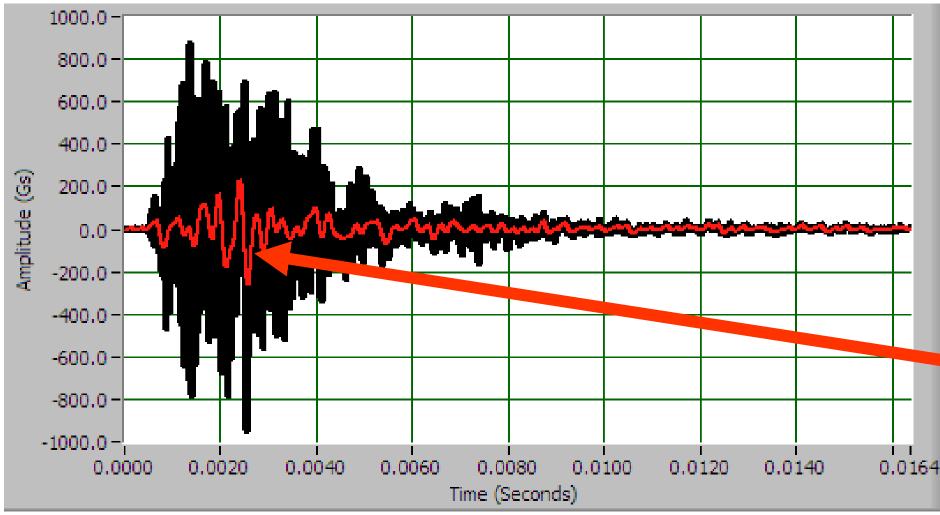
Suppose (in our Infinite Wisdom) We Decide that
We Only Care About Energy Below 5 KHz.



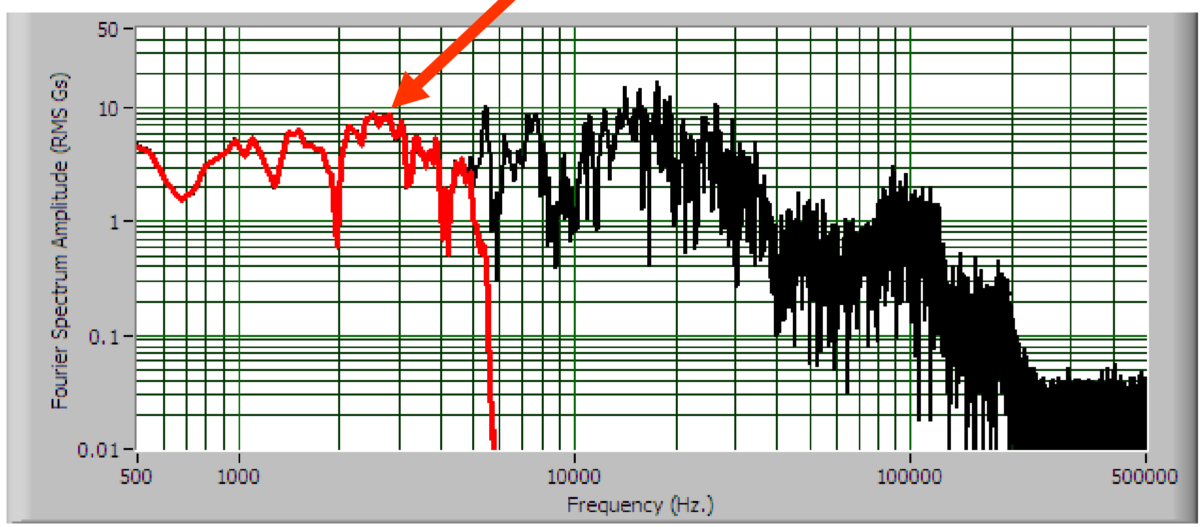
Then: Energy Below 5KHz
is *"In-Band"*

And: Energy Above 5KHz
is *"Out-Of-Band"*

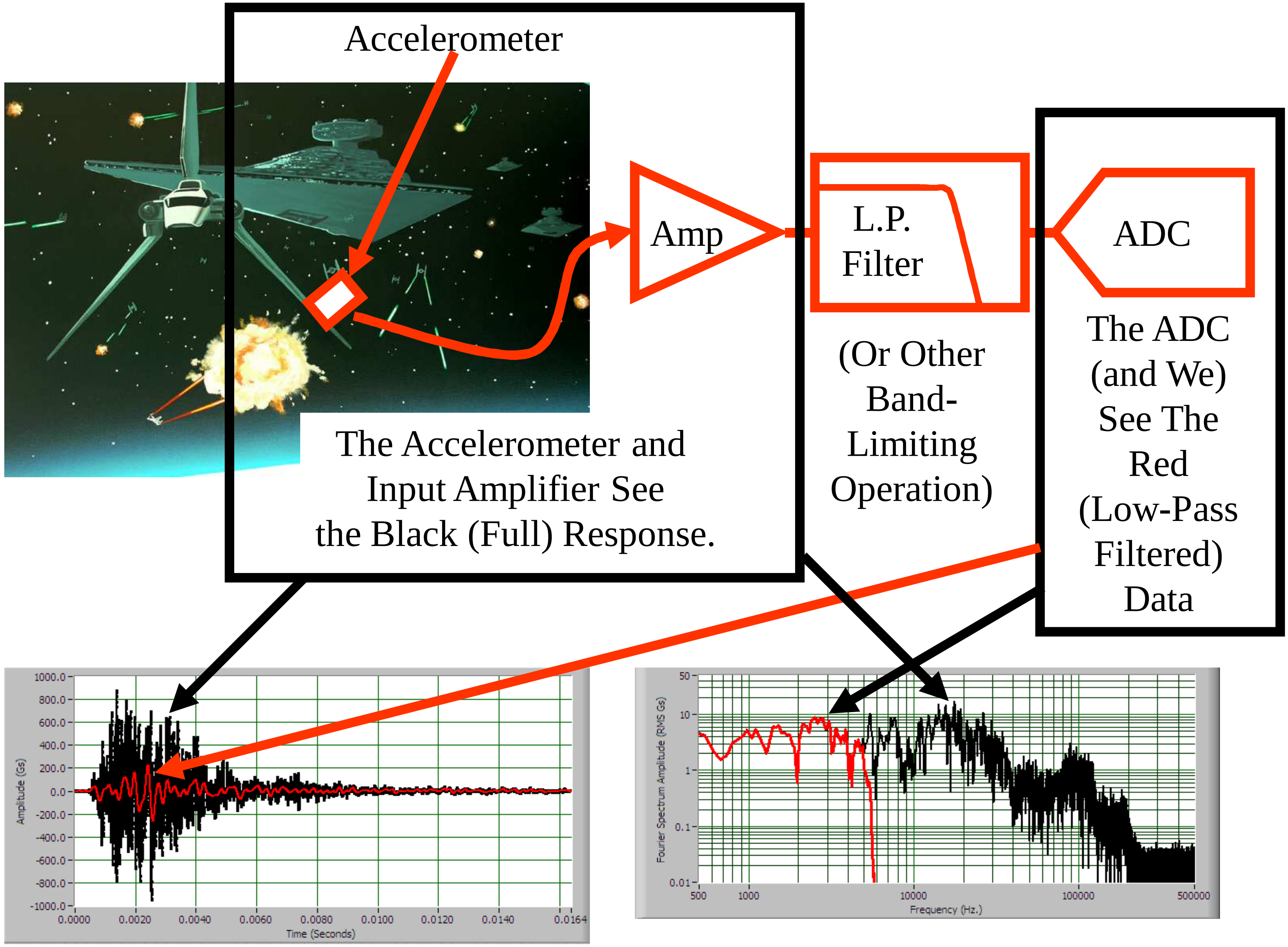
So What?



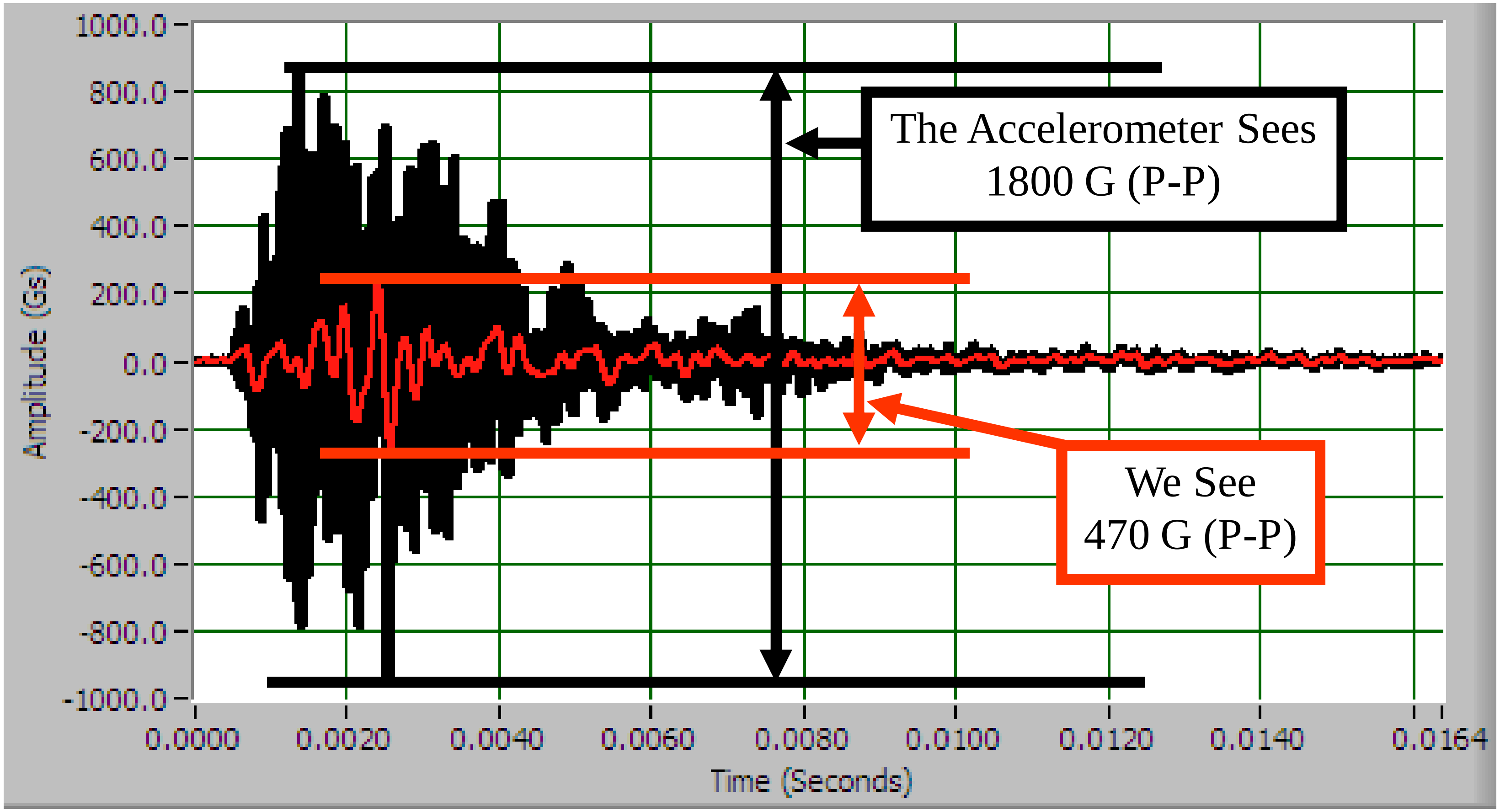
What We Care About is the "Red-Curve" Data



So What II?


Accelerometer
Amp
L.P.
Filter
(Or Other
Band-
Limiting
Operation)
ADC
The ADC
(and We)
See The
Red
(Low-Pass
Filtered)
Data
The Accelerometer and
Input Amplifier See
the Black (Full) Response.
Amplitude (Gs)
Time (Seconds)
Fourier Spectrum Amplitude (RMS Gs)
Frequency (Hz.)

Headroom



So, to cover this, we need a headroom of at least $\frac{1800}{470} = \sim 4$

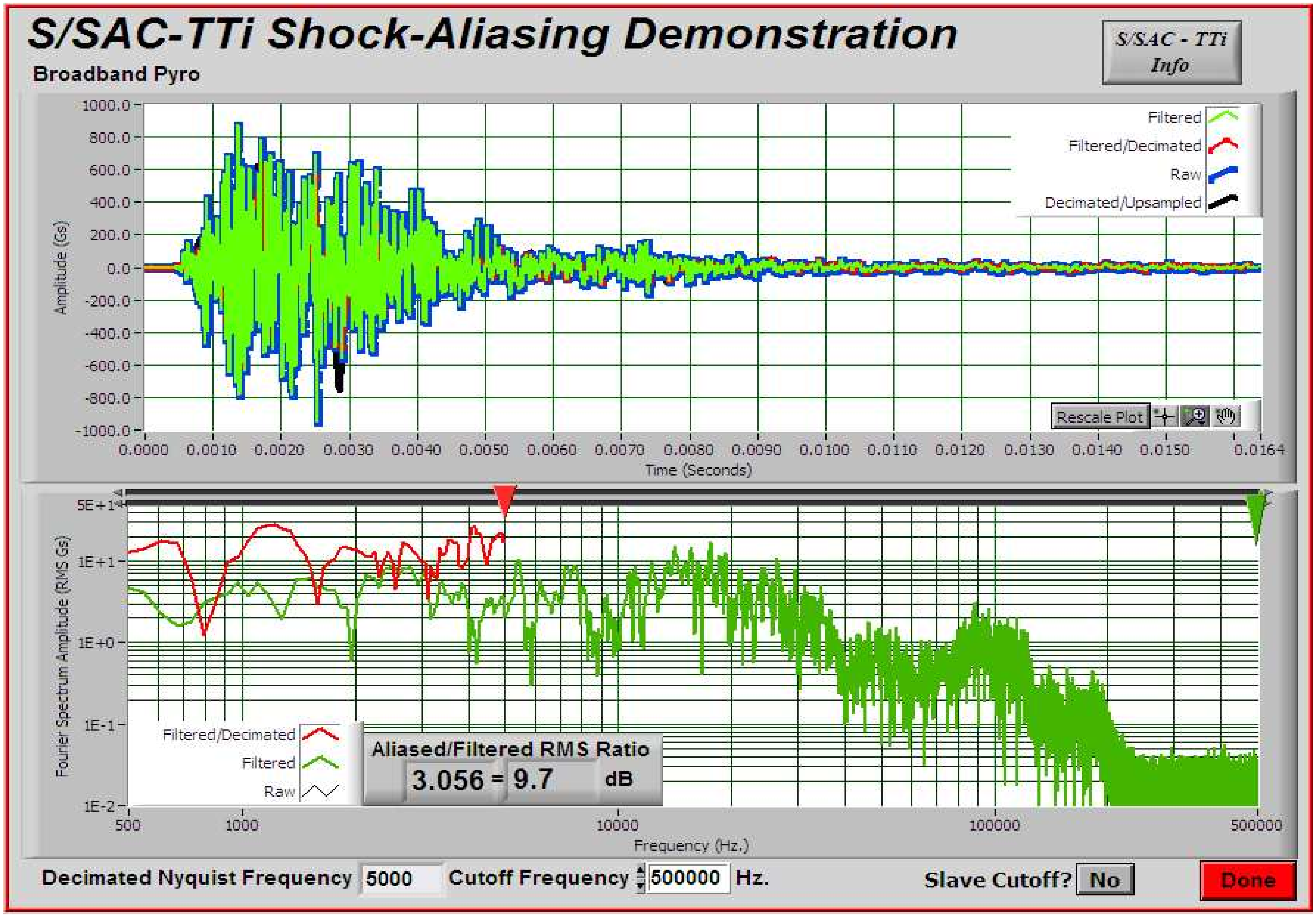
To be Safe, We Should Use 10!

What Happens When We Don't Do It Right?

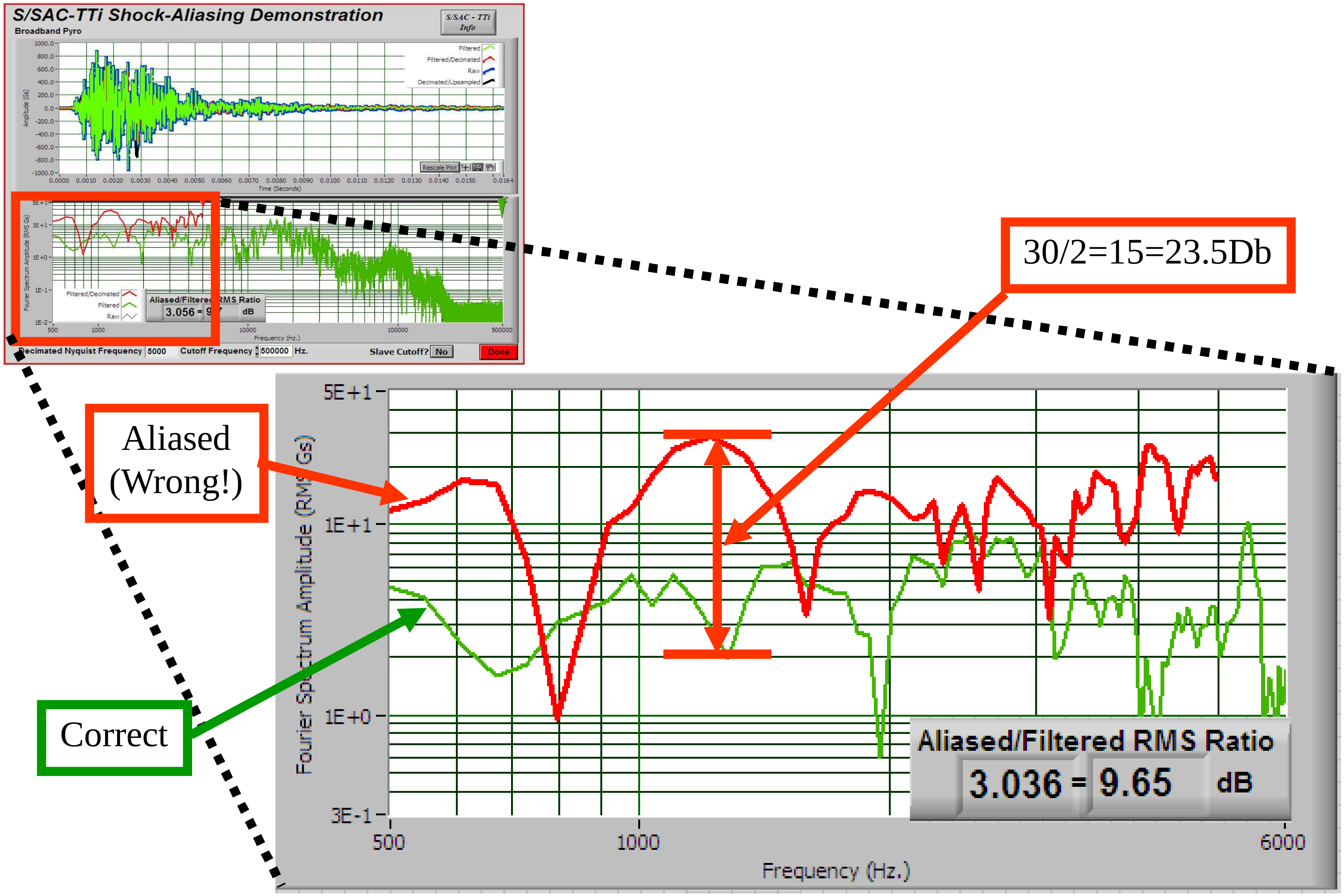
- We are going to Use the Data Set Shown Earlier but Recognize that there are many instances of Test Data that have much higher High-Frequency Content.

- We are going to Emulate what would Happen if we *Sample Too Slow and Don't Use a Low-Pass Filter!*

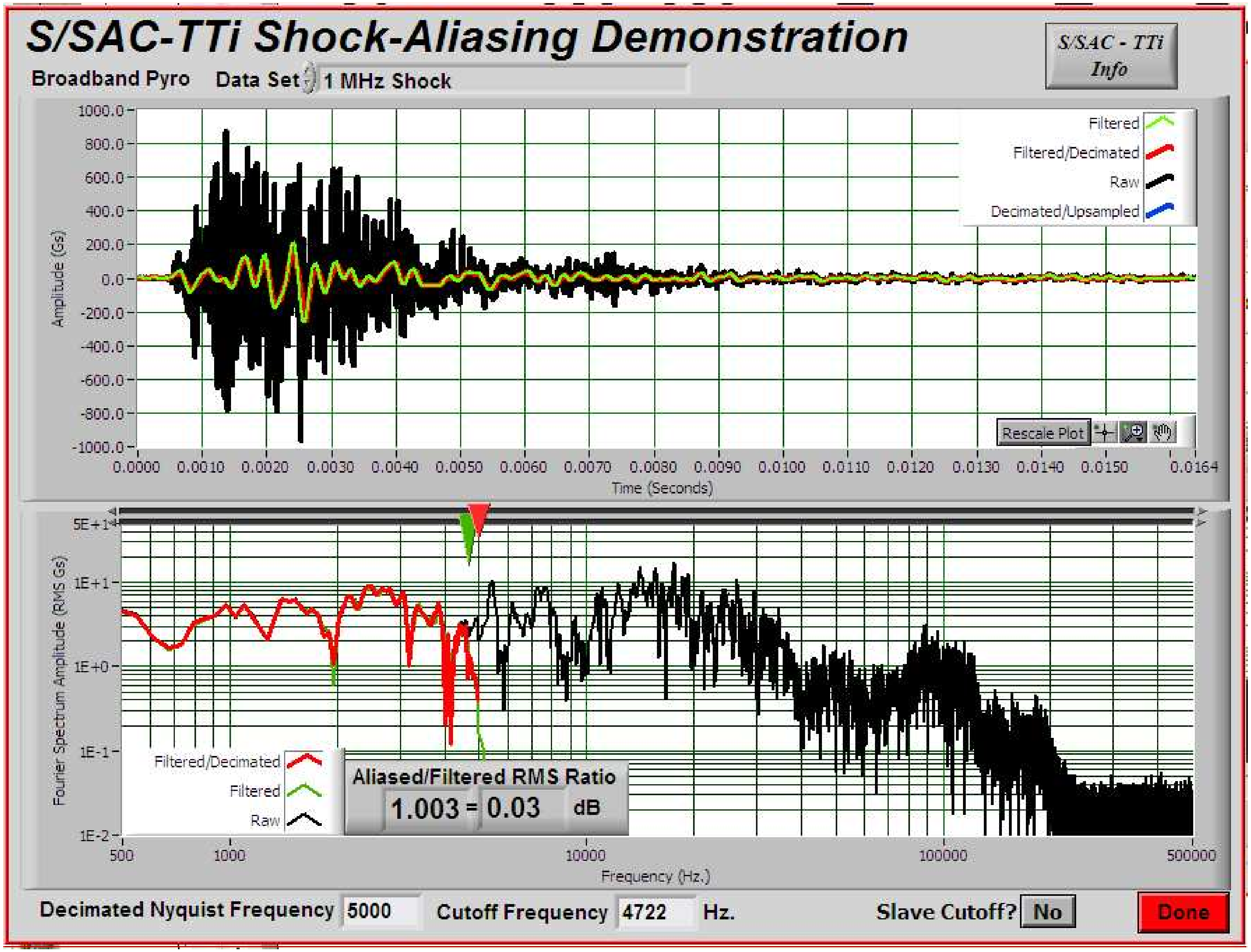
Shock Aliasing Demo



A Closer Look at the Spectrum



Now.. We Will Filter The Data



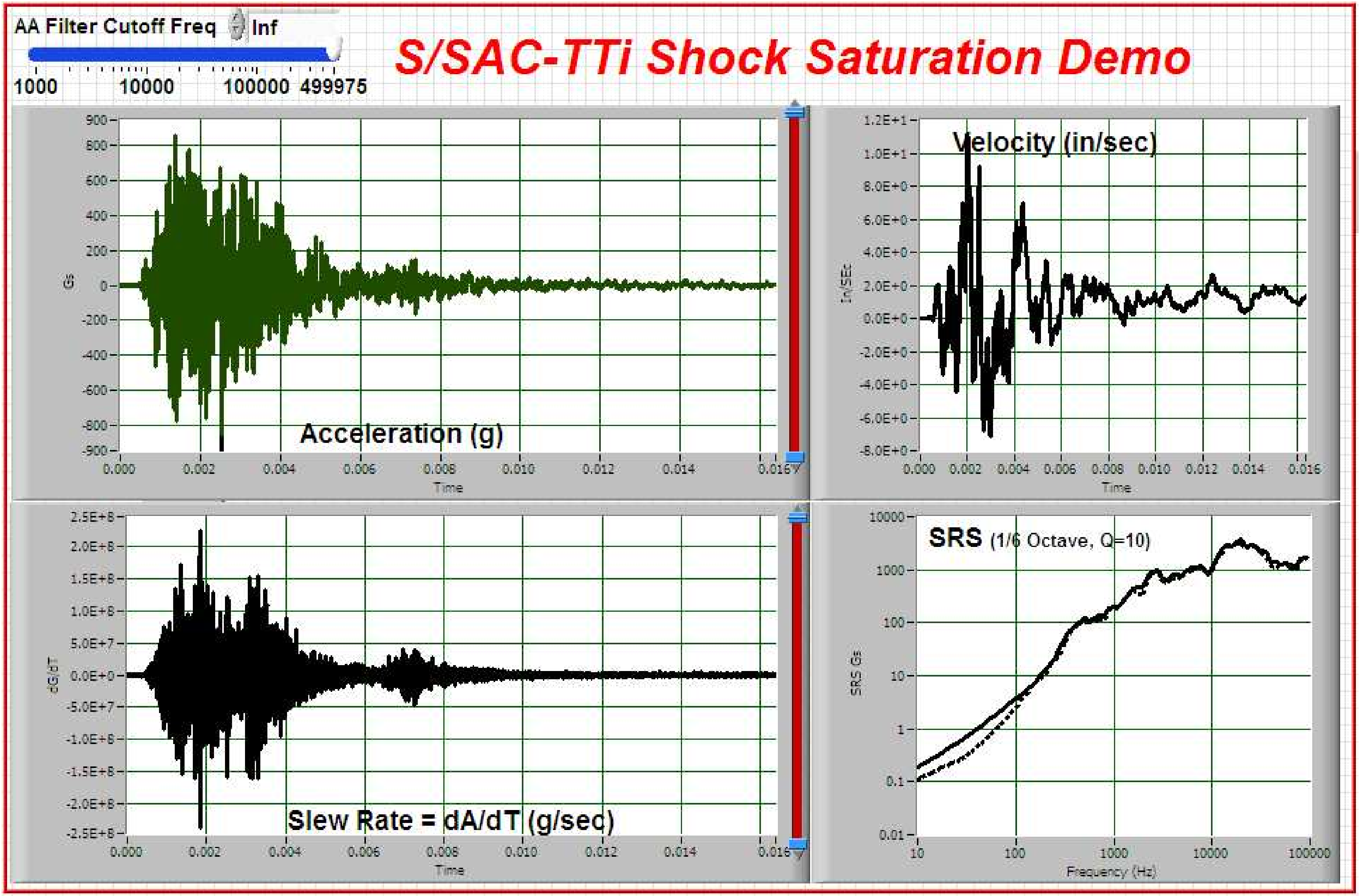
Rule #1

- We must always either:
  - Sample So Fast that We Know that All Significant Frequency Components are Below the Nyquist Frequency (S/2) ….or
  - Filter and Sample with a Strategy that Assures that Our Data Set is *Adequately Alias-Protected* in the *Frequency Range of Interest*.

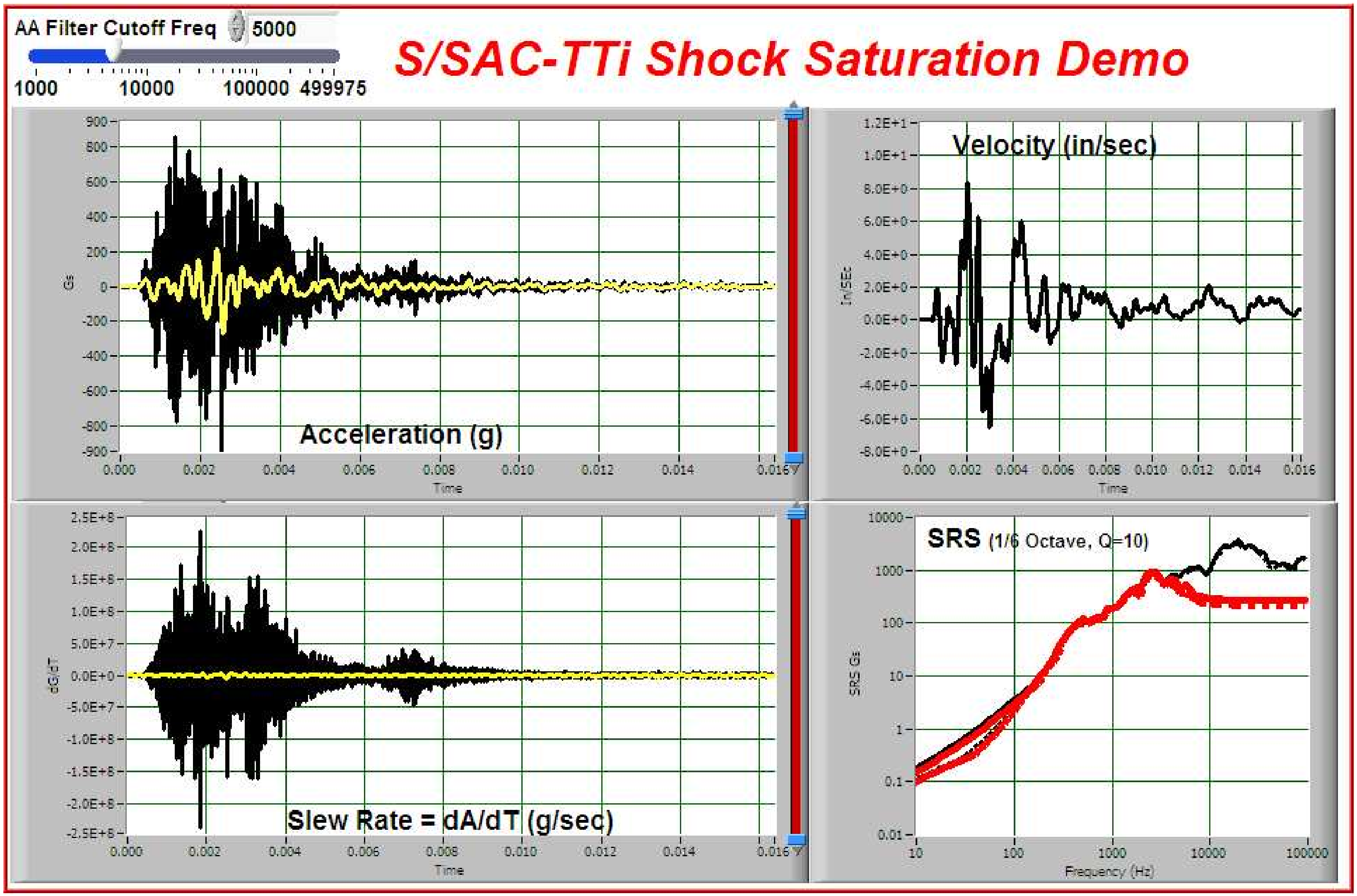
This is Really Dangerous

- Best Solution: Sample Really Fast with a Filter that Assures that We are Safe From Aliasing.
  - Available but Really Expensive

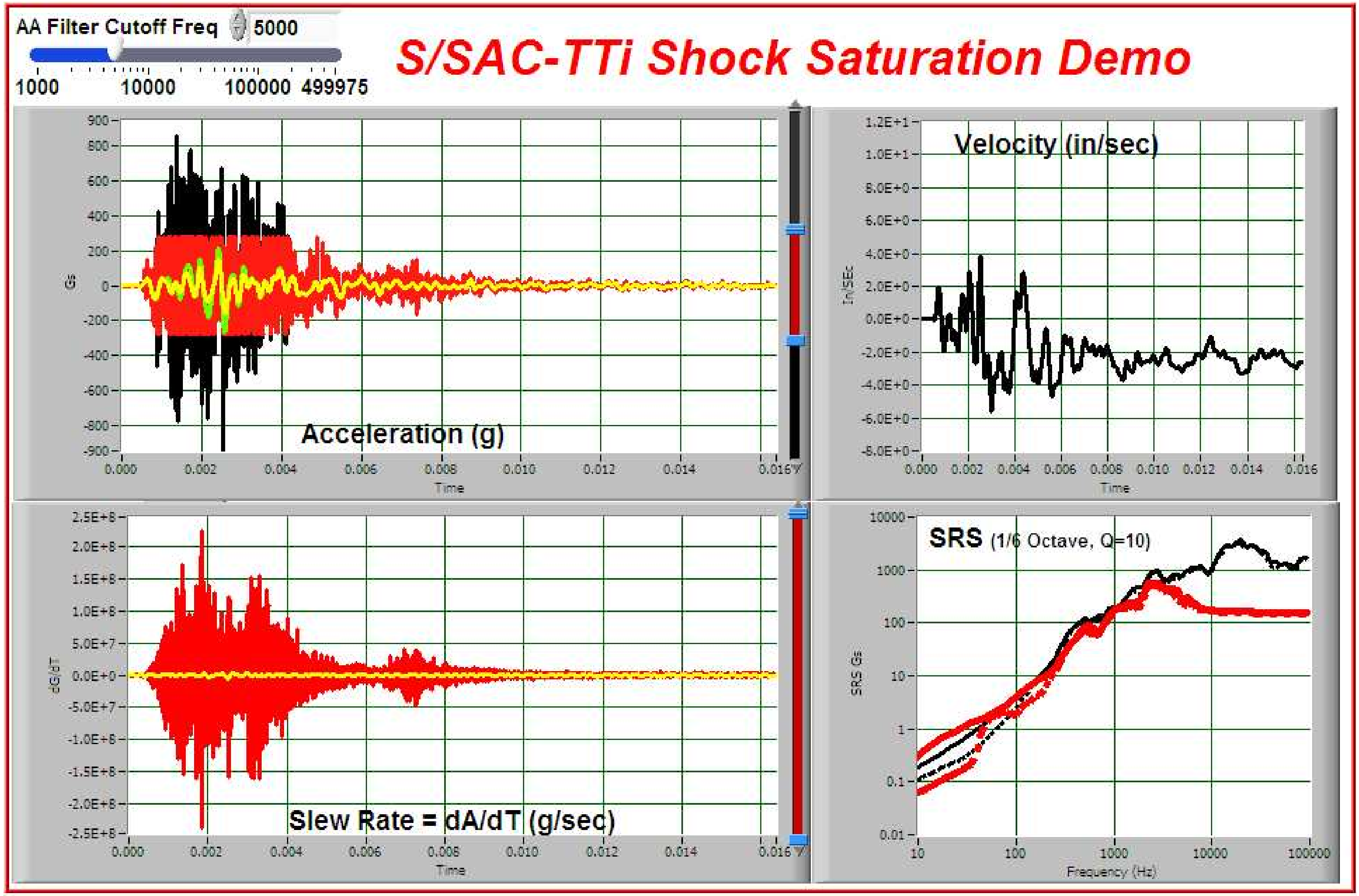
Problem #2---Slew Rate



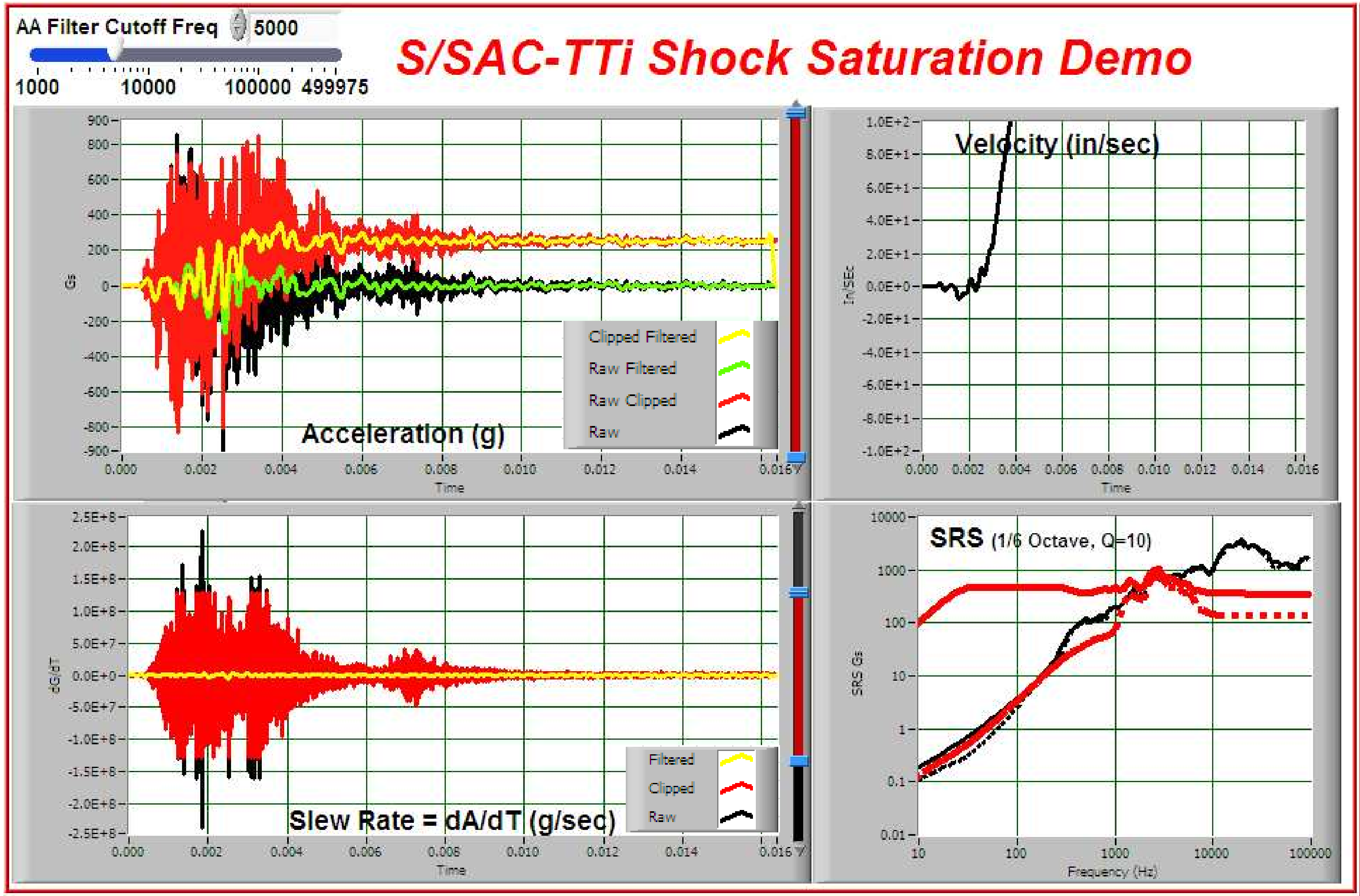
Problem #2---Slew Rate
---Limiting Bandwidth



Problem #2---Slew Rate
---Out-of-Band Saturation



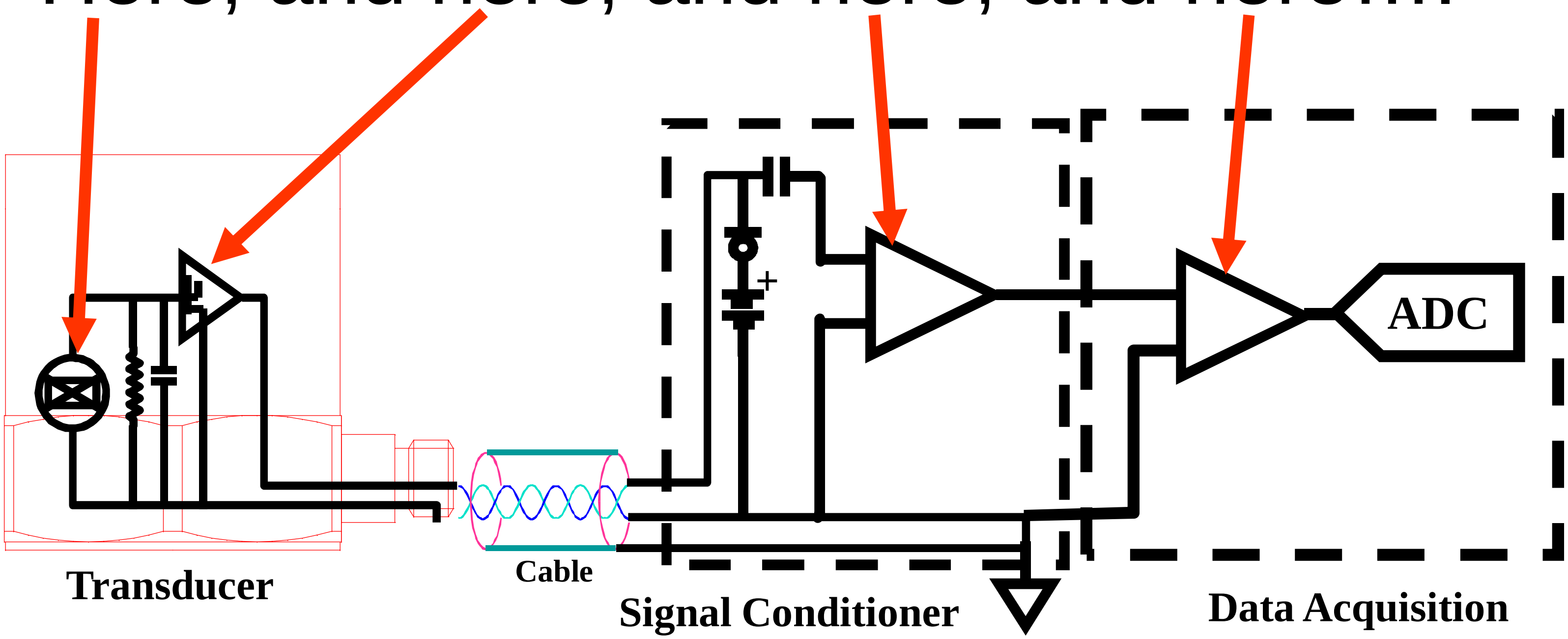
Problem #2---Slew Rate
---Out-of-Band Slew Saturation



Slew Saturation Causes an *Offset*

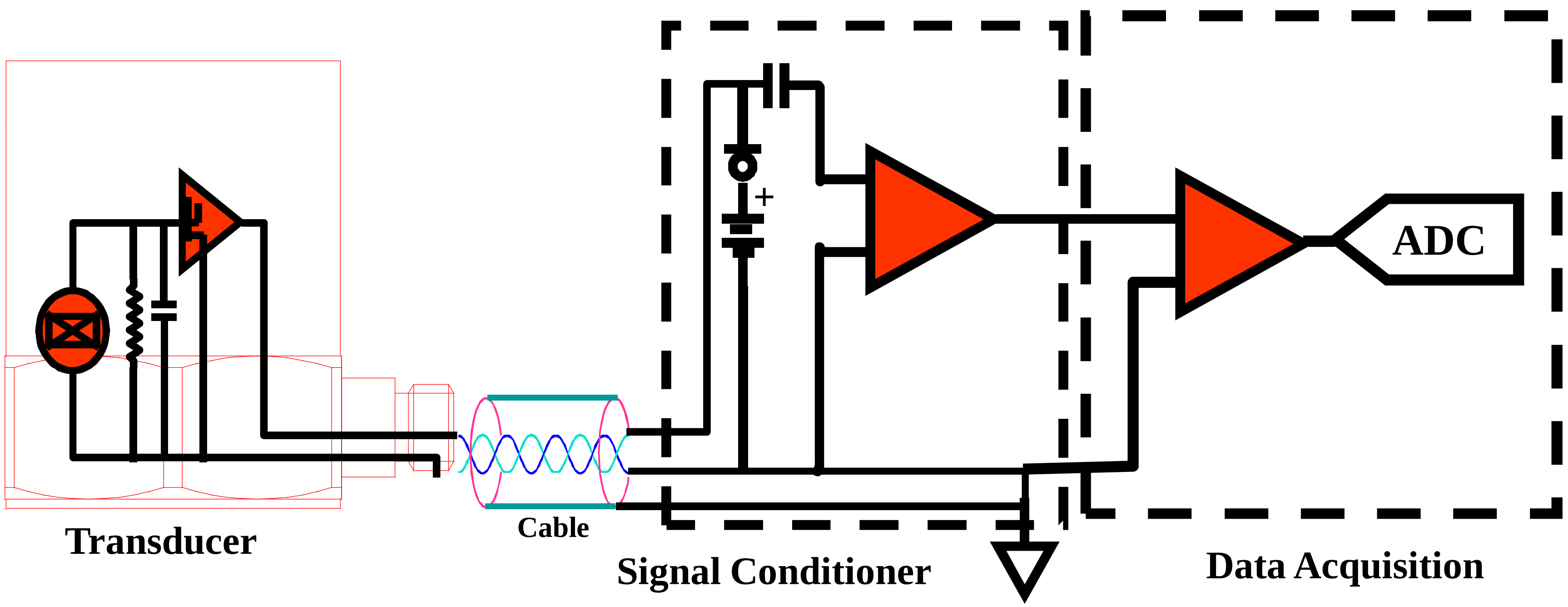
So…

- The Demo Shows That Saturation in Slew Is *One Possible Cause* of the Offsets We See in Shock Testing.
- Where Can Slew-Rate Limiting Occur?
- Here, and here, and here, and here….



So, In Principle

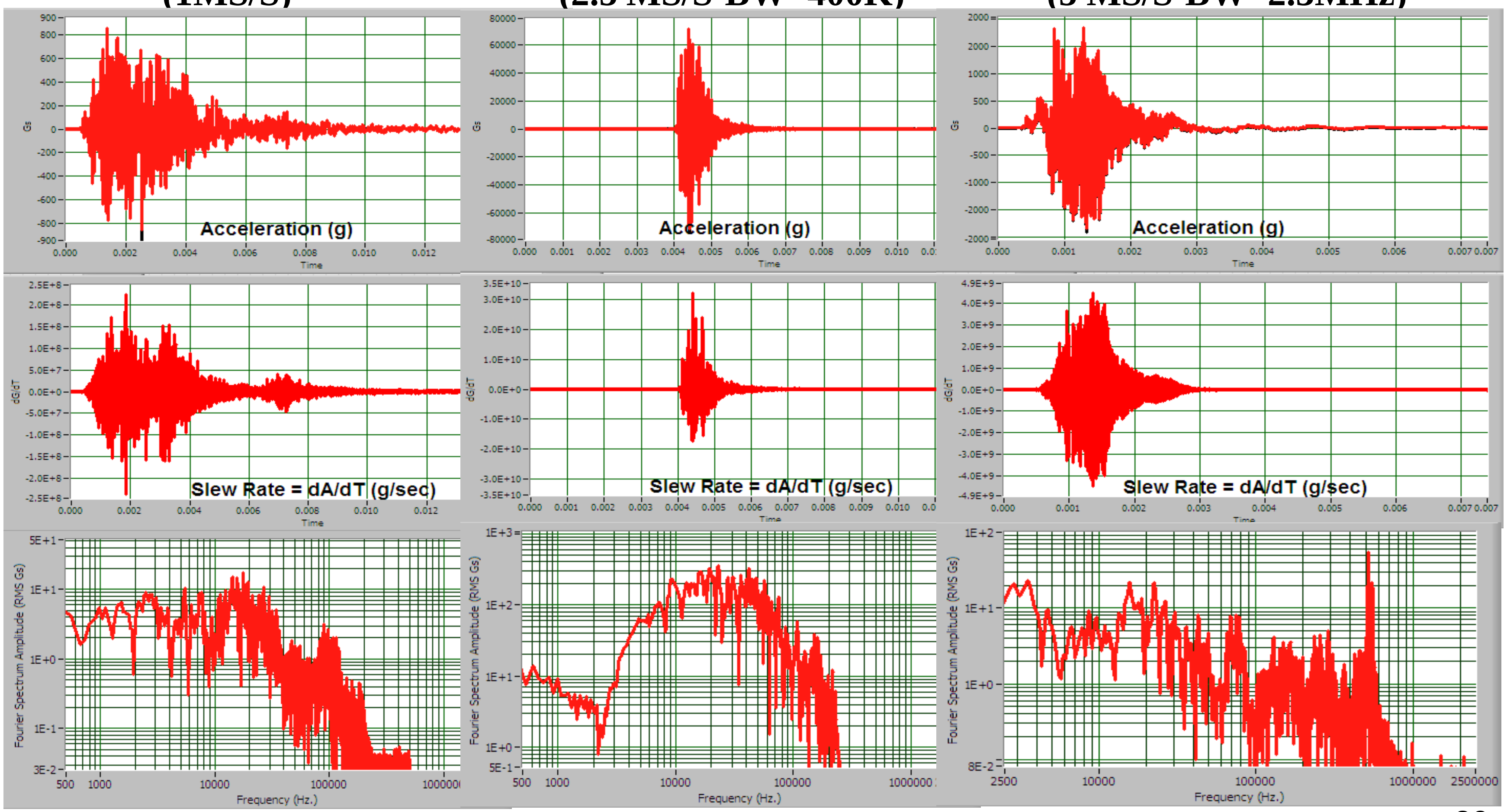
We Need to Know What the Slew Rate Capability of Each of the Components Is



And

We need to Have an Estimate of the Maximum Slew Rate We Can Expect From Our Tests.

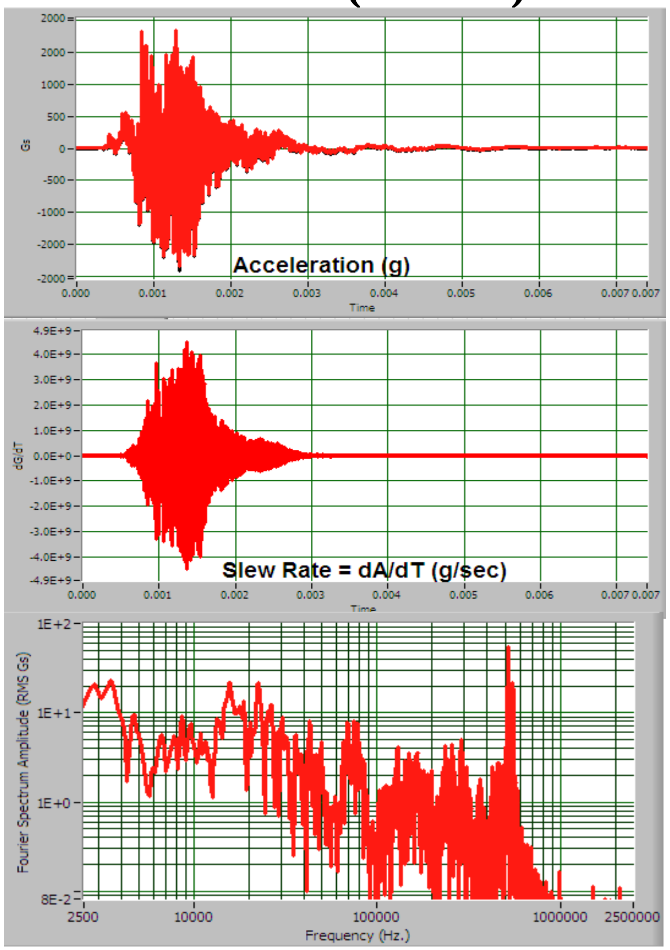
Smith (1MS/S) | **Bateman (2.5 MS/S-BW=400K)** | **Remelman (5 MS/S-BW=2.3MHz)**



The Worst of These

Is the “Remelman” Set

Remelman (5 MS/S)



If We
“Normalize/Calibrate”
the Data to a
5 Volt Maximum
we get

12.5 Volts/uS

(Is this the Real Worst?)

Next

We need to
Define a set of
Data-Acquisition-System Tests
that will Assure that the
In-Band Energy
is Well Represented
and the
Out-of-Band Energy
Does Not Interfere With the Measurement

A Proposed
Validation Test Suite
for
Data Acquisition Systems
used for
Pyrotechnic Tests

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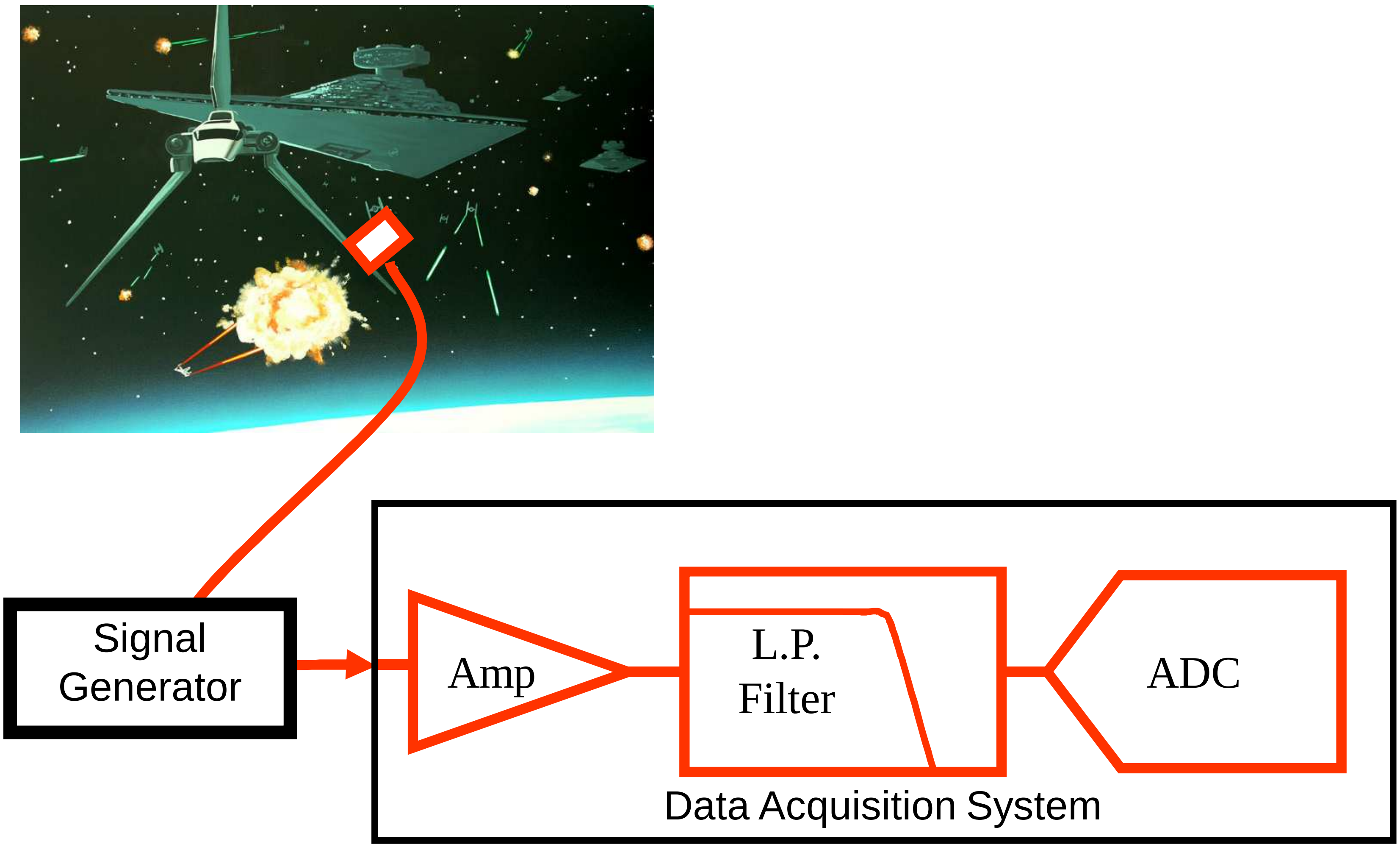
What Are We Going to Do/Not Do

- **Do:**
  - **Show that the System**
    - **Has an Understandable and “Useful” Transfer Function.**
    - **Has Adequate Protection against Aliasing.**
    - **Will not produce Strange Results When Subjected to Expected Out-of-Band Energy.**
    - **Has Adequate Dynamic Range to Assure that the In-Band Energy is Well Characterized in the Presence of Large Out-of-Band Energy.**
- **Not Do:**
  - **Calibrate the System to .01% (or even 10%).**

What are we Testing?



Task #1

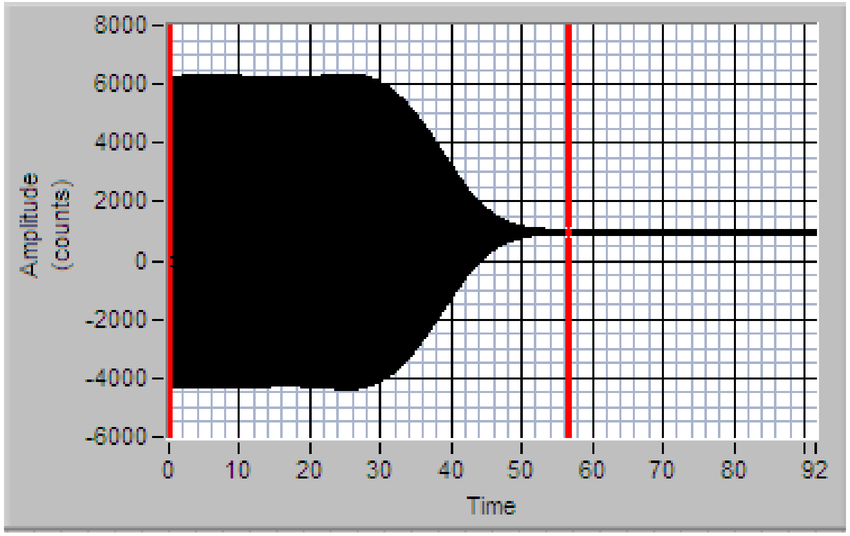
- Assure that the In-Band Signal is Properly Recorded

  and that

- Near-in-Band Aliasing Energy is Adequately Rejected

In-Band Characterization and Alias-Protection Verification

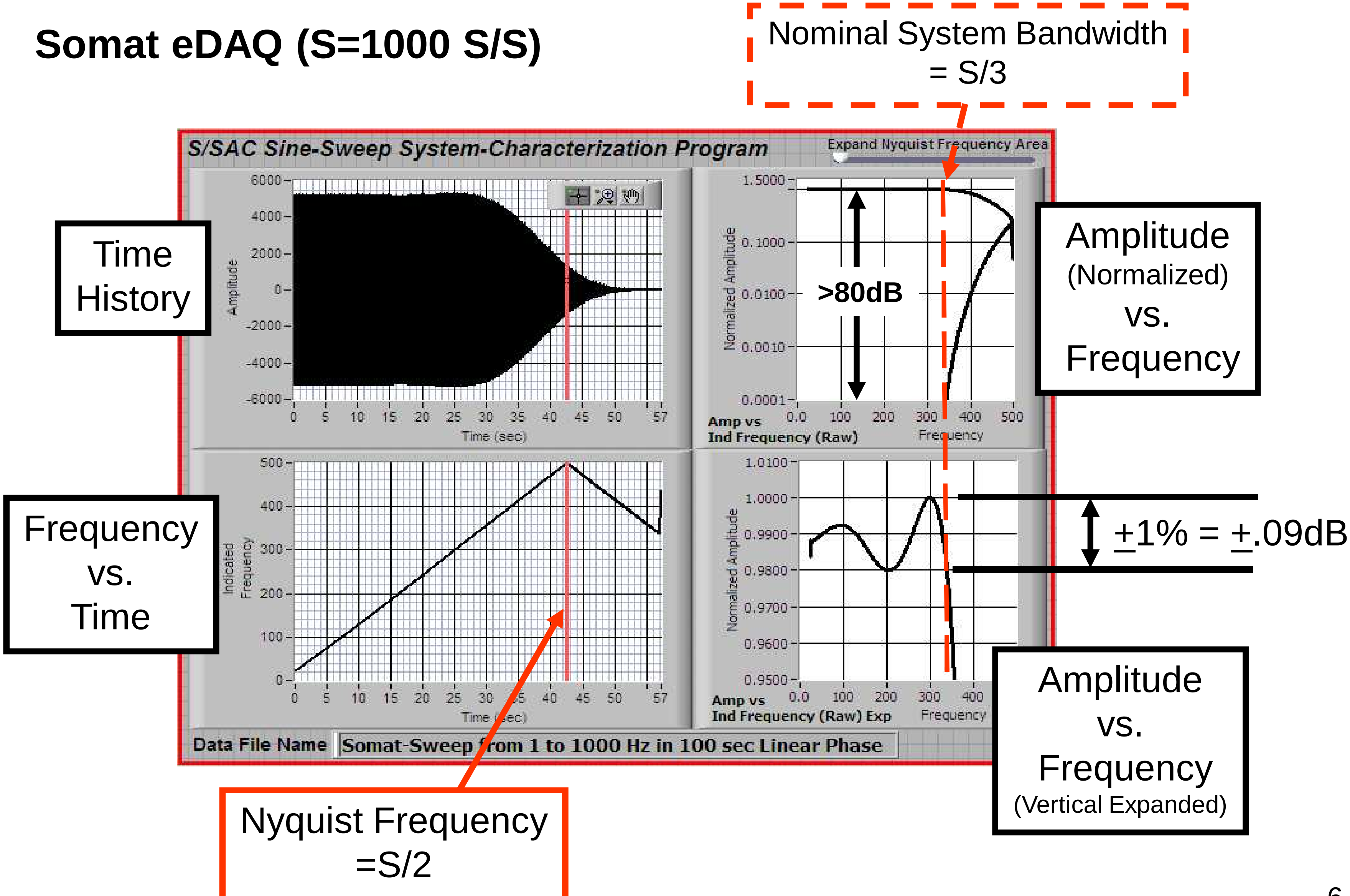
- The Test:
  - Perform a Sine Sweep
    - Frequency: .01 x Sample Rate to the Sample Rate.
    - Amplitude: 90% of Full Scale



- Analysis
  - Perform Amplitude Vs Frequency Characterization.

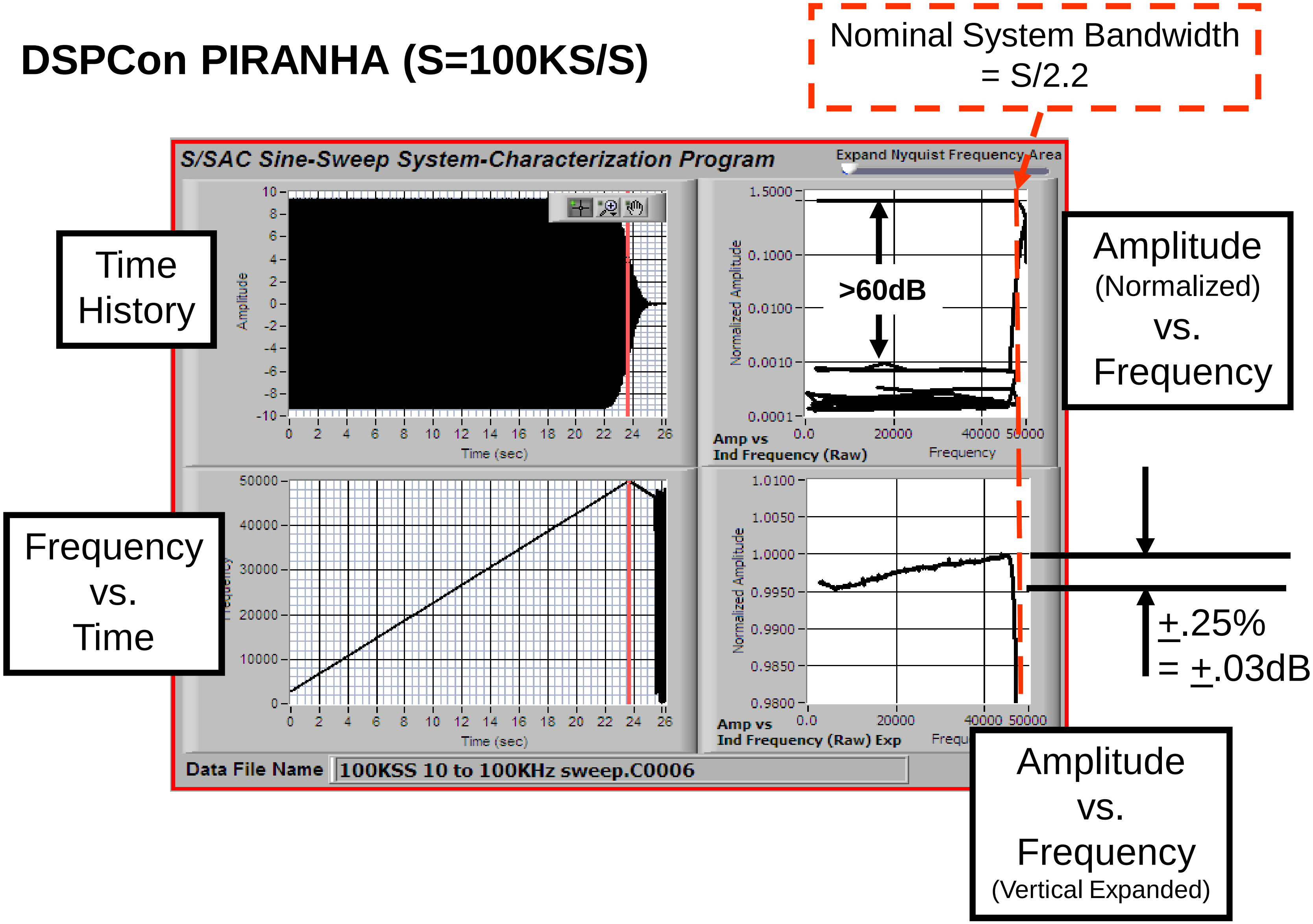
The In-Band Gain/Aliasing Analyzer

Somat eDAQ (S=1000 S/S)



A More-Modern Sigma-Delta System

DSPCon PIRANHA (S=100KS/S)



Out-of-Band Behavior Characterization

- There is Nothing New Here!
  1984 System Specification:
  - *The system shall have the capability of handling input frequencies up to at least one megahertz at a level of at least 10 volts peak.*

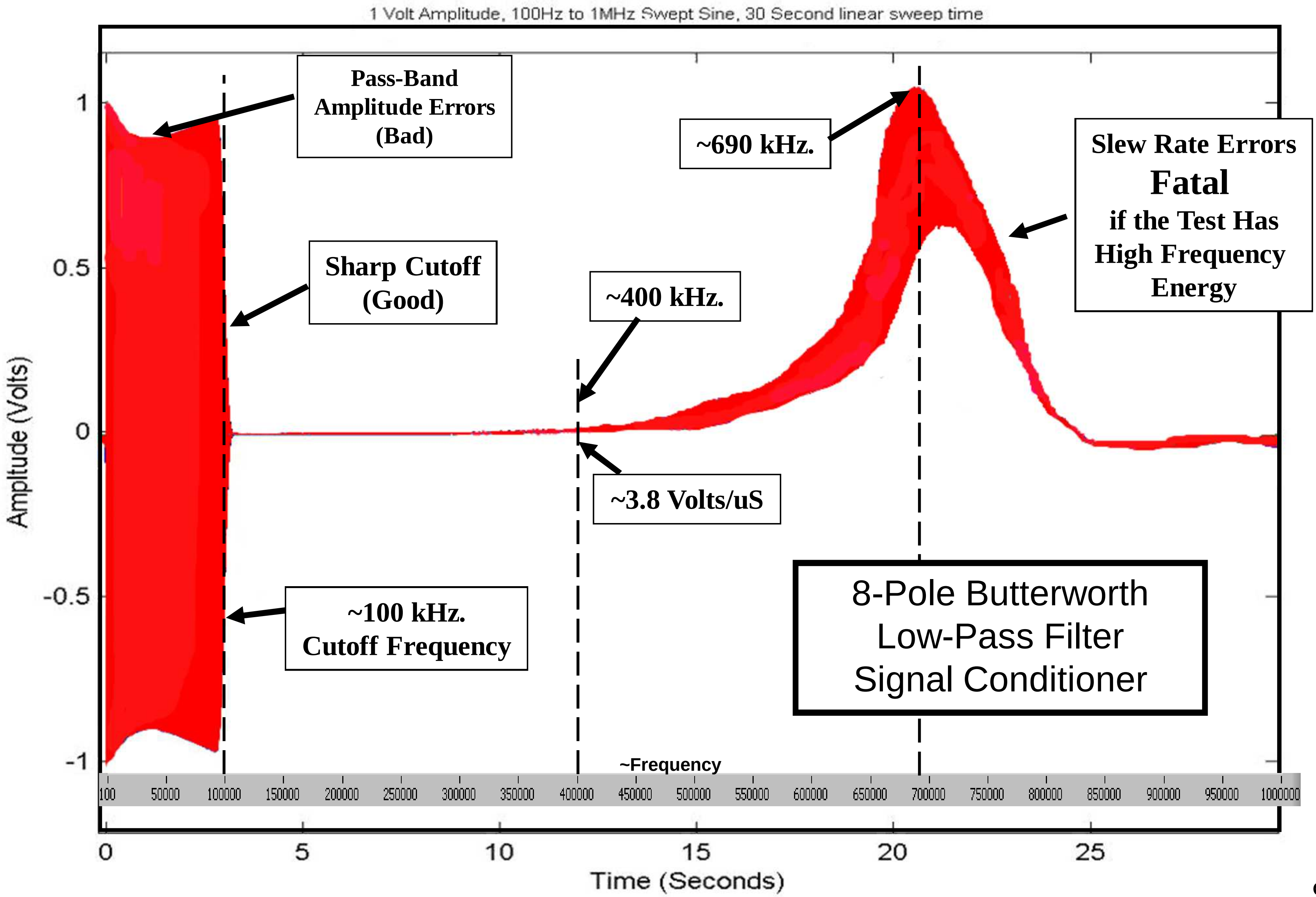
- They may not have known why, but they knew that high-frequency, high-level, (out-of-band) signals caused

  Data Corruption.

- Many Systems Built in the 1980's Could Meet the Spec.

- Many Systems Built in the 2000's Can't.

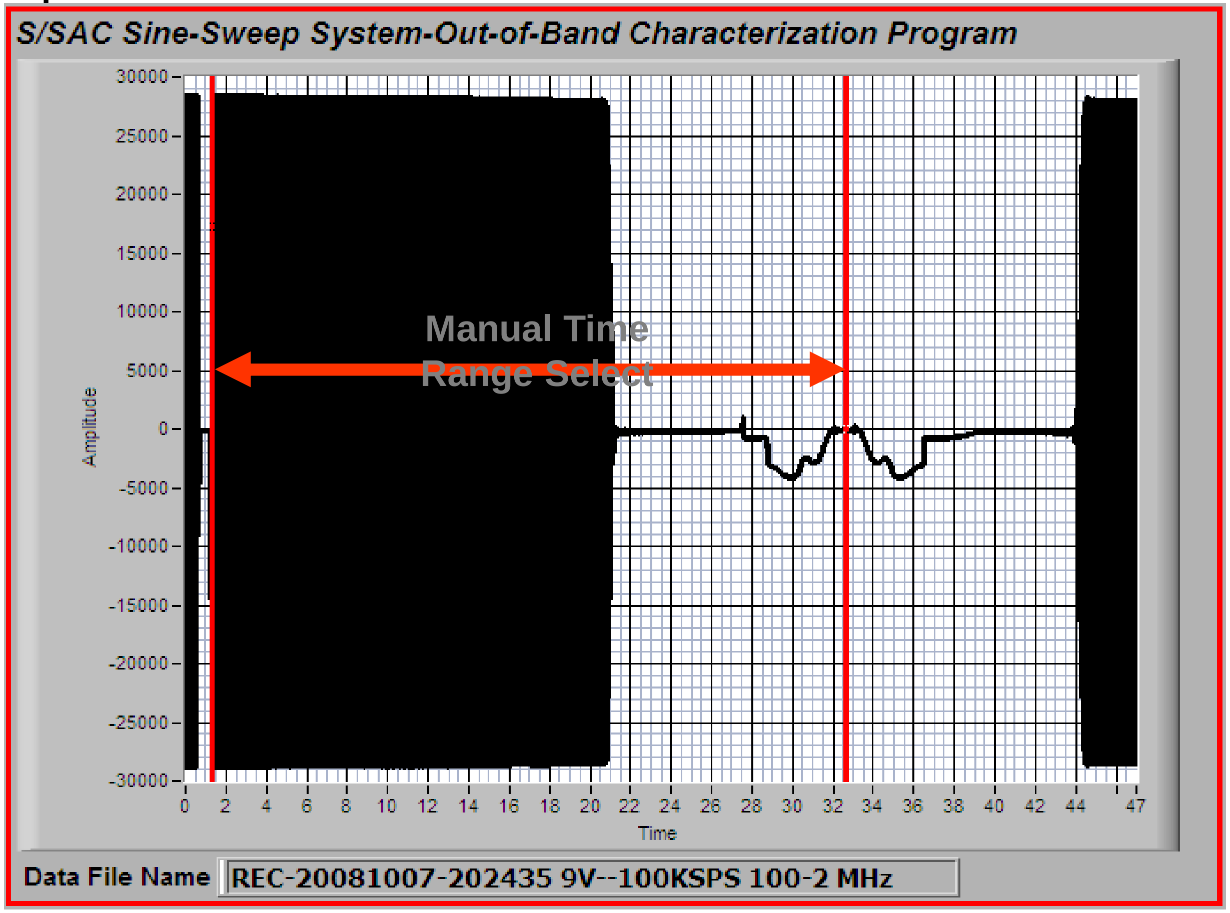
Scary!!



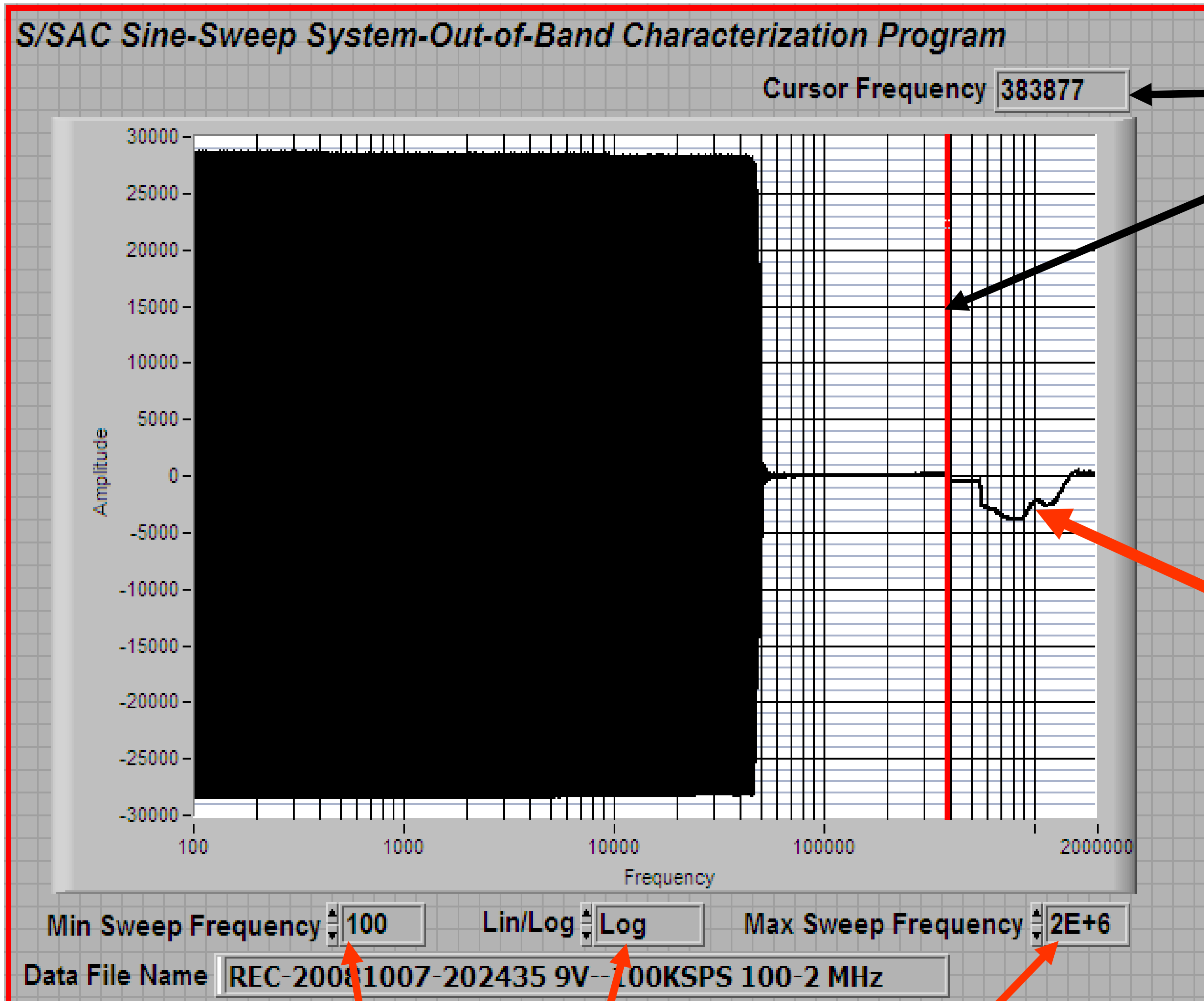
1 Volt Amplitude, 100Hz to 1MHz Swept Sine, 30 Second linear sweep time
Pass-Band Amplitude Errors (Bad)
Sharp Cutoff (Good)
~100 kHz. Cutoff Frequency
~400 kHz.
~3.8 Volts/uS
~690 kHz.
Slew Rate Errors Fatal if the Test Has High Frequency Energy
8-Pole Butterworth Low-Pass Filter Signal Conditioner
~Frequency
Amplitude (Volts)
Time (Seconds)
1
0.5
0
-0.5
-1
100 50000 100000 150000 200000 250000 300000 350000 400000 450000 500000 550000 600000 650000 700000 750000 800000 850000 900000 950000 1000000
0 5 10 15 20 25

Out-of-Band Behavior Analysis

- The Test:
  - Perform a Sine Sweep
    - Frequency: .1 x Sample Rate to 2 MHz.
    - Amplitude: 90% of Full Scale



Out-of-Band Behavior Analysis--II

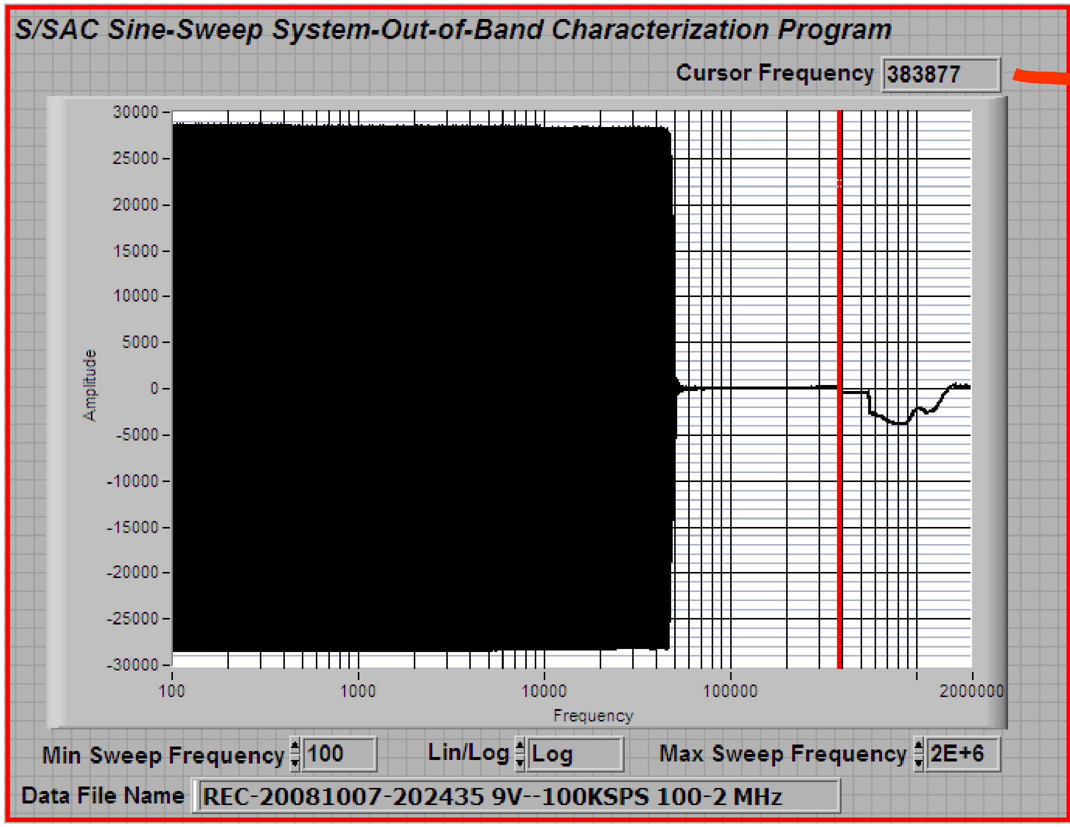


Manual Cursor At Problem Frequency

Anomalous Behavior

Manual Entry of Nominal Sweep Parameters

Out-of-Band Behavior Analysis--III



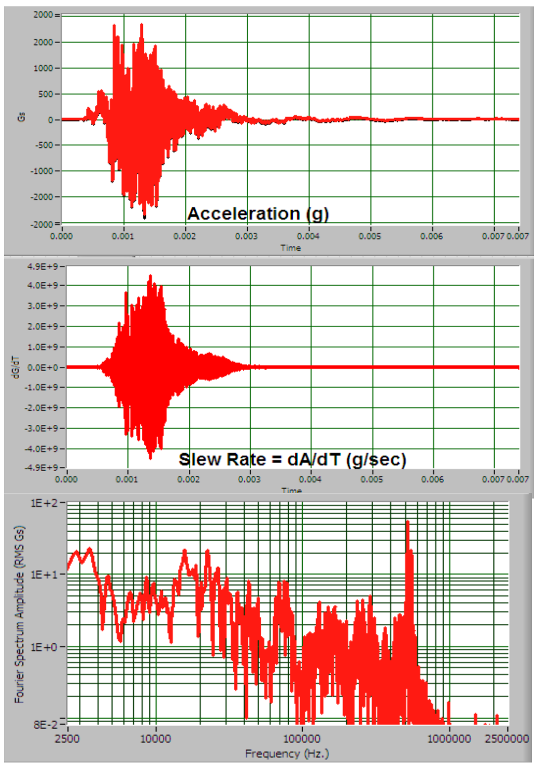
Calculate Problem Slew Rate

= 2 x ∏ x A(pk V) x Problem Frequency

= 2 x ∏ x 9 x 383,877 = 21.7 V/uS

Assess the Results

In the Previous Paper we saw that the “Real Experiment” Worst Case (so far) Voltage Slew Rate is the “Remelman” Set



Where we saw a Maximum of

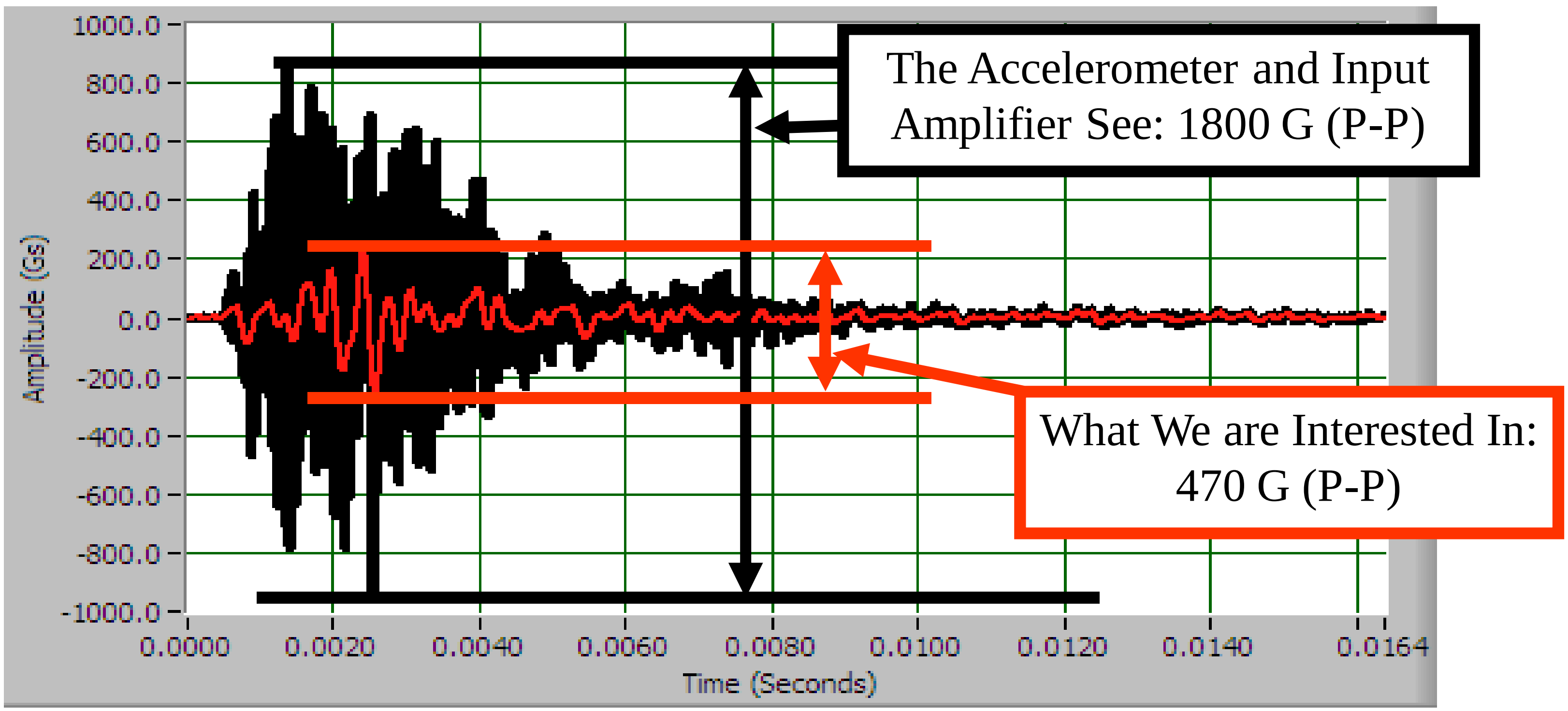
12.5 Volts/uS

This leads us to the Conclusion that the Tested System is OK.

…on the (perhaps rash) assumption that the Remelman data is a worst case.

Dynamic Range Determination

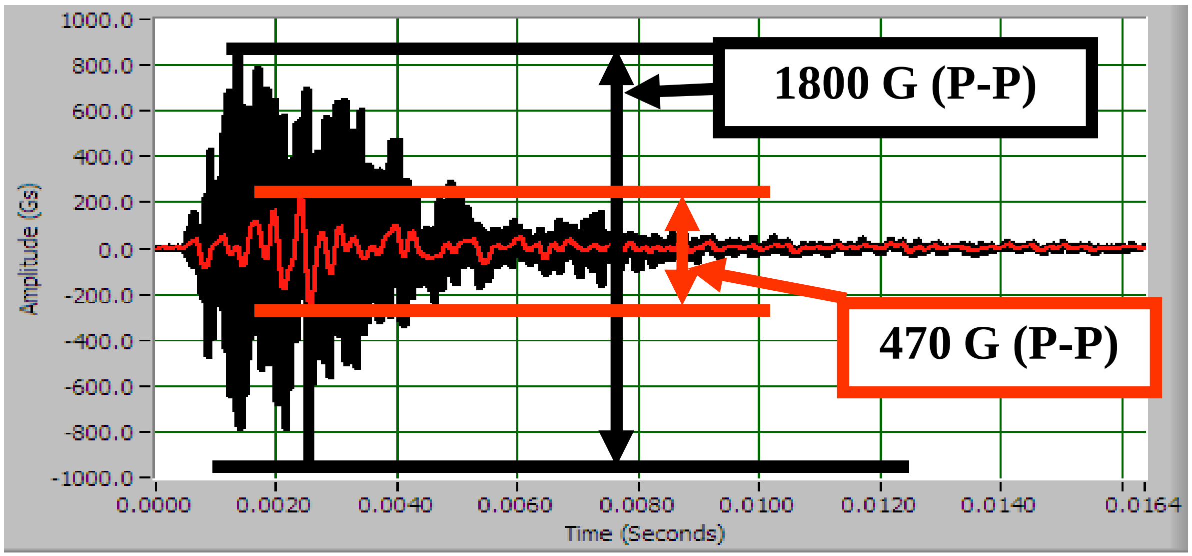
In the Previous Paper we saw that the Energy that we are Interested In (in=band) is a Small Fraction of the **Total**.



Dynamic Range Requirement

This Result Indicates that a Measurement Headroom of 10 is Required.

– Accelerometer and Input Amplifier Range=5KG



$$\text{Headroom} = \frac{\text{Range}}{\text{Expected Max}}$$

1% Accuracy ➡ Minimum Dynamic Range = 1000/1 = 60dB

➡ Desired Dynamic Range=10000/1 = 80dB

The Recommended Test..
“Effective Bits”

- *Objective:* Characterize the Time-Domain Accuracy of a Digital measurement System.
  - Using a Signal that:
    - Exercises the Full Range of the System
    - Is “Dynamic” (Changing Rapidly).
- Analyze the Recorded Signal in a Way That:
  - Determines Individual-Point Accuracy (***Worst Case***)
  - Determines RMS Accuracy (***“Average” Error***)

Effective Bits.. The Basic Idea

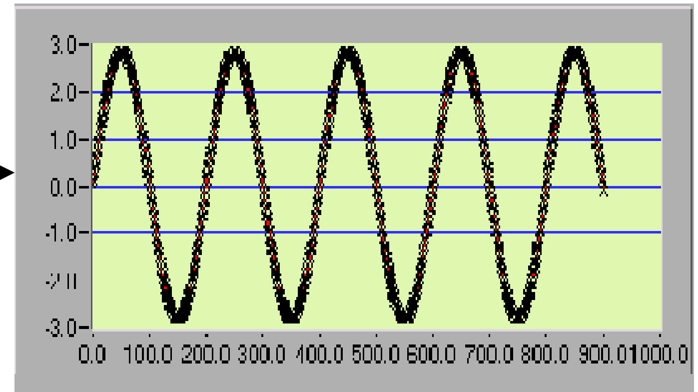
Ultra-Low Distortion Sine Oscillator

F~Sample Rate/100
Amplitude=.95×Full Scale

Data Acquisition System

Variables:
Sample Rate
Gain

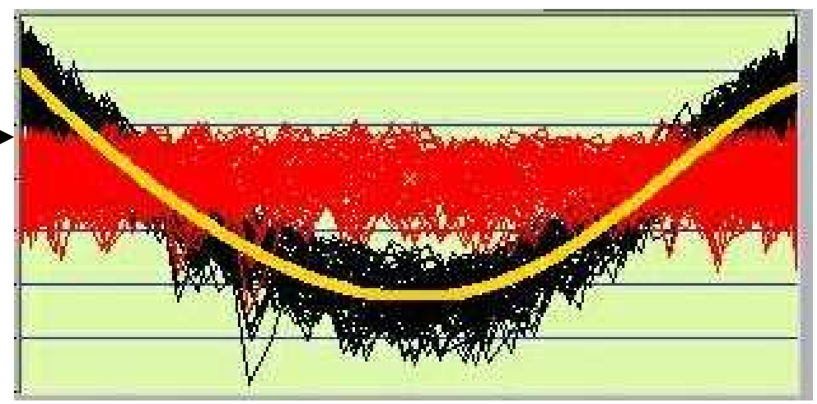
10-100 Cycles



Least-Square Curve Fit
y=a + b×sin(cx +d)

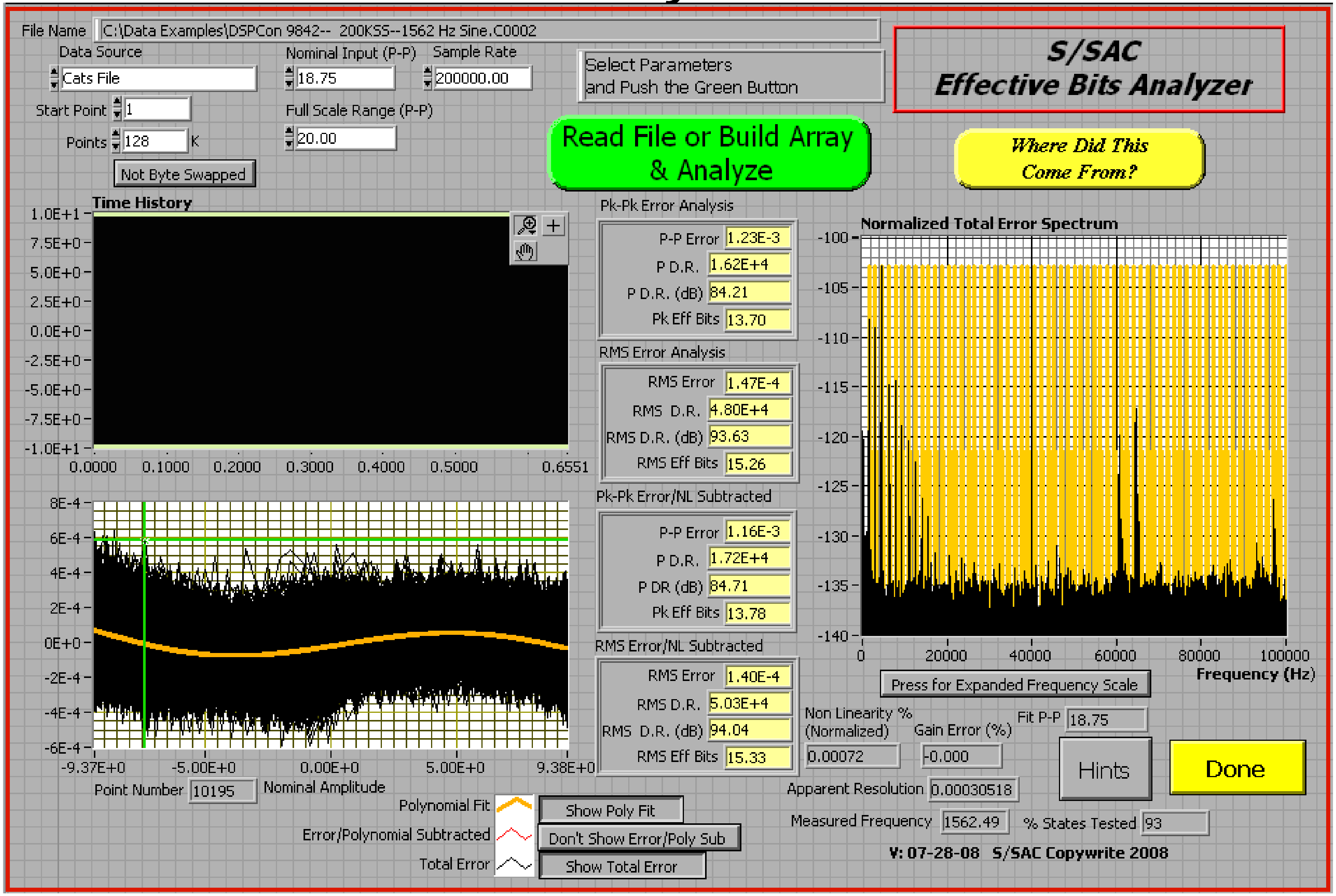
−

“Error”

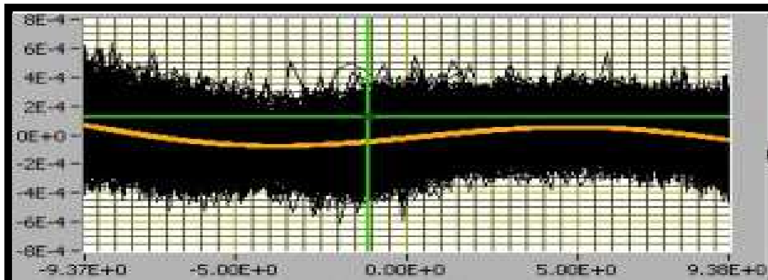


Amplitude

The Effective Bits Analyzer



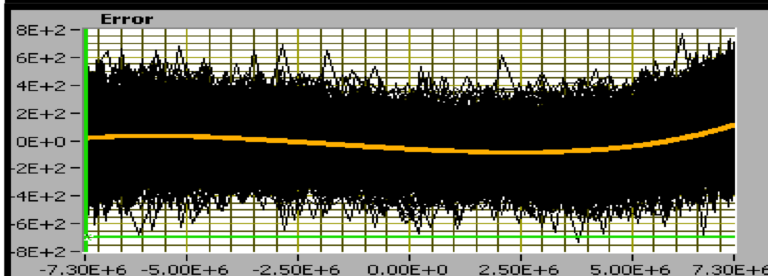
Some Effective Bits Results



DSPCon PIRANHA 200KS/S (Volts (16 bit))

	Dyn Range(dB)	Eff B
RMS	93.8	15.3
P-P	84.2	13.69

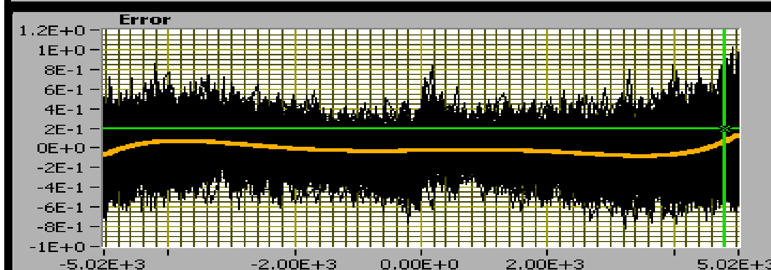
Non Linearity .0007%



ICS/DaqScribe 610—1MS/S (Counts (24 bit))

	Dyn Range(dB)	Eff B
RMS	90.4	14.7
P-P	80.9	13.14

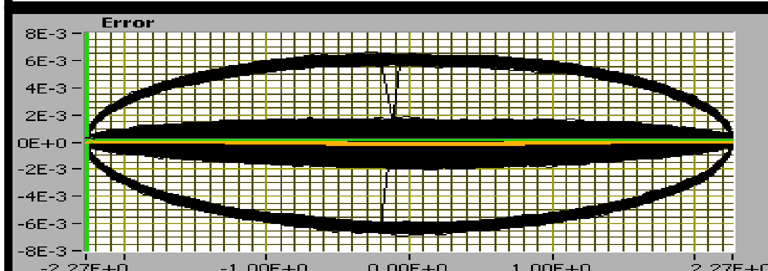
Non Lin .0042%



Spectral Dynamics 2824—2.5MS/S (Counts)

	Dyn Range(dB)	Eff B
RMS	83.9	13.65
P-P	74.7	13.6

Non Linearity .0013%



Expensive VXI A/D
(Dropped Point)

Requirements!!!!!

Bandwidth	**30KHz[1]**
In-Band Gain (Flatness)	**<± 1% = ~ ± .1dB[2]**
Minimum Alias Rejection	**>1000/1 = 60dB**
Minimum Error-Free Slew Rate	**15V/uS**
"Effective Bits" RMS Dynamic Range (*Time Domain*)	**80dB**

[1] 3 x Max SRS Analysis Frequency

[2] May be corrected in Post Processing