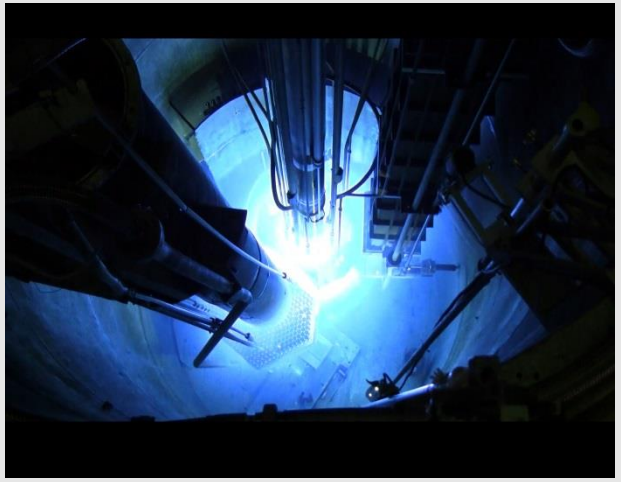
SAND2016-1390C

Exceptional service in the national interest

Sandia National Laboratories

Abstract: Electromagnetic and Radio Frequency interference limiting practices



Ken Mulder

Abstract SAND report number tracking number 319026
Abstract SAND report number SAND2015-6272 A

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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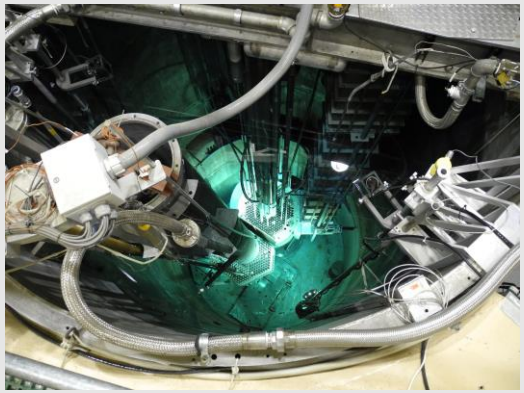
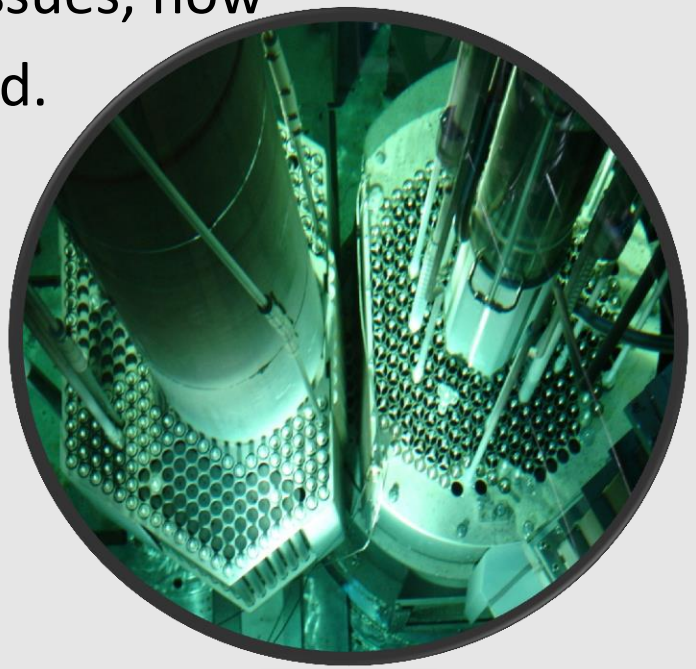
Overview/Abstract

The author will present:

- A 10 year history of noise and ground issues, how they have been identified and fixed.
- Details of control and Indication issues.
  - Power distribution
  - Fission detectors
  - Legacy wiring
  - Legacy design
  - Security radar
  - Security drone



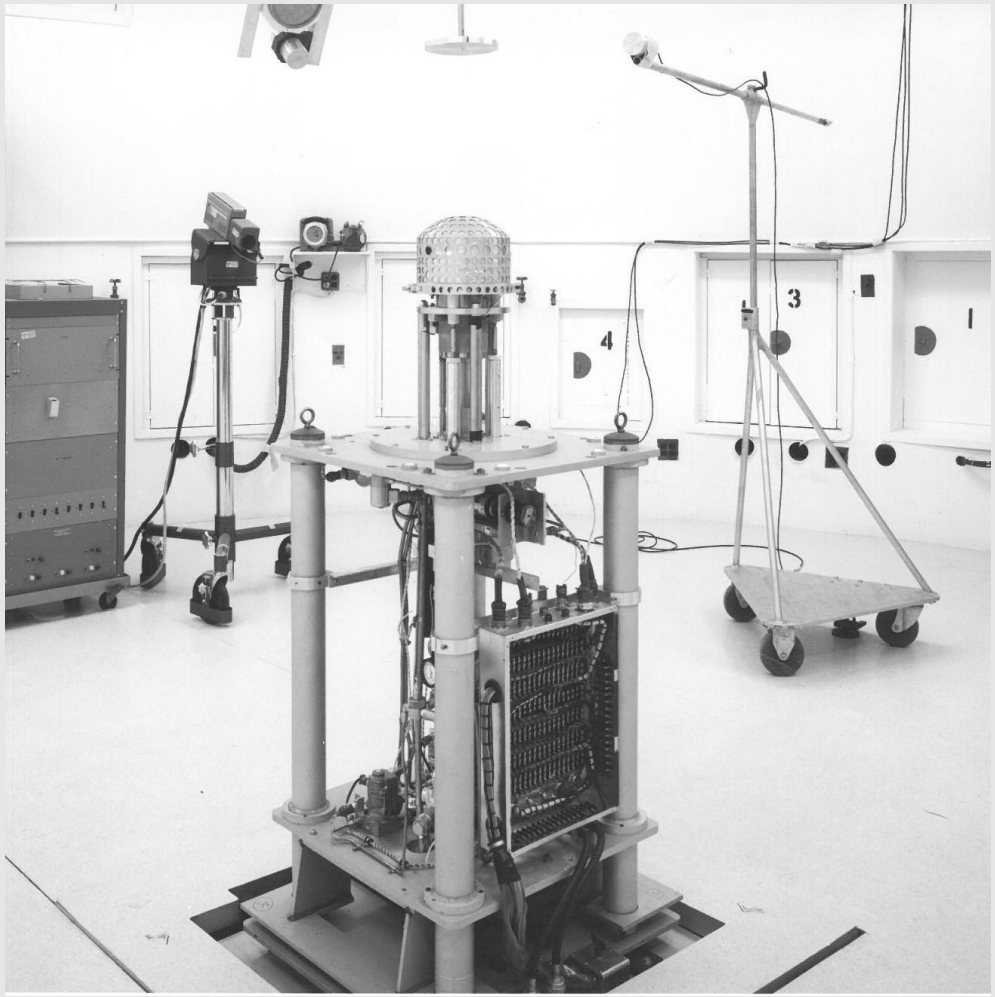


What do we do at Sandia National Laboratories?

Sandia National Laboratories

- SNL is one of three weapons laboratories in the DOE complex.
- SNL is the engineering lab, while Los Alamos and Lawrence Livermore are the physics labs.
- SNL weaponizes the physics packages designed by the physics labs.
- SNL is responsible for the assuring the viability of the nuclear stockpile. (environmental testing, STS, safe transport)
- SNL designs and builds systems to test the fissile and non-fissile components of nuclear weapons (reactors, accelerators, sled tracks, drop towers, burn facilities…)

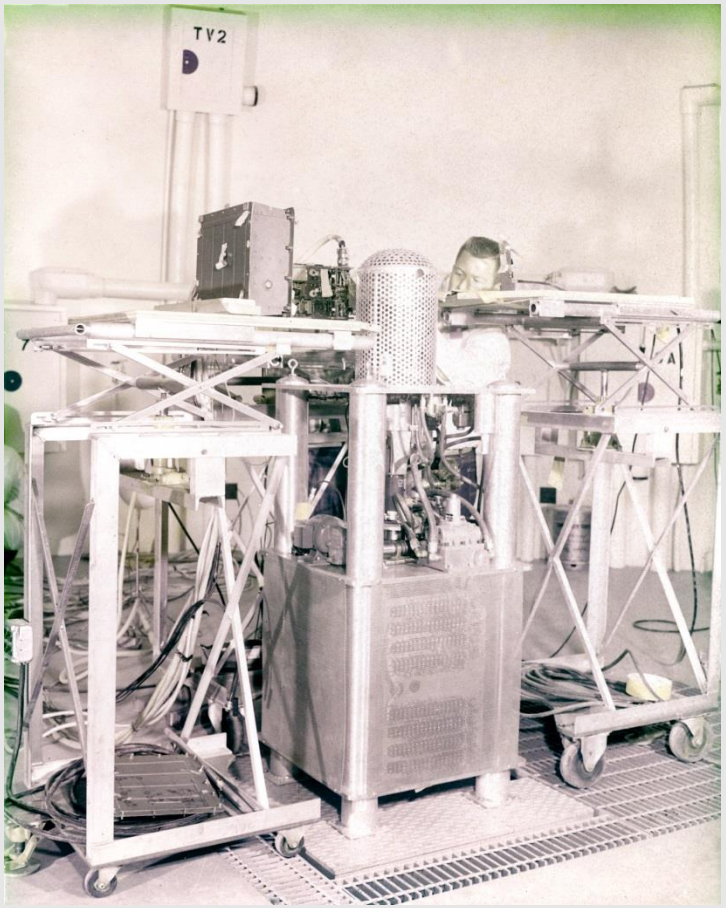
Sandia Pulsed Reactor



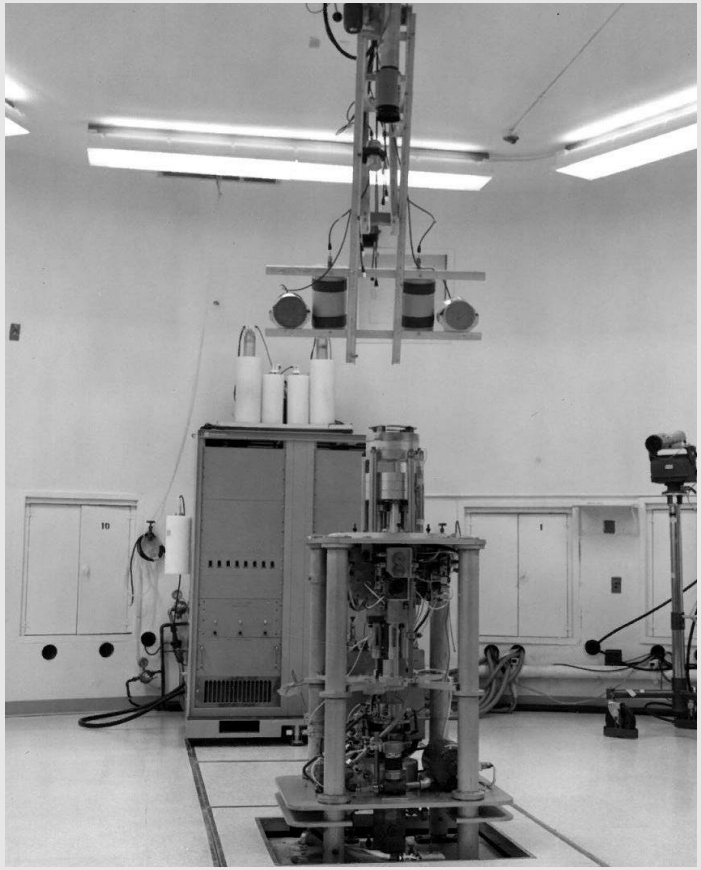
- Fuel Mass = 57 Kg
- Core Diameter = 7 inches
- Core Height = 5.6 inches
- Pulse Width = 50 $_u$sec
- Flux = 4e17 n/cm^2-s
- Fluence = 2e13 n/cm^2
- γ = 3e7 rads/s
- Max temp rise = 212° F

SPR Experiment Setup

Sandia National Laboratories



Sandia Pulsed Reactor II



- Fuel Mass = 106 Kg
- Core OD = 8 inches
- Core ID = 1.5 inches
- Core Height = 8.2 inches
- Pulse Width = 40 $_{u}$sec
- Flux = 2e19 n/cm^2-s
- Fluence = 8.1e14 n/cm^2
- γ = 4.1e9 rads/s
- Peak Power = 200,000 Mw
- Max temp rise = 842° F

SPR III Minute Man III IMU Test

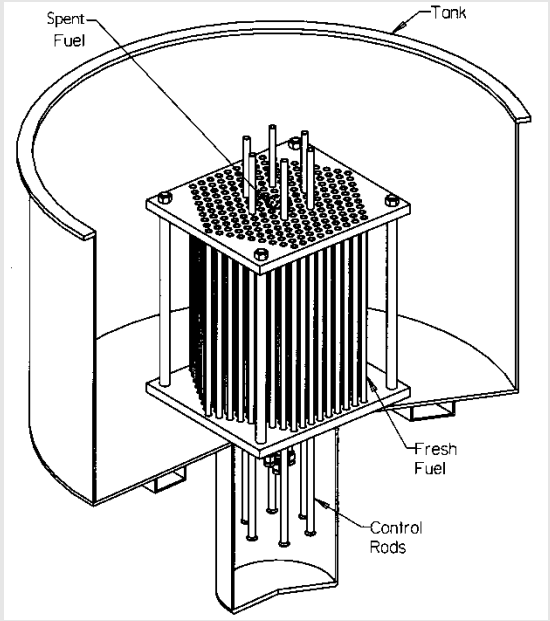
Space Nuclear Thermal Propulsion

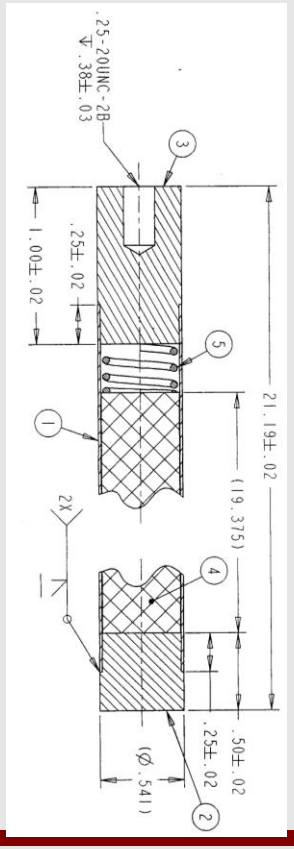
Sandia National Laboratories

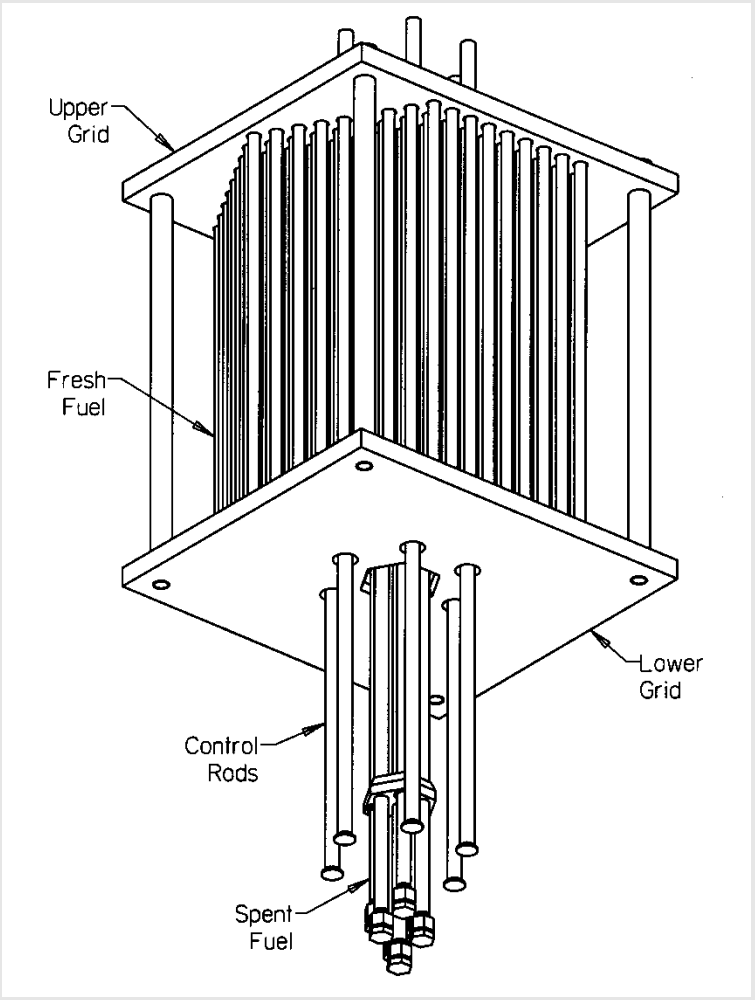
- **Fuels testing for a nuclear rocket engine**
- **SDI**
- **1989 to 1993**

Spent Fuel Safety Experiment

SFSX was a fuel-replacement experiment. The central seven fuel rods of an array of unirradiated fuel would be replaced with spent fuel and the effect on the array size measured. The safety basis documents were written and the fuel built but the experiment was not completed.







The BUCCX assembly operated in the reactor room of the SPR Facility

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Annular Core Research Reactor

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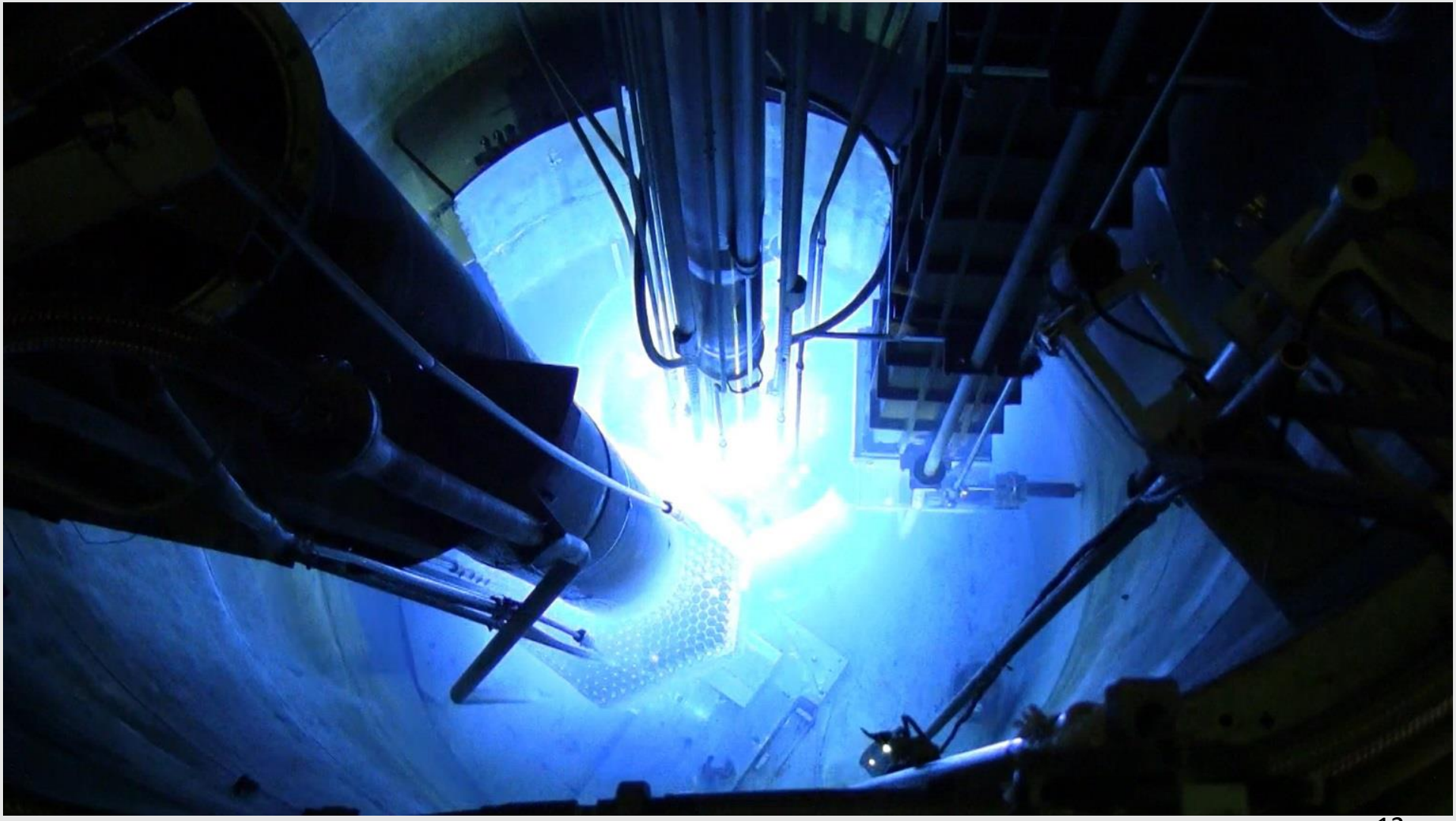

Control Room

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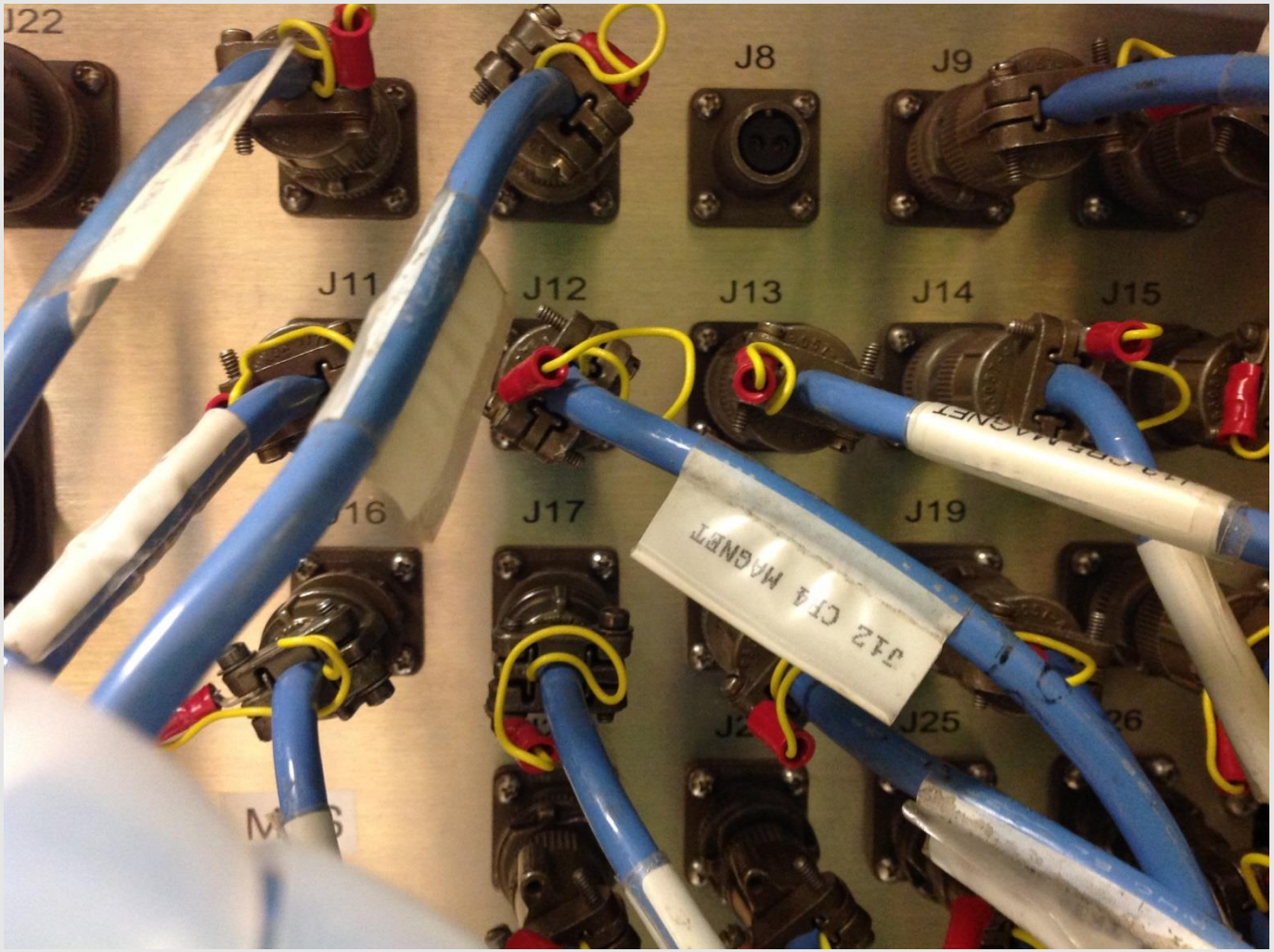
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J12 C14 MAGNET

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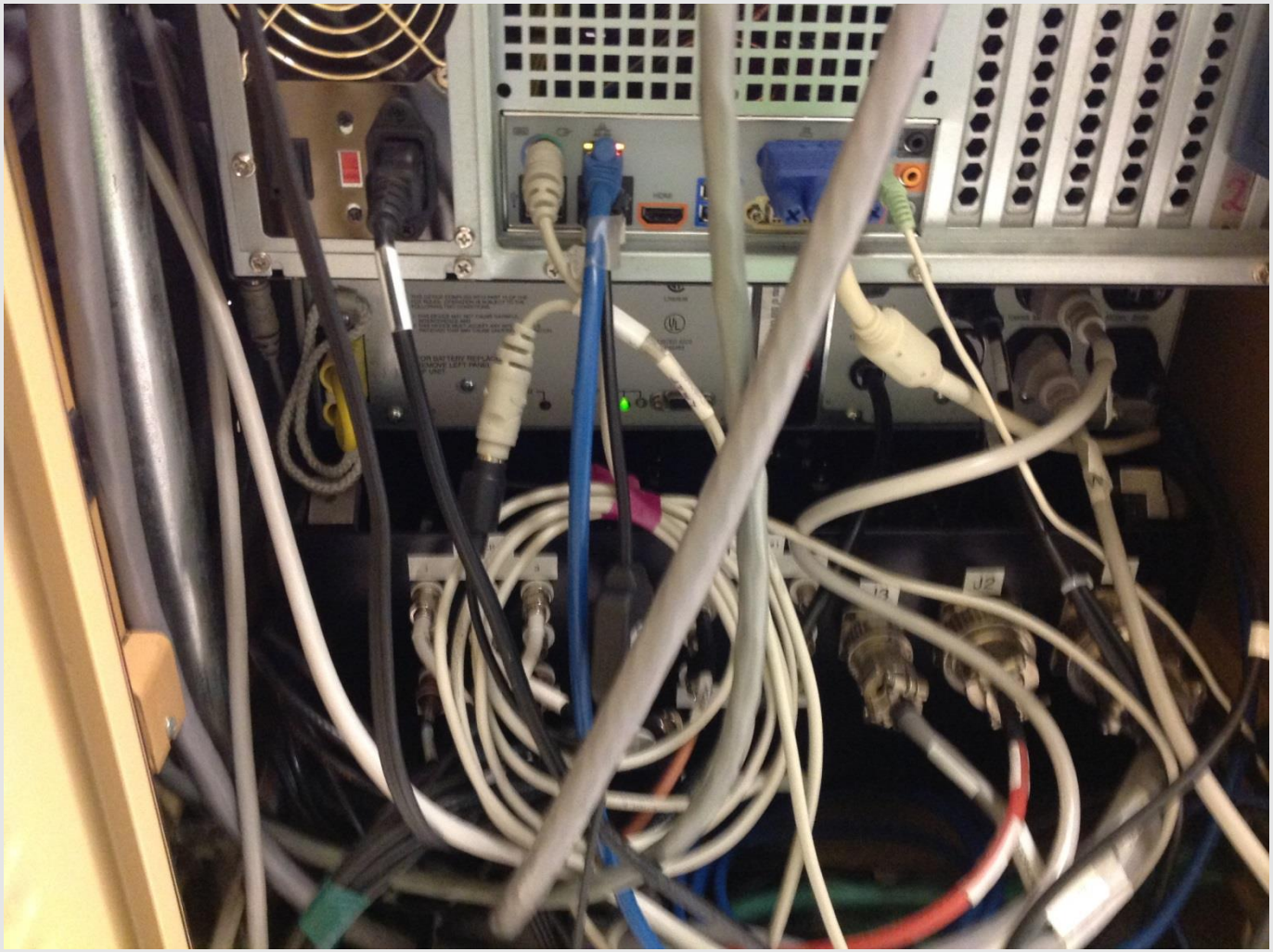

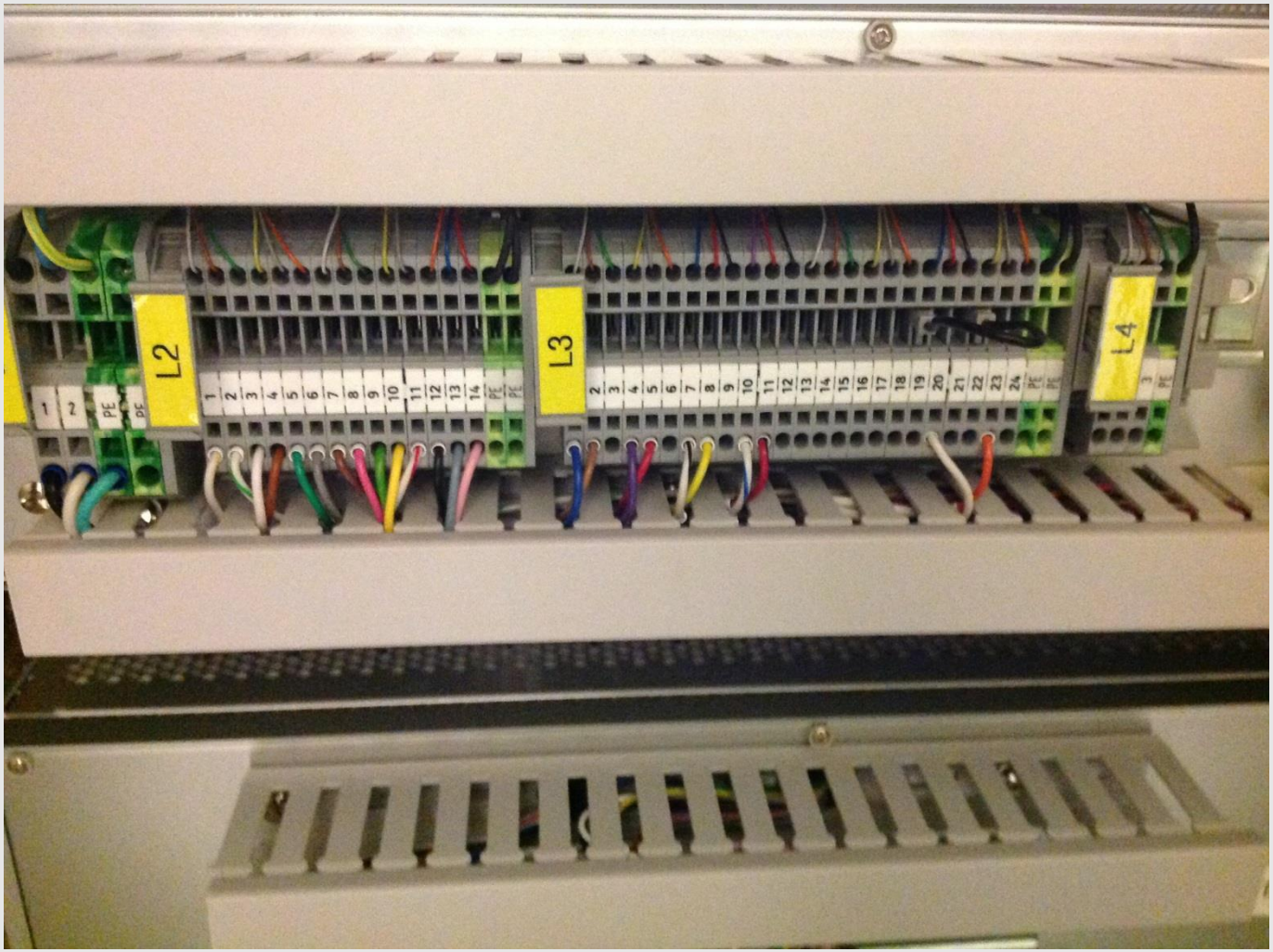
L2
L3
L4

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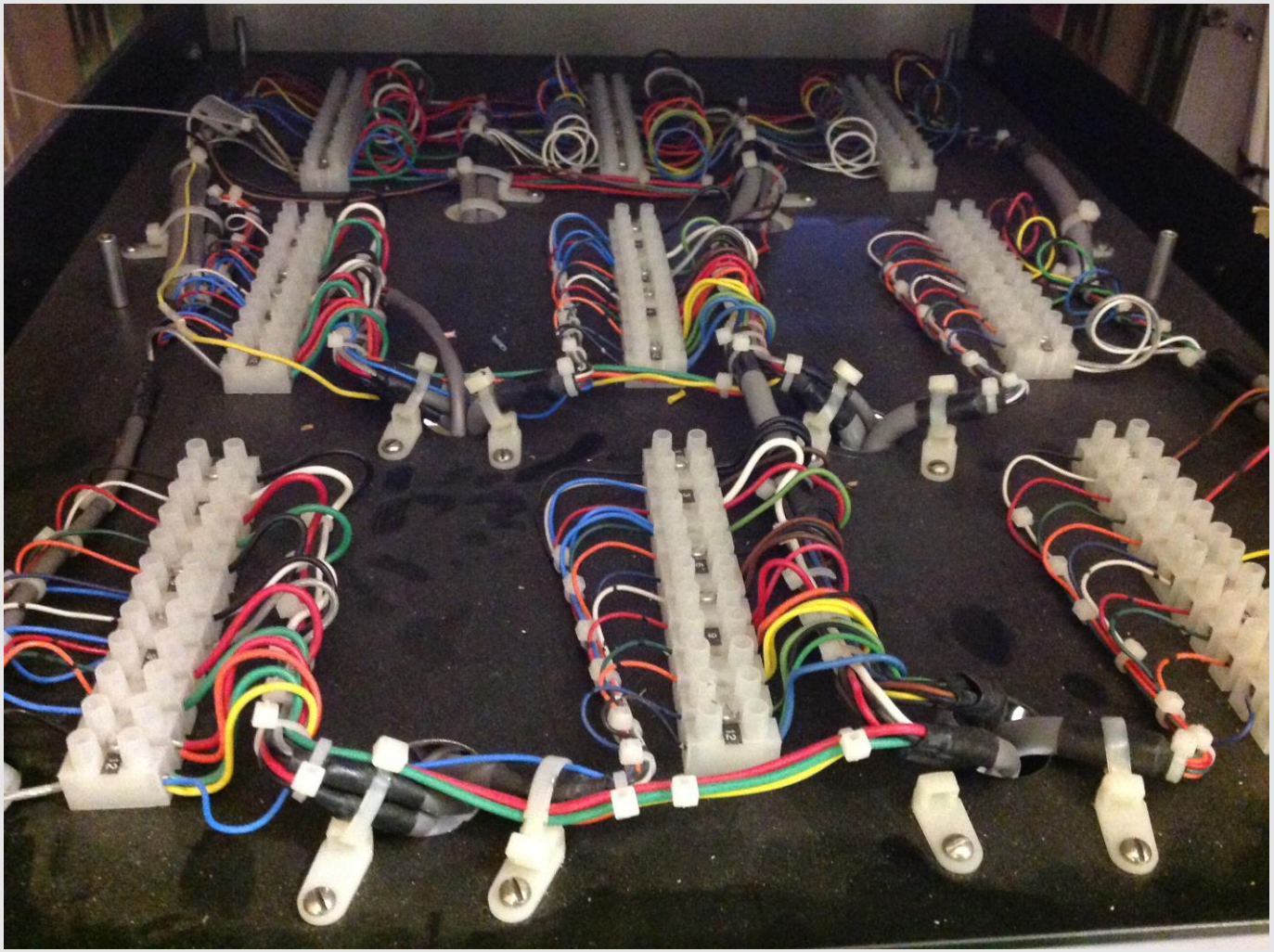

Rules of Thumb

- Current returns to its source (not to ground).
- Current may pass through ground to get back its source.
- Noise Couples through your equipment, then back to it's source:
  - Conductively (Think short circuit or physical connections)
  - Electromagnetically (Think RF antenna or EMI)
  - Magnetically (Think inductive)
  - Electrically or Electrical field (Think capacitive coupling, or think Radcon's "point" and "line" source. If you are close to the emitting source, say next to the antenna, you are within the electrical field. If you are miles away, but picking up the radiated EM wave, you are electromagnetically coupled or picking up EMI. Essentially, if you a wavelength or less, you are not picking up EMI, you are within the electrical field.

Rules of Thumb Page

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- Low Frequency, <10 KHz, current goes everywhere through every connection. Continuity testing, resistance testing works well. Ohms Law, Kirchhoff's Law

- High Frequency, >10 KHz, current travel is selective! Don't forget current travels to lowest impedance, vice lowest resistance. Continuity testing and resistance measurements will mask faults. We must understand impedance, $X_L = 2\pi f L$, or at least think "skin effect", wave guides or surface area.

- High Frequency, current takes the smallest loop.

Rules of Thumb

- Sharp edge pulses, even in a direct current application, emit high frequencies. Recall that a Square wave, can be built by combining every odd harmonic. Specifically note that arcing also emits all frequencies.
- High impedance connections will emit electrical fields, and are susceptible to other electrical fields.
- Antennas must be at least ¼ as long as the wavelength to couple the signal, preferably ½ for the common dipole antenna. Think submarine ELF communications, at 76 hertz we had to use antennas in Wisconsin and Michigan nearing 32 miles long, with dedicated power plants to drive them. So look for conductive or magnetic coupling if your getting 60Hz.

Rules of Thumb

- High Frequency Coax, the signal travels →on the skin of the center conductor (the wire center mass is irrelevant and could be hollow). The signal returns ← on the INSIDE skin of the braided shield. This permits you to ground the outside skin, conduct all kinds of noise without affecting the signal return. Not so if used for low Frequency applications!
- Foil shielding on power supplies is a waste, since the impedance is low, it is virtually immune to electrical field coupling.
- Large voltages promote Electrical field coupling.
- Large currents promote Magnetic field coupling.

Rules of Thumb

- Changing Magnetic fields induce voltage.
- People affecting the circuit? Consider a capacitive effect near high frequency arcing (You are near a loose connection).
- Use larger diameter wires to reduce ringing, $X_L \downarrow$
- Analog boards <10 KHz: Resist the temptation to use board plane for return. Use two traces.

ACRR has a history of **fixing** Ground and Noise issues

Sandia National Laboratories

- New design (-101) PPS Fission chamber (1999)
  - Welded housing riser
  - Underwater Flange eliminated.
  - Eliminated connector corrosion induced noise
- New designed PPS signal processors (1999-2004)
  - Advanced electronic filtering
  - New electronic systems
  - Signal output is Isolated, eliminated ground loops.
- Upgraded the Wide Range Nuclear channels (2001-2003)
  - Improved display and electronics
  - Optical signal isolation added, eliminating ground loop noise
- Replaced noisy Self powered Cadmium detector (2006)
  - Same design installed.
  - Failed, with high noise levels, in 2012

ACRR has a history of **fixing** Ground and Noise issues

Sandia National Laboratories

- New Wide Range fission detector designed (2005)
  - Hermetic sealing
  - Welded housing and noise shield
  - unguarded design(better application for the large dynamic range required)
  - Extended life
  - Inert gas over pressure, mitigates signal noise from corrosion.
- Design (-101) Fission Chamber installed as PPS2 (2005)
  - Welded riser
  - Purge tubing
  - Guarded Design, improved noise immunity.
- Wide Range Nuclear Detector installation (2006)
  - Manufacture oversight of new detector installation.
  - System groomed for noise immunity,
  - Signal return/grounding paths reviewed, problems mitigated

ACRR has a history of **fixing** Ground and Noise issues

Sandia National Laboratories

- Improper distribution system bonding (2007-2008)
  - Known problem gradients bonded to control noise. All distribution system panel bonds review/renewed.
- Electrical distribution system panel refurbishment (2007)
  - New clean connections.
  - New breakers.
  - New buss bars.
  - Numerous neutral wire and grounding connections fixed.
  - Several hot wire issues resolved.
- Removed ground loops from power feeds (2007)
  - Multiple old buildings with separate legacy power system integrated.
  - Neutral to Ground bonding moved to supply transformer
  - Individual panel neutral to grounds removed.

New PPS Fission Chamber

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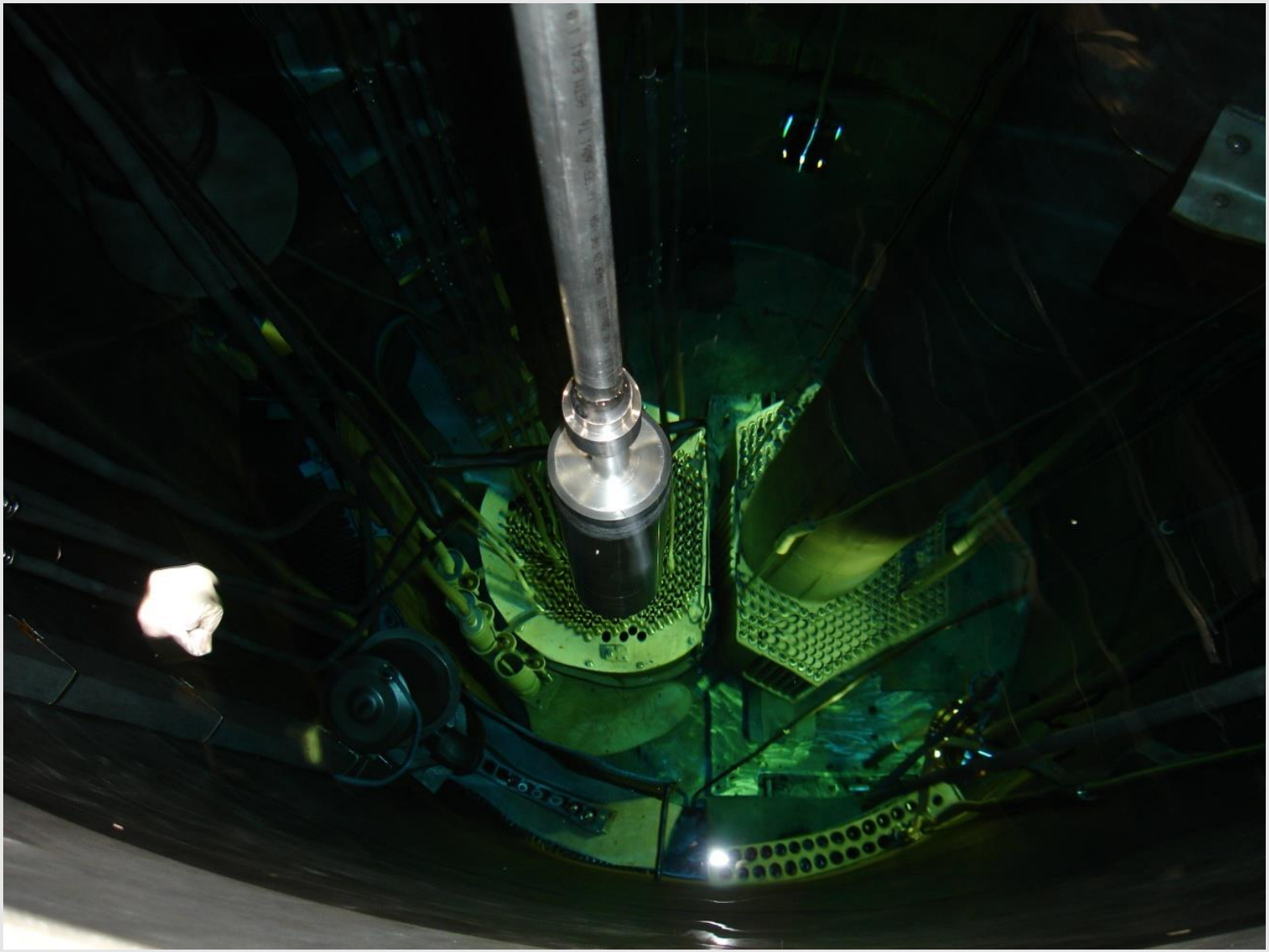

ACRR has a history of **fixing** Ground and Noise issues

Sandia National Laboratories

- Extensive new lighting protection system (2004-2007)
  - Building wide system installed.
  - Effectively shields the ACRR from direct hits.
  - Effective in protecting equipment.
  - Power supply and other electronic system failures due to lightning strikes are zero.
  - Compare lightning strike damage to corporate server failures, which are very frequent.
- EBW experiment noise removed. (2007)
  - Attenuated by 70% which permitted the experiment to complete.
  - Better bond to ground. This shunted away the noise source.

ACRR has a history of **fixing** Ground and Noise issues

Sandia National Laboratories

- New Pulse diagnostic system installation (2008)
  - Modern amplifiers.
  - Voltage gradient from control room to reactor mitigated during installation.
  - Advance wave/pulse shaping algorithms neutralize noise signature.
  - System designed for high pulse power: Signal/noise degrades and prevents use at extremely low Steady State levels.
- Design (-102) Fission Chamber installed as PPS1 (2012)
  - Complete Hermetic seal
  - Easy Helium backfill pressure head
  - Advanced Holster positioning system
  - Guarded fission chamber noise immunity
  - No baseline data obtained No Time Domain Reflectometer

ACRR has a history of **fixing** Ground and Noise issues

Sandia National Laboratories

- New Design (-103) Fission Chamber (2013)
  - Custom bends accommodate installation in all holster positions
  - Custom bend eliminated all streaming concerns
  - Custom length for easy pool side testing of Helium
  - backpressure
  - Simple signal and HV connectors
  - 4 inch housing prevents 1/2 inch movement in holster
- New Design (-103) Fission Chambers purchased (2014)
  - On Site
  - 2 spares provide over 40 years of backup.

ACRR has a history of **fixing** Ground and Noise issues

Sandia National Laboratories

- New Design WR amplifier, New WR Fission chambers
  - Installation removed in-house breakout terminal board in control room where we had inadvertently defeated twisted pair noise immunity by opening loops by as much as 8-14 inches.
  - Installation re-routed signal cables around our home designed analog relay permissive, known (repeatable) to produce relay field collapse noticeable during low signal conditions.
  - Detected/corrected new fission chamber mineral cable connector vulnerability.
  - Hermetically sealed Fission chamber design, rated for 40 years.
  - Eliminated in house wiring that turned twisted pair into a single ended scheme with one common to 8 signals.

ACRR has a history of **fixing** Ground and Noise issues

Sandia National Laboratories

- Shielded CAT 6 cables and new routing eliminated intermittent watchdog time-outs and TCP/IP issues. TCP is a connection centric design, from bogging down the network when communications are lost. Discovered in house installation had failed to route the old CAT 5 cables perpendicular to power lines.
- Discovered power line slap triggers some sensitive equipment brown-out trips and subsequent PPS HV Non-Ops.

Noise issues still remaining

In terms visible readings of reactor power

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- 28% re-created in EBW firing.
- 13% re-created during EMI testing.
- 7 % observed during a recent trip.
- 1.5% observed in bad detector connections.
- 0.5% observed in 18 hour study of PPS1.
- 0.1% observed in WR during rod movement.

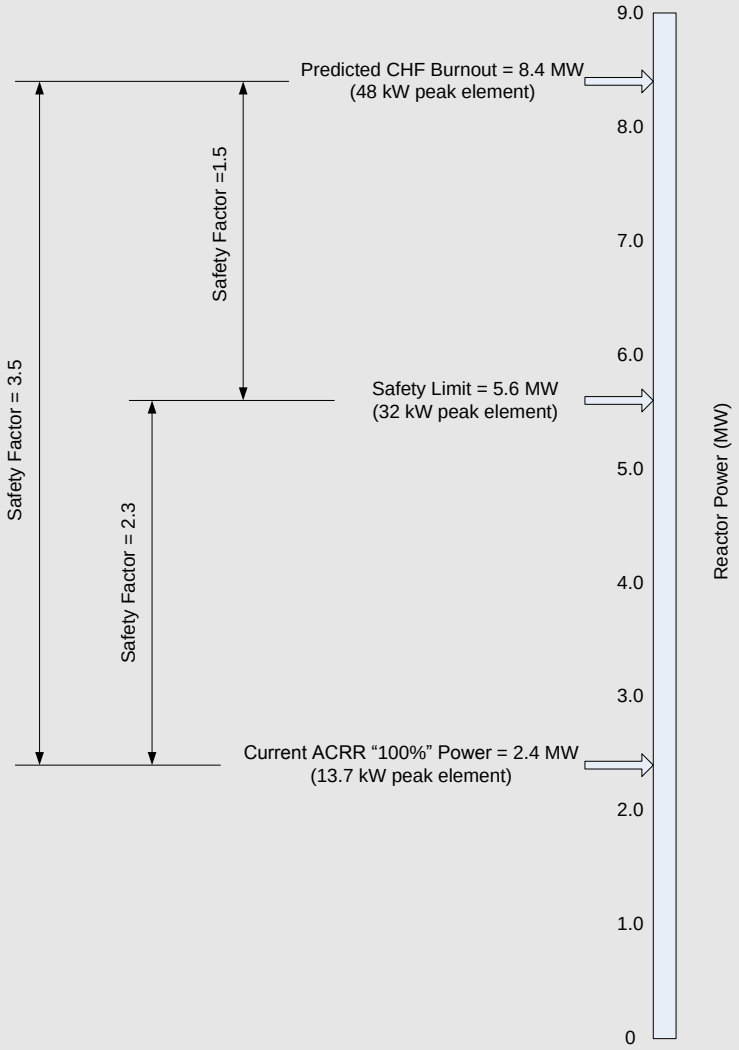
Impact to Operations and Experimenters.

- We have found noise levels at SPR and ACRR to be lower than those compared to testing at LANSCE and WSMR and FBR.[Don King.. CASPR experimenter]

- So……Noise is manageable…care is exerted to:
  - Use correct impedance matching.
  - Insure single point grounding is maintained.
  - Use differential amplification, permitting common mode noise rejection.
  - Filter noise as required.

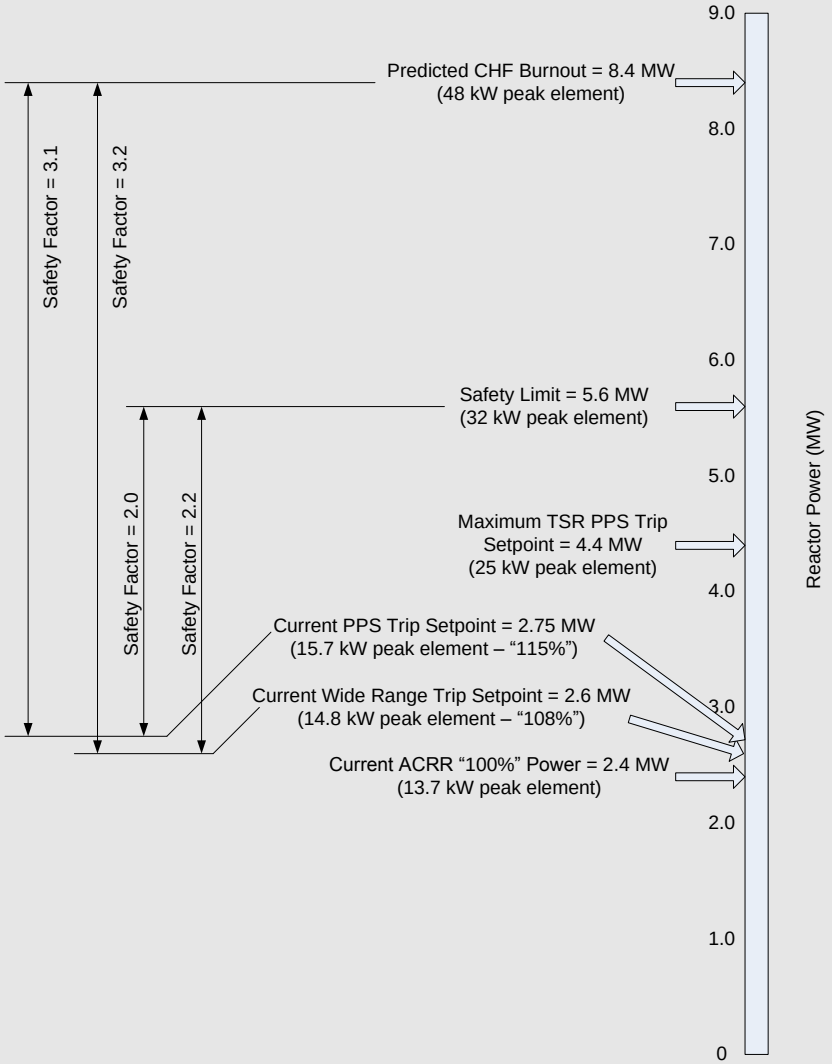
ACRR Safety Limit and Operating Point

- ACRR safety analysis predicts fuel clad failure could occur at 8.4 MW (48 kW peak element)
  - Design limit
- A fuel safety limit is conservatively defined as 5.6 MW (32 kW peak element)
  - TSR limit
- Current 100% power is defined as 2.4 MW (13.7 kW peak element)
  - Administrative limit
  - Arbitrary selection tied to previous pool water cooling capability (now upgraded to 5 MW)
  - Significant safety factors to safety limit and clad failure point



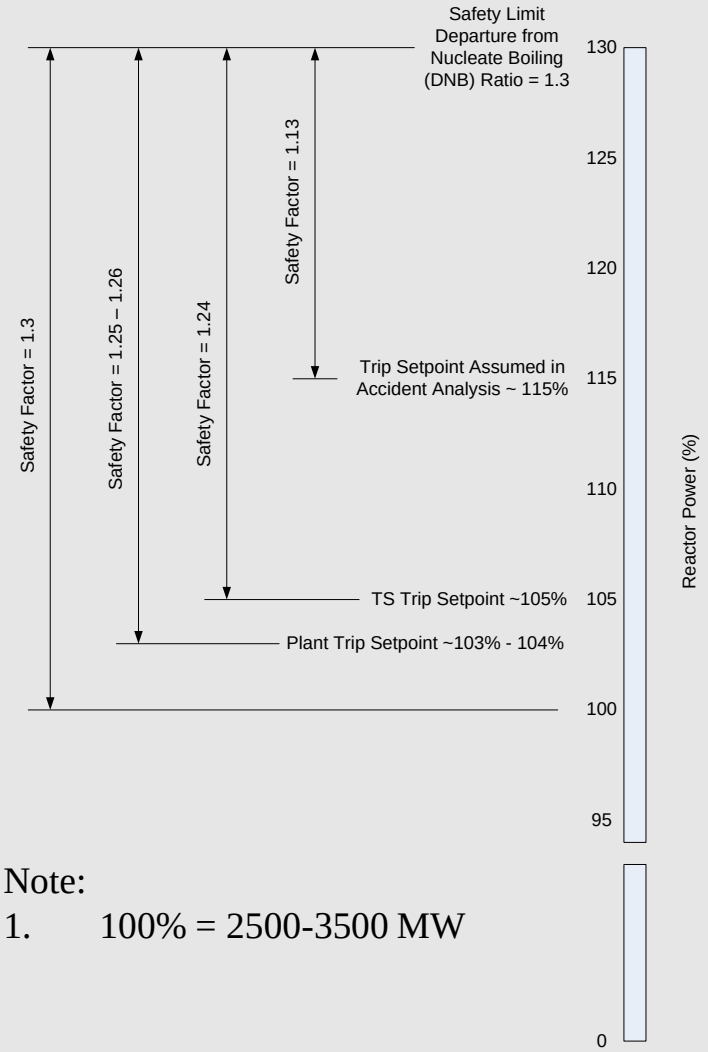
ACRR Trip Setpoints

- ACRR maintains two power level trip monitors
  - Plant Protection System (PPS)
  - Wide Range (WR) Power Monitoring System
- PPS is the safety-significant trip system
  - Trip level is TSR controlled
  - Maximum allowable is 4.4 MW
  - Currently set at 2.75 MW
- WR is not safety-significant and provides a conservative “pre-trip”
  - Trip level is contractor controlled
- Current PPS and WR trip setpoints are well below TSR limits
- Current PPS and WR trip setpoints does not provide adequate margin for noise spikes



Compare to a Commercial Power Reactor

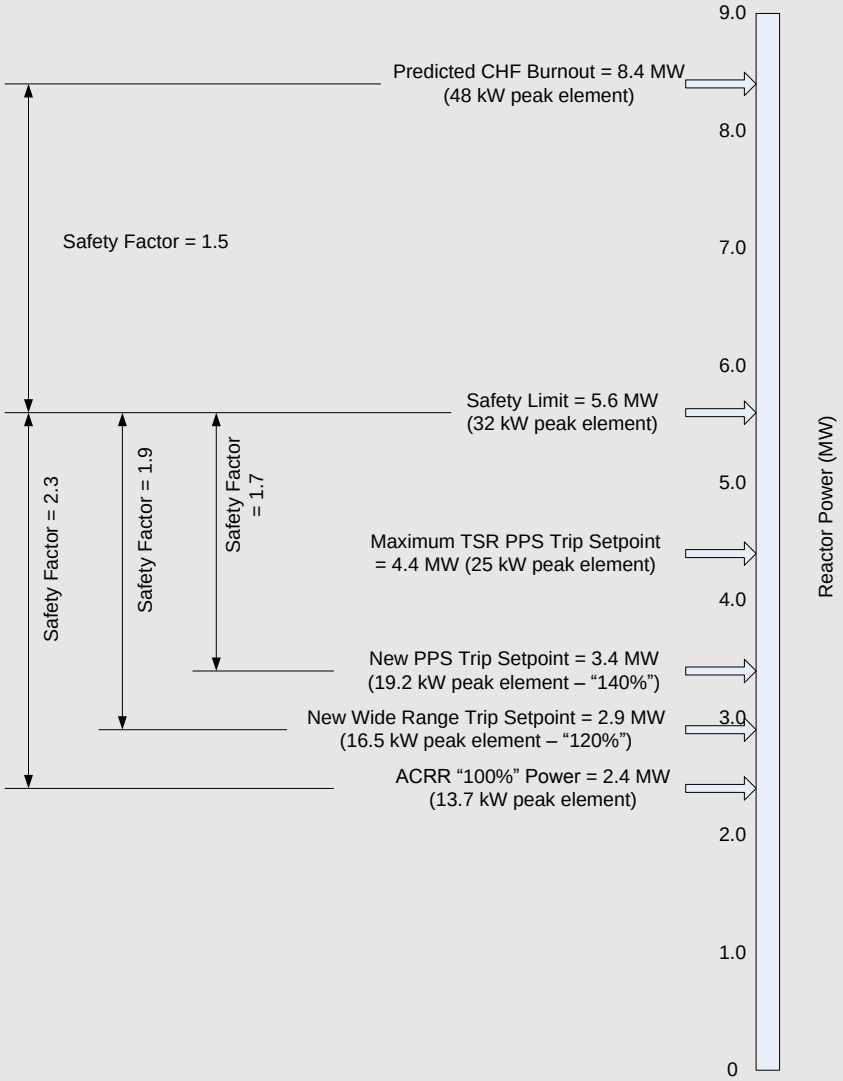
- Commercial Reactor Approach
  - Achieve maximum safe power output
  - “Small” but very well defined and defended margins
- Example: Flowrate Uncertainty Recovery Power Increase
  - Many $$ spent to “recover” ~1.5% of power level measurement uncertainty to raise licensed power level
- Safety factor at 100% power
  - ACRR - 3.5
  - Commercial power reactor - 1.3



Note:
1. 100% = 2500-3500 MW

Proposed ACRR Trip Setpoint Change

- Increase PPS and Wide Range trip setpoints
  - PPS Trip 115% → ≤140%
  - WR Trip 108% → ≤ 120%
- WR trip provides margin to accommodate noise spikes without inadvertent shutdown
- PPS and WR trips still below TSR PPS limit and well below fuel safety limit



Path forward, Items in progress

Sandia National Laboratories

- New designed CAD detector
  - For use in Diagnostics and PPS.
  - Detectors are designed and built.
  - Higher signal output—better signal/noise.
  - Prototype detectors found miss-wired.
  - Project stalled when Vendor miss-wired detector and Export issues with obtaining more CAD detectors

Path forward, Items in progress

Sandia National Laboratories

- New designed High Voltage NON operational card for PPS.
  - This will give the PPS NON OP channel 100% noise immunity from EBW fire set testing while in the pulse mode, available with PPS3.
  - Fully funded.
  - Design complete.
  - Manufacturer's acceptance testing completed.
  - Part on hand (PPS3)
  - Needs Safety Committee review and Engineering change package .
- New designed Fission chamber health monitoring circuit.
  - This circuit includes printed circuit card noise shields that fully surrounding the low level signal path.
  - This circuit will utilize the available alpha current from a fission detector, and alarm when that current is missing or overwhelmed by noise.
  - Design completed.
  - Manufacturing funded.
  - Waiting Engineering change package development and testing.
  - Reversion (Back to original design) to support ready spares in progress 2015.

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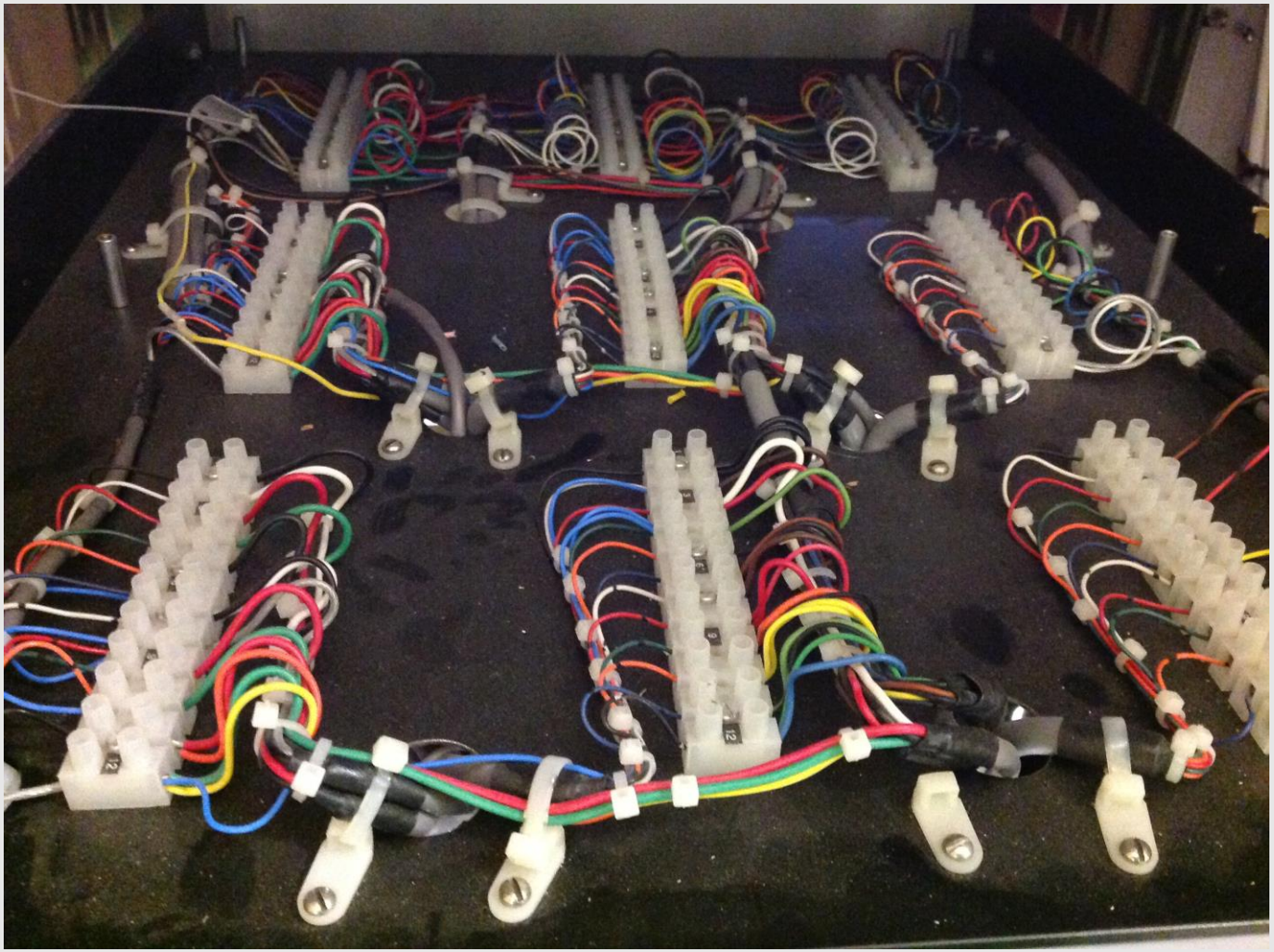
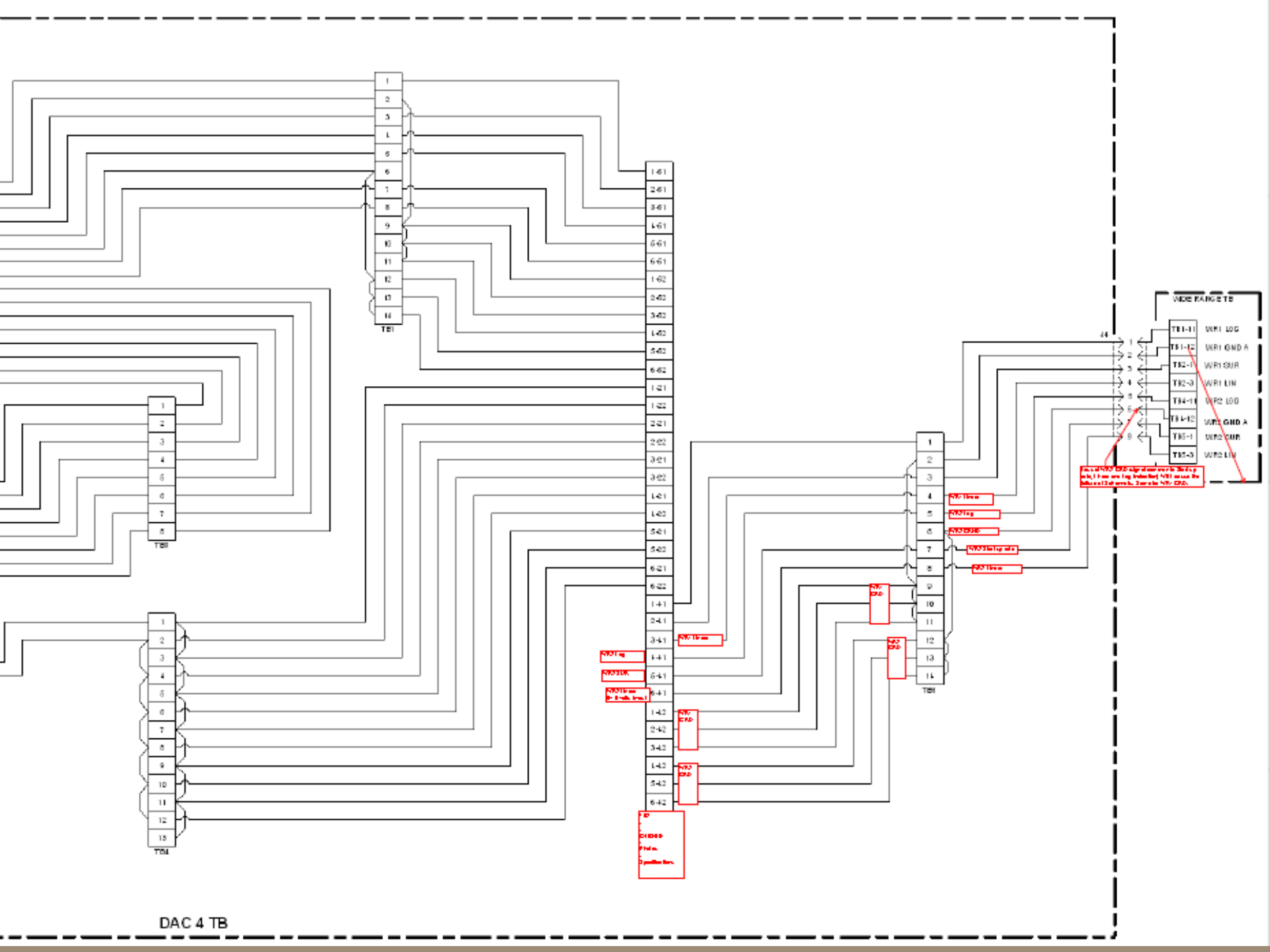
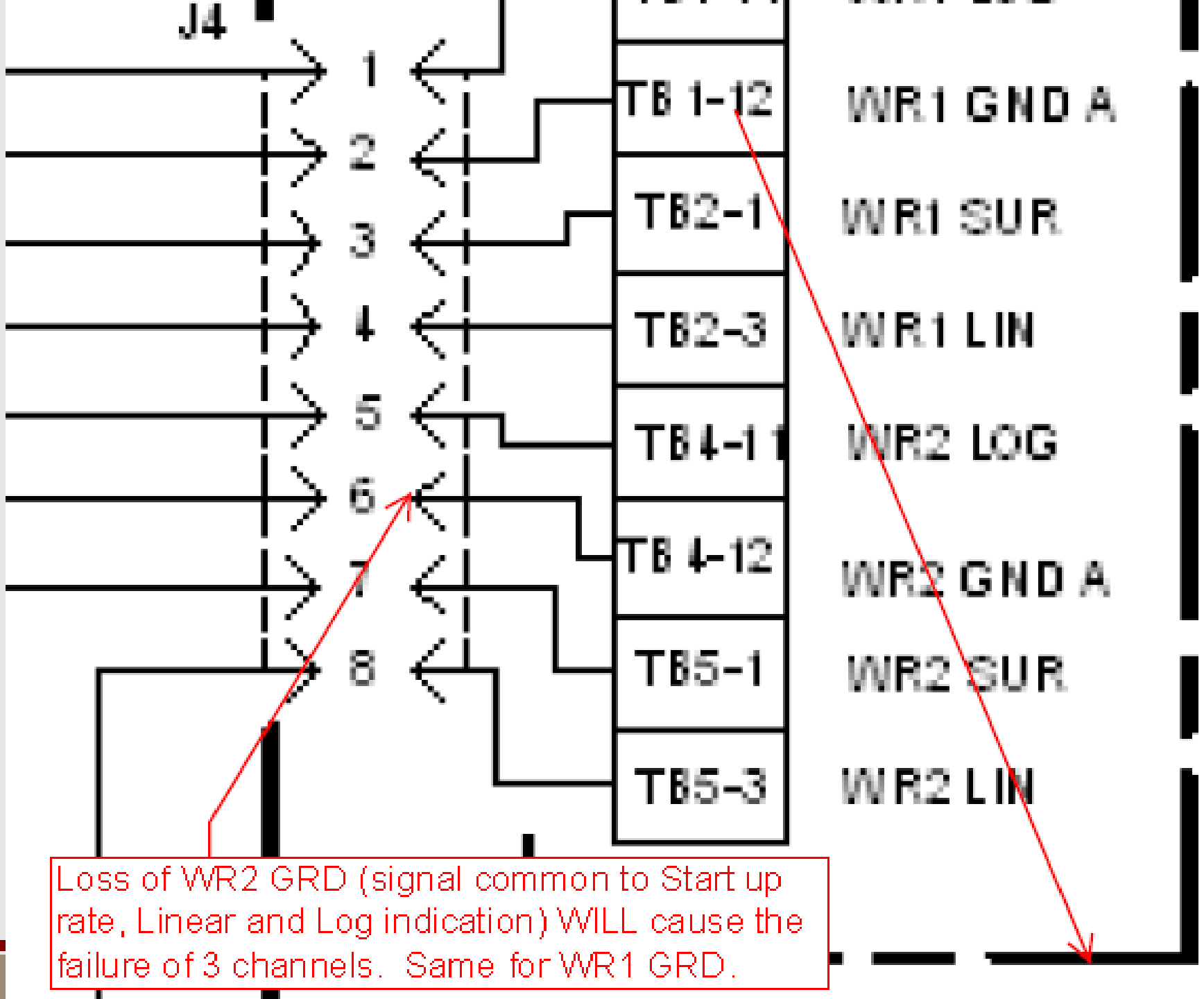



DAC 4 TB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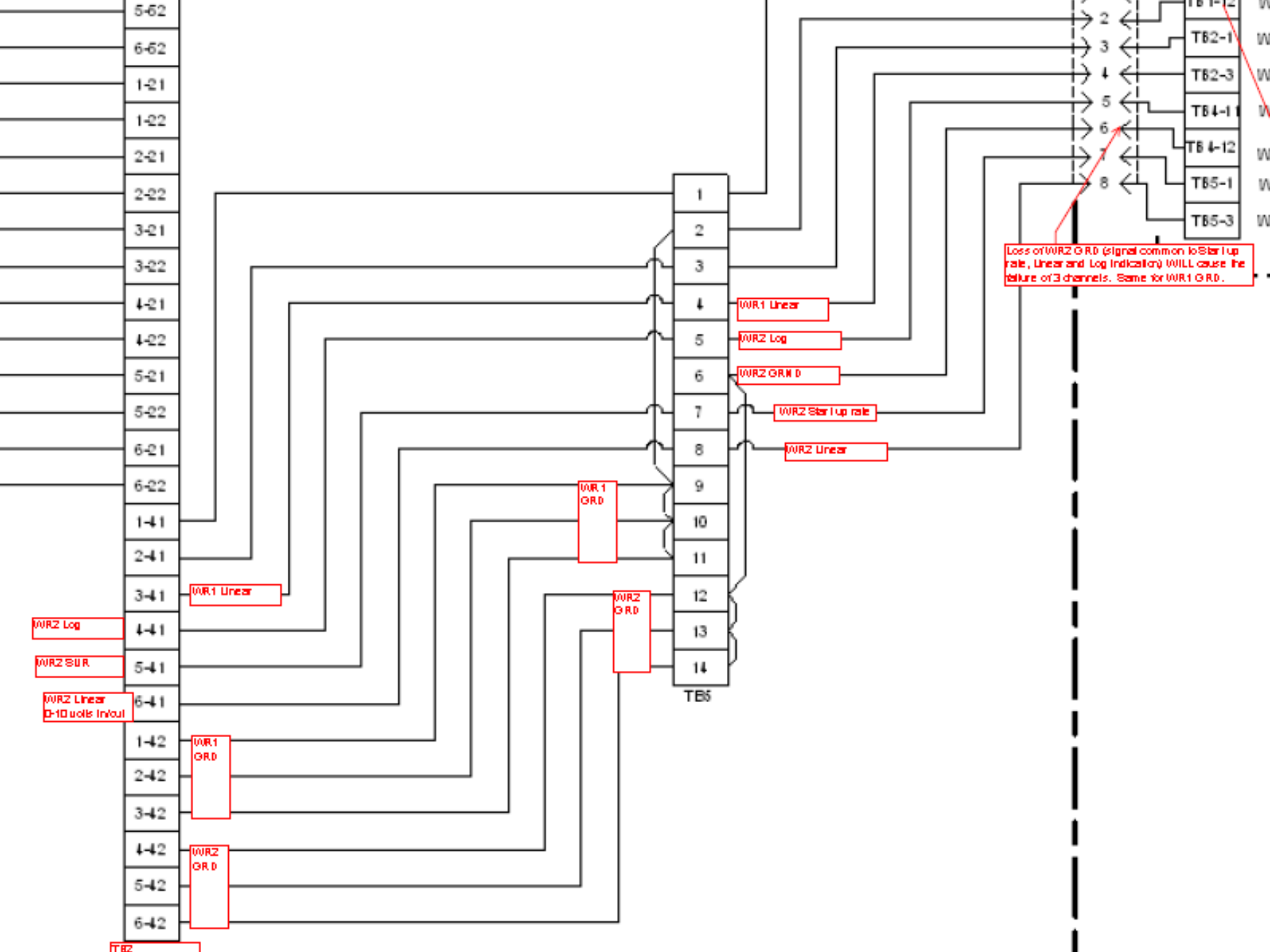
8
TB 1-12
TB2-1
TB2-3
TB4-11
TB 4-12
TB5-1
TB5-3
WR1 GND A
WR1 SUR
WR1 LIN
WR2 LOG
WR2 GND A
WR2 SUR
WR2 LIN
Loss of WR2 GRD (signal common to Start up rate, Linear and Log indication) WILL cause the failure of 3 channels. Same for WR1 GRD.


5-62
6-62
1-21
1-22
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2-22
3-21
3-22
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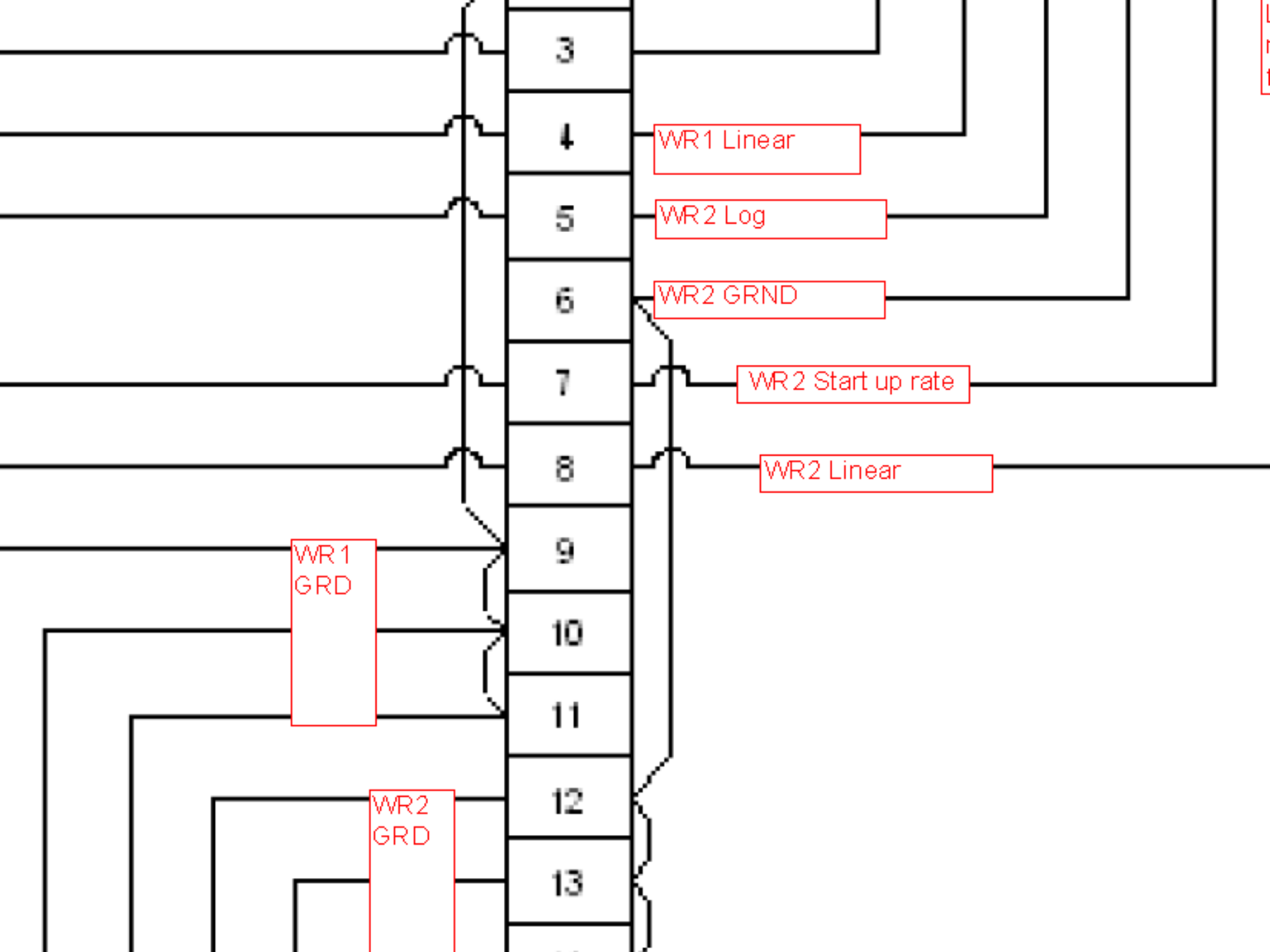
6-21
6-22
1-41
2-41
3-41
4-41
5-41
6-41
1-42
2-42
3-42
4-42
5-42
6-42
TB2
WR1 Linear
WR2 Log
WR2 SUR
WR2 Linear 0-10 volts in/out
WR1 GRD
WR2 GRD
WR2 GRD
1
2
3
4
5
6
7
8
9
10
11
12
13
14
TB5
WR1 Linear
WR2 Log
WR2 GRND
WR2 Start up rate
WR2 Linear
WR1 GRD
WR2 GRD
2
3
4
5
6
7
8
TB2-1
TB2-3
TB4-11
TB4-12
TB5-1
TB5-3
Loss of WR2 GRD (signal common to Start up rate, Linear and Log indicators) WILL cause the failure of 3 channels. Same for WR1 GRD.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12
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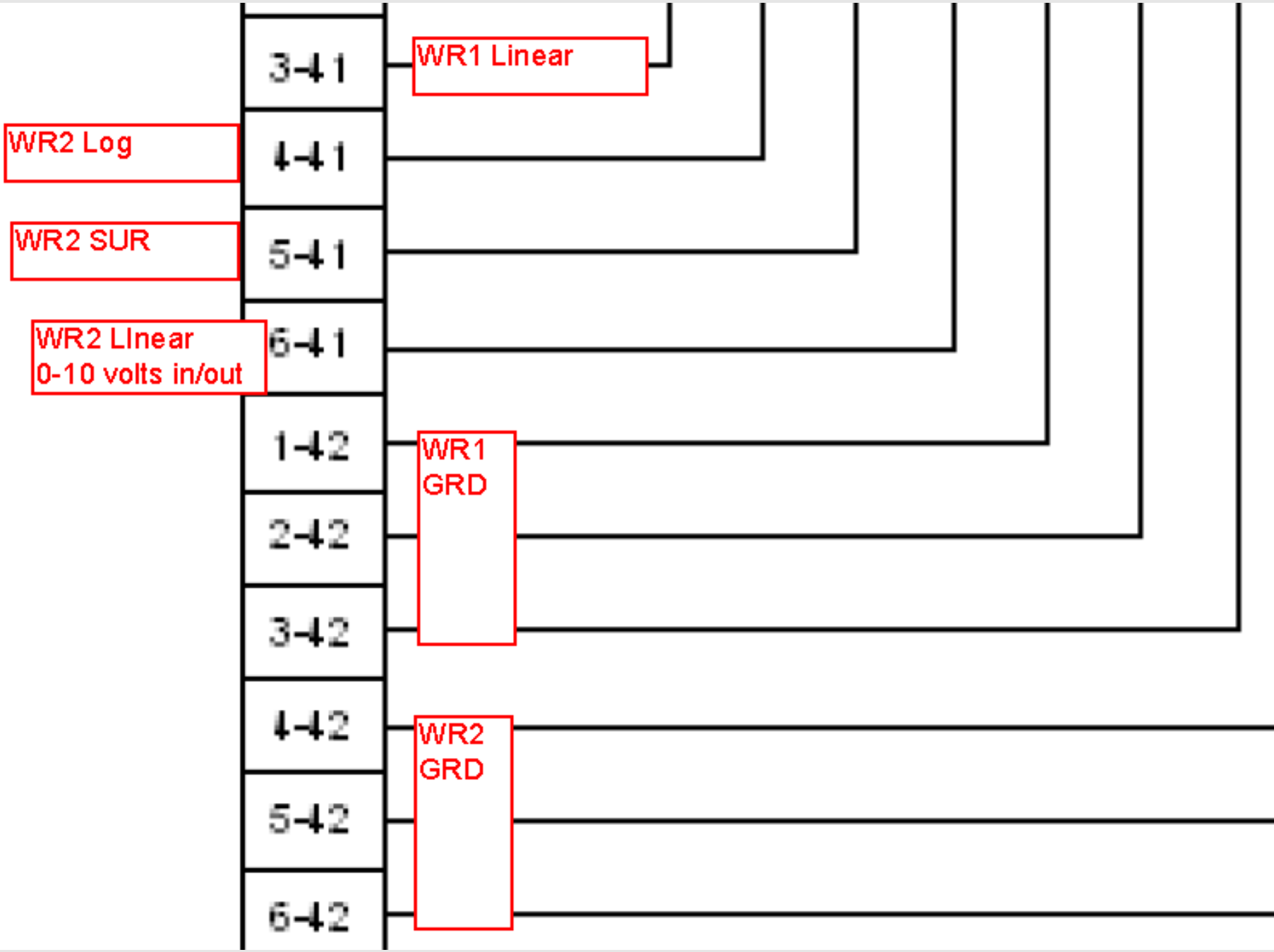
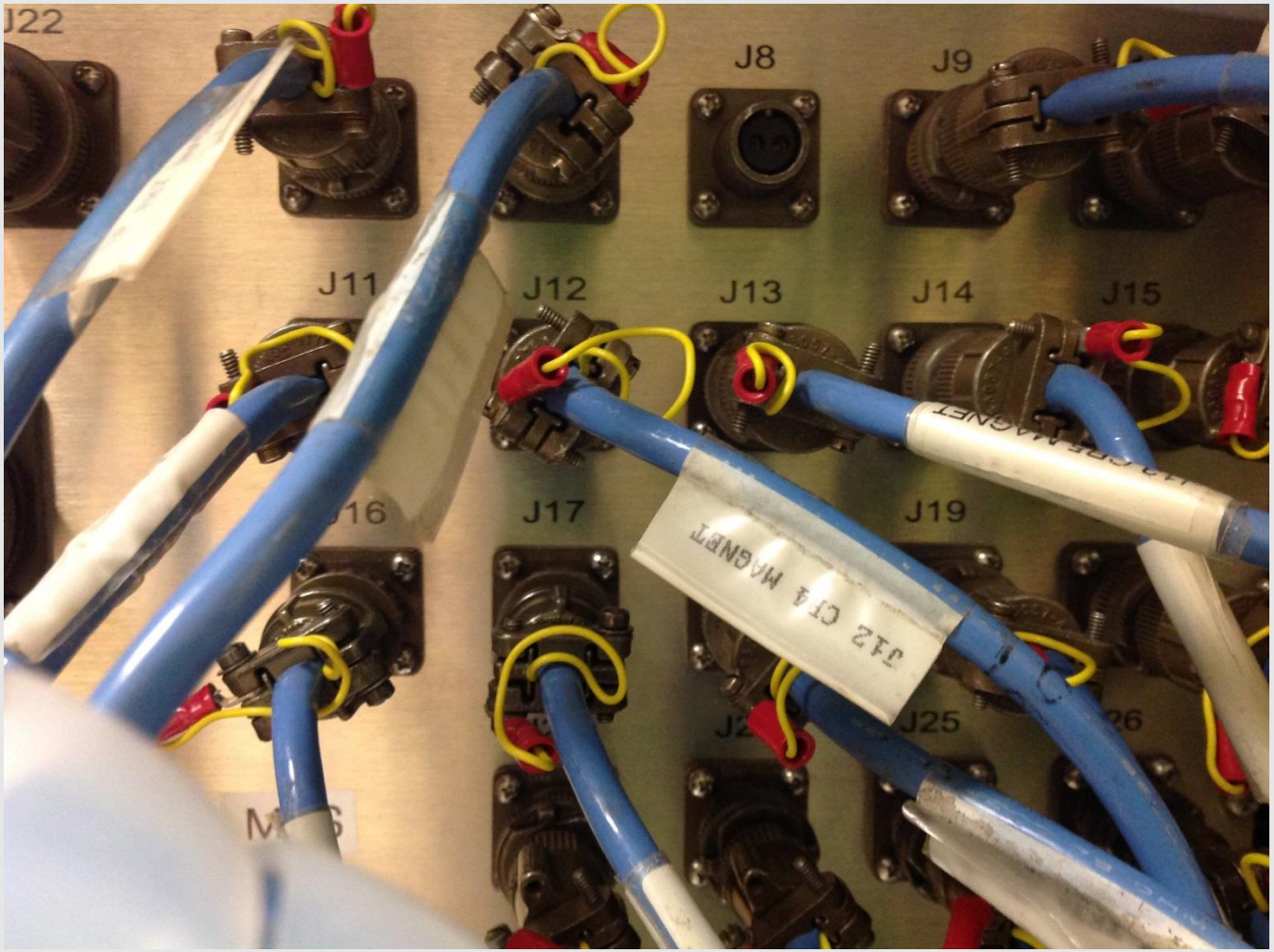
WR1 Linear
WR2 Log
WR2 GRND
WR2 Start up rate
WR2 Linear
WR1 GRD
WR2 GRD


3-41
WR1 Linear
WR2 Log
4-41
WR2 SUR
5-41
WR2 LInear
0-10 volts in/out
6-41
1-42
WR1
GRD
2-42
3-42
4-42
WR2
GRD
5-42
6-42

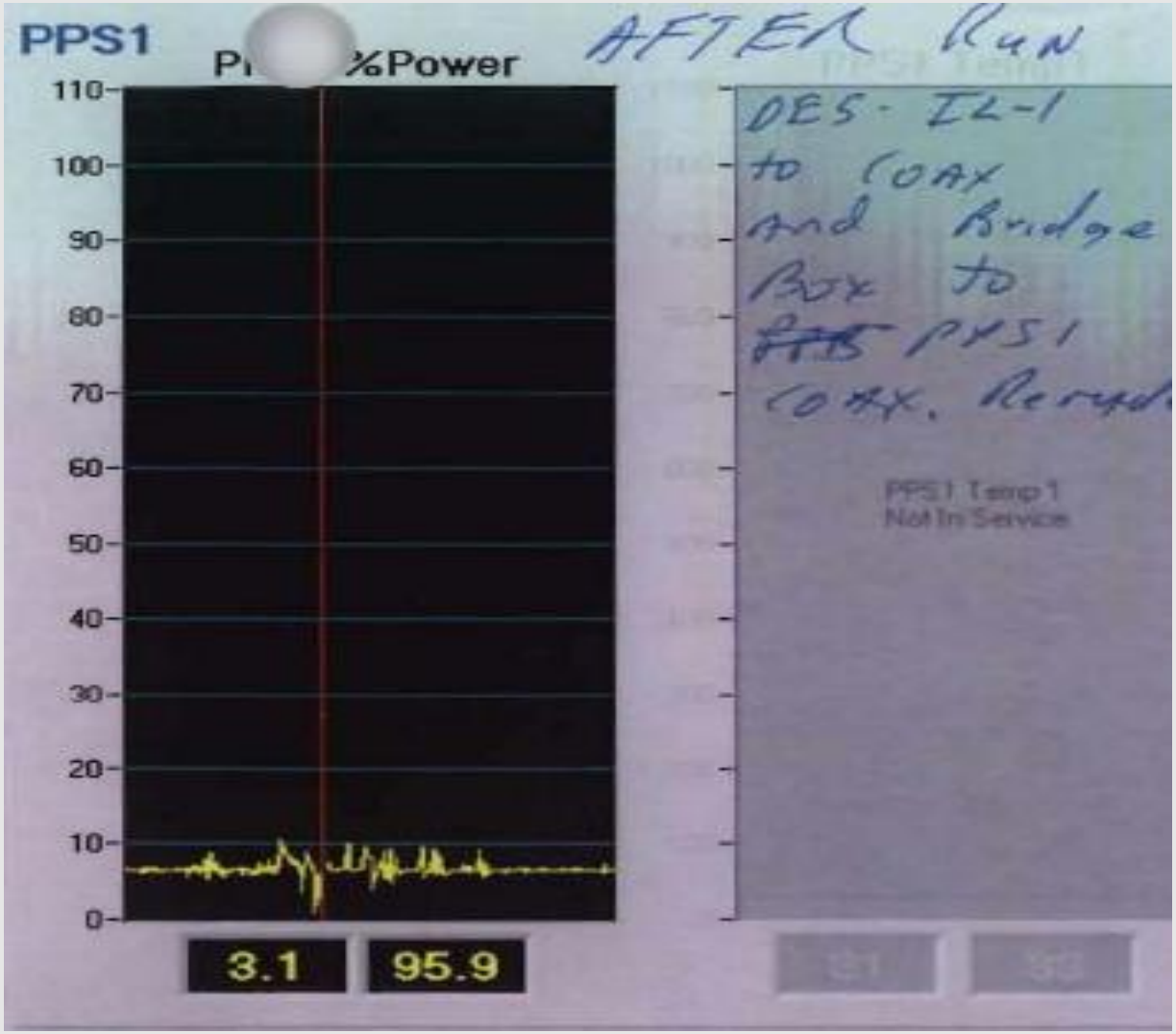
Grounding via solid wire from shield



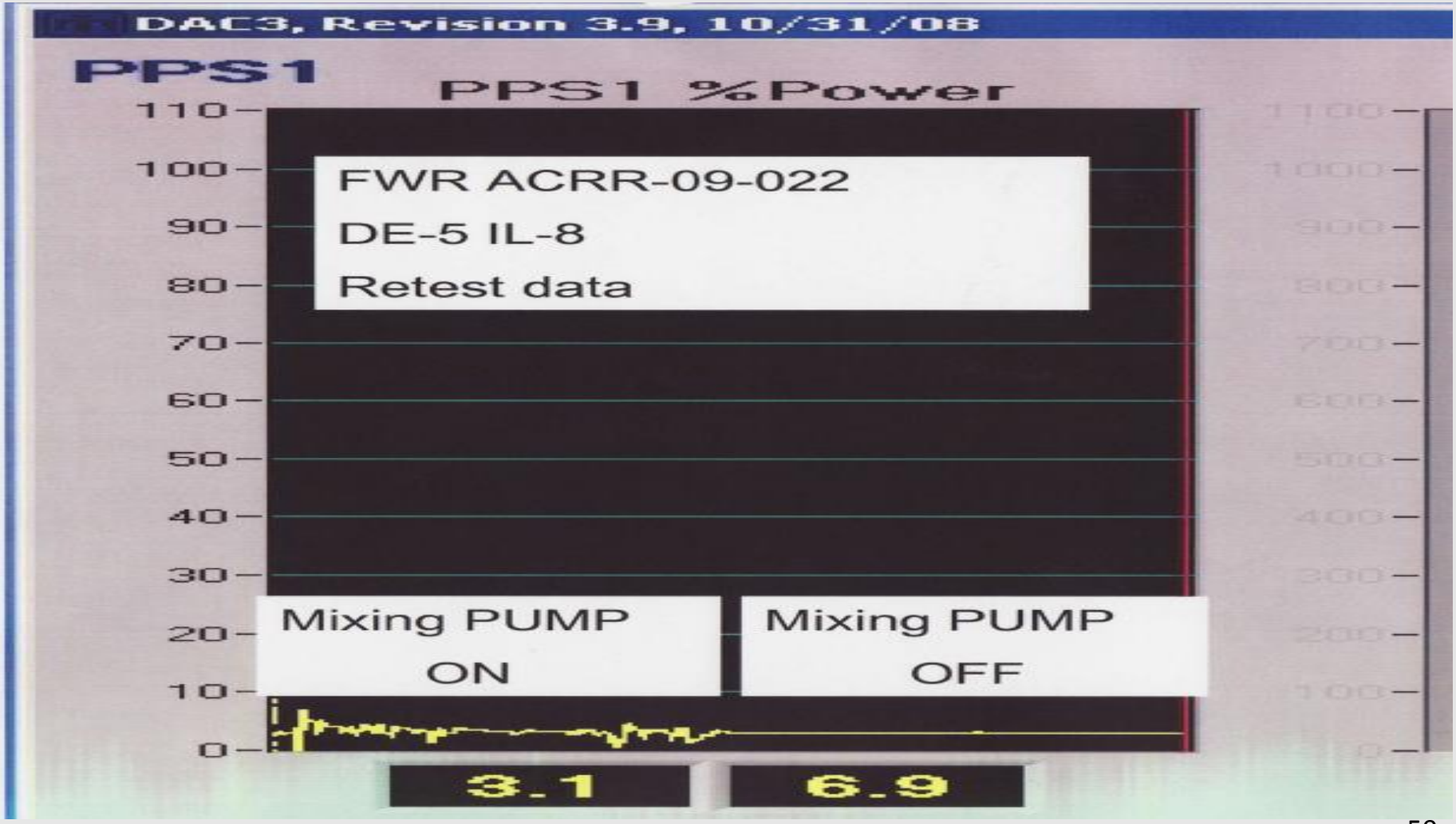
Solid vs braided wire creates High Impedance path to ground

- Sharp edge pulses, even in a direct current application, emit high frequencies. Recall that a Square wave, can be built by combining every odd harmonic. Specifically note that arcing also emits all frequencies.
- High impedance connections, in your DC circuits will emit electrical fields.
- Large voltages promote Electrical field coupling.
- Full credit to AMS for pointing out this vulnerability.

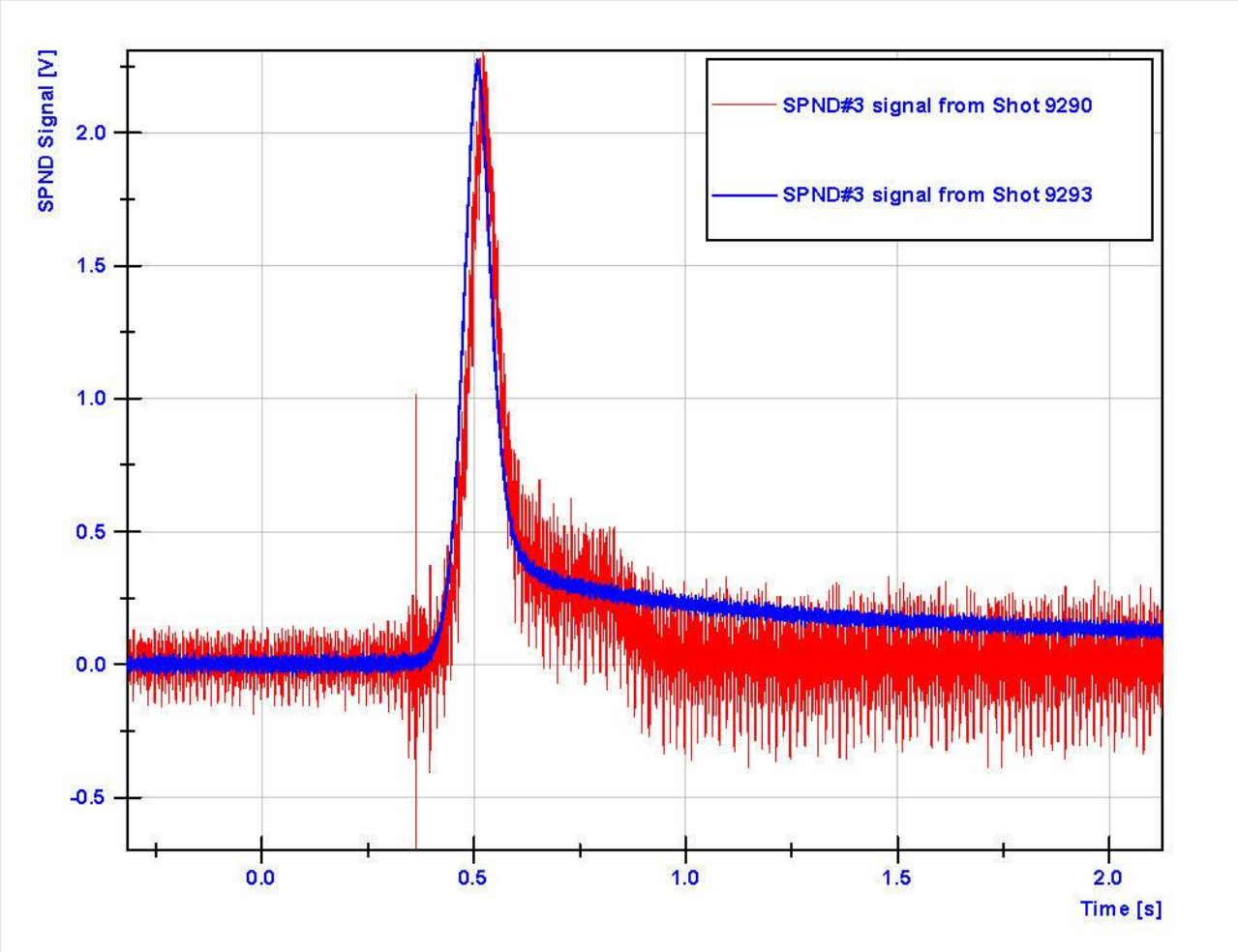
Noisy PPS1 Channel



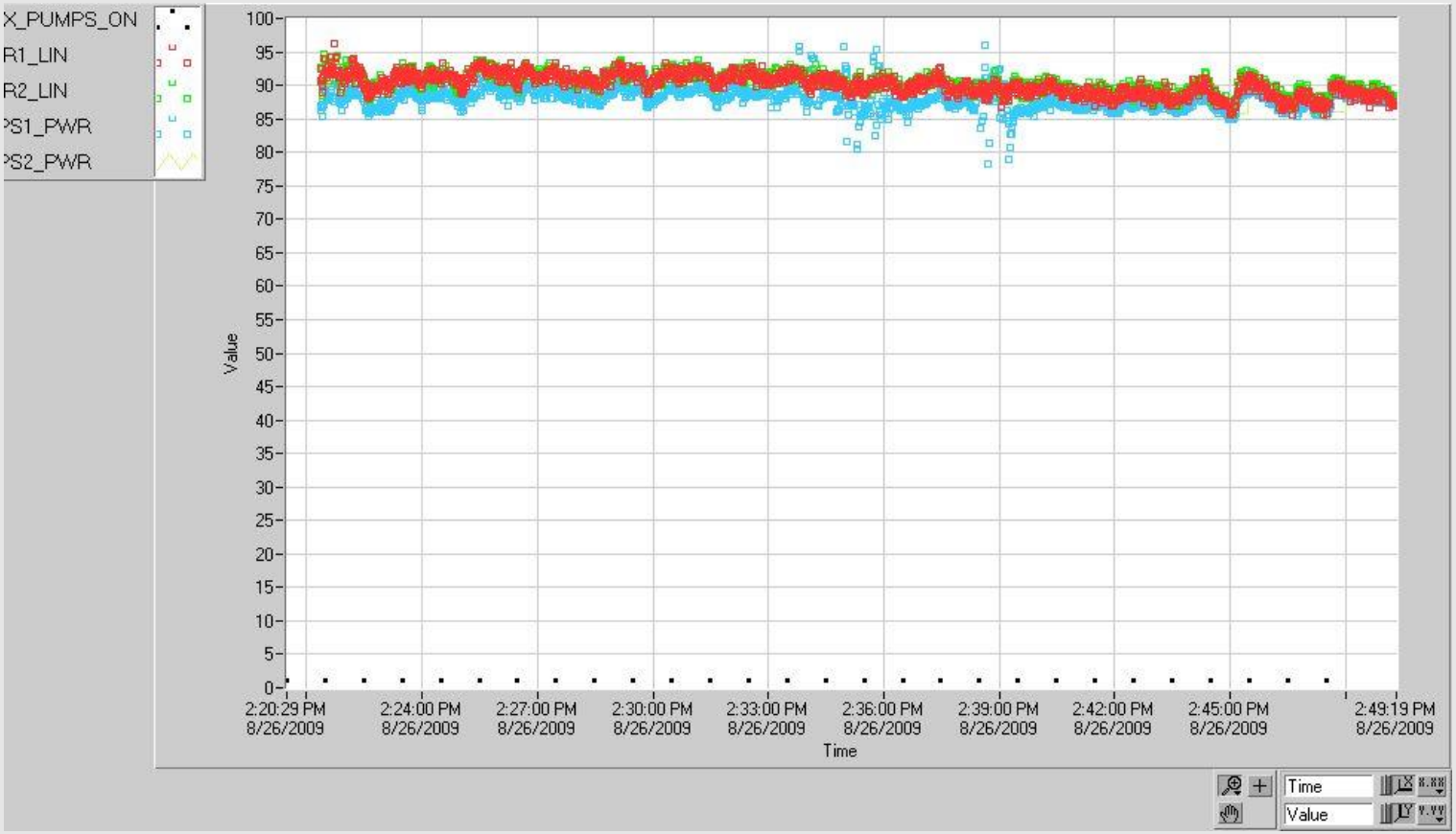
Noisy PPS1 Channel



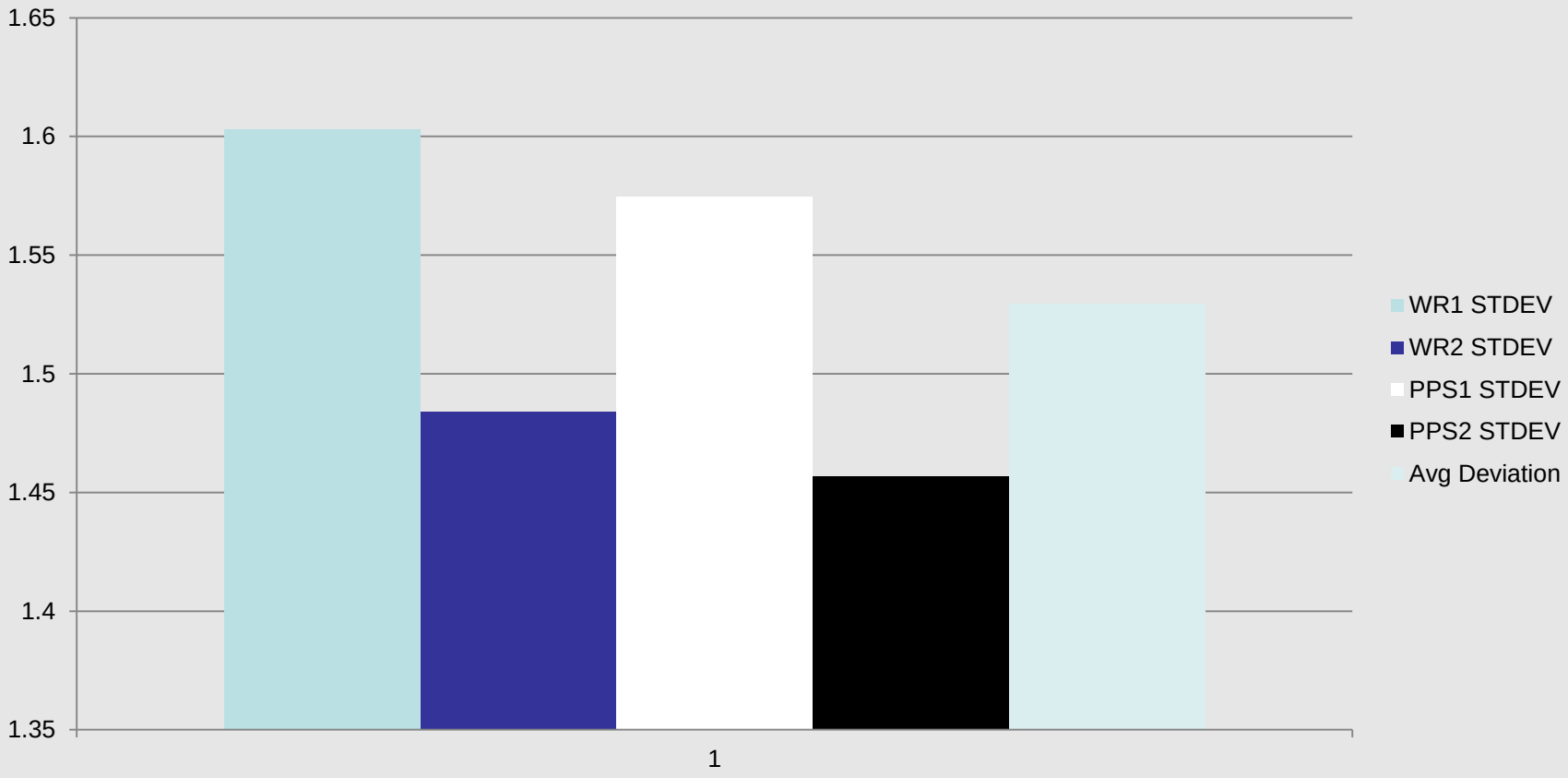
Noisy PPS1 Channel



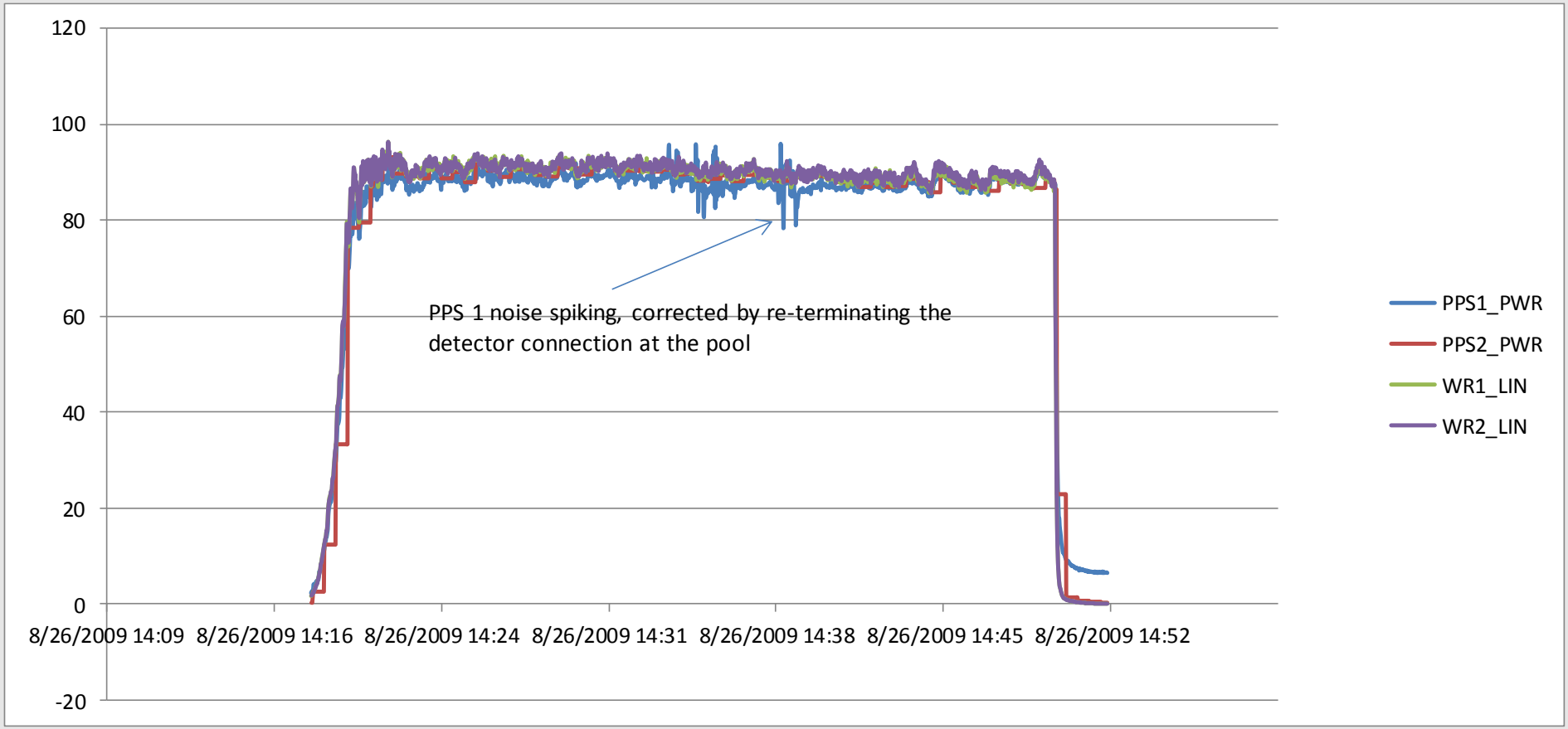
Noisy PPS1 Channel



Noisy PPS1 Channel

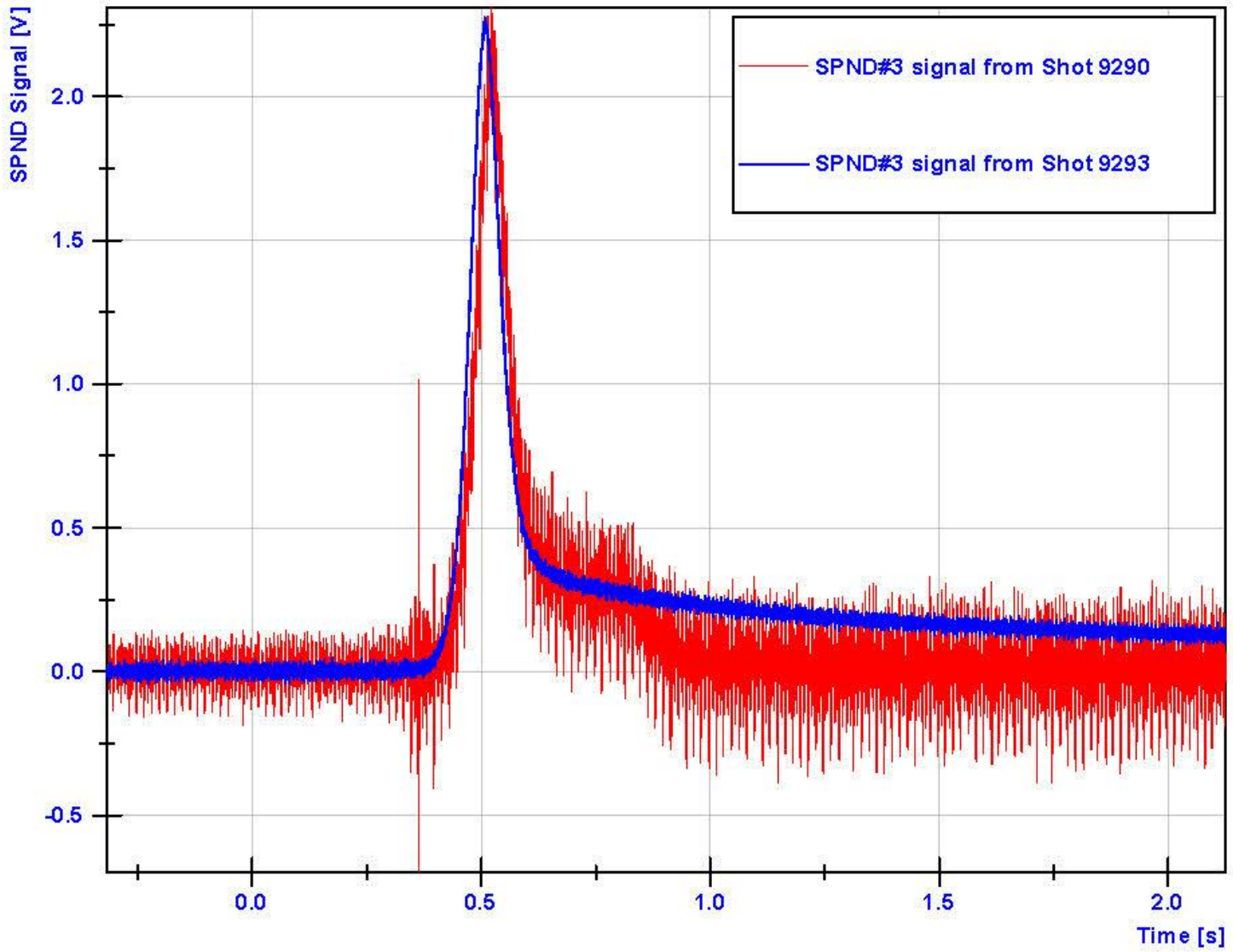


Noisy PPS1 Channel

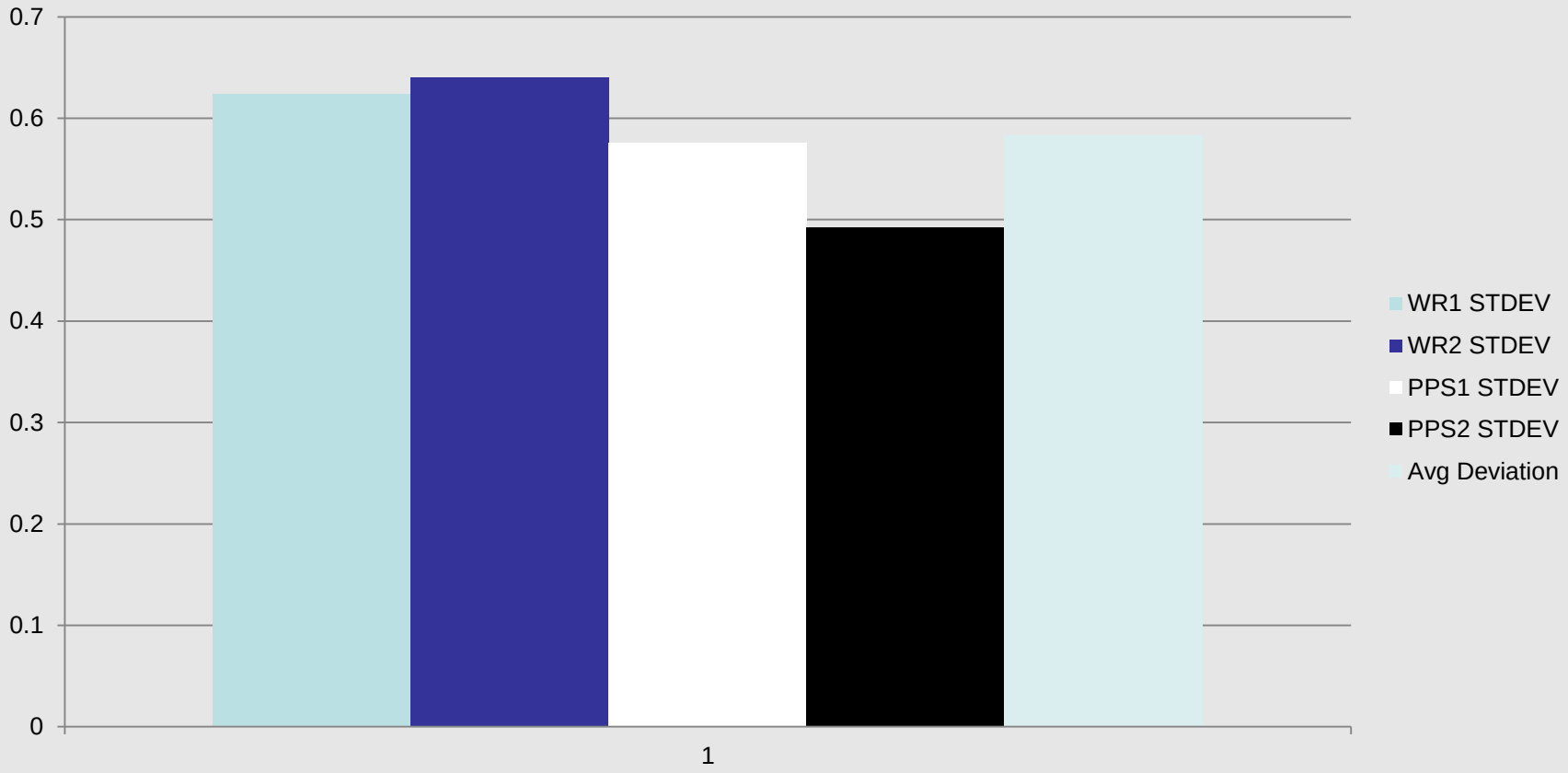


- Coax connector, opened circuited the signal and the leakage current from mixing pump.
- Note that arcing from loose connections, emits all frequencies.
- High impedance connections will emit electrical fields, and are susceptible to other electrical fields.
- The co-mingling of the arcing signal electrical field, the arcing at the loose connection (inner skin of shielded braid carrying signal return, outer skin of shielded braid shunting the nearby mixing current away from the signal). All combined to generate High Frequency noise, permitting capacitive cross coupling.

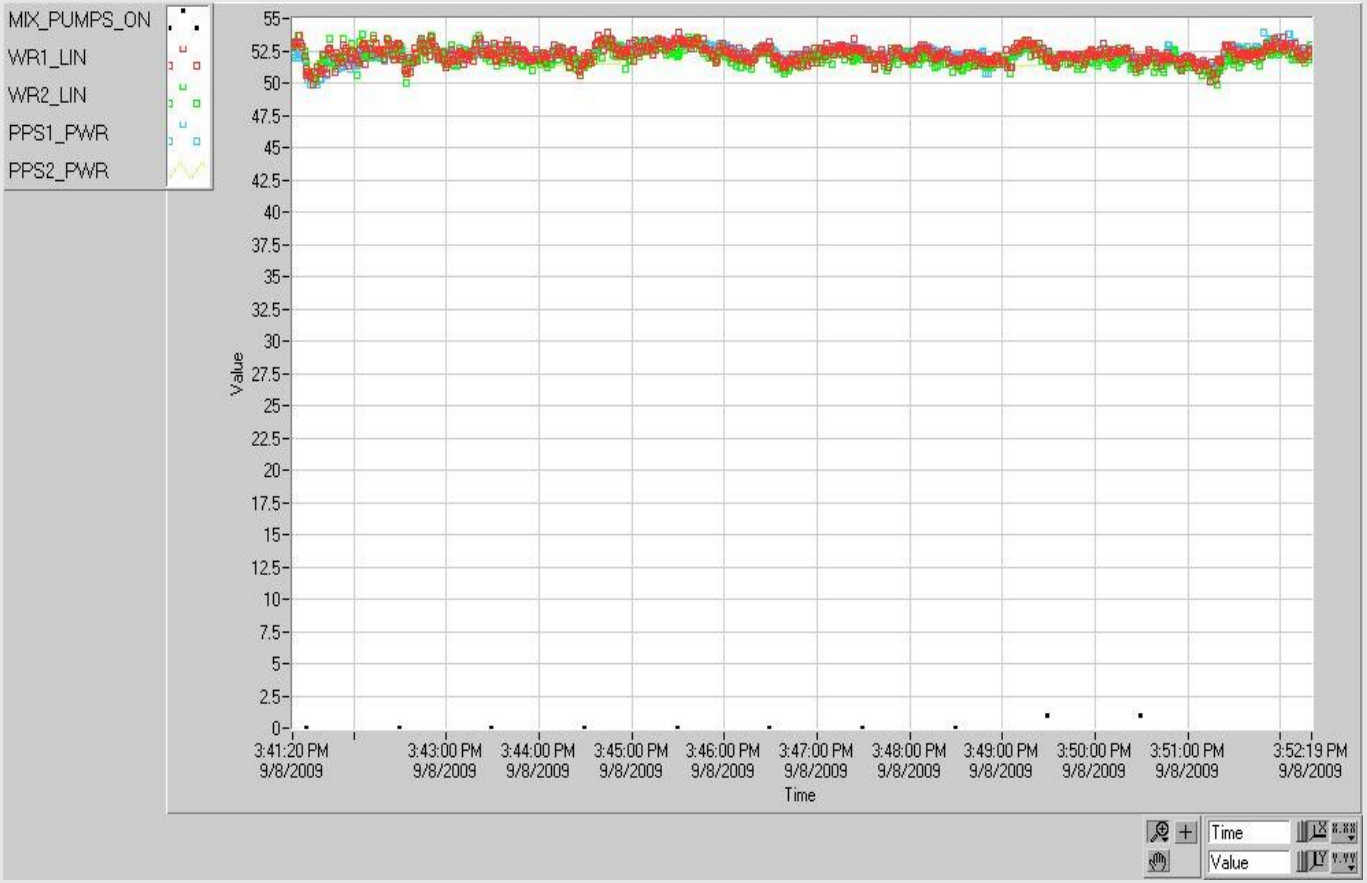
Noisy PPS1 Channel



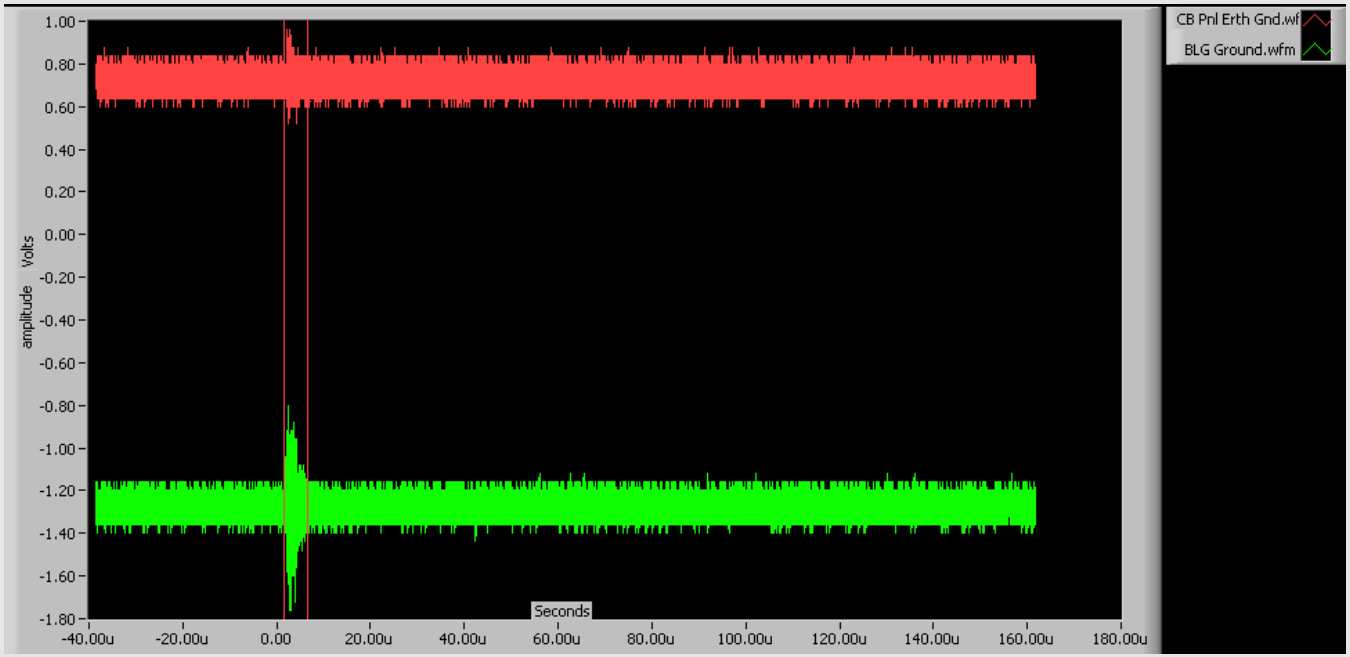
Noisy PPS1 Channel Post Repair



Noisy PPS1 Channel Post Repair



ACRR Repeatable Noise Attenuated by improved ground



Noise reduction of 70%

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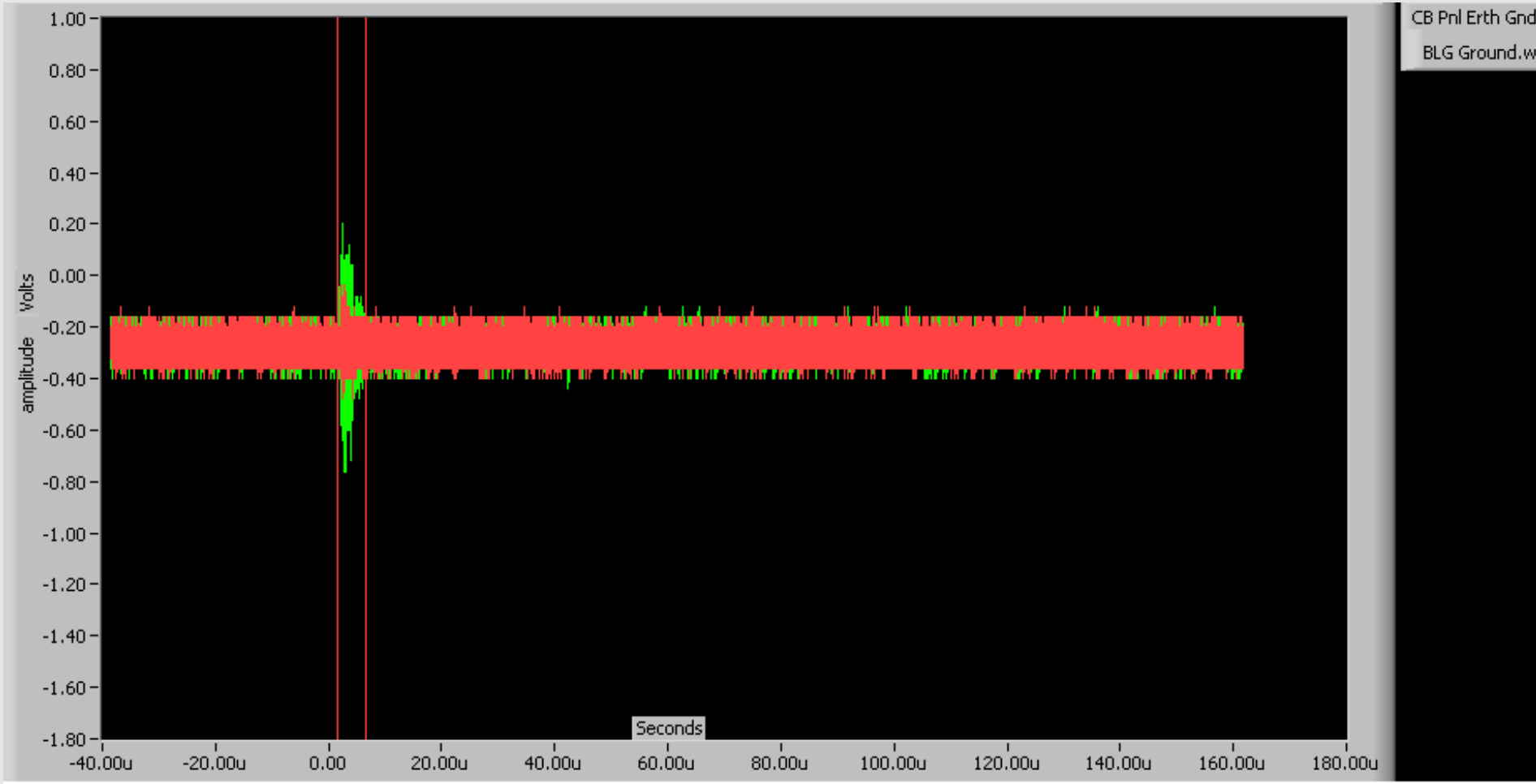
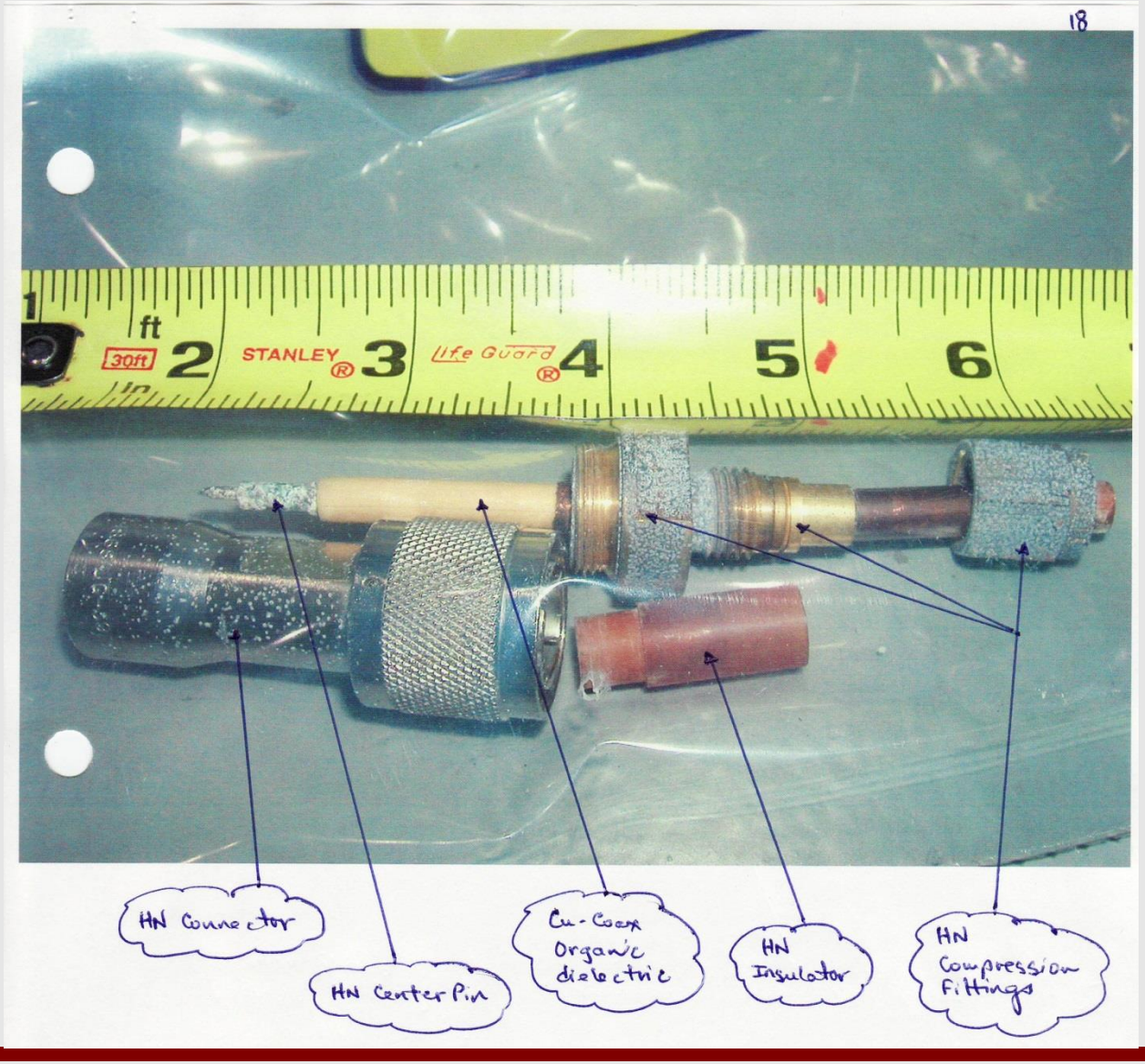


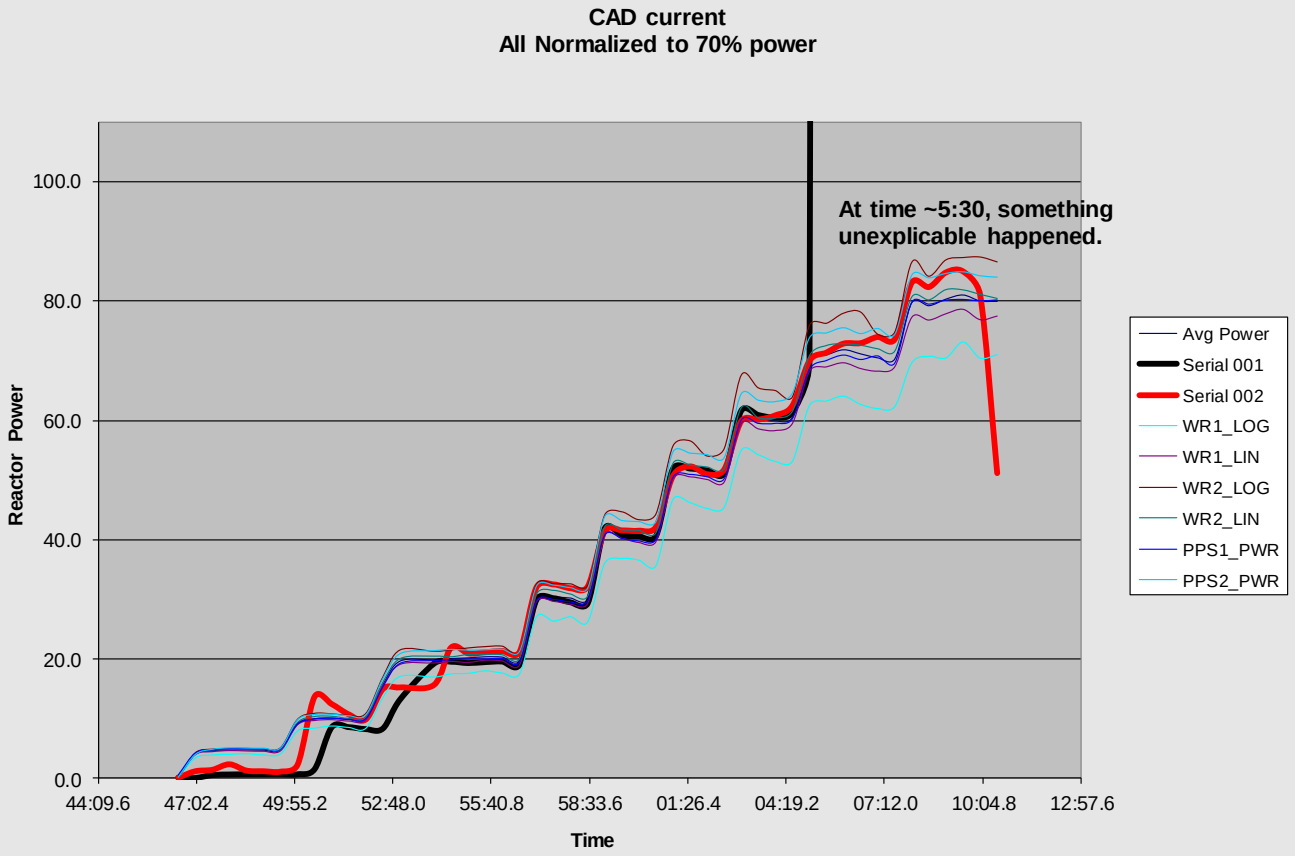

EXIT
Connected directly to building ground vice extension cord

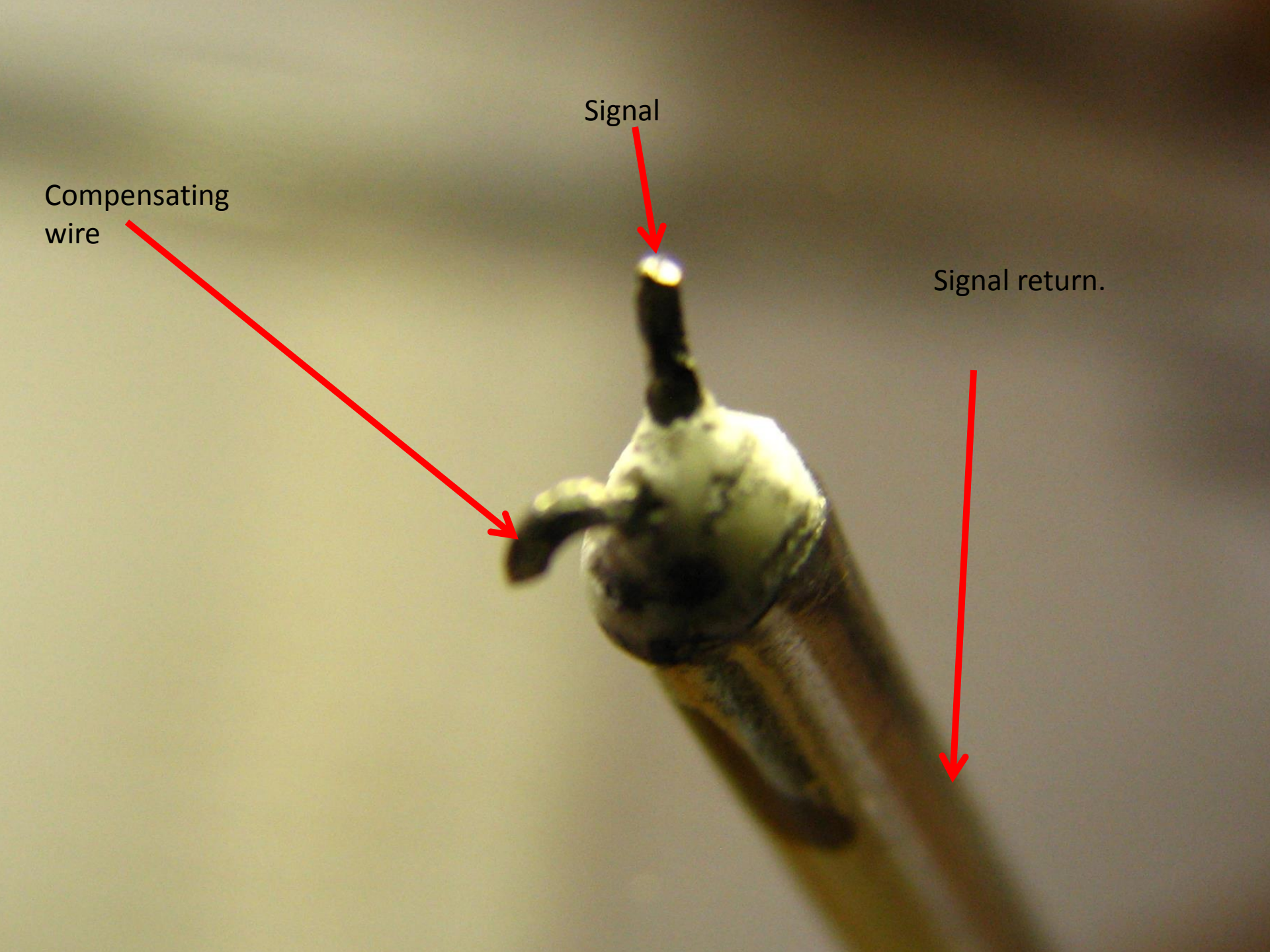

FED FROM PANEL

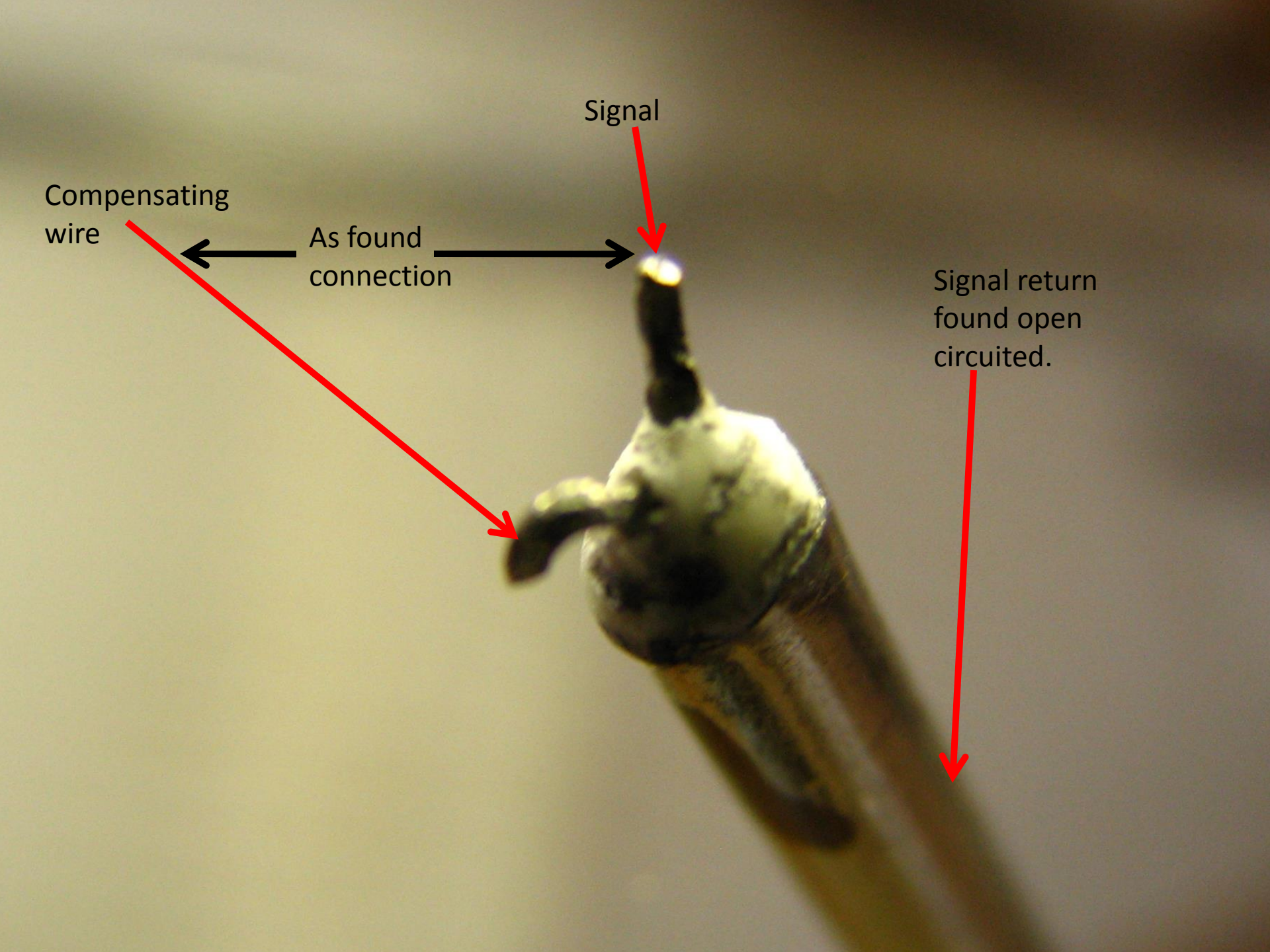
Another Coax Noise Issue

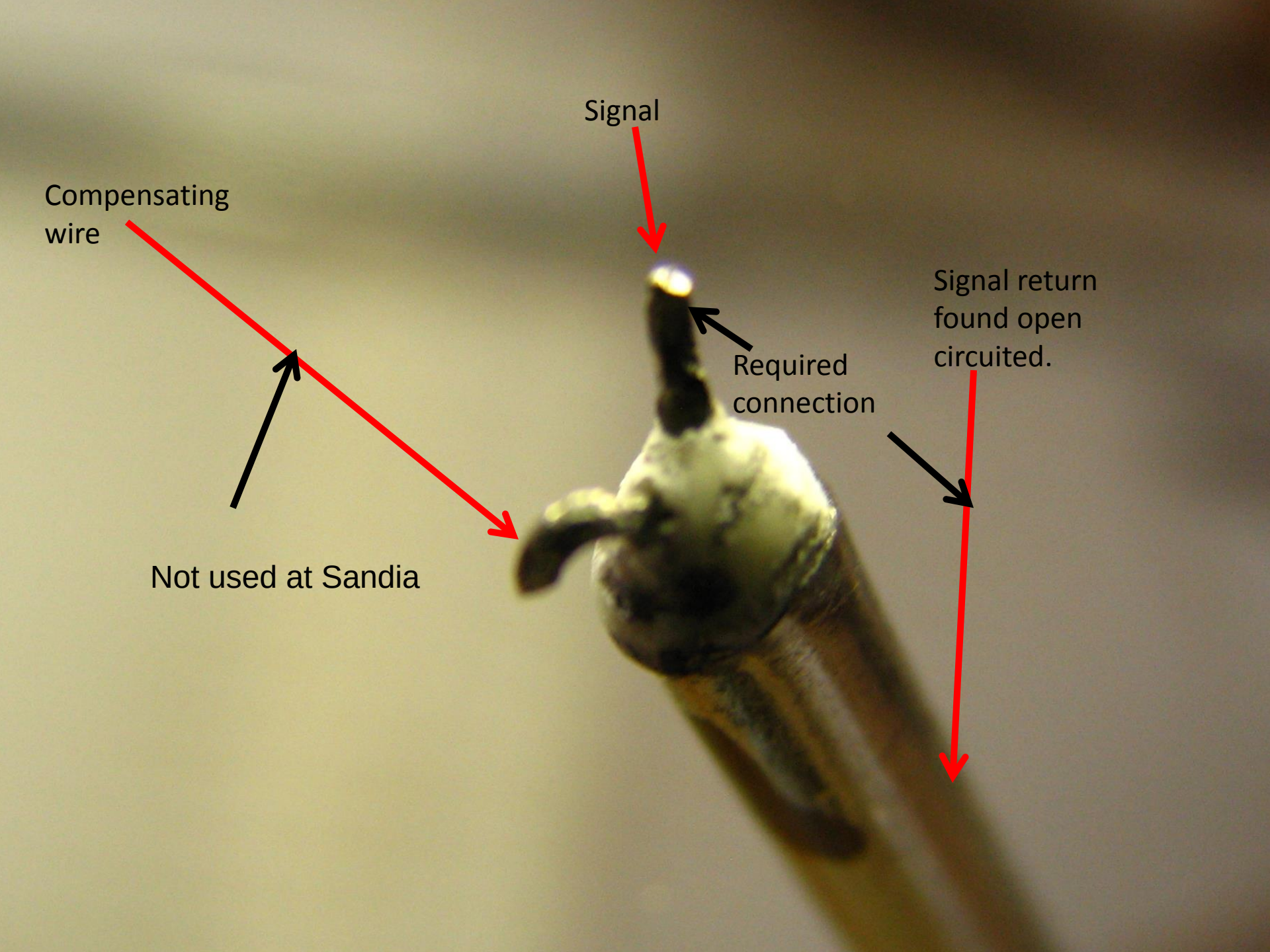


New CAD 001 and 002 did not work as expected.



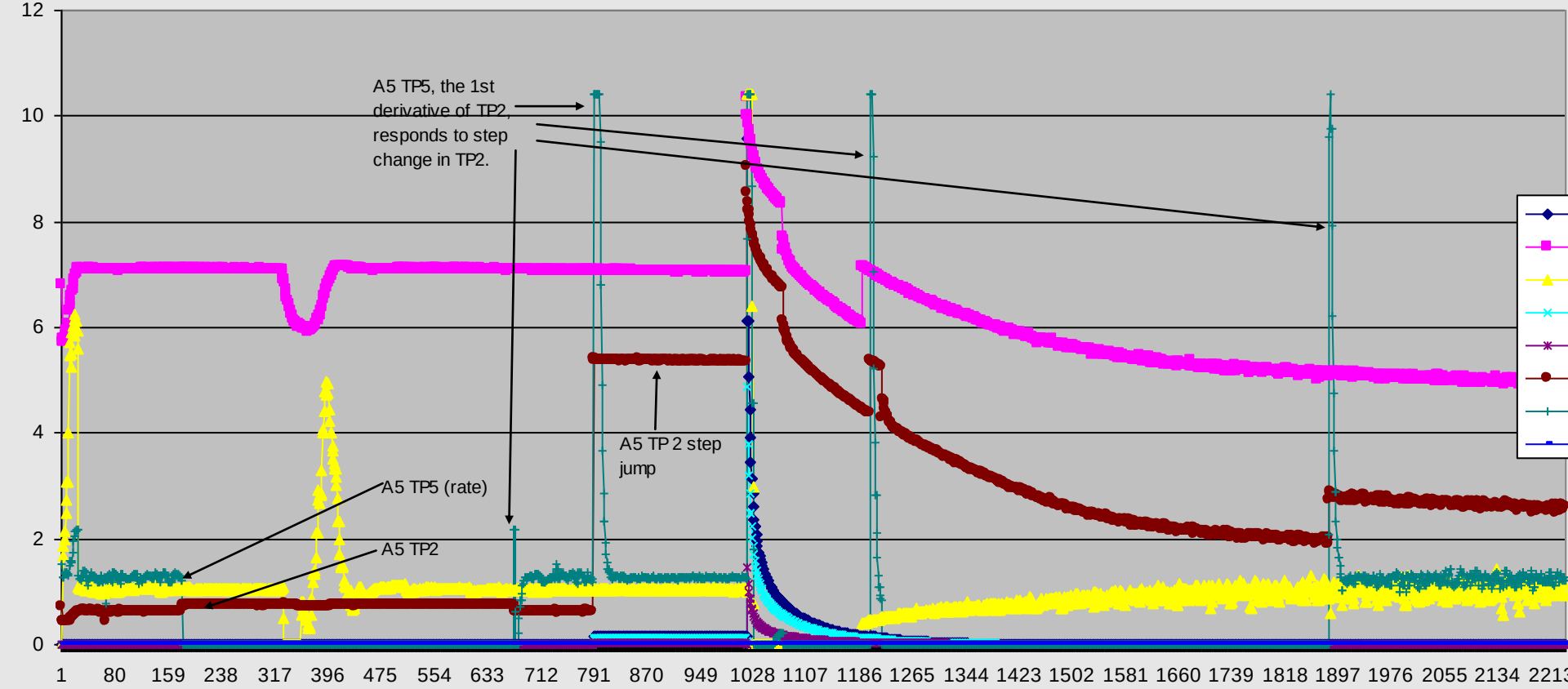

Signal
Compensating wire
Signal return.


Signal
Compensating wire
As found connection
Signal return found open circuited.


Signal
Compensating wire
Signal return found open circuited.
Required connection
Not used at Sandia

Sandia National Laboratories

Saved data



Expected Response

- **SR LCR [O-10V = 0.1-105CPS]**

  VDC TP2 = (Log CPS + 1) / 0.6

  CPS = 1 O(Volts x 0.6 -1)

- **WRLCR**

  VDC TP2 = Log CPS + 0.4

  CPS = 1 O(Volts - 0.4)

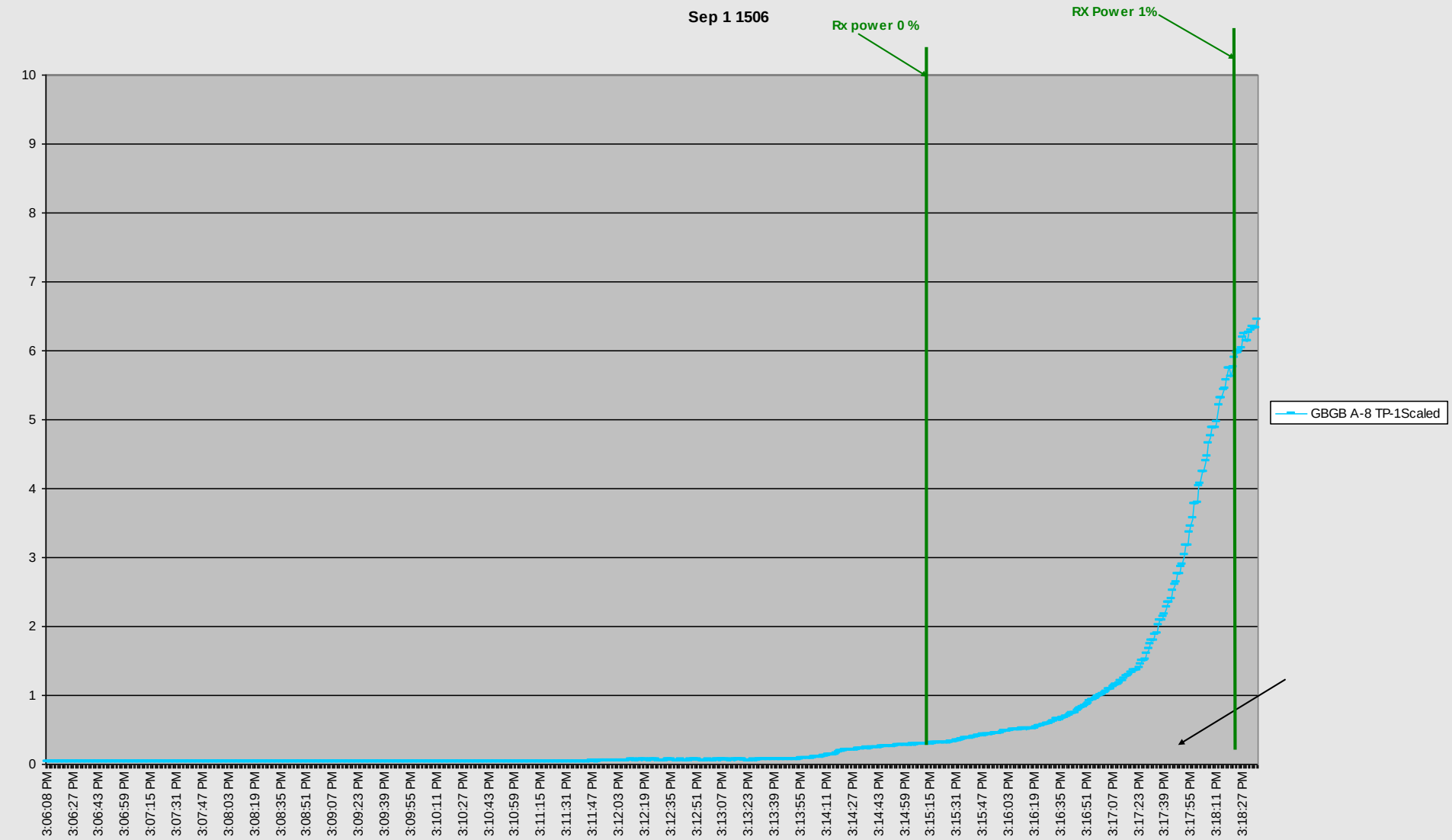
- **WR Log Amp**

  VDC TP2 = Log (pin 43 / 10980) x 2 + 16.167

- **WR % Power [O-10V = 10-8-100%]**

  VDC TP6 = Log (% Power) + 8

  % Power = 1 O(Volts - 8)


Sep 1 1506
Rx power 0 %
RX Power 1%
10
9
8
7
6
5
4
3
2
1
0
3:06:08 PM
3:06:27 PM
3:06:43 PM
3:06:59 PM
3:07:15 PM
3:07:31 PM
3:07:47 PM
3:08:03 PM
3:08:19 PM
3:08:35 PM
3:08:51 PM
3:09:07 PM
3:09:23 PM
3:09:39 PM
3:09:55 PM
3:10:11 PM
3:10:27 PM
3:10:43 PM
3:10:59 PM
3:11:15 PM
3:11:31 PM
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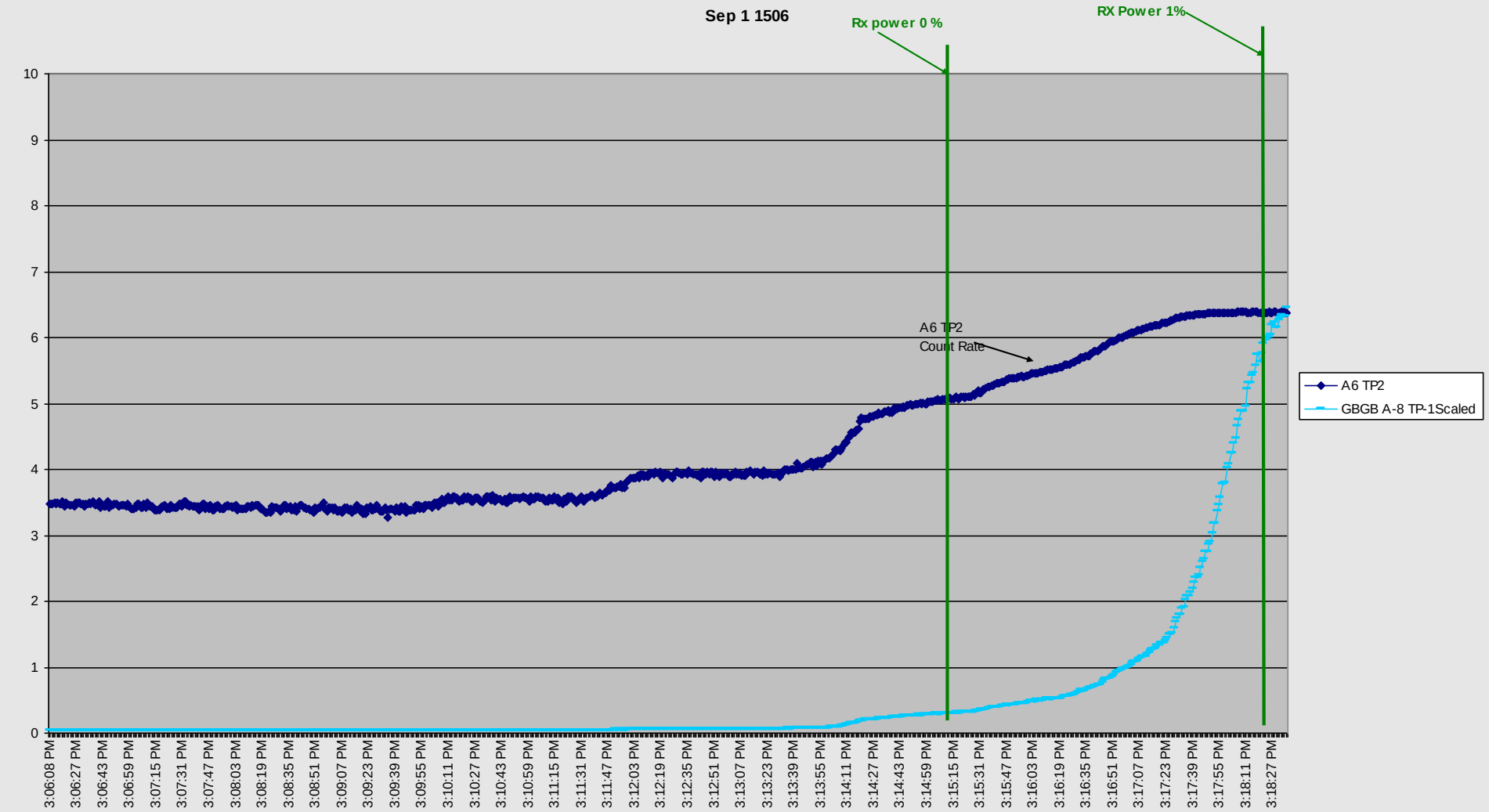
3:16:03 PM
3:16:19 PM
3:16:35 PM
3:16:51 PM
3:17:07 PM
3:17:23 PM
3:17:39 PM
3:17:55 PM
3:18:11 PM
3:18:27 PM
GBGB A-8 TP-1Scaled

70


Sep 1 1506
Rx power 0 %
RX Power 1%
A6 TP2
Count Rate
A6 TP2
GBGB A-8 TP-1Scaled
10
9
8
7
6
5
4
3
2
1
0
3:06:08 PM
3:06:27 PM
3:06:43 PM
3:06:59 PM
3:07:15 PM
3:07:31 PM
3:07:47 PM
3:08:03 PM
3:08:19 PM
3:08:35 PM
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3:09:07 PM
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3:11:15 PM
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3:17:39 PM
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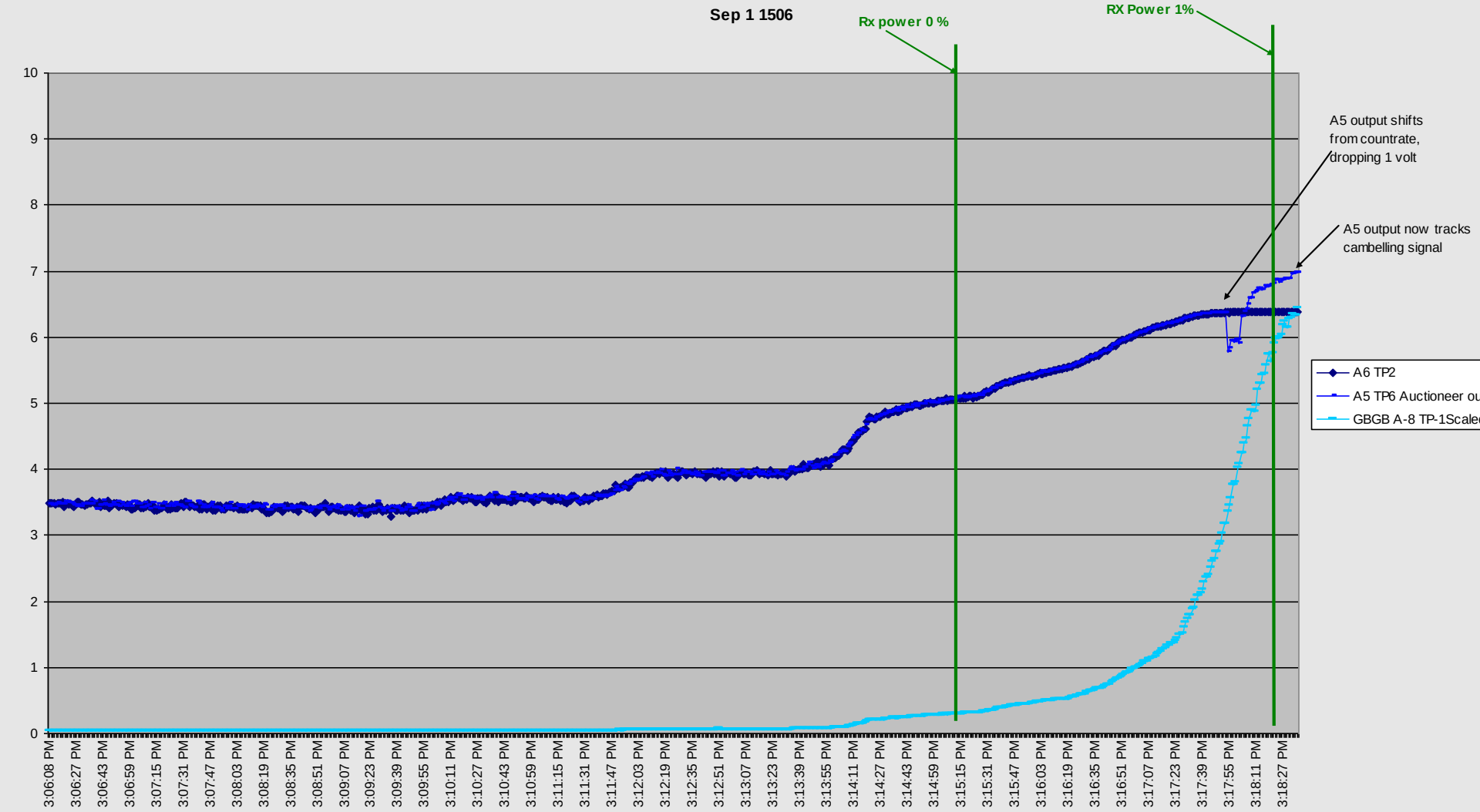
3:18:27 PM


Sep 1 1506
Rx power 0 %
RX Power 1%
A5 output shifts from countrate, dropping 1 volt
A5 output now tracks cambelling signal
A6 TP2
A5 TP6 Auctioneer ou
GBGB A-8 TP-1Scale
10
9
8
7
6
5
4
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2
1
0
3:06:08 PM
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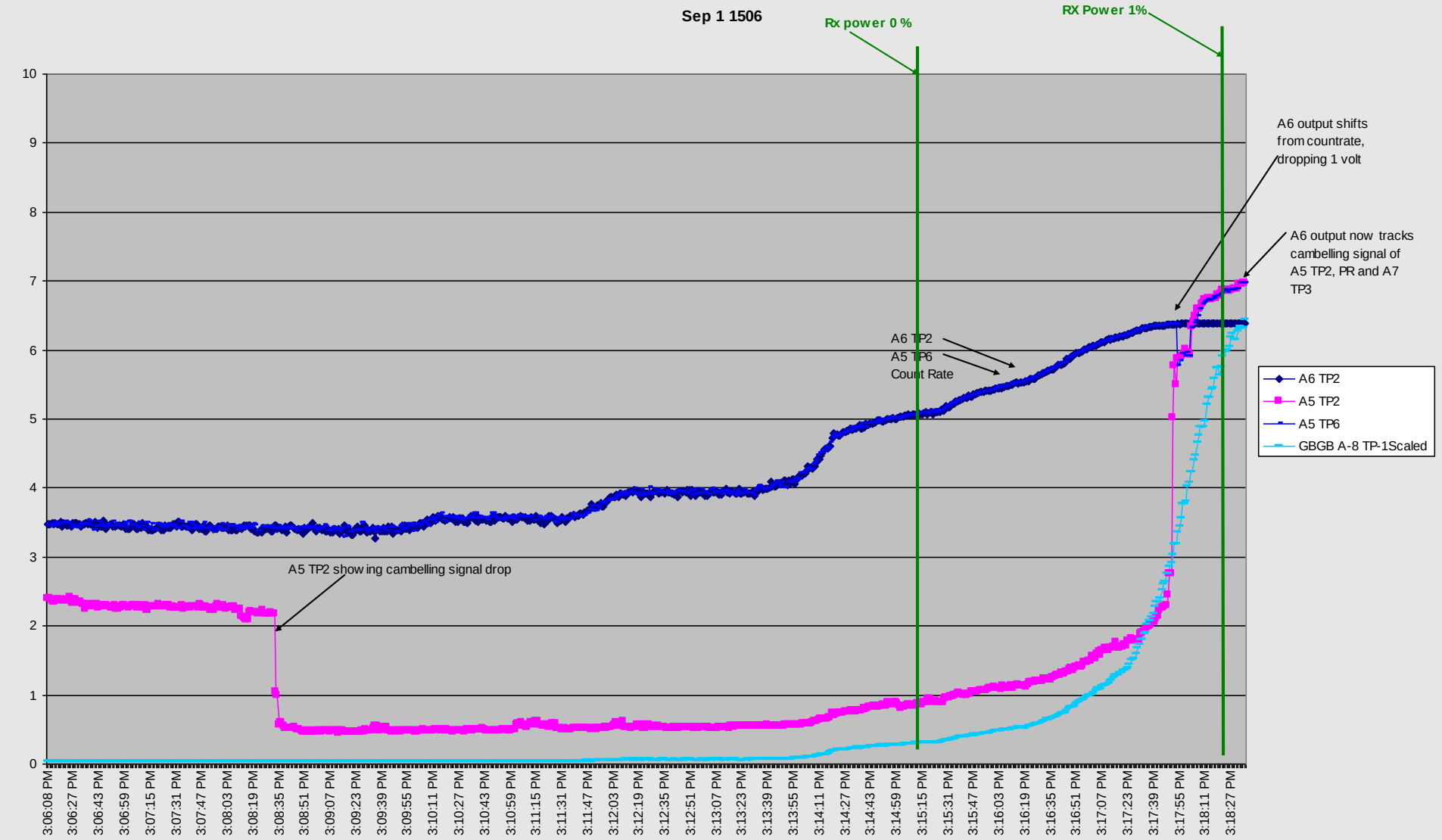
3:17:55 PM
3:18:11 PM
3:18:27 PM


Sep 1 1506
Rx power 0 %
RX Power 1%
A6 output shifts from countrate, dropping 1 volt
A6 output now tracks cambelling signal of A5 TP2, PR and A7 TP3
A6 TP2
A5 TP6
Count Rate
A5 TP2 showing cambelling signal drop
A6 TP2
A5 TP2
A5 TP6
GBGB A-8 TP-1Scaled
10
9
8
7
6
5
4
3
2
1
0
3:06:08 PM
3:06:27 PM
3:06:43 PM
3:06:59 PM
3:07:15 PM
3:07:31 PM
3:07:47 PM
3:08:03 PM
3:08:19 PM
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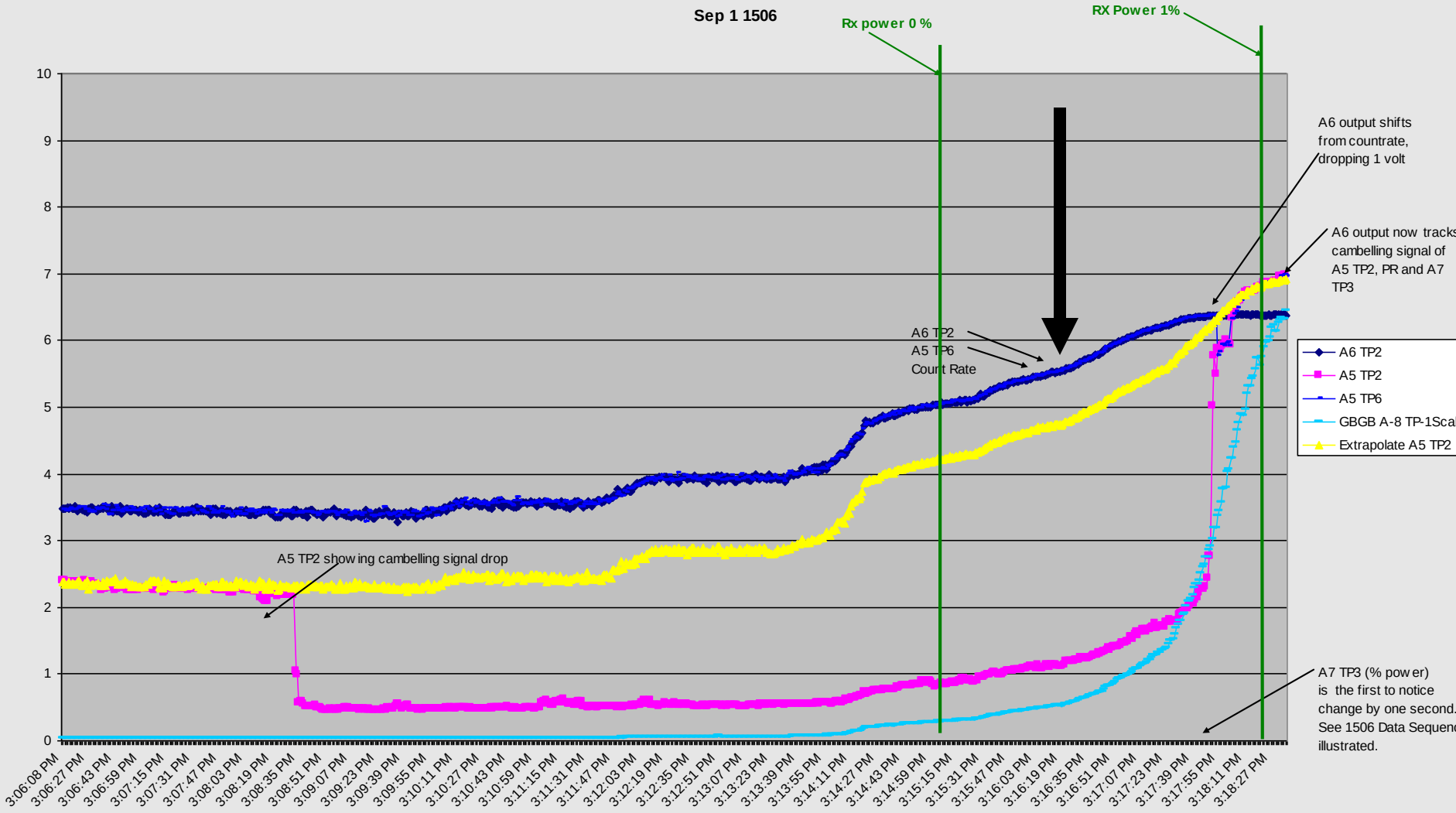
Sep 1 1506
Rx power 0 %
RX Power 1%
A6 output shifts from countrate, dropping 1 volt
A6 output now tracks cambelling signal of A5 TP2, PR and A7 TP3
A6 TP2
A5 TP6
Count Rate
A5 TP2 showing cambelling signal drop
A7 TP3 (% power) is the first to notice change by one second. See 1506 Data Sequence illustrated.
A6 TP2
A5 TP2
A5 TP6
GBGB A-8 TP-1Scal
Extrapolate A5 TP2
10
9
8
7
6
5
4
3
2
1
0
3:06:08 PM
3:06:27 PM
3:06:43 PM
3:06:59 PM
3:07:15 PM
3:07:31 PM
3:07:47 PM
3:08:03 PM
3:08:19 PM
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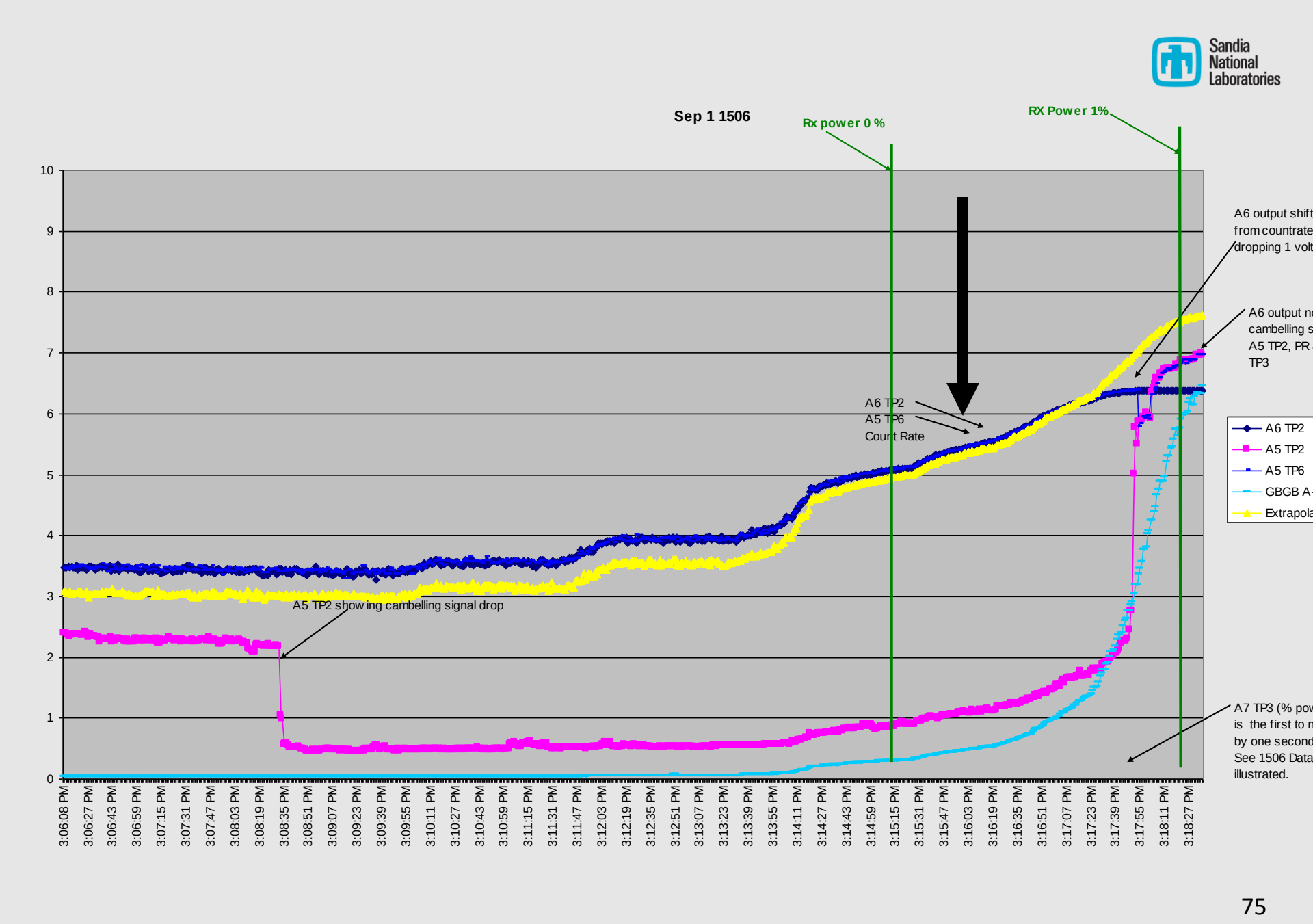
Sep 1 1506
Rx power 0 %
RX Power 1%
A6 output shift
from countrate
dropping 1 volt
A6 output n
cambelling s
A5 TP2, PR
TP3
A6 TP2
A5 TP6
Count Rate
A5 TP2 showing cambelling signal drop
A6 TP2
A5 TP2
A5 TP6
GBGB A-
Extrapola
A7 TP3 (% pow
is the first to n
by one second
See 1506 Data
illustrated.
10
9
8
7
6
5
4
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2
1
0
3:06:08 PM
3:06:27 PM
3:06:43 PM
3:06:59 PM
3:07:15 PM
3:07:31 PM
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3:08:03 PM
3:08:19 PM
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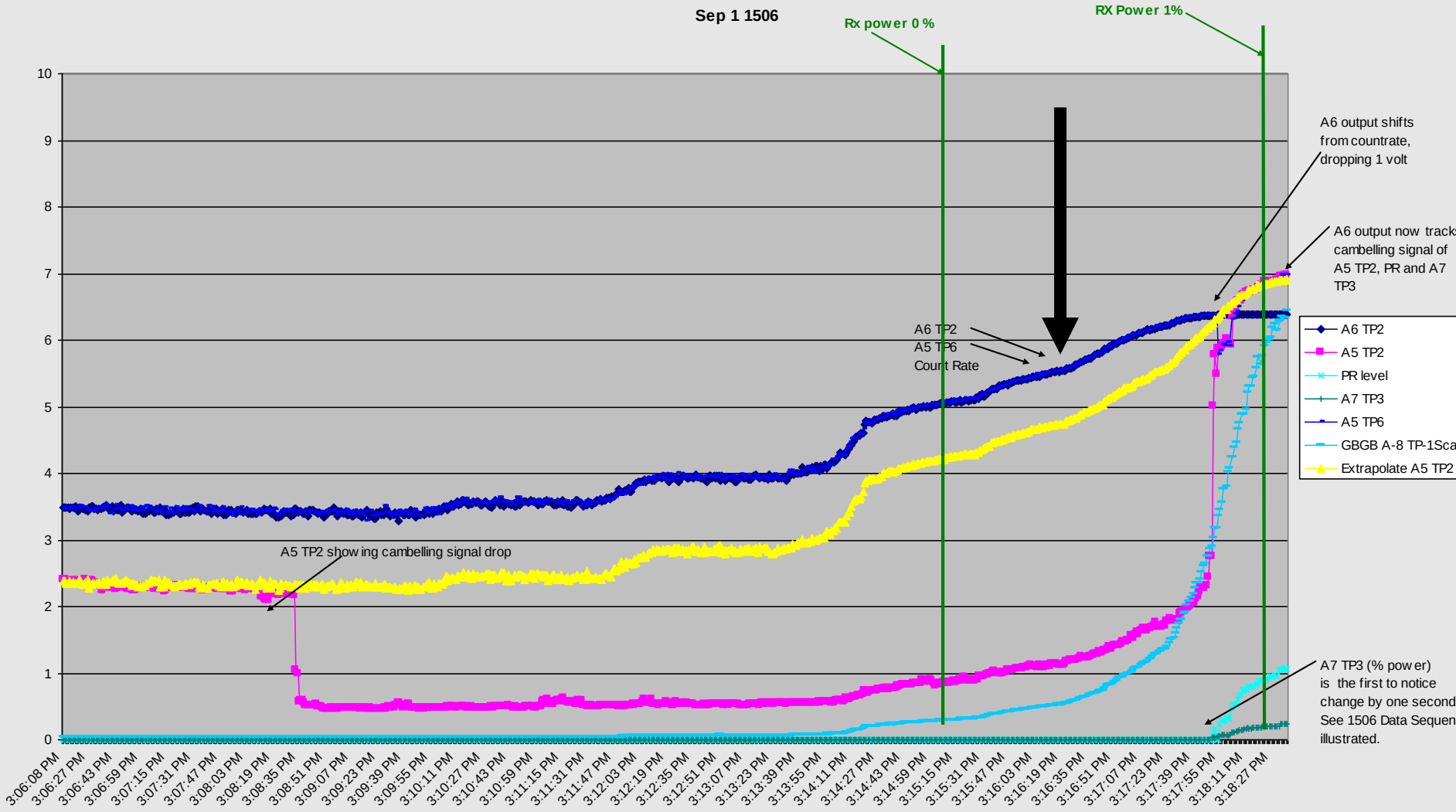
Sep 1 1506
Rx power 0 %
RX Power 1%
A6 output shifts from countrate, dropping 1 volt
A6 output now tracks cambelling signal of A5 TP2, PR and A7 TP3
A6 TP2
A5 TP6
Count Rate
A5 TP2 showing cambelling signal drop
A7 TP3 (% power) is the first to notice change by one second See 1506 Data Sequen illustrated.
A6 TP2
A5 TP2
PR level
A7 TP3
A5 TP6
GBGB A-8 TP-1Sca
Extrapolate A5 TP2
10
9
8
7
6
5
4
3
2
1
0
3:06:08 PM
3:06:27 PM
3:06:43 PM
3:06:59 PM
3:07:15 PM
3:07:31 PM
3:07:47 PM
3:08:03 PM
3:08:19 PM
3:08:35 PM
3:08:51 PM
3:09:07 PM
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3:09:39 PM
3:09:55 PM
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3:11:47 PM
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3:17:23 PM
3:17:39 PM
3:17:55 PM
3:18:11 PM
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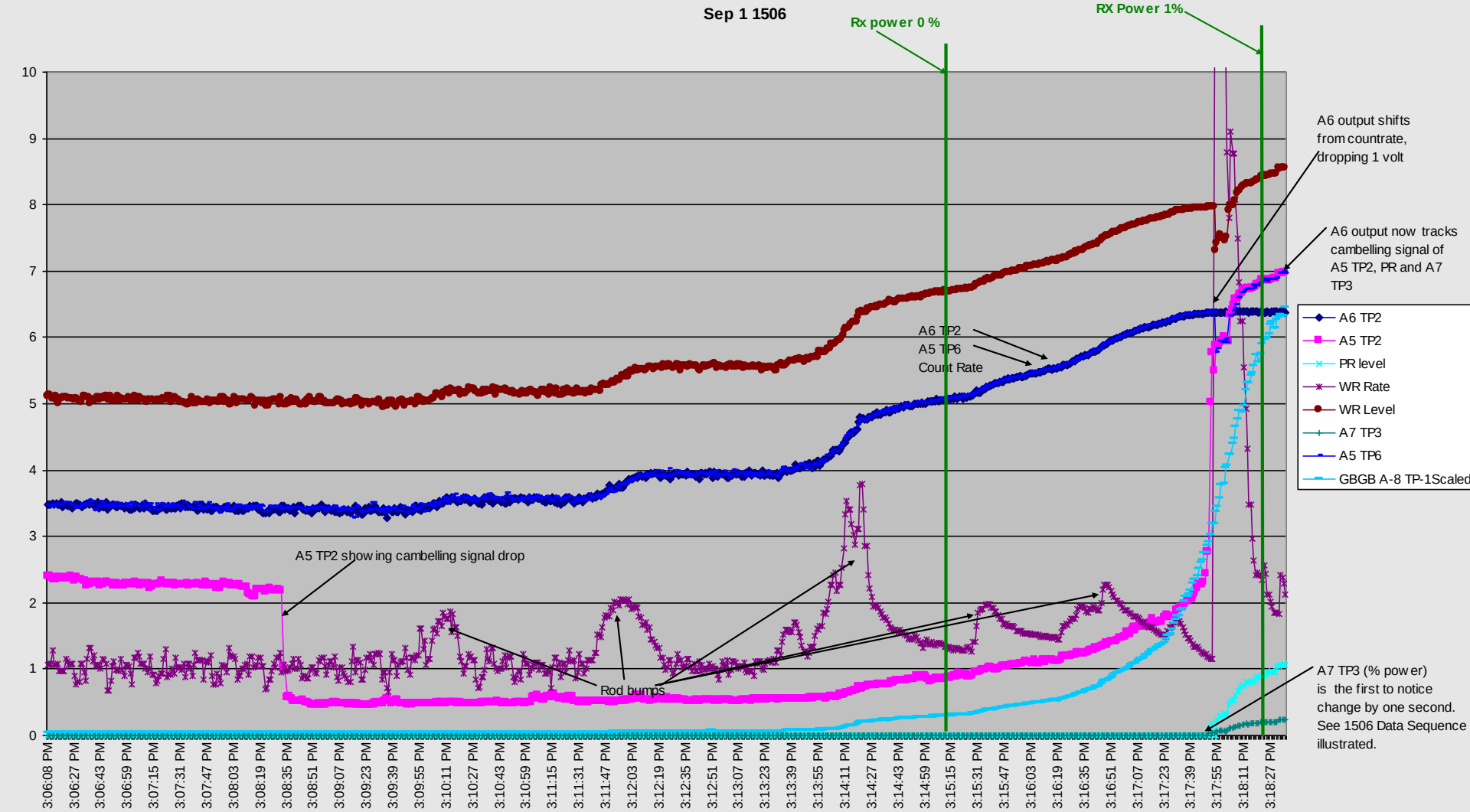
Sep 1 1506
Rx power 0 %
RX Power 1%
A6 output shifts from countrate, dropping 1 volt
A6 output now tracks cambelling signal of A5 TP2, PR and A7 TP3
A6 TP2
A5 TP6
Count Rate
A5 TP2 showing cambelling signal drop
Rod bumps
A7 TP3 (% power) is the first to notice change by one second. See 1506 Data Sequence illustrated.
A6 TP2
A5 TP2
PR level
WR Rate
WR Level
A7 TP3
A5 TP6
GBGB A-8 TP-1Scaled
0
1
2
3
4
5
6
7
8
9
10
3:06:08 PM
3:06:27 PM
3:06:43 PM
3:06:59 PM
3:07:15 PM
3:07:31 PM
3:07:47 PM
3:08:03 PM
3:08:19 PM
3:08:35 PM
3:08:51 PM
3:09:07 PM
3:09:23 PM
3:09:39 PM
3:09:55 PM
3:10:11 PM
3:10:27 PM
3:10:43 PM
3:10:59 PM
3:11:15 PM
3:11:31 PM
3:11:47 PM
3:12:03 PM
3:12:19 PM
3:12:35 PM
3:12:51 PM
3:13:07 PM
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3:13:39 PM
3:13:55 PM
3:14:11 PM
3:14:27 PM
3:14:43 PM
3:14:59 PM
3:15:15 PM
3:15:31 PM
3:15:47 PM
3:16:03 PM
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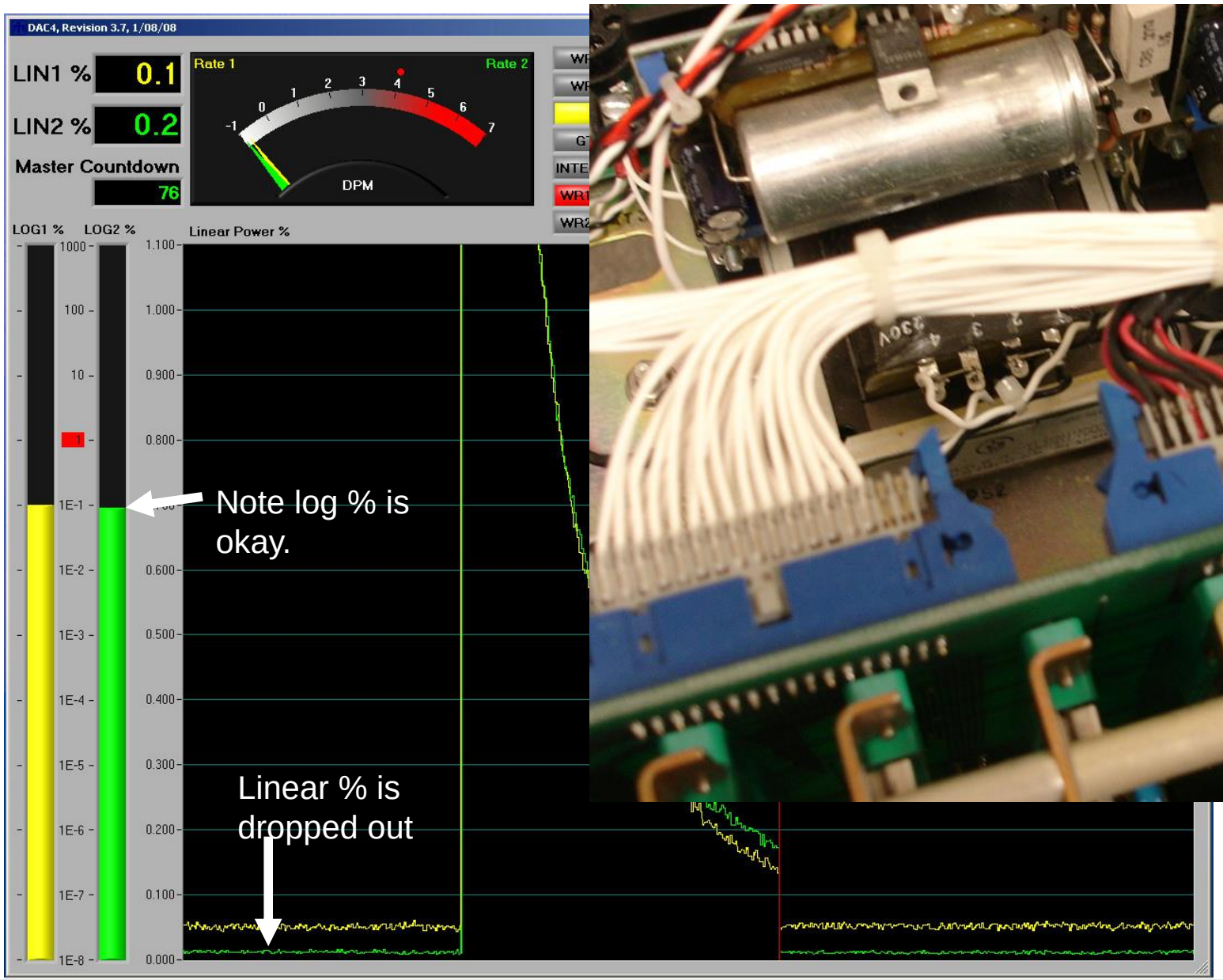
3:16:35 PM
3:16:51 PM
3:17:07 PM
3:17:23 PM
3:17:39 PM
3:17:55 PM
3:18:11 PM
3:18:27 PM

Drop out or loss of signal traced to signal processor high resistance connector.



New challenges: Drones Radar.

U.S. NUCLEAR REGULATORY COMMISSION

Revision 1
October 2003

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.180

(Draft was issued as DG-1119)

GUIDELINES FOR EVALUATING ELECTROMAGNETIC AND RADIO-FREQUENCY INTERFERENCE IN SAFETY-RELATED INSTRUMENTATION AND CONTROL SYSTEMS

Exclusion zone in meters (d)

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- An exclusion zone is defined as the minimum distance permitted between the point of installation and where portable EMI/RFI emitters are allowed to be activated.

- The size of the exclusion zones should be site-specific and depend on the effective radiated power and antenna gain of the portable EMI/RFI emitters used within a particular nuclear power plant.

Exclusion zone in meters (d)

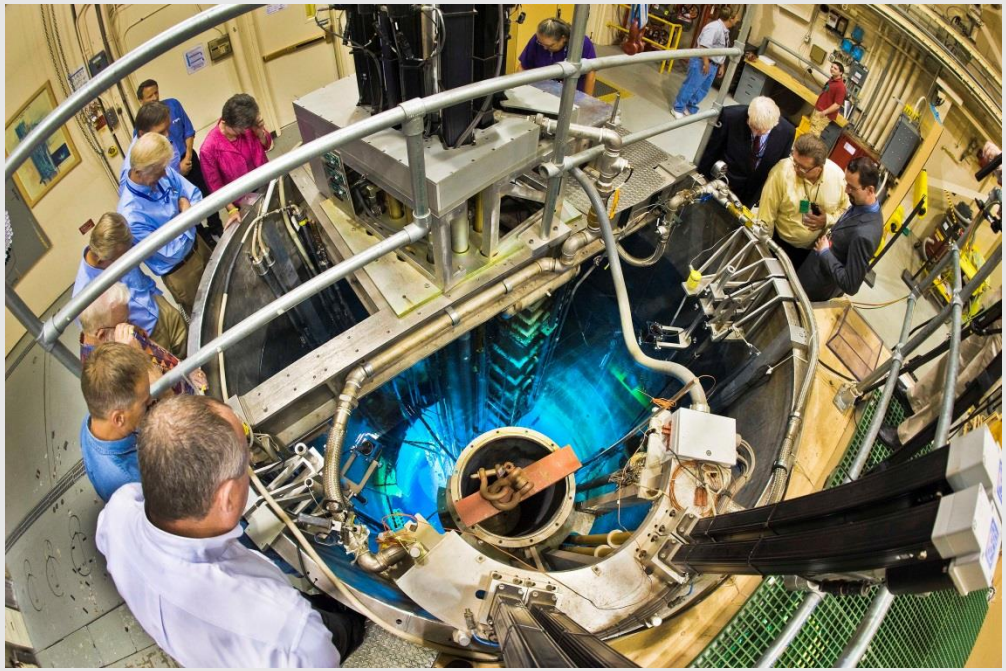
- P_t = the effective radiated power of the EMI/RFI emitter (in Watts);
- G_t = the gain of the EMI/RFI emitter (dimensionless); and,
- E = the allowable radiated electric field strength of the EMI/RFI emitter (in Volts/meter) at the point of installation.
- Radiated electric fields emanating from the portable EMI/RFI emitters are limited to 4 V/m (132 dBµV/m) in the vicinity of safety-related I&C systems.

Exclusion zone in meters (d)

- $d = \frac{\sqrt{P_t G_t}}{E}$


DAC4, Revision 3.8, 5/15/08
LIN1 %
99.0
LIN2 %
99.3
Master Countdown
0
Rate 1
Rate 2
-1
0
1
2
3
4
5
6
7
DPM
WR1_HPP
0.0
WR2_HPP
0.0
NOP
GT4DPM
INTEGRAL_SD
0.0
WR1_LIN_SD
0.0
WR2_LIN_SD
0.0
AUTO
Propose
1
Set
0
Lin Pwr (%)
99
LOG1 %
LOG2 %
Linear Power %
CR Align
AutoLevel
FAST
1000
100
10
1
1E-1
1E-2
1E-3
110.000
100.000
90.000
80.000
70.000
60.000
50.000
Worst case noise recreation

Questions?



10,000 Pulse Video

Ken Mulder

KMulder@sandia.gov

Sandia National Laboratories

Annular Core Research Reactor (ACRR)

Albuquerque, New Mexico

Back up slides

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Junk slides

>106% Reactor Power

- This “close” lighting strike tripped both Wide Range channels.
- The $216,000 lighting protection system installed on the building did protect the equipment from damage.
- The spike probably went much higher than the trip.

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28%

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- This experiment used a 1000VDC electrostatic discharge.
- This experiment simulated:
  - Striking a welding arc!
  - At the center of the reactor!
  - During power operations!
- ACRR Staff reduced it to 19%.

13%

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- Worst case EMI created by holding a transmitter against the signal processor
- EMI reception decreased drastically to 0% by moving the transmitter less than 2.5 feet.
- 0% was the norm. The only area we could get interference to register was from the control room

Other studies finding less noise: Expressed in Percent Power readings, on the PPS channel.

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- 1.5% observed in bad detector connections.
- 0.5% observed in 18 hour study of PPS1.
- 0.145% observed in WR2 during rod movement.

The Basis for 43% margin

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- The review of several years worth of engineering reports, involving hundreds of man-hours concluded the worst noise re-creation possible is 28%. (Other than a lighting strike)

The Basis for 43% margin

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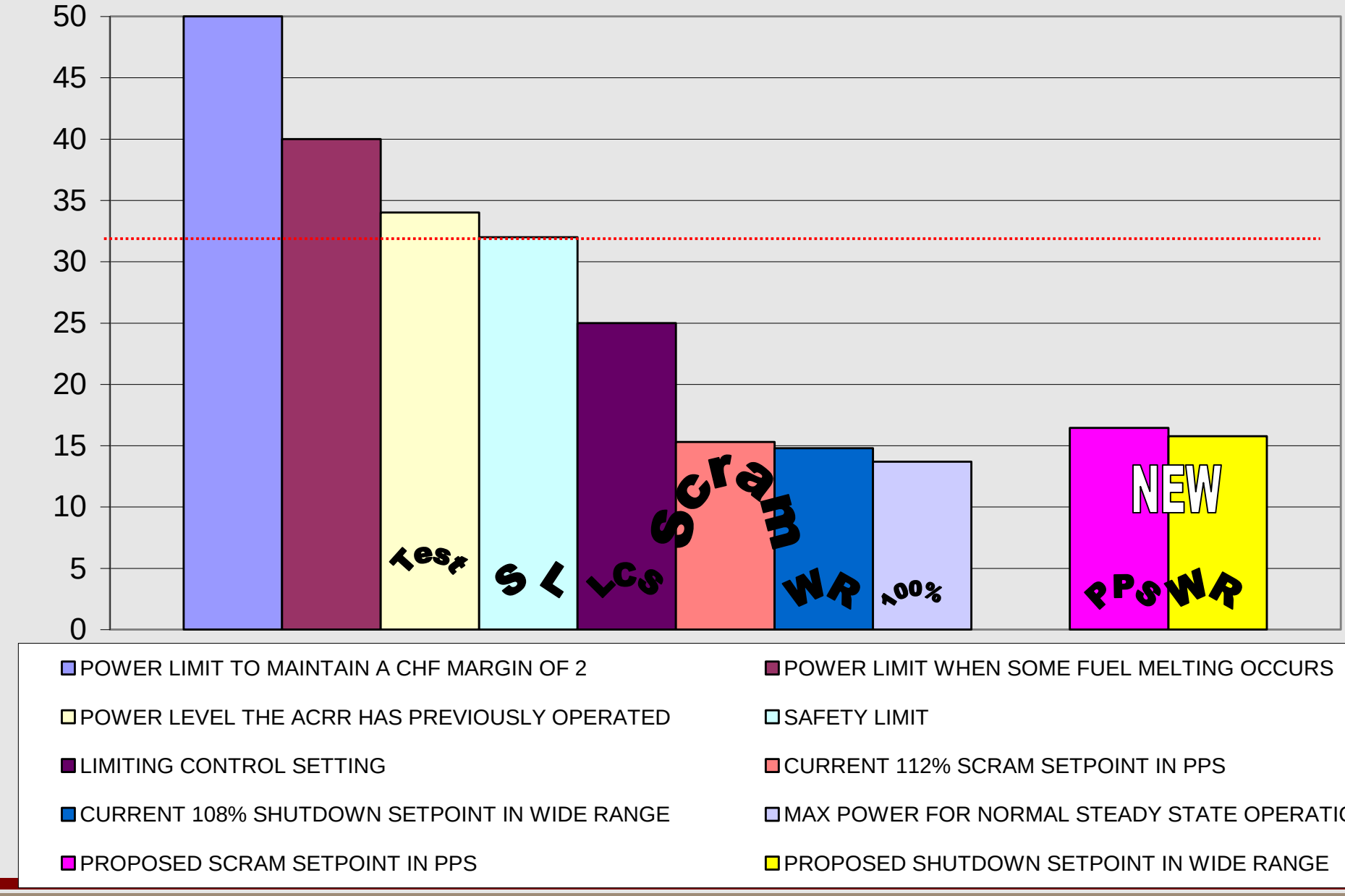
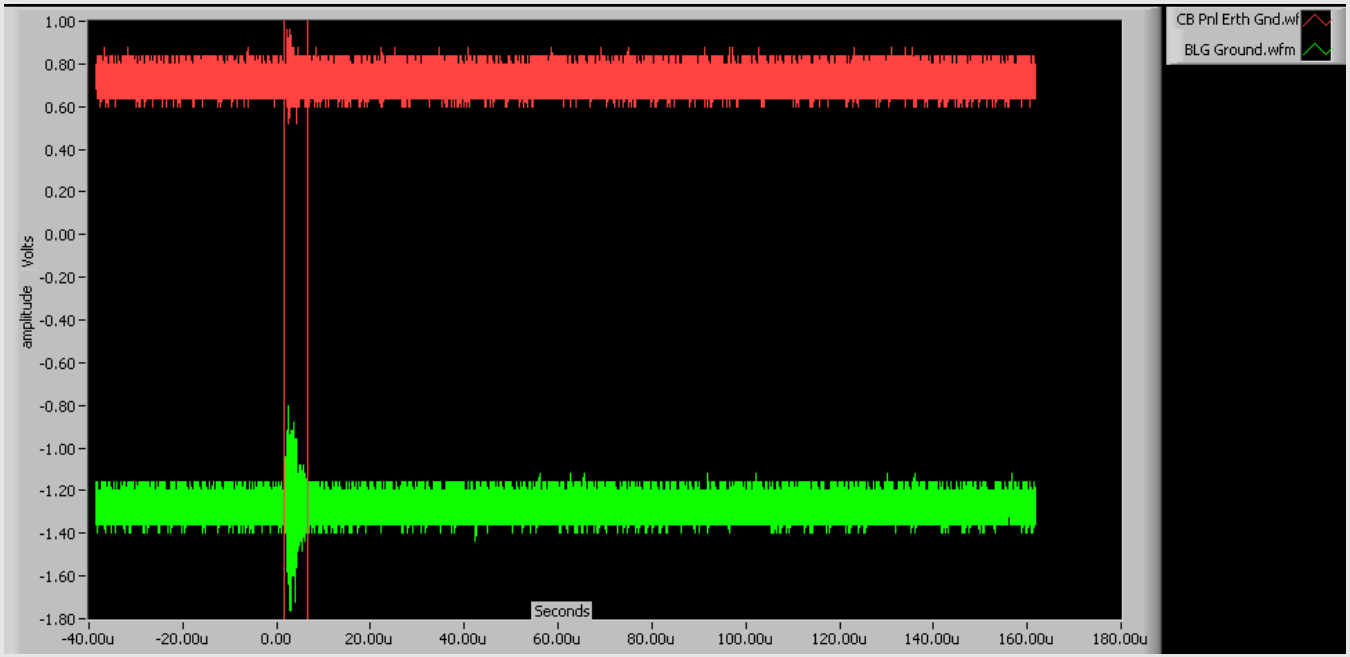
- This 28% noise test was repeatable, isolable and in the end successfully demonstrated techniques to attenuate this noise 70%
- This final attenuated noise of 19% supports a 20% margin between system operations and trip setpoints

POWER LEVEL COMPARISION



ACRR Noise fixed by improved ground



Noise reduction of 70%

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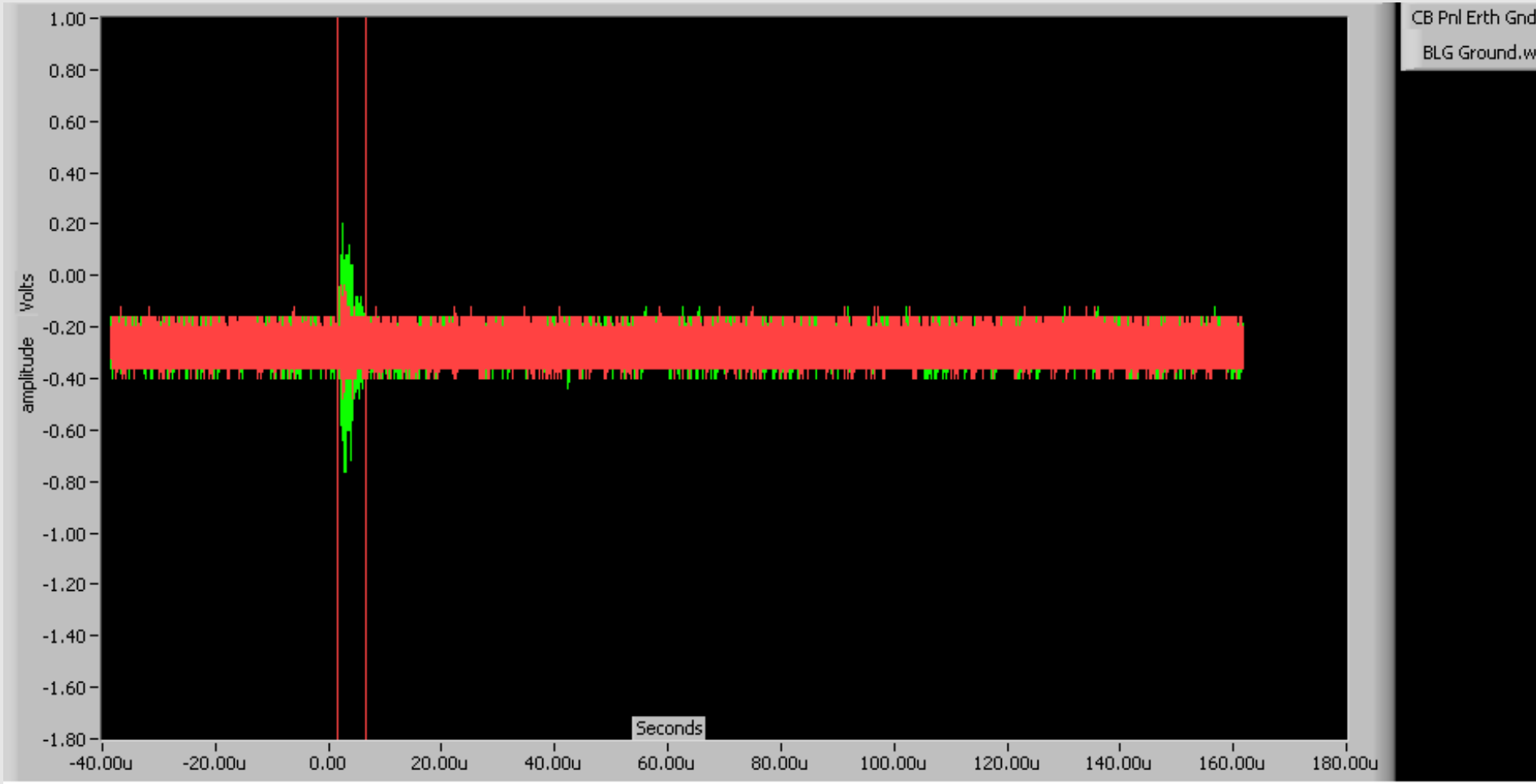
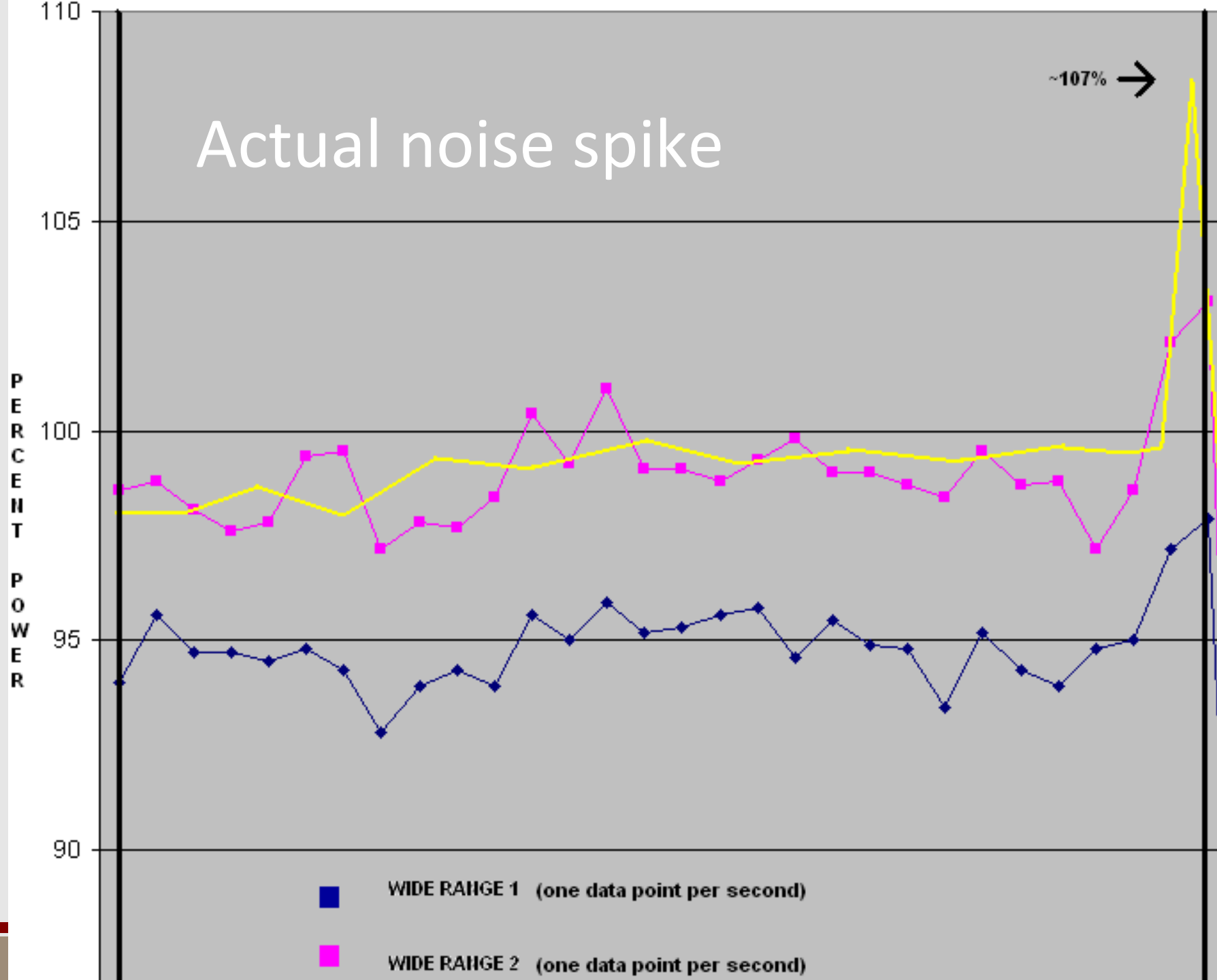



EXIT
Connected directly to building ground vice extension cord


FED FROM PANEL

Actual noise spike



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Noise needs:

- Interference source
- Means to couple the source to a susceptible system

Only 4 coupling methods exist

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- Conductive coupling (shared impedance)
- Magnetic field (shared inductance)
- Electric Field (shared capacitance)
- Electromagnetic wave

Grounding misconceptions

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- Signal return is ground
- Currents go to ground
- Current flows to path of least resistance

Ground conductors are not signal routing conductors

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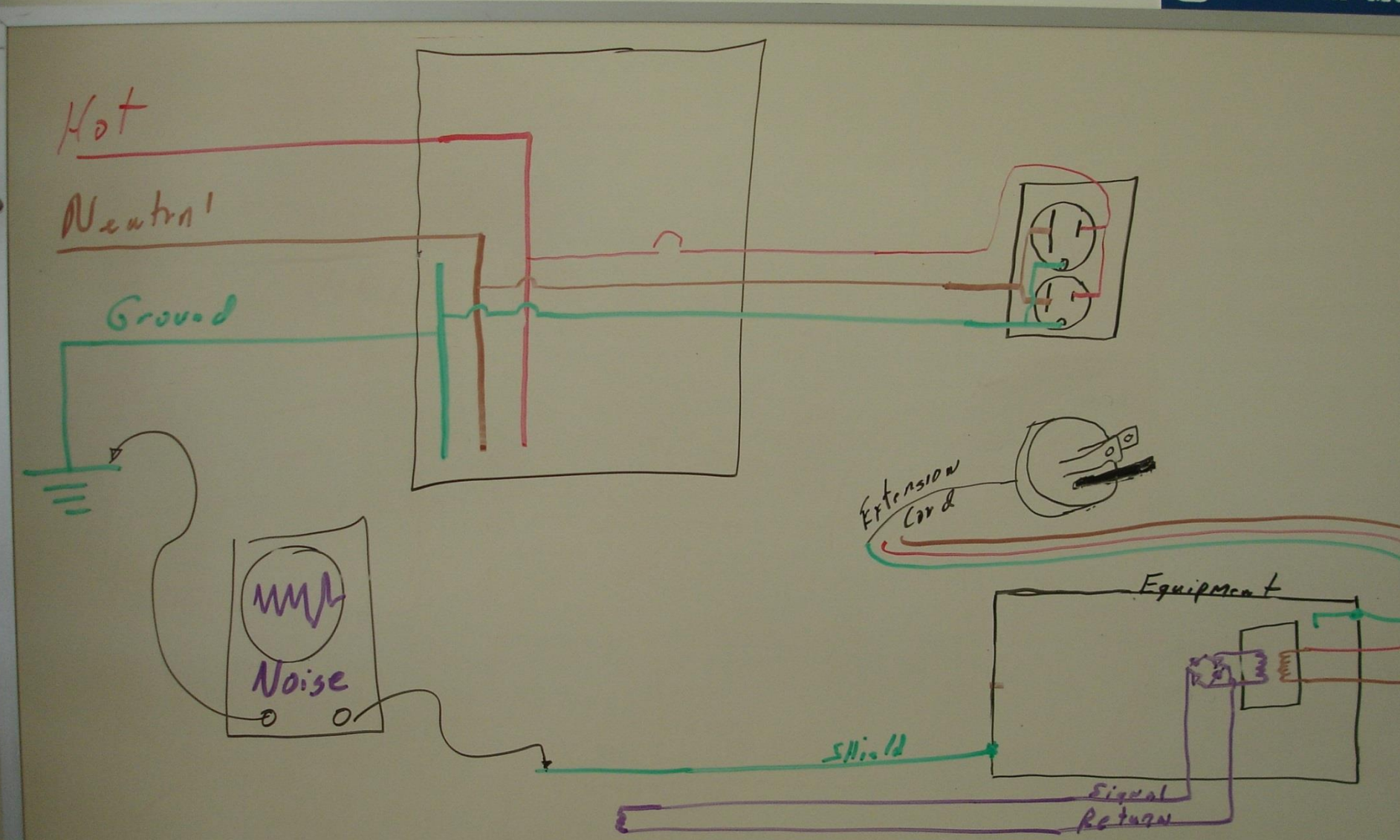
- Grounding has only two purposes:
  - Voltage reference
  - Safety
- Safety grounds reduce the voltage differences between exposed metal surfaces that could become energized.
- Voltage references that have different voltages will power a noise signal through connected equipment.


Hot
Neutral
Ground
Noise
Extension Cord
Equipment
Shield
Signal Return

To fix noise we need to know:

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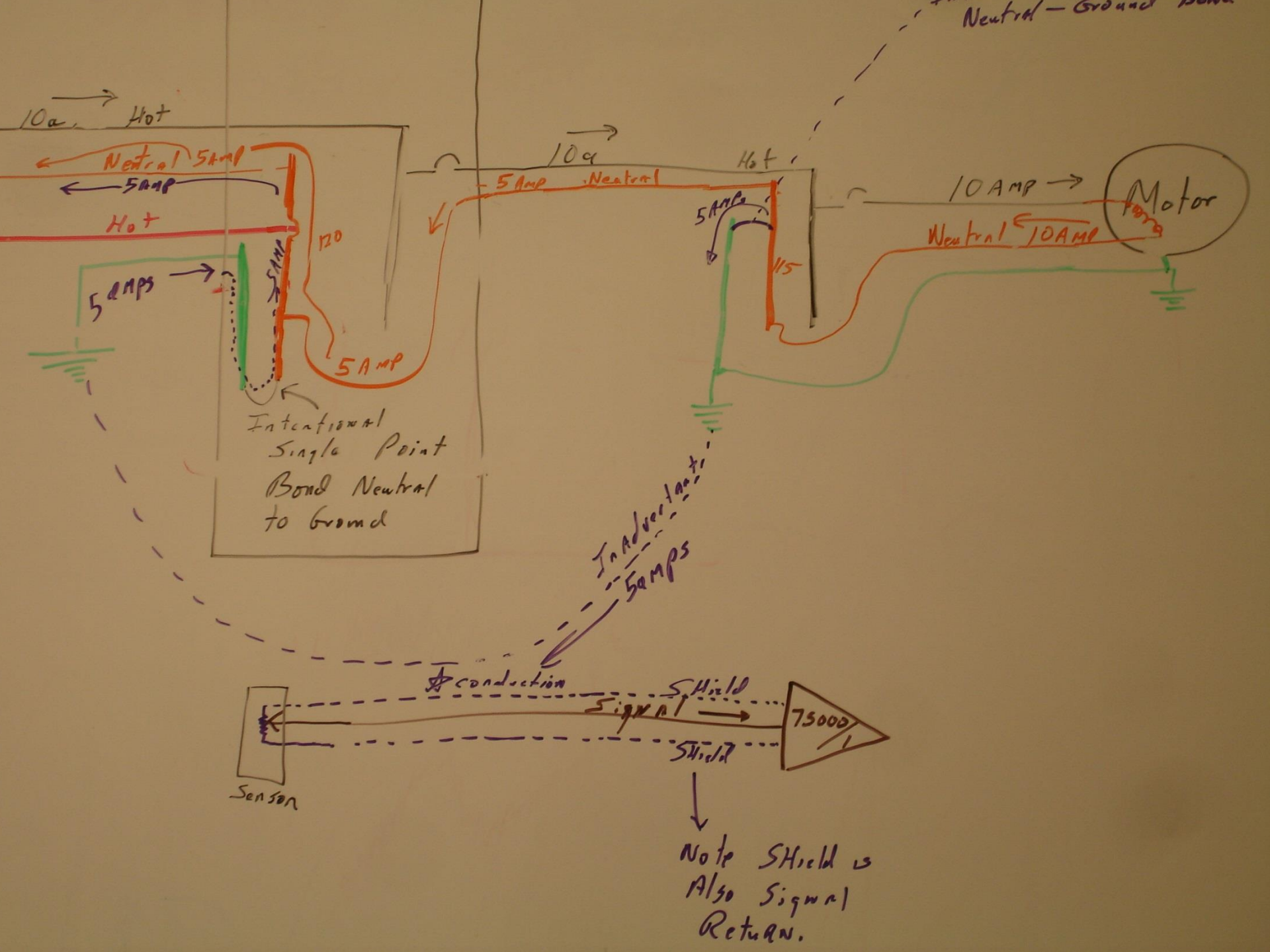
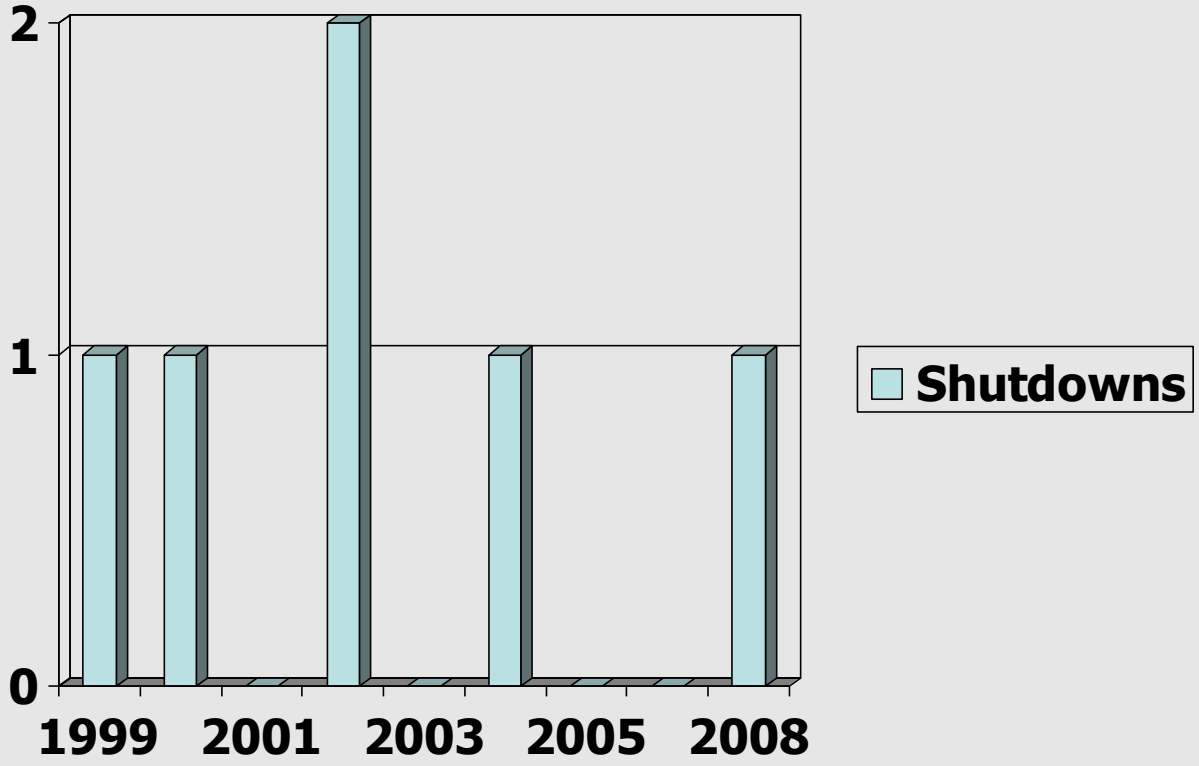
- Source of noise $
- Coupling method $
- Location of the coupling $


10a
Hot
Neutral 5Amp
5Amp
Hot
120
5 Amps
5Amp
5Amp
Intentional
Single Point
Bond Neutral
to Ground
10a
5Amp
Neutral
Hot
5Amp
115
10AMP
Motor
Neutral 10AMP
Inadvertant
5amps
conduction
Shield
Signal
Shield
75000
Sensor
Note Shield is
Also Signal
Return.

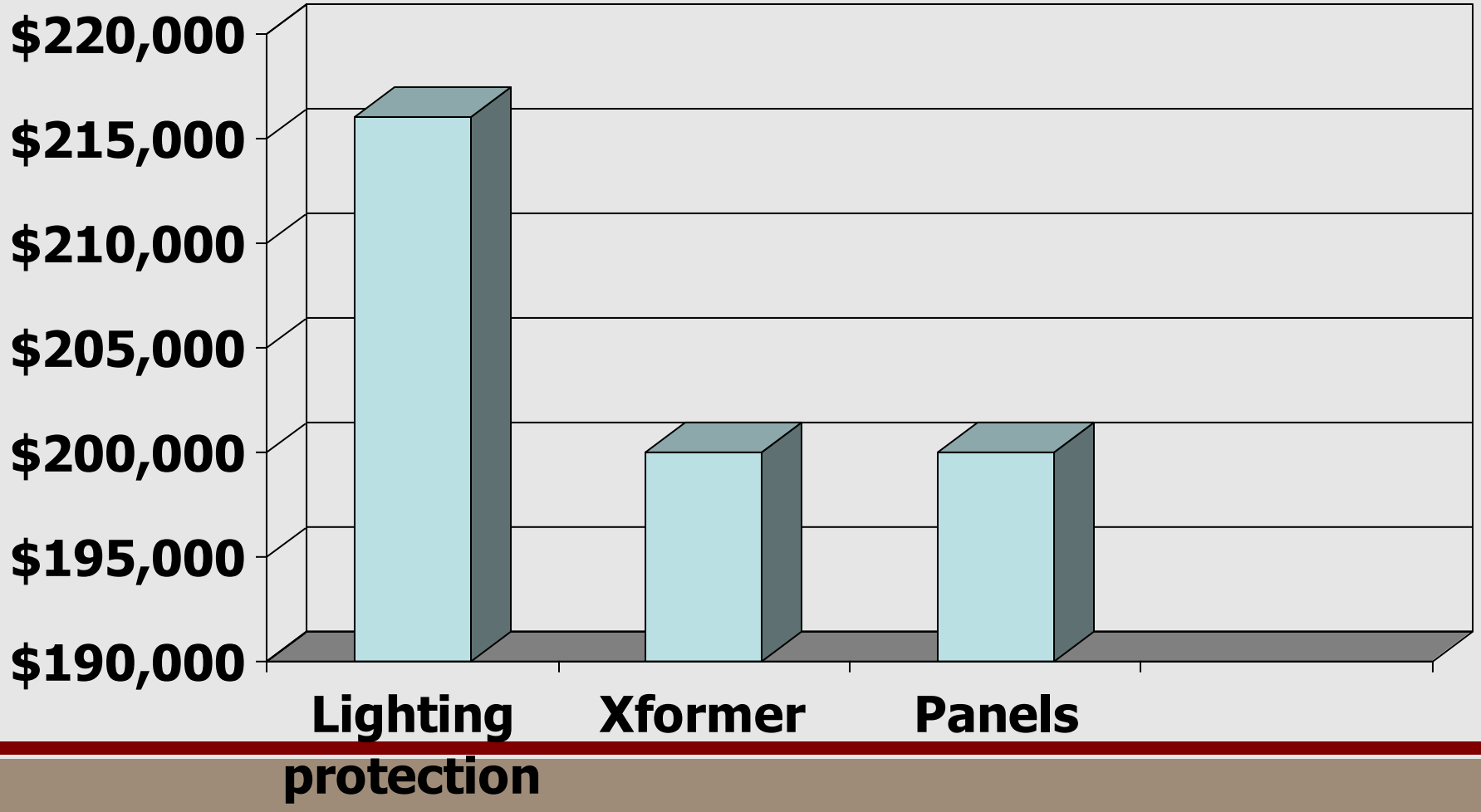
Unplanned Shutdowns from Noise

Date	Channel	Recorded Trip
12/6/99	WR #2	52.8%
5/3/00	WR #1	100.2%
2/21/02	WR #2	103.1%
5/31/02	WR #2	103.9%
2/27/04	WR #2	54%
8/12/08	WR #2	102.6%

ACRR Noisy channel shutdowns



Building investment
Near diminishing return point?



Submarine life cycle is limited by:

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- Hull material fatigue?
- Reactor life cycle?
- Shaft torque?
- Sonar?
- Turbines?
- Oxygen generator?

Submarine life cycle is limited by:

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- The Wiring.

ACRR has a huge safety margin.