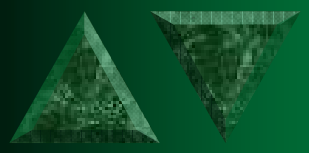
Why Should We Care

José A. Marrero

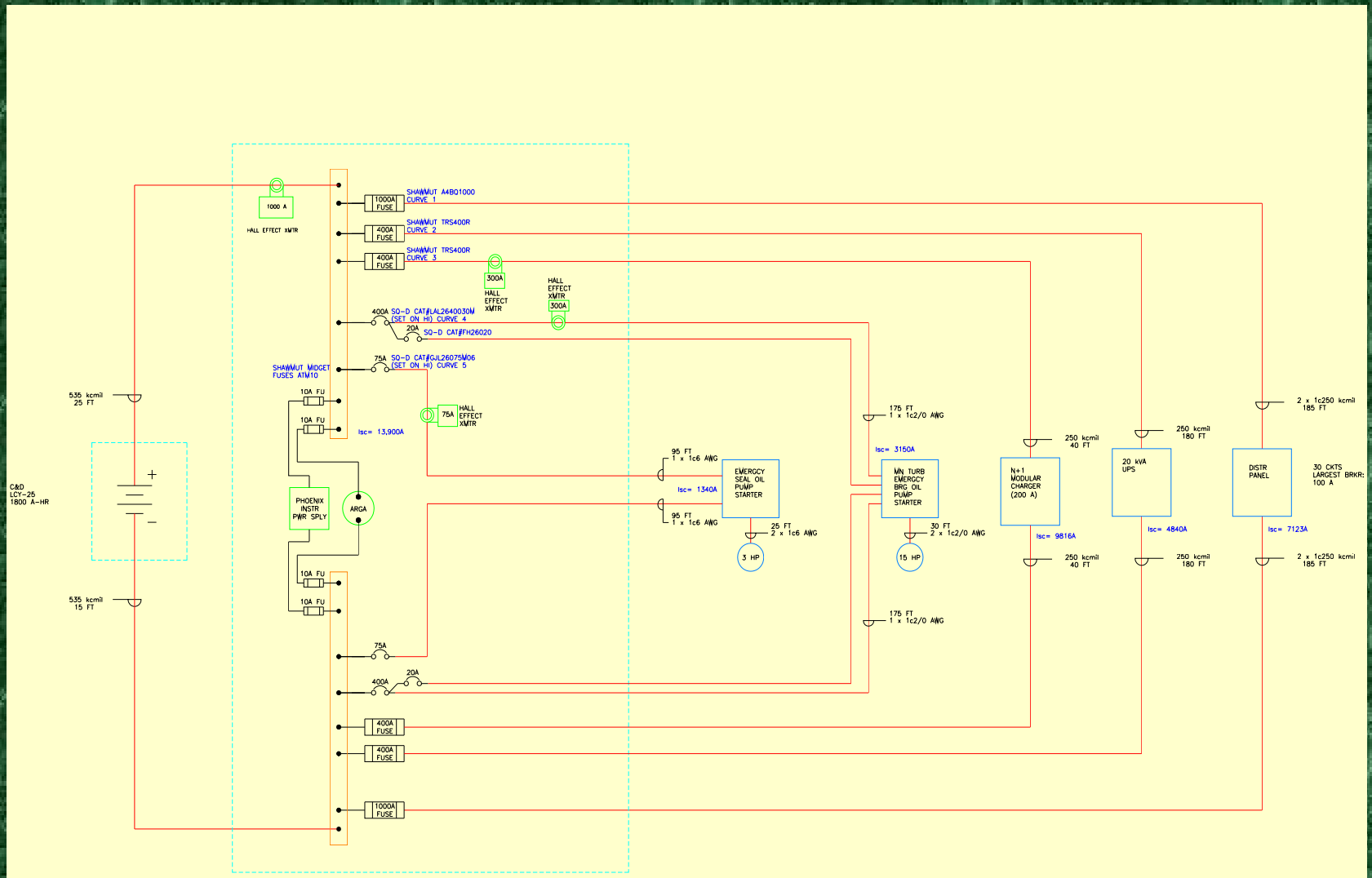
Ripple V/I/F versus Battery Damage for Lead-Acid Batteries



DC Systems Overview

- Higher profile and priority in past couple years
- "Last Line of Defense" in the event Station Service is lost
- Critical – Absolutely MUST Operate
- Three Major Components:
  - Battery Bank (energy storage)
  - Charging System
  - Distribution System
    - DC & AC via Inverters

DC System Overview



Charging System Requirements

- Keep the battery bank charged and ready for emergency use (Float/Stationary Service)
- Supply miscellaneous house loads without discharging the battery
  - Switchgear & controls
  - Indicator lights & metering
  - Periodic large DC loads (such as motor test runs, or during start-up/shut-down)
  - Inverters/ups (for Critical AC loads)

DC System Overview

- However, the DC power required for charging is normally generated by converting the available AC power to an acceptable form of DC power.
  - Charger / Rectifiers
- Similarly, the AC power required for critical AC load is normally obtained by converting the available DC power to an acceptable form of AC power.
  - Inverters/converters

What Is It

- What is Float/Stationary Service
  - In short when a battery connected to a DC bus with its potential just greater then its Open-Circuit Potential (OCP) is said to be in float service.
  - What this potential is dependent on the following battery parameter:
    - Temperature
    - Specific Gravity
    - Technology & Construction

What Is It

- As the bus potential fluctuates greater or lesser then the battery OCP the battery will charge or discharge accordingly
- As defined in float service we tend to place a preferential to potential and only concern ourselves with current indirectly
- So it is interesting & surprising that when we start to look into ripple and its effects on battery operation and life. We concentrate on current and very little is said about the potential

What Is It

- Battery in float service, current will either enter or exit the battery depending on weather the ratio (buss potential : OCP) is positive or negative.
- In other word, depending on the buss potential the energy/power flow of the buss will charge or discharge the battery
- This is true regardless

What Is It

- Regardless of what?
  - Regardless of the form the buss energy presents itself
  - The charge/discharge effect will present its self whether it come from the ac or dc
  - Since the battery will see both and the only difference in the battery's response between then is in the efficiency of the transfer

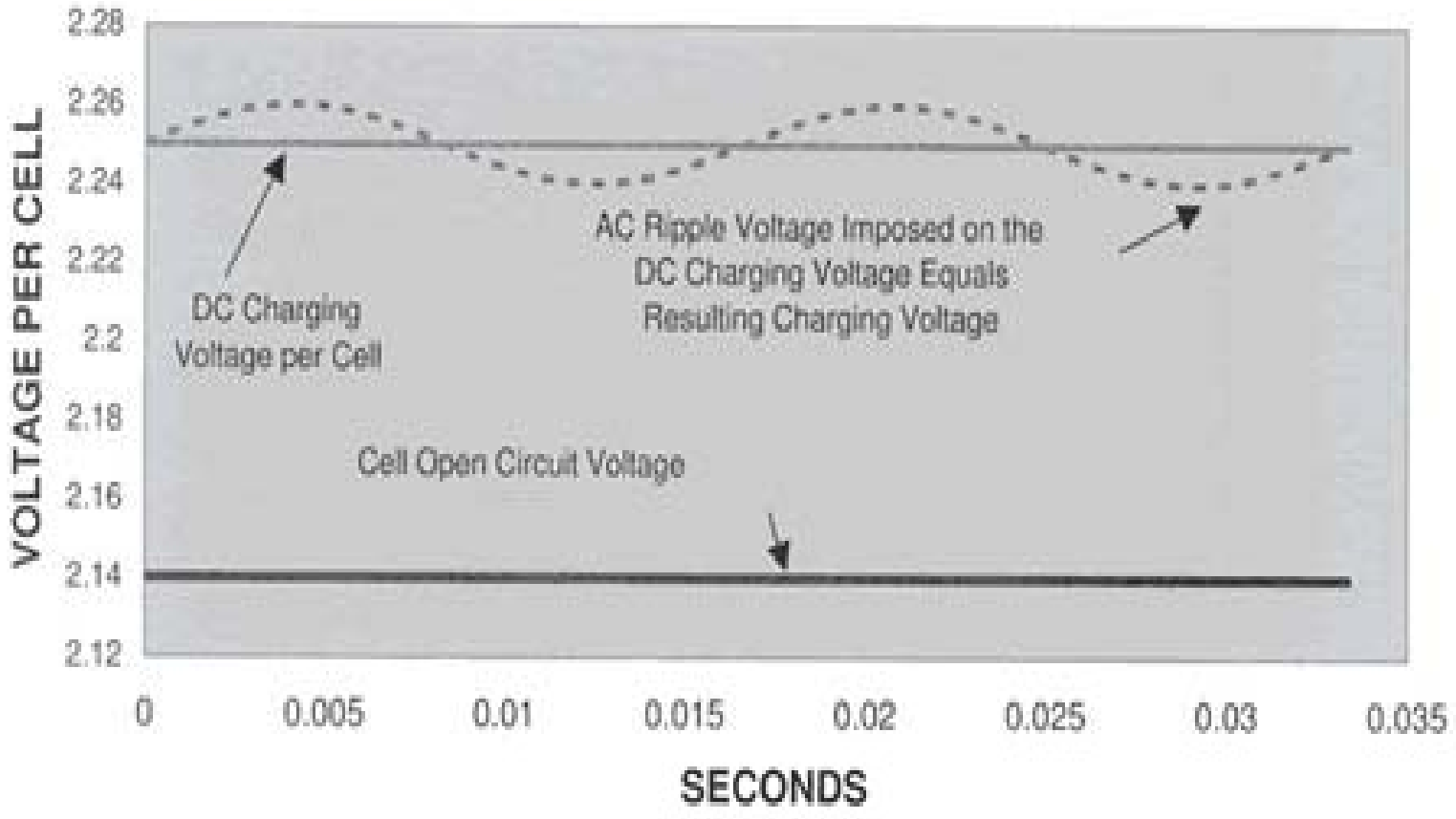
What Is It

	Min Battery Overcharge Voltage	Float Range
SG	25ºC	25ºC
1.200	127.4	129.0-134.3
1.225	128.9	130.2-135.6
1.250	130.4	132.6-138.0
1.280	132.2	133.8-139.2
1.300	133.4	135.0-140.4

Why

- Every conversion step produces residual AC ripple in the output voltage of the charging system.
- The frequency of the ripple will be a function of the charger/inverter design and will have less impact the higher the frequency.

Why
Ripple Voltage on Charger Output (individual cell)



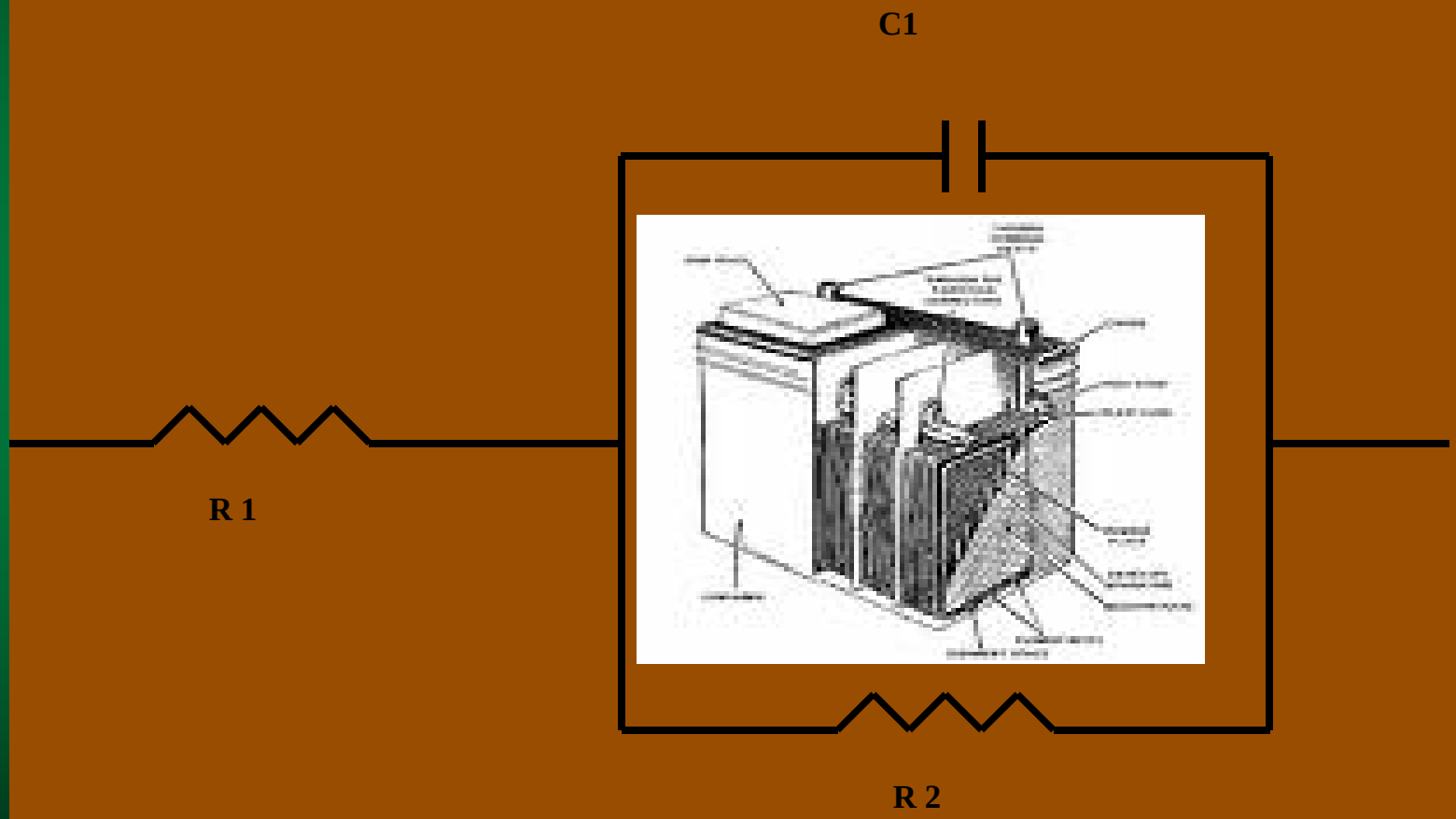
So What's the big deal with ripple?

- Simplified, ripple is (of concern to us) "medium-frequency" (<3 kHz) AC riding on top of the charger's DC output
- Ripple can causes internal heat generation and have a major impact on service life.
- Ripple can causes accelerated decay of batteries, as it effectively charges and discharges cells each cycle as they respond to the voltage fluctuation
- Plates deteriorate, and the resulting sediment in the bottom of the jar can short them together

Why

- **Cell Model Very simplistic version**
  - R_{metal} is a very low resistance comprised of strap, post, plate & electrolyte resistances
  - $R_{electrolyte}$ is known as charge transfer resistance or contact resistance between plate and electrolyte
  - $R_{leakage}$ is a very high resistance that causes self-discharge
  - C is the battery's inherent capacitance which is about 1.5 farads per 100 AH capacity

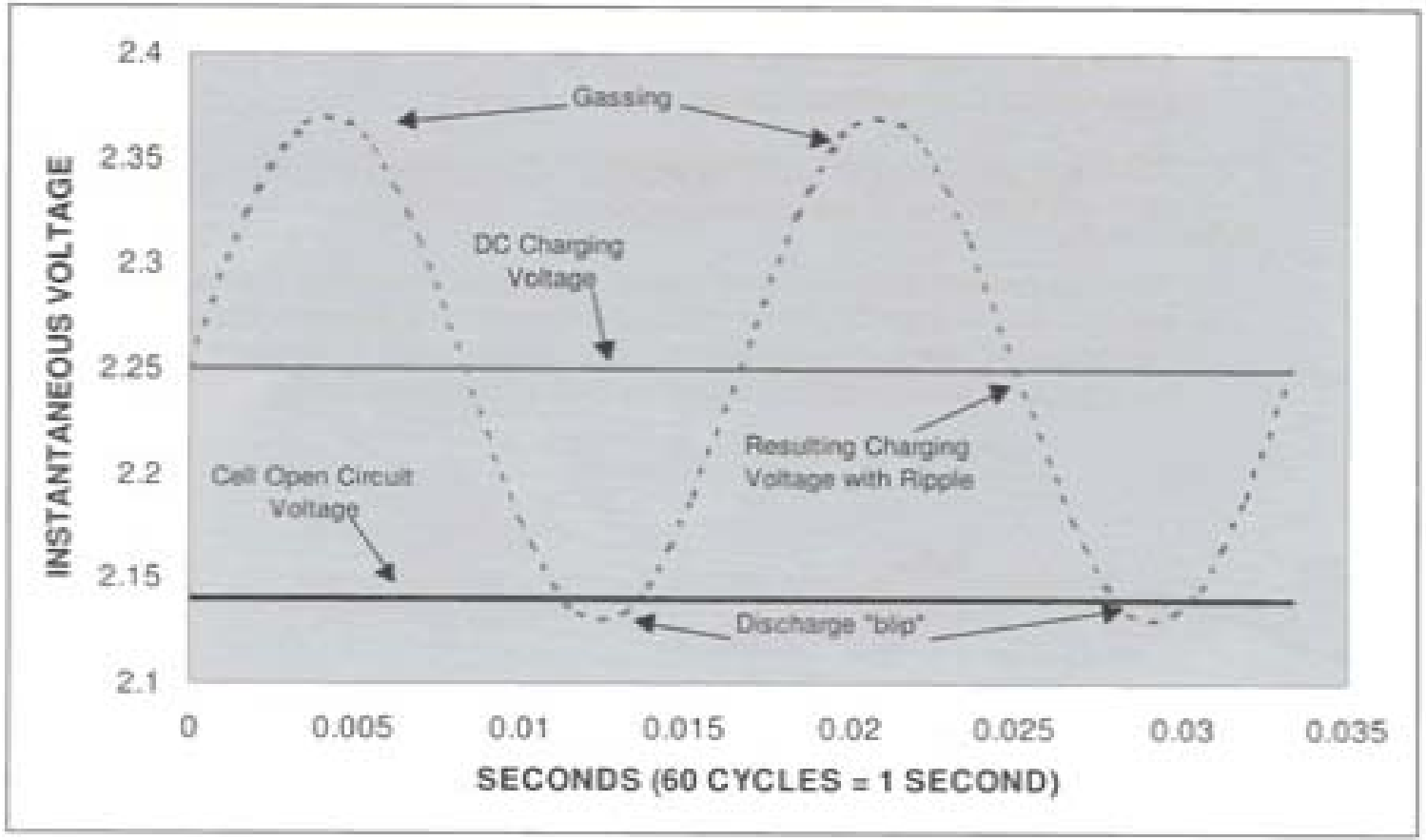
Why



Why

- So in essence we have a resonant cavity
- In reality we multiple cavity whose response spectrum somewhat alien, to make a battery.
- The magnitude and frequencies of the energies it sees determine its response.
  - Charge/discharge (normal/expected)
  - Heating
  - High frequency shallow cycling

Cell discharging each time Ripple Voltage drops below Open-Circuit individual cell voltage



Ripple

(The abridged version according to Jose)

- Ripple
  - The ac energy superimposed on the dc buss, regardless of its source
  - Which is either added to or subtracted from the dc energy being supplied to the dc buss
  - But Ripple 'Energy'
    - Ripple energy is actually the **vector** product of voltage and current, so the inherent phase separation angle decreases the ripple energy actually transferred to the battery even further.

Ripple

(The abridged version according to Jose)

- Ripple 'Energy'

  Has several components and in order for them to cause us problems they must meet the following

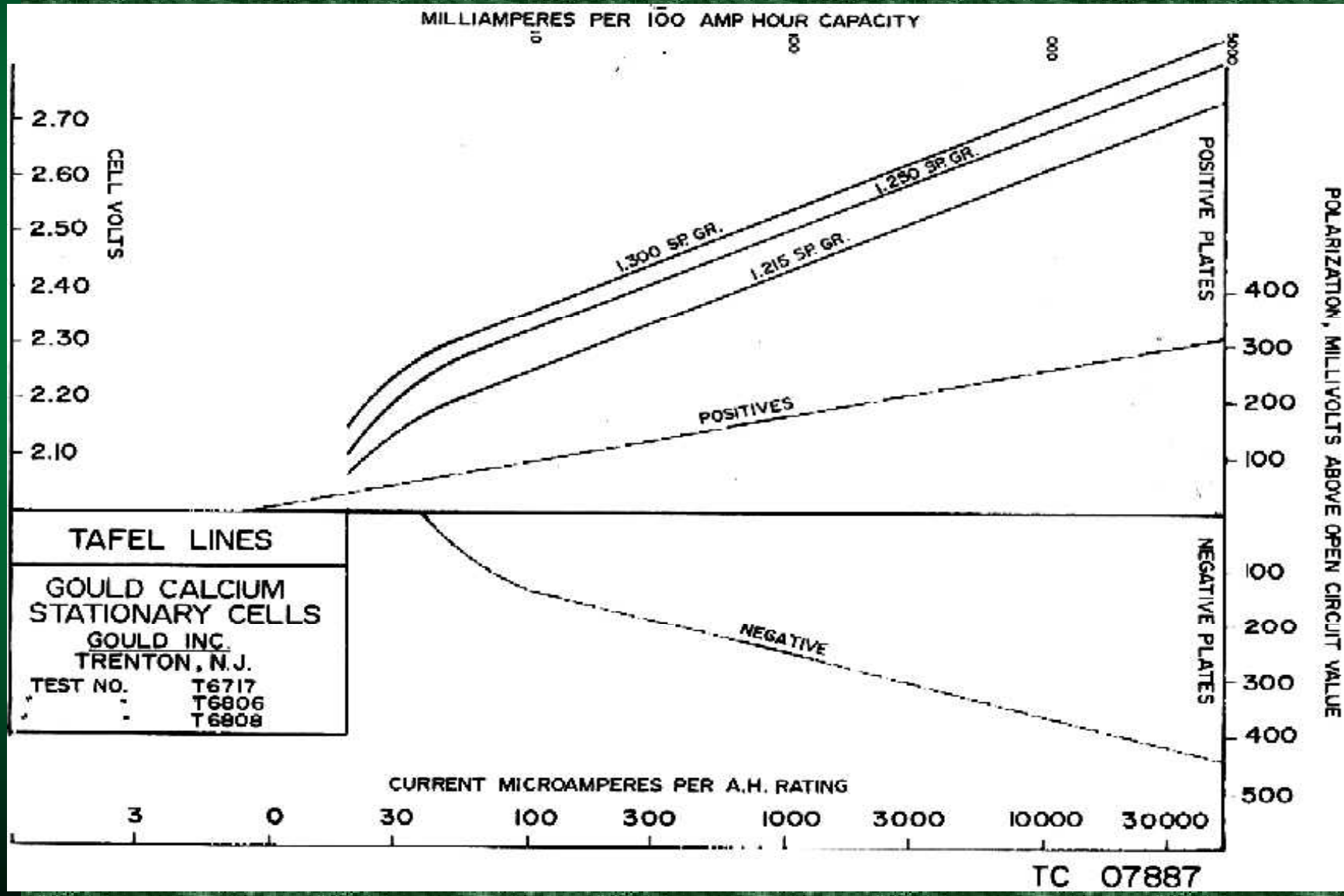
  - Potential ($R_{p/v}$)
    - Must be of sufficient magnitude to drive the battery below its Open Circuit Potential (OCP)
    - Remember that OPC is dependent on the battery's specific gravity and operating temperature

Ripple

(The abridged version according to Jose)

- Current (R_I)
  - Must have sufficient magnitude to over come the float charge current
- As we know, but have not discussed both R_I & R_P have a frequency component

Typical Tafel Curve



Ripple

(The abridged version according to Jose)

There is a more detrimental effect on Calcium cells verses Antimony cells. This is due to the Antimony cells float current is 5-10 time that of Calcium cells as they age.

The effects should be the similar for low Antimony cells especially during the first half of their life.

@ 25^{0}C		0-40^{0}C
SG	OCP	mV/^{0}C
1.200	2.054	0.30
1.225	2.067	0.27
1.250	2.098	0.24
1.280	2.125	0.20
1.300	2.148	0.18

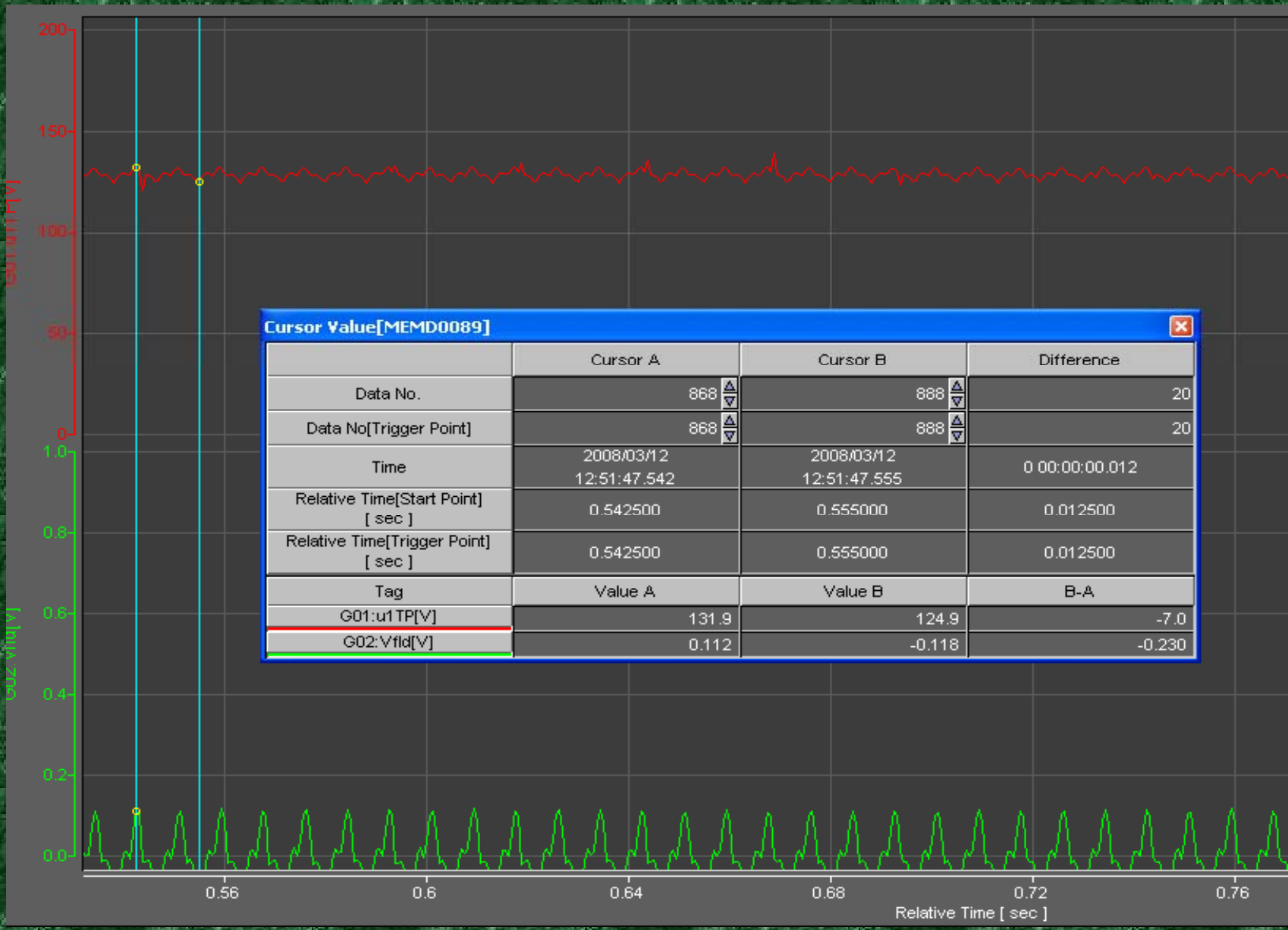
Mostly from Vinal, Storage Battery 4th Ed.

What we still use

Ferroresonant Charger

Early SCR Charger

Actual Charger Output



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	Cursor A	Cursor B	Difference
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Data No[Trigger Point]	868	888	20
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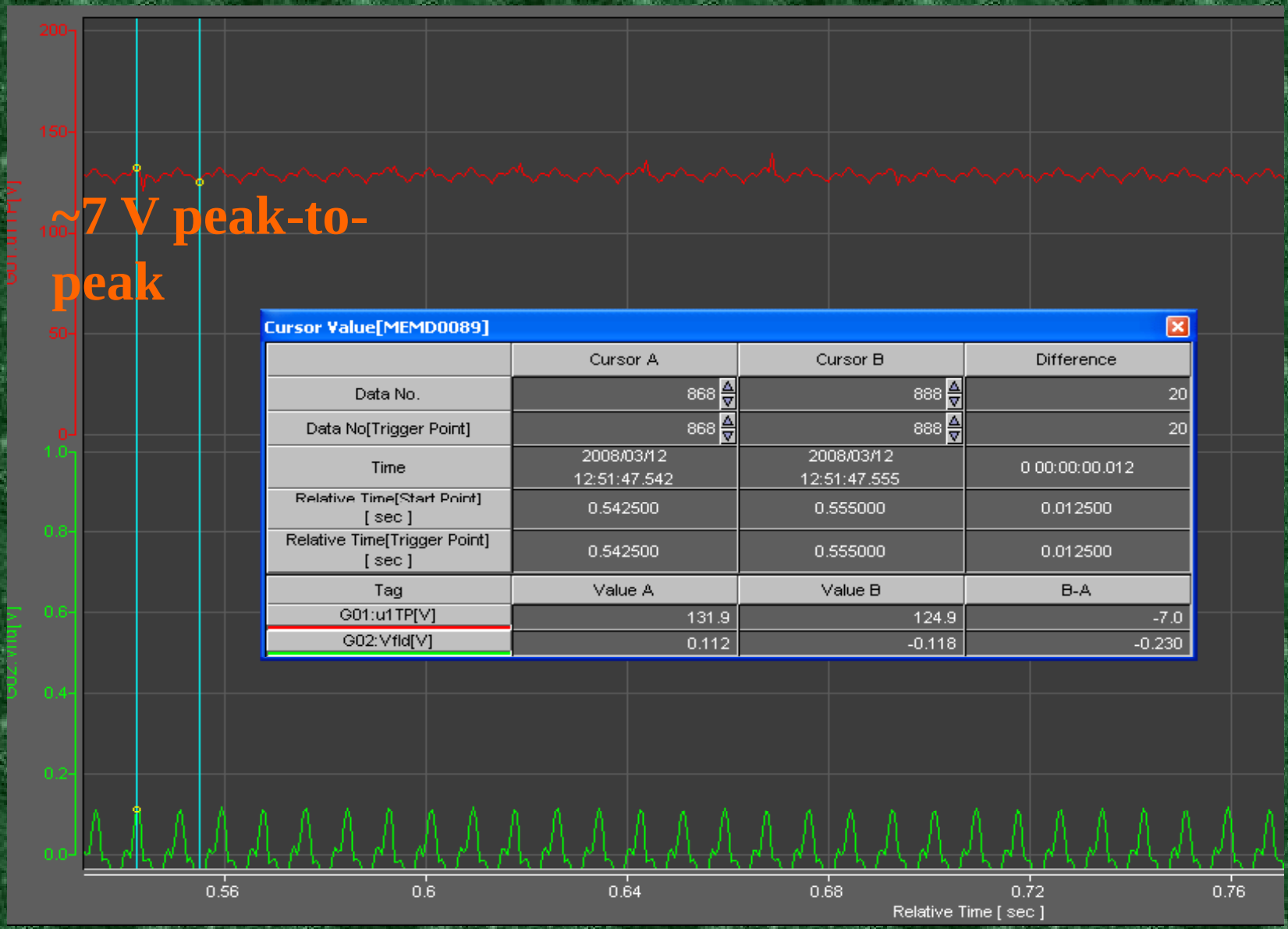
Relative Time[Start Point] [sec]	0.542500	0.555000	0.012500
Relative Time[Trigger Point] [sec]	0.542500	0.555000	0.012500
Tag	**Value A**	**Value B**	**B-A**
G01:u1TP[V]	131.9	124.9	-7.0
G02:Vfld[V]	0.112	-0.118	-0.230

Actual Charger Output



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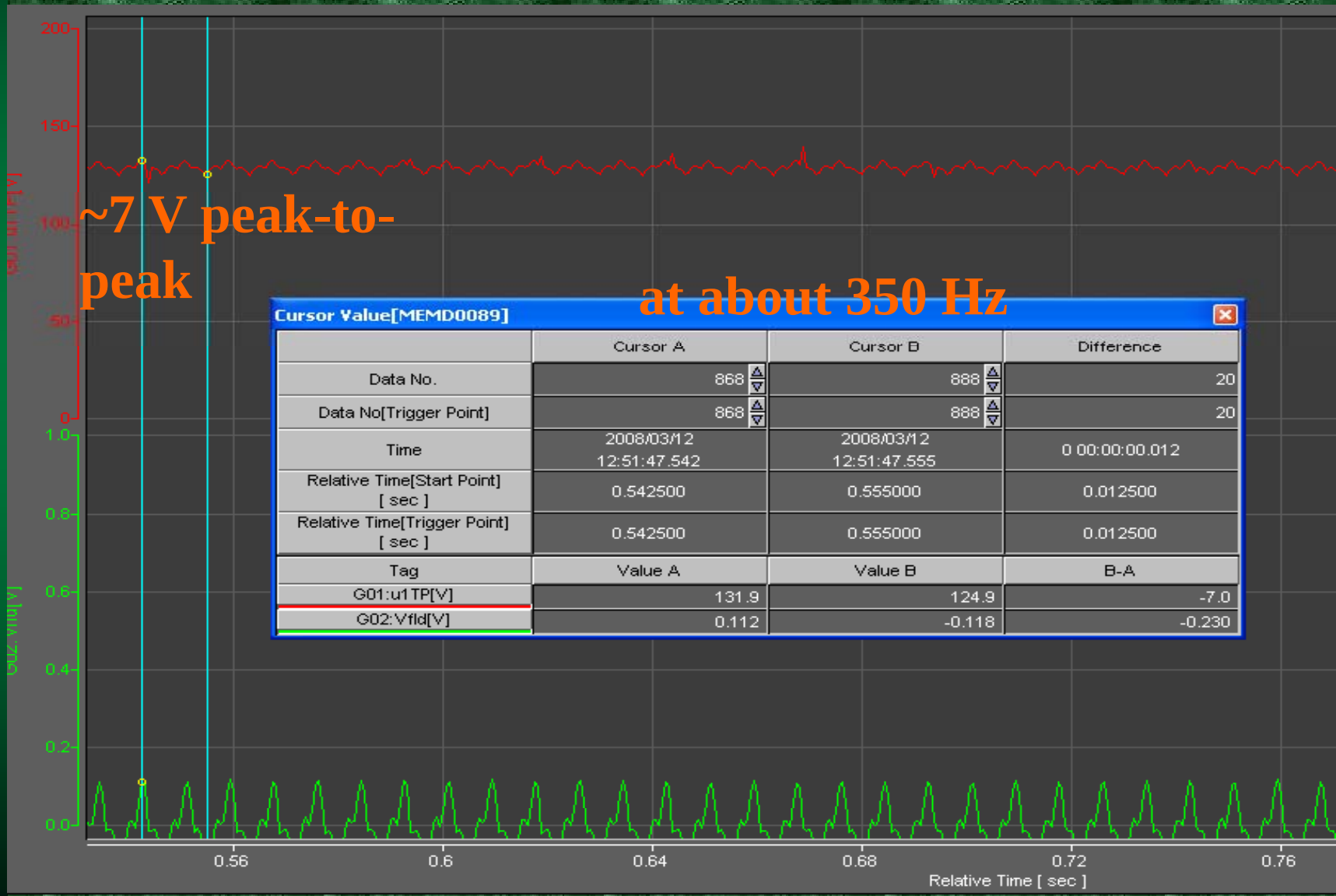

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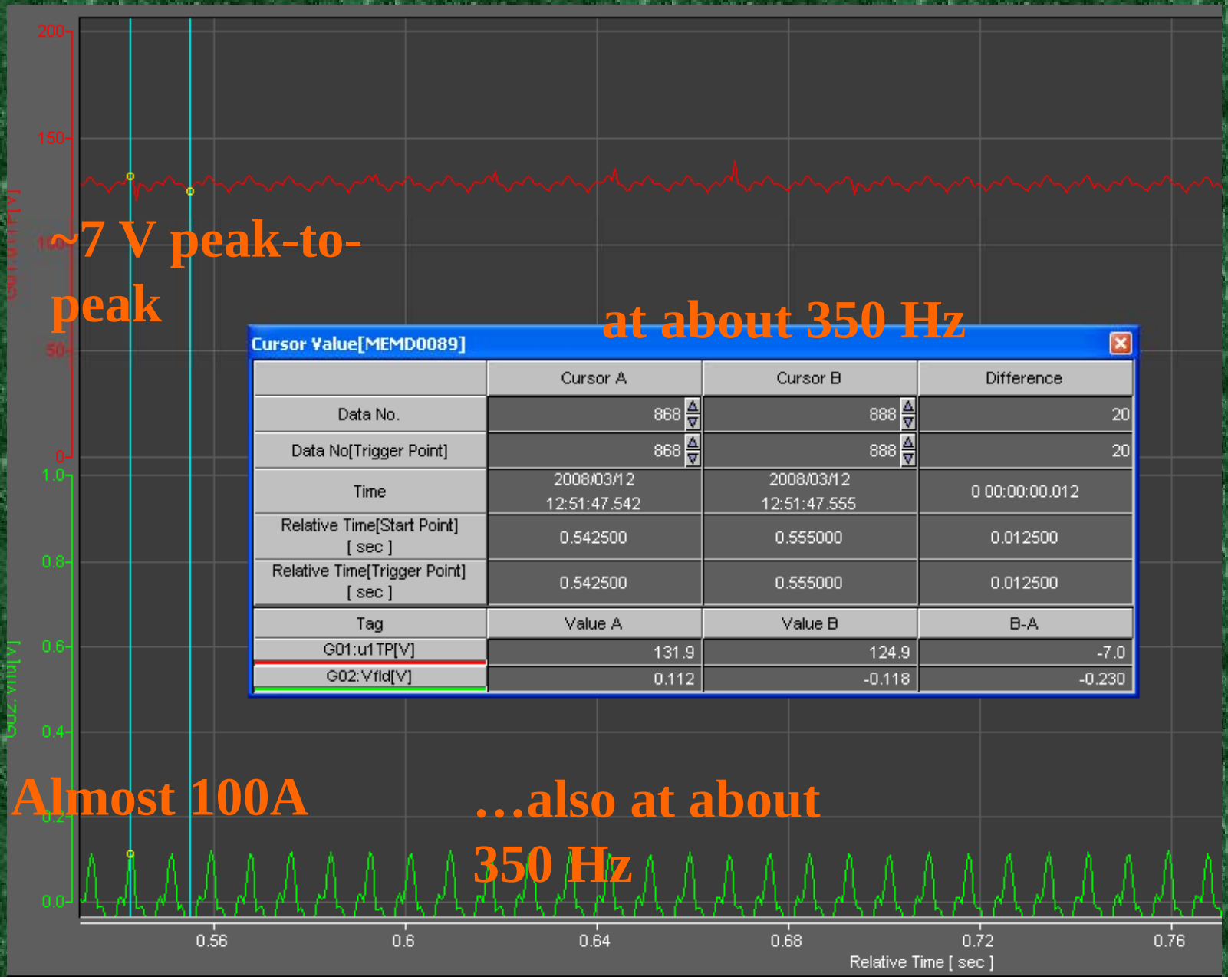

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Sampling

Measured Battery Bank Voltage and Amp 8-11-11

Station	Volts (mVAC)	Amps (AAC)	Freq. (Hz)	Battery Charger Type
Unit 1A	94	4.3	159	12 pulse
Unit 1B	94	1.7	0	12 pulse
Unit 2A	71	2.3	0	12 pulse
Unit 2B	53	1.6	0	12 pulse
Unit 3A	45.3	1.6	0	12 pulse
Unit 3B	55	0.6	0	12 pulse
Unit 4A	58	2.3	3.9	12 pulse
Unit 4B	48	1.5	0	12 pulse

TWIP	Volts (mVAC)	Amps (AAC)	Freq. (Hz)	Battery Charger Type
Unit 1	240	3.5	60	12 pulse
Unit 2	134	1.7	3.5	12 pulse
Unit 3	175	1.5	0	12 pulse
Unit 4	548	1.3	60	12 pulse

DCS	Volts (mVAC)	Amps (AAC)	Freq. (Hz)	Battery Charger Type
Unit 1	415	19.1	120	6 pulse
Unit 2	489	21.2	120	6 pulse
Unit 3	348	11.6	120	6 pulse
Unit 4	459	19.6	120	6 pulse

A Victim of Ripple

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Ripple
Why Do I Care

- Not sure it you do
- For us (SCG) two year ago, we have had to replace (unscheduled) 18 batteries. Their failures all do in part or solely to rectifier malfunction (Ripple)
- At a cost of some 2 million USA dollars unplanned for, not a tremendous amount but when you consider that all the batteries came from four plant sites it may change your perception

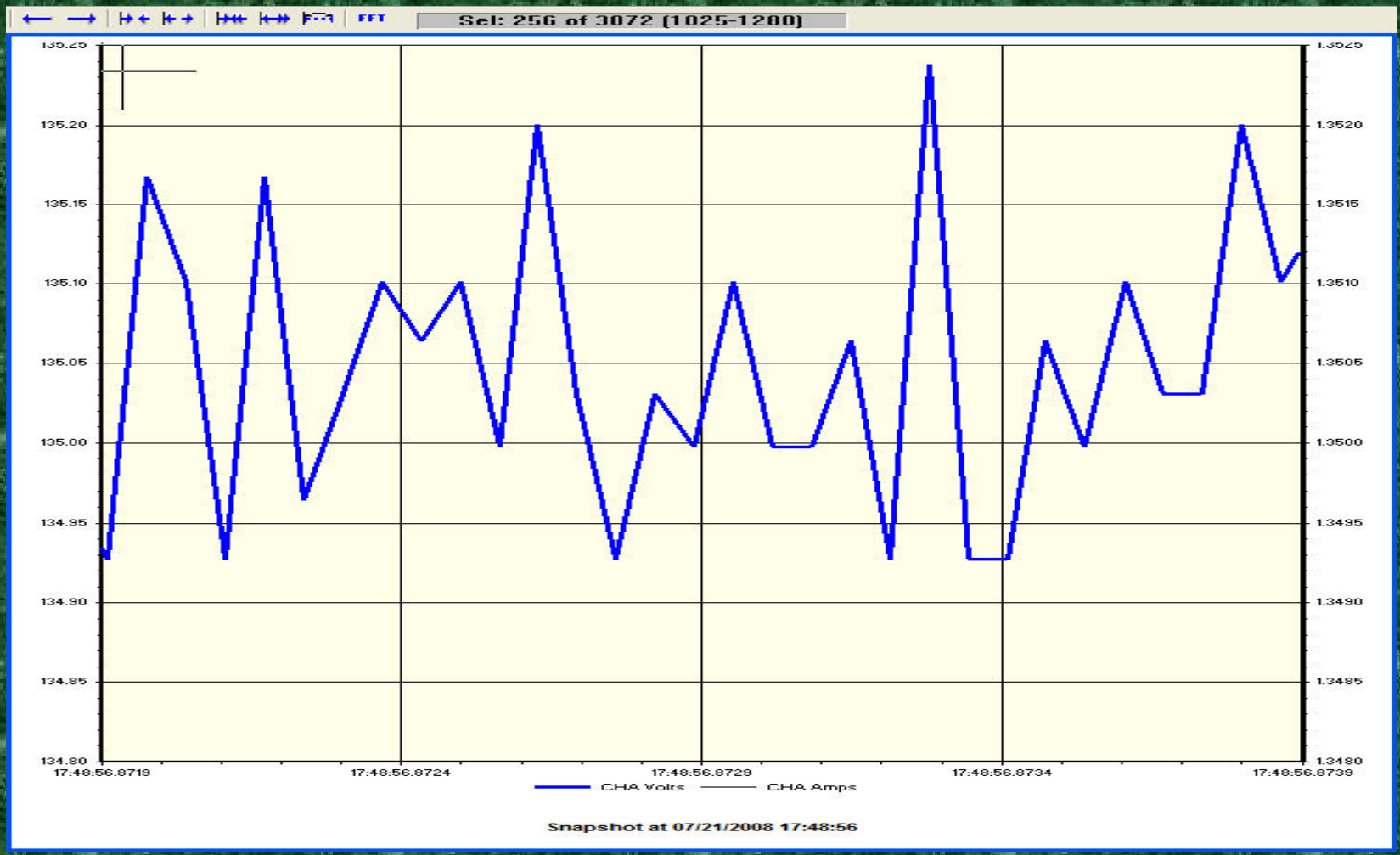
Ripple
Why Do I Care

- What we did and are doing
- We determine a thresholds for ripple
  - Warning
    - R_P > 1.0V for 60 cell string of 1.225 spgr
    - R_I > 10 A for 60 cell string of 1.225 spgr
  - Action
    - R_P > 5.0V for 60 cell string of 1.225 spgr
    - R_I > 10 A for 60 cell string of 1.225 spgr

Ripple
Why Do I Care

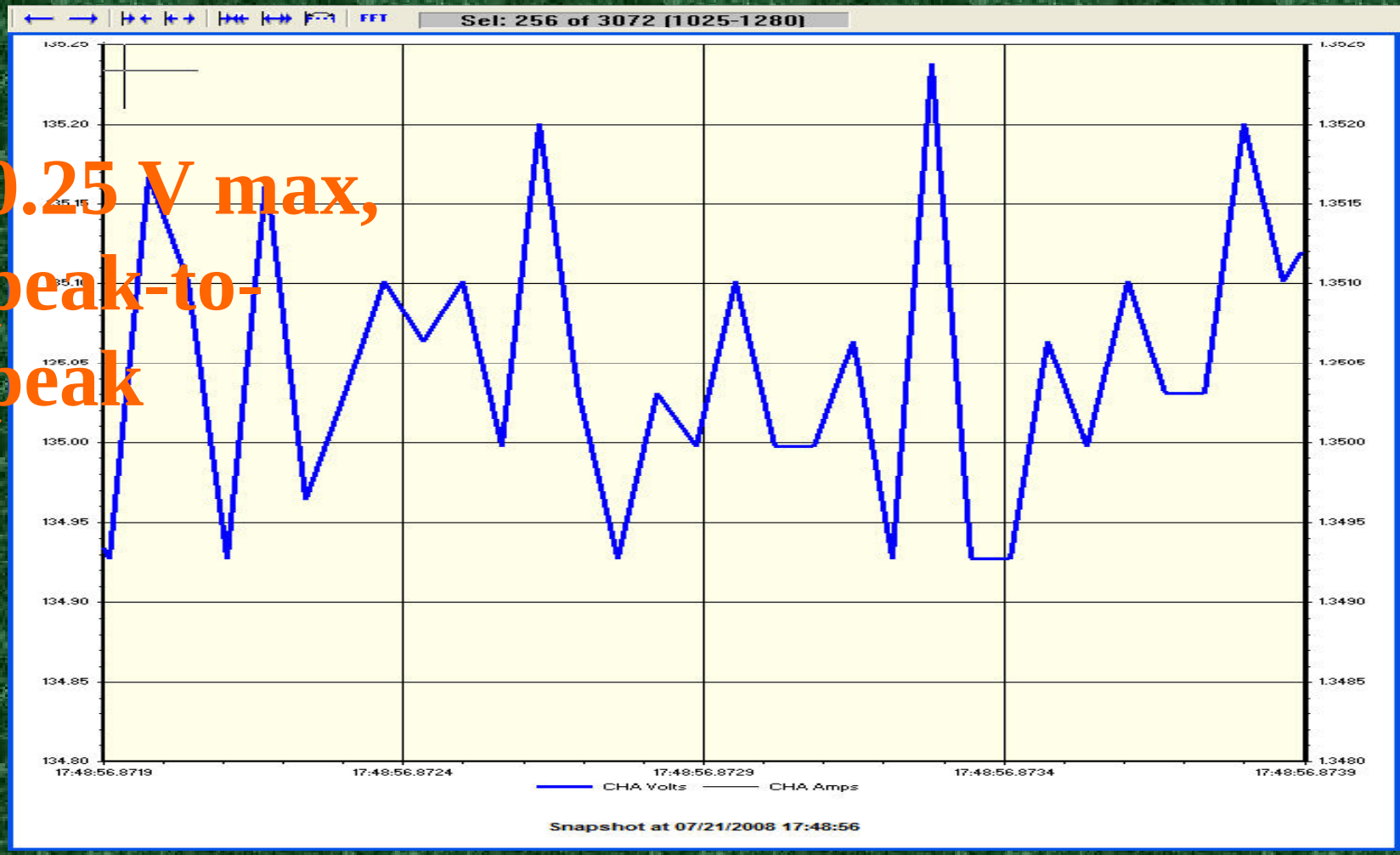
- Changed our Specs. To mandate a maximum RE of 1 W, with frequency up to 3KHz.
- Monitor Additional Battery Parameters
  - R_P & R_I monthly/weekly (depending on site PMs)
  - Frequency annually

IGBT Output Voltage

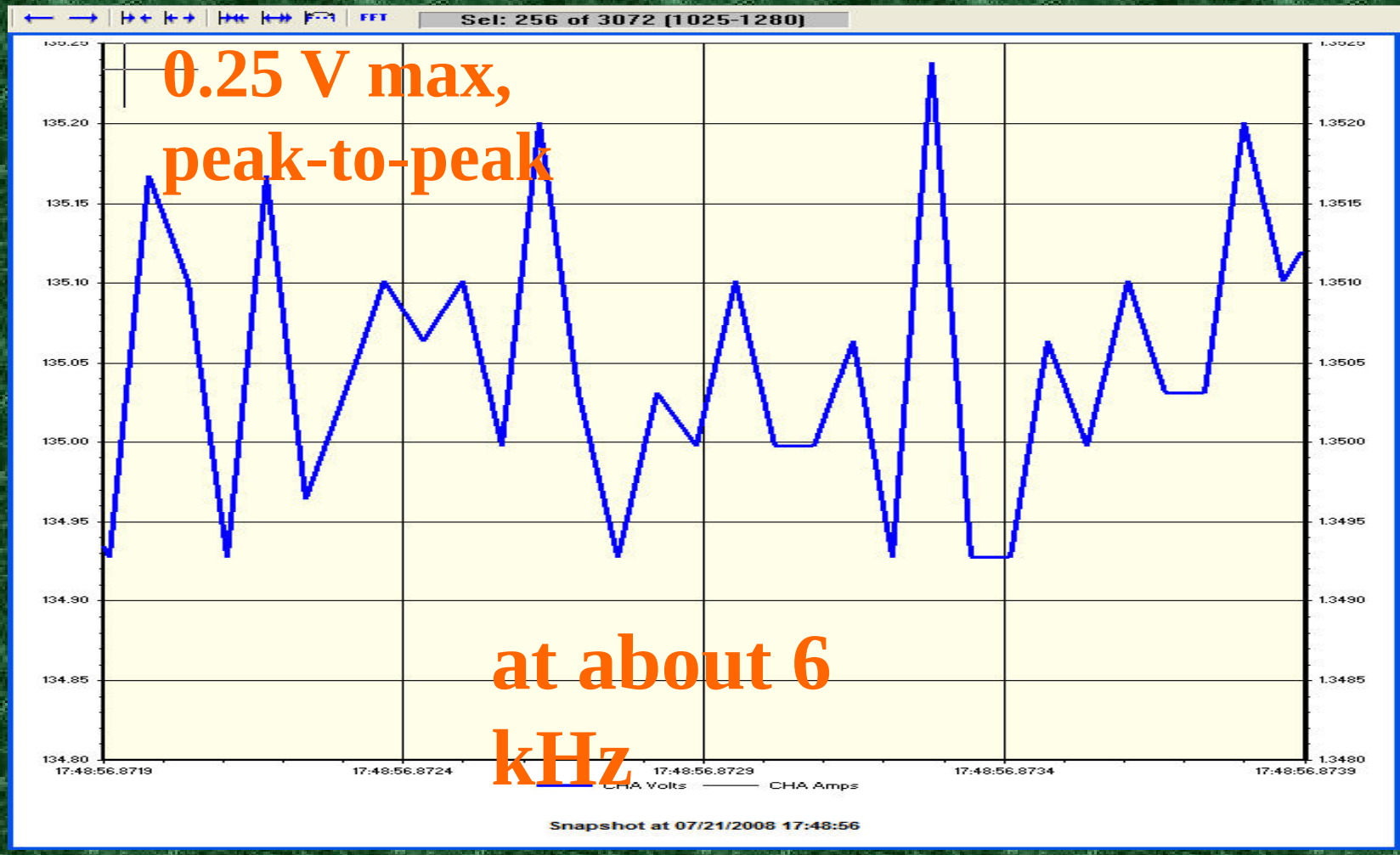


IGBT Output Voltage

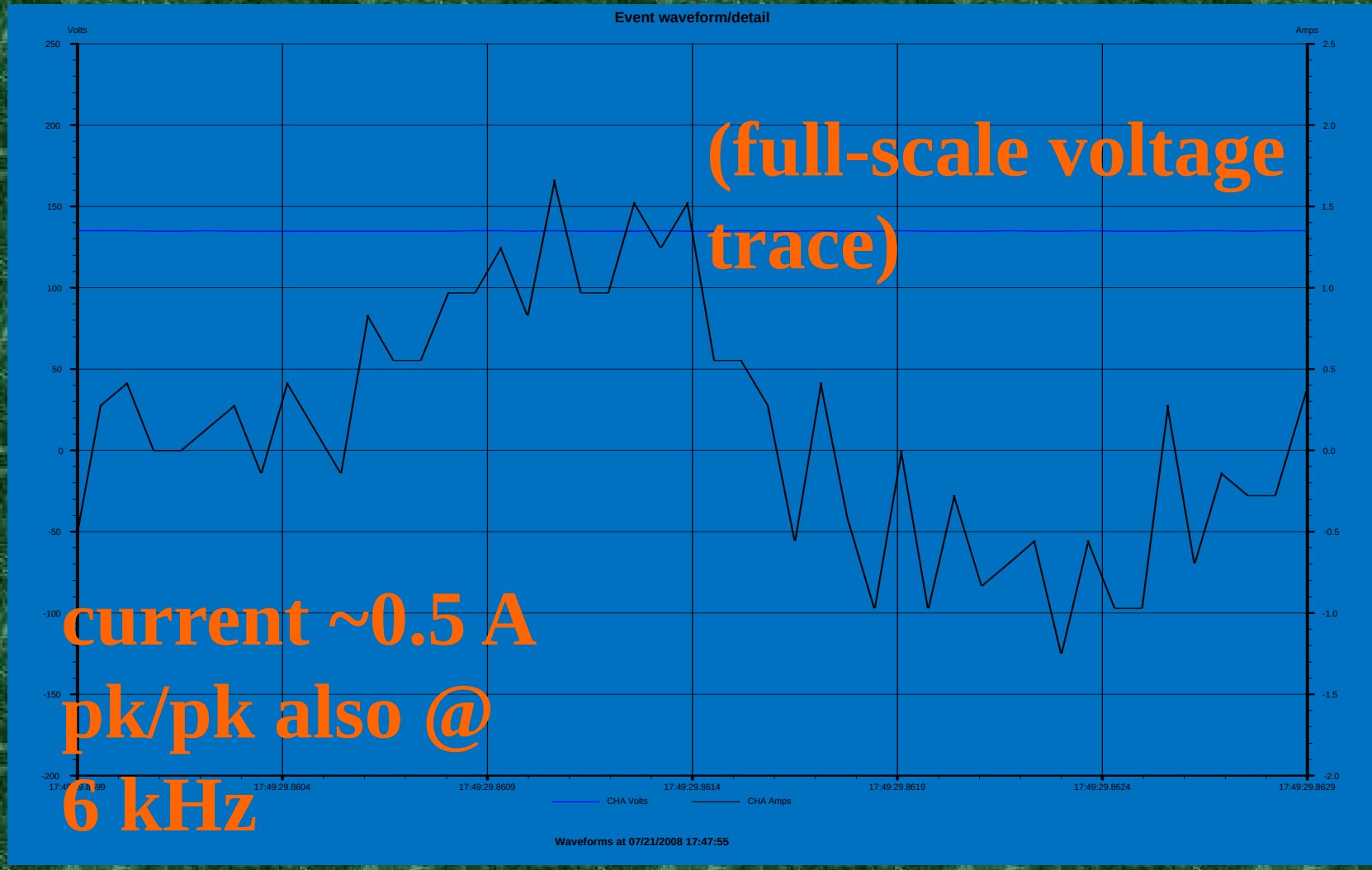
0.25 V max, peak-to-peak



IGBT Output Voltage



IGBT Output Current



Output Waveforms

- So yes, technically there still is some ripple, but the battery never sees it or responds to it because
  - Voltage never drops below the battery bank's 132V
  - Frequency of 6 kHz is far beyond the physical limit of the cells' response time
- Ripple energy is actually the **vector** product of voltage and current, so the inherent phase separation angle decreases the ripple energy actually transferred to the battery even further.

Charging & Ripple Currents