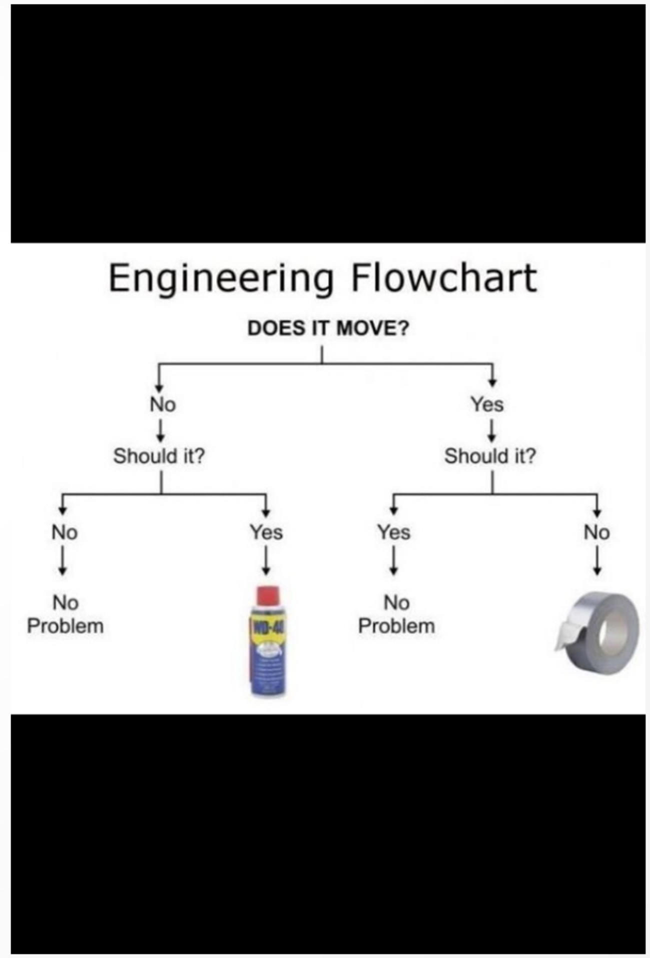
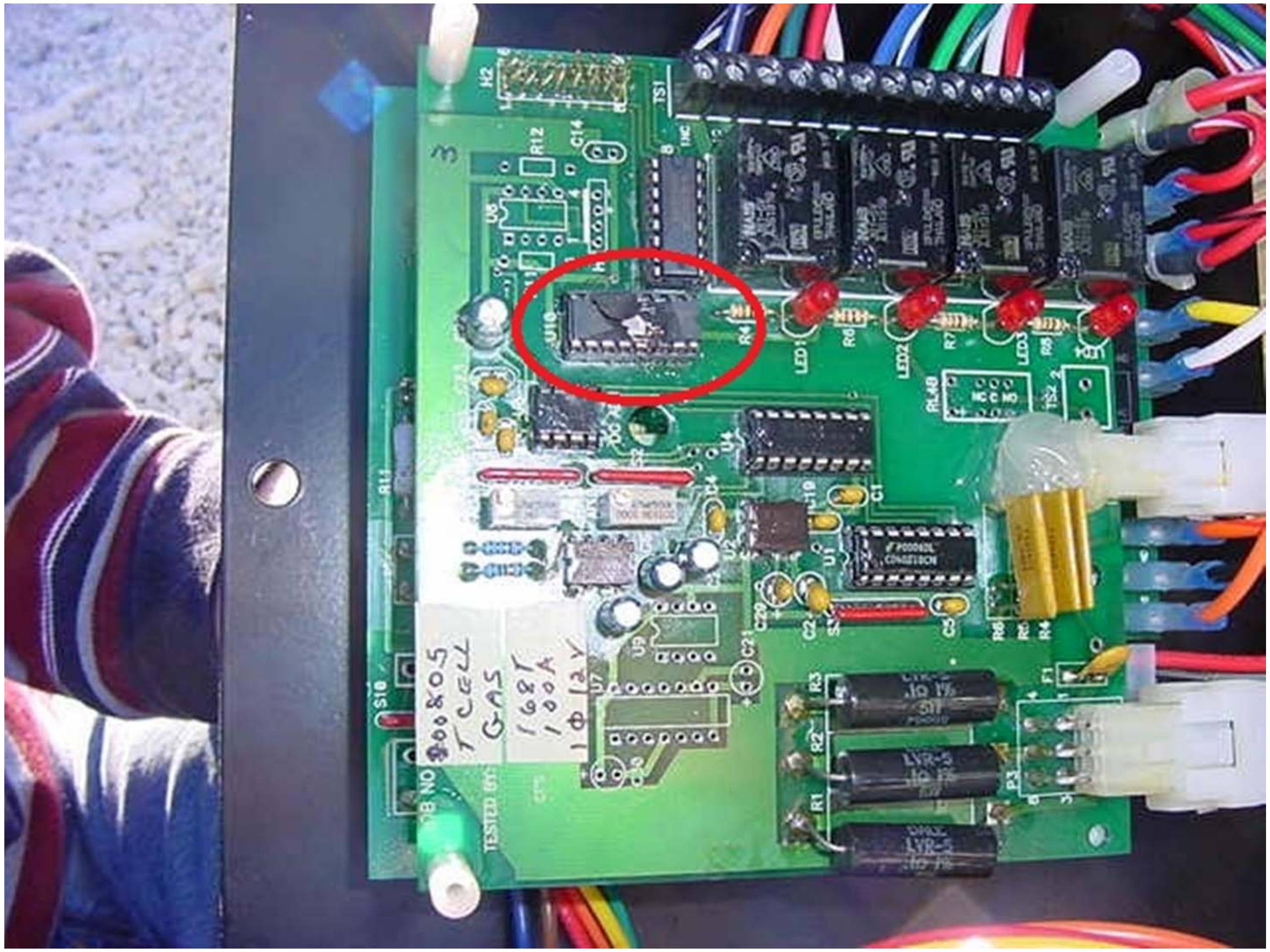
Measured Surge Activity at Cellular Sites

Alabama Engineering

- I am honored to make this presentation among such a group of distinguished persons.
- My background although not an engineering major, has a wealth of experience and field proven methodologies.
- Being from the South however, we have tried and true approaches to engineering fundamentals and the laws of Physics.



It Is Hard To Put Smoke Back In Once It Has Been Removed



There are the obvious signs, but then there are those that are not.
Which raises the question, how did this happen?

Presentation Objective

- Provide an understanding of Transient Voltage/Surge propagation on AC Power circuits at cellular sites
  - o Field surge testing conducted in 1997-1998. At that time, this was cutting edge information.
- Present "As Installed" performance data of Surge Protection Devices (SPD), not manufacturing claims. (Transient Voltage Surge Suppression (TVSS) was the name SPD's were originally referred to)
- Discuss limitations of SPD design (lack of protection modes) and marketing strategies used by SPD manufacturer's
- Discuss the effectiveness of Isolation Transformers
- Discuss findings from case studies

Background

- Seemingly continuous lightning issues occurred at cellular sites along the Alabama Gulf Coast, in North Alabama, the Southeast, and everywhere.
- A plethora of solutions were sweeping the industry with a myriad of promises and claims. Snake Oil
- Misleading theories & marketing strategies exploited
  - Non-degrading components-at some point in time there was degradation axial leads being left after ceramic rupture on a PCB was proof
  - Installation instructions that specified larger conductors
  - Massaging of alarm circuits to benefit the manufacturer
    - Some modules used multiple components while only monitoring 1 component
  - Measurement of Joules to sell a candidate device
  - Let-through/clamping voltage performance claims
    - Component or module values used as the Clamping Voltage.
- Money was no objective. Some units were >$20k

History-BMI

- In the late 1980's, Gulf Coast Cellular built out its network in Mobile, AL, and was the "B" or unregulated network.
- Gulf Coast Cellular was sold to BellSouth Mobility (BMI). BMI became Cingular which became AT&T Mobility.
- In Birmingham, BMI was the "A" or regulated network.
- Used AstroNet, Hughes, and Ericsson Equipment.
  - Incorporated Isolated and integrated grounding architecture
  - Radio frames were bonded to CRGB
  - The rectifier frame and some MW frames were bonded to halo

History-BMI

Differences Between Birmingham and Mobile

- Both locations experienced similar damage to equipment
- Mobile, AL
  - Used 4/0 stranded conductors
  - CRGB/MGB in different location than Birmingham
  - Used SAD only technology-modules constantly failing
  - L-N protection paths (series L-L) only. No L-G or N-G modes
- Birmingham, AL
  - Used 2 AWG SBTC conductors
  - Used isolation transformers
  - Used MOV as well as MOV/SAD technology
  - L-N protection paths (series L-L) only. No L-G or N-G modes
- Conductor size made no difference to issues
  - Surge testing using 1/0 and 2AWG vs. 10AWG had <1% difference on MLV
  - Data supports 2AWG SBTC will carry fault current of 20kA for 500mS before fusing.
  - Cost/benefit of larger vs. smaller conductors clearly supported smaller gauge wire.
  - In KY, one site had a section of the buried ring blown out of the ground

History-BMI Case Study

- Bald Rock Mountain

- Previous audits at other sites in the BMI-Birmingham market revealed issues, but Operations took no corrective actions.
- Repeated lightning strikes at BR took down Harris MegaStar radios, all of East Alabama traffic, backplane was damaged.
- Persons present: BMI corporate, Directors, EE firm, contractor, Harris, techs, local and regional managers.
- Cellular equipment was in one building, MW radios were in another. T1 circuits ran between buildings.
- Found compromised grounding, cables secured to MW coax's, lack of SPD on AC power, T1/Signal, and Obstruction Lighting. Isolation Xfmr was thought to be protective measure.
- Ground loops on 25 pair between cross connect panel & MW radios. Surges on coax created frame voltage differential)

History-BMI

- Success

- After grounding upgrades were completed and Surge Protection installed, equipment downtime was virtually eliminated.
  - Added 2nd lead to ground bars, replaced mechanical lugs.
  - Re-routed data circuits that were secured in parallel on coax
  - Installed new frame grounds from rectifier & MW, bonded to CRGB
  - Removed ground loops on shields of data/signal circuits
- *Bald Rock was hit several more times but equipment came back up. To date, there have been no more issues.*
- Still, local and regional BMI Operations and engineering wanted to better understand why their system had been failing.
- There was a "want to know" why the isolation transformers were not working as "designed"

BMI Testing Schedule

- The testing program was initiated to:
  - Determine how transients propagated within a cell site on AC Power Circuits.
  - Establish real world, as installed, Measured Let Through (MLV) voltages of SPD performance on AC power circuits
  - Educate the customer: How transients generated on AC power circuits affect DC powered equipment? Or did they?
- Site locations Selected:
  1. Rohn Manufacturing-Shelter Manufacture in Birmingham.
  2. Birmingham-De-commissioned cell site behind MSC with isolation XFMR, electrical circuits still intact with working HVAC, TVSS
  3. Mobile-Completed shelter build out, tower and coax, Service riser built, waiting for AC power service drop.

Testing Models

- IEEE Standard C62.41-1991
- Surges were generated using a Velonex model 587E Surge Generator. (Mick does not pronounce this correctly)
  - 120v AC input
  - Produced both Combination and Ring Wave transients (see picture next slide)
- A LeCroy model 4310AM Dual, 400 MHz Digital Storage Oscilloscope (DSO) recorded the MLV by a trigger signal from the Velonex.
- Traces were printed using the DSO's internal printer and were also stored on 3.5" floppy discs. (lost during move)
- Test equipment was placed and powered inside shelter.
  - Output circuit of the Velonex was run to shelter/service disconnect with 10AWG trimmed for 3kA surge calibration
  - Surge voltage ranged from 5.8 to 6.2kV.
  - Scope leads were connected to the buss of panel DP-1 inside the site.
  - Dynamic (power applied) and static (non powered) tests were conducted depending on site.

Testing Equipment

Velonex 587

LeCroy DSO

Velonex Technical Data

TABLE 1 - TECHNICAL DATA	WAVEFORMS			
			Contiuous Dual Exponential	
	Oscillatory 100 kHz	**Exponential 1.2/5µsec (Open Circuit)**	**1.2/50µsec (Open Circuit)**	**8/20µsec (Short Circuit)**
Maximum Peak Voltage (E_o)	6.0kV	6.0kV	6.0kV	—
Maximum Peak Current (I_o)	200A/500A	30A	—	3.0kA
Rise Time (t_R)	0.5μsec	1.2μsec	1.2μsec	8.0μsec
Decay Time(t_d)	60% of Previous Peak	50μsec	50μsec	20μsec
Source impedance (Z_S)	30/12 Ohms	200 Ohms	2.0Ohms	2.0Ohms
Phase Adjust (5% Resolution)	0^o — 360^o	0^o — 360^o	0^o — 360^o	0^o — 360^o
Repentition Rate	0.1Hz/1.0Hz	0.1Hz/1.0Hz	0.04Hz	0.04Hz
Polarity	User Selected			
Output isolation§	Floating			

IEEE C62.41-1991 Location Categories

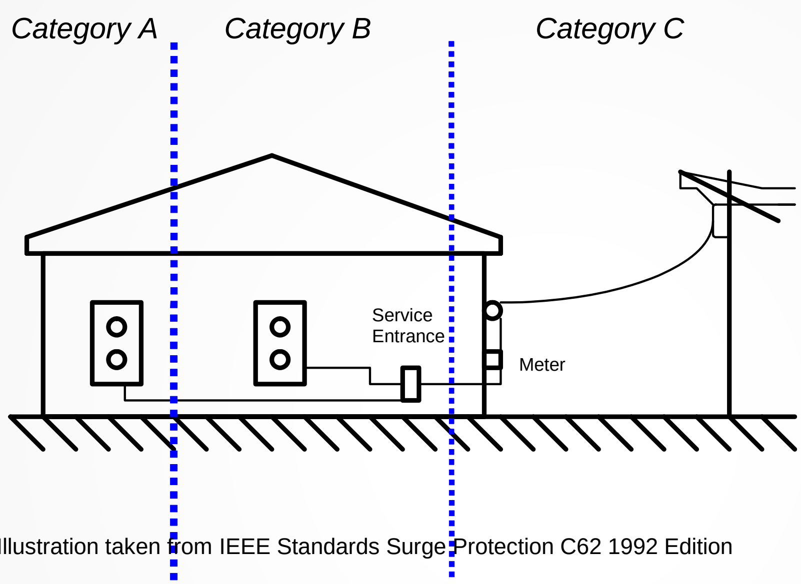


Illustration taken from IEEE Standards Surge Protection C62 1992 Edition

Location C: Basically service entrance
Location B: Feeder and equipment just inside facility
Location A: Branch circuits

ANSI / IEEE C62.41-1991 Wave Forms

- **2 Wave Forms used in the Location Categories.**

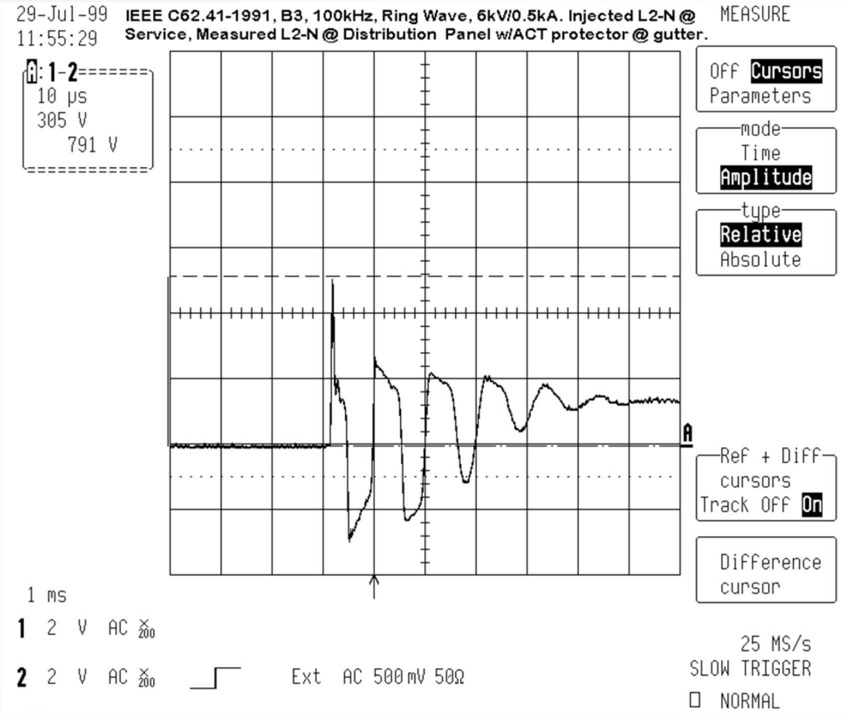
- 100 kHz Ring Wave - 0.5 *µs* x 10 *µs*

- Combination Wave, Open-Circuit Voltage - 1.2 *µS* x 50 *µs*

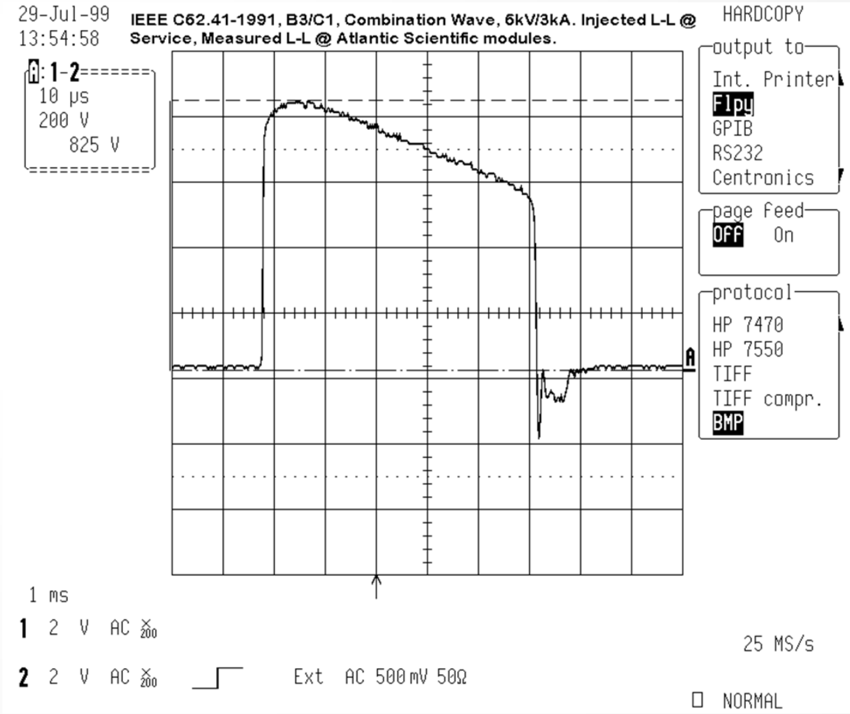
- Combination Wave, Short-Circuit Current - 8 *µs* x 20 *µs*

ANSI / IEEE C62.41-1991

100 kHz Ring Wave



Combination Wave



ANSI / IEEE C62.41-1991

Exposure Locations 100 kHz Ringwave

Location Category	System Exposure	Voltage (kV)	Current (kA)	Effective Impedence
A1	Low	2	0.07	30
A2	Medium	4	0.13	30
A3	High	6	0.2	30
B1	Low	2	0.17	12
B2	Medium	4	0.33	12
B3	High	6	0.5	12

ANSI / IEEE C62.41-1991

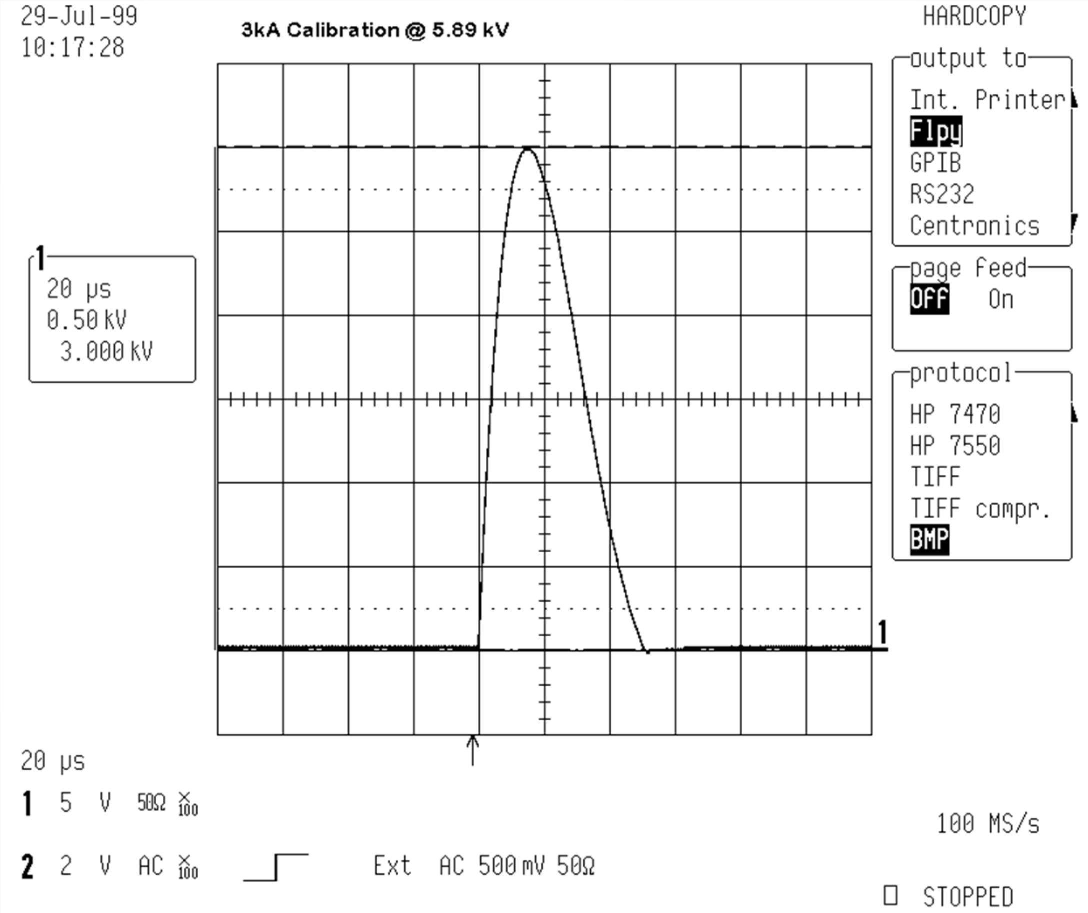
Exposure Locations Combination Wave

Location Category	System Exposure	Voltge (kV)	Current (kA)	Effective Impedence
B1	Low	2	1	2
B2	Medium	4	2	2
B3	High	6	3	2
C1	Low	6	3	2
C2	Medium	10	5	2
C3	High	20	10	2

Surge Calibration

- The testing was in accordance with IEEE C62.45-1987.
- Surge Current Calibration was accomplished using a 100:1 CT. 3kA value was achieved by adjusting the open circuit voltages between 5.8kV and 6.24kV.
- Up to 40 feet of 10 AWG stranded THHN conductors was used between the Velonex output and the service main or other EUT (Equipment Under Test) to obtain the 3kA value.
- At all times, a BMI technician assisted in the testing to ensure data was not compromised.

Graph-3kA Calibration



Vertical = 500 volts/division

Testing at Rohn

- Testing performed with shelter sitting on timbers.
  - o Shelter was fully manufactured waiting for truck transport and was sitting on large wooden timbers, isolated from earth
- Halo leads not connected to a ring. Shelter ground was "floating" except AC power to Velonex
- BMI and ROHN personnel present during testing.
- Surges were injected at shelter/Service disconnect on shelter exterior.
- MLV recorded on buss of DP-1
- Every time a surge was generated, the conduits buzzed and fluorescent fixtures illuminated momentarily.

Chart-Testing at Rohn

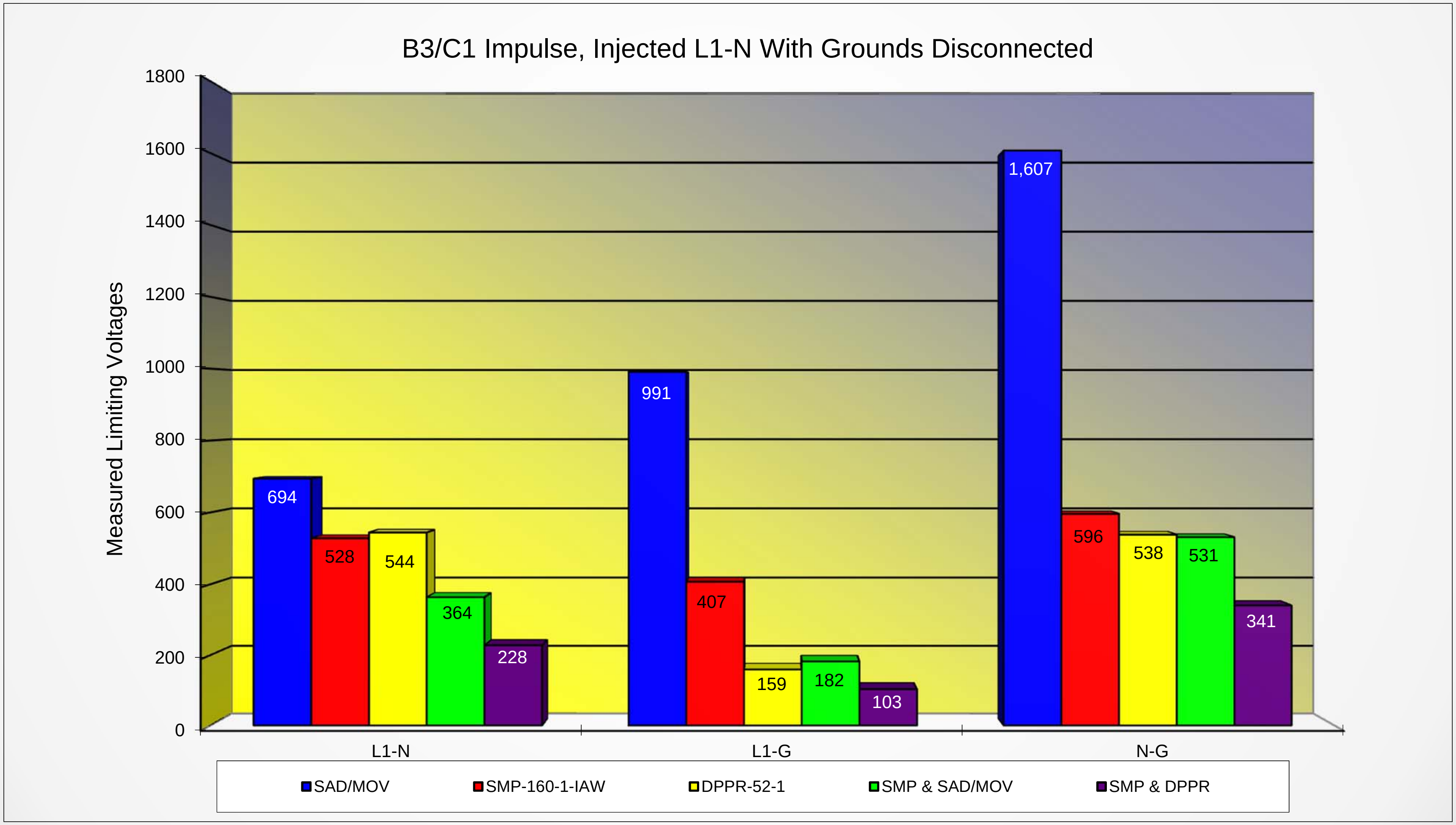
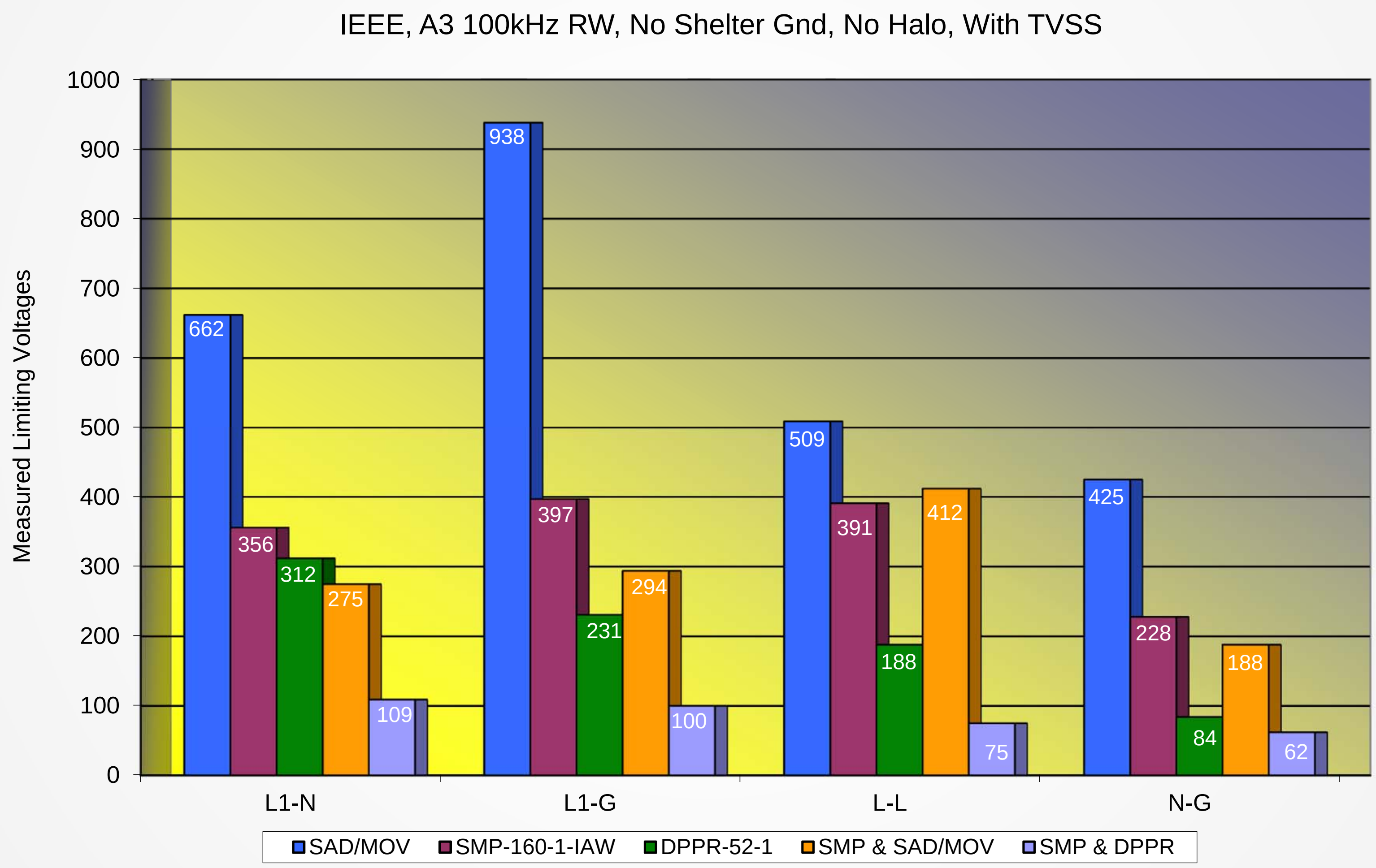


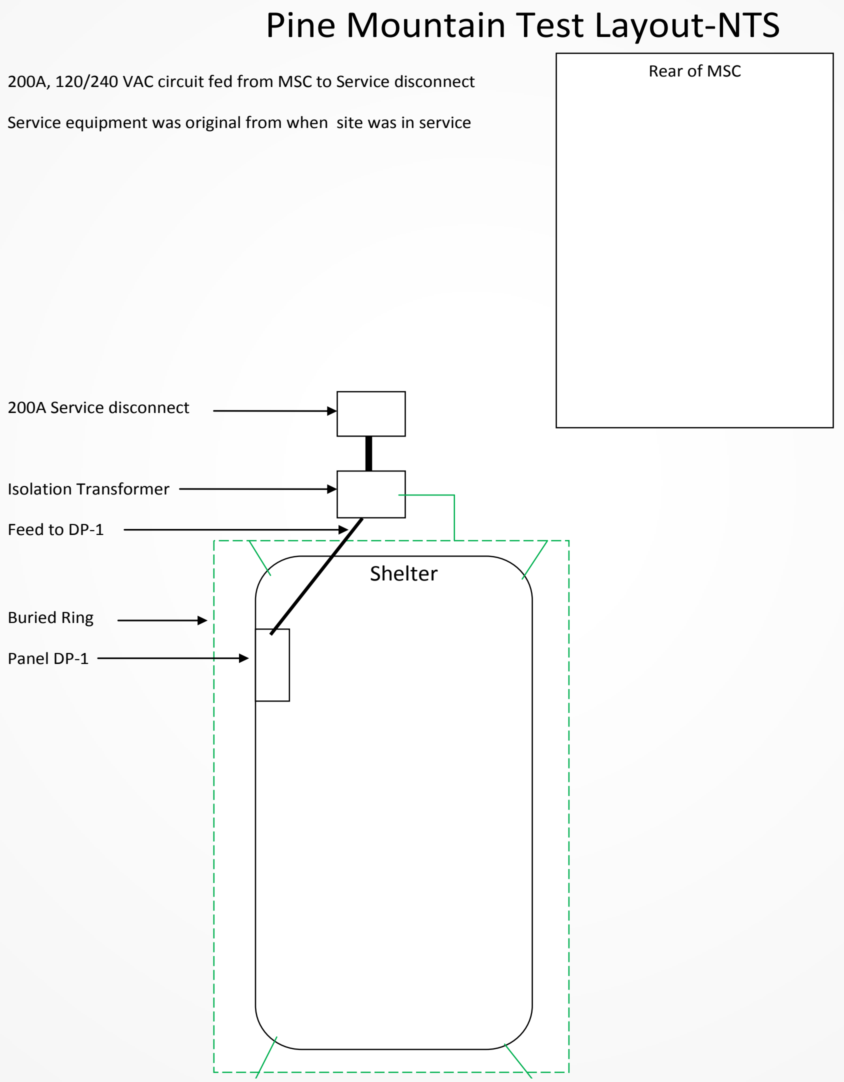
Chart-Testing at Rohn



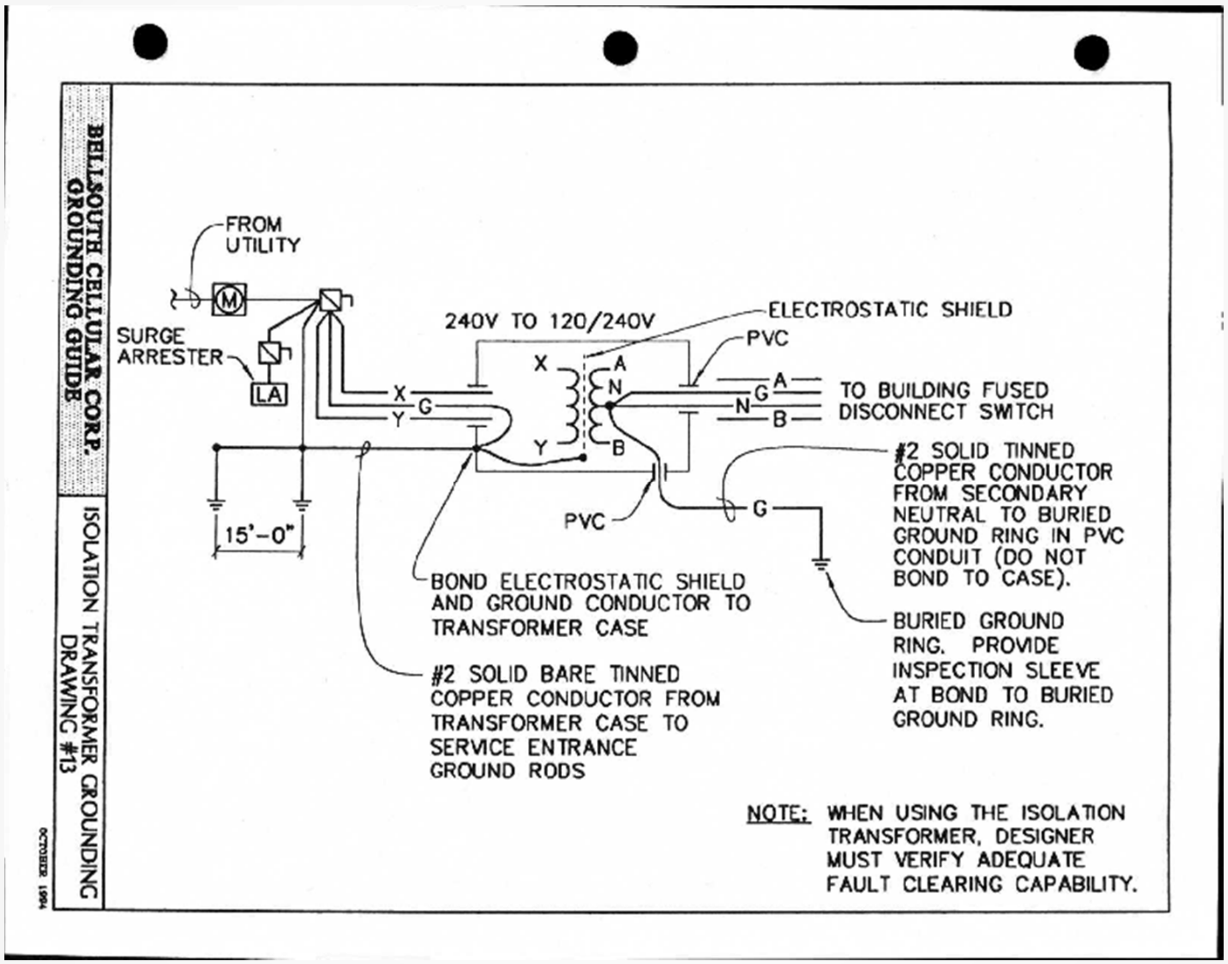
Isolation XFMR Testing

- Output of Velonex wired to Service disconnect on pole: 120/240V, 200A Fused Disconnect fed from a circuit in the MSC.
  - Static testing. All conductors of MSC feeder were removed and isolated.
- Buried ring around shelter 2 AWG SBTC was also bonded to transformer enclosure.
- Primary and secondary grounds were bonded together
- "Transformer Bypassed" means primary and secondary conductors were removed from transformer and tapped together as if no transformer was installed
- "Transformer Isolated" means the primary and secondary grounds were isolated from each other
- Transients injected at Disconnect, Measurements recorded on buss of panel DP-1 inside
- SMP installed at disconnect, all others at panel DP-1

Isolation XFMR

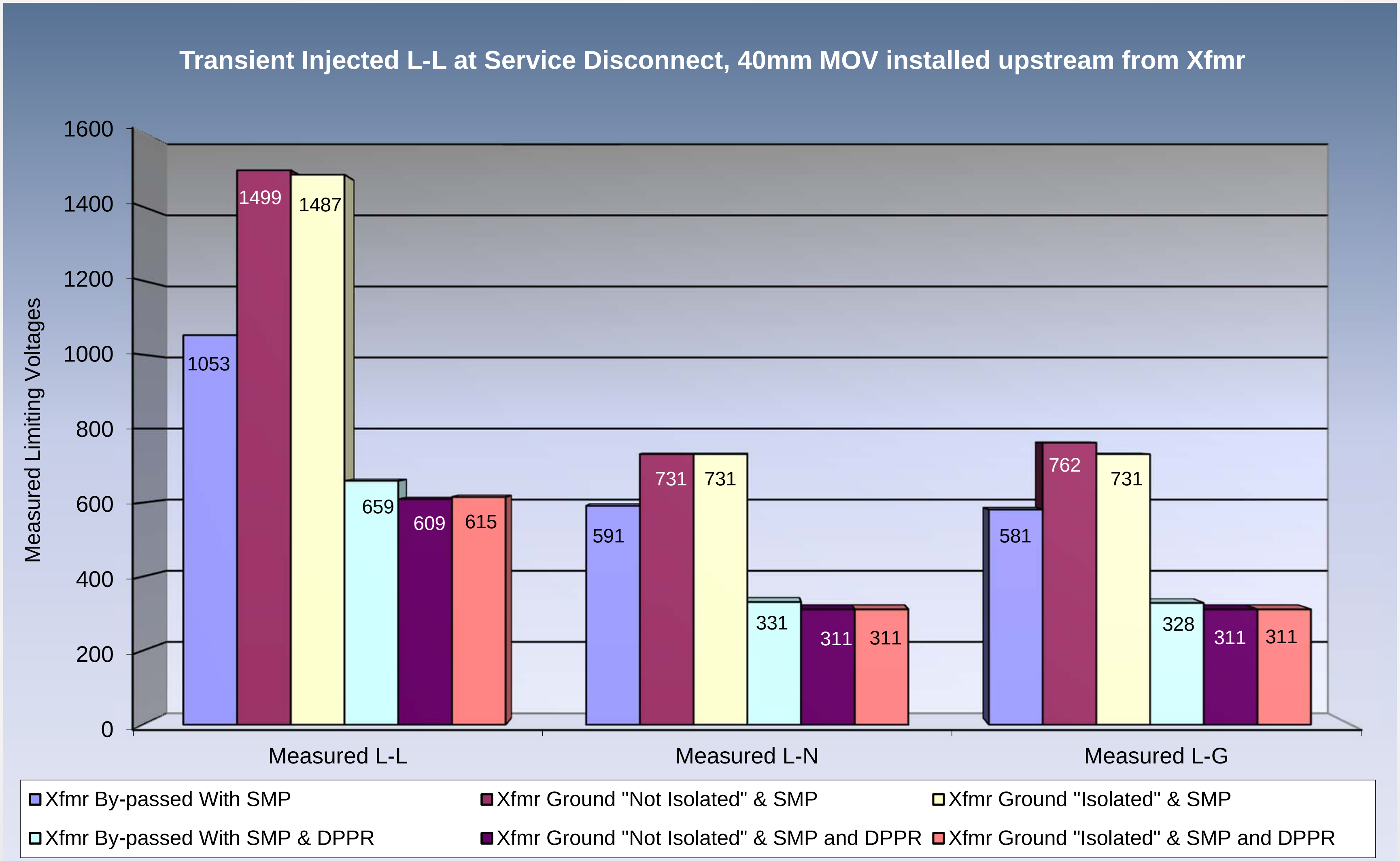


BMI Isolation Transformer

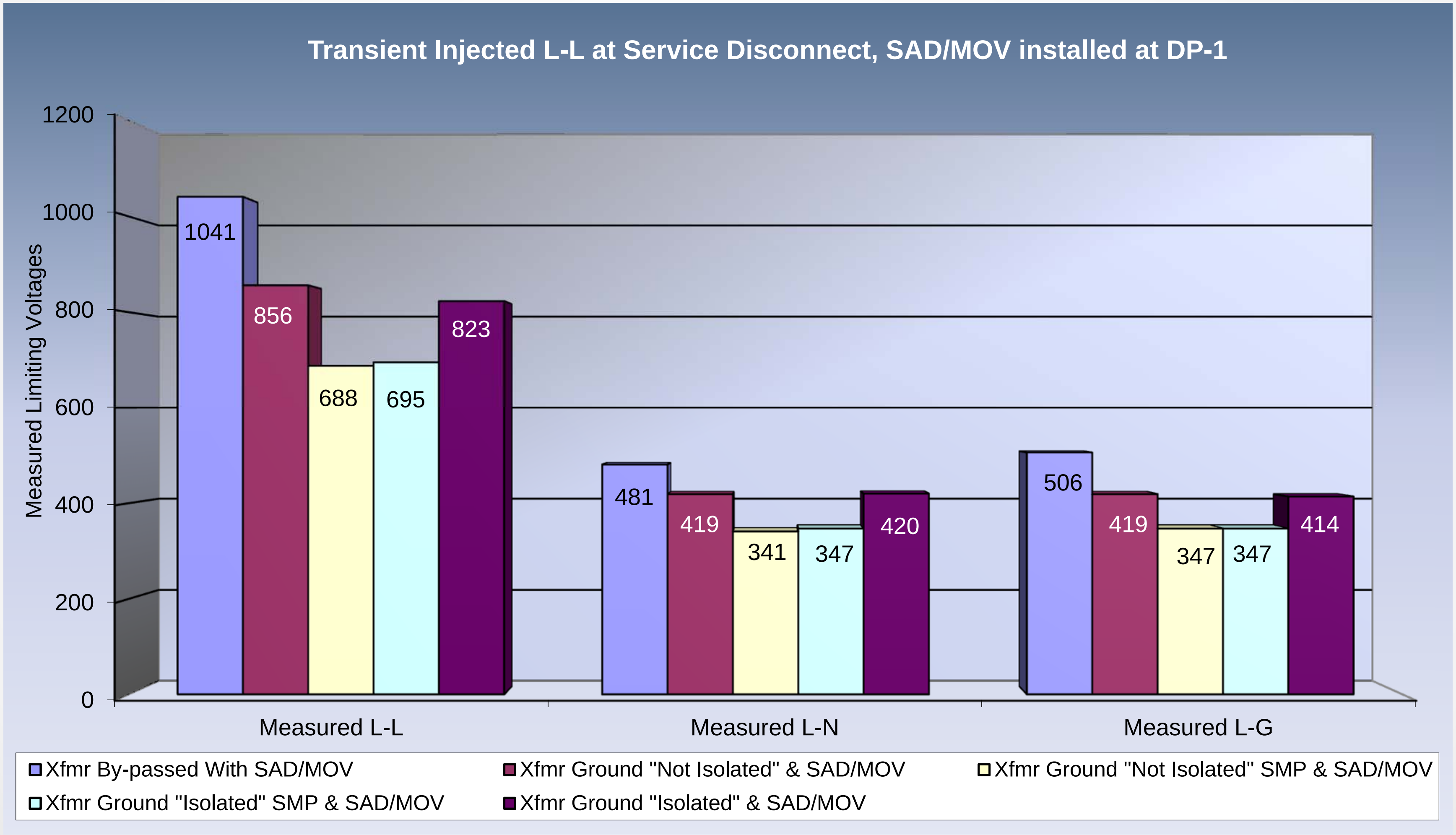


Isolation of primary and secondary was specified in engineering drawings. Practice by contractors rarely, if ever followed this.

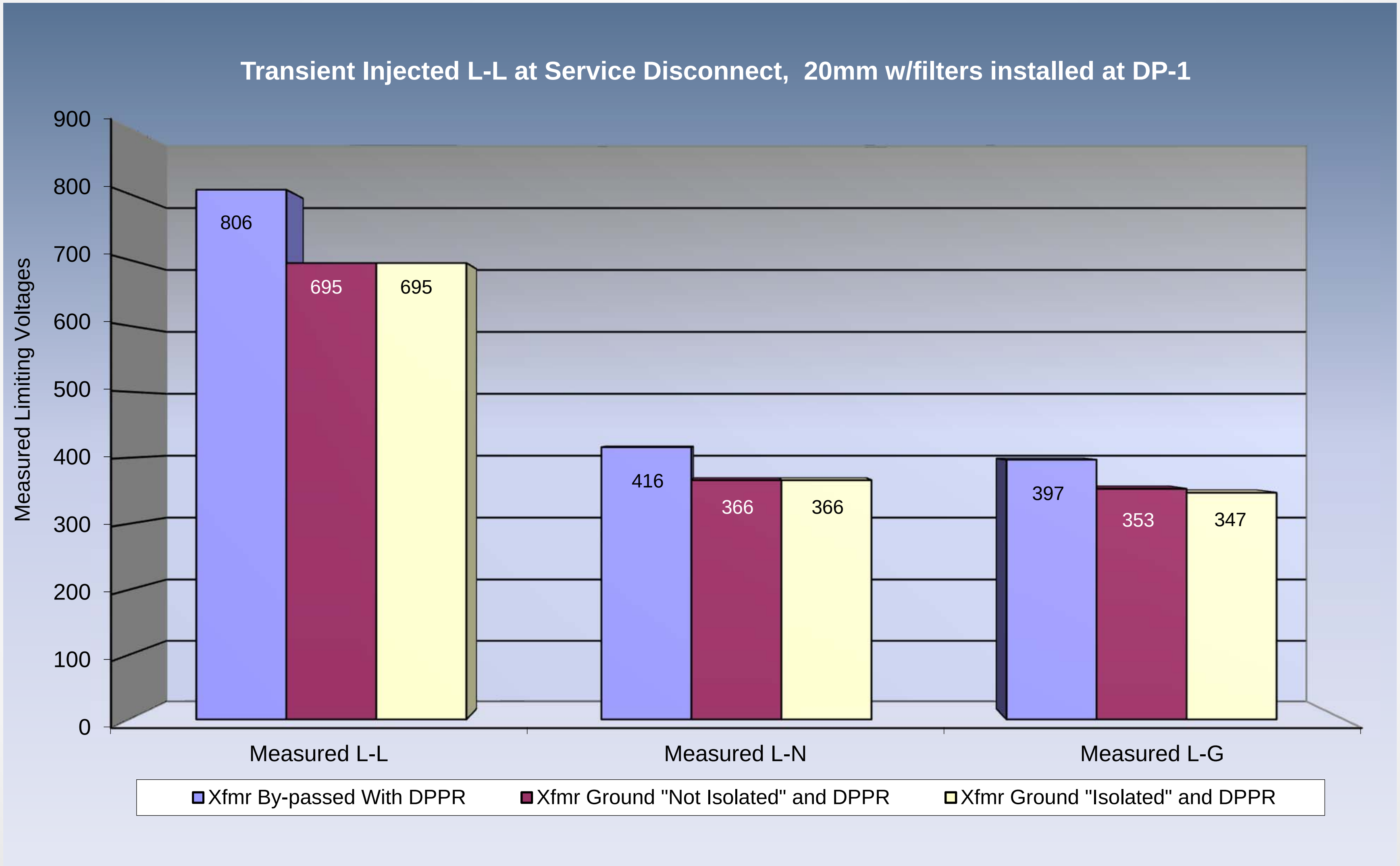
Isolation XFMR, L-L



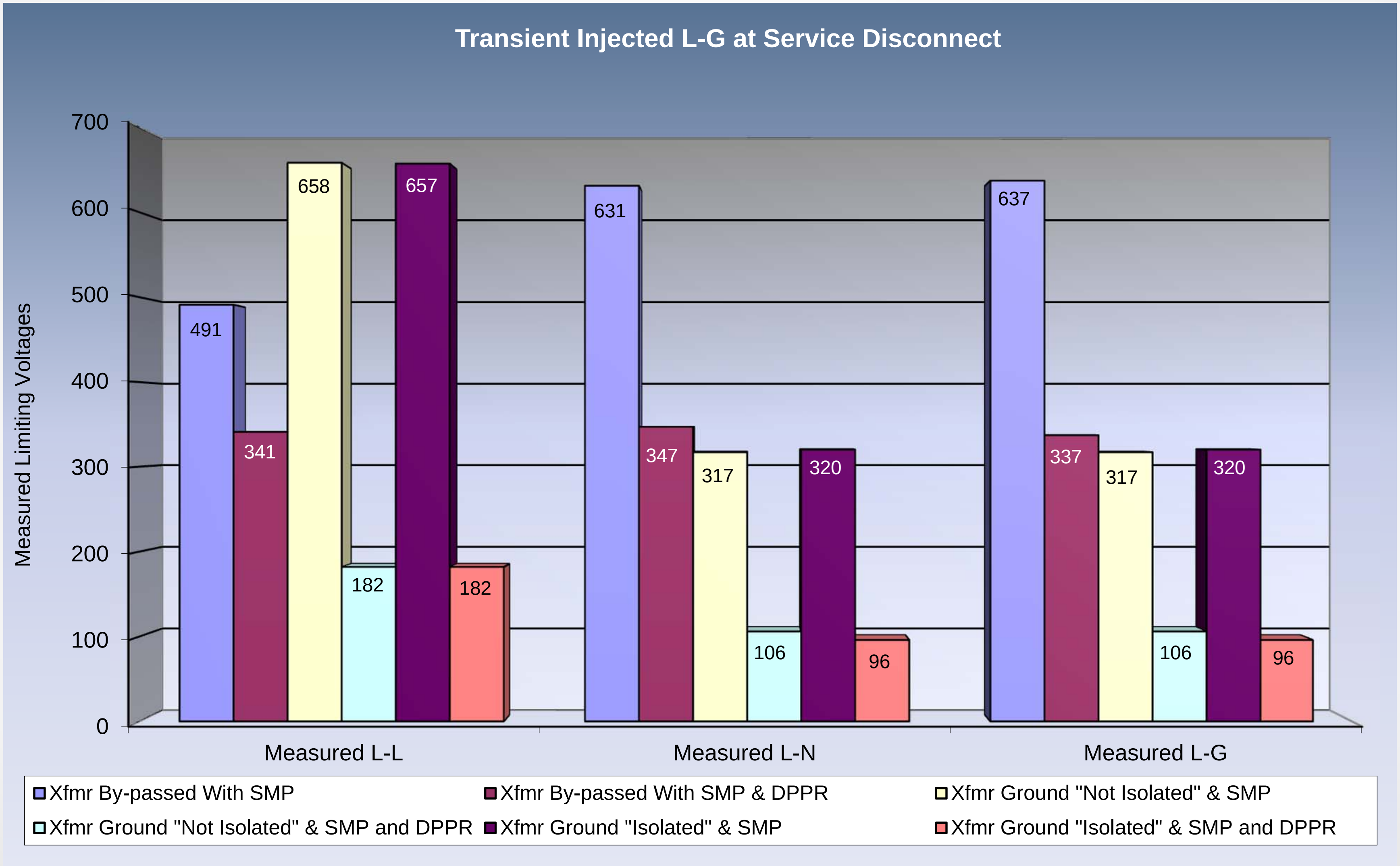
Isolation XFMR, L-L



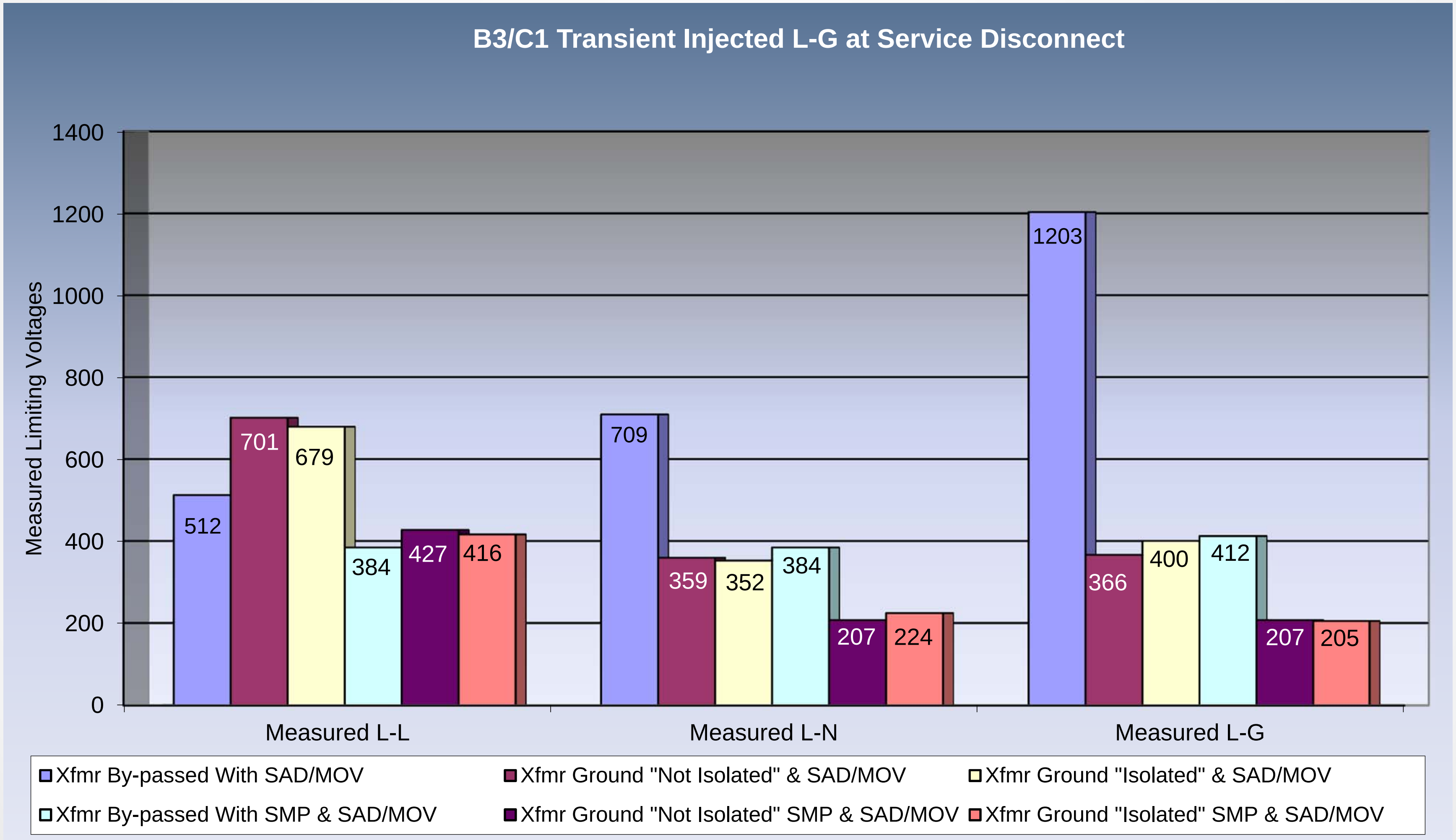
Isolation XFMR, L-L



Isolation XFMR, L-G



Isolation XFMR, L-G



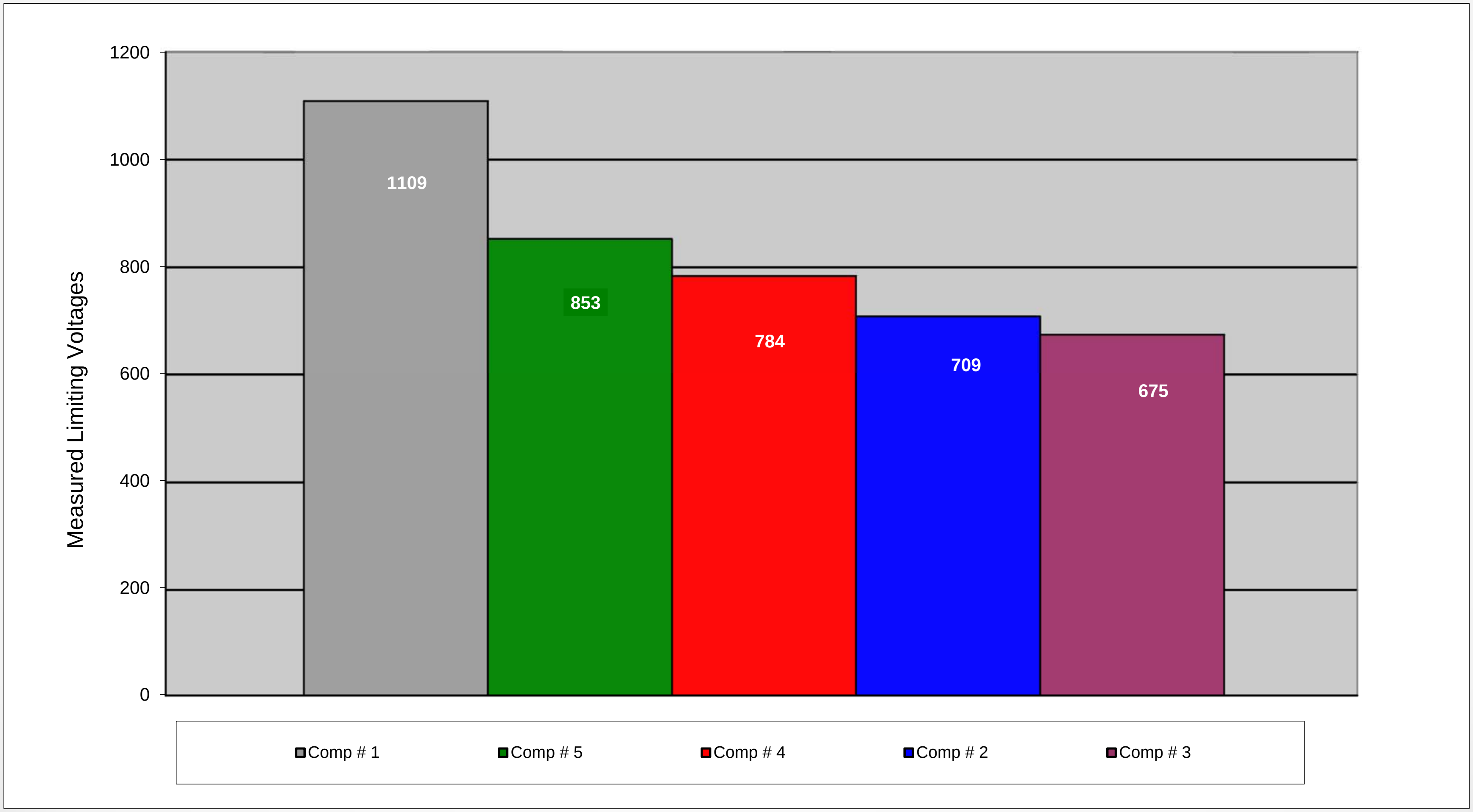
XFMR Discoveries

- Transformer did offer some protection, but not as desired.
- The windings of the transformer were additive depending on polarity of the transient.
- Equipment exposure to high surge voltage if interior SPD failed.
- Combination Wave Transients could become a Ring Wave transient through the transformer windings
- Two SPD's offered better protection
- Two level SPD protection with filtering tuned to IEEE 100kHZ transient provide best protection
- Transformer Saturation cost alone cost over $27,000.00 through out the market (60 sites (??) at the time)
- Data from testing showed cost and performance of two level SPD outweighed cost and performance of transformers
- As a result, Isolation XFMR's were not purchased after testing

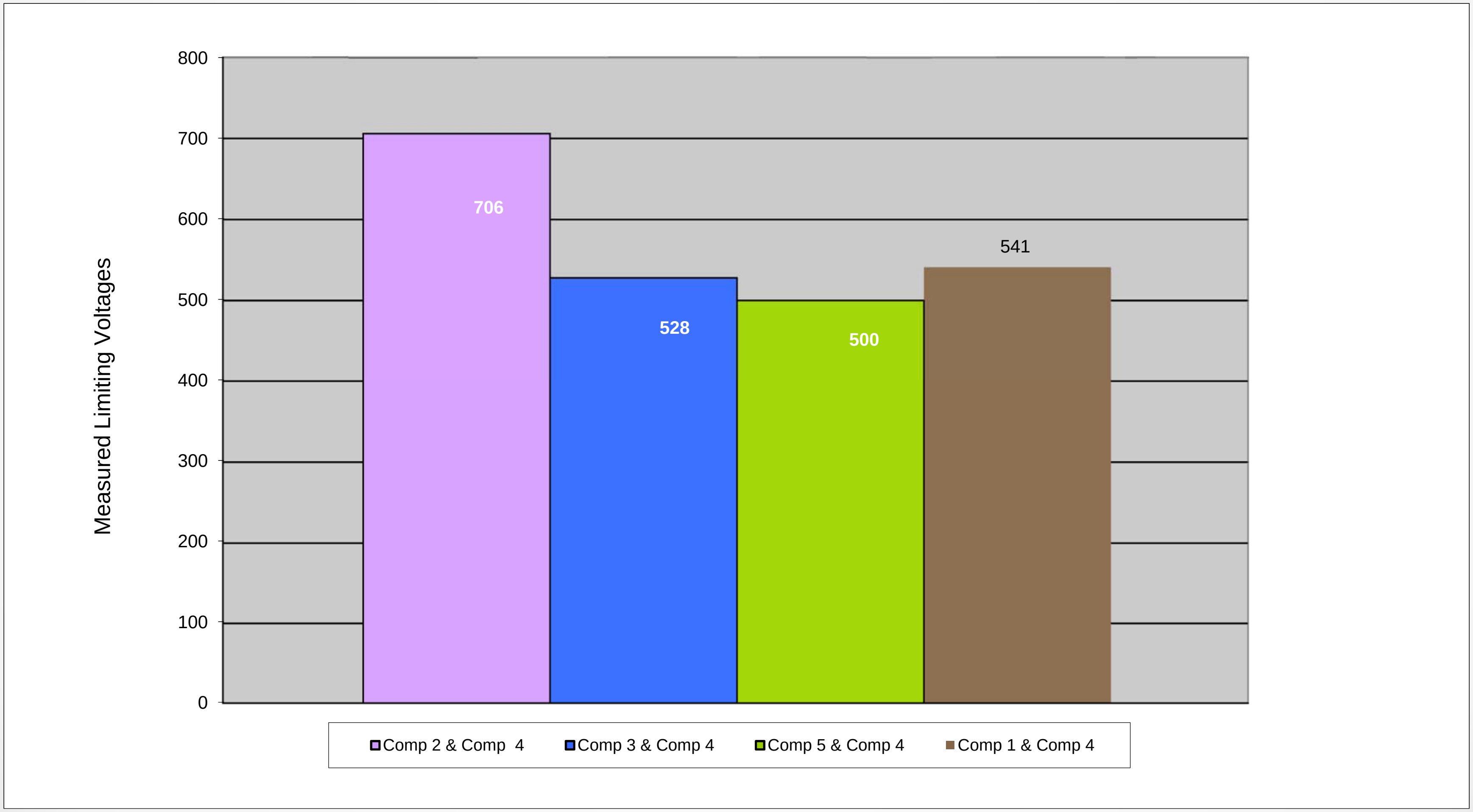
BMI-Schillinger Road

- New Site, all grounds connected but service drop not installed
- Transients were injected at the service disconnecting means located on the utility pole (20 feet from the shelter).
- The MLV was taken at panel DP-1.
- The transients were injected L-N for all tests except L-L which was injected L-L.
- Values shown in the following charts are the average of 10 impulses
- Power fail relay was accidentally blown up.
- Provided real data of transient activity on ALL circuit paths of the shelter AC Power system if all mode protection is not used.
- Summary of findings is found at end of BMI section.

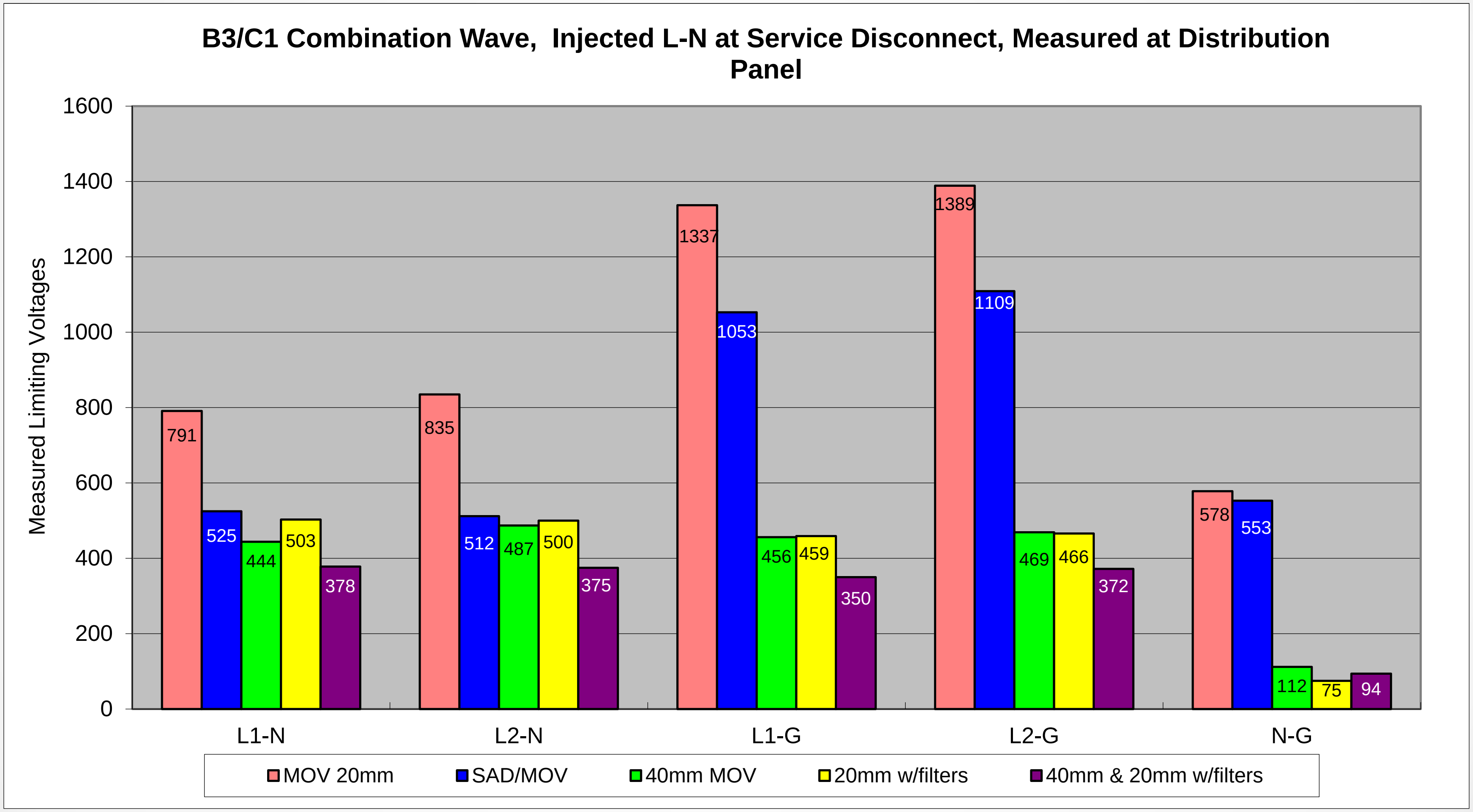
BMI-Schillinger Rd, Single Unit, L-L



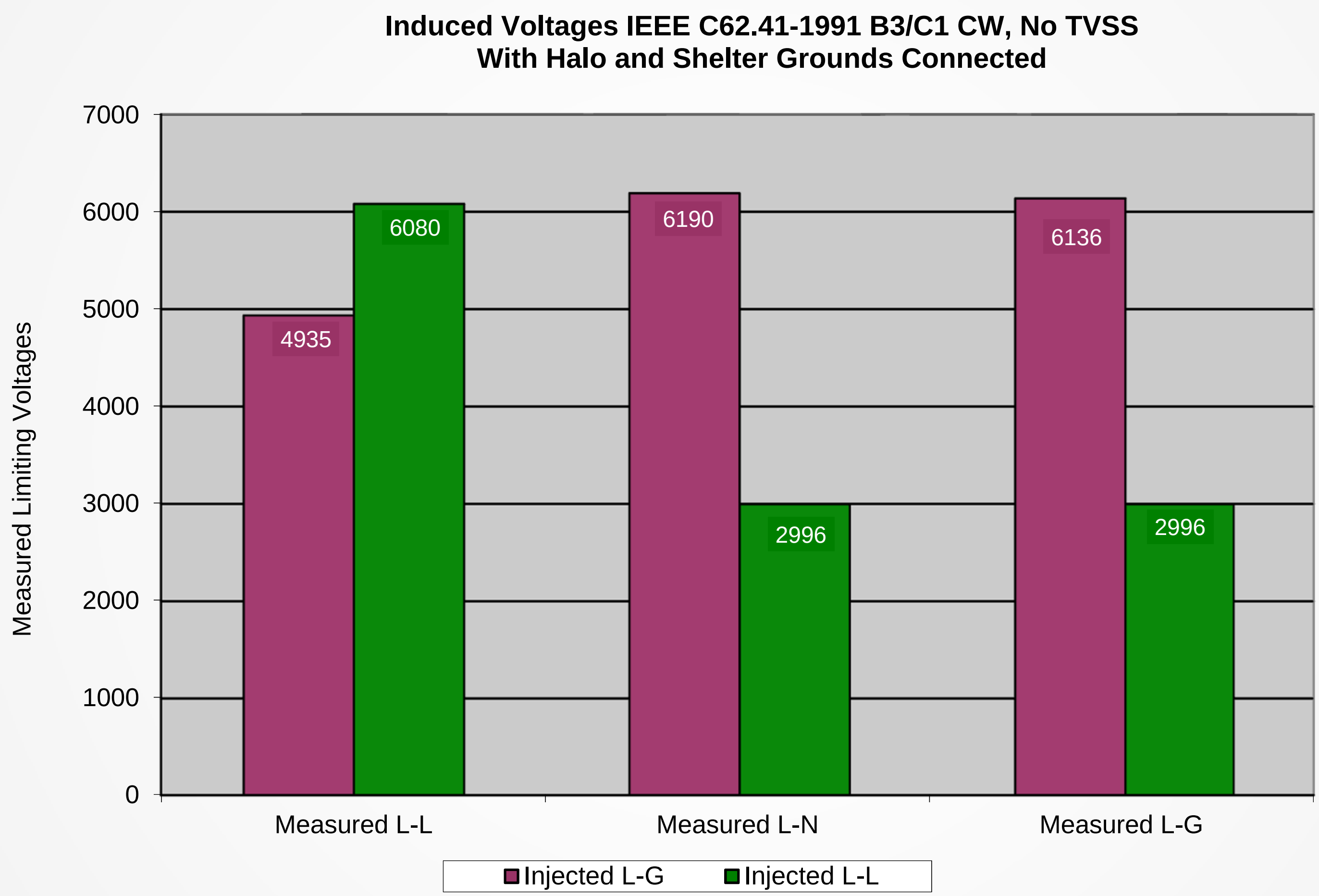
BMI-Schillinger Rd, Combined, L-L



Schillenger Road

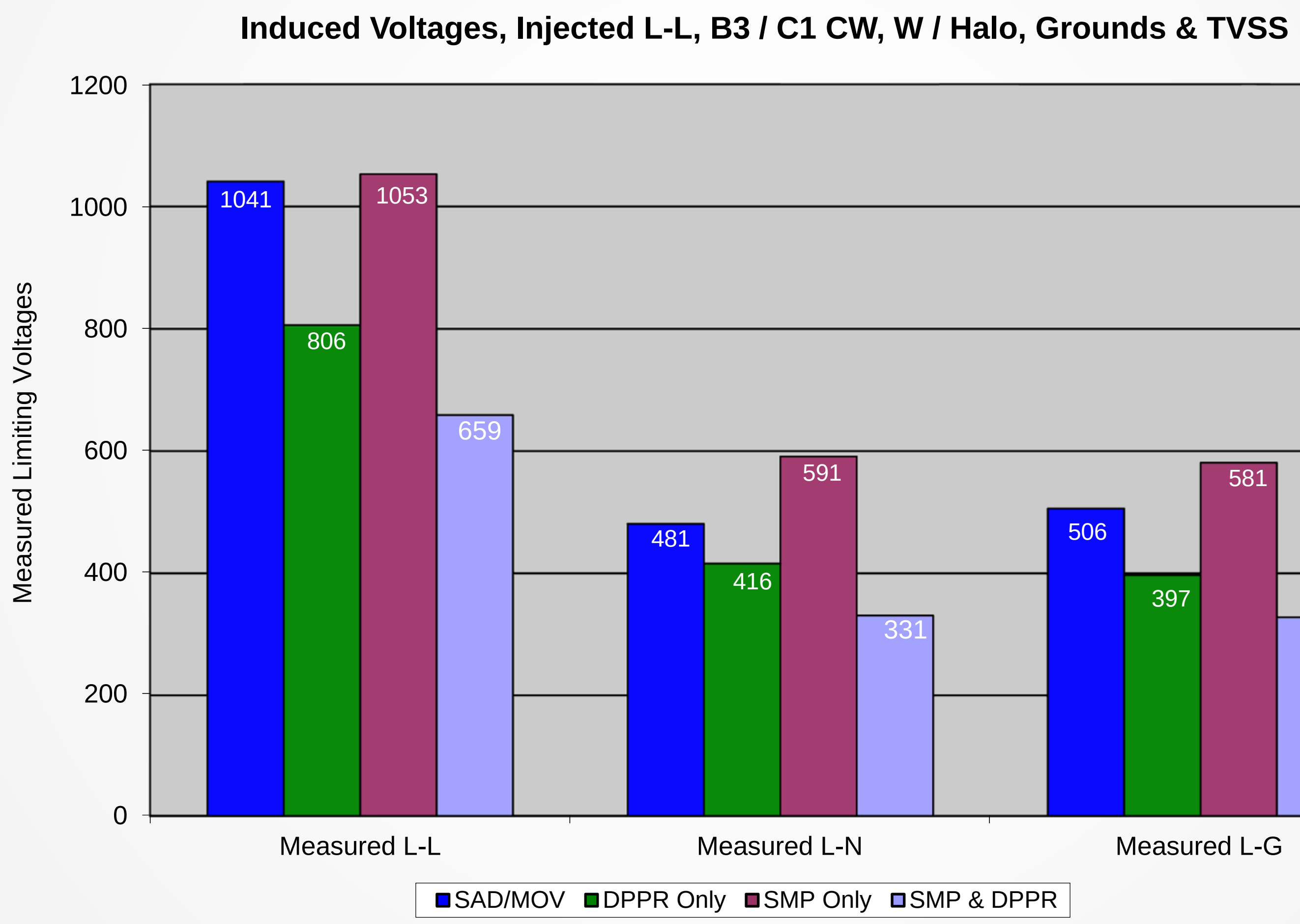


BMI-Schillinger RD, Induced Voltages



6kv Transient injected L-N created 4.9kv transient on L-L
6kv transient L-L induced 2.9kv on L-N/L-G

Induced Voltages



BMI Conclusions

- Cell site exposure to high surge currents and voltages due to compromised grounding and lack of all mode SPD.
- Larger SPD enclosures reduced protection because of longer lead length
  - MLV increases on average 10-20 volt per inch of conductor depending on surge amplitude
- SAD technology did not perform as advertised. (Clamping Voltage)
- SAD's proved to be not as robust as MOV's at locations exposed to very high surge currents. Constant failures.
- All mode (L-L, L-N, L-G, N-G) SPD provided better protection
- 2 level "All Mode" approach provided best solution
- Isolation transformers were a waste of money, literally
- Upgrading grounding/bonding, providing protection for all exposed circuits (tower lighting, DC, TMA, alarm, etc.) eliminated lightning issues.

History-Contel/GTE

- As with BMI in the late 1980's, Continental Telephone began building out its network under the name Contel Cellular . In Mobile, AL, they were the "A" network.
- Contel Cellular in Birmingham was originally McCaw cellular. They were the "B" side
- Contel Cellular became GTE MobilNet, then VZW.
- Used AT&T AutoPlex / Lineage 2000 equipment
  - Incorporated an integrated ground system
  - DC Return was bonded directly to the buried ring at many sites
  - All thread for seismic bracing not isolated from iron work
  - 2 frame grounds per cabinet w/bi-directional Y's bonded to aisle ground
  - Aisle ground bonded to halo on each end of shelter
  - MW radios were bonded to halo

GTE MobilNet/VZW

- Overview
- Contel/GTE used integrated ground (next slide)
- Surge Testing was not performed, however...
- Bell Labs/AT&T created a report in 1994 titled "Induced Lightning Voltage on the RS422 Alarm Bus - Autoplex Series II Cell Site"
- The report addressed frame differential and inductive coupling issues and included a spice model of a typical cell site
- Request copies at jpfau@qpsllc.net
- Performed audits across the network

Autoplex Grounding Architecture

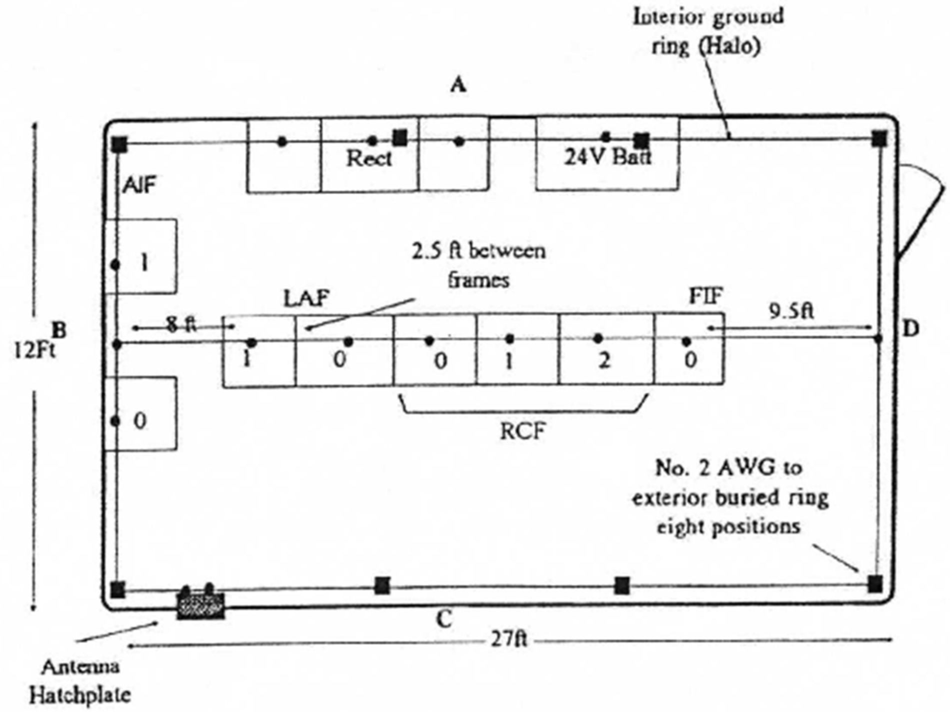


Figure 2: Typical Series II Cell Site Floor Plan.

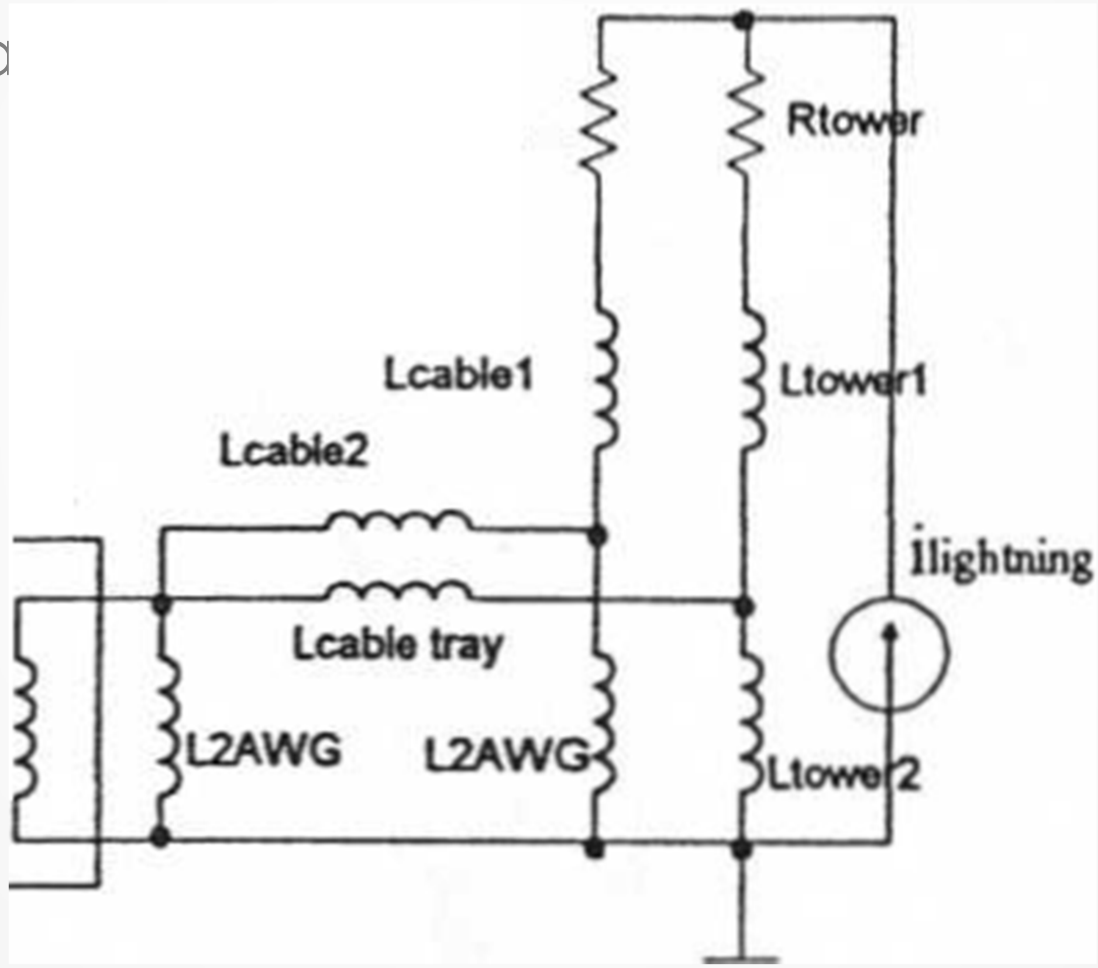
Bell Labs (ATT) Report, 1994

- Induced Lightning Voltage on the RS422 Alarm Bus - Autoplex Series II Cell Site

- The output of the transmit chip in the UN166 board is connected to the inputs of the receiver ICs in the LAF and the OIF frames through RS422 cable.
- In addition, all transmit ICs in the LAF and the OIF frames are connected to the receiver circuitry of the UN166 board. The ground for each of the driver and receiver circuit in each board is connected to the frame which is then connected to the cell site interior ground ring.
- Therefore, any frame voltage differential will appear at the input (output) of the receiver (transmit) ICs since the driver and receiver pairs on the separate frames are linked via the RS422 bus.

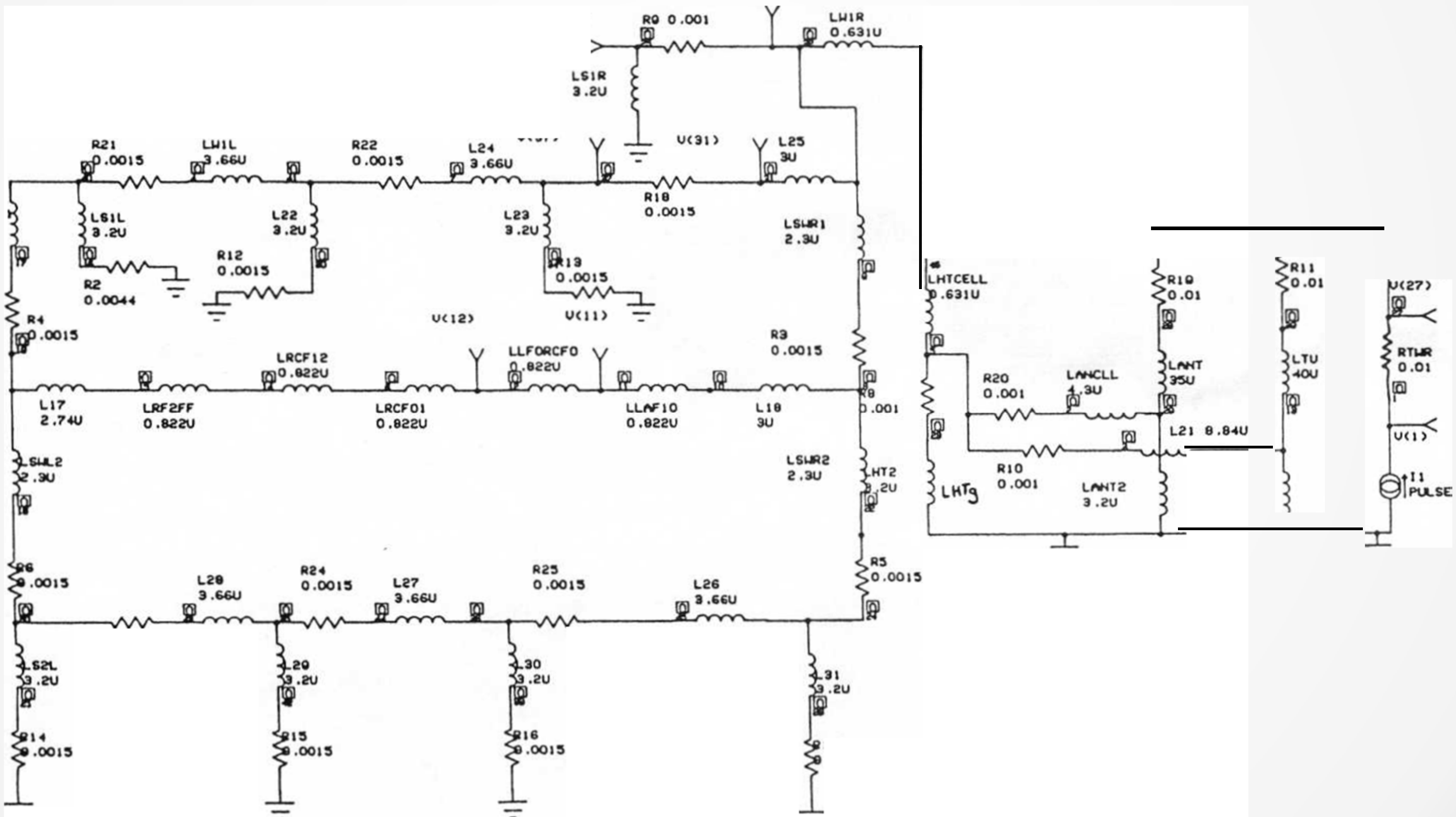
Bell Labs (ATT) Report, 1994

- Electrica



Bell Labs (ATT) Report, 1994

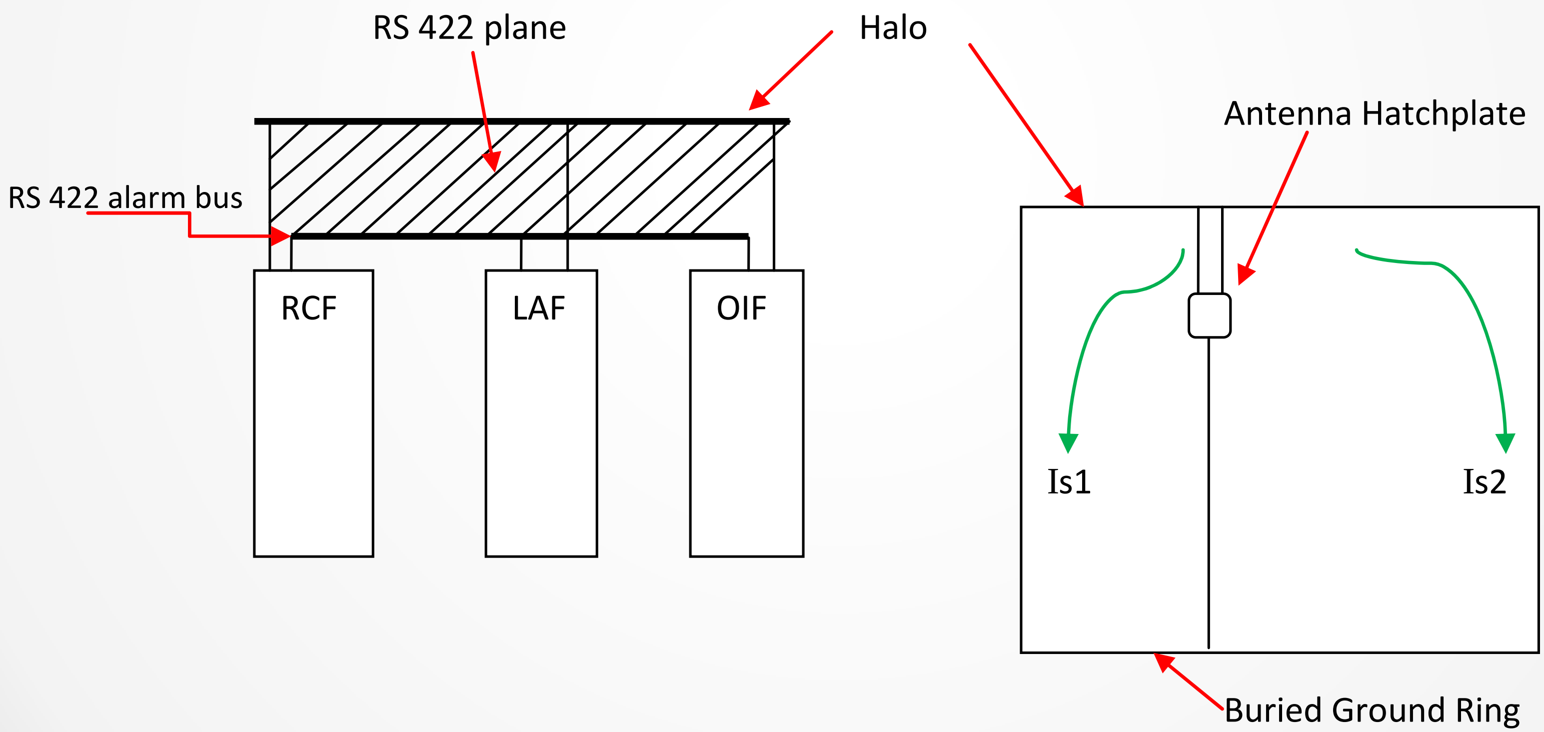
- Spice Model



Bell Labs (ATT) Report, 1994

Coupled Voltages

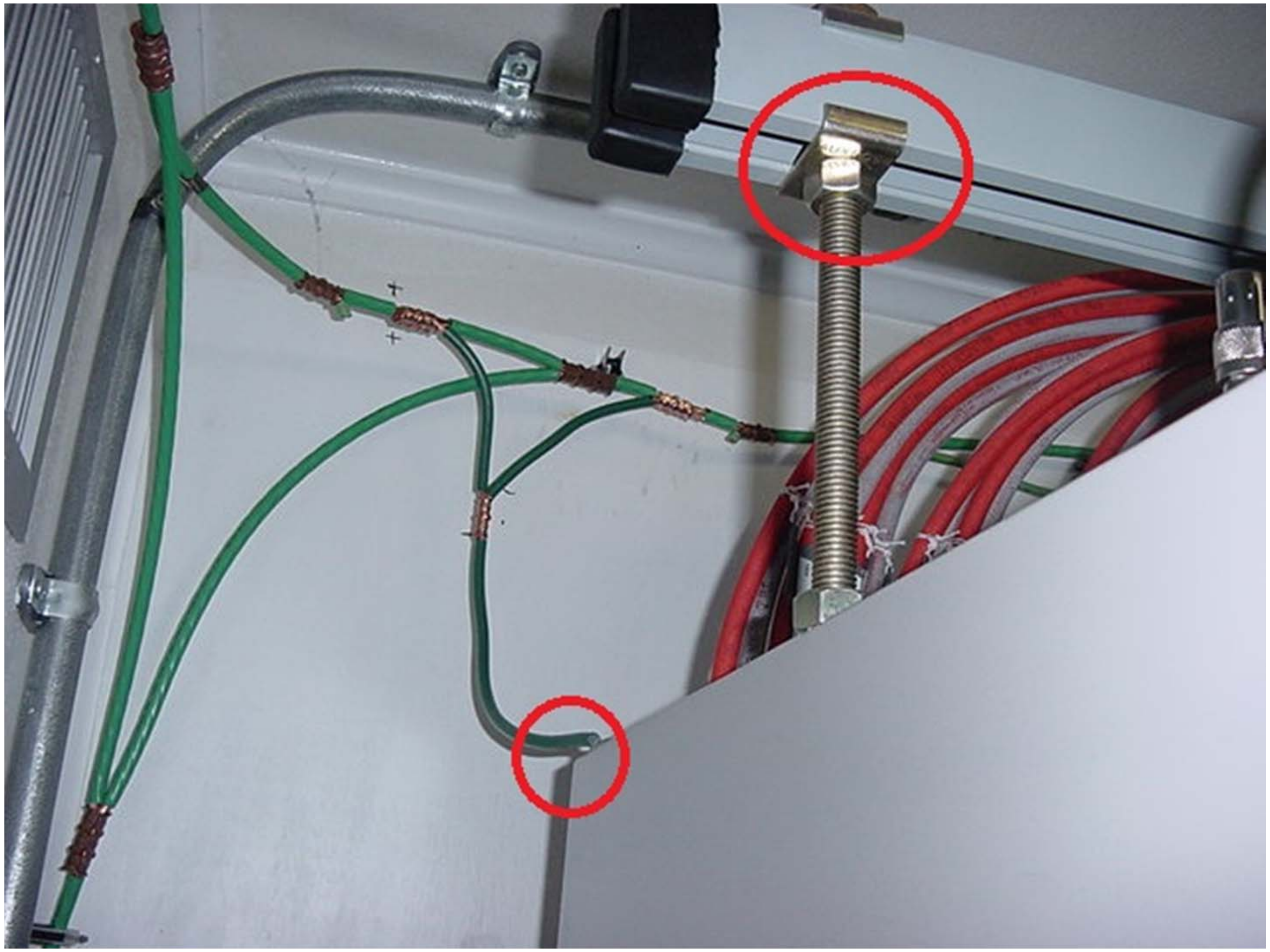
The total transient voltage at the RS422 receiver input of a LAC could be as high as 730V (350V +380V) for a lightning current of 100kA in a typical six sector cell site configuration.



GTE/VZW-Toyota

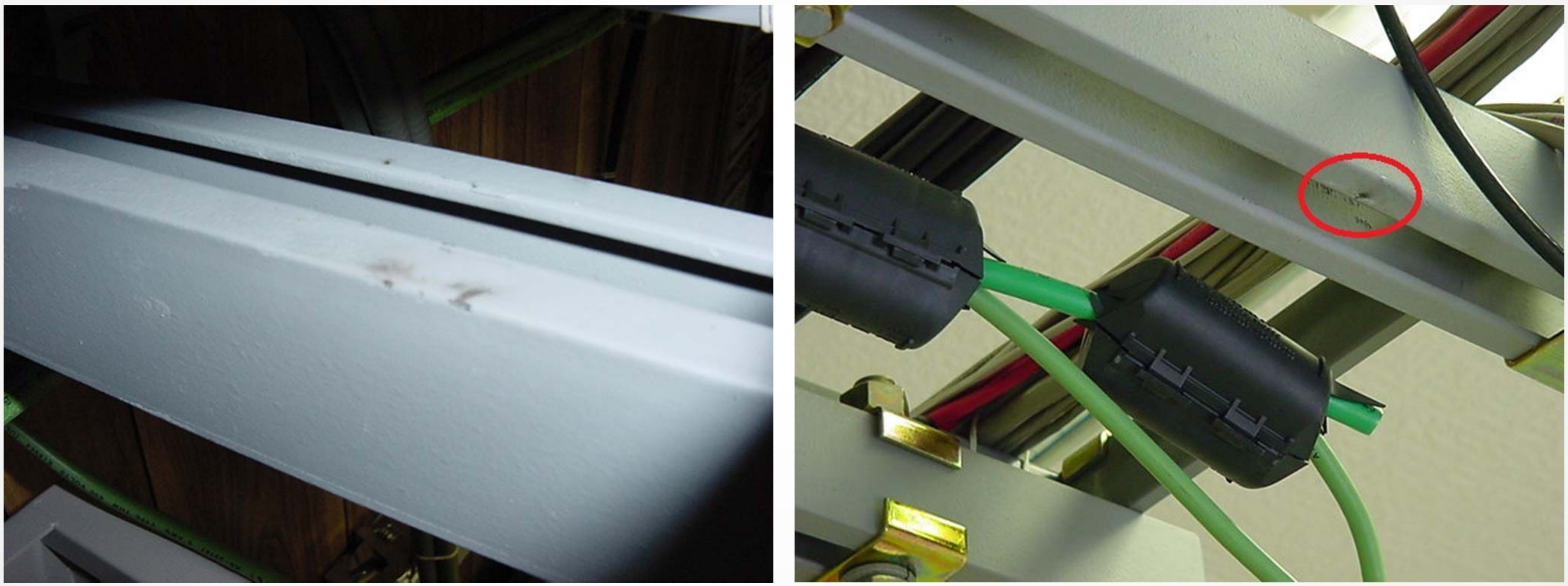
- Site is north of Lexington, KY of I-75.
- Unlike other sites, this site experienced abnormal lightning activity causing damage to AutoPlex Equipment, DIF Frame in particular.
- T1 Protection was purchased and installed but DIF frame still had issues
- Audit revealed numerous issues of DC current flow on AT&T AutoPlex frame grounding
- Grounding architecture modification was recommended and upgrade work performed

Toyota: AutoPlex Frame

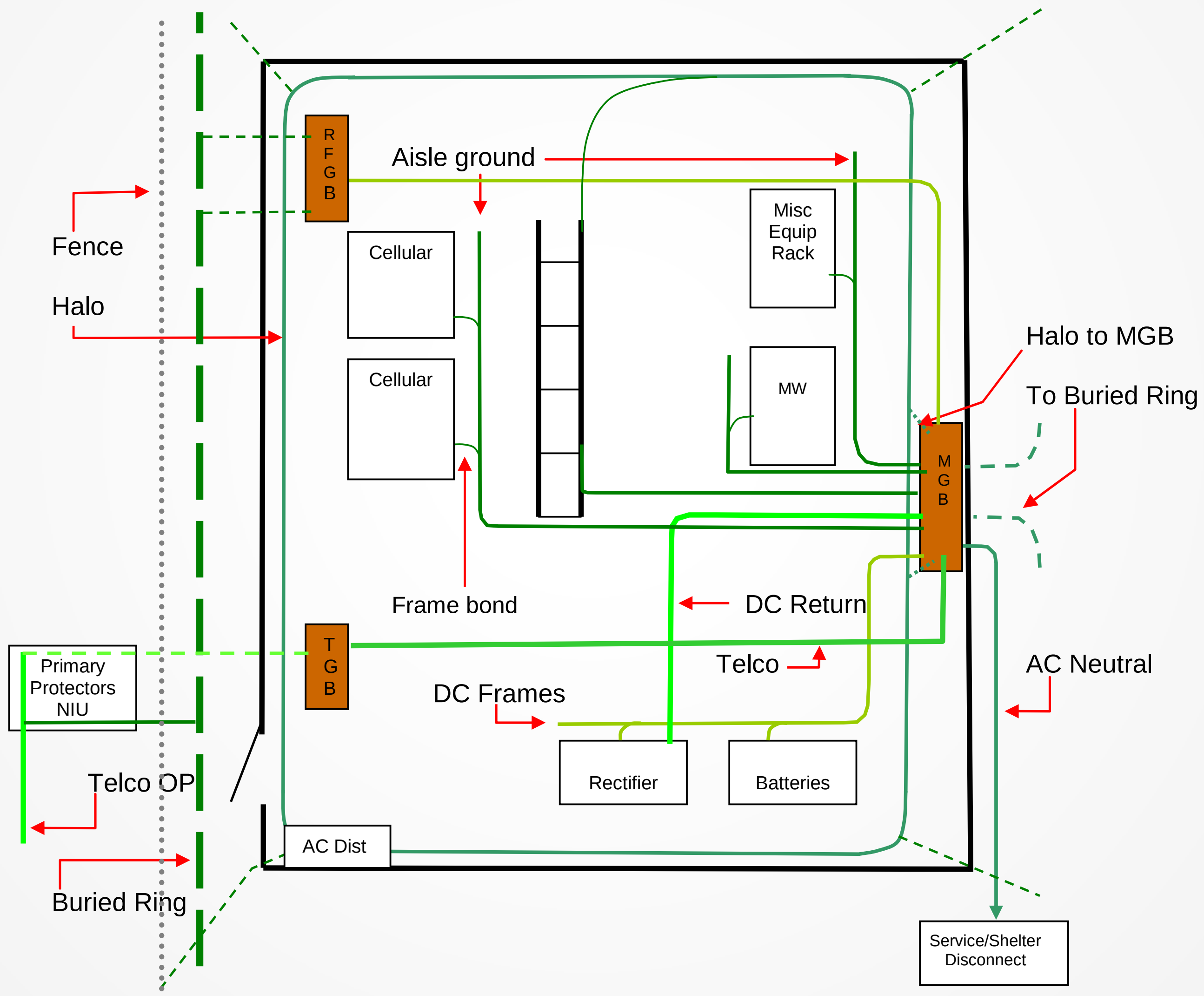


DC current was measured on all thread and 6AWG, + and - polarities

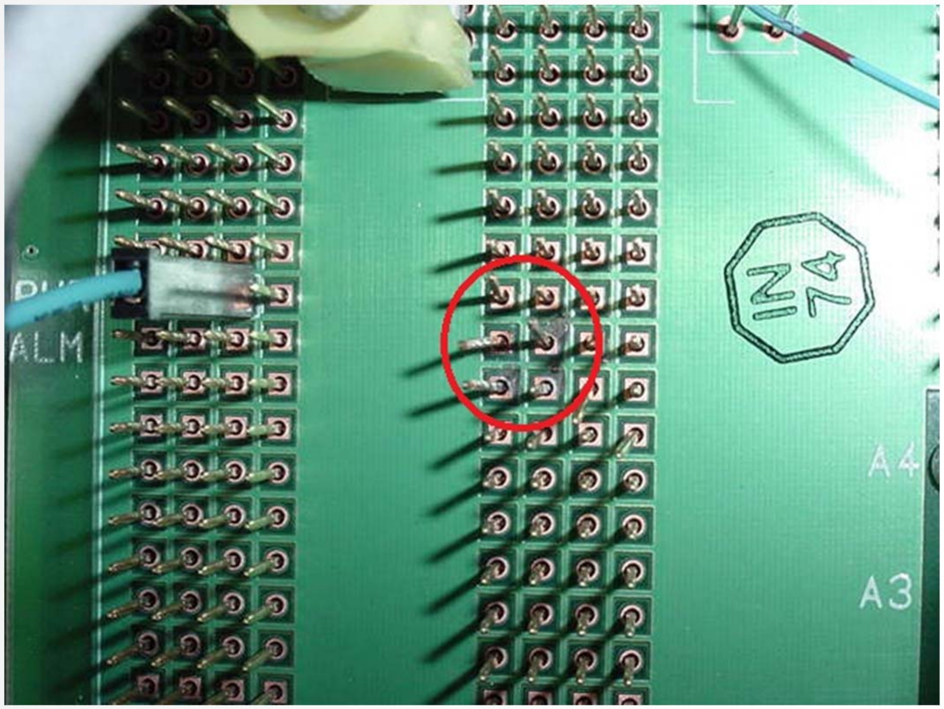
Toyota: Frame Arcing



IGZ Based Cell Site Grounding Architecture



Toyota-DIFI Board



- May 2004, Site was hit again.
- Lost Digital Interface Frame
- Second audit was performed before damaged cabinet could be removed.
- Careful examination of RS422 buss.

Toyota-Tower

- Tower and shelter ring were dug up and visually inspected, no issues found. 2AWG SBTC conductors installed per VZW standards
- 3 Point Ground resistance test was 4.75Ω. Copy of test given to VZW Engineering.
- Using binoculars, the top coax collector bar ground discharge leads looked as if they were bonded. Tower crew was dispatched "just to see" and found ground floating.
- The first of a line of severe storms that deluged KY that year was on the horizon.
- Installed a temporary ground clamp bond to the tower structure.
- There have been no issues since.

GTE/VZW Contribution

- Data supported transition from integrated grounding architecture to IGZ based architecture
  - Provided data showing DC current flow through all frame ground points
  - Provided data supporting isolation of equipment frames from cable tray
- Provided data confirming Telco shields should not be bonded inside shelter and outside equipment.
  - Removal of shield ground loop stopped lightning issues of customer equip
- Provided data supporting that any SPD installed at the service disconnect will fail if GEC does not reference the buried ring.
  - Case studies where repeated failure of device had occurred
  - After bonding GEC to buried ring, failures ceased
- Developed SPD for Obstruction Lighting.
  - Became the OEM for Hughey & Phillips, TWR, and Flash Technology
- Assisted w/input on SPD specifications used in standards.

Results of DC Return Current Flow

Effects of High current flow on buried ring

Buried Ring Integrity

Importance of monitoring contractors

RF Grounding on Towers

Importance of insuring proper installation

Tower Bonding

Verify Installation Methods

Utility Maintenance

Utility Maintenance

Findings

- AC power circuit transients limited to AC loads such as HVAC, Rectifiers, 120v test equipment and 120v rectifiers.
- Damage to Cellular and MW equipment is believed to be caused by direct lightning strikes to the tower, not AC power.
- Frame differential between AC power EGC and DC return conductors creates issues with rectifiers.
- High surge current between Utility system grounded conductor and site LPS will cause SPD failure if not bonded together. (GEC not bonded to buried ring)
- During Lightning strikes on the tower, improper bonding of Telco equipment inside site caused issues with NIU's, channel banks, not AC power transients.
- Telco equipment can be damaged from far away lightning strikes by capacitive discharge on tower. (BMI Chapel Church)
- Use of short metallic vs. non-metallic conduits made no difference with SPD performance.

Conclusion

- SURGE IMMUNITY CAN BE ACHIEVED IF:

- Follow engineering fundamentals for safety and grounding
  - Provide proper equi-potential grounding inside site
  - Provide a proper earth grounding system
  - LTE DC circuits. Ground cable assemblies to buried ring at tower.
- Provide 2 level SPD philosophy for AC power circuits
- Provide Protection for all other exposed circuits
  - Data
  - Obstruction lighting
  - DC Power-use all mode: +/-, +/ground, -/ground
  - TMA (Tower Mount Amp)
- Size Matters, smaller SPD's facilitate shorter lead length and better performance. Reduce installation costs.
- Verify with pictures and onsite inspections work progress.
- Follow up on contractors who may accidentally compromise the grounding architecture during modifications
- Don't solely rely on your techs to perform audits or inspections.

BAM!!!

Glossary

- MLV: Measured Let Through Voltage:
  - Maximum magnitude of voltage, measured at the leads of the specified waveform and amplitude
- SPD: Surge Protective Device:
  - A device w/one or more non-linear component, intended for limiting surge voltages by diverting surge current
- TVSS: Transient Voltage Surge Suppression
  - Name used prior to UL 3rd Edition
- Modes of Protection: Electrical path where SPD offers defense
  - L-N, L-G, L-L, N-G
- EUT: Equipment Under Test
- CRGB: Cell Reference Ground Bar. Synonymous with MGB
- Isolation Transformer: 240v primary. 120/240v secondary.
  - Static shielding between primary and secondary, not wound on same iron core.
  - Neutral is derived on secondary side.

SPD Manufacturer & Model

- **Competitor 1**: MOV with L-N protection only. L-L protection is a series circuit of the L-N modules. NEMA 4 Steel enclosure 12 x 14 inches. Fuses provided: 60 amp FRN-R.
- **Competitor 2**: SAD only L-N protection only. L-L protection is a series circuit of the L-N modules. NEMA 12 Steel enclosure 20 x 22 inches. Fuses provided: None.
- **Competitor 3**: SAD and MOV, L-N protection only. L-L protection is a series circuit of the L-N modules. NEMA 4 Steel enclosure 20 x 22 inches. Fuses provided: None.
- **Competitor 4**: MOV with All mode protection. Single module in NEMA 4X Fiberglass enclosure 10 x 12 inches. 60 amp fuses provided.
- **Competitor 5**: MOV and 100 kHz filtering, all mode protection. Single, NEMA 12 steel enclosure. No fusing, 30" leads provided cut to length and terminated on 2 pole 30 amp breaker.
- **ACT Communications "Assault, part number 472-120-3D3G**. MOV based, L-N protection, Fused disconnect, NEMA 12 Steel enclosure.