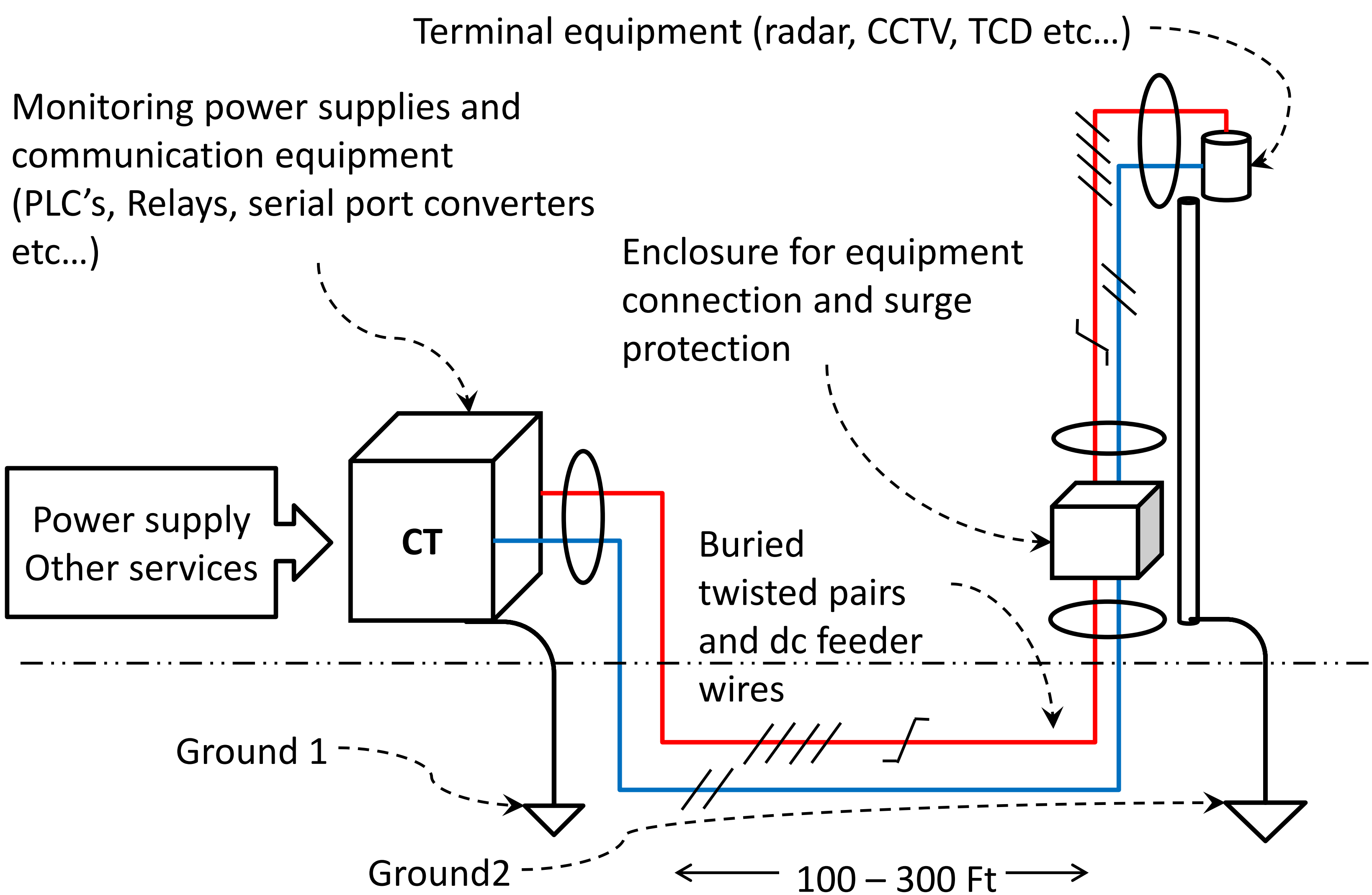
Cases study: Road equipments facing surges in rough environment.

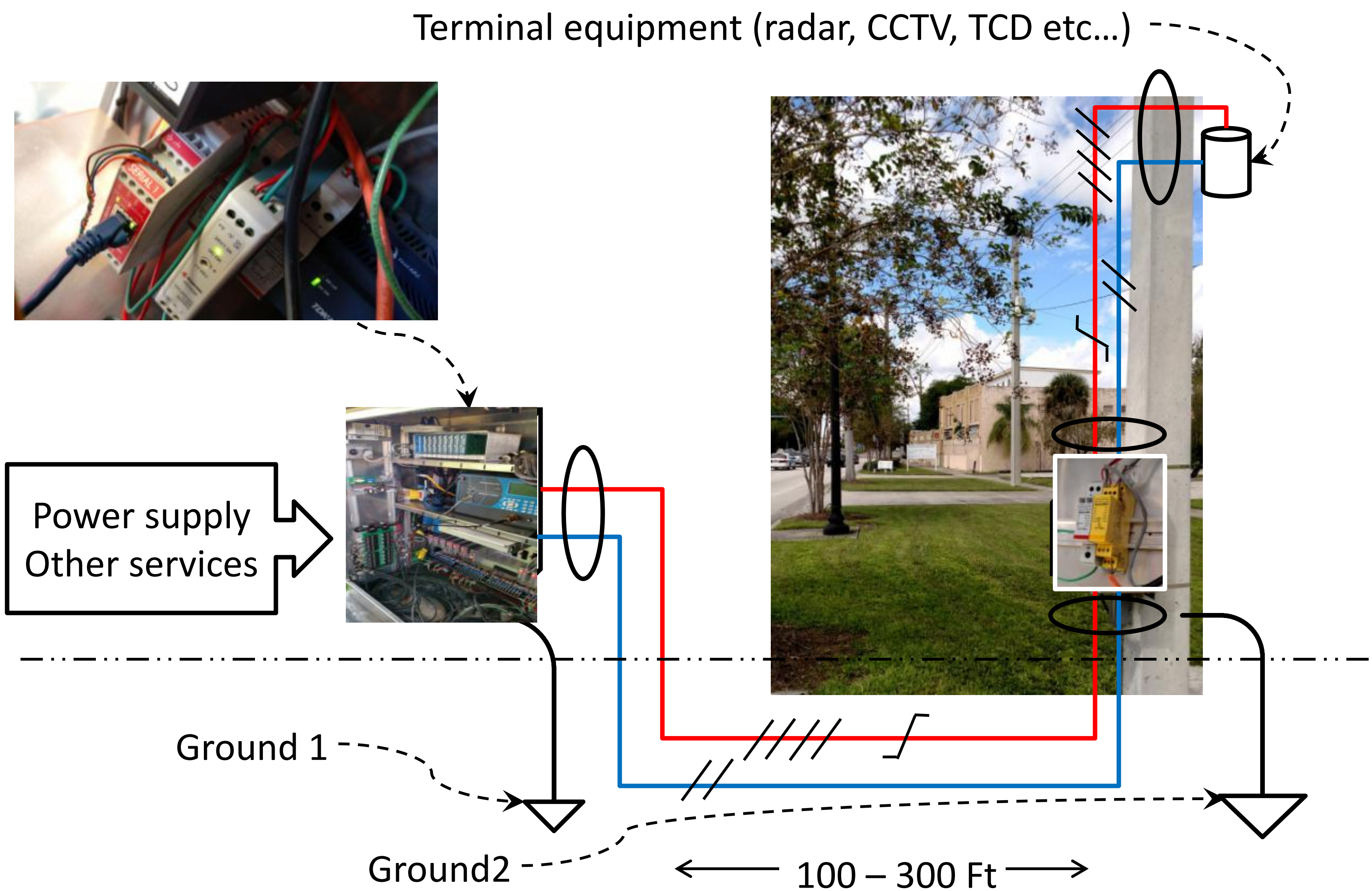
PEG CONFERENCE

Presented by:
Vincent Crevenat
Director of Engineering
Citel

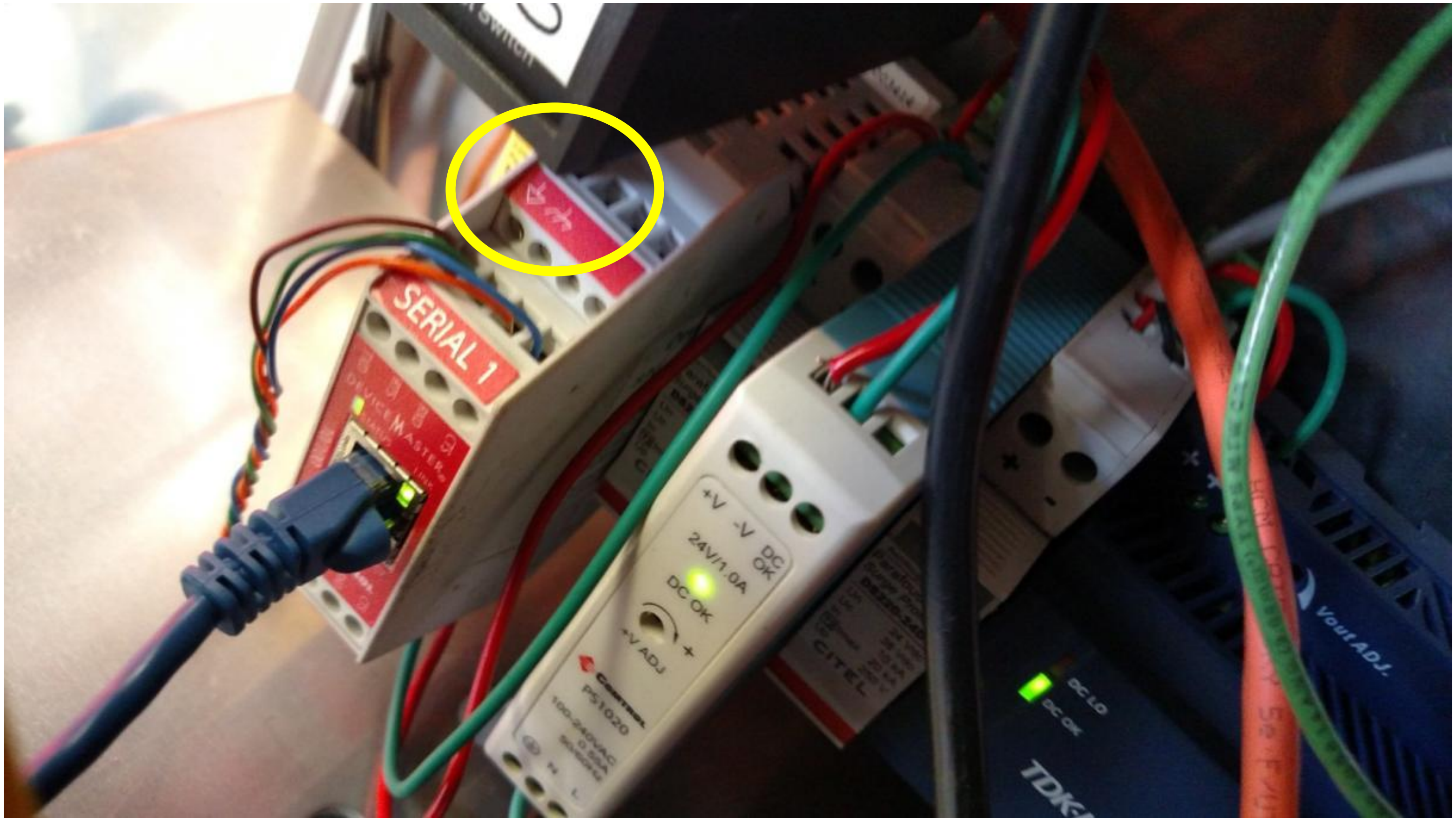
Case 1


Terminal equipment (radar, CCTV, TCD etc…)
Monitoring power supplies and communication equipment (PLC's, Relays, serial port converters etc…)
Enclosure for equipment connection and surge protection
Power supply
Other services
CT
Buried twisted pairs and dc feeder wires
Ground 1
Ground2
100 – 300 Ft

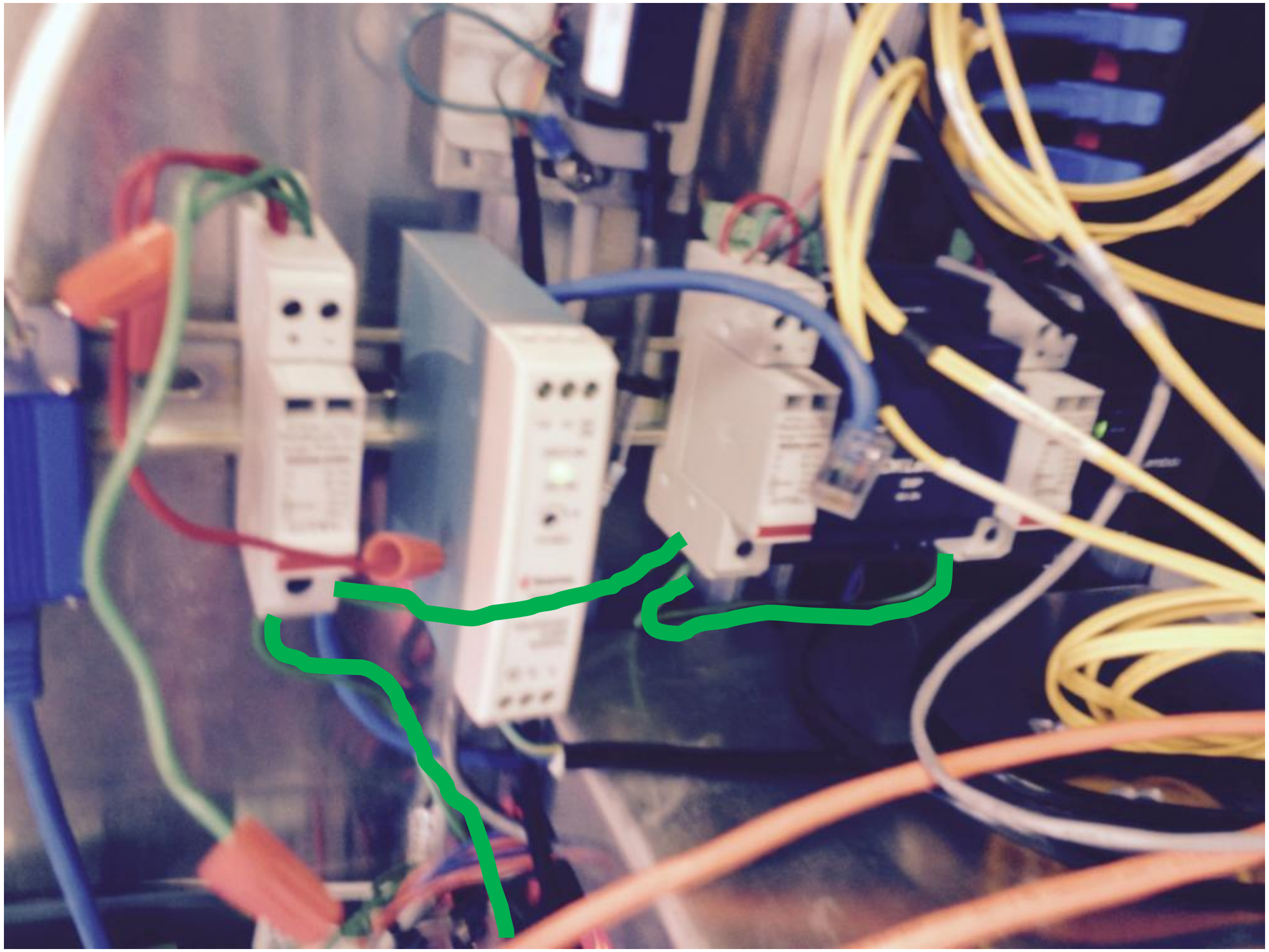
Case 1


Terminal equipment (radar, CCTV, TCD etc...)
Power supply
Other services
Ground 1
Ground2
100 – 300 Ft

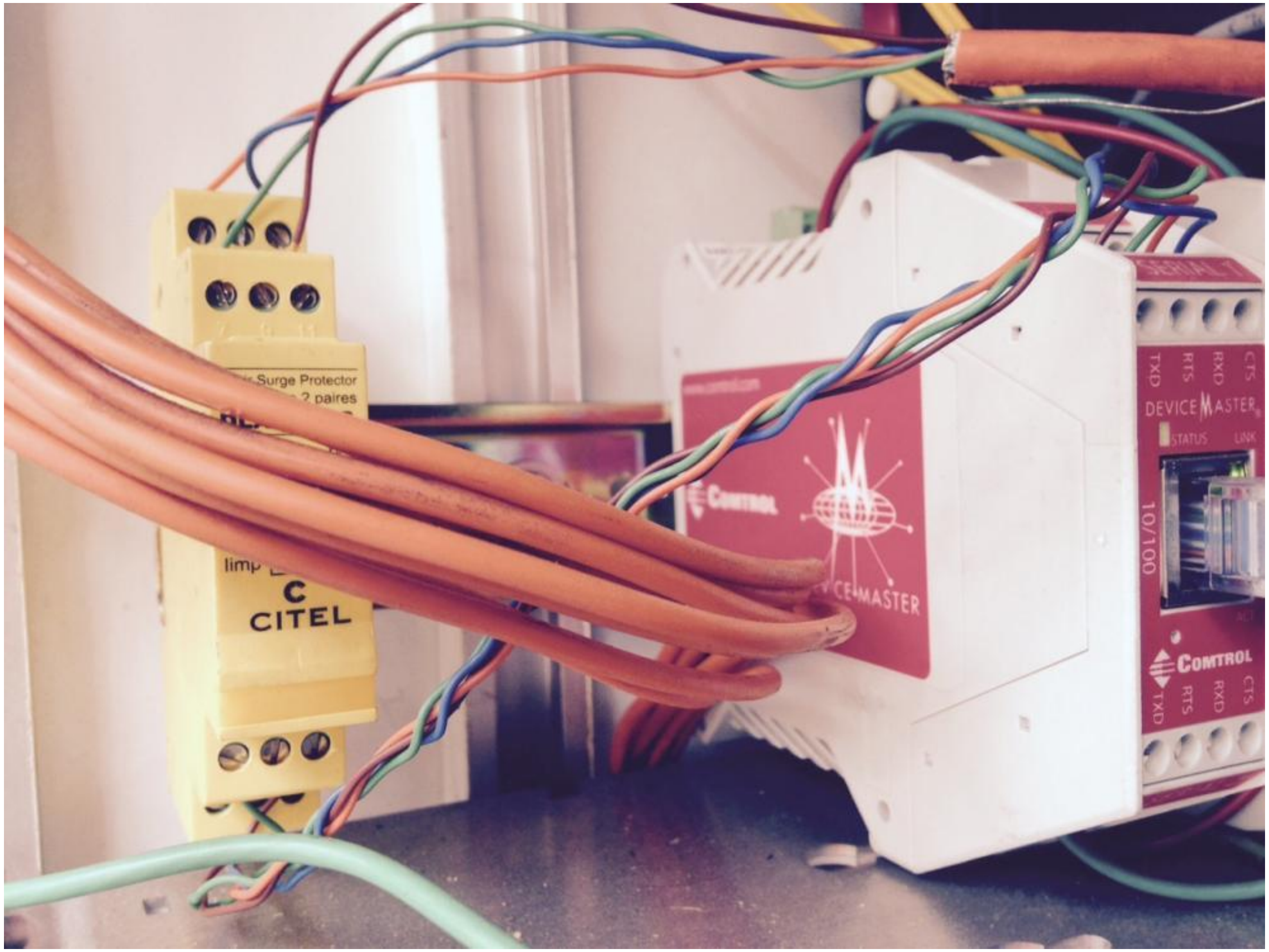
Case 1 (before in CT)



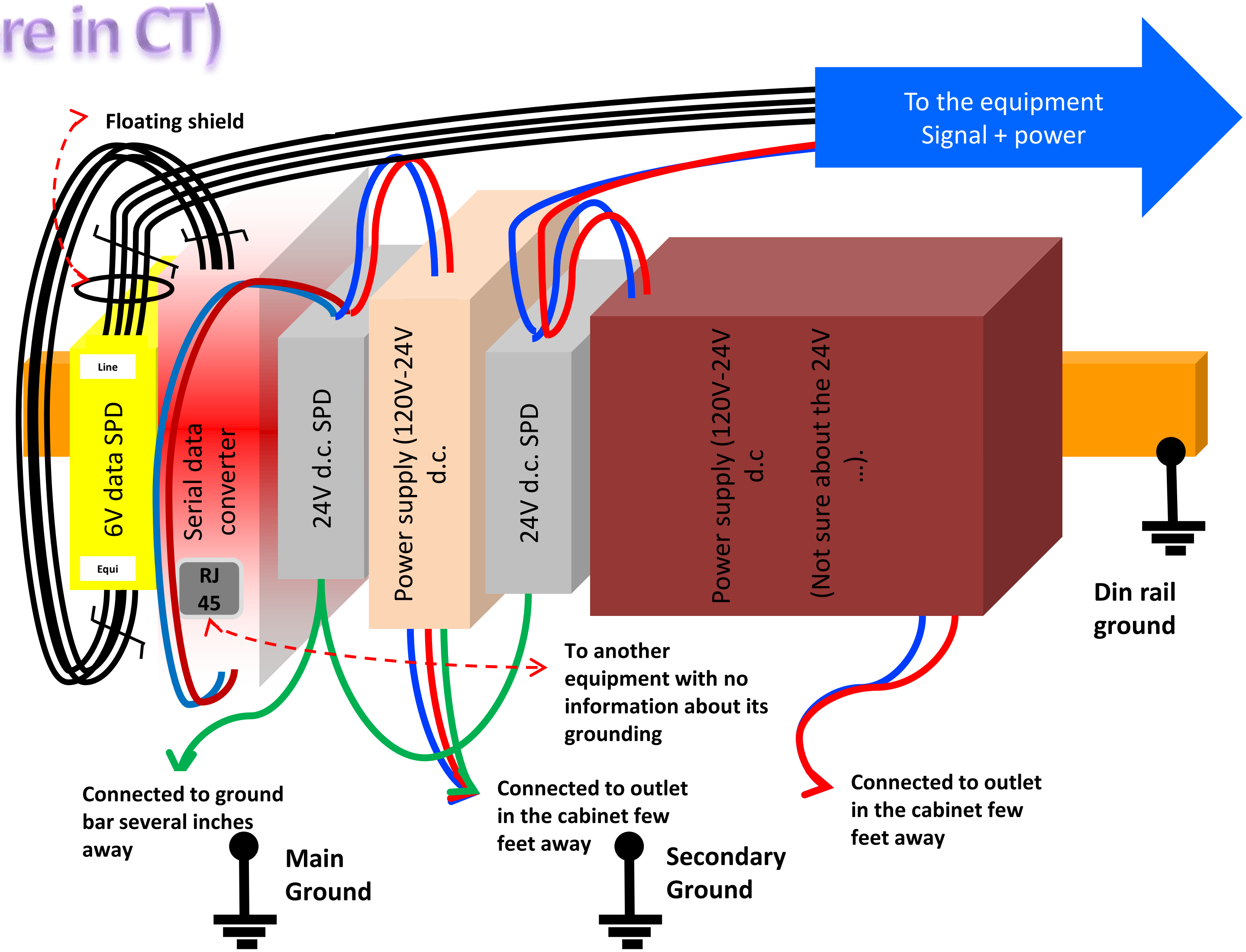
Case 1 (before in CT)

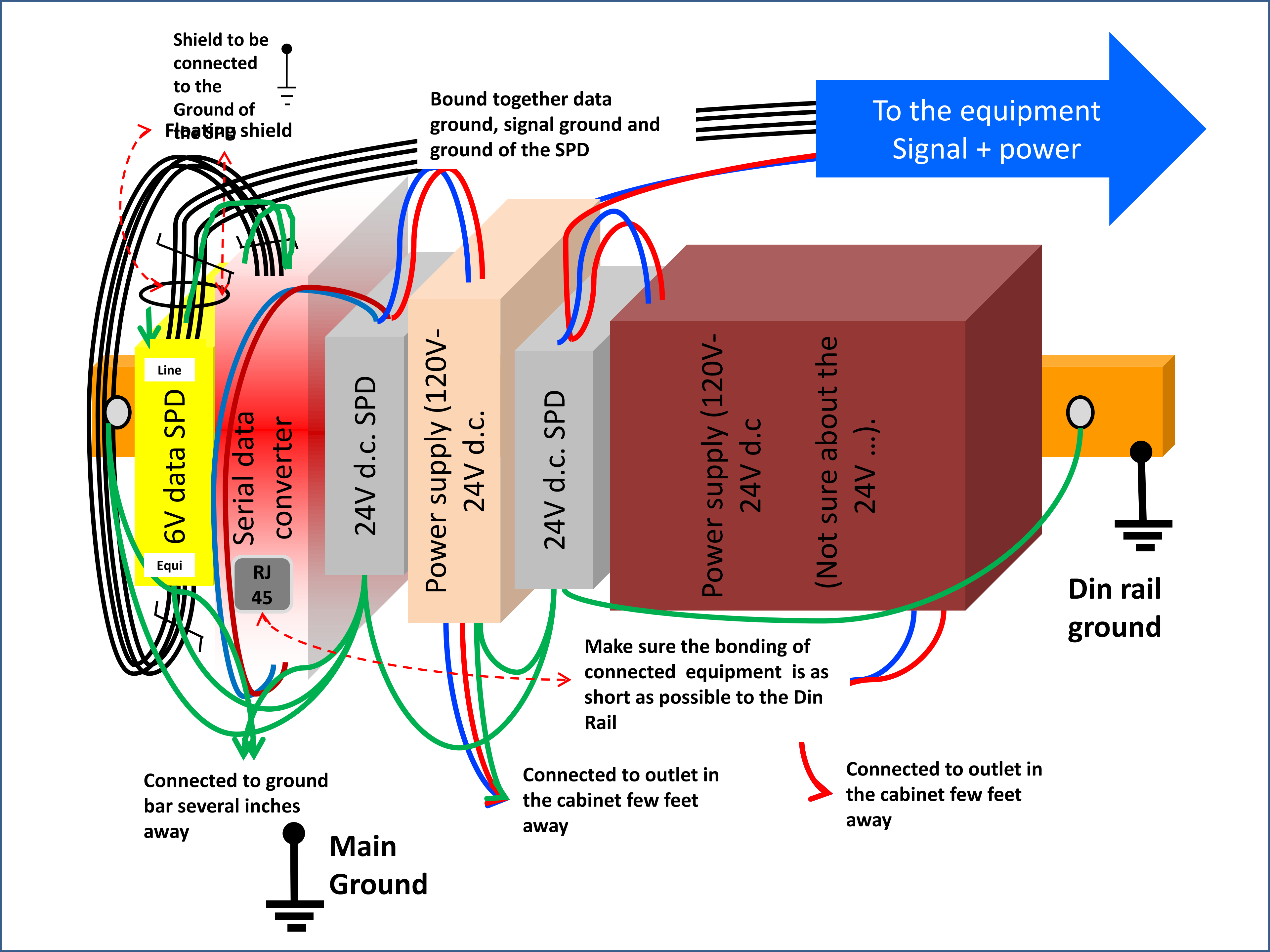


Case 1 (before in CT)



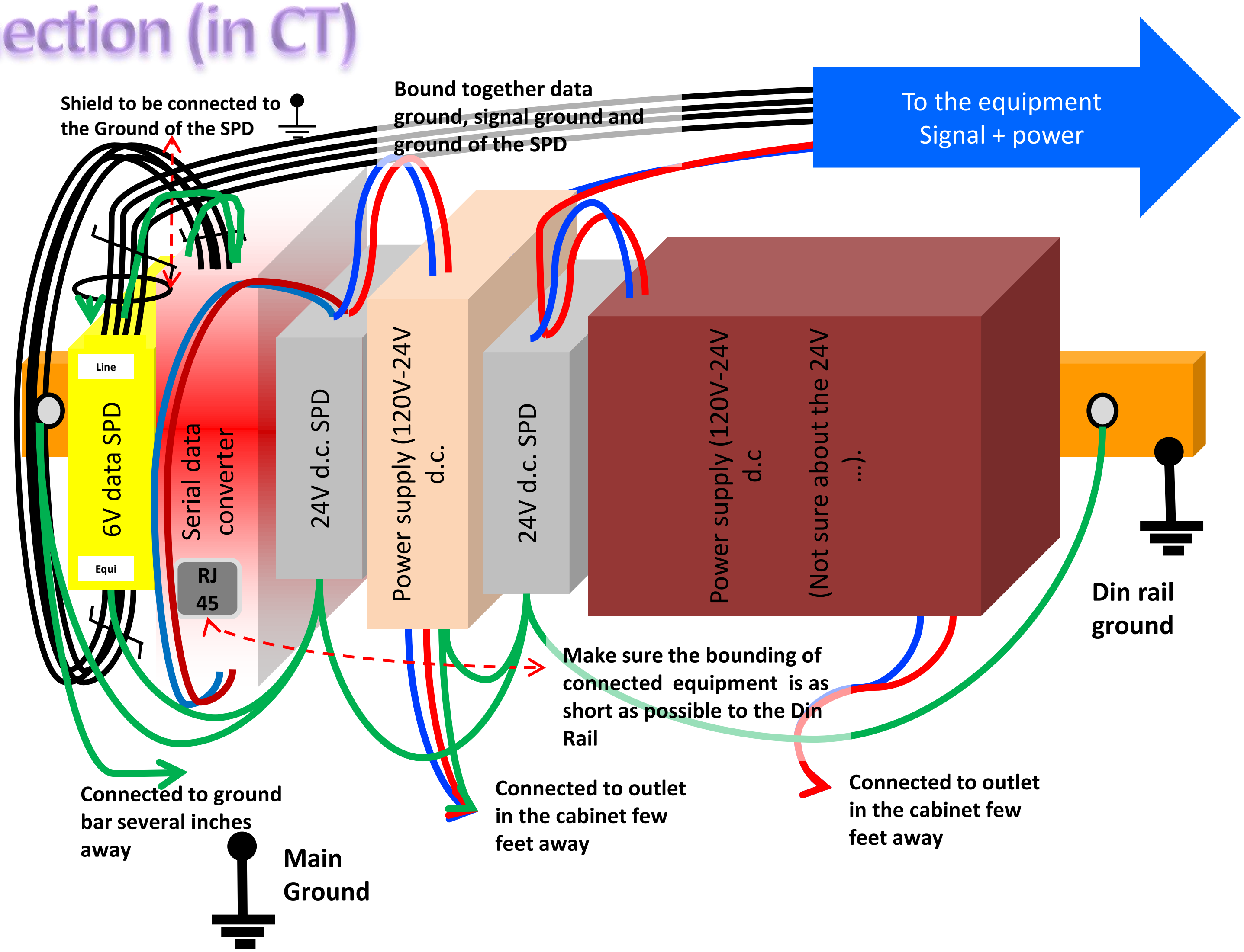
Case 1 (before in CT)





Shield to be connected to the Ground of the SPD
Floating shield
Bound together data ground, signal ground and ground of the SPD
To the equipment Signal + power
Line
6V data SPD
Equi
Serial data converter
RJ 45
24V d.c. SPD
Power supply (120V-24V d.c.
24V d.c. SPD
Power supply (120V-24V d.c
(Not sure about the 24V …).
Din rail ground
Make sure the bonding of connected equipment is as short as possible to the Din Rail
Connected to ground bar several inches away
Main Ground
Connected to outlet in the cabinet few feet away
Connected to outlet in the cabinet few feet away

Proper connection (in CT)



Protection Engineers Group

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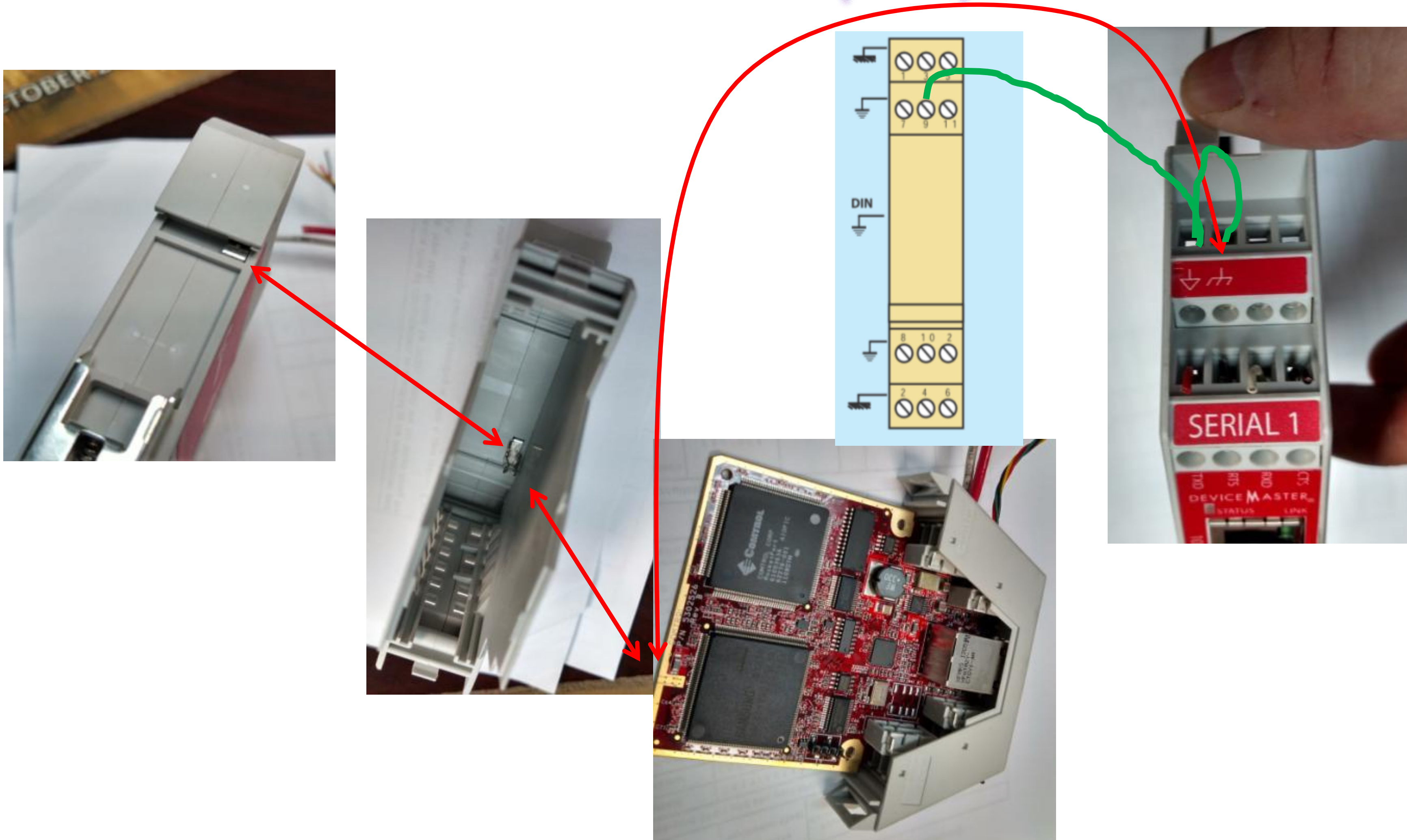
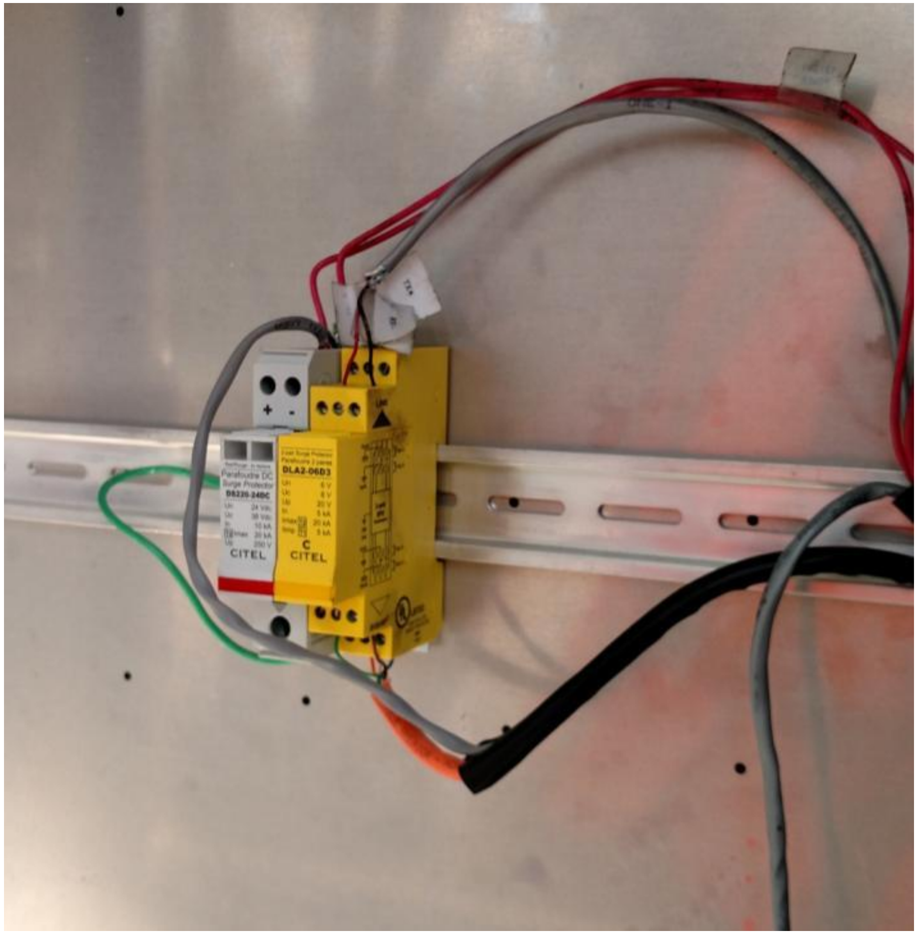
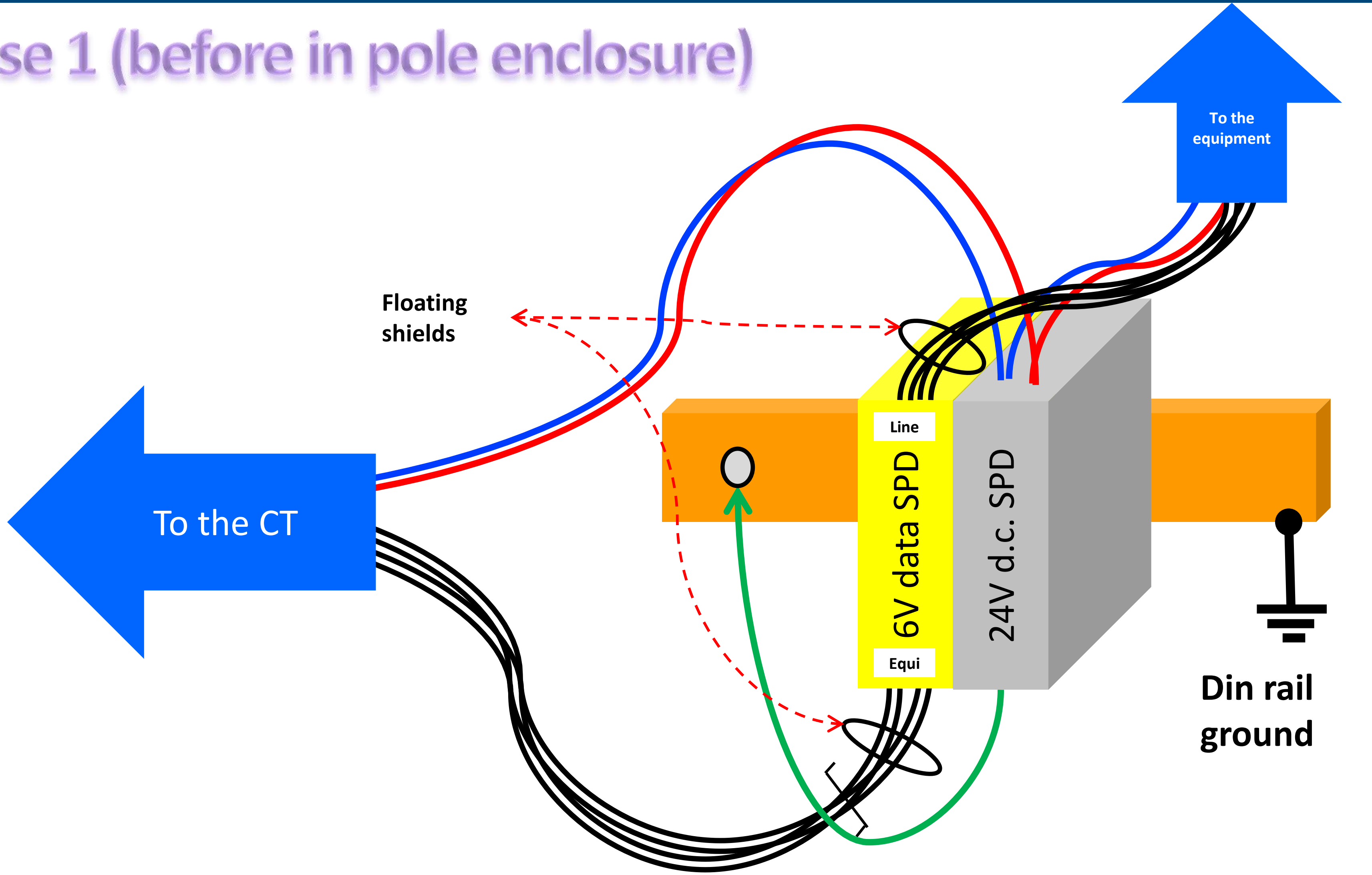
Ground connection serial converter (in CT)



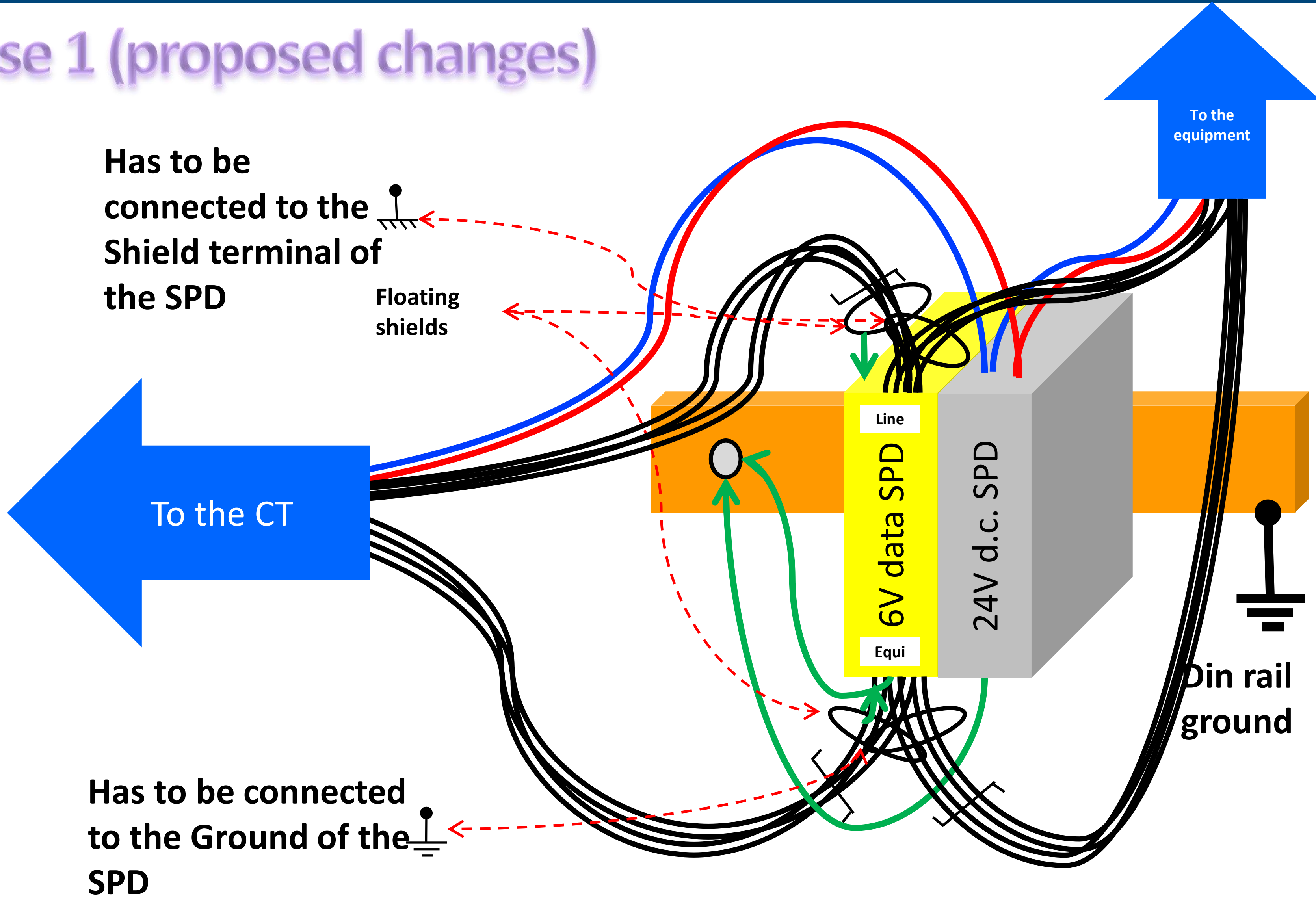
Case 1 (before in pole enclosure)



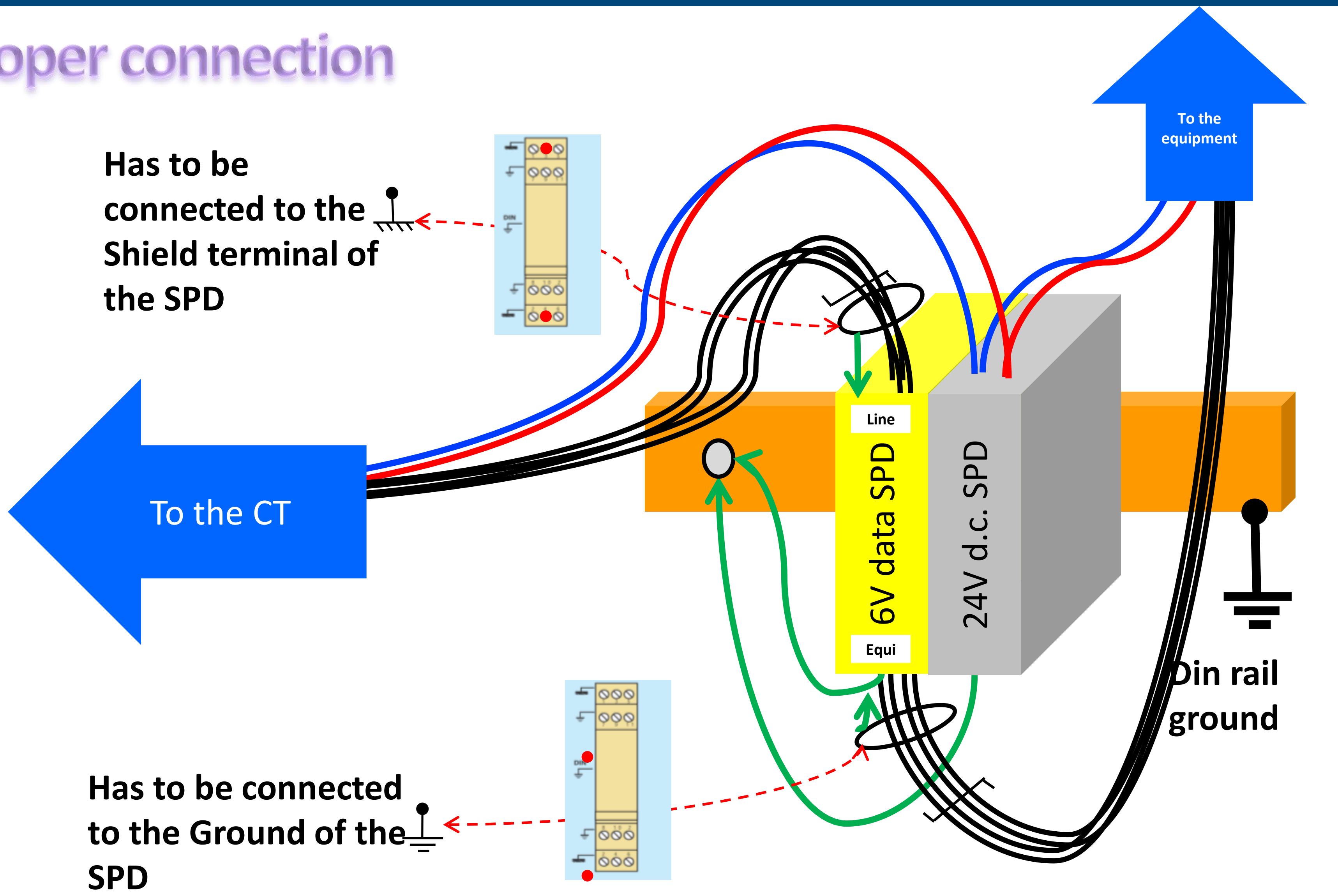
Case 1 (before in pole enclosure)



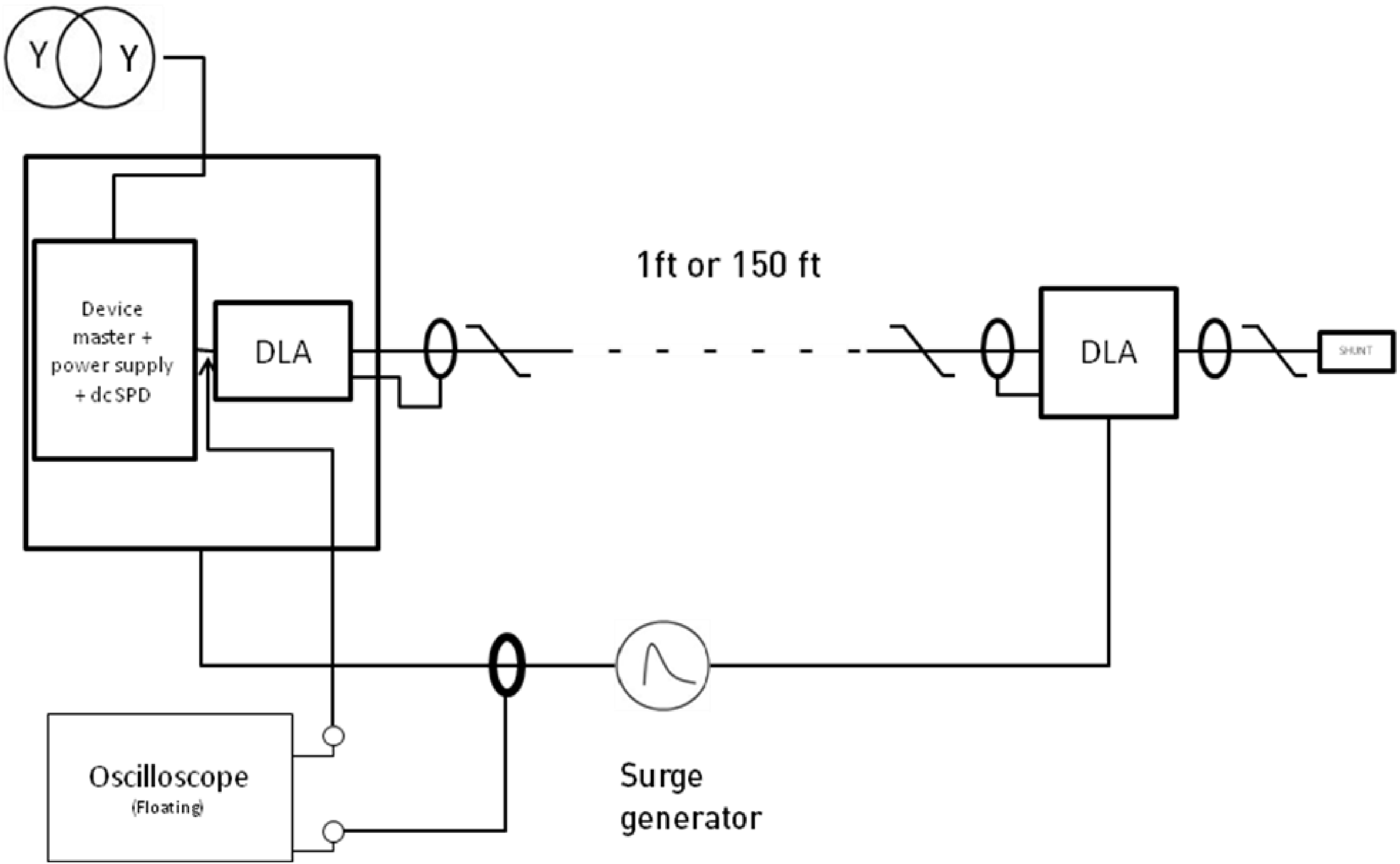
Case 1 (proposed changes)



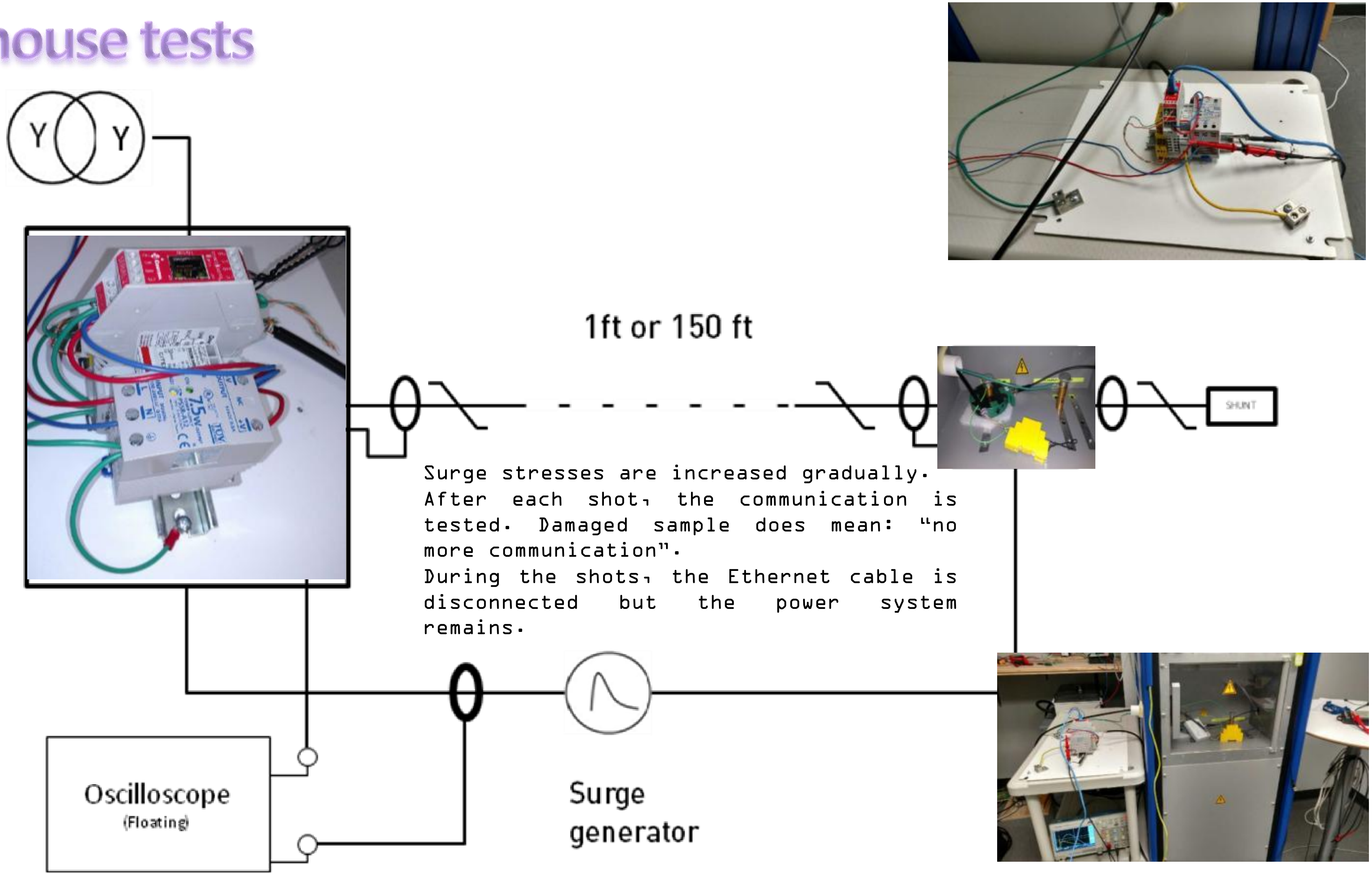
Proper connection



In house tests



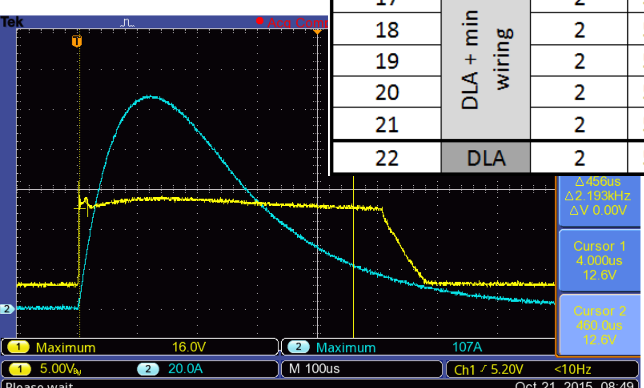
In house tests



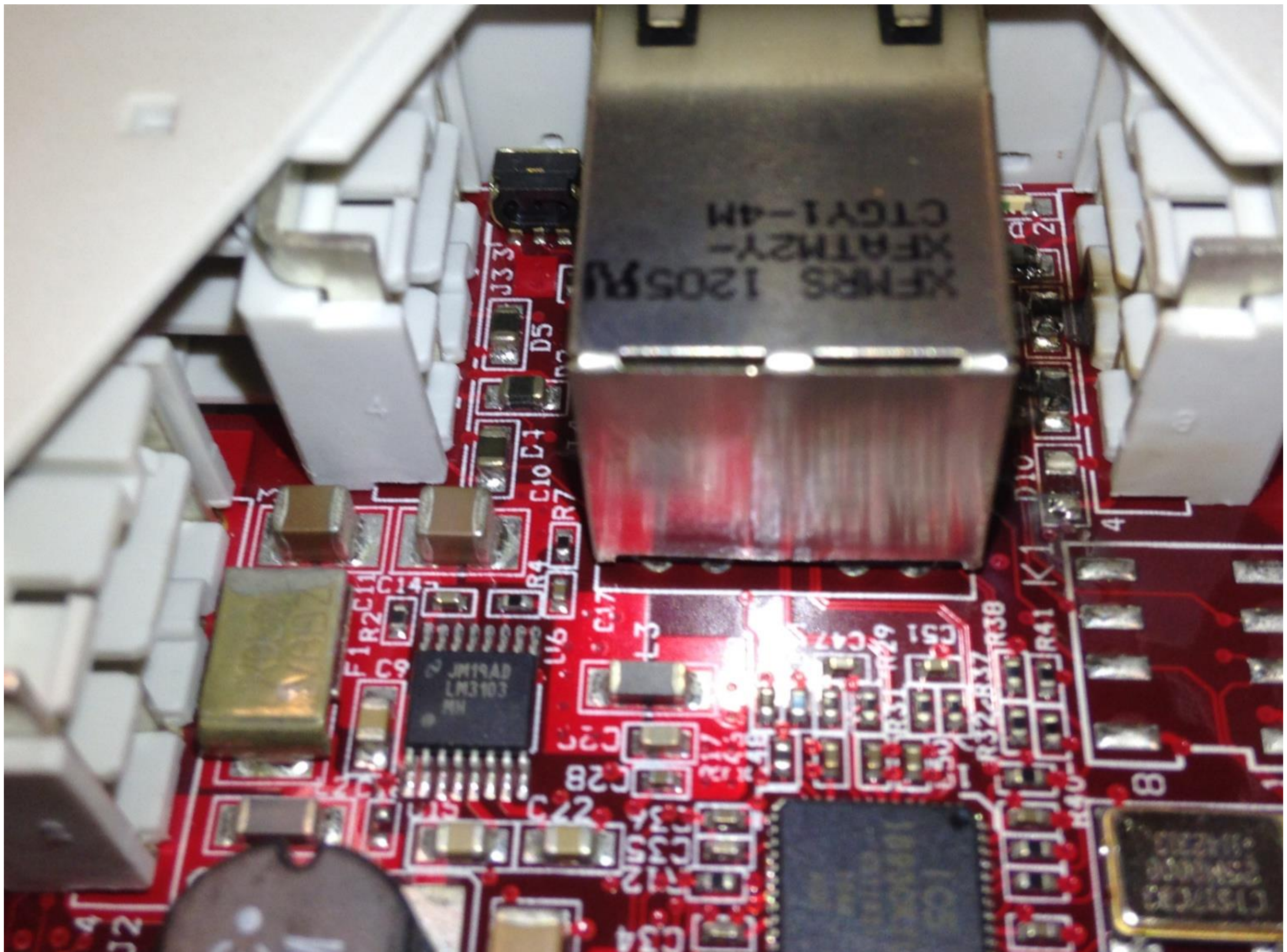
Surge stresses are increased gradually. After each shot, the communication is tested. Damaged sample does mean: "no more communication".
During the shots, the Ethernet cable is disconnected but the power system remains.

In house tests

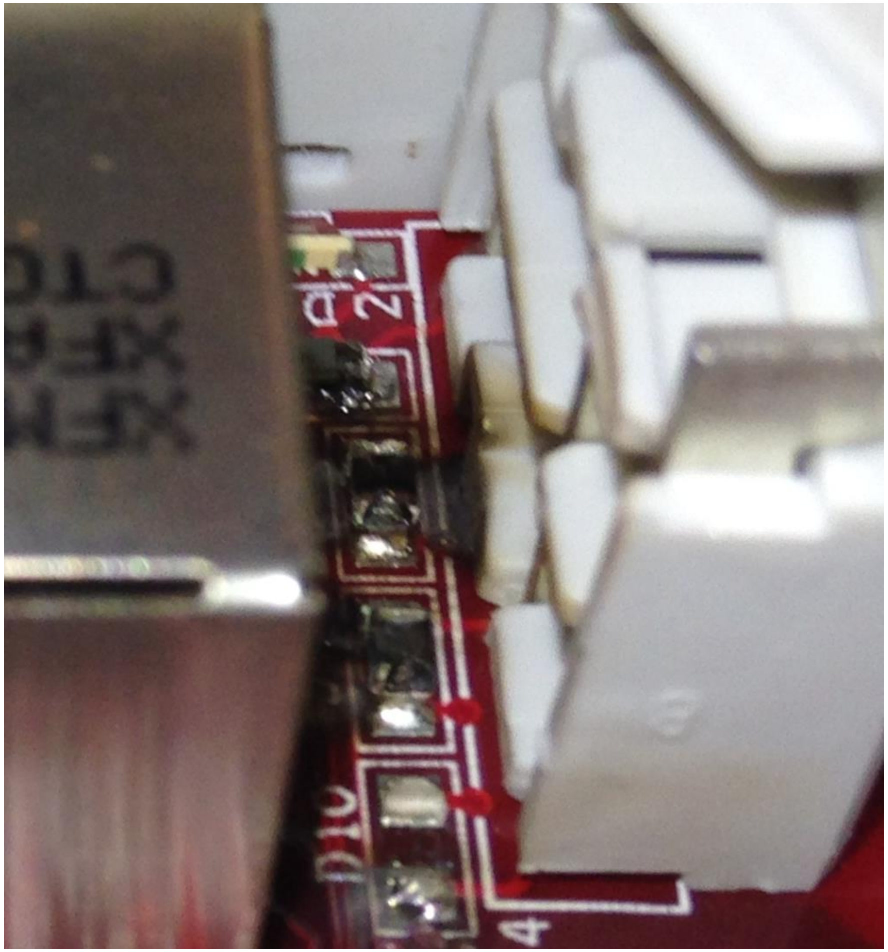
Shot number	Test seting	Tested port	Wave shape	Charging voltage (V)	peak current (A)	peak residual voltage (V)	long residual voltage	approximate stress duration (µs)	status after shock	record	Note
1	DLA + good wiring	1	50/300	2740	60	/		/	OK	/	
2		1	50/300	3000	82	14.4	14.0	480	OK	50	
3		1	50/300	4000	107	16.0	14.0	510	OK	51	
4		1	50/300	6000	160	18.0	15.0	590	OK	52	
5		1	50/300	10000	274	25.0	17.0	560	OK	53	
6		1	50/300	15000	412	27.6	22.0	676	OK	56	
7		1	50/300	20000	556	29.2	24.0	690	OK	57	
8		1	50/300	25000	700	27.6	26.0	700	OK	58	
9		1	8/20	2740	1300	/	/	/	OK	/	
10		1	8/20	2740	1300	30.0	30.0	20	OK (after reset)	59	
11		1	8/20	3000	1480	28.0	20.0	20	OK (few com errors)	60	
12		1	8/20	3000	1480	32.0	19.0	20	OK (few com errors)	61	
13		1	8/20	4000	1960	44.0	20.0	20	OK (after reset)	63	
14		1	8/20	6000	2900	41.2	24.0	25	OK	64	
15		1	8/20	10000	4800	47.0	28.0	25	OK	65	
16		1	8/20	12000	5840	60.0	32.0	27	NOK	66	I *2 from plot
17	DLA + min wiring	2	50/300	3000	68	16.4	16.4	450+	OK	69	
18		2	50/300	6000	140	22.4	22.4	450+	OK	70	
19		2	50/300	10000	258	24.4	24.4	450+	OK (after reset)	72	
20		2	50/300	20000	528	33.2	30.0	450+	OK	73	
21		2	50/300	25000	664	36.6	36.6	450+	NOK	74	
22	DLA	2	50/300	25000	664	90++	90++	450+	Explosion	75	



In house tests



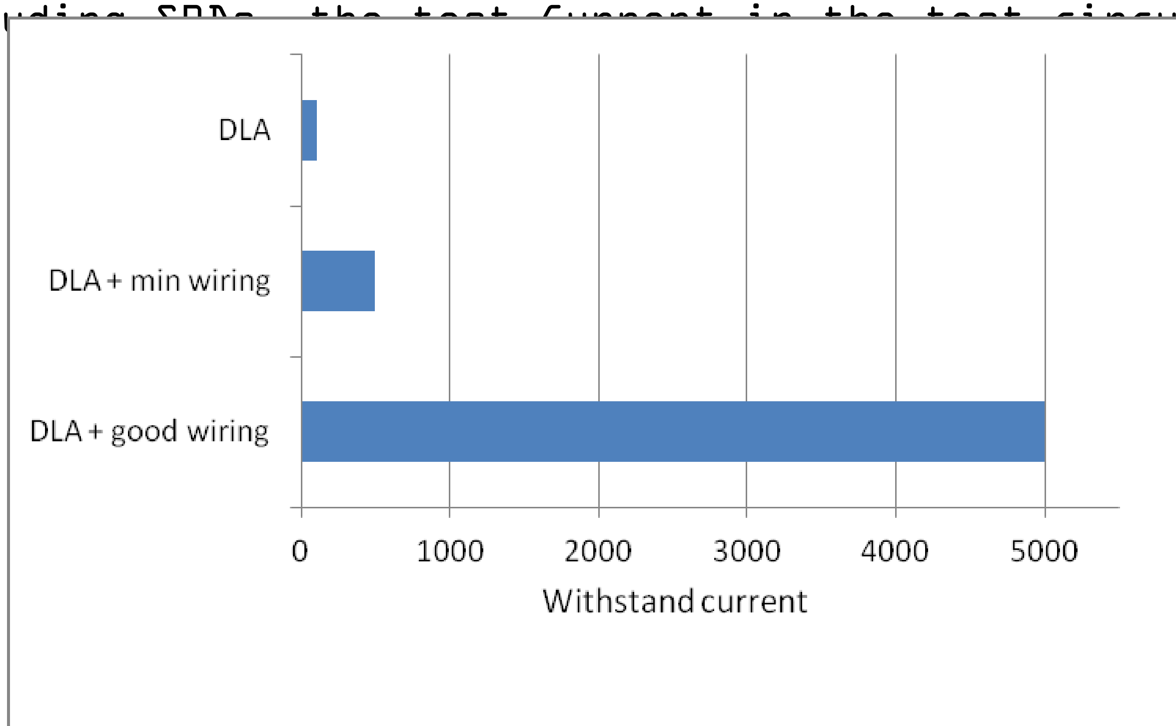
In house tests



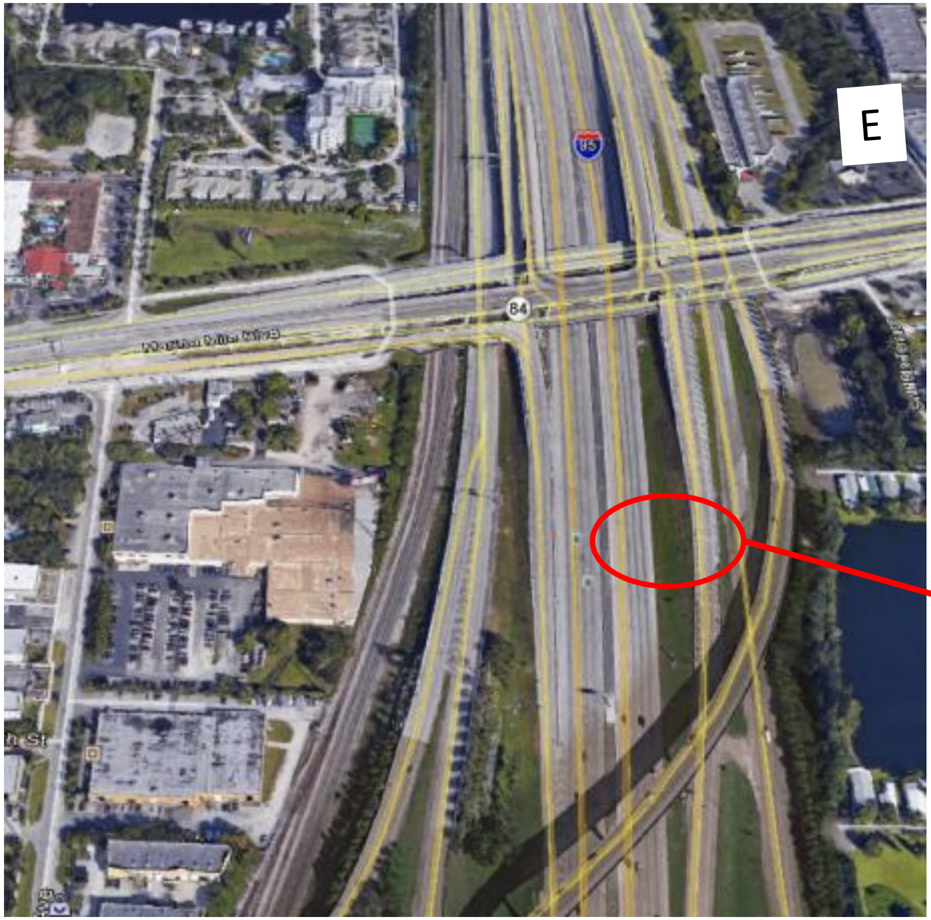
In house tests

When the device is subject to surge stress and when wiring does not include SPD, withstand can be estimated 100A but no information on this is available.

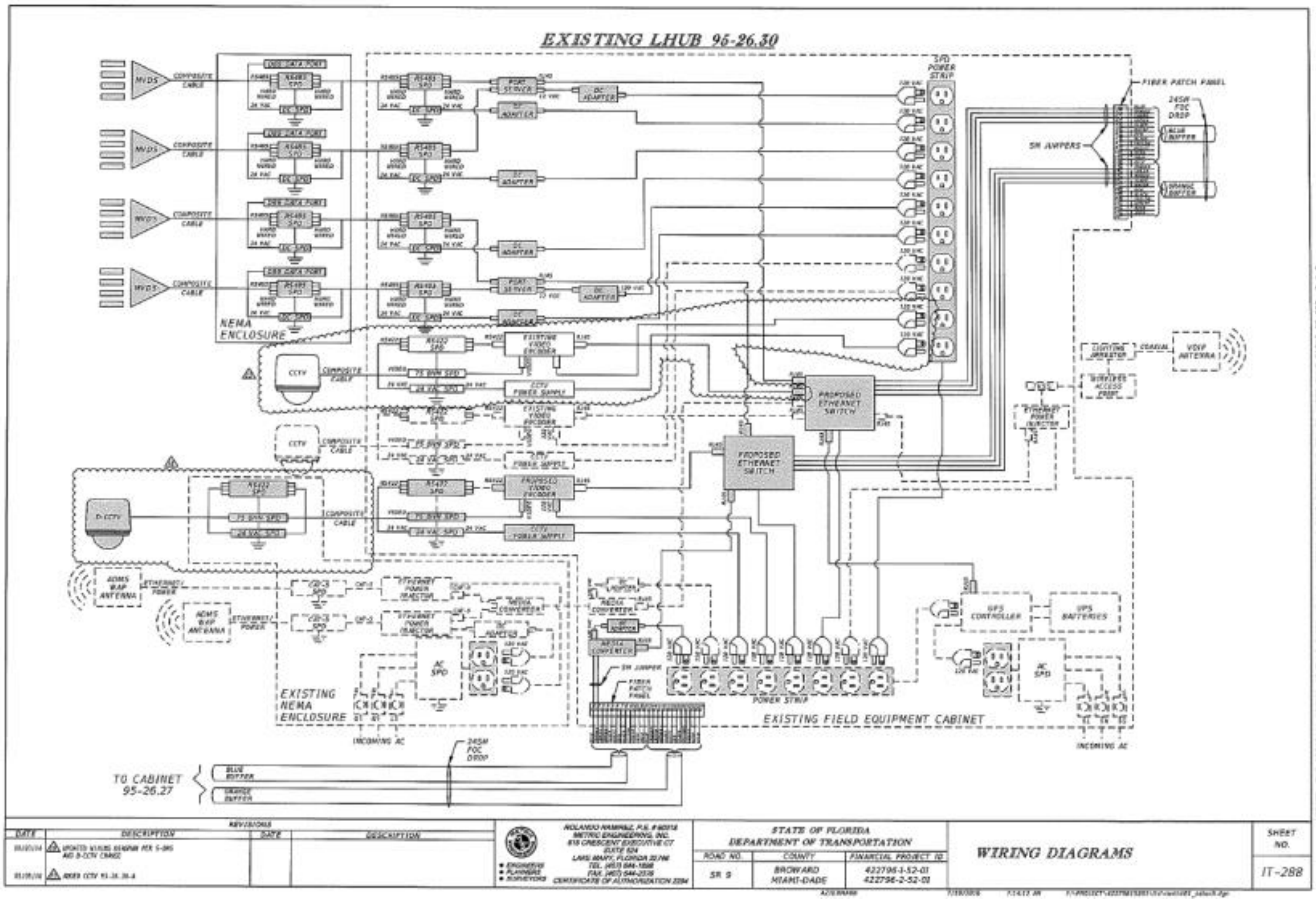
- When the device is subject to surge stress and when wiring is not optimised including SPDs, the maximum Current in the test circuit was **528A** 50/300
- When the device is subject to surge stress and when wiring is optimised including SPDs, the test Current in the test circuit was **4800A** 8/20.



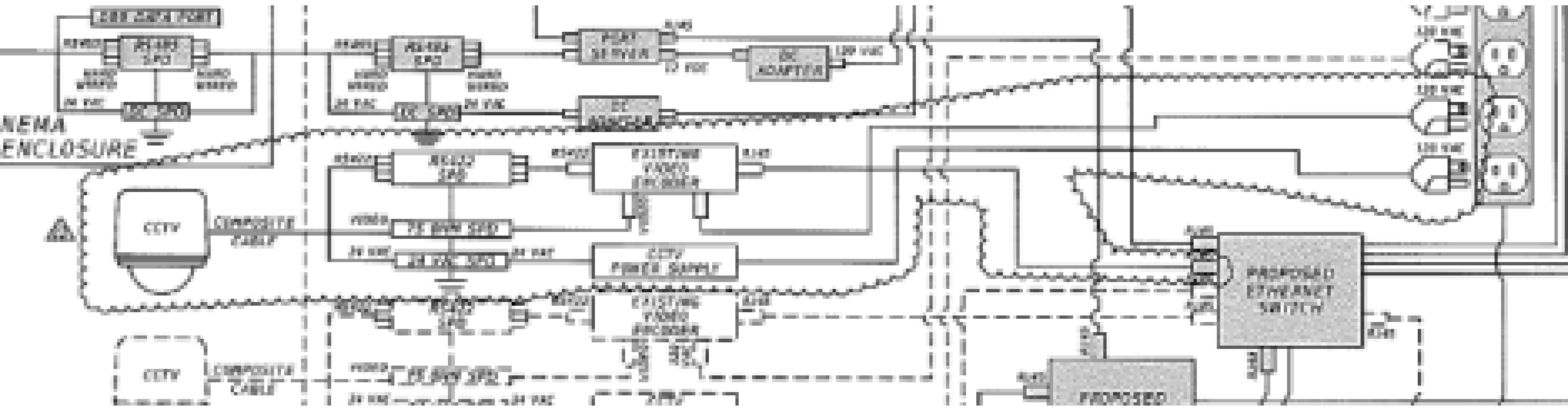
Case 2



Case 2

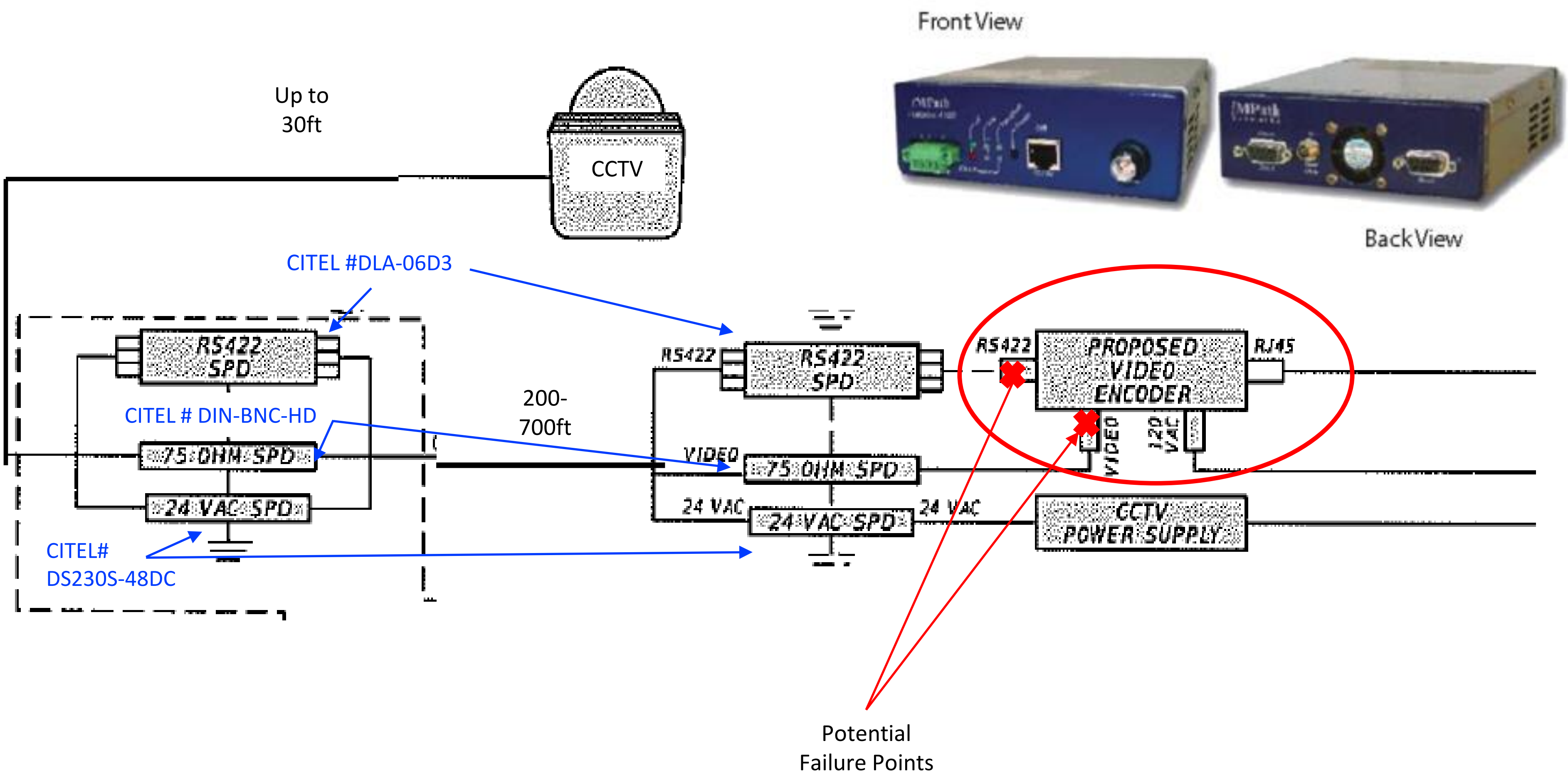

EXISTING LHUB 95-26.30
MVDS
COMPOSITE CABLE
NEMA ENCLOSURE
SPD POWER STRIP
FIBER PATCH PANEL
SM JUMPERS
CCTV
PROPOSED ETHERNET SWITCH
UPS CONTROLLER
UPS BATTERIES
AC SPD
POWER STRIP
EXISTING FIELD EQUIPMENT CABINET
EXISTING NEMA ENCLOSURE
INCOMING AC
TO CABINET 95-26.27
BLUE BUFFER
ORANGE BUFFER
STATE OF FLORIDA
DEPARTMENT OF TRANSPORTATION
SR 9
BROWARD
MIAMI-DADE
WIRING DIAGRAMS
IT-28B

Case 2

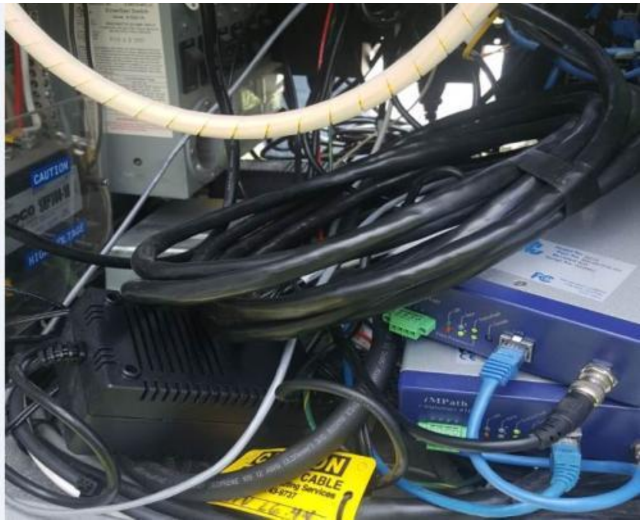


Reports from a costumer stated the Impath Encoders are failing at multiple locations. The Impath Encoder is only device failing through serial (RS422) and video (BNC), the serial ports are protected by CITEL surge protective devices (SPD's). The CCTV camera is 30ft from Cabinet with CITEL SPD's then a run of 200-700ft to a second cabinet with CITEL SPD's and the Impath Encoder.

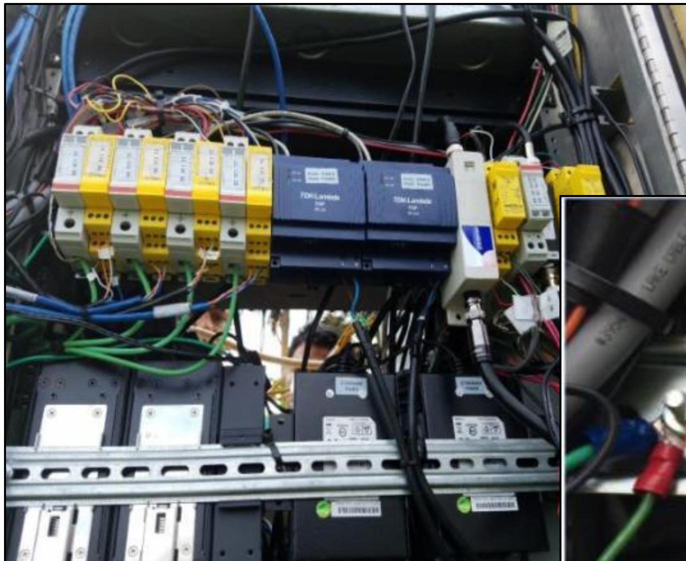
Case 2


Front View
Back View
Up to
30ft
CCTV
CITEL #DLA-06D3
RS422
SPD
CITEL # DIN-BNC-HD
75 OHM SPD
24 VAC SPD
CITEL#
DS230S-48DC
200-
700ft
RS422
RS422
SPD
VIDEO
75 OHM SPD
24 VAC
24 VAC SPD
24 VAC
RS422
PROPOSED
VIDEO
ENCODER
RJ45
VIDEO
120
VAC
CCTV
POWER SUPPLY
Potential
Failure Points

Case 2

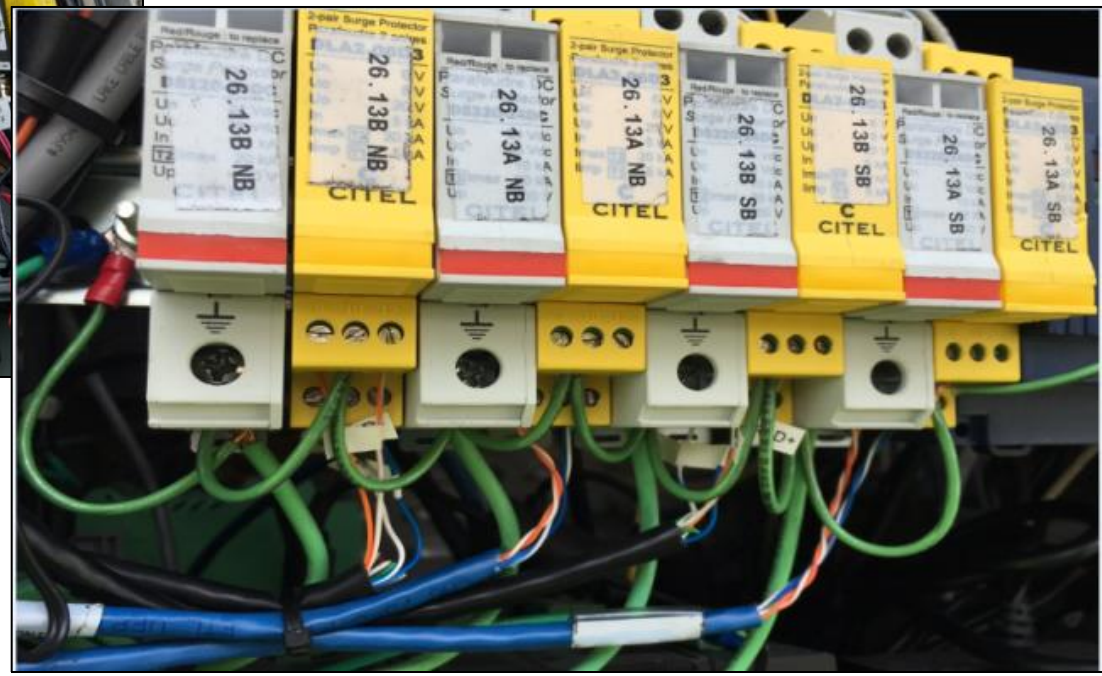


Case 2



Before

After

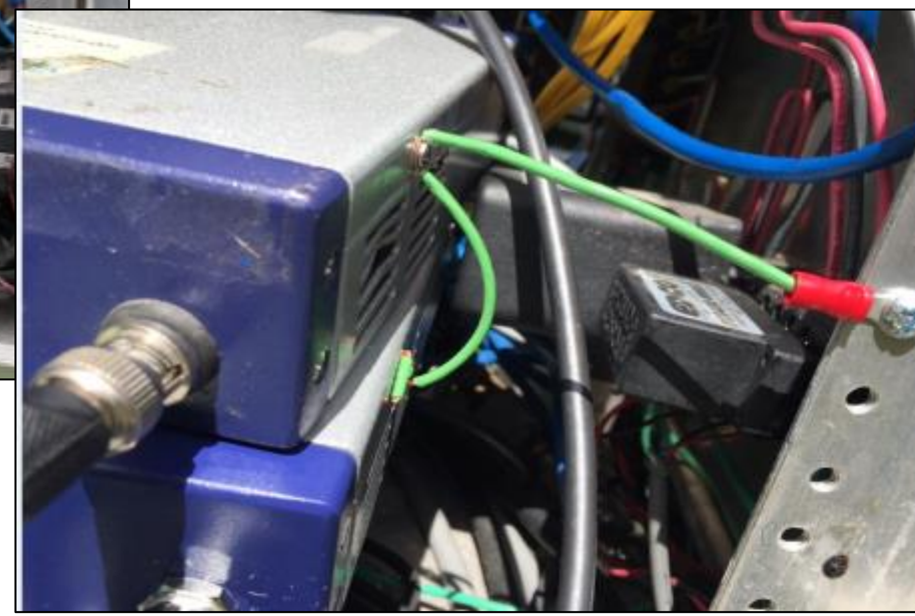


- Reduced failures once implementation our recommendation to bond all equipment's.
- Reduce failures by limiting wire loops in the cabinets which builds up coupling

Case 2

Before

After



- Reduced failures once implementation our recommendation to bond all equipment's.
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Case 2

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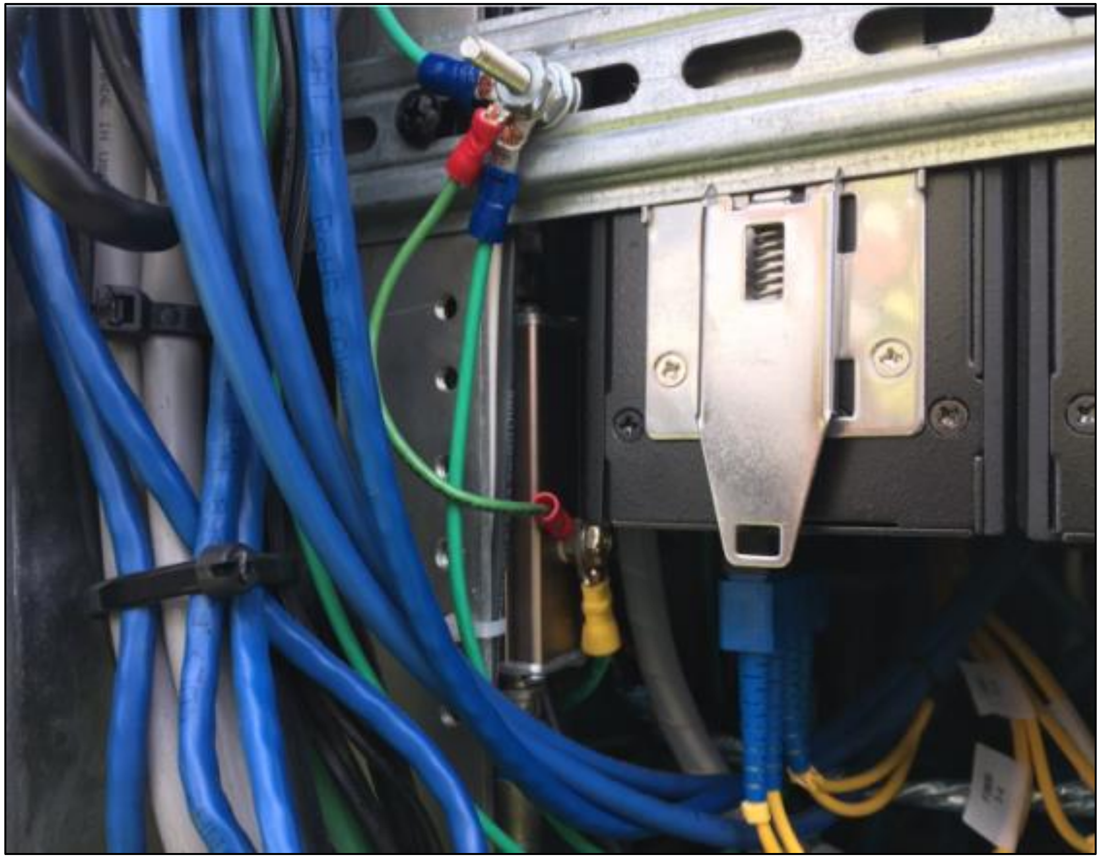
Case 2



- Reduced failures once implementation our recommendation to bond all equipment's.
- Reduce failures by limiting wire loops in the cabinets which builds up coupling

In house tests

RS232 Port Test:

BNC Port Test:

In house tests: No SPD

RS232 Test:

Impath Network Decoder	Shot #	PIN RS232	Sample #	No SPD	Generator		Decoder		Plots	Comment
					kV	kA	(A)	(V)	Lecroy	
27.7	1	3 & 2	4	N/A	2.7	1.1				Small arcing at port A, no boot when power applied, did an internal reset system started.

BNC Coaxial Test:

Coaxial Immunity Test without / SPD	Sample #1	Sample #1	Sample #1
Voltage Nominal Generator	2.7kV	4kV	4kV
Generator Peak Display	0.15kV / 1.38kA	0.21kV / 1.37kA	1.23V / 1.79kA
Oscilloscope Results	N/A	N/A	N/A
Oscilloscope Plot Number	N/A	N/A	278
Status	Pass	Fail	Fail
Comments	Video display works after 1 impulse surge test with no damage.	During test small arc at BNC input of encoder with no physical damage to PCB. Retest video, fails to display live stream images.	We removed all chassis to test at PCB level to trace arcing. As generator impulse surge large arc destroyed IC U29 and surrounding capacitors.

In house tests: No SPD

RS232 Test:

Impath Network Decoder	Shot #	PIN RS232	SPD	Sample #	Generator		Decoder		Plots	Comment
					kV	kA	(A)	(V)	Lecroy	
26.03	1,2,3,4	3 & 2	DLA2-06D3	2	2.7	1.39	1.39	134	255	No damages, applied power to decoder boots with no errors
26.03	5	3 & 2	DLA2-06D3	2	4	2.04k	2.04 k	164	256	No damages, applied power to decoder boots with no errors
26.03	**22**	**3 & 2**	**DLA2-06D3**	**2**	**28**	**13.5k**	**13.5k**	**512**	**266**	**Loud noise from SPD but no damage to decoder, applied power boots with no errors.**
26.03	23,24,25,26,27	3 & 2	DLA2-06D3	2	30	15.5k	15.5k	568	267	Loud noise from SPD but no damage to decoder, applied power boots with no errors.

BNC Coaxial Test:

Coaxial Immunity Test with / SPD	Sample #1	Sample #1	Sample #1	Sample #1	Sample #1	Sample #1	Sample #1
Voltage Nominal Generator	2.70kV	5kV	8kV	12kV	16kV	20kV	25kV
Generator Peak Display	0.17kV / 1.37kA	0.53kV / 2.53kA	0.6kV / 4.06kA	0.7kV / 6.11kA	1kV / 8.15kA	1.2kV / 10.1kA	2.5kV / 12.7kA
Oscilloscope Results	8.68V / 625A	8.9V / 1.18kA	24V / 1.9kA	24V / 2.87kA	49.6V / 3.84kA	114V / 4.06kA	209V / 4.37kA
Oscilloscope Plot Number	271	272	273	274	275	276	277
Status	Pass	Pass	Pass	Pass	Pass	Pass	Pass

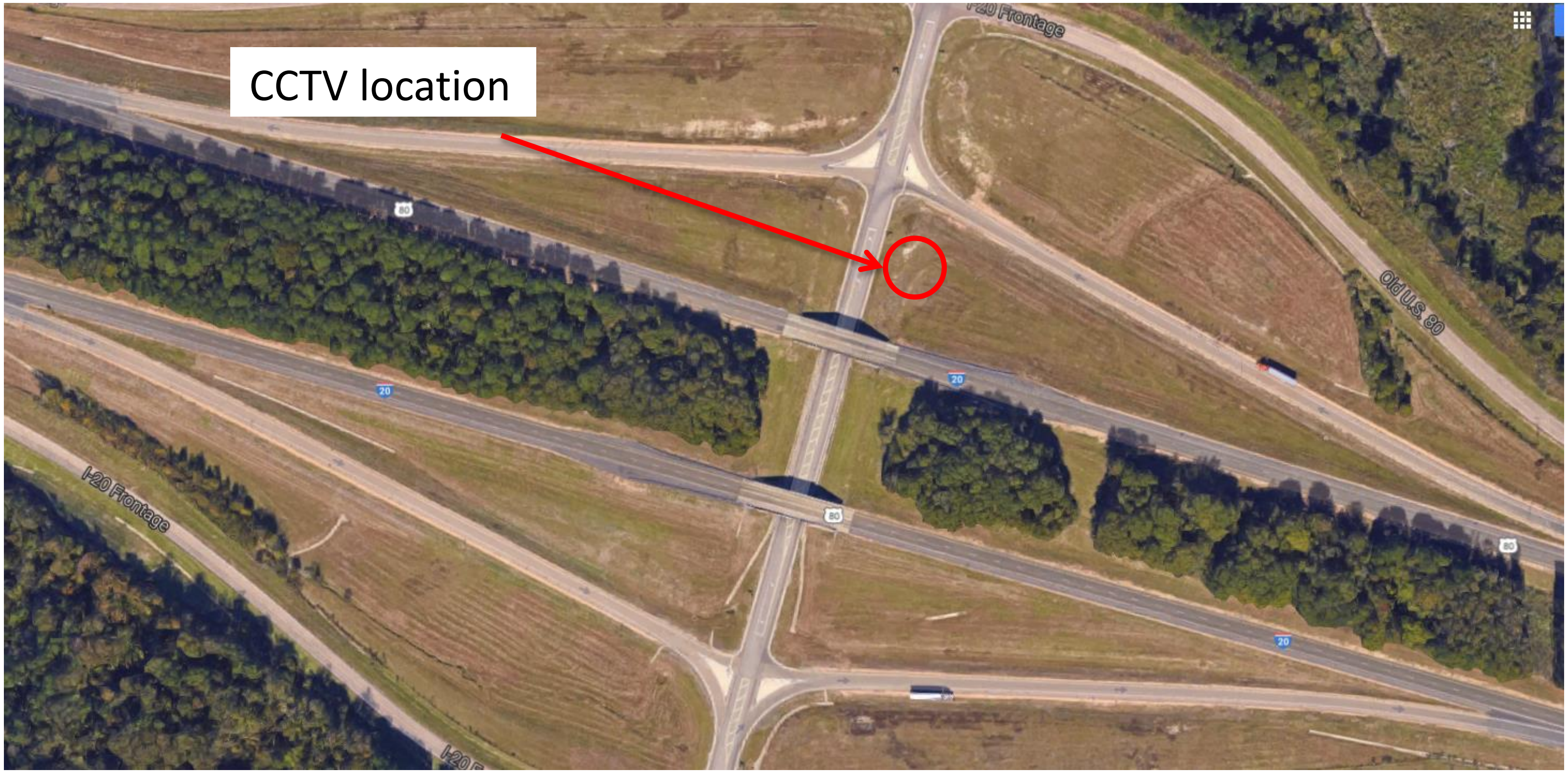
3: Risk Assessment

- This risk assessment is the approach taken by IEC ,IEEE and NFPA 780. Providing an analysis to determine risk to a standing structure when it comes to lightning and surges.
- This calculation is used to determine if lightning protection is needed.

Factors:

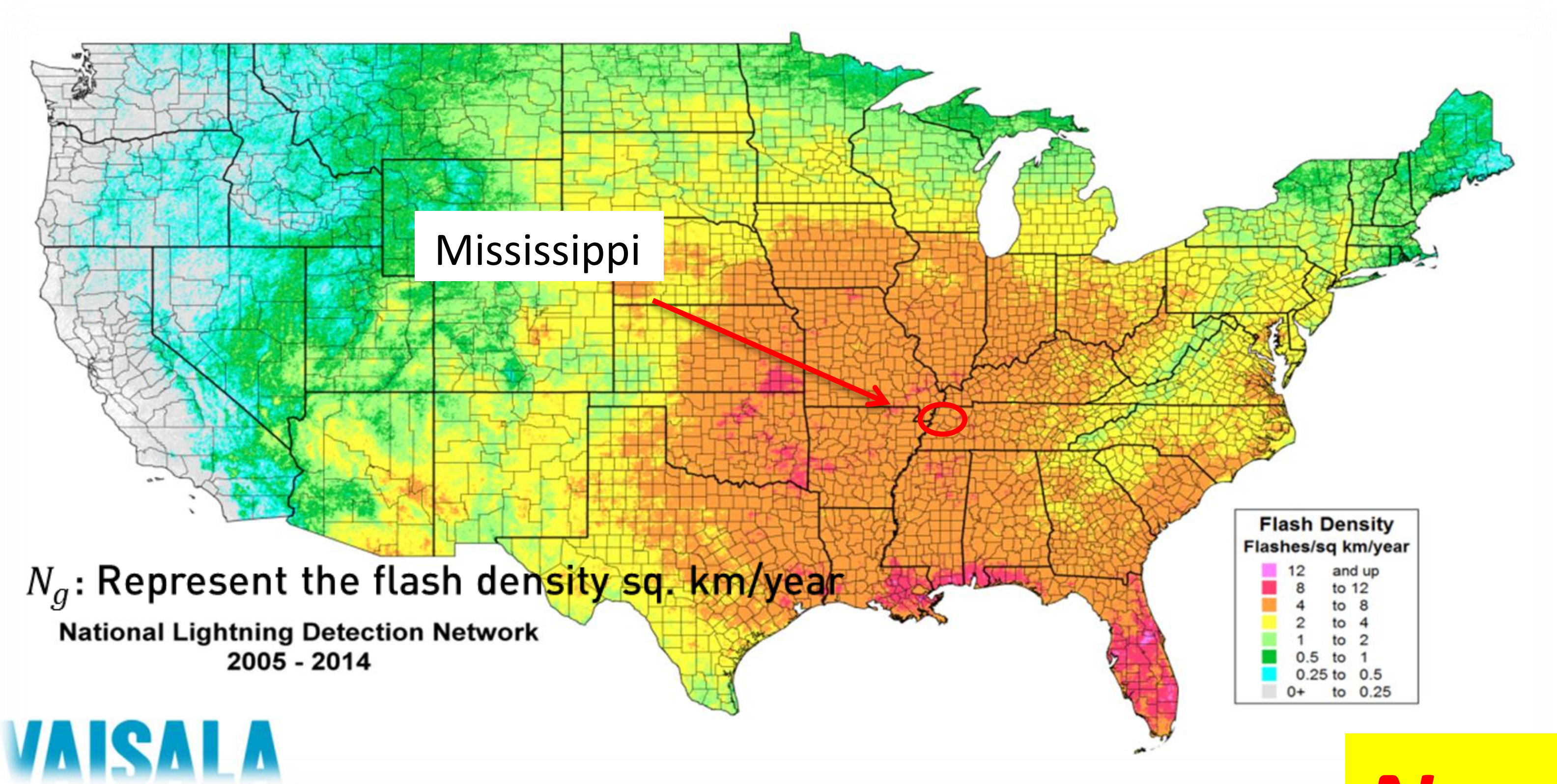
- Height of structure
- Surrounding area
- Location of lightning flash activity
- Environmental risk

Mississippi Norrel Road and I-20 RAMP



Isolated structure on hilltop

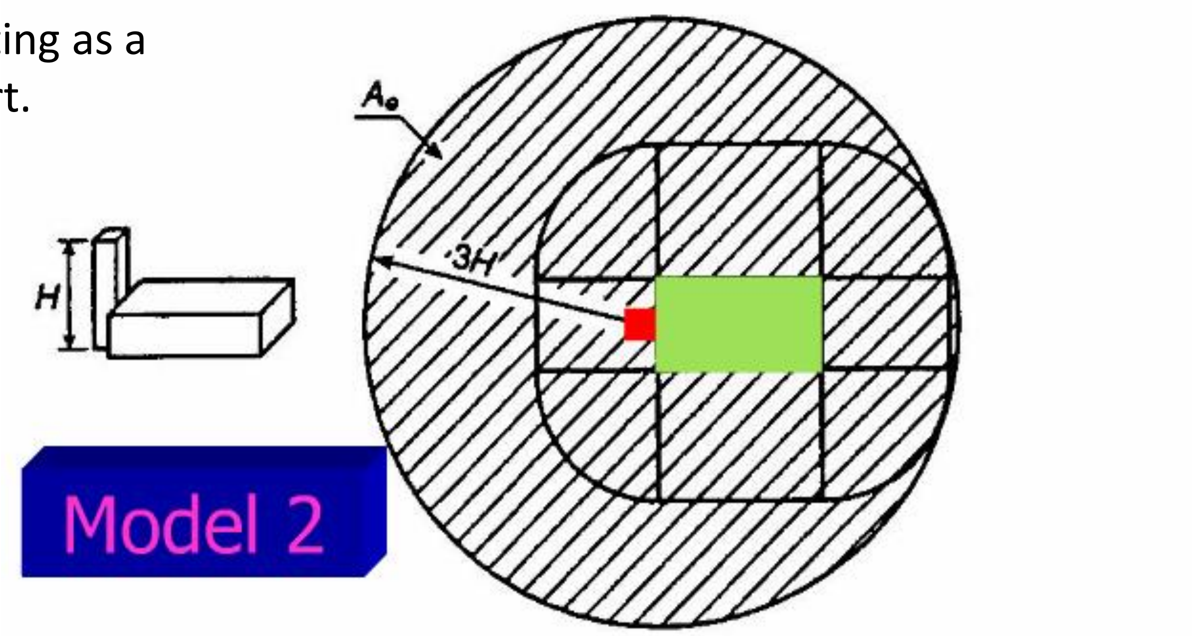
Mississippi Norrel Road and I-20 RAMP


Mississippi
N_g: Represent the flash density sq. km/year
National Lightning Detection Network
2005 - 2014
Flash Density
Flashes/sq km/year
12 and up
8 to 12
4 to 8
2 to 4
1 to 2
0.5 to 1
0.25 to 0.5
0+ to 0.25
VAISALA

Ng=6

Risk assessment

The pole is acting as a prominent part.



Note: For a structure where a prominent part encompasses all portions of the lower part, $A_e = \pi 9H^2$

NFPA 780

Pole 16 meters (50’)

Coefficient Values: C1; Environmental

Table H.4.3 Determination of Environmental Coefficient C_1

Relative Structure Location	C_1
Structure located within a space containing structures or trees of the same height or taller within a distance of 3H	0.25
Structure surrounded by smaller structures within a distance of 3H	0.5
Isolated structure, no other structures located within a distance of 3H	1
Isolated structure on a hilltop	2

Relative Structure Location	C1
Structure located within a space containing structures or trees of the same height or taller within a distance of 3H	0.25
Structures surrounded by smaller structures within a distance of 3H	0.5
Isolated structure, no other structures located within distance of 3H	1
Isolated structure on hilltop	2

NFPA 780

Coefficient Values: C2 & C3; Structure & content

C_2 — Structural Coefficients

Structure	Roof: Metal	Roof: Nonmetallic	Roof: Flammable
Metal	0.5	1.0	2.0
Nonmetallic	1.0	1.0	2.5
Flammable	2.0	2.5	3.0

Table H.5(b) Determination of Structure Contents Coefficient C_3

Structure Contents	C_3
Low value and nonflammable	0.5
Standard value and nonflammable	1.0
High value, moderate flammability	2.0
Exceptional value, flammable, computer or electronics	3.0
Exceptional value, irreplaceable cultural items	4.0

NFPA 780

C2 - Structural Coefficients			
	Roof		
Structure	Metal	Nonmetallic	Flammable
Mettal	0.5	1	2
Nonmetallic	1	1	2.5
Flammable	2	2.5	3

Structure Contents	C3
Low value and nonflammable	0.5
Standard value and nonflammable	1
High value, moderate flammability	2
Exceptional value, flammable, computer and electronics	3
Exceptional value, Irreplaceable cultural items	4

Coefficient Values: C4 & C5; Occupancy & consequences

Table H.5(c) Determination of Structure Occupancy Coefficient C_4

Structure Occupancy	C_4
Unoccupied	0.5
Normally Occupied	1.0
Difficult to evacuate or risk of panic	3.0

Table H.5(d) Determination of Lightning Consequence Coefficient C_5

Lightning Consequence	C_5
Continuity of facility services not required, no environmental impact	1.0
Continuity of facility services required, no environmental impact	5.0
Consequences to the environment	10.0

Structural Occupancy Coefficient	C4
Unoccupied	0.5
Normally occupied	1
Difficult to evacuate or risk of panic	3

Lightning Consequence Coefficient	C5
Continuity of facility service not required, no environmental impact	1
continuity of facility service required, no environmental impact	5
Consequences to the environment	10

NFPA 780

Risk Calculation

- CCTV pole flash density location = 6
- Environmental Coefficient = 2
- Equivalent collective area = 0.000254 km^2
- Average annual frequency of a direct flash (**Nd**) = **3.048 x 10^-3**

Matching the average annual frequency to the tolerable occurrence (**Nc**) which = **2 x 10^-3**

NFPA 780

Risk Assessment Review

Assessment Results for lightning :

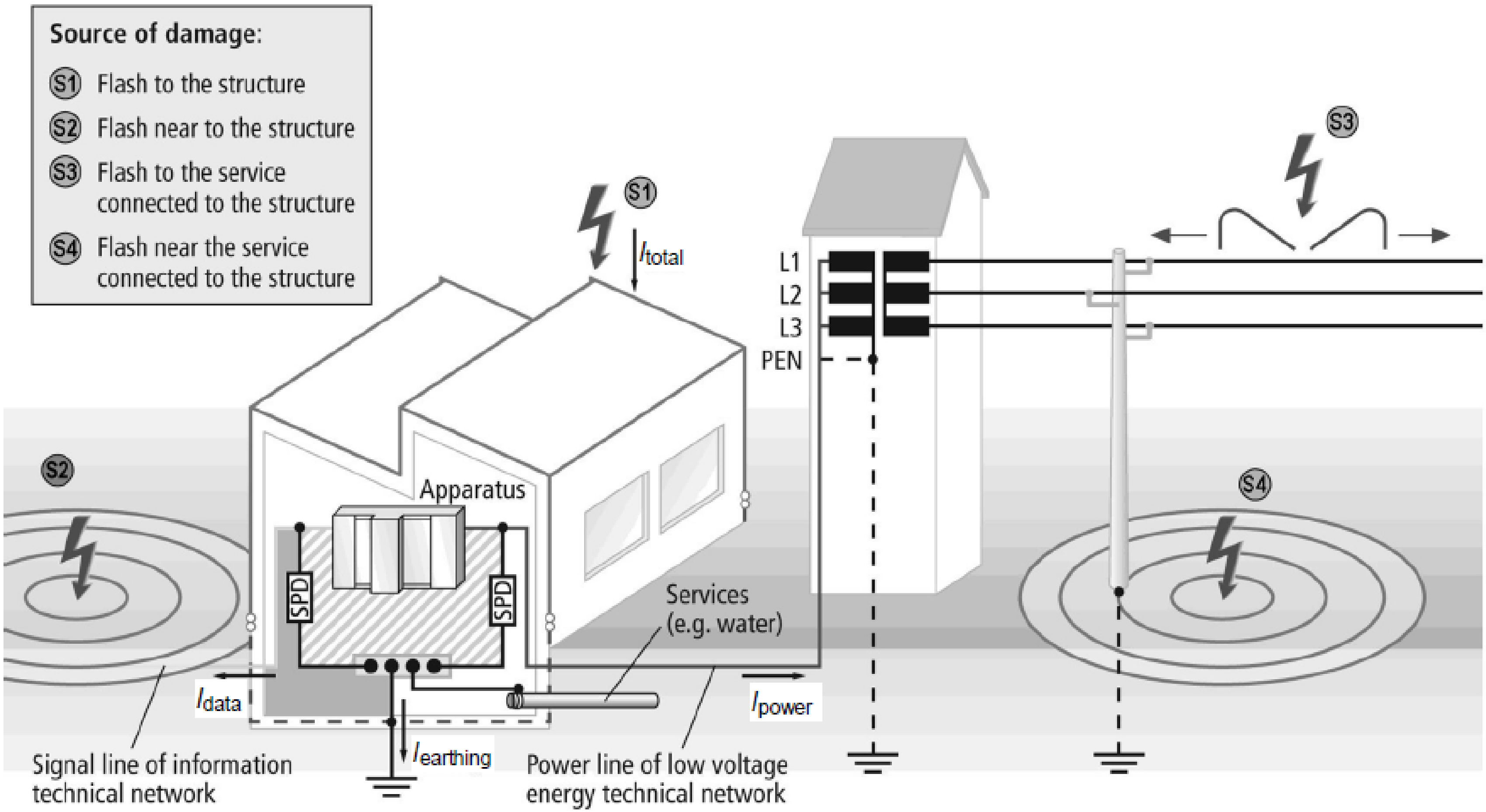
- If $N_d > N_c$ Lightning Protection is required.
- Coefficients values can be viewed on the next slides.

Nd = 3.048 x 10^-3 > Nc = 2 x 10^-3

We see that the average annual frequency of a direct flash measures at a high risk.
➔ Which in fact calls for a lightning protection system.

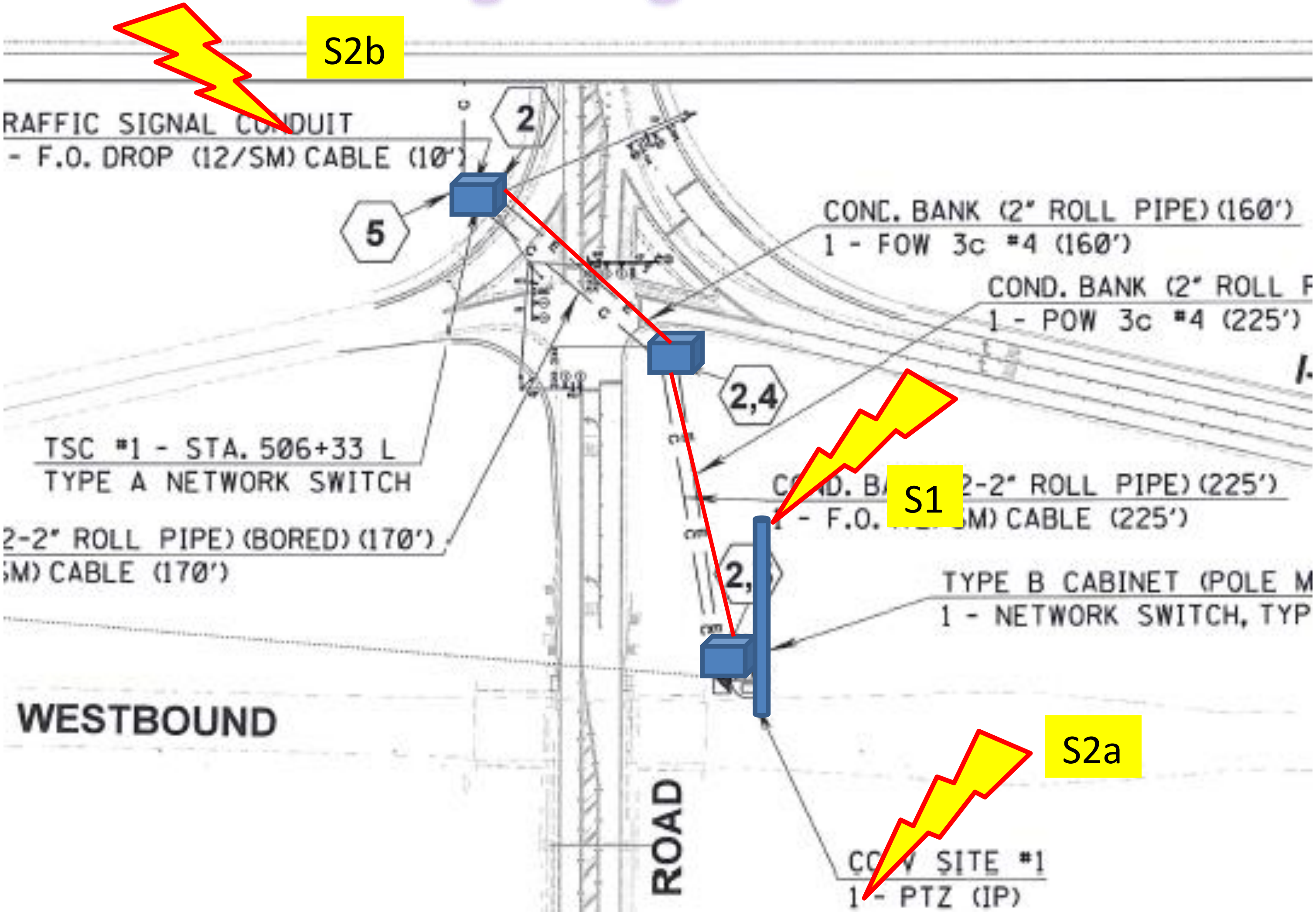
NFPA 780

Scenarios to consider: Lightning strike location



IEC 2813/10

Scenarios to consider: Lightning strike location



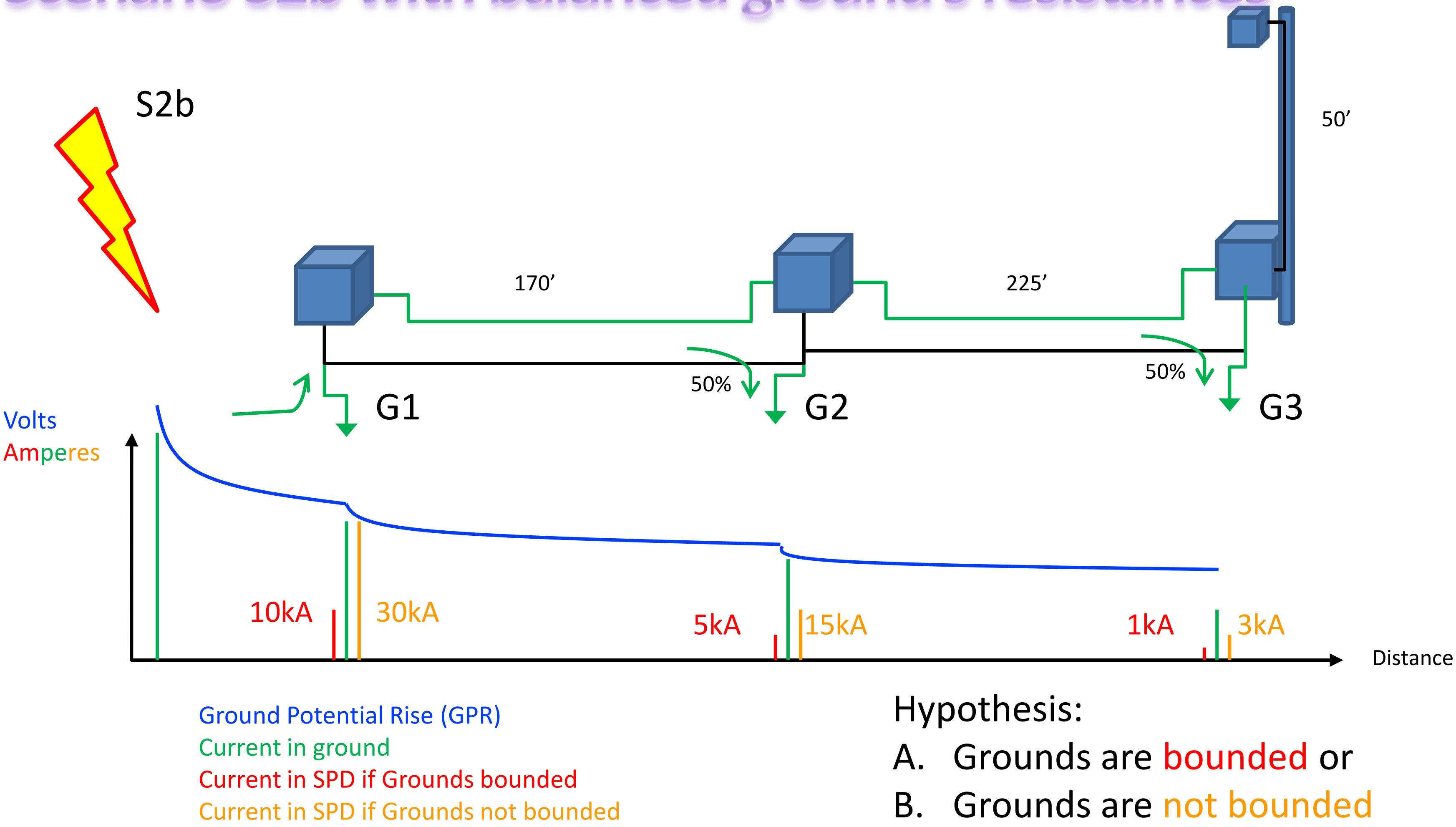
Important note

SPD current is always the so called Itotal in this presentation. This means that it is the sum of all currents flowing from ground to any conductive wires (or reverse) irrespectively of their function. For correct SPD selection, number of connections must be indentified and considered (Line, Neutral, twisted pair, coaxial etc…)

SPD installation is not addressed here and could be another topic to address (location inside the cabinet, Ground plane use, ground wire length etc…)

Grounding and bounding techniques are not addressed either in this presentation.

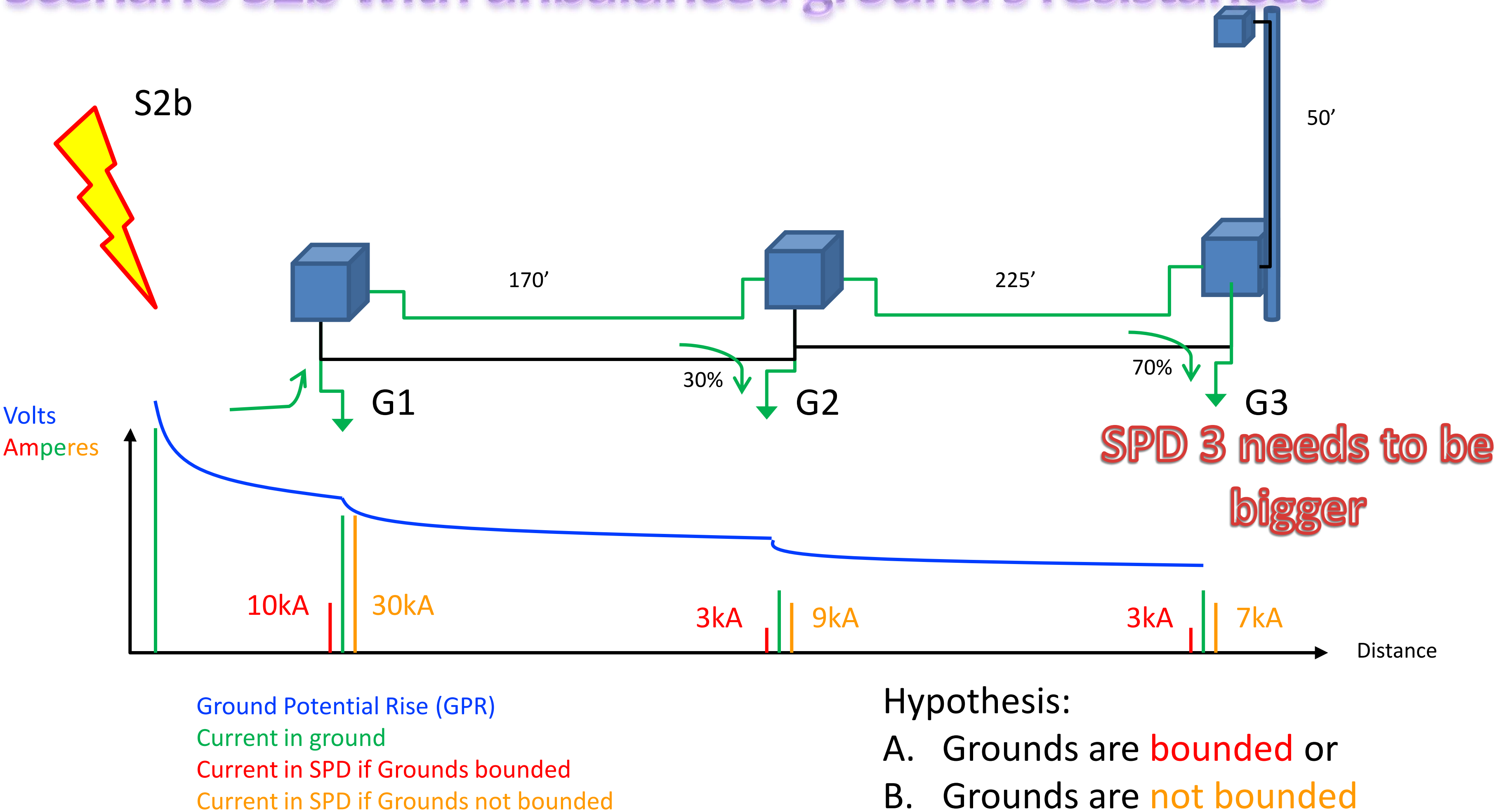
Scenario S2b with balanced ground's resistances



Hypothesis:

A. Grounds are bounded or
B. Grounds are not bounded
C. G1 = G2= G3 = few ohms (ex: 20Ω)

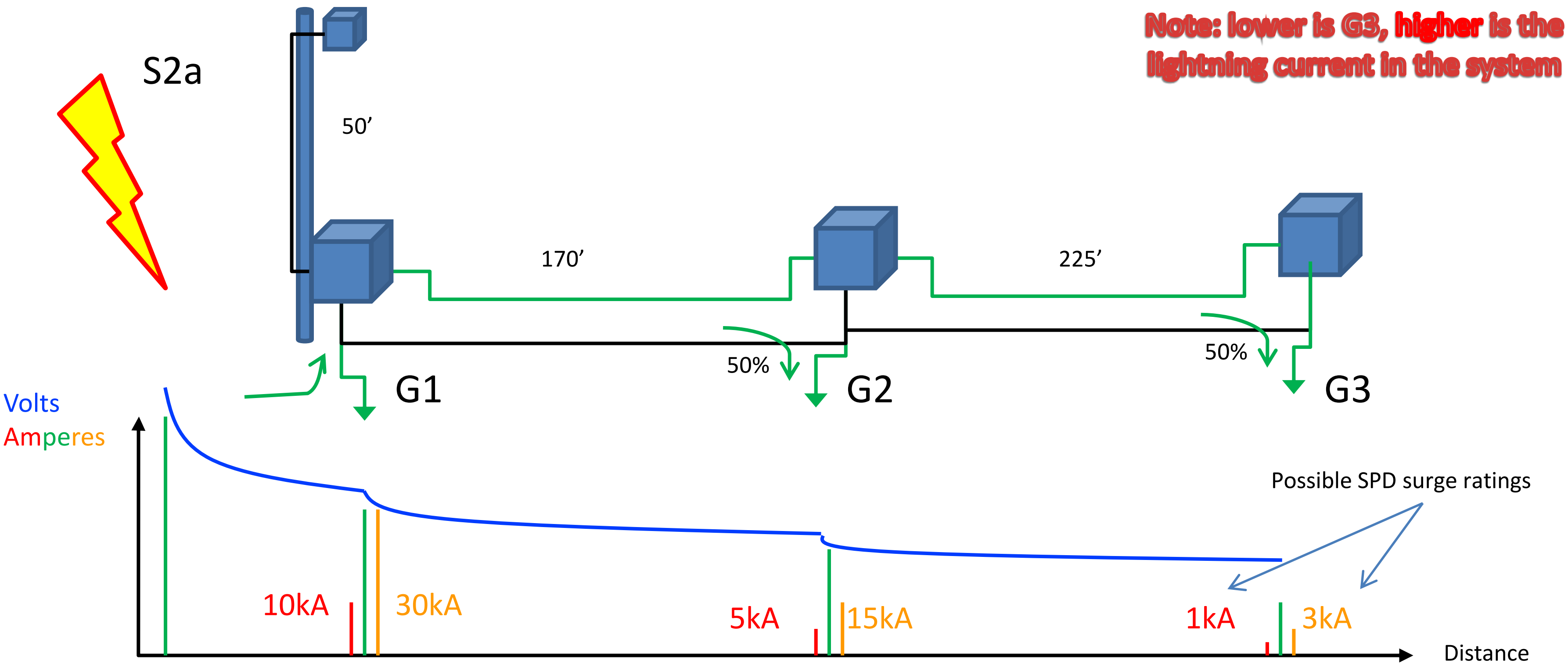
Scenario S2b with unbalanced ground's resistances



Hypothesis:

A. Grounds are bounded or
B. Grounds are not bounded
C. G1 = G2= G3 = few ohms (ex: 20Ω)

Scenario S2a with balanced ground's resistances

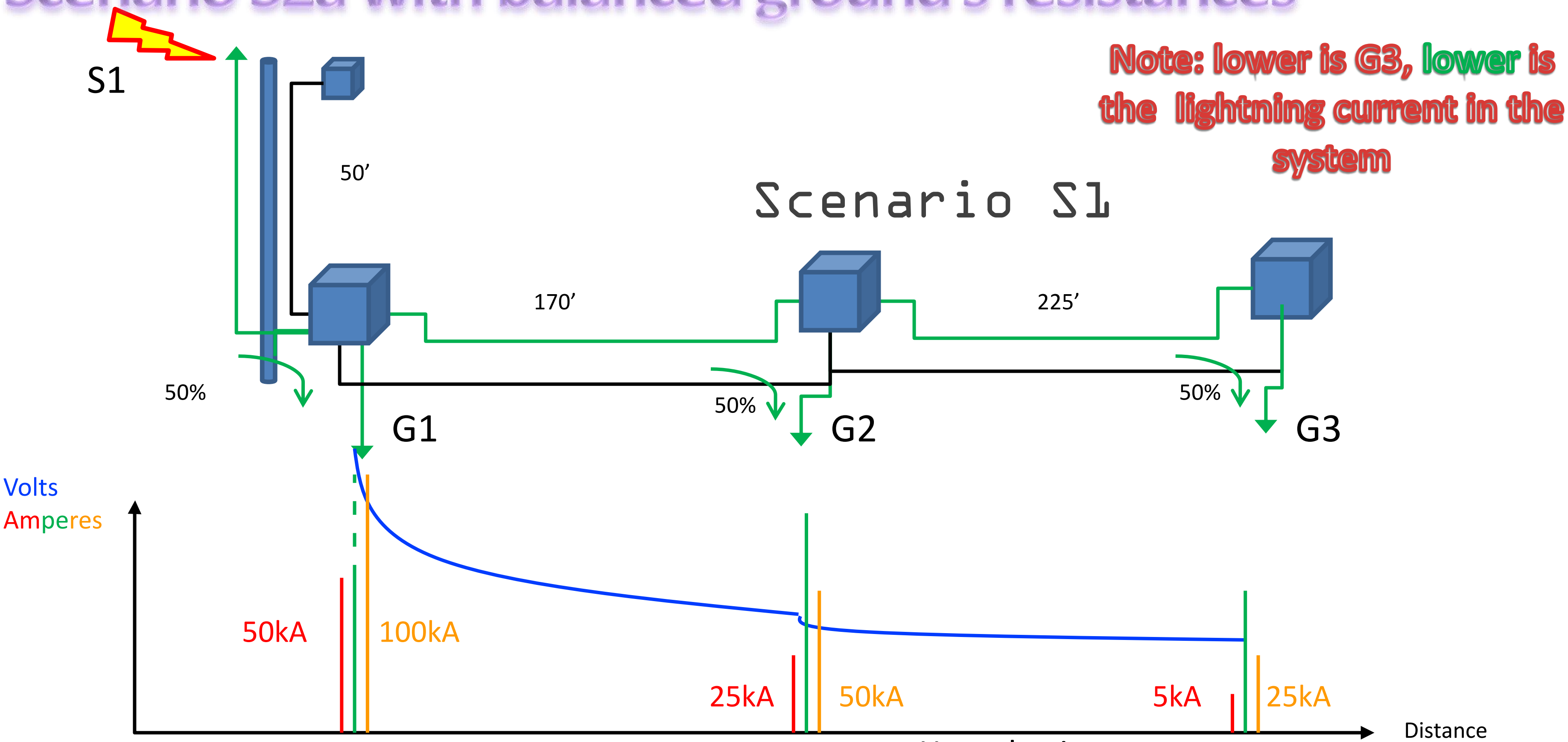


Ground Potential Rise (GPR)
Current in ground
Current in SPD if Grounds bounded
Current in SPD if Grounds not bounded

Hypothesis:

A. Grounds are bounded or
B. Grounds are not bounded
C. G1 = G2= G3 = few ohms (ex: 20Ω)

Scenario S2a with balanced ground's resistances



Ground Potential Rise (GPR)
Current in ground
Current in SPD if Grounds bounded
Current in SPD if Grounds not bounded

Hypothesis:

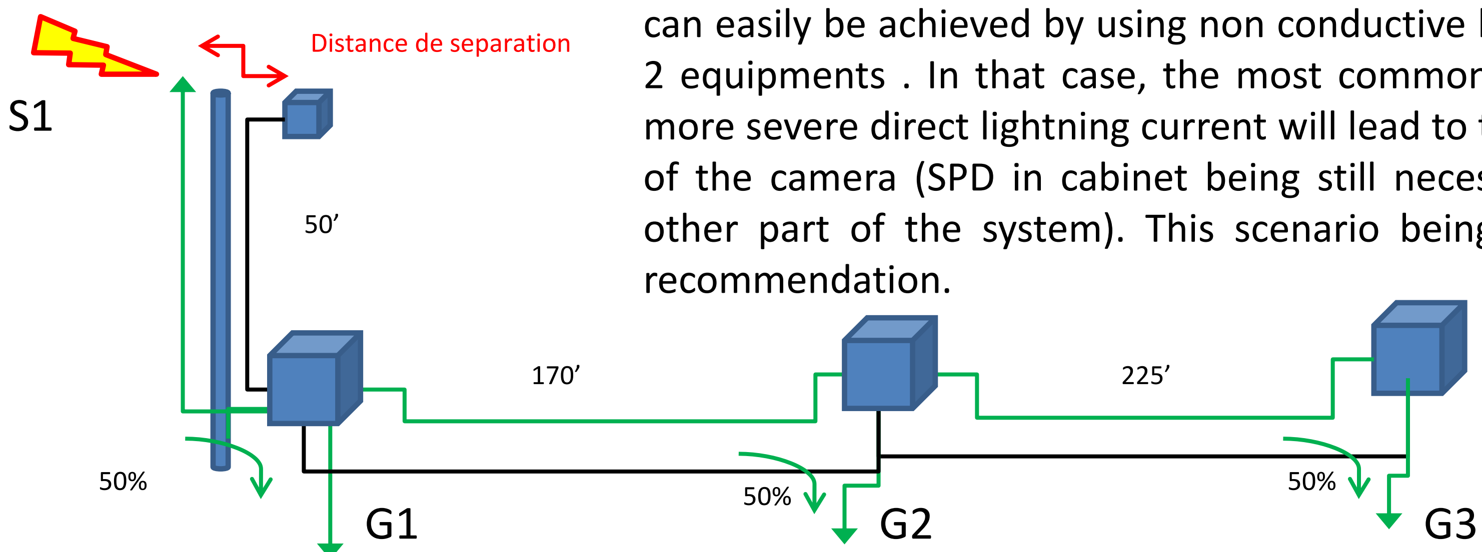
A. Grounds are bounded or
B. Grounds are not bounded
C. G1 = G2= G3 = few ohms (ex: 10Ω)

Scenario S1

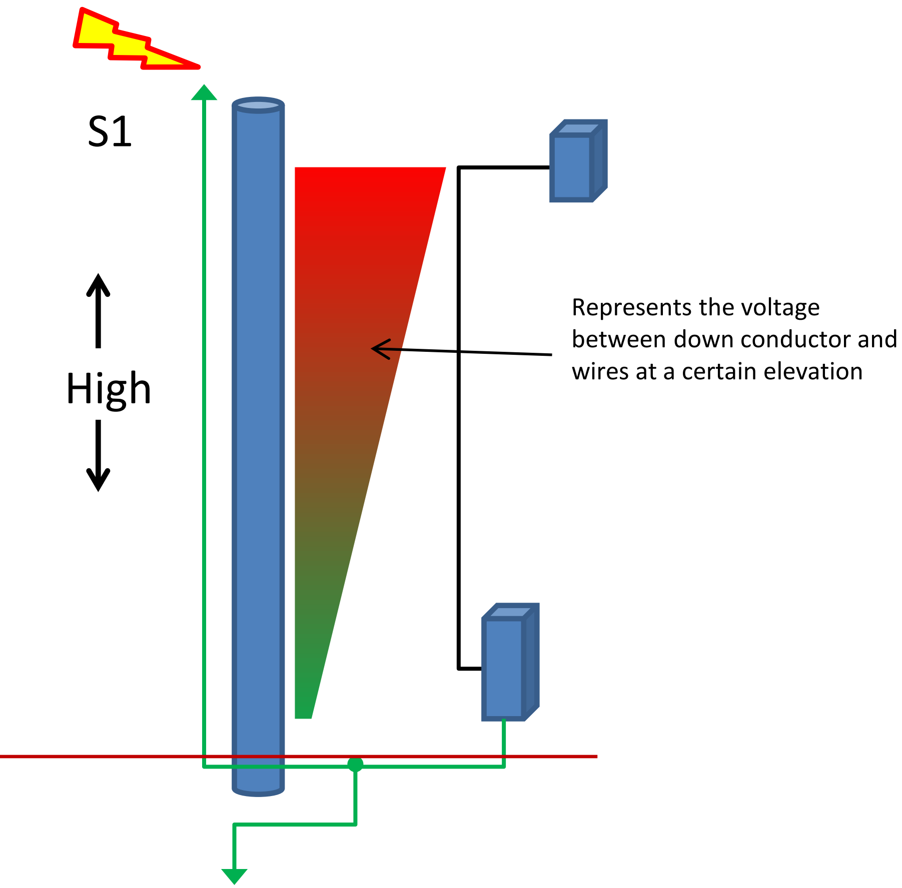
- If separation distance is achieved, there is no need for extra protection at the camera’s location. This means that several feet of air distance or clearance are between down conductor and other conductive parts (distance is depending of lightning current): For example and for a 50’ pole, if 100kA lightning current is considered, a minimum of 2 feet air distance is necessary and 2 to 4 feet of insulating means (depending on material),

- If separation distance is not achieved, bounding of the camera to the down conductor is requested and SPD able to handle direct lightning current is necessary at Camera’s location.

NOTE: If lower lightning current is considered, separation distance can easily be achieved by using non conductive housing and/or class 2 equipments . In that case, the most common risk is covered but more severe direct lightning current will lead to the total destruction of the camera (SPD in cabinet being still necessary to protect the other part of the system). This scenario being rare, it is still my recommendation.



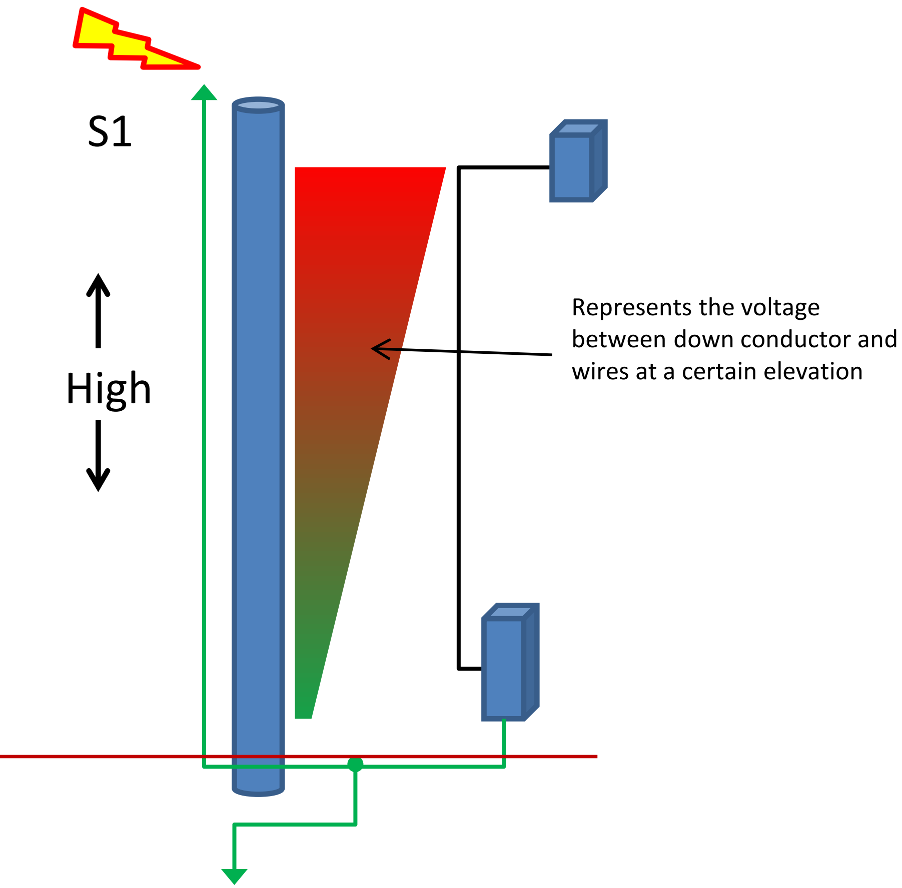
Scenario S1: Some values



From various field survey and statistical analysis, once can assume that typical dI/dt of the lightning current can be from around thousands of amperes per µsec to several hundreds of kilo Amperes per µsec. It is common to use medians as a parameter for simulation. It has to be noted that depending on the type of lightning (positive, negative, ascendant and descendant) and depending on the strike we consider.

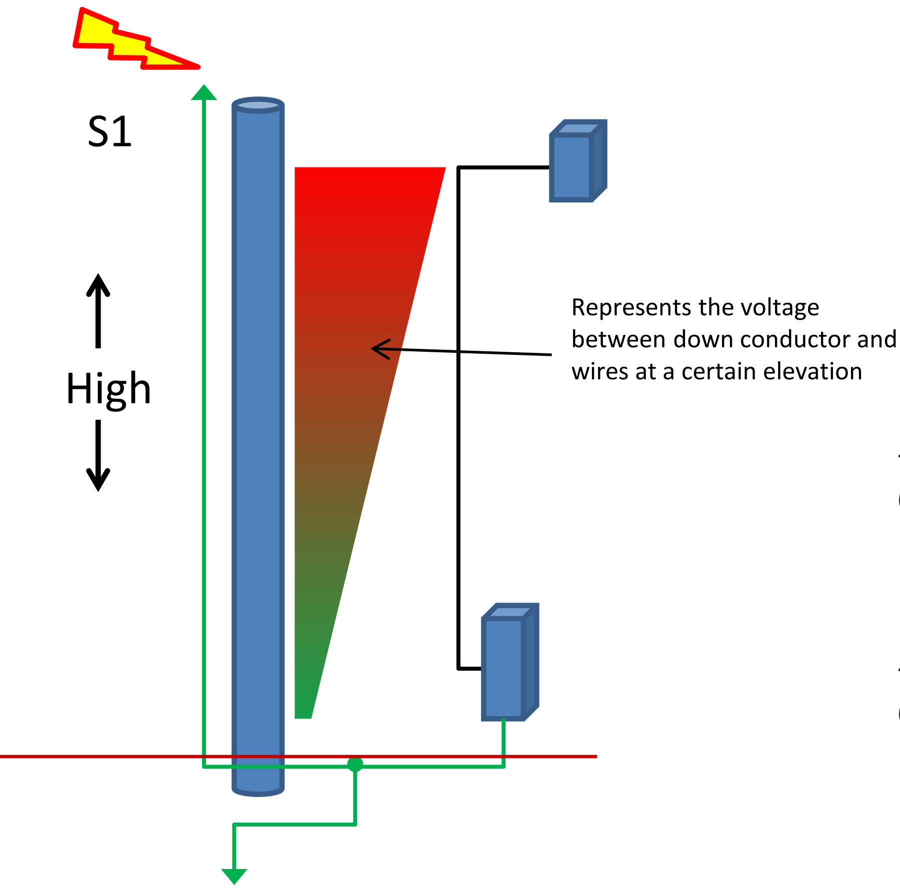
Let's pick ***<u>10kA/µs</u>*** to ease our calculation for an example…

Scenario S1: Some values



Inductance of a wire can be set approximately from 0.1 to few µH per meter (3’). When there is an attempt to estimate the impedance of the path from the air terminal to ground, it is then depending on the type of down conductor (shape), number of down conductor and if the pole can be considered itself as a down conductor… Let’s use **0.5µH per meter** to ease the calculation. This leads to estimate the total inductance of our traffic pole to ***8µH*** (Pole high is 16m).

Scenario S1: Some values

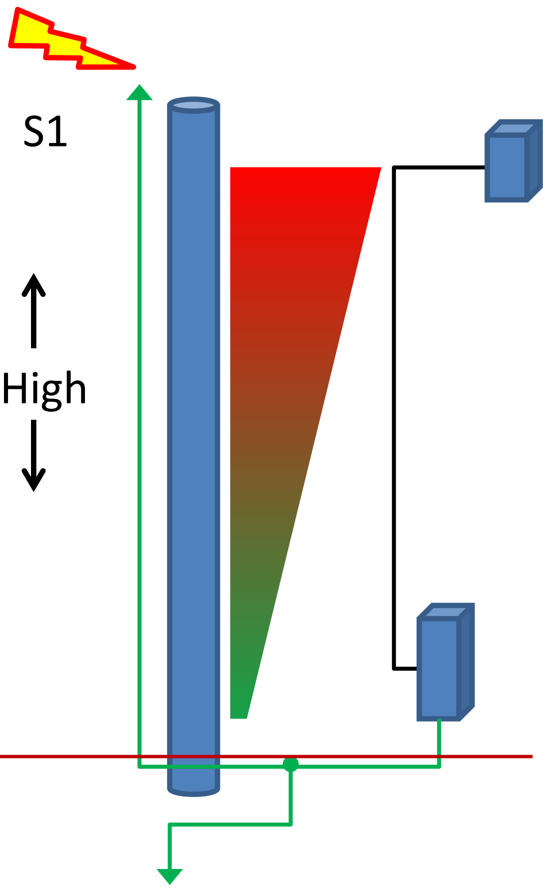


If we consider, that no SPD is installed at top of the pole, we can assume that the voltage between the down conductor and the equipment that is connected to an SPD in the bottom pole cabinet will be of 80kV.

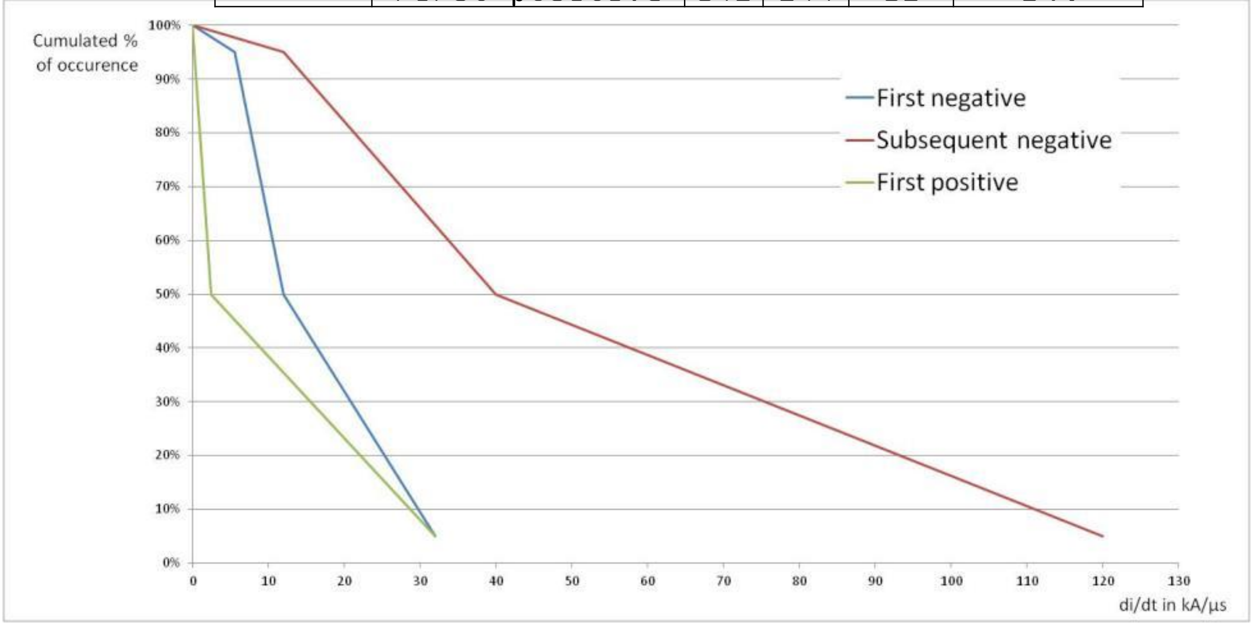
$$U = L \cdot \frac{di}{dt} = 8\mu H \cdot \frac{10kA}{1\mu s}$$

$$U = 80{,}000V = 80kV$$

Some statistics

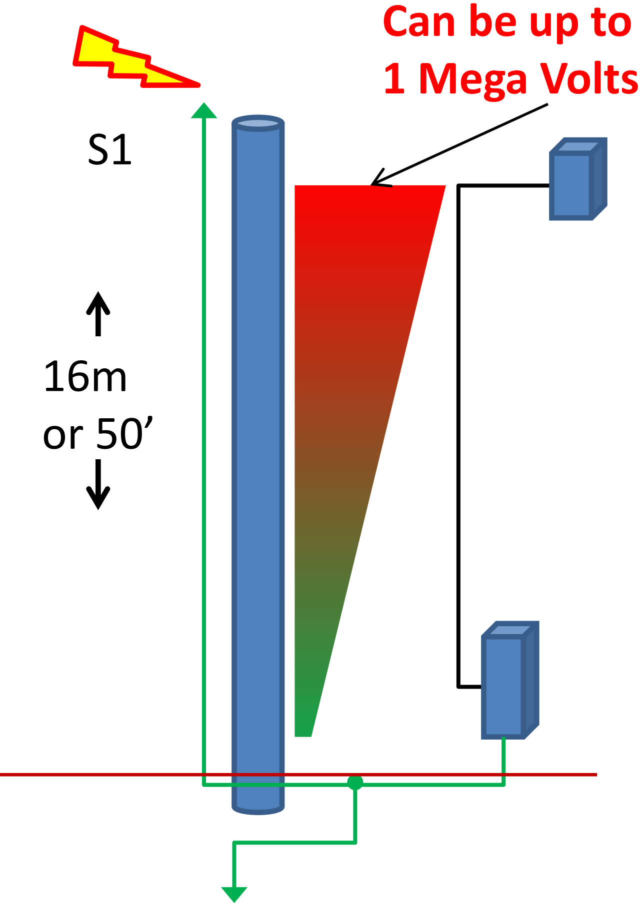


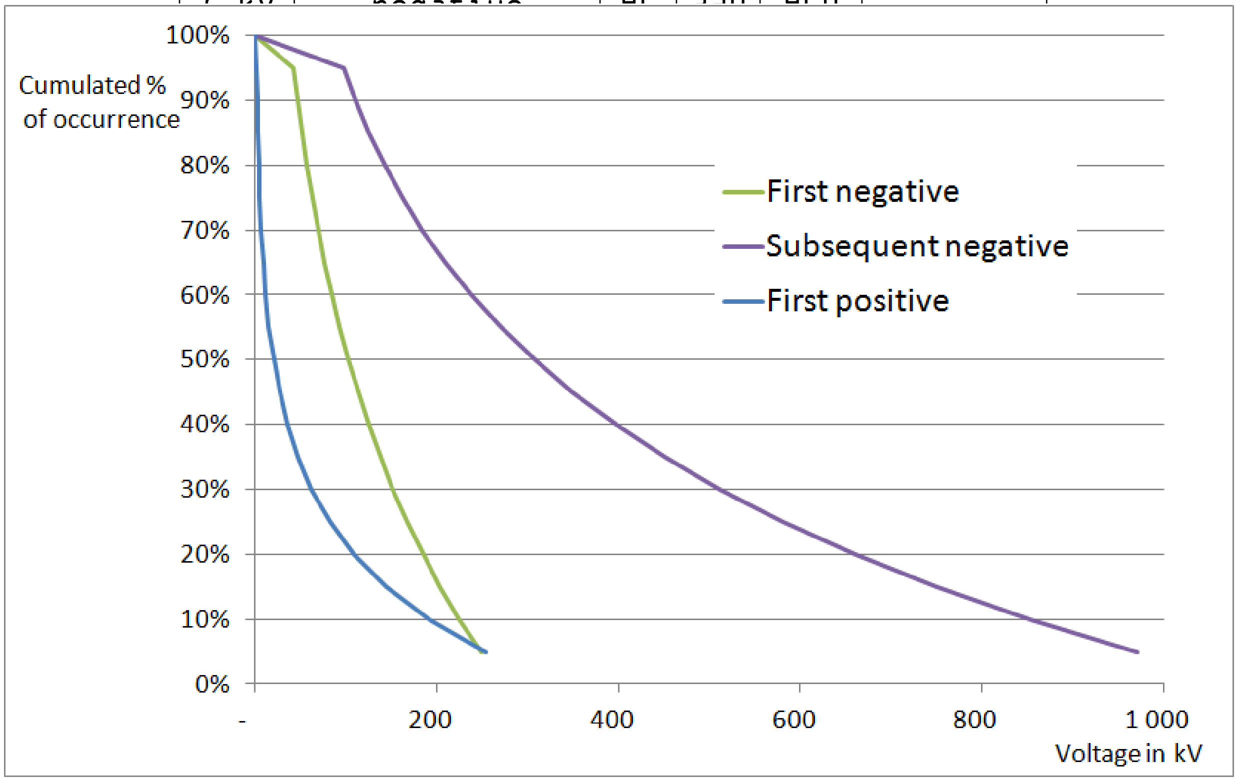
		95%	50%	5%	Occurrence
di/dtmax (kA/ms)	First negative	5,5	12	32	81%
	Subsequent negative	12	40	120	
	First positive	0,2	2,4	32	19%



Considering our pole when S1 occurs

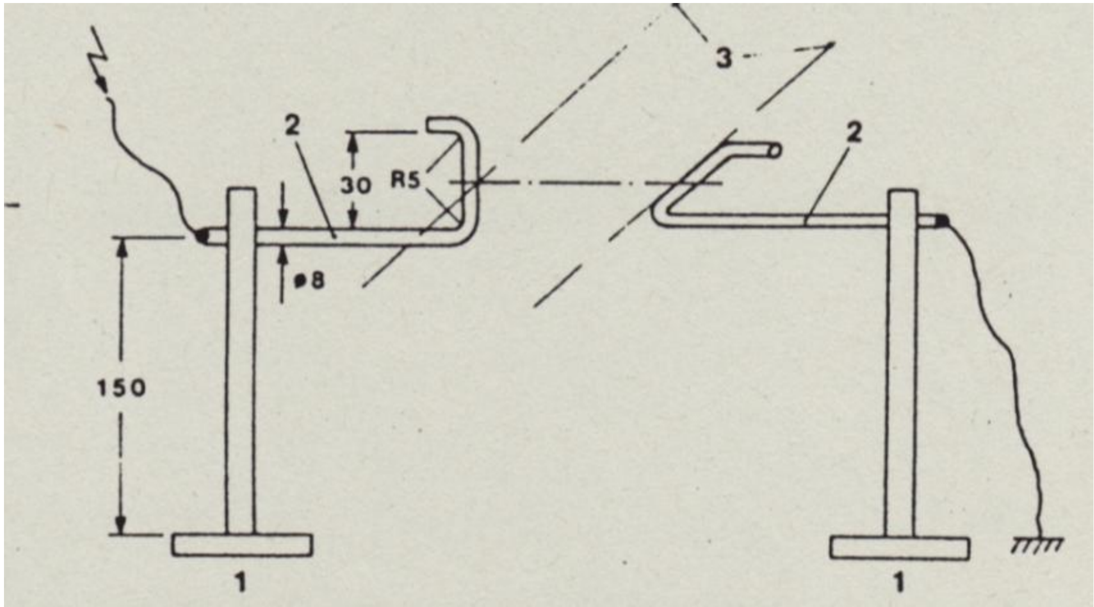
		95%	50%	5%	Occurrence
Voltage (kV	First negative	44	96	256	81%
	Subsequent negative	[illegible]	[illegible]	[illegible]	





Air distance breakdown in controlled environment

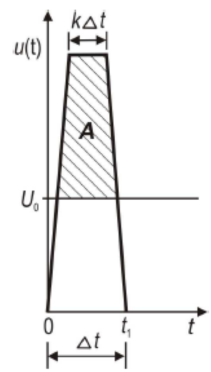
Example of test performed to determined arcing distance between 2 conductive parts when an impulse voltage is applied (approximately 1 µsec)



1: support insulator; 2: Electrode of metal rods 8 mm diameter; 3: Gap distance s

Zischank,W.: Der Einfluss von Baustoffen auf die Stoßspannungsfestigkeit von Näherungsstrecken bei Blitzeinschlägen. 18th ICLP 1985 Munich, Germany.

Air distance breakdown in controlled environment

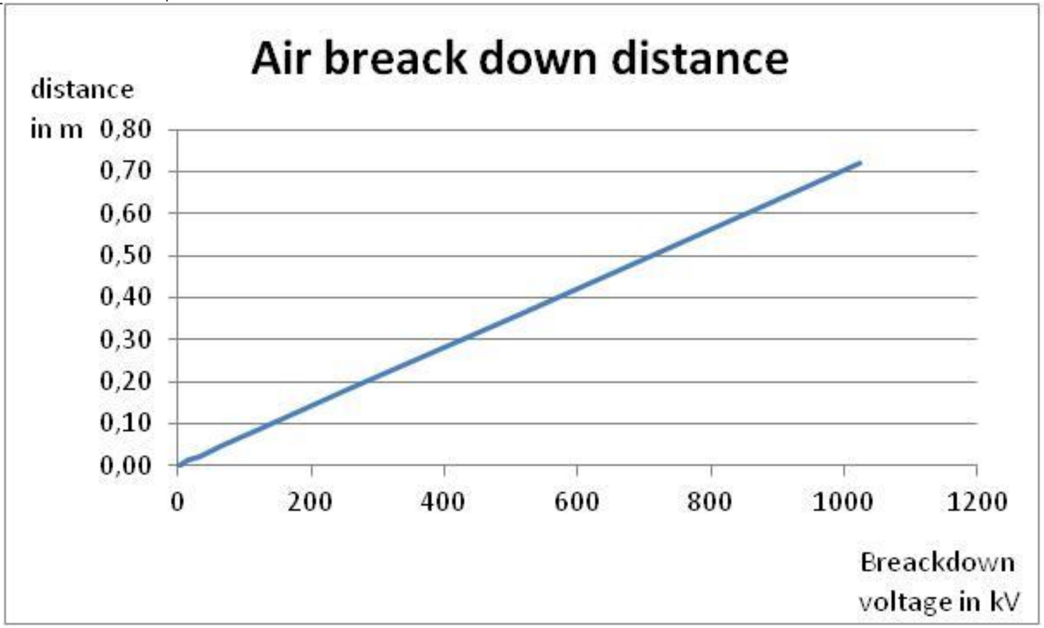


$$U \approx \frac{2s}{1+k} \cdot \left(630 + \frac{590}{\Delta t}\right)$$

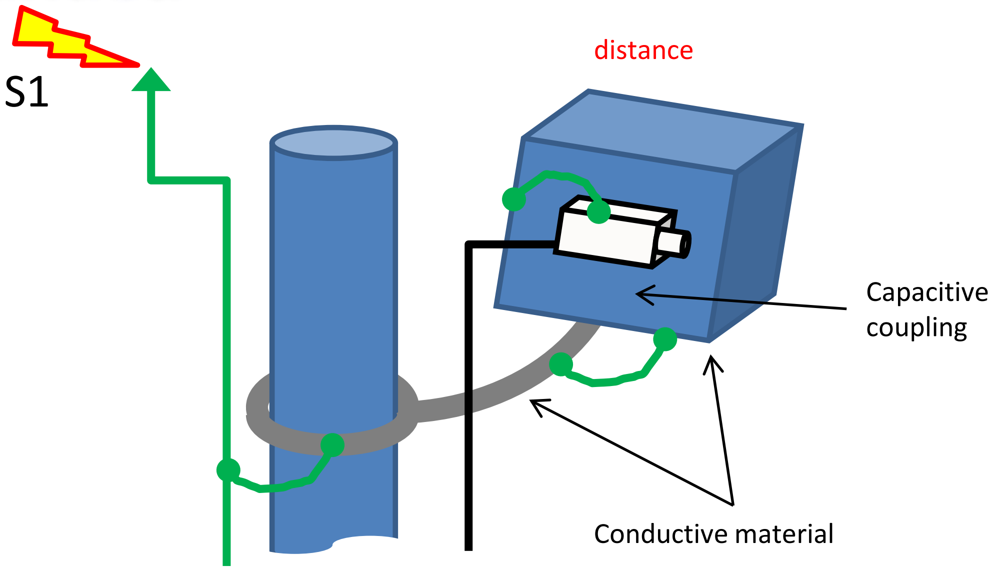
$$s \approx \frac{(1+k) \cdot \Delta t \cdot U}{2 \cdot (630 \cdot \Delta t + 590)}$$

Various models can be applied here but this one gives a good idea of the distance to expect a breakdown when considering a lightning overvoltage.
(dt=2 and k=0,3)

Once can estimate the distance breakdown on a surface material as equal if the material is not conductive and clean. In practice a coefficient up to 2 can be applied. For example, the safety distance for concrete will be set to 1.4 m for 1000 kV surge voltage.



Close up on equipment installation at top of the pole: bounded



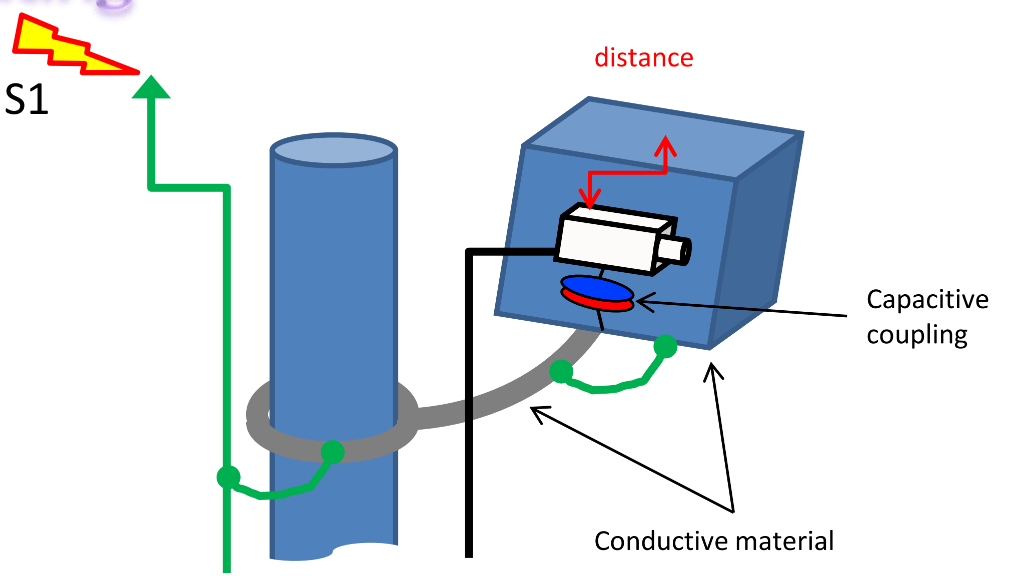
In that type of installation a local SPD is highly recommended. Surge rating of this SPD must consider the partial lightning current conducted through bounding.

Uwithstand = Equipment withstand (manufacturer declaration)

Example in this system : Uw camera = 2kV

Risk of destruction can be estimated to 99.9% of occurring events if no additional measures are taken (such as SPD installation)

Close up on equipment installation at top of the pole: floating



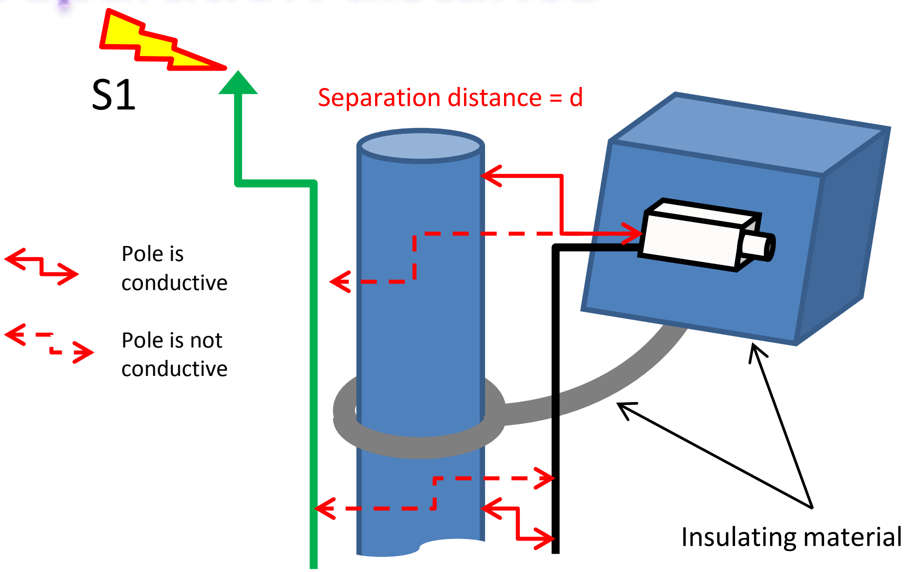
In that type of installation, the camera fixture may be insulating material to have a better control of the insulation between active parts (camera's internals) and the conductive housing.

Uwithstand = *Fct* (capacitive coupling and/or distance)

Example in this system : Uw camera = 50kV

Risk of destruction can be estimated to 90% of occurring events if no additional measures are taken (such as SPD installation)

Close up on equipment installation at top of the pole: Separation distance



Static charges can accumulates and a mean to evacuate these is highly recommended (via the ground wire of the camera).

The selection, installation or routing of the wires is be considered in order to not break the insulation property of the system.

Uwithstand = *Fct* (separation distance and/or Insulation withstand)

Example in this system : Uw camera = 600kV (if 60cm) and considering some safety margin)

Risk of destruction can be estimated to 10 to 20% of occurring events.

Sum up for equipment installation at top of the pole

- Separation distance
  - Uwithstand is depending on distance/creapage but can be in the range of worst case expected voltage (our example: 600kV).
  - SPDs at top are not existing.
  - For our example, large majority of lightning events are covered (80to 90%).
- Floating
  - Uwithstand is depending on distance/creapage but inside the top enclosure and will be limited by the size of the enclosure itself (our example: 50kV)..
  - SPDs at top could be needed
  - For our example, few lightning events are covered (10%)
- Bounded
  - Uwithstand is the one declared for the equipment to protect (our example: 2kV)
  - SPDs at top are requested and surge rating of this SPD must consider the partial lightning current conducted through the bounding (hundreds of kA)
  - For our example, almost all lightning events would destroy the equipment if no SPD!

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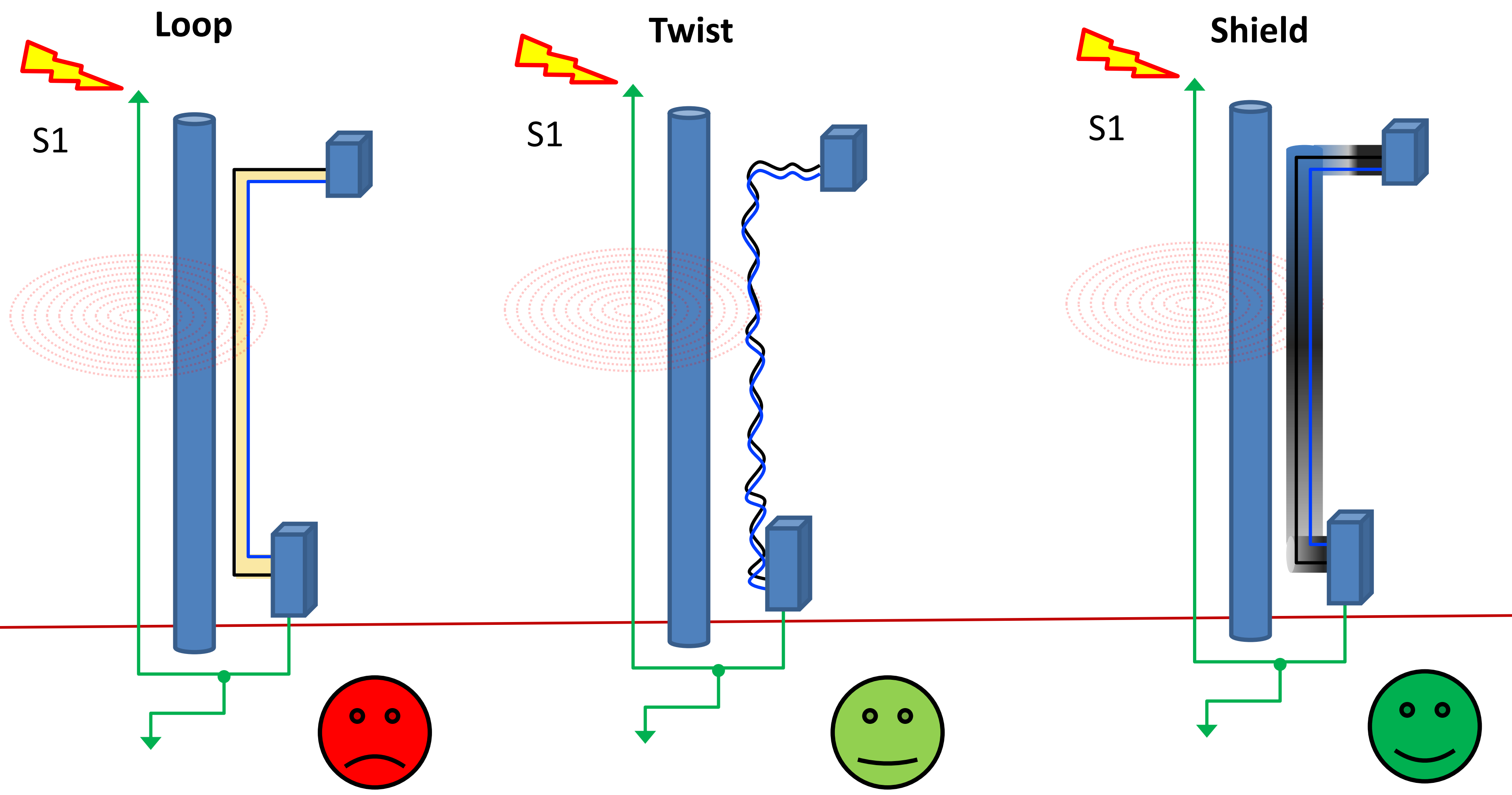
Down connection along the pole (if S1)



Recomendations

- SPDs are requested to be installed on each conductive wires/circuitry as soon as a local ground is present and/or equipment have to be protected…
- Ground bounding is highly recommended to avoid any SPDs over sizing.
- If S1 (direct lightning on the pole) is considered, selection of SPDs will cover the other scenarios (nearby lightning strike). Note: More than 500ft of ground bounding becomes useless (depending of the shape of the wire, soil resistivity and other complex parameters).
- Lower the ground resistance of the lightning pole is, lower the current to expect in the system is (SPD sizing).
- When S1 is not considered, balancing the locale ground resistance is recommended (+ bounding). Lower ground resistance value will possibly be requested by other needs but not because of surge protection 's. Distance has also some impact in this analysis.
- If S1 is considered, applying the separation distance is preferable if possible to achieve. It is highly recommended to avoid loops between various wires connecting top to bottom equipments. Shielding or twisting these is a recommendation.
- If bounding is done between top pole equipments and down conductor, SPDs are necessary even for low current direct strike. SPD can be avoided if once consider S1 to be a destructive event as this could be considered as very low probability of occurrence (nevertheless I do not recommend!)

Conclusion

- ✓ SPD installation is to be more explained to installers…
- ✓ Surge protection is more a matter of installation than SPD itself…
- ✓ If surge protection is part of the design from the beginning, it is more easy to implement and size correctly.