BRINGING THE WORLD TOGETHER

THE STRUCTURE OF POWERING

Looking at what powers electronics and the impact it has with circuit protection

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Compliance Engineer

March 2018

Agenda

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- Introduction
  - The House of POWERing.
- AC Mains configurations.
  - Types of AC mains configurations.
  - How this affects surge to equipment.
- DC configurations.
  - External building powering.
  - 48 V system internal powering.

Introduction

- Attended the Nov 2017 ITU-T meeting in France.
- One country was dominating the world!
  - Want to have ENORMOUS surge tests on AC mains ports!
  - Want internal ports to have the same tests as external ports!
- Some believe that lightning is significantly different around the world.

…and surge tests in the standards simulate actual lightning stresses.

- Circuit protection TOPOLOGY and DEPLOYMENT methods are key to help mitigate surge stress to equipment.

The “House” of Power

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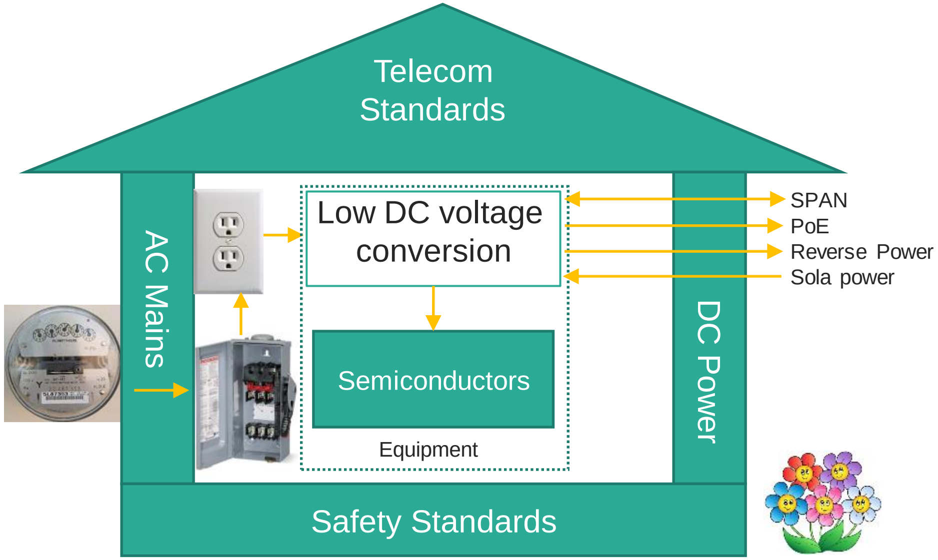
- Wide range of external power sources out there.
  - AC Mains is a “wall of power”.
  - External DC powering is the other “wall of power”.
- AC/DC or DC/DC conversion is required and can be internal and/or external of the equipment.
- Safety standards are the foundation.
- Telecom standards are the roof.
- A weak foundation or leaking roof will bring down the house.



Telecom standards often try to pick up the pieces when safety standards fail to do what they should.

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  - External building powering.
  - 48 V system internal powering.

AC Mains Powering

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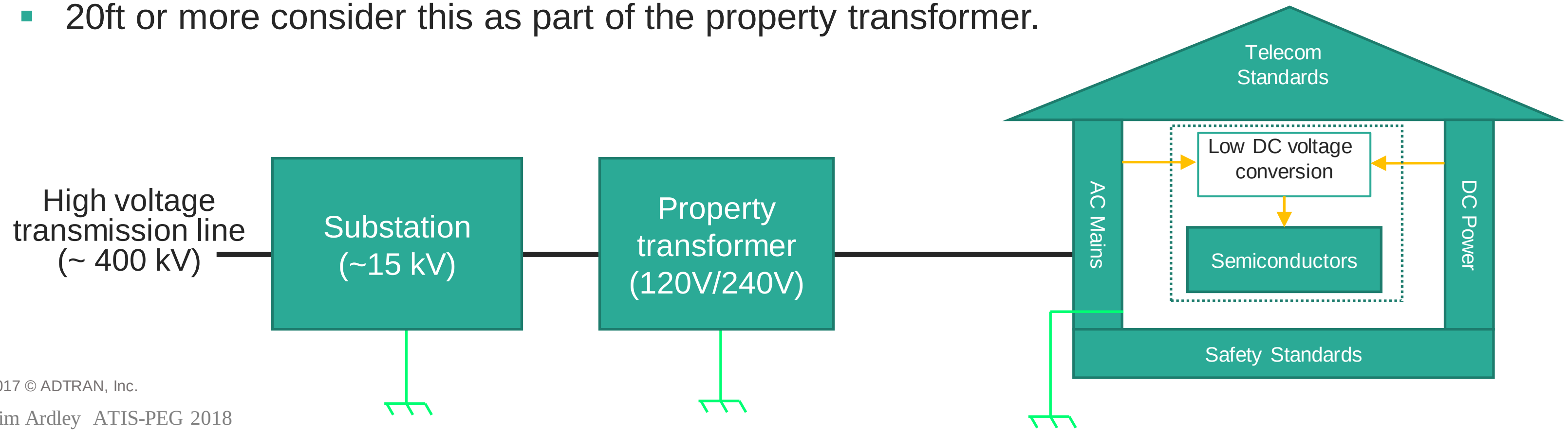
- AC voltage to the consumer (building) is done in stages:-
  - Distribution from power stations is in the region of 400 kV.
  - Substations drop this down to around 15 kV.
  - Subdivision or property transformers drop 15 kV down to local AC voltages.
- AC to buildings can be single phase, 2-phase or 3-phase.
  - Industrial buildings can also be powered from multiple transformers/substations.
  - Multi-tenant buildings with individual supplies can be a headache!
- There are a wide variety of AC mains topologies used around the world!
- The AC meter can also be located some distance from the property.
  - 20ft or more consider this as part of the property transformer.



Earthing Systems

- There are 4 letters designated to identify the type of EARTHING system.
  - **T**erre (French for Earth) and indicates a direct connection to earth.
  - **N**eutral
  - **C**ombined
  - **S**eparate
  - **I**solation (Earth) can also come into the equation.

- The letters are grouped together to identify the type of earthing used.
  - 1st letter identifies how the AC power source (transformer) is earthed.
  - 2nd letter identifies how the AC power source installation is earthed.
  - 3rd & 4th letters identifies the relationship of Neutral and Earth.

TN-S Power Systems

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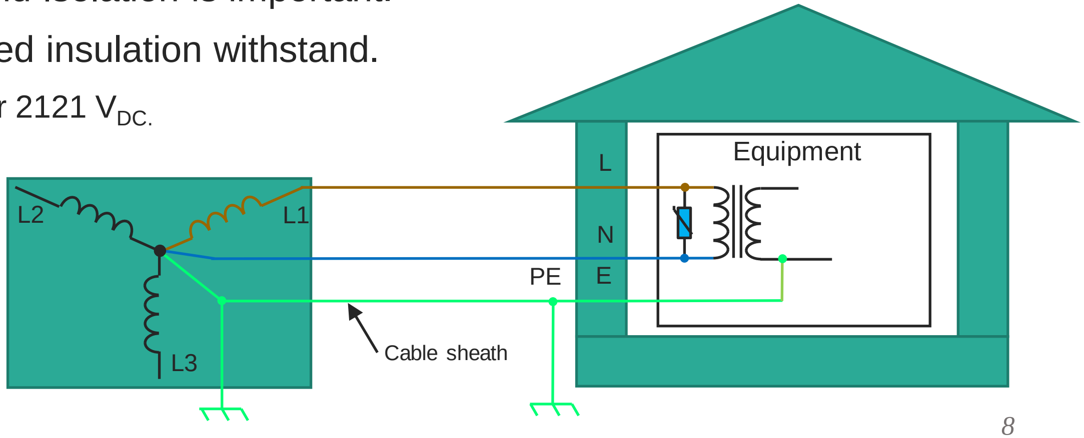
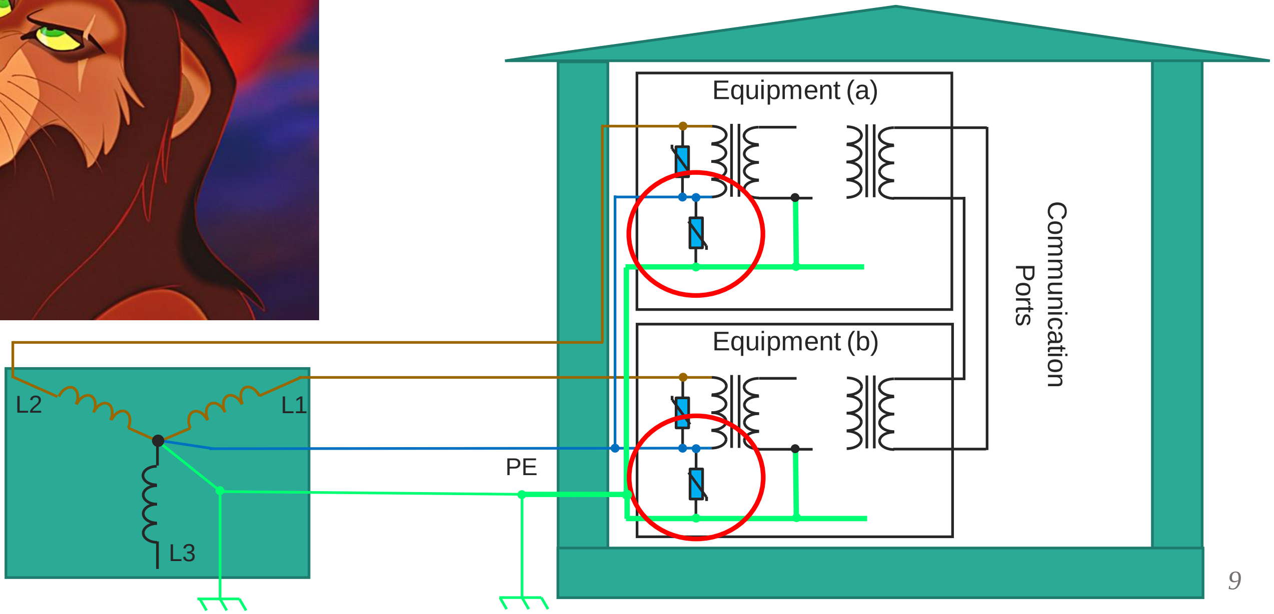
- TN-S has earthed (**T**) **N**eutral and Neutral is **S**eparated at the consumer.
- The consumers earthing (E) is connected to the metal cable sheath.
  - Provides a nice “clean” Earth. Older houses in the UK for example can use TN-S.
- Lighting surge events can be developed between Live & Neutral and Neutral & Earth.
  - Overvoltage protection between the L-N on the AC interface for an isolated system.
  - Ideally, the equipment is isolated by the transformer…. but we are not in an ideal world.
- Connecting digital GND to Earth is a common practice when Earth is available.
  - AC mains transformer insulation and Isolation is important.
  - Safety standards call out the required insulation withstand.
    - This is basic insulation of 1500 V_{RMS} or 2121 $V_{DC.}$



TN-S Intra-building

- With Earthed equipment, the equipment is now interconnected with a common ground.
- When the AC interface is earth referenced with overvoltage protection:-
  - Two phases are protected, but provides a common grounding path between the two.
- Heard that Earth connection at the building entrance can be questionable in some regions!
  - Looks like a safety issue to me……..



TN-S Intra-building

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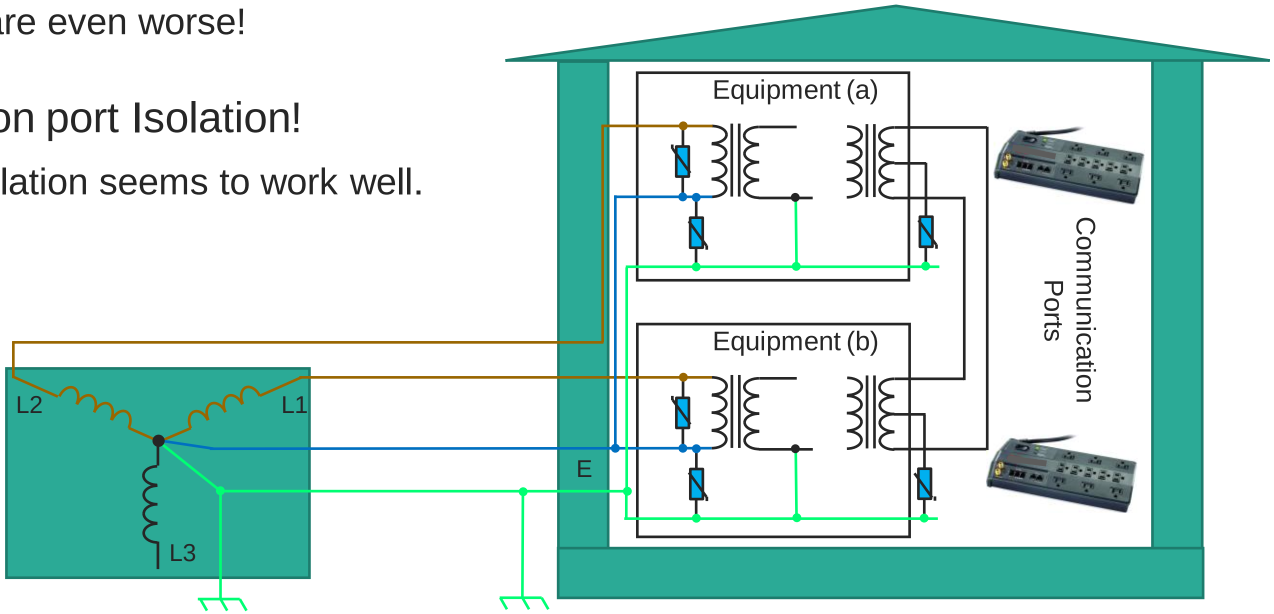
- When communication ports are also referenced to earth through overvoltage protection.
  - A current path through the two equipment is caused by the low overvoltage protection to Earth.
- What happens when the Neutral also has ground referenced protection?
  - More current paths and back-firing of the power supply protection is possible.

2-phase AC service exacerbates the problem but

Multi-dwelling buildings are even worse!

- Rely on communication port Isolation!
  - 4 kV to 6 kV surge isolation seems to work well.



TN-S External Building Systems

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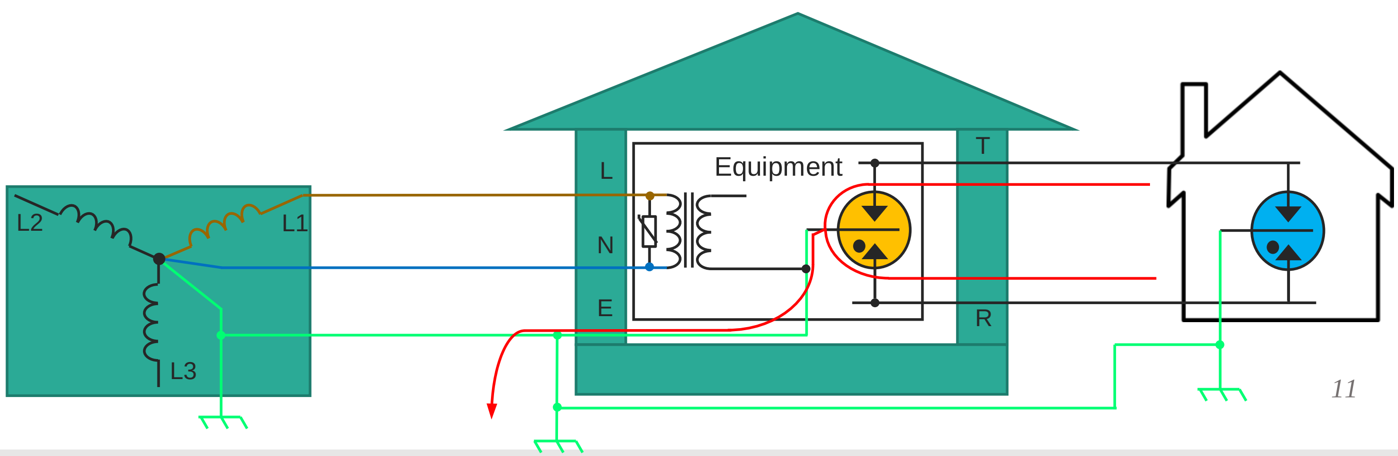
- Equipment with internal OVERVOLTAGE protection to Earth can cause issues.
  - High surge currents are being pulled through the building wiring!
    - Causes Ground Potential Rise issues inside the building and between equipment.
    - Equipment can easily be designed to support high surge currents with an Earth on the AC plug.
  - External communication cable without a shield bond will provide higher GPR's.
  - Communication cable bonded to the customer premise building Earth will help limit GPR's.
    - The shield on the cable + interconnects has to be able to support the fault current!
      - Might sound logical, but standard Ethernet shielded cable + interconnects have been thought of as good reliable Earths???
    - Countries not doing this is probably due to trying to save costs!

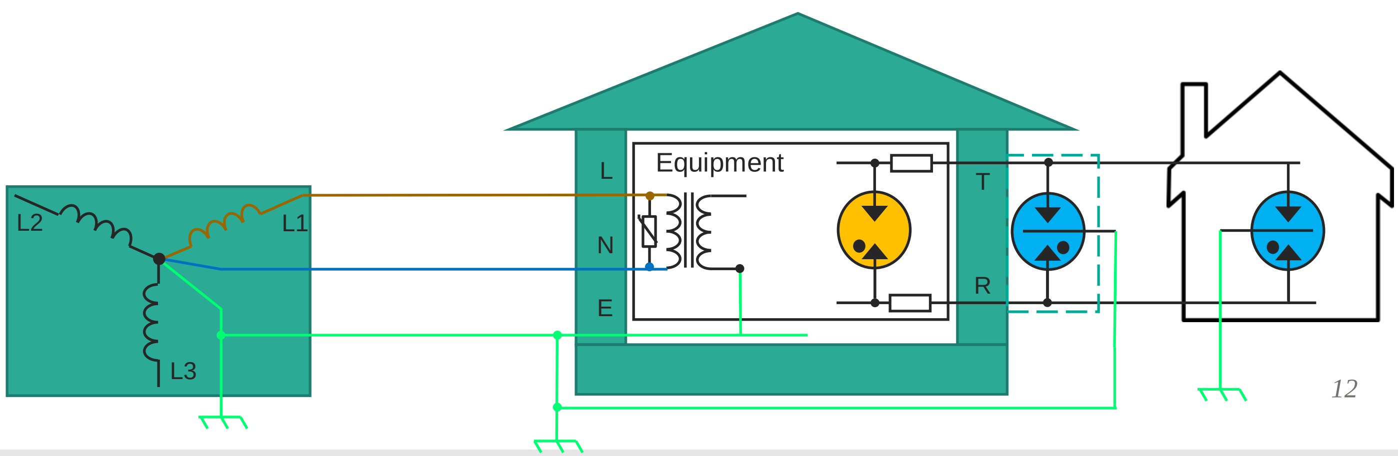


TN-S External Building Systems

- The definition of what is a “**Primary Protector**” has also been skewed.
  - Overvoltage primary protector defined components are being used as “secondary protectors” in a primary protection role. Not a big issue but………
  - A “secondary over voltage protector” should have an O/C protector in front of it?
    - Designs using 5kA-10kA protectors without over current protection looks like a primary protection solution.

      Does it look like a duck, walk like a duck, swim like a duck and quack like a duck…

- NID boxes should ideally be used where possible.
  - Countries not doing this are probably trying to saving costs!

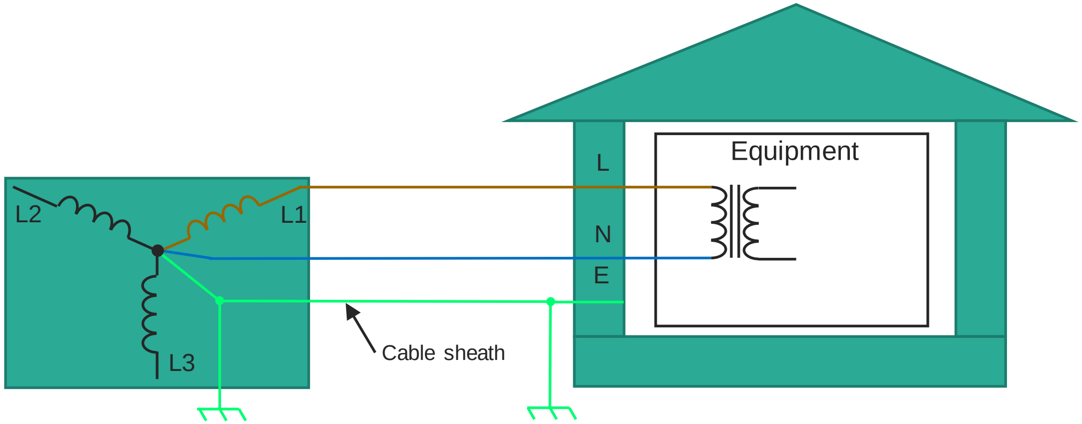


Question?

- What happens if the cable sheath of the AC cable on a TN-S corrodes and loses its connection to the consumer Protected Earth?

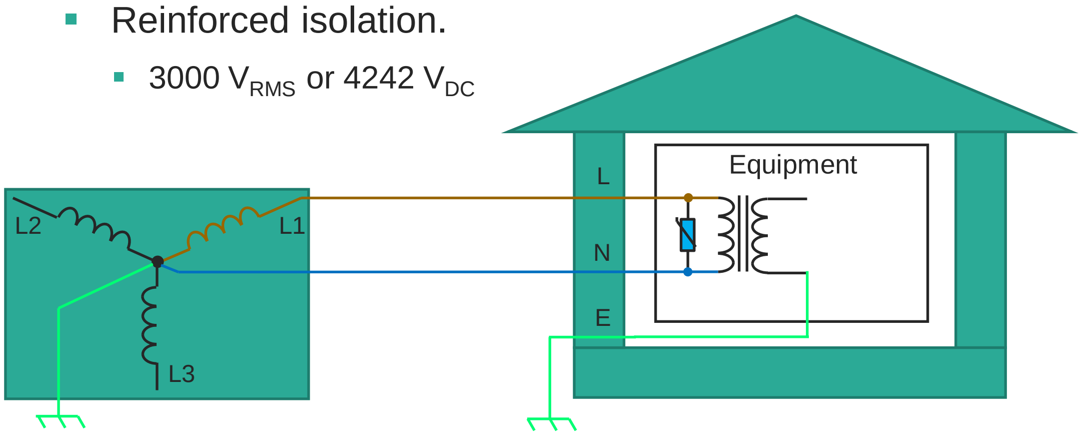
The structure becomes a TT Power System!

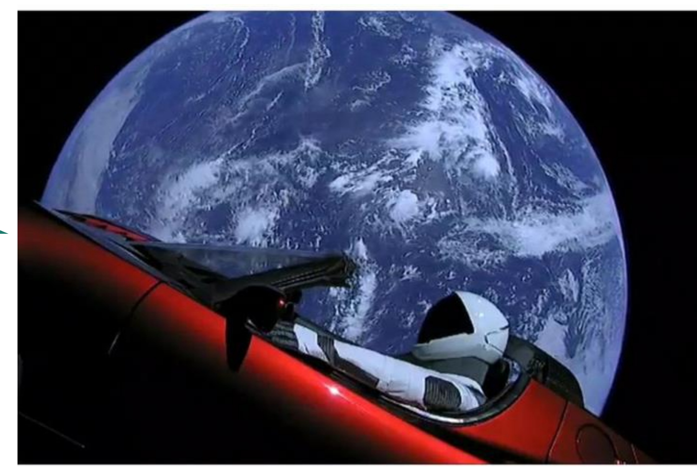
(Terra Terra)



TT Power Systems

- Japan uses this configuration, but is also used in other countries around the world.
  - Common where over-head power lines are used.
- The substation & consumer is independently earthed - No Earth wire between the two.
  - ISOLATION is your friend!
  - Digital ground connected to Earth places importance on power supply transformer insulation.
- GFCI’s are important in this configuration to detect earth loop currents.
- What is the typical recommended isolation?
  - 6 kV to 10 kV seems to work well.
  - Reinforced isolation.
    - 3000 V_{RMS} or 4242 V_{DC}





Tesla Rocket Man

TT Power Systems

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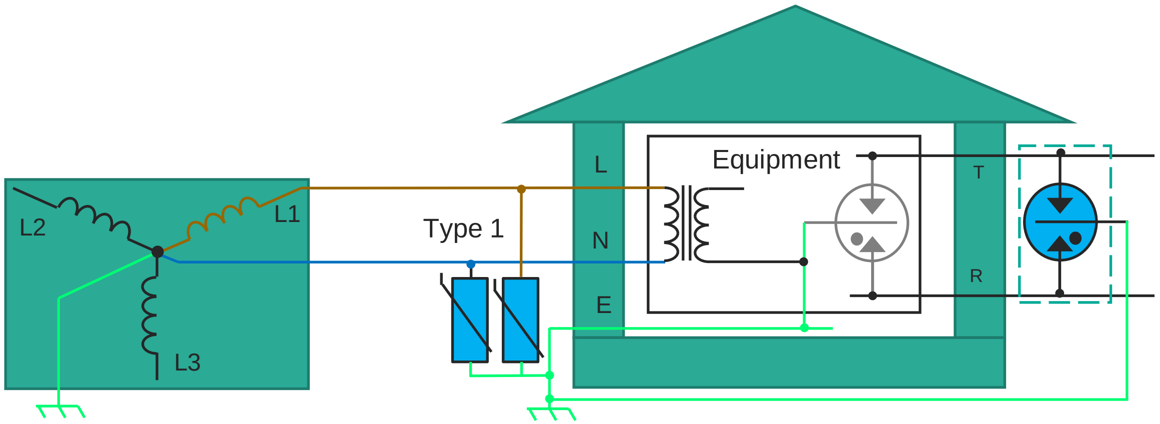
- GPR between the property and substation is dependent on ground resistance.
  - Japan has been requesting 13 kV to 15 kV surge tests for AC interfaces in ITU-T K.20 (central office) & K.21 (customer premise).
    - These levels are very possible depending on SOIL RESISTIVITY and DEPLOYMENT method.
  - Need to be sensitive to internal building protection topologies to limit current paths.
    - Isolation is internal port building TT's friend!
  - Countries might need suitable AC building entrance protection.
  - Might also need external communication building entrance protection too!



Question?

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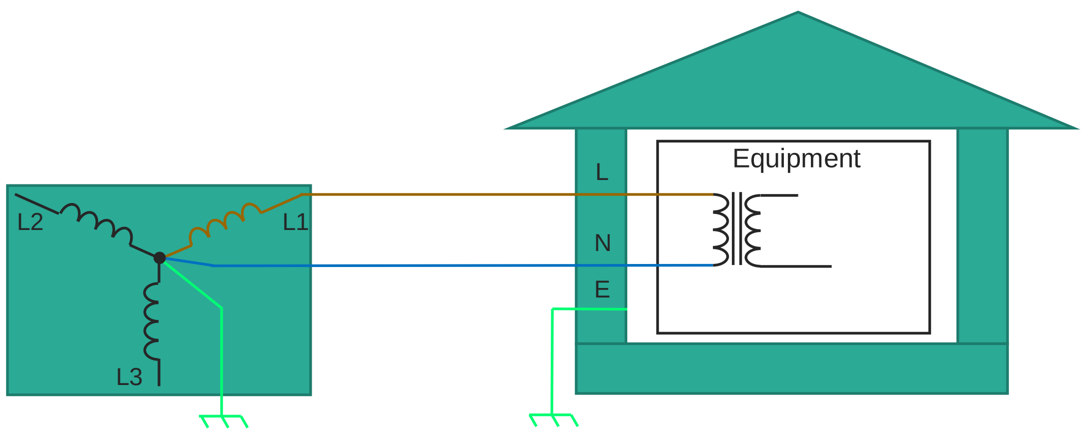
- What if the substation or transformer feeding the consumer building isn't Earthed on a TT system?

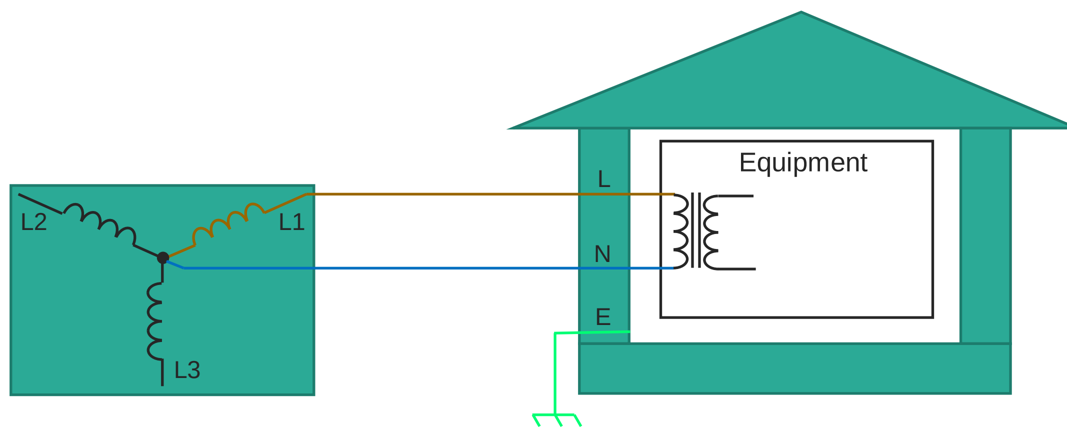
The structure becomes an IT Power System!

(Isolated Terra)



IT Power Systems

- Mainly used in military applications where reliability is needed as fault current can be present while the equipment is not affected.
- Not used in residential as fault currents are difficult to detect and can be high causing safety issues such as fire through sustained high arc currents for example.



TN-C Power Systems

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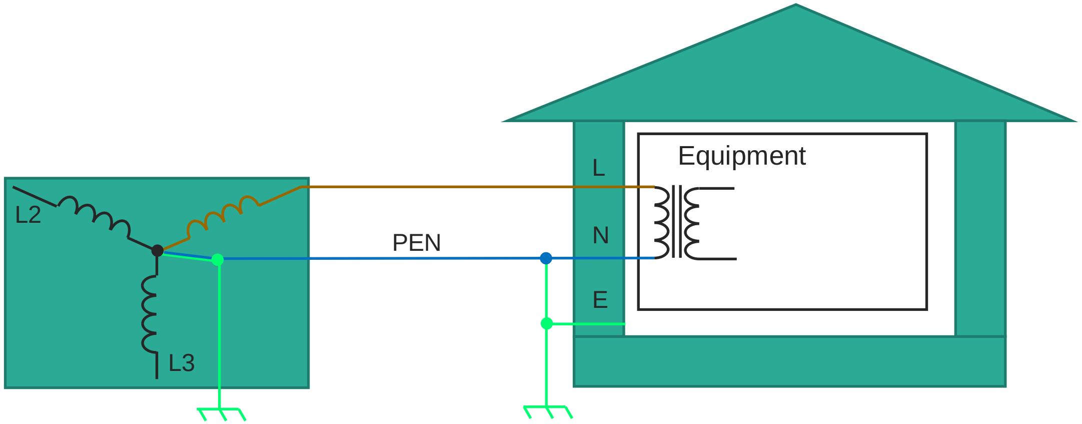
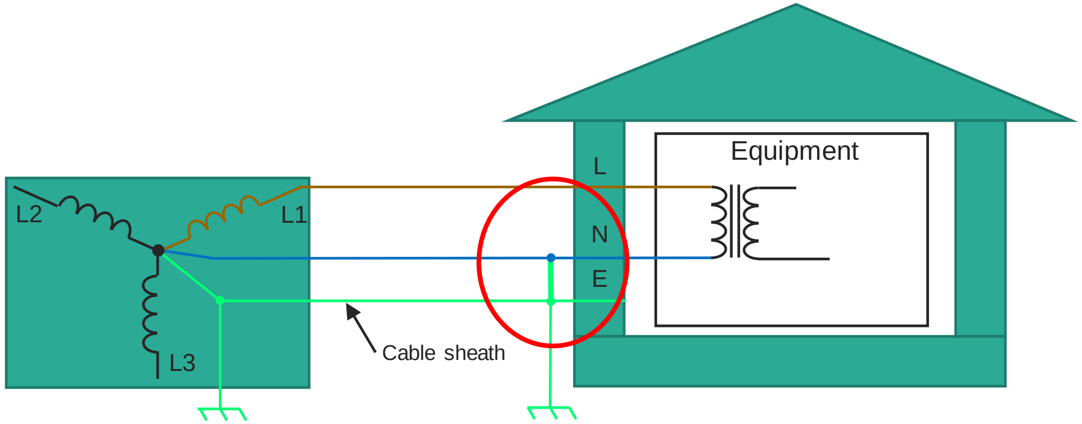
- TN-C combines the Neutral and Earth that is then broken out at the customer premise.
- Two options of Earthed or Unearthed (just Neutral) consumer premise.
- This is often called PEN (Protected Earth & Neutral).
  - Can also be called:-
  - PME or **P**rotective **M**ultiple **E**arthing.
  - MEN or **M**ultiple **E**arthed **N**eutral.
  - MGN **M**ulti-**G**rounded **N**eutral.
- If the Neutral is lost, return currents will be through the Earth conductor.



Question?

- What is the difference between a TN-S and TN-S-C?
- TN-S-C has earthed (T) Neutral and Neutral is Separated at the consumer with a **C**ommon Earth connection at the consumer.



TN-C-S Power Systems

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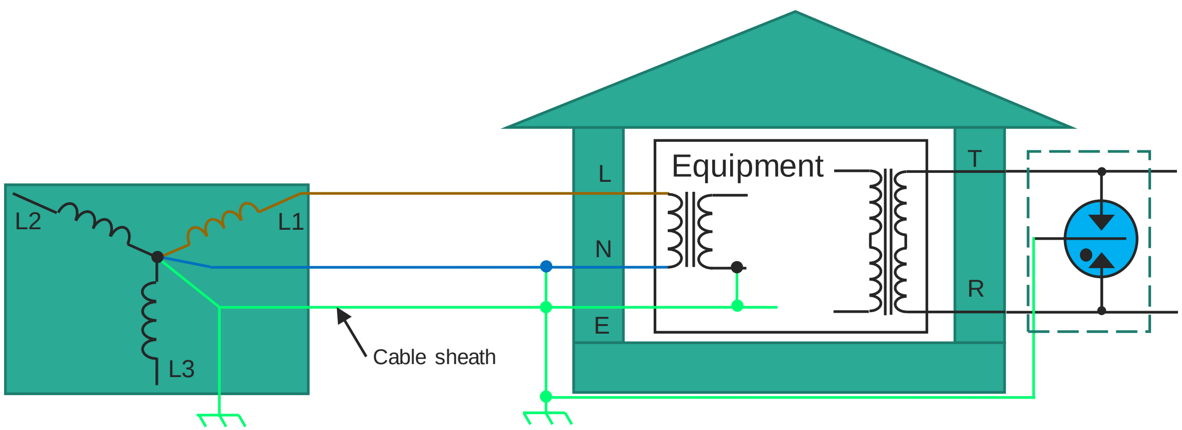
- The Neutral is bonded to the Earth at the customer premise.
  - Earth rod is normally at the same location as the AC mains meter.
    - The most common topology for newer housing.
- The Neutral and Earth for the property is broken out at the junction box.
  - House wiring is then wired for 3-wire (L, N & E) sockets.
- Communication termination is also done at the building entrance to help mitigate surges through the building wiring even if equipment is referenced to Earth.
  - AC surge withstand of 2 kV to 3 kV seems to work very well.
  - Basic insulation of 1500 V_{RMS} or 2121 V_{DC}.



TN-C-S Intra-building

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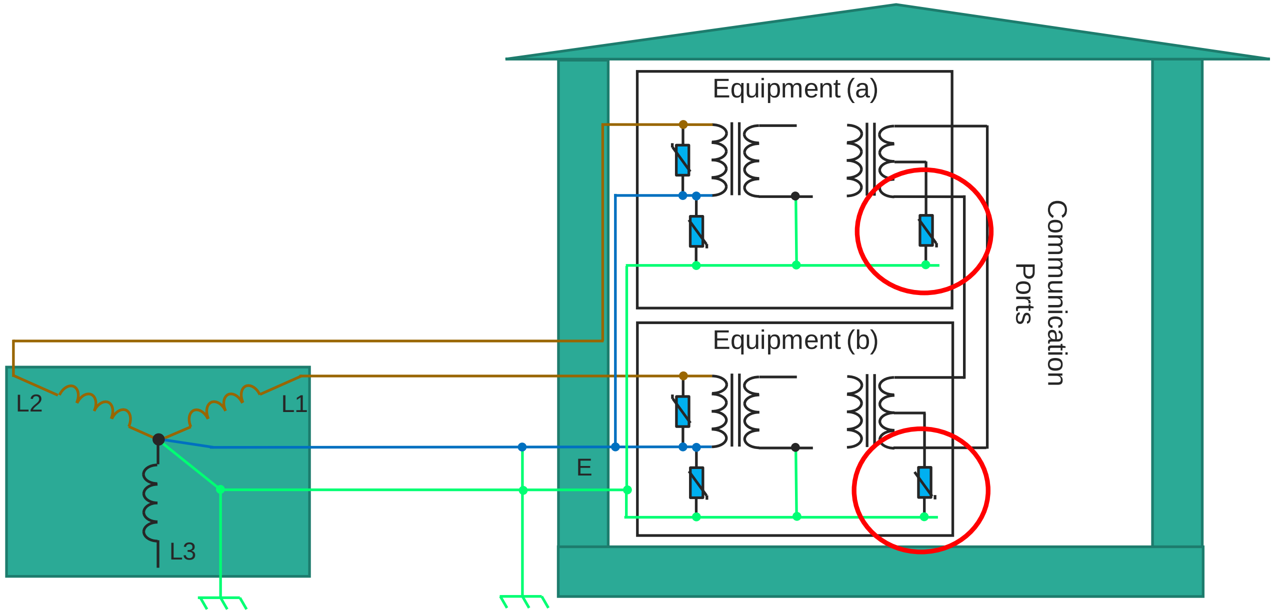
- Using a Neutral-Earth protector provides minimal protection.
  - Rely on isolation of the transformer on the AC mains interface (no protection between N-E).
- Adding protection on a ground referenced termination can still be problematic!
  - Neutral-Earth connection with OV protection in the AC provides a current path.



AC Mains Summary

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- The Grounding structure of the high voltage transformer and AC Mains at the consumer premise can make an enormous difference in surge stress levels.
- Find out what TOPOLOGY of AC is being used and design accordingly!
- TN-C-S
  - Consider 2 kV to 3 kV surge isolation withstand.
  - Basic insulation of 1500 V_{RMS} or 2121 V_{DC}
- TN-C
  - Consider 4 kV to 6 kV surge isolation withstand.
  - Reinforced insulation of 3000 V_{RMS} or 4242 V_{DC} is ideal.
- TT
  - Consider to 6 kV to 10 kV with Japan to 15 kV.
  - Reinforced insulation of 3000 V_{RMS} or 4242 V_{DC} as a minimum.

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DC configurations.

- **External building powering.**
- **48 V system internal powering**

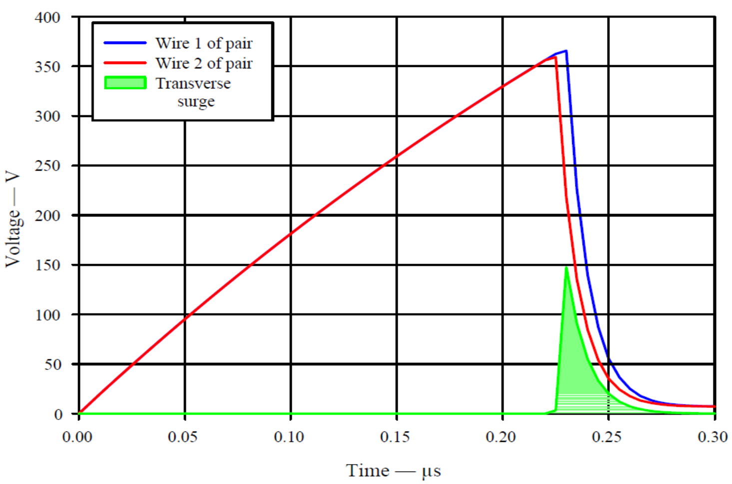
Transverse Surge with an Isolated Interface

- A transverse surge can ONLY occur if the ISOLATION is compromised.
  - Ethernet & PoE reminds me of the days when DSL interfaces had a wide array of protection options being designed to GND!

- Breakdown of isolation can be caused by:-
  - Having over-voltage protection to ground/Earth.
  - Socket is not suitably rated to provide the required isolation.
  - Poor trace/clearance layout attributes.
  - Insulation rating of the transformer is not suitably rated.
  - Bob Smith components (capacitors) breakdown.

- The transverse surge should be a lot smaller…. however, ITU standards have increased transverse surge currents for Ethernet & PoE.

WHY?



Graph from ITU-T K.44, (05/2012)

PoE Protection to GND

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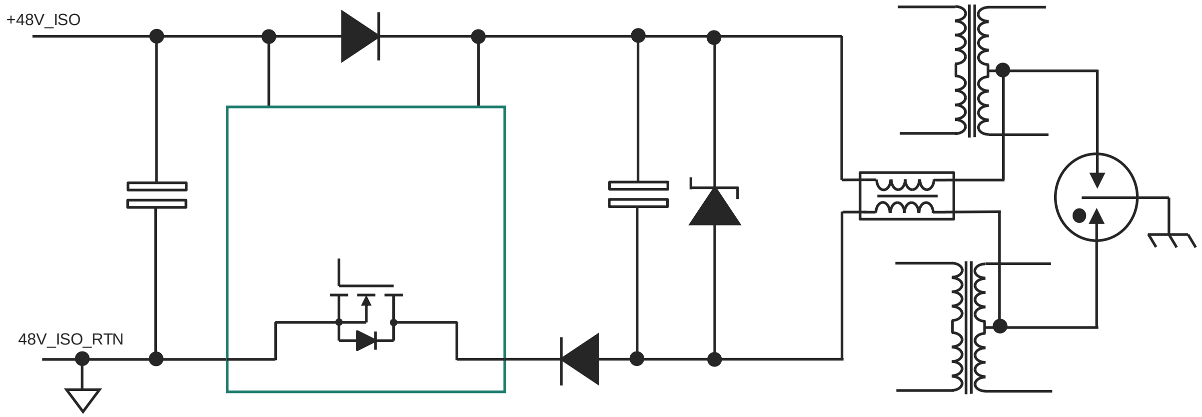
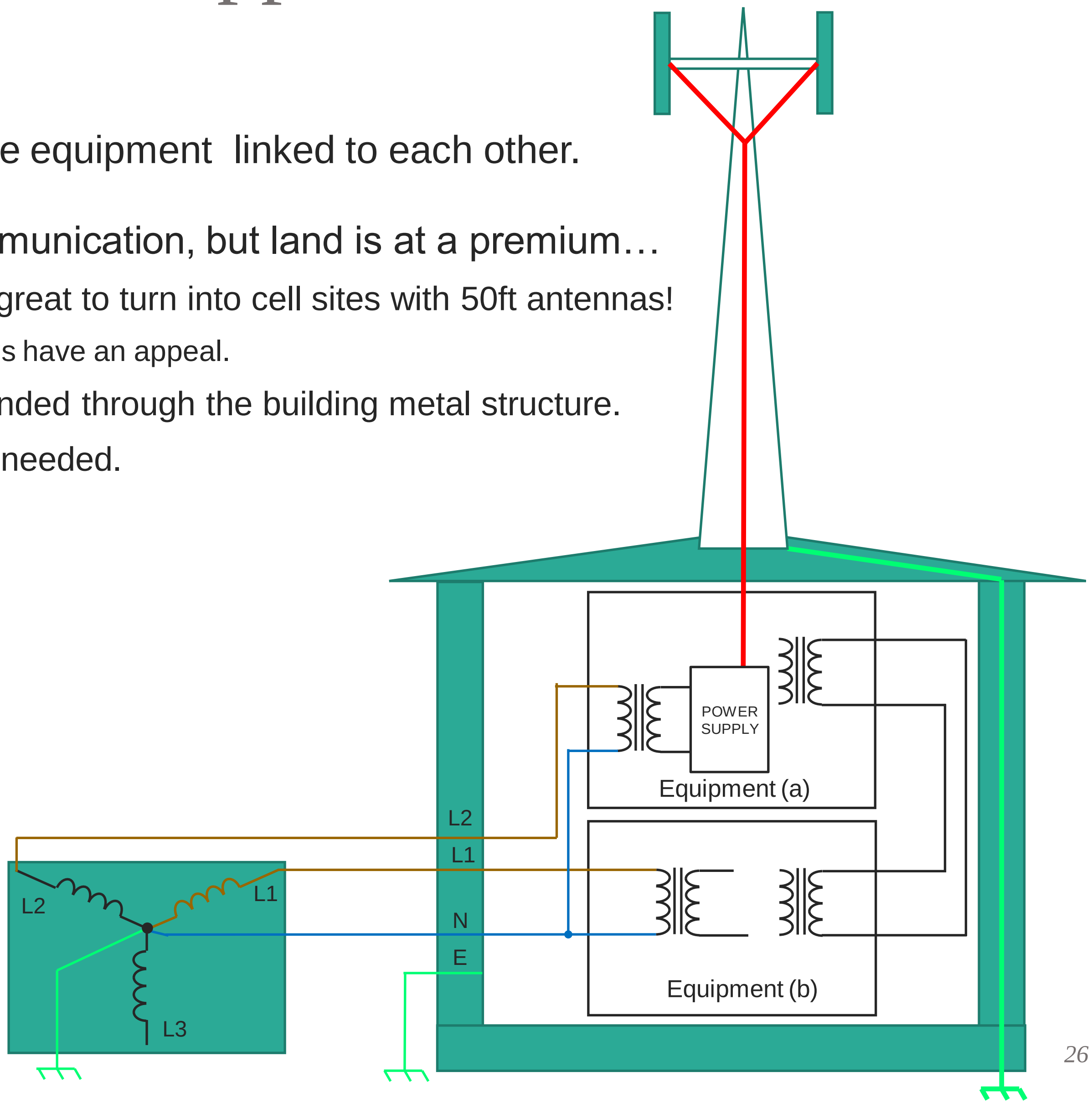


- One explanation is overvoltage protection to the center tap of the transformer.
  - The differential pair is “grounded” at the same time when the protection operates, limiting transverse surge on the Ethernet interface but…
    - Isolation of the interface is limited by the overvoltage protector.
    - **ALL** the fault current goes through the transformer winding.
    - Transformer now becomes the fuse for the overvoltage protector.
  - **Might explain why transverse surge currents have escalated!**
  - Can create a large differential voltage for the powering circuit if a crowbar type protection is used.

Why did ITU-T have 6 kV longitudinal surge for Ethernet interfaces for internal CO applications?

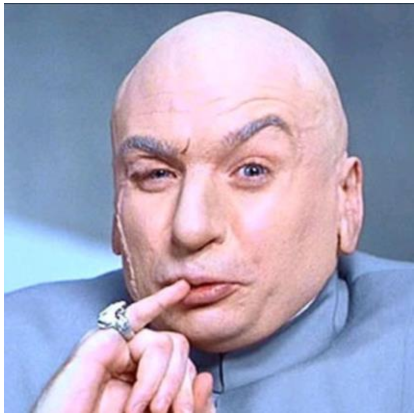
Antenna System Application

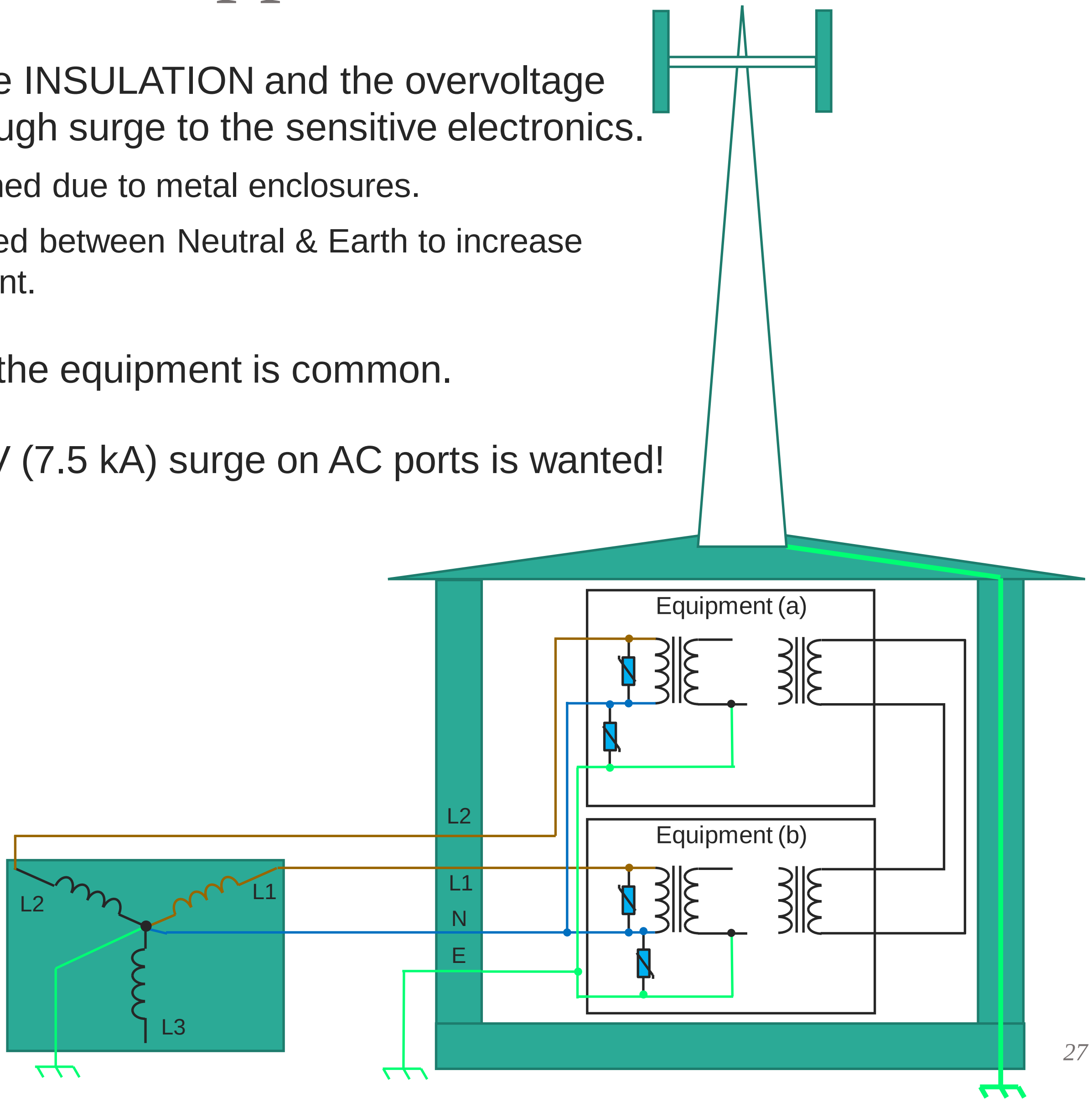
- CO building with multiple equipment linked to each other.
- Need antennas for communication, but land is at a premium…
  - Building structures look great to turn into cell sites with 50ft antennas!
    - Even commercial buildings have an appeal.
  - Earth of antenna is grounded through the building metal structure.
  - Head-end power is also needed.



Antenna System Application

- AC transformers provide INSULATION and the overvoltage protection limits let-through surge to the sensitive electronics.
  - Equipment is often Earthed due to metal enclosures.
  - Protection probably added between Neutral & Earth to increase reliability of the equipment.
- Digital GND to Earth in the equipment is common.
- Might explain why 15 kV (7.5 kA) surge on AC ports is wanted!





Antenna System Application

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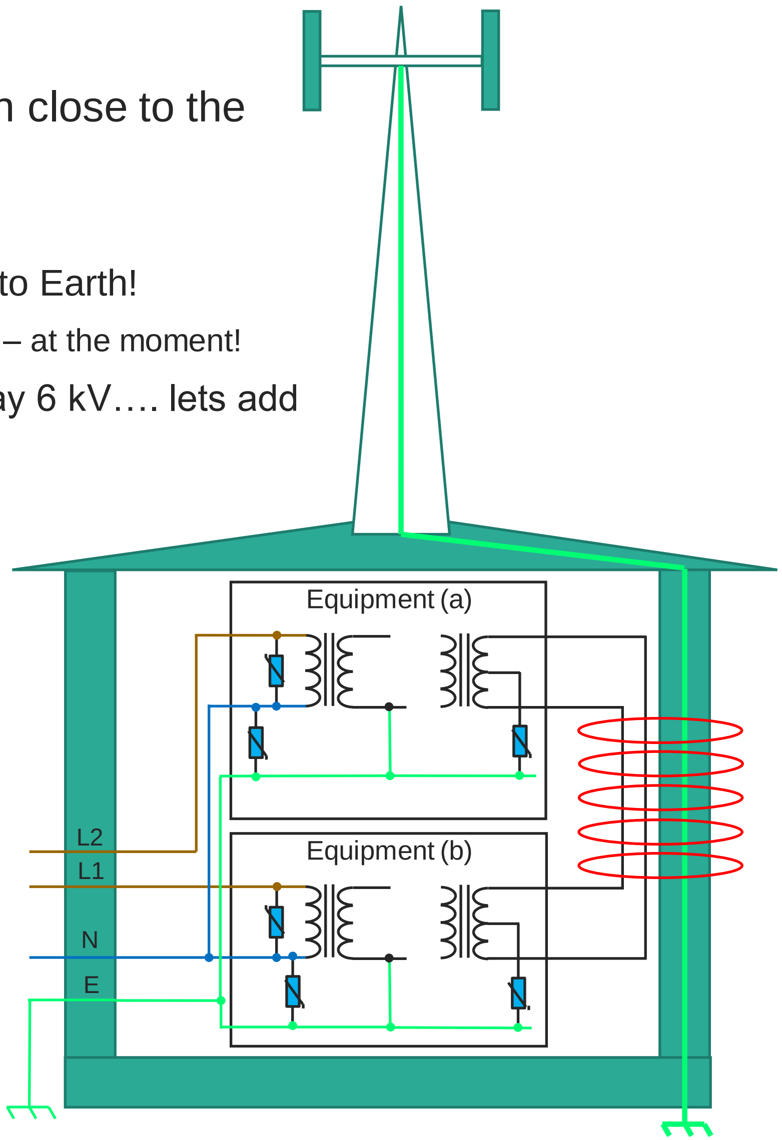
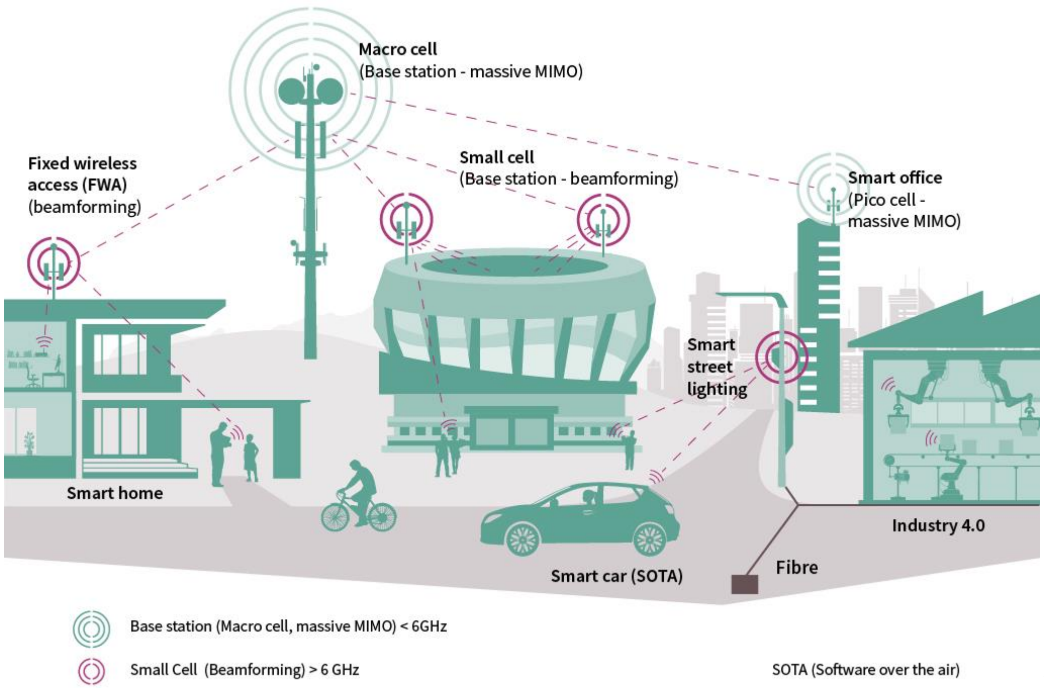
- Internal building communication wiring will also run close to the building structure.
  - Surge coupling onto isolated communication cables!
  - Problems would have increased with Digital GND tied to Earth!
    - Std Ethernet for example just has to meet 1500V_{rms} Isolation – at the moment!
  - Rather than increase the isolation of the interface to say 6 kV…. lets add overvoltage protection!
- Over-voltage protection converts stress from voltage to current.
- A.C is now directly coupled to the communication ports.
- Explains why CO internal surges were 6 kV.
  - ITU-T plans to have a separate test for this type of cell tower deployment.



Developing 5G Applications

- External PoE have largely been driven by consumer & industrial applications to date.
  - Security cameras, remote WiFi, guard house telephones etc
- Protecting 5G PoE network will also be a challenge!
  - Both ends of the cable need equal consideration and the same circuit protection topology.

Smart and connected - the communication of tomorrow with 5G



Artwork by Infineon

Grounded G.FAST Deployment

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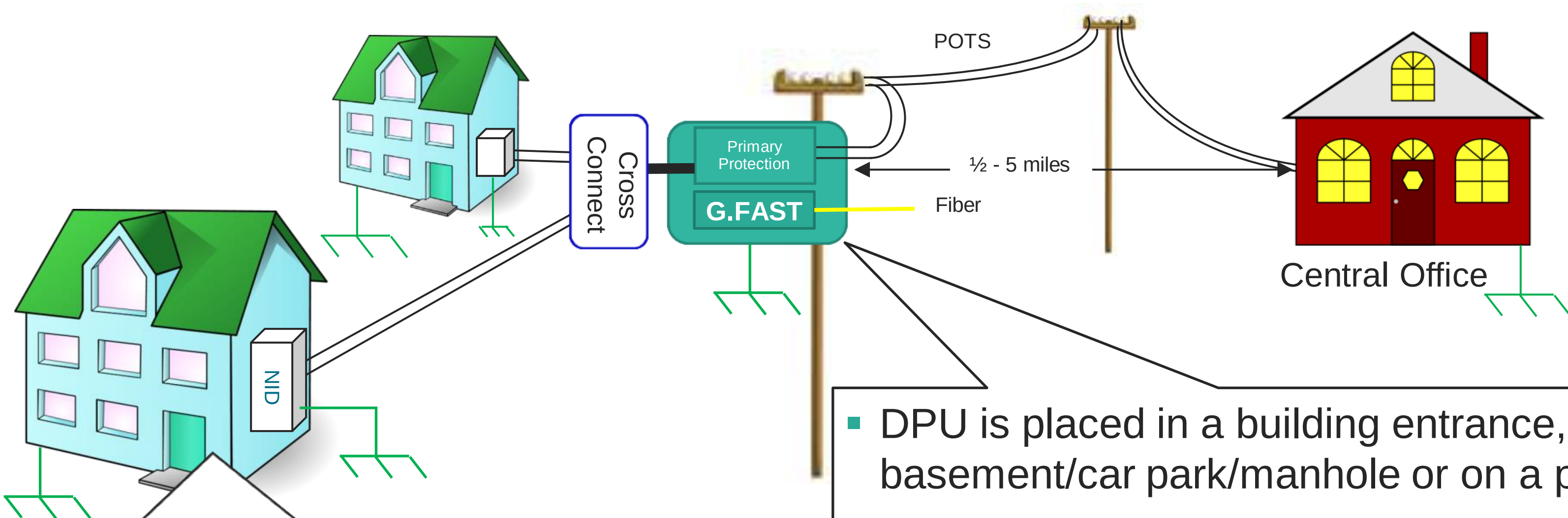

- G.FAST is very similar to VDSL2.
  - Modem to provide customer service.
  - Reverse powering is also an option.
  - Inside building primary protectors to be above 120/240 V rms voltages.
- NID box on house to terminate OSP cables.

- DPU is placed in a building entrance, basement/car park/manhole or on a pole.
- Can be powered by ±190 V SPAN, AC, DC or reverse power depending on model.
- Option to switch-to POTS service or combine POTS with G.FAST.
- The DPU metal enclosure is suitably grounded and bonded.

Note: USA prefer deployments with only G.FAST.

Grounded G.FAST Deployment

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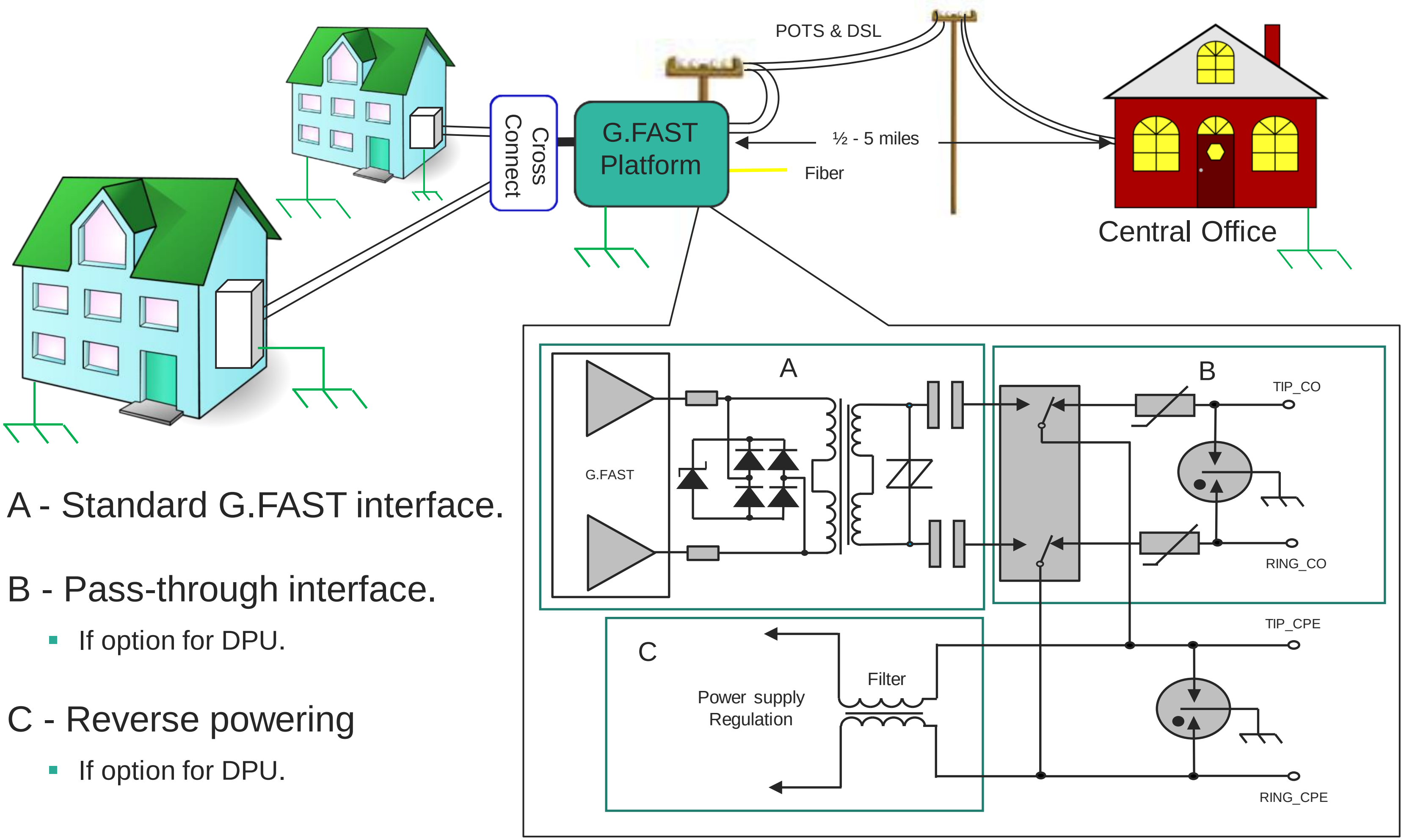

- A - Standard G.FAST interface.
- B - Pass-through interface.
  - If option for DPU.
- C - Reverse powering
  - If option for DPU.

Note: USA prefer deployments with only G.FAST.

DPU Reverse Powering

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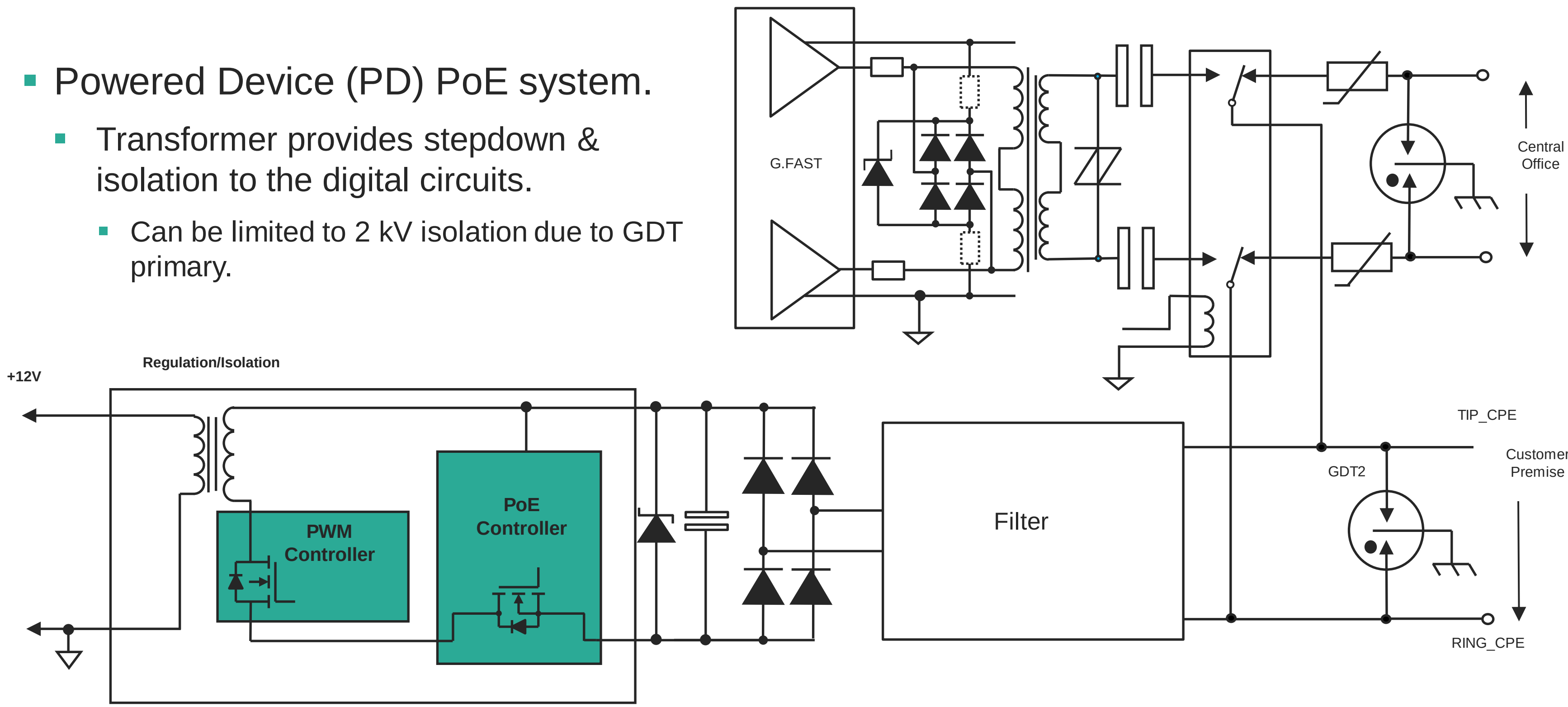
- Powered Device (PD) PoE system.
  - Transformer provides stepdown & isolation to the digital circuits.
    - Can be limited to 2 kV isolation due to GDT primary.



- The filter is the most important aspect of the design for circuit protection.
  - Seen designs where the reverse powering protection does not allow the primary to operate.
  - Adding series resistance (DCR) is problematic as it reduces power/line length.
  - First level AC coordination is problematic due to low impedance interface.

Floating International Deployment.

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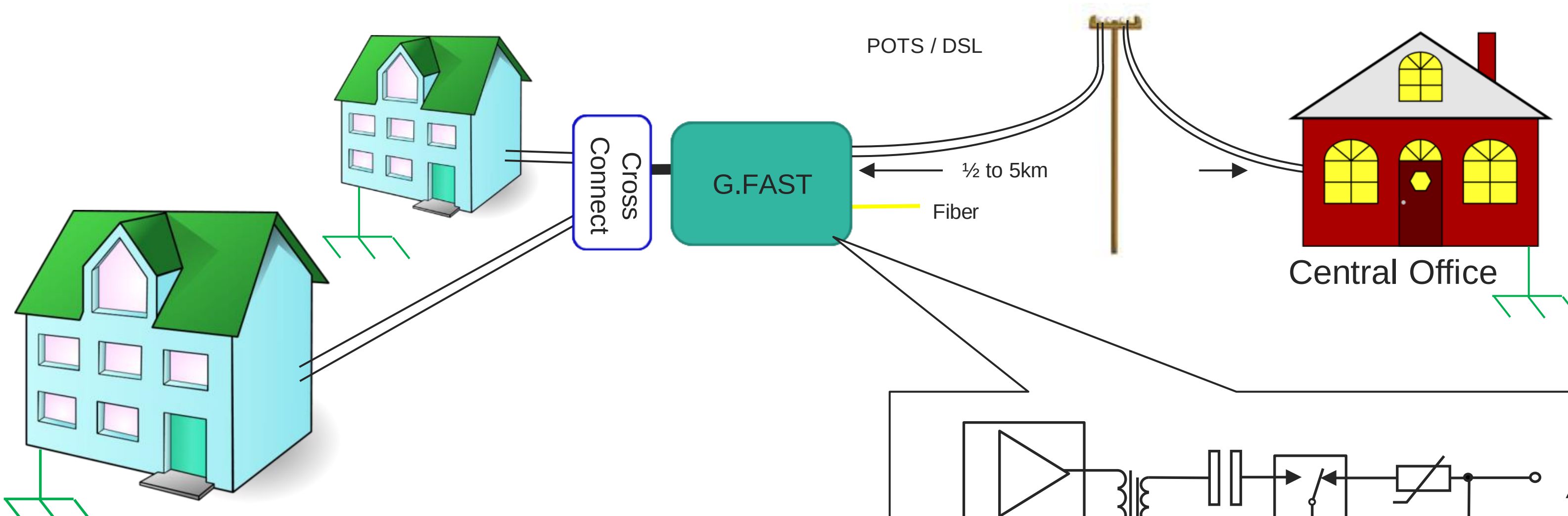
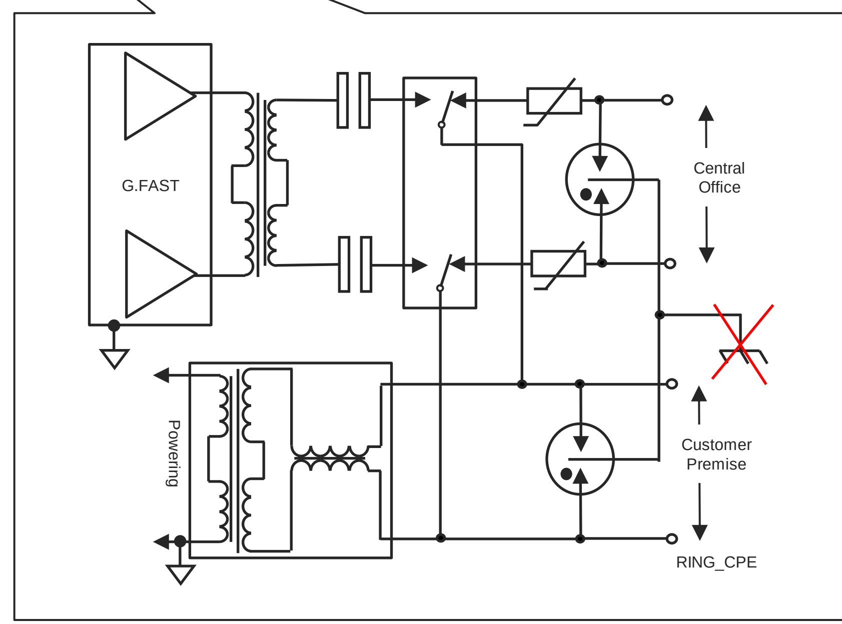


- Issues in one deployment:-
  - OSP DPU is floating!
    - No ground rods have been installed at locations.
    - DPU placed under ground as typical deployments.
    - No provision for primary protection to Earth in the cross-connect.
  - Can't rely on NID boxes at the customer premise location.

……and up to 5 km of cable to the DPU.



What will break down first in the network?

Agenda

March 2018

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Introduction

The House of POWERing.

AC Mains configurations.

Types of AC mains configurations.

How this affects surge to equipment.

DC configurations.

External building powering.

48 V system internal powering

48 V System Powering

- A framework can be either:-
  - IBN (Isolated Bonded Network)
    - The equipment is isolated from the frame and a separate ground is run to a central bonding location.
  - CBN (Common Bonded Network)
    - The equipment is connected to the frame that is grounded.
- There are THREE methods for grounding the 48 V RTN.
  - DC-I (Isolated DC return)
  - DC-C (Common DC return)
  - Either DC-C or DC-I

- Issues arose when looking at SFP's or other sub-assemblies when inserted into a system. They could change the characteristics of the shelf!

DC-I System Configuration

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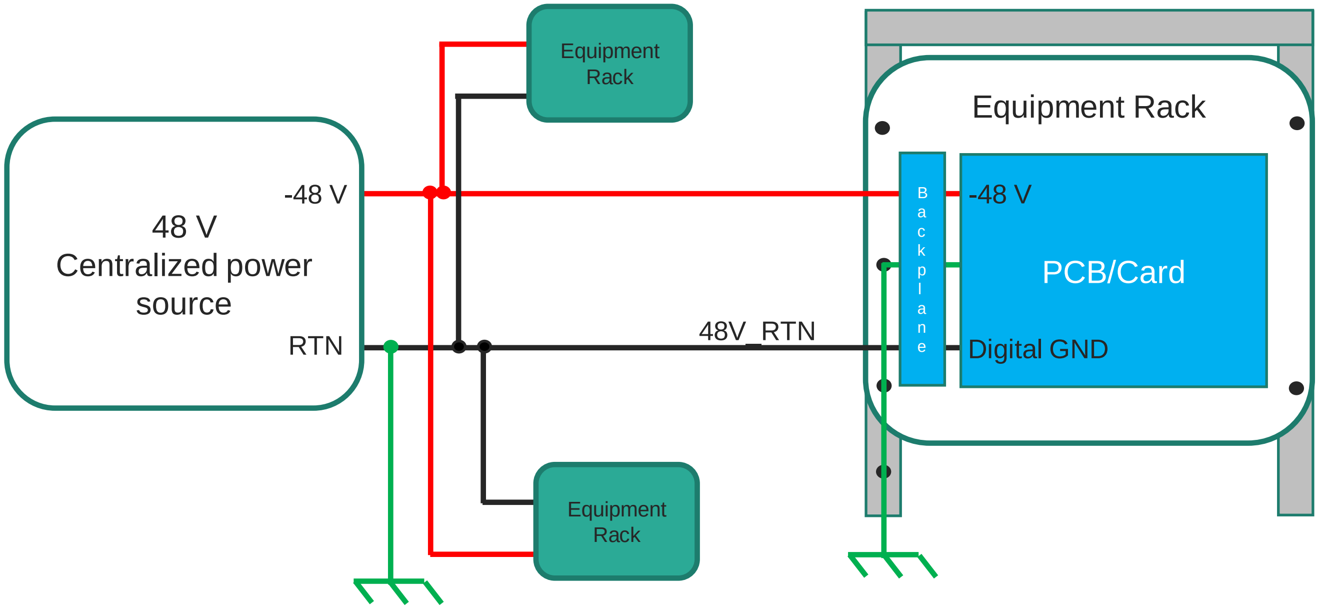

- Commonly used in the CO environment in the USA.
- The centralized power source can be a long away from the equipment.
  - Can often be on another floor or in the basement for example.
- System current is via -48V & RTN only.
  - No current should be seen in the chassis Earth connection.

DC-I System Configuration

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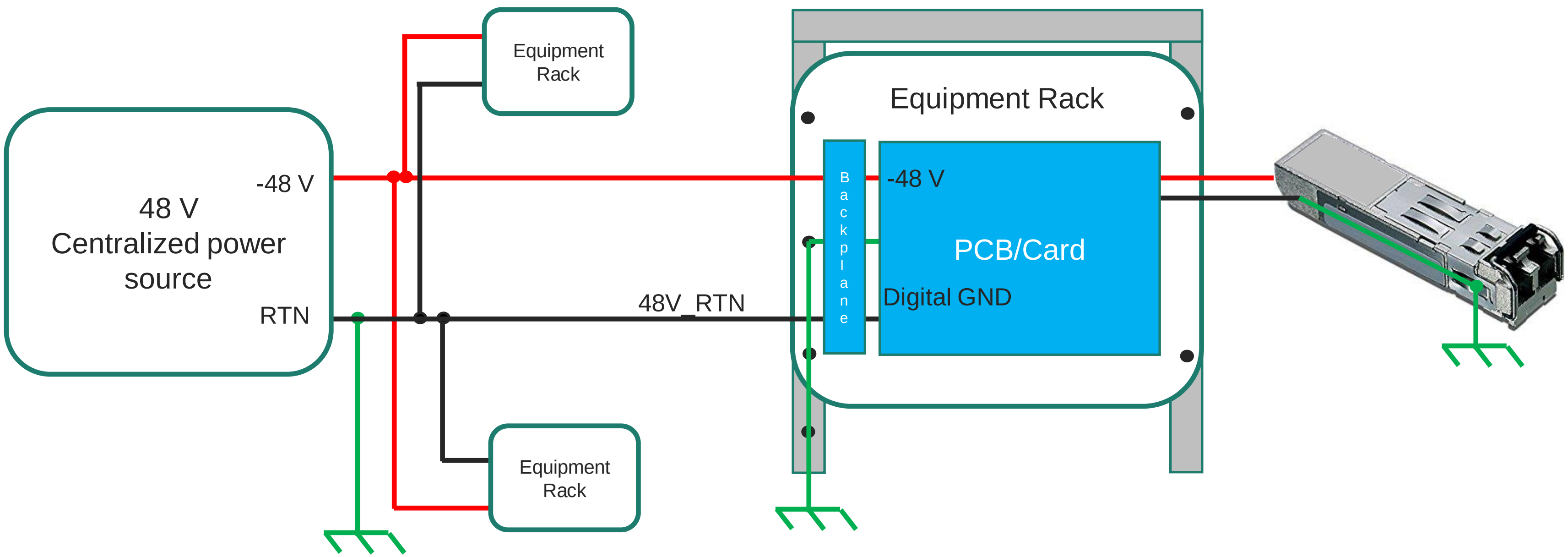

- Use an SFP for example that has its 48V_RTN connected to its metal case.
- When the SFP is plugged in, it makes an uncontrolled connection between Digital GND & Chassis GND/Earth.
  - Turns the system into an uncontrolled DC-C configuration.
  - Causes a current loop in the Earth return at a point that is a weak grounding point.
  - **Safety Issue (fire)?**

GR-1089-CORE Tests for DC-I

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- New tests in GR-1089-CORE, issue 7.
- The following 3 tests confirms DC-I capability:-

1. Resistance shall be equal or greater than 100 kΩ between 48V_RTN and chassis.
   - DVM use low voltages (up to 9 V) signals to measure resistance, so a good indication if a connection is present.
2. Voltage withstand shall be equal or greater than 500 V_{DC}.
   - Tests the insulation of the interface and any capacitors between 48V_RTN and Earth on the card.
   - Same test as seen with Ethernet transformers.
   - With a Hi-POT tester, a 90s ramp time to allow any capacitance to charge and 500 V is maintained for 60s without causing breakdown (sudden step increase in current).
   - Tests to ensure EMI capacitors to Earth are suitably rated.
3. Impulse surge with 1 kV, 1.2/50-8/20 surge, ±1 surge with 0 Ω external resistance.
   - No indication of breakdown of the isolation.
   - Impulse stresses the isolation barrier to ensure the components with a dynamic waveform as in deployment.

Confusion With DC-I Test

22	8a	Tower Mounted Transceiver Fed with Remote DC Power Test (Longitudinal)	±6000	See Note [7]	1.2/50 voltage and 8/20 current with 2-Ω internal impedance[3]	N/A	5	See Figure 4-16. Feed and return to shield simultaneously	See Section 4.6.2.1.7 for a description of when this test applies. Primary protectors are installed for this test.
23	8, 8b	DC Power Port	See ITU-T K.20 Table 7 (enhanced level) See Note [8]	See ITU-T K.20 See Note [8]		See K.20 and K.44 for coupling network details	5	See K.44 for the test procedures and setup diagrams	See Section 4.6.2.1.7 for details.

8. Currently, ITU-T K.20 is using 1000V as the open-circuit test voltage for enhanced levels. The short-circuit current is approximated by the open-circuit voltage divided by the specified 2-ohm internal resistance, in series with another 10-ohm resistor, in series with 9 uF and equates to the open-circuit voltage divided by 12 (83.33 A's for K.20 assuming a single output configuration). If changes to values are made to the ITU-T K.20 and K.44 standards, those changes are to be followed in GR-1089 as well.

Table 7 – Lightning test conditions for ports connected to internal cables

Test no.	Test description	Test circuit and waveform (see figures in Annex A of [ITU-T K.44])	Basic test levels (also see clause 7 of [ITU-T K.44])	Enhanced test levels (also see clauses 5 and 7 of [ITU-T K.44])	Number of tests	Primary protection (clause 8 of [ITU-T K.44])	Acceptance criteria (clause 9 of [ITU-T K.44])	Comments
7.8	Floating d.c. power interface	Figures A.3-5 (1.2/50-8/20 CWG) and A.6.6-2 $R = 0\ \Omega$ Coupling element: 10 Ω + 9 μF in series	$U_{c(max)} = 500$ V	$U_{c(max)} = 1$ kV	Alternating ±5 surges (60 s between successive surges)	None	A	For d.c. power supplies with both sides floating.
7.9	Earthed d.c. power interface	Figures A.3-5 (1.2/50-8/20 CWG) and A.6.6-1a $R = 0\ \Omega$ dpf1 coupling element: 10 Ω + 9 μF in series dpf2 connected to generator return, where dpf indicates dedicated power feed	$U_{c(max)} = 500$ V	$U_{c(max)} = 1$ kV	Alternating ±5 surges (60 s between successive surges)	None	A	For d.c. power supplies with one side earthed.

NOTE 1 – For equipment without an earth connection, wrap the equipment in foil and connect the foil to the generator return.
NOTE 2 – When the cabling is fitted with SPDs, the equipment user and manufacturer may use different test conditions upon mutual agreement; this topic is currently under study.

Confusion with DC-I Test

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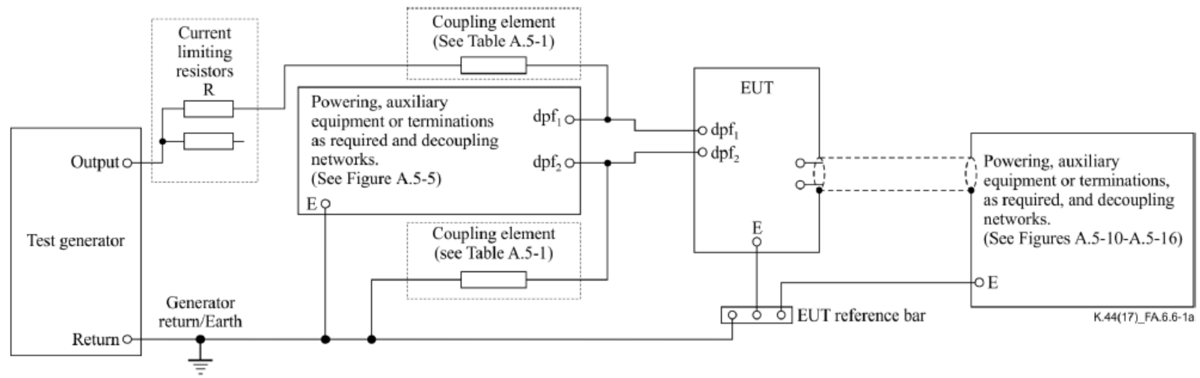
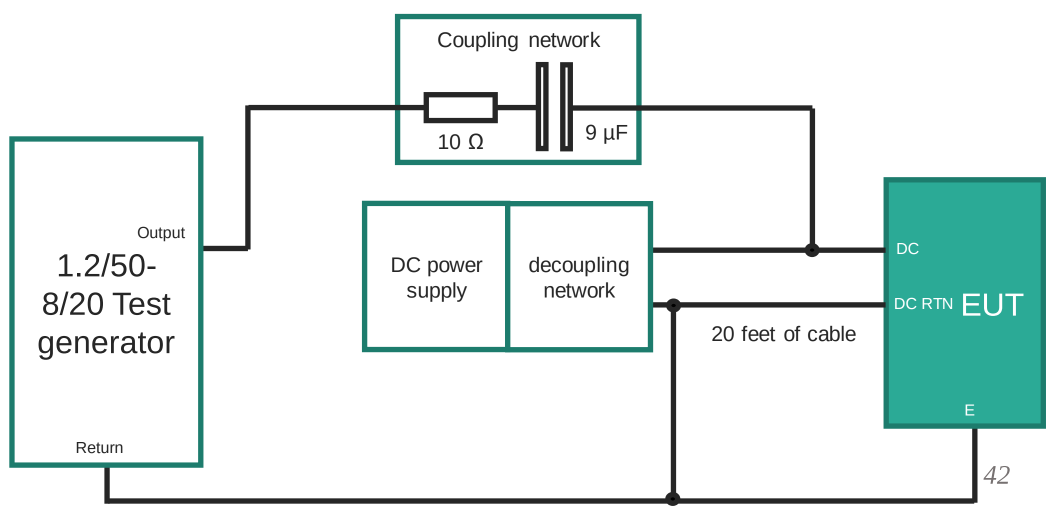


EUT earthing is as follows:
1) If the equipment has an earthing point, connect this point to the EUT reference bar;
2) If the equipment has a conductive case, but does not have an earthing point, connect the case to the EUT reference bar;
3) If the equipment has neither an earthing point nor a conductive case, let the equipment float.

Figure A.6.6-1a – Example of a test circuit for a transverse/differential overvoltage or overcurrent on a d.c. power interface port (dpf2 grounded)

7.9	Earthed d.c. power interface	Figures A.3-5 (1.2/50-8/20 CWG) and A.6.6-1a *R* = 0 Ω dpf1 coupling element: 10 Ω + 9 μF in series dpf2 connected to generator return, where dpf indicates dedicated power feed



DC-C Only Configuration

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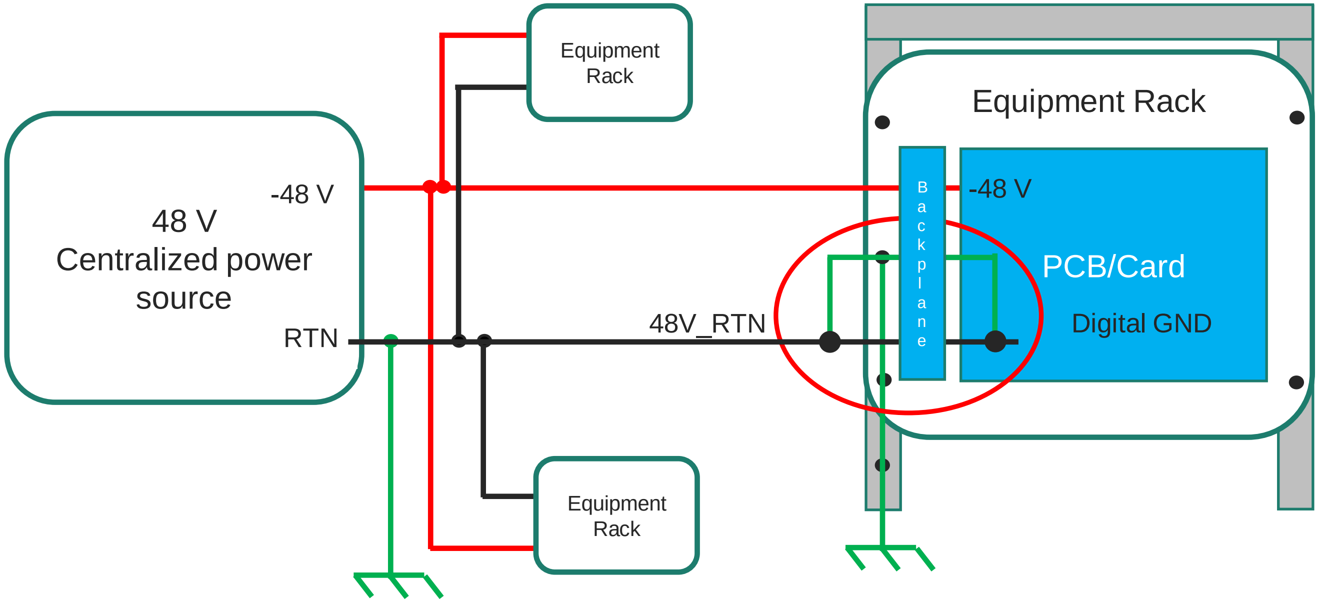

- Connect 48V_RTN to Earth on chassis.
  - Commonly used in remote cabinets in the USA as the source supply is close to equipment.
  - Commonly used around the world in central office locations too.
  - Power supply is directly connected to -48 V bus but equipment can provide DC isolation to the line cards.
    - Adds additional safety for regions where -48V is not stable or can experience large voltage spikes.
  - Ensure Earth return to the power source is a good connection.

Either DC-C or DC-I System

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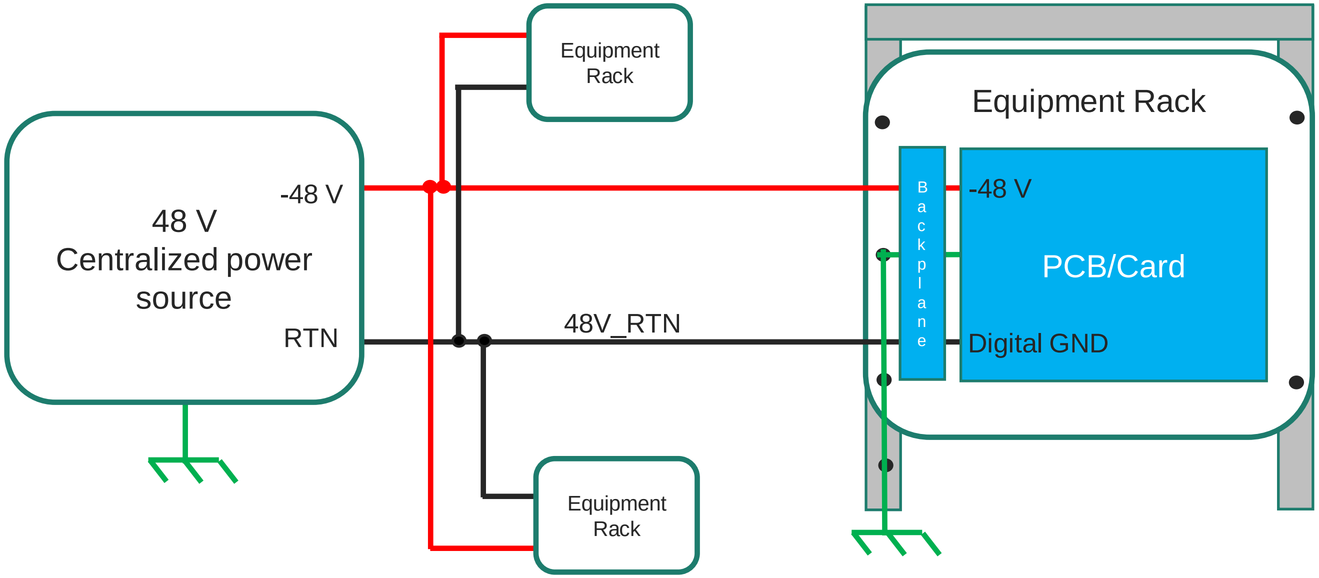

- Either DC-C or DC-I indicates that the equipment can be used in both configurations.
  - A floating or Isolated DC interface is neither DC-I or DC-C.
    - Isolated interface can be used in either.
  - No Earth currents should be present in the chassis.
    - Ensure Earth return to the power source is a good connection.
    - Not common in USA, but it is used internationally.

Table 7 – Lightning test conditions for ports connected to internal cables

Test no.	Test description	Test circuit and waveform (see figures in Annex A of [ITU-T K.44])	Basic test levels (also see clause 7 of [ITU-T K.44])	Enhanced test levels (also see clauses 5 and 7 of [ITU-T K.44])	Number of tests	Primary protection (clause 8 of [ITU-T K.44])	Acceptance criteria (clause 9 of [ITU-T K.44])	Comments
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NOTE 1 – For equipment without an earth connection, wrap the equipment in foil and connect the foil to the generator return.

NOTE 2 – When the cabling is fitted with SPDs, the equipment user and manufacturer may use different test conditions upon mutual agreement; this topic is currently under study.

Summary

- The House of POWERing.
  - The Grounding structure of the AC can make a difference in surge stress levels.
  - Overvoltage protection on Ethernet & PoE can make a difference in surge stress levels.
    - Recall DSL interfaces were swamped with overvoltage protection to protect a poorly rated transformer.
    - Overvoltage protection certainly has a place, but needs to be better controlled within the network.
  - Fix the root cause of the problem and not the symptom.
  - The three DC configurations (two for the USA) need to be considered in the design.
    - Knowing what the relationship is between 48V_RTN and Earth & Digital GND and Earth is important.

Final Thought…..

Lightning is not significantly different around the world, but Earth resistivity, building structure, equipment protection topologies and grounding solutions **are**.

Thank you

Questions?

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