Fundamentals of Power Quality

Power Quality Through Better Wiring and Grounding Practice

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Overview of This Presentation

Elements of building infrastructure that can alleviate or cure power quality problems before they affect operations

For Today:

- A bit of theory
- Case studies
- Recommended practice

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What is Poor Power Quality?

Poor power quality...

is evidenced by characteristics of the incoming power to a device that deviate from the customary “pure” 60 Hz sine wave, and that can affect reliable and safe operation of the sensitive equipment

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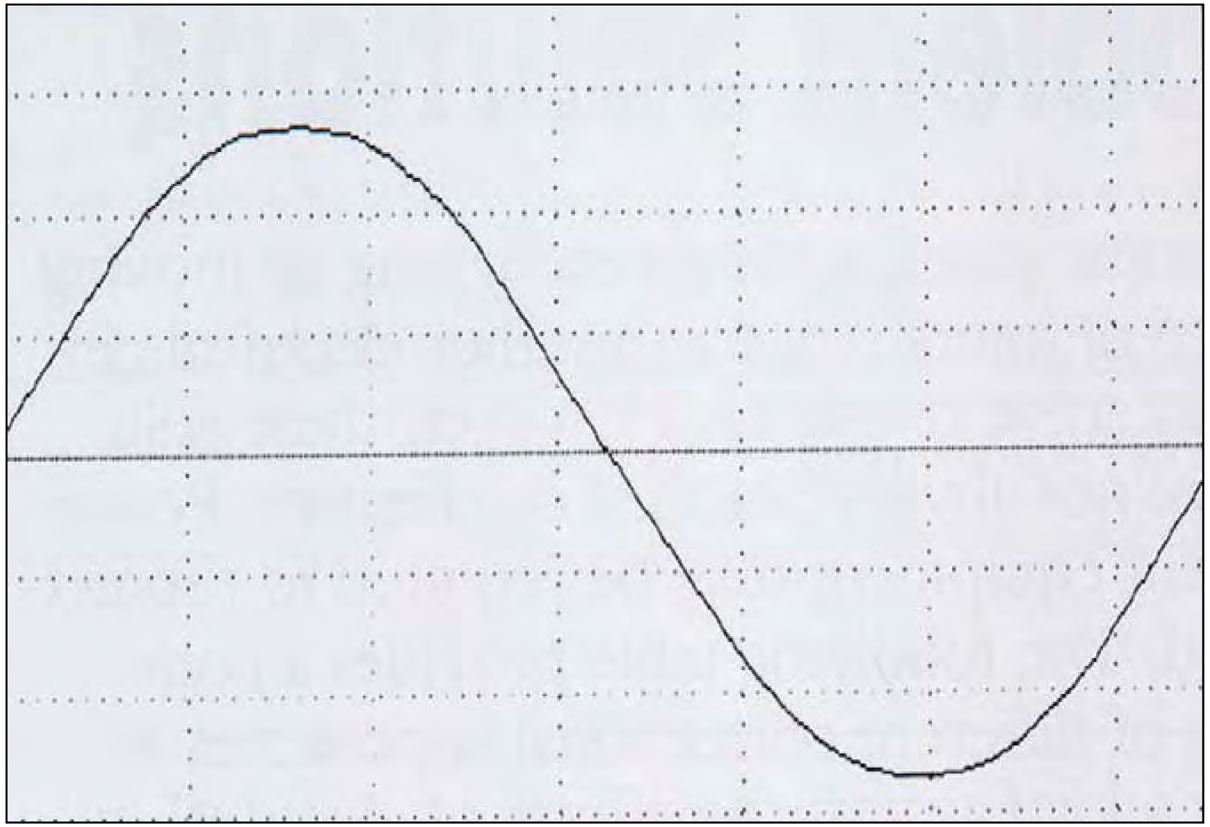
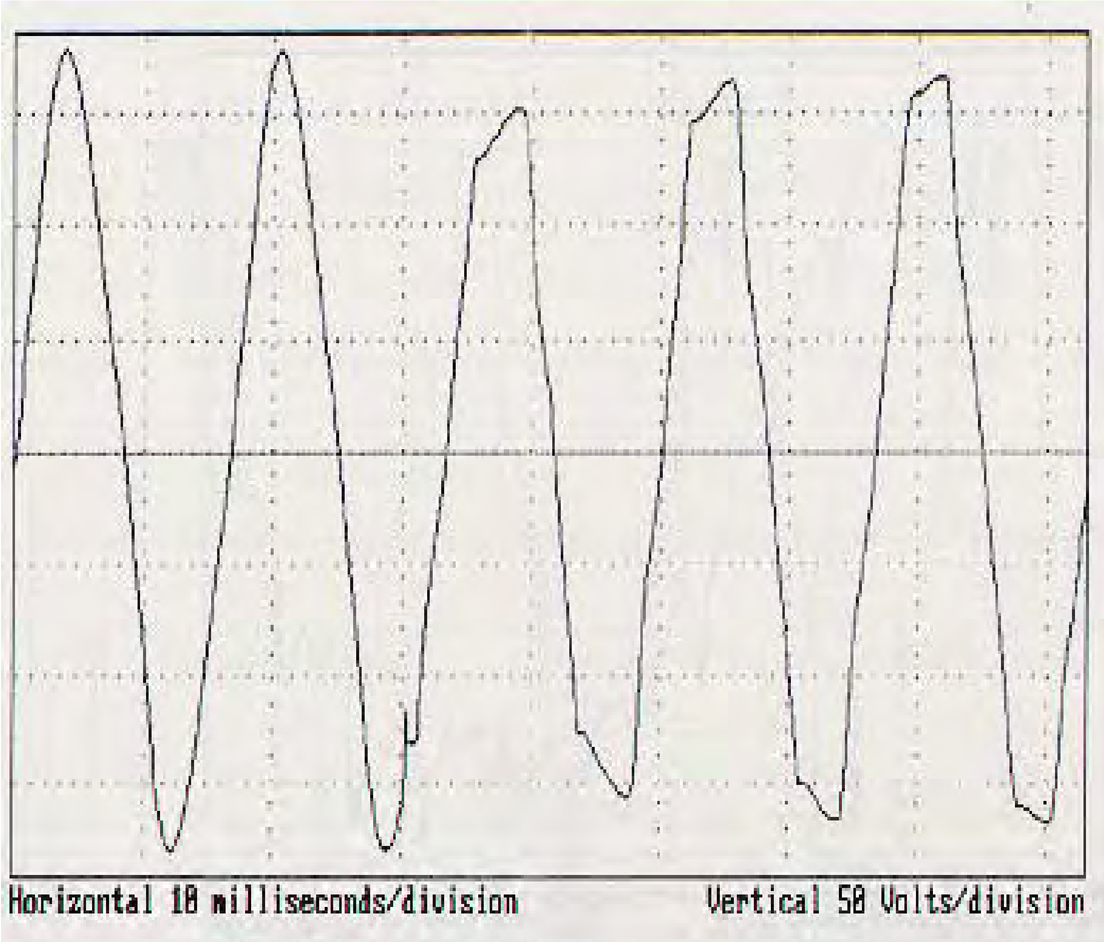
What the Equipment Wants



What the Equipment Gets



Real Cost

The real cost of poor power quality is in lost productivity (downtime).

- Estimated at $15-30 billion per year in US
- Exceeds $1 million/yr. at some buildings

Equipment is usually a secondary consideration

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Where Are Sensitive Loads?

Manufacturing Plant

Resort Hotel

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Where Are Sensitive Loads?

Office Buildings

Bakery

Sensitivity is Increasing

- Spread of microprocessors to every type of load
- Micro circuits are getting faster (radio frequency range)
- Circuits are getting smaller
- Operating voltages are lower ("1" may be 1-3 volts)

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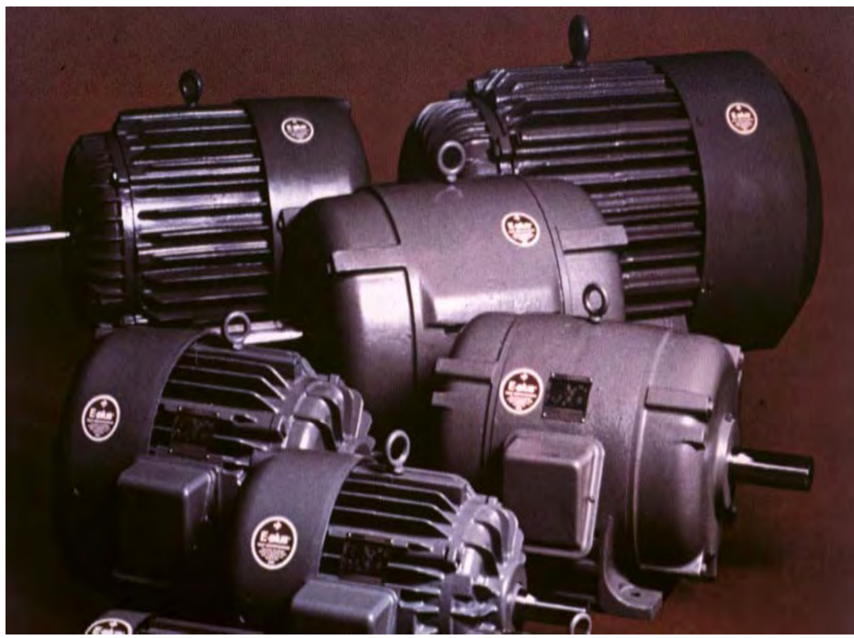
Macro View

What used to be acceptable service characteristics are no longer sufficient



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Surprising Facts

Most power quality problems are related to grounding and neutral size issues

Over 80% are internally caused

source: EPRI

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Major Issues

- Harmonics
- Transients
  - Internally caused
  - Externally caused

What Are Harmonics?

Harmonics are integer multiples of the fundamental frequency, i.e.:

2^{nd} harmonic = 120 Hz

3^{rd} harmonic = 180 Hz

4^{th} harmonic = 240 Hz

etc…

Fourier Analysis

A wave of any shape and amplitude can be created by some combination of sine waves of various amplitudes and frequencies

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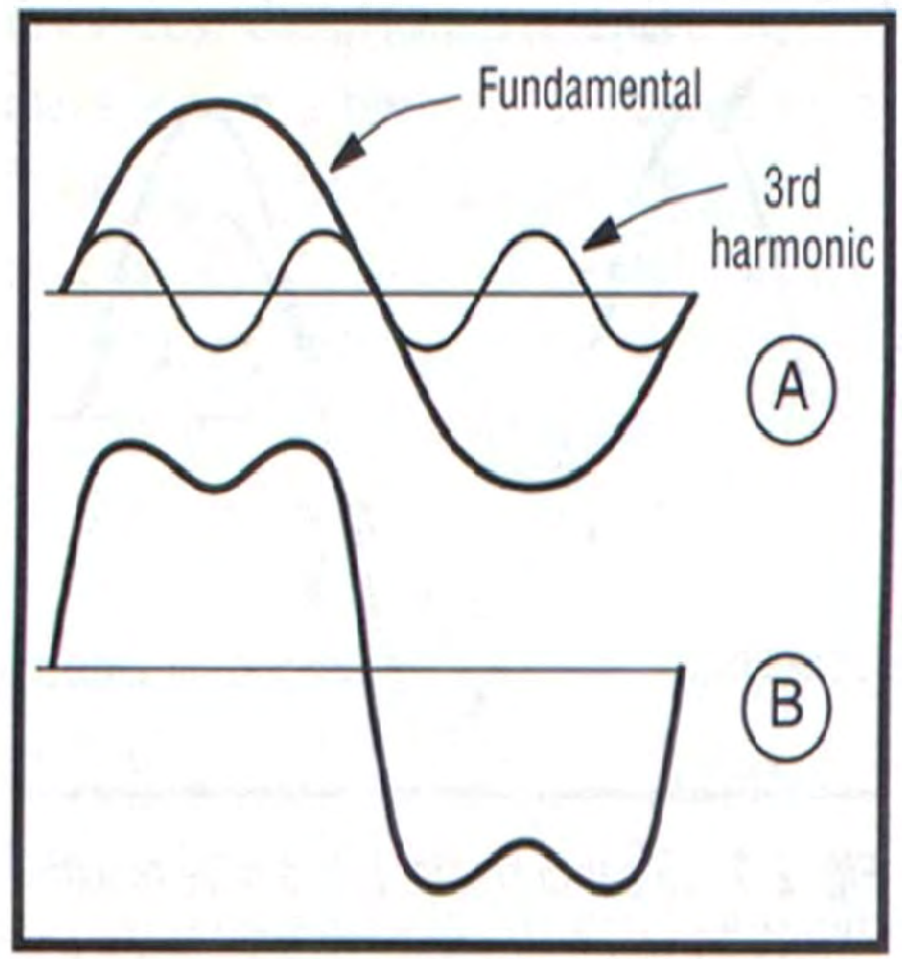
Corollary

An odd-shaped wave contains harmonics of some fundamental

No Longer Sine Waves

Fundamental and third harmonic added



Source: EC&M Practical Guide to Power Dist for IT Equipment

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In 3-ϕ, 4-W Circuits:

Neutral carries the vector sum of the three phase currents.

Normally, the vector sum of three balanced phase currents 120º out of phase is zero.

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In 3-ϕ, 4-W Circuits:

“Triplen” harmonics <u>add in the neutral.</u>

Triplen harmonics are odd multiples of the 3rd harmonic, i.e.. the 3rd, 9th, 15th, etc.

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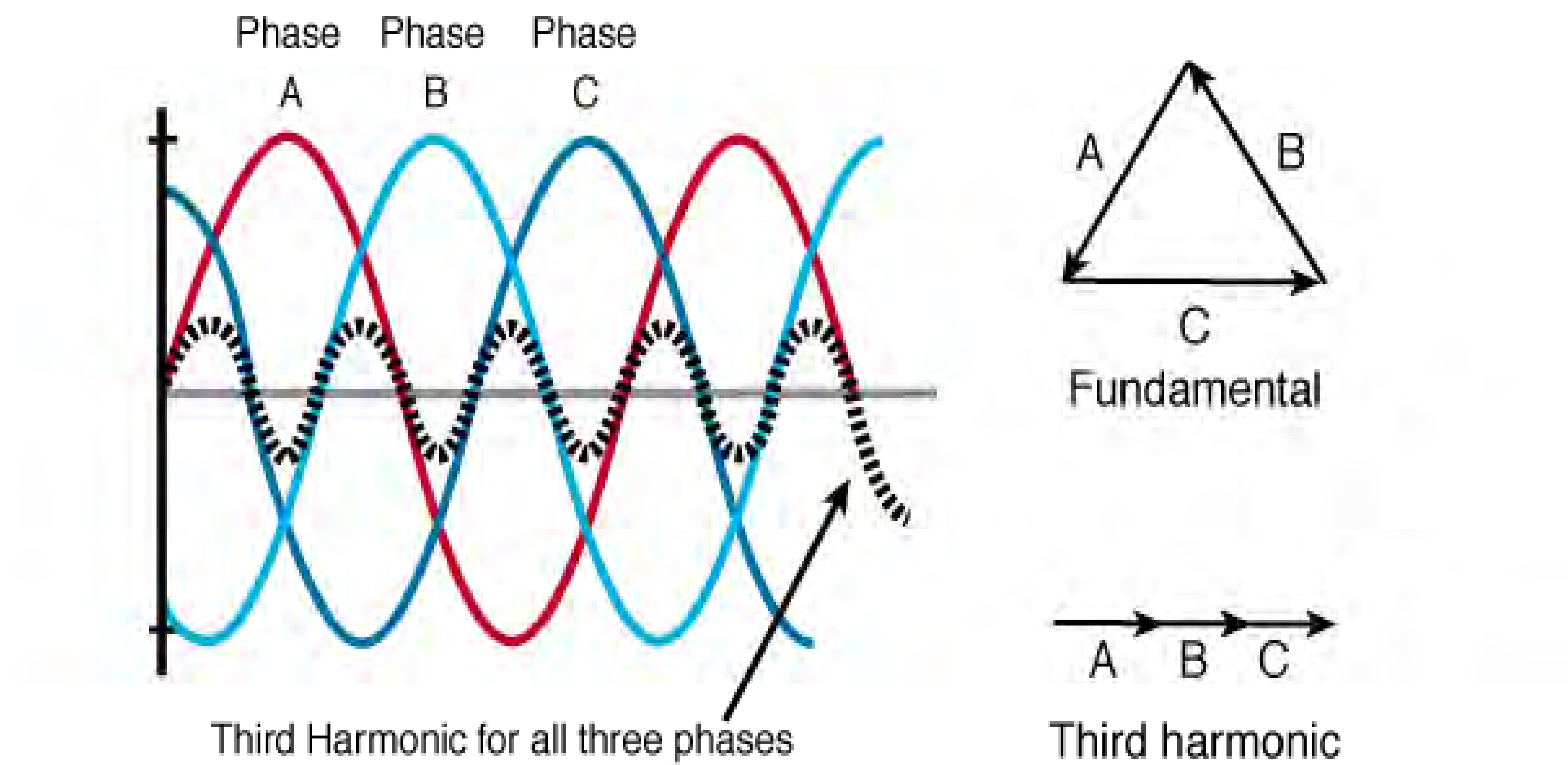
Harmonics Add in Neutral



Adapted from EC&M Guide to Power Dist. For IT Equip.

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Harmonics Can Be Trouble

Cause heating

- **in the neutral wire**
- **in motor windings**
- **In transformer windings**

Can cause capacitor failure

Can cause nuisance tripping

Source: IEEE Emerald Book

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Common Sources of Harmonics

Anything that draws current in a non-linear manner

Such As

- Anything Operated by a MICROPROCESSOR
- Switched Mode Power Supplies (computers)
- Variable Speed Drives
- SCR Controlled devices
- UPS Systems
- Arc-Operated Devices (welders, lighting)
- Capacitor Switching
- Etc.

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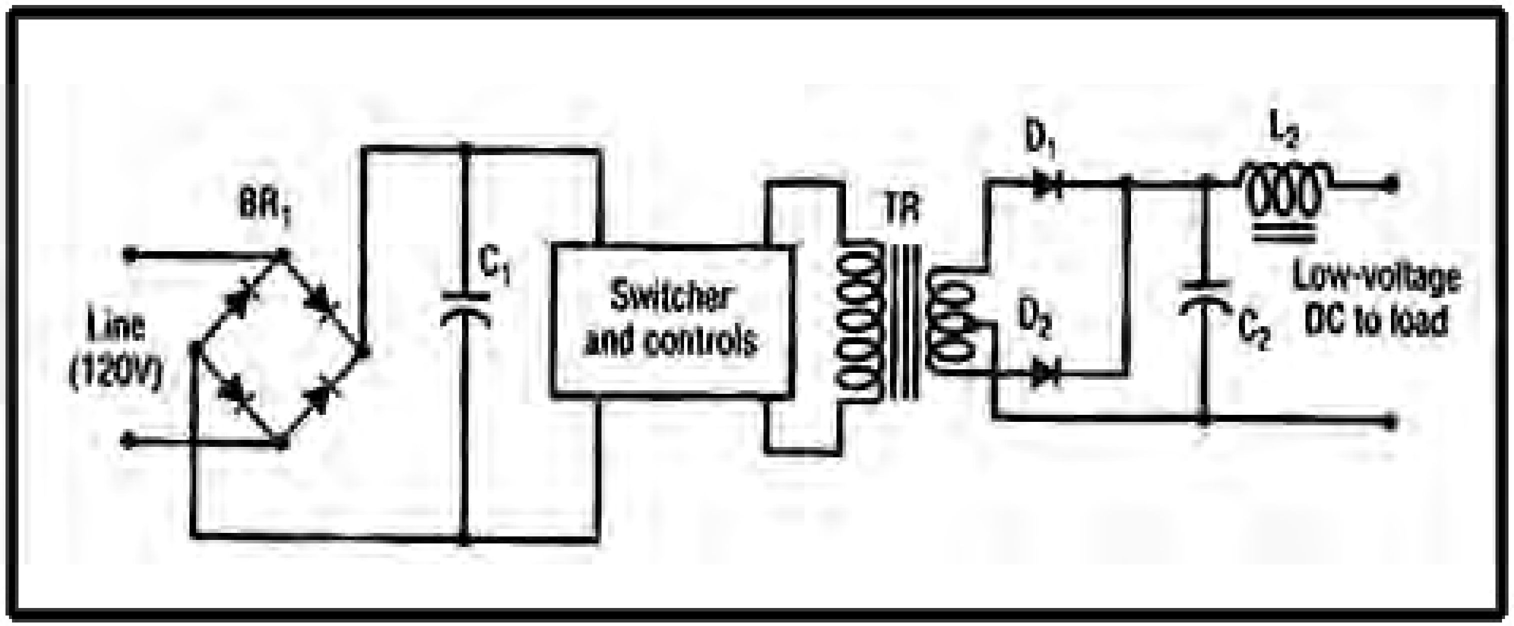
Switched Mode Power Supply

SMPS:



Source: EC&M

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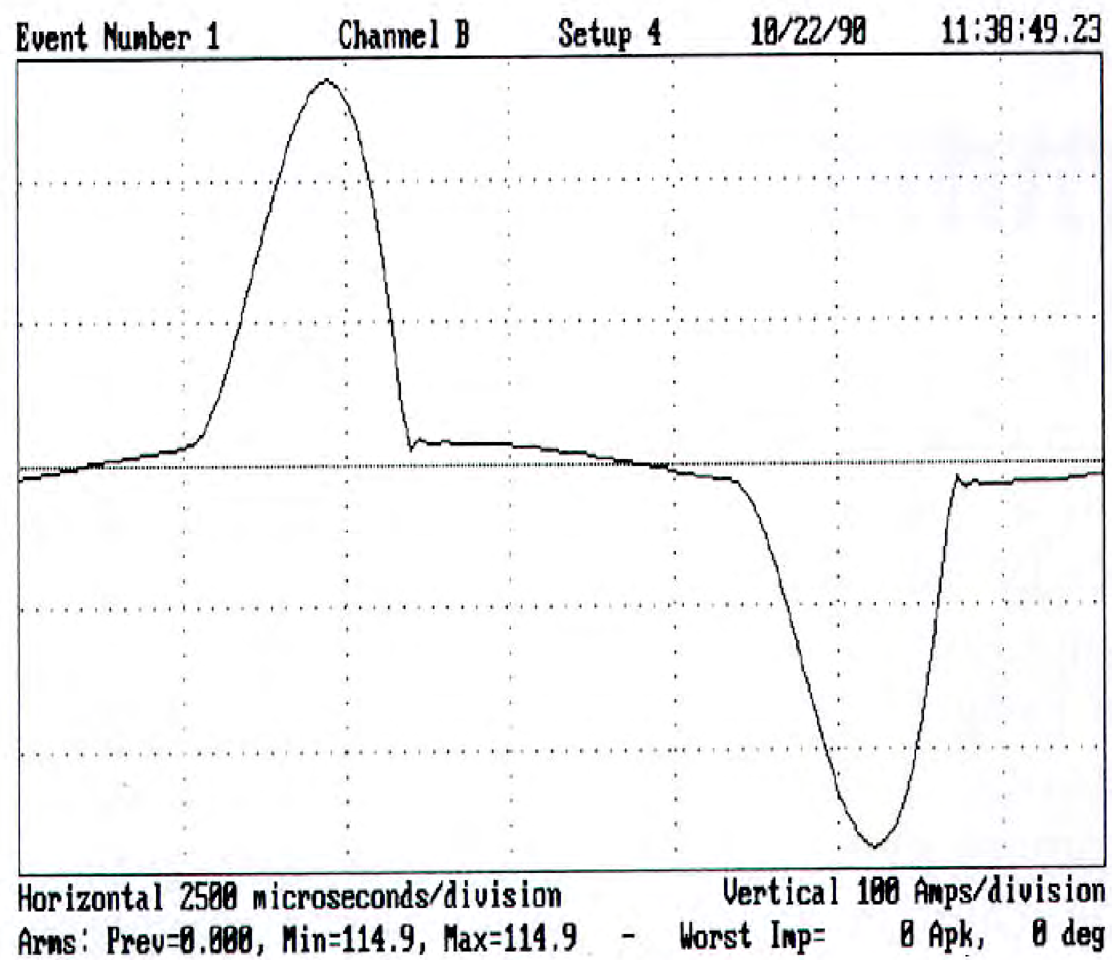
Potential Cause of PQ Problems

SMPS

draws current

In pulses



Source: Dranetz Field Handbook

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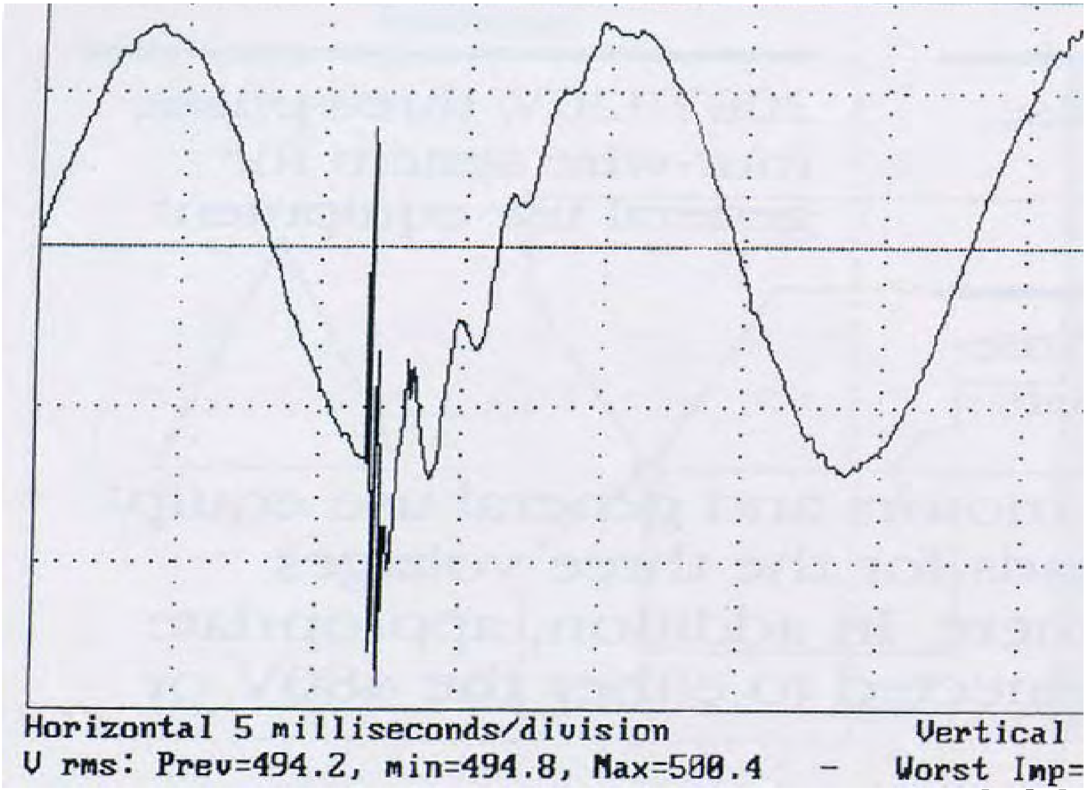
Other Causes of PQ Problems

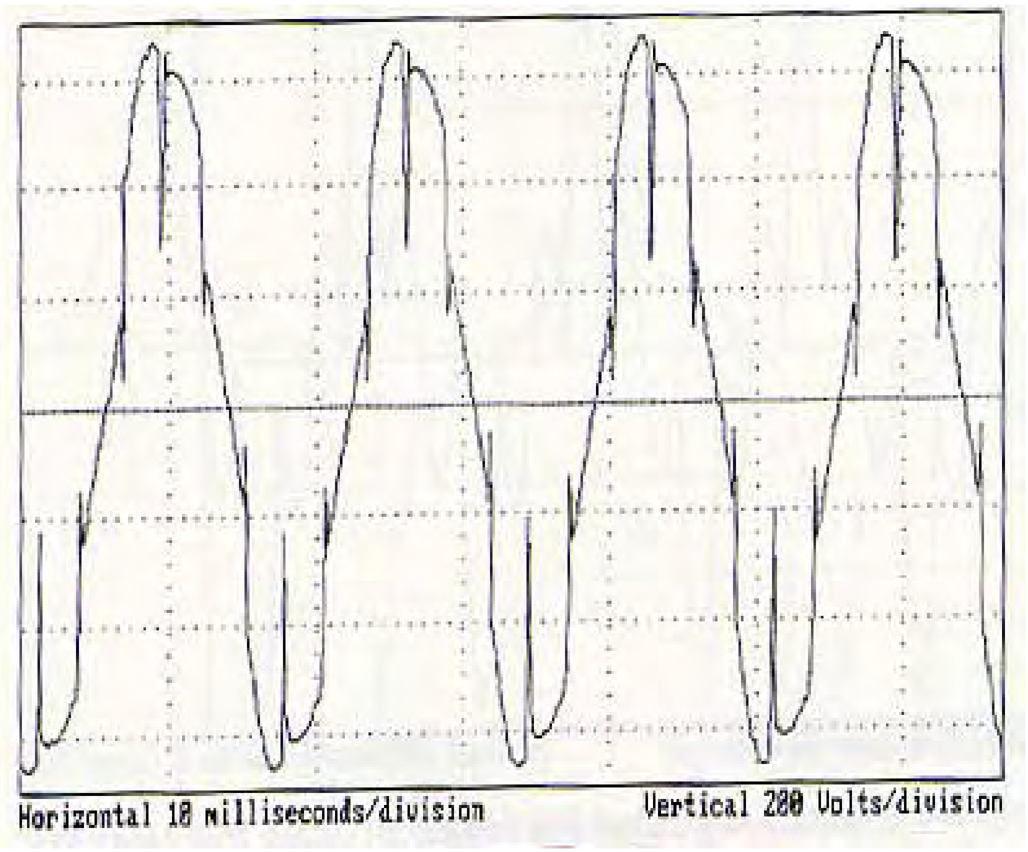
Power Factor Capacitor Switching:



Source: Dranetz Field Handbook

Other Causes of PQ Problems

Variable Frequency Drive:



Source: Dranetz Field Handbook

Transient PQ Problems

<u>EXTERNAL:</u>

- Utility switching or outages
- Vehicle hits
- “Galloping conductors”
- Poor or inadequate grounding
- Intermittent connections
- Voltage reductions
- etc.

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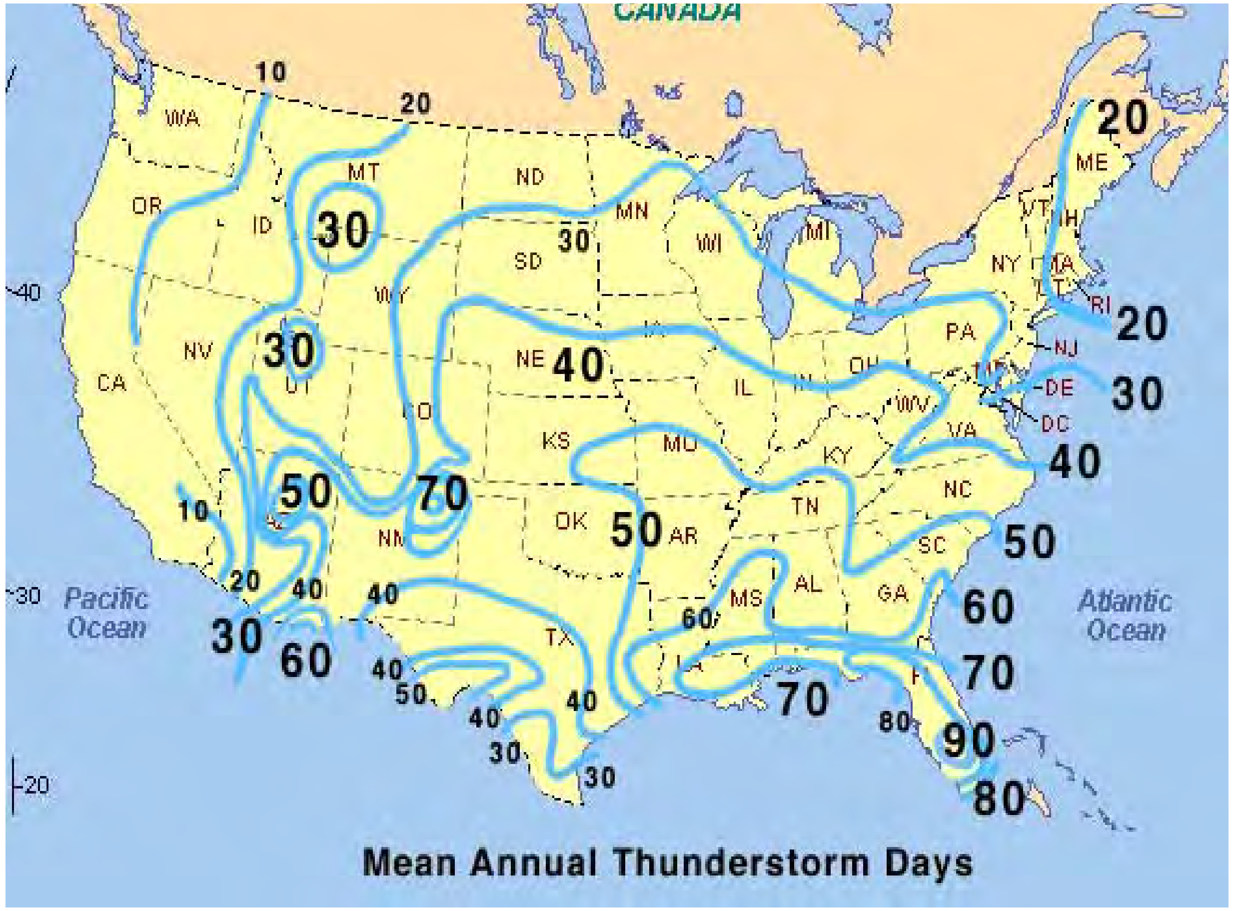
#1 Transient

Lightning

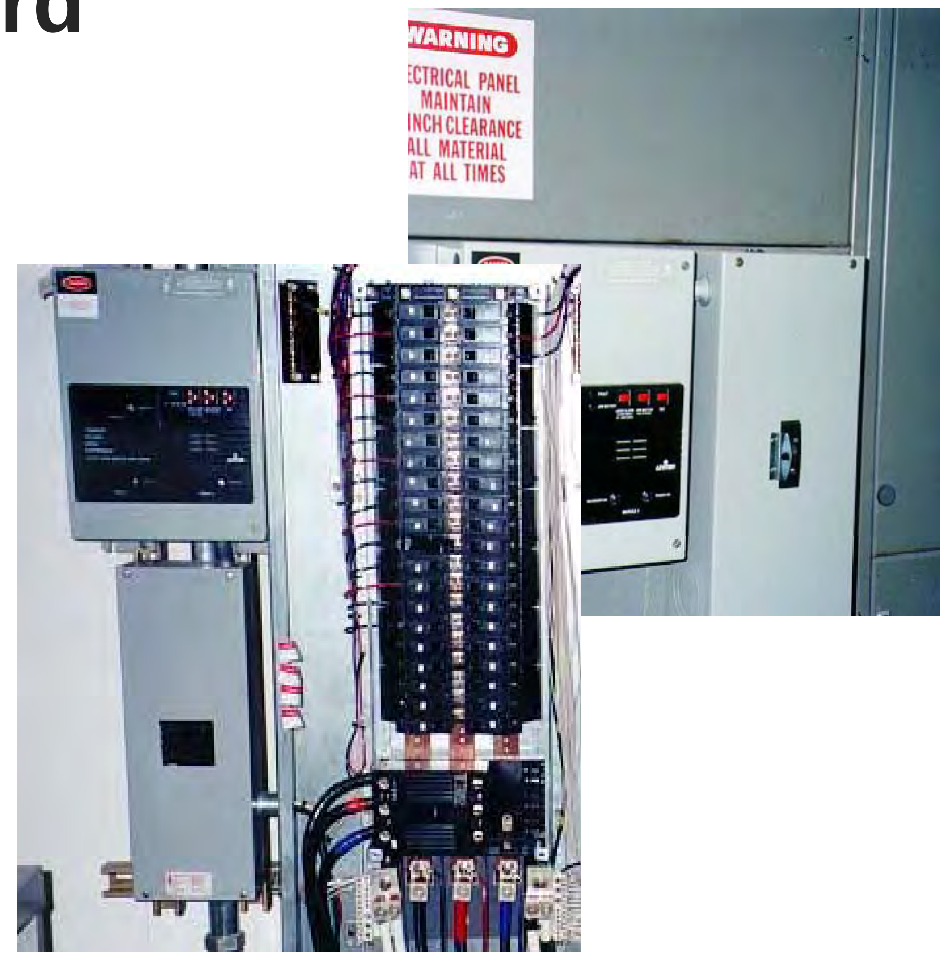
Isokeraunic Map

Thunderstorm days



Surge Suppressors

- at the service
- at the panel board
- at the load



Surge Suppressors

at the service level

Category C devices

150 kA per mode

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Surge Suppressors

at the feeder level

Category B devices

75 kA per mode

Surge Suppressors

at the device level

Category A devices

25 kA per mode

Surge Suppressors

- **Leads as short as possible**

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Surge Suppressors

All-mode protection: ϕ-ϕ, ϕ-G, ϕ-N, N-G

Listed to UL 1449, Version 2

High Joule rating

Have filtering, fuses, indication

Must be well-grounded

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Other Causes of PQ Problems

- Shared circuits
- Too many outlets / uses per circuit
- Inadequate neutrals
- Poor or inadequate grounding
- Intermittent connections
- Standard equipment and wiring
- etc.

What Can We Do About It?

Better wiring and grounding will prevent or alleviate most problems

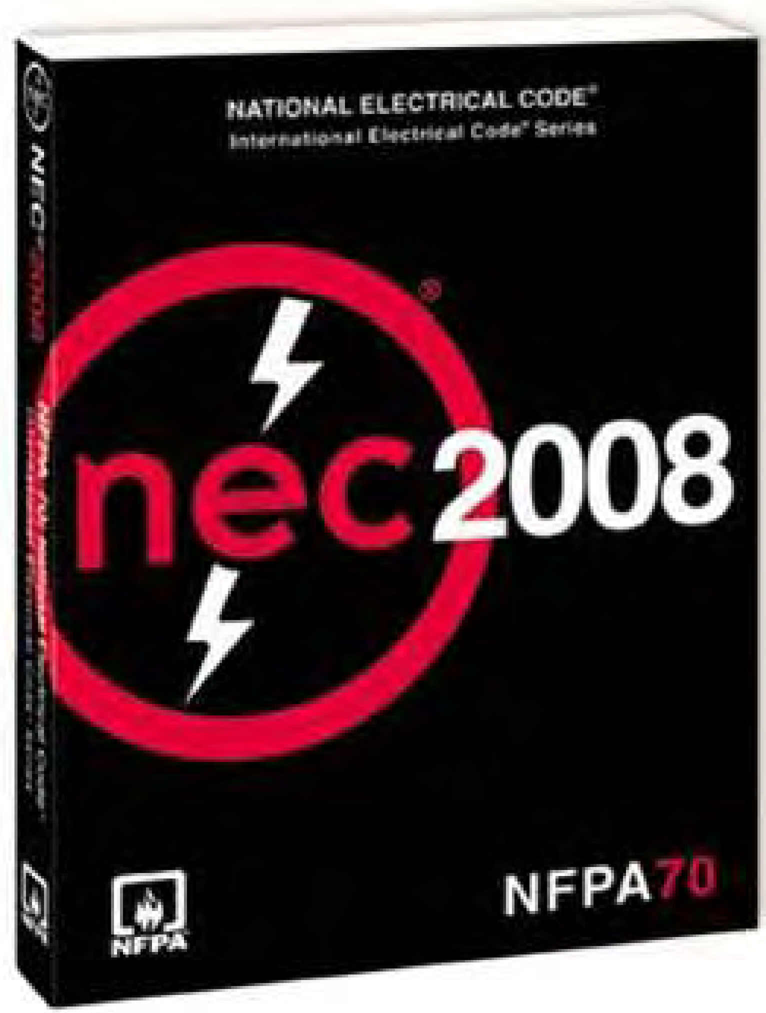
at little cost

(Power quality need not be expensive)

National Electrical Code

Good starting point

But not usually sufficient for power quality



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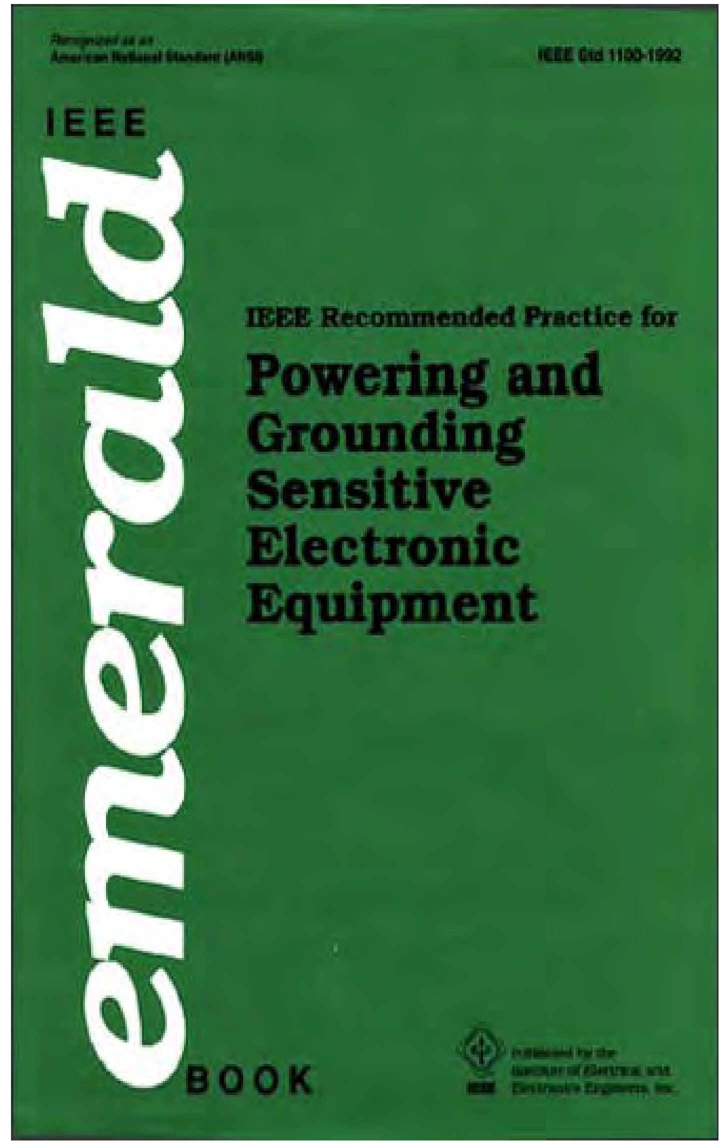
More Useful

ANSI/IEEE 1100 Recommended Practices are needed for power quality.



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Elements of Power Quality Design

- System Grounding (earthing)
- Equipment Grounding (bonding)
- Neutral Sizing
- General Wiring
- Extra Effort Steps

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System Grounding

Needed for:

- **Establishing a voltage reference**
- **Discharge high transient voltages (esp. lightning)**
- **Static Discharge**
- **Personnel Safety**

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To Meet Code

To Meet Article 250-50(a)(2):

Water Pipe and 2 ground rods, even if result exceeds 25 ohms.

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For Power Quality

Desired Grounding Resistance:

- **5 ohms or less desired for power quality**
- **Many mfgrs. specify <u>under 2 ohms</u>**
- **IEEE Std. 142 recommends 1-5 ohms (Green Book)**

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Low Impedance

- Ring ground
- Ufer Grounds
- Multiple, deep rods
- Moisture (bentonite)

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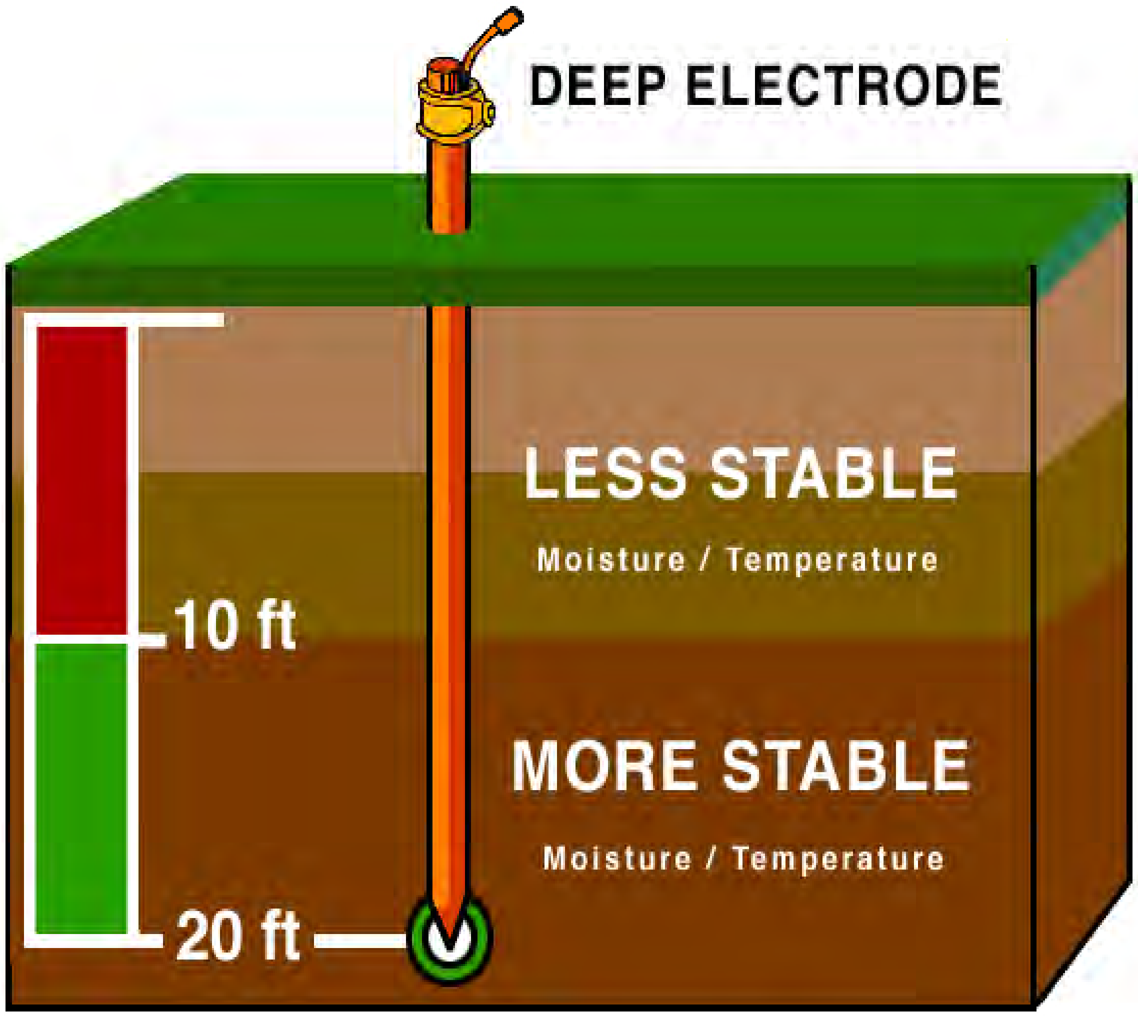
Deep Earth Electrodes



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Ground Rods

How to Minimize Resistance:

Preferred spacing = 2 X rod length

System Grounding Example

Mt. Washington, NH

<u>Before:</u>

3-4 major events in 2 years (lightning)

$120,000 avg damage per year

Plus lost ad revenue (station downtime)

Source: Ground Testing, Inc.

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System Grounding Example

Difficult Case: Mt. Washington, NH

Two 600 feet deep copper rods placed in 8 inch diameter well casings

Backfill with bentonite grout

Interconnect with 500 kcmil copper cable

Achieved 6 ohm resistance

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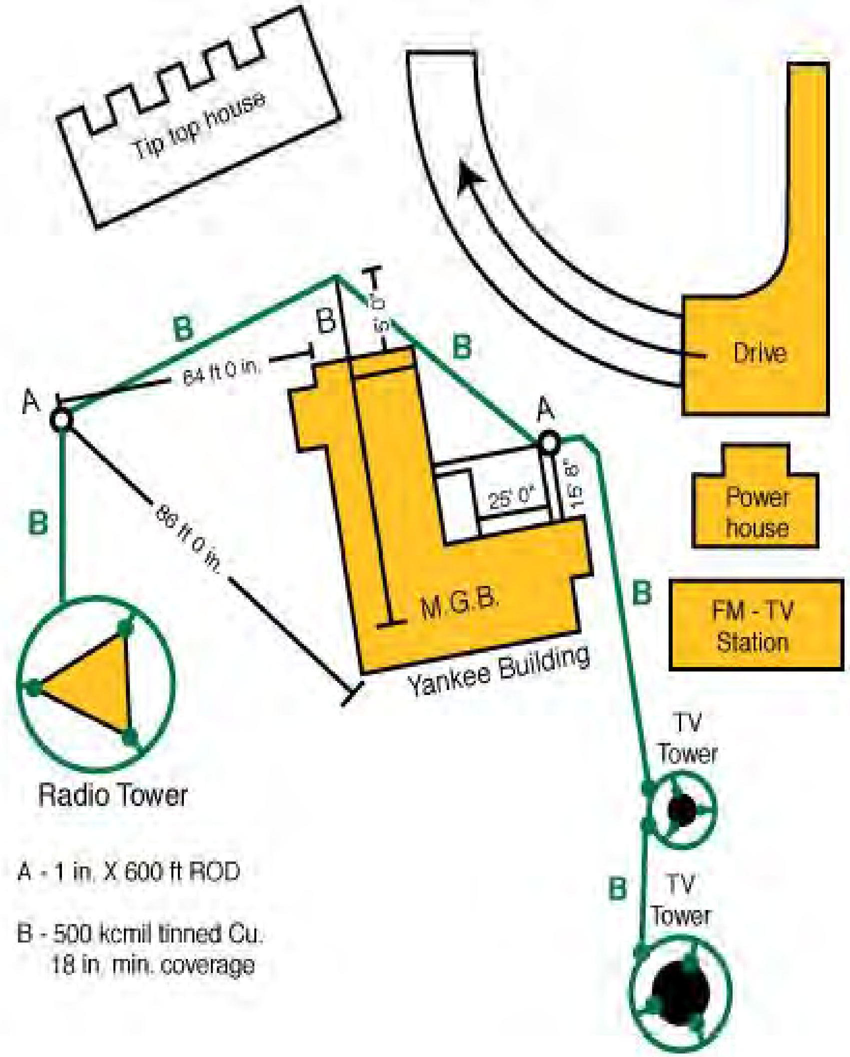
System Grounding Example

- 500 kcmil ring grounds
- 2-600 ft deep vertical electrodes



System Grounding Example

After:

No damages or disruptions in 5 years since improved grounding

Source: R. Cushman, Chief Engineer, WMTW-TV

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Las Vegas Casino/Hotel

- Each slot machine is a computer
- High Resistivity Soil
- High Cost of Failure

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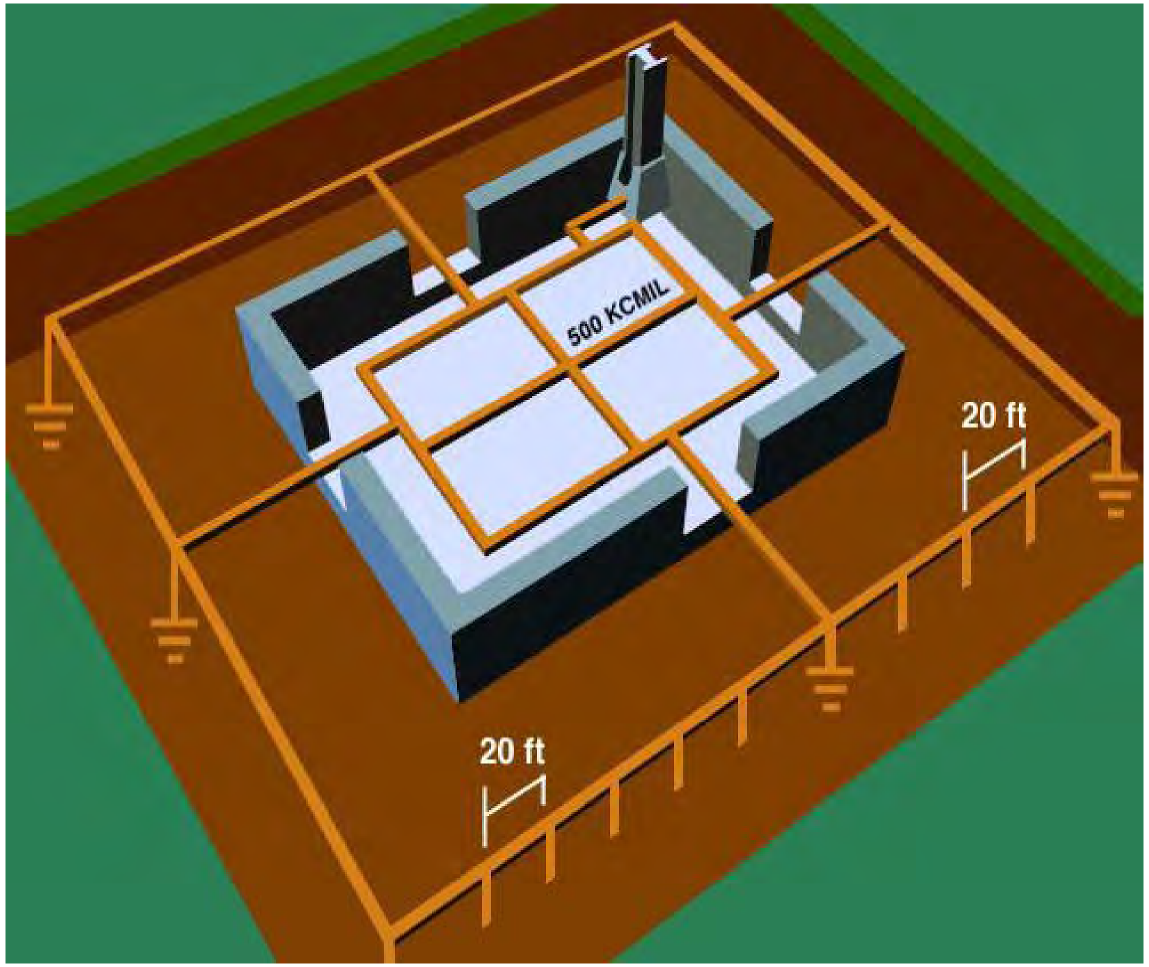
System Grounding

Las Vegas Casino Hotel



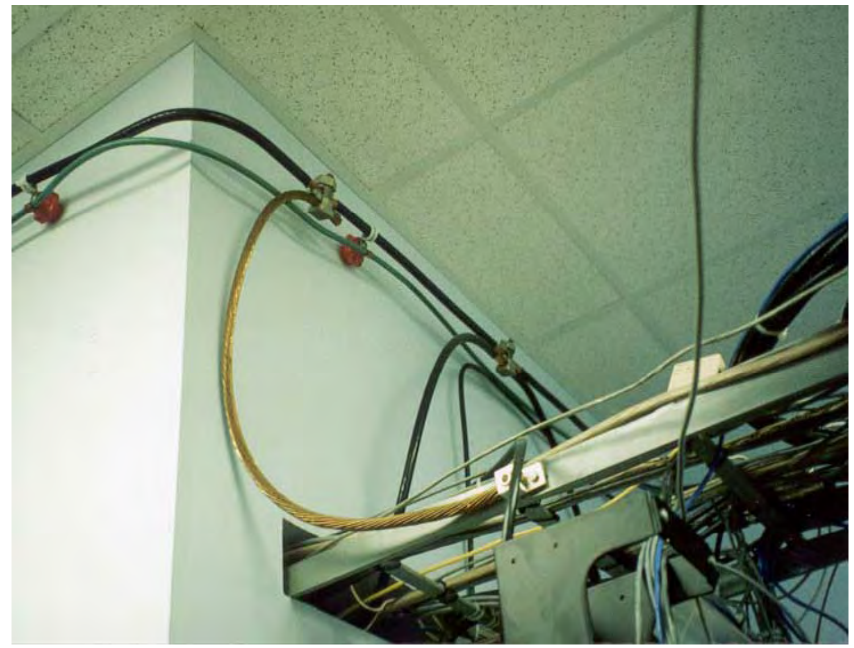
Ground Bus

Interior ground bus for easy connections:

Source:
Allegro Corp.

“Halo” Grounding

Interior “halo” ground for easy connections:



Note large radii bends

Source: Power & System Innovations,

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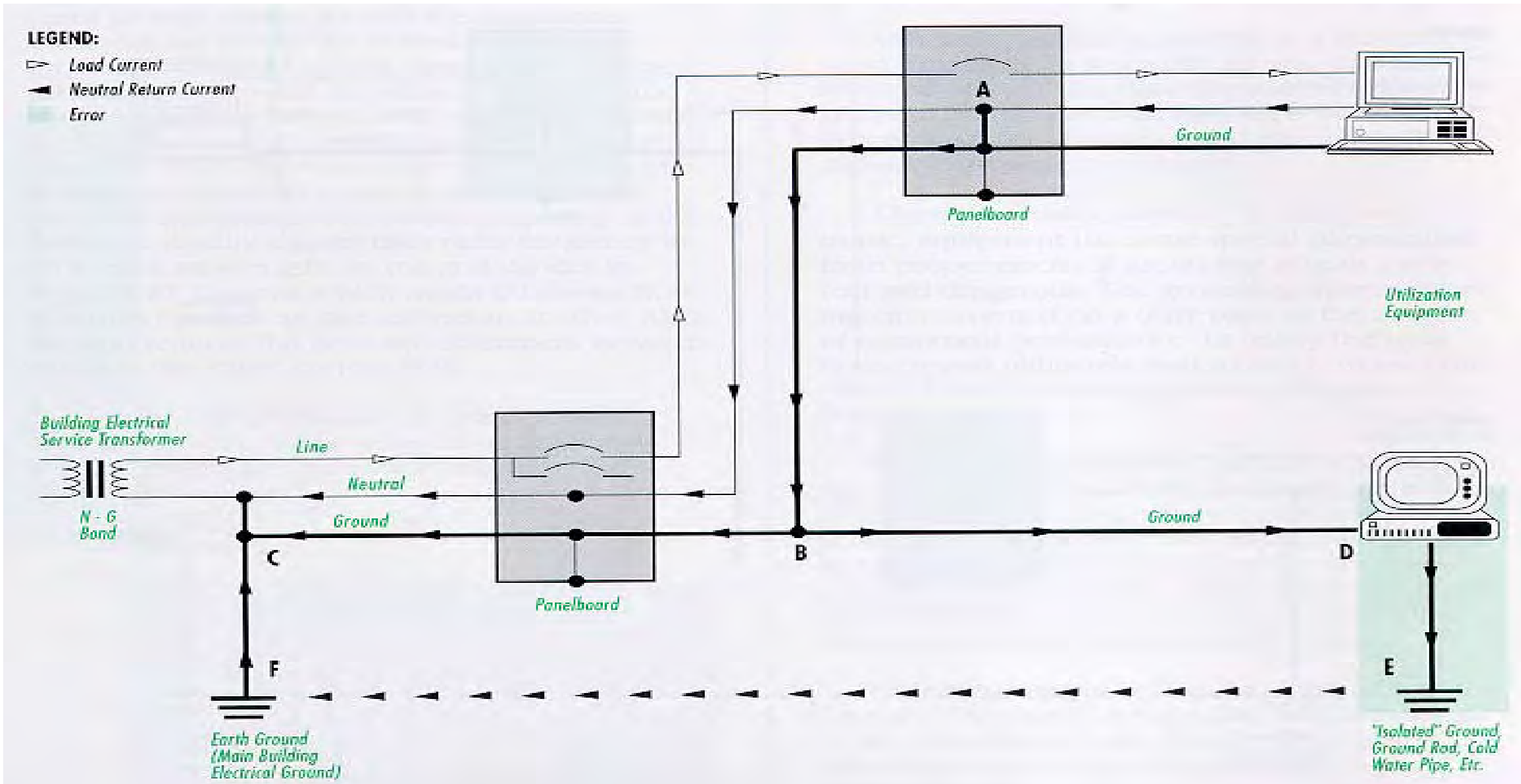
Ground Loops

Earth cannot be ground path:



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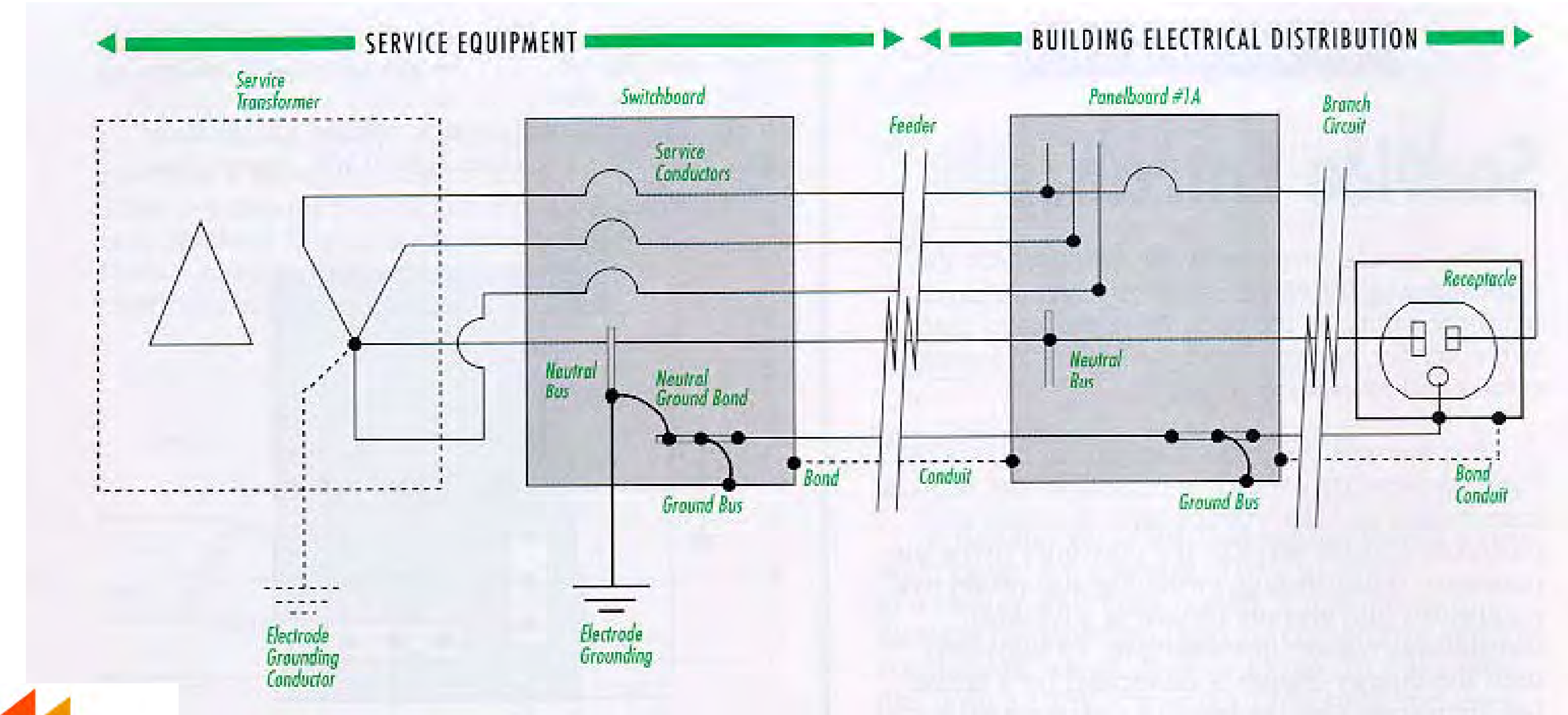
Ground Loops

There should be ONE central point connecting the interior wiring to the ONE exterior grounding electrode system



Source: Dranetz Field Handbook

Recommended Wiring Practice

Sensitive loads should be separated:

- **Separate branch circuits**
- **Separate panelboards**
- **Separate feeders**
- **Separate transformers**

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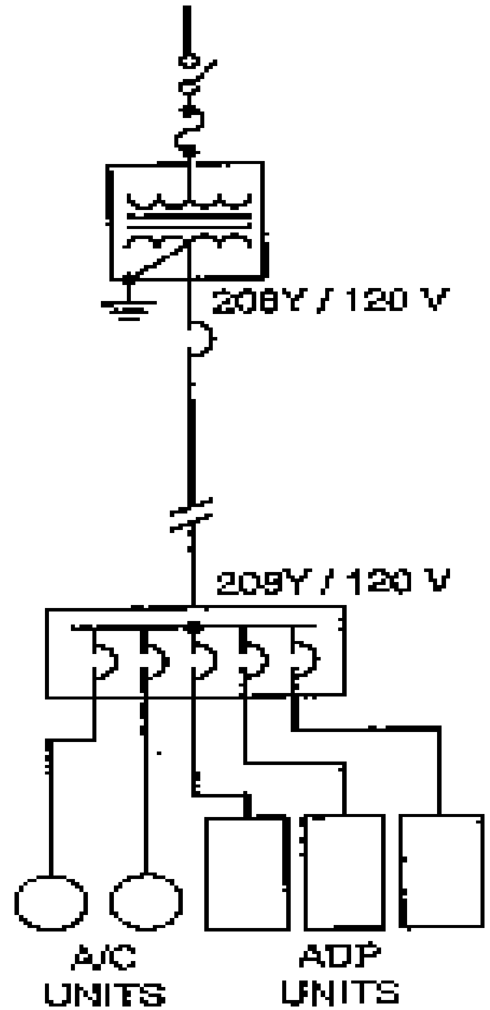
Isolate Sensitive Loads

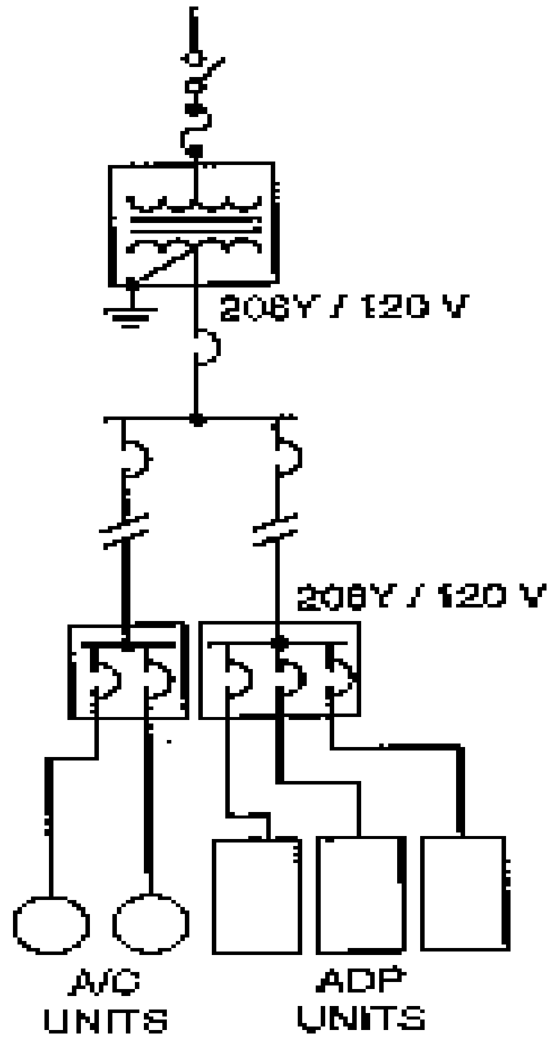


a) WORST!

source: IEEE

Emerald Book

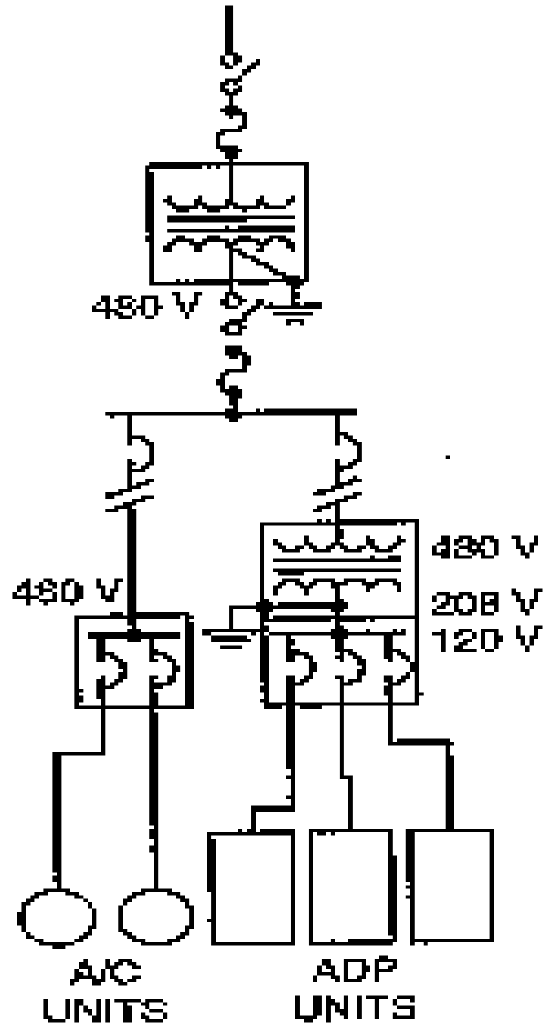
Isolate Sensitive Loads



b) FAIR!

source: IEEE Emerald Book

Isolate Sensitive Loads



c) BETTER!

source: IEEE
Emerald Book

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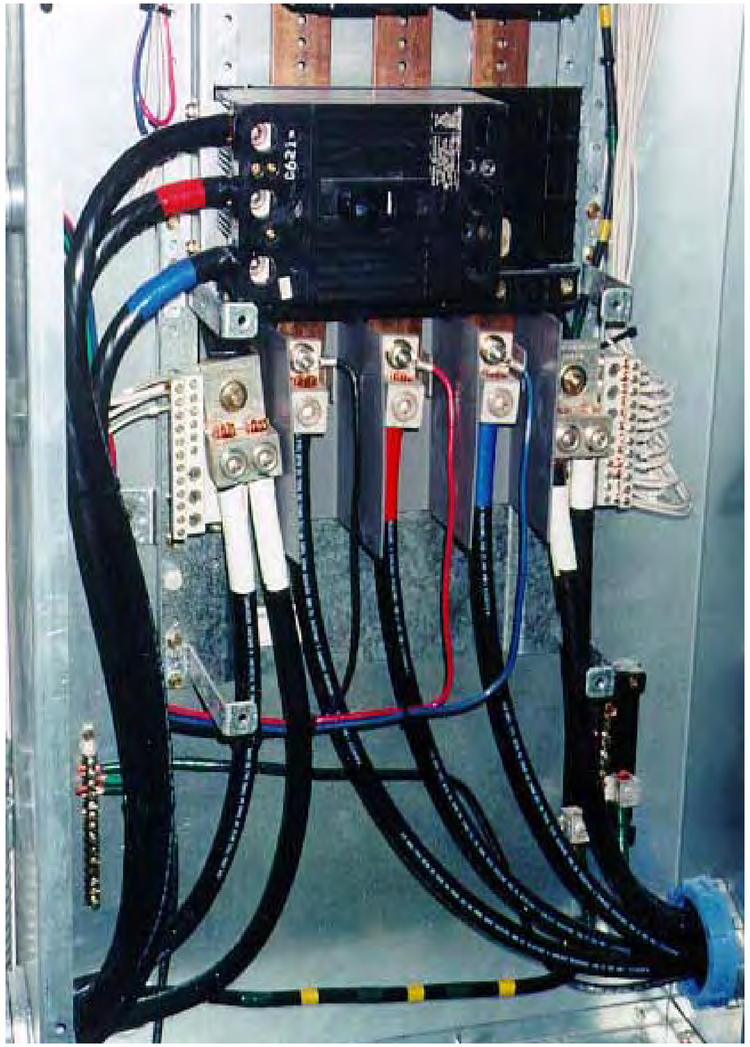
Safely Handling Harmonics

Use double size neutral or one neutral per phase conductor



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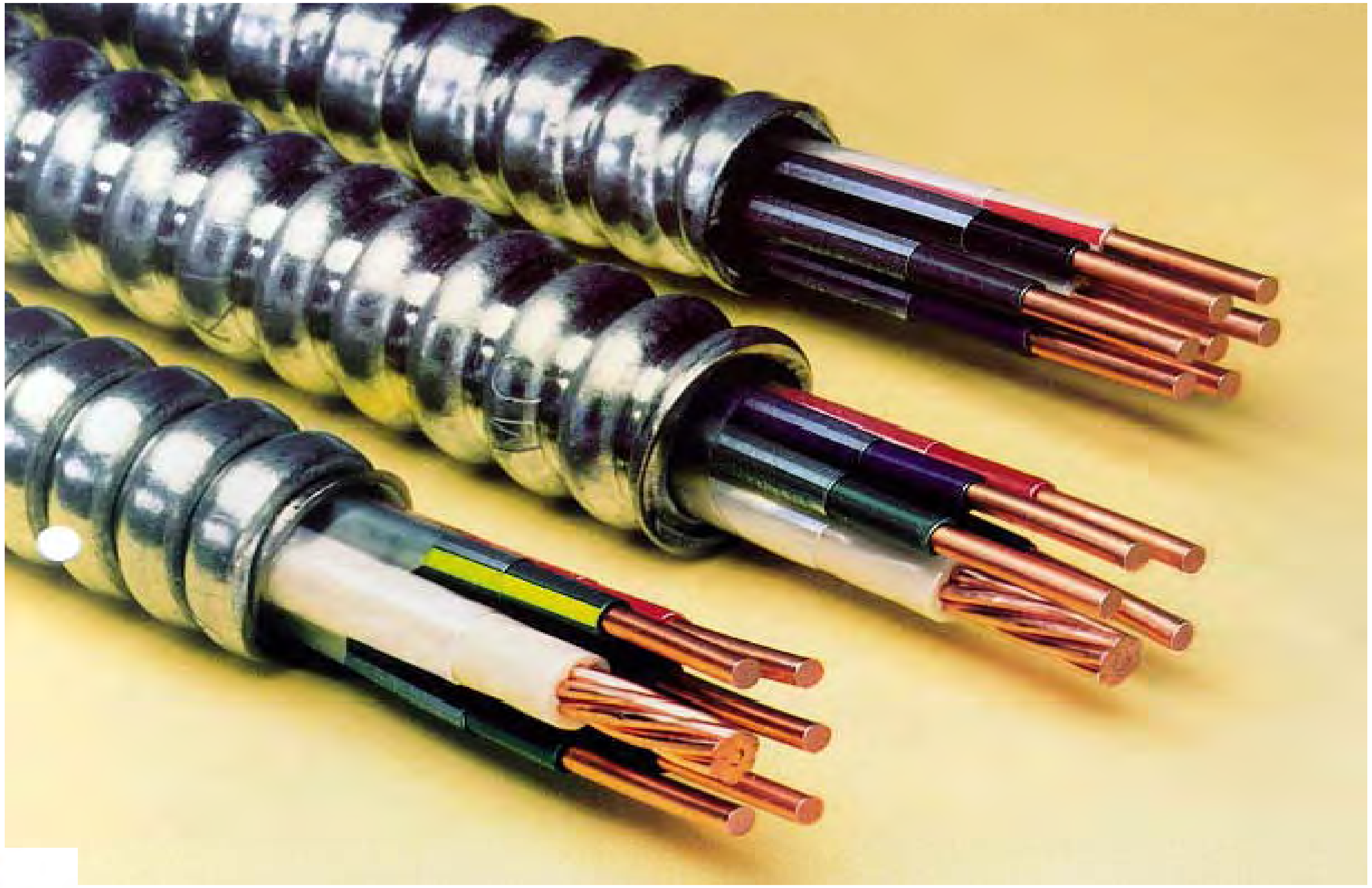
Safely Handling Harmonics



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Safely Handling Harmonics

Use K- Rated transformers, panelboards.

Case Study: M.I.T.

Current Design Standards:

- Separate computer feeders, panels, and branch circuits
- 4 outlets per 20 amp. Branch circuit

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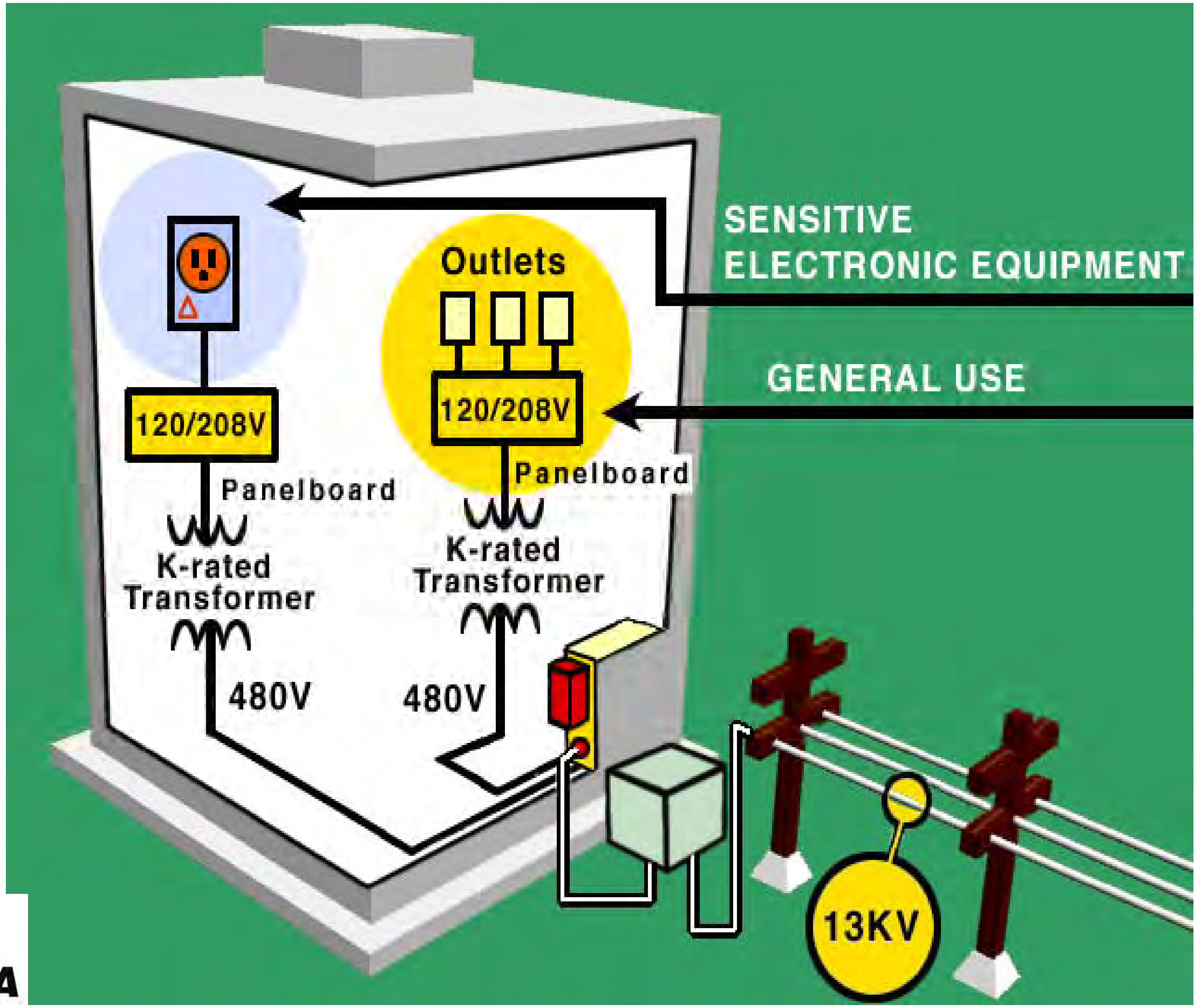
Case Study: M.I.T.



Case Study: M.I.T.

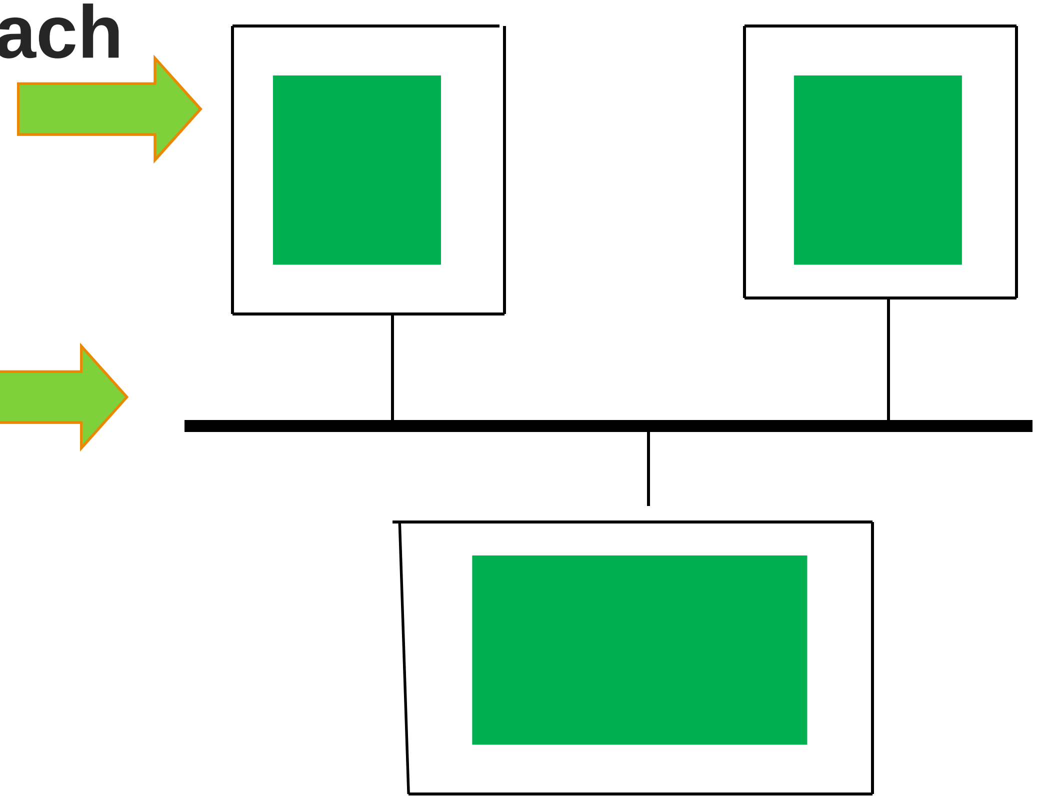
Current Design Standards:

- **10 ohms or less grounding resistance**
- **Double (and sometimes triple) neutrals**
- **K-rated transformers**
- **Always a separate grounding conductor**
- **Always copper conductors**

M.I.T. Basic Grounding Layout

500 kcmil ring ground around each building

1000 kcmil spine



Case Study: M.I.T.

Cost for all PQ improvements:

Adds about 1 1/2% added to the overall cost of construction, but….

Never has to revisit infrastructure for foreseeable future

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Case Study: "Clean Grounds"

McAfee Tool and Die

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Case Study: McAfee Tool & Die

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Case Study: McAfee Tool & Die

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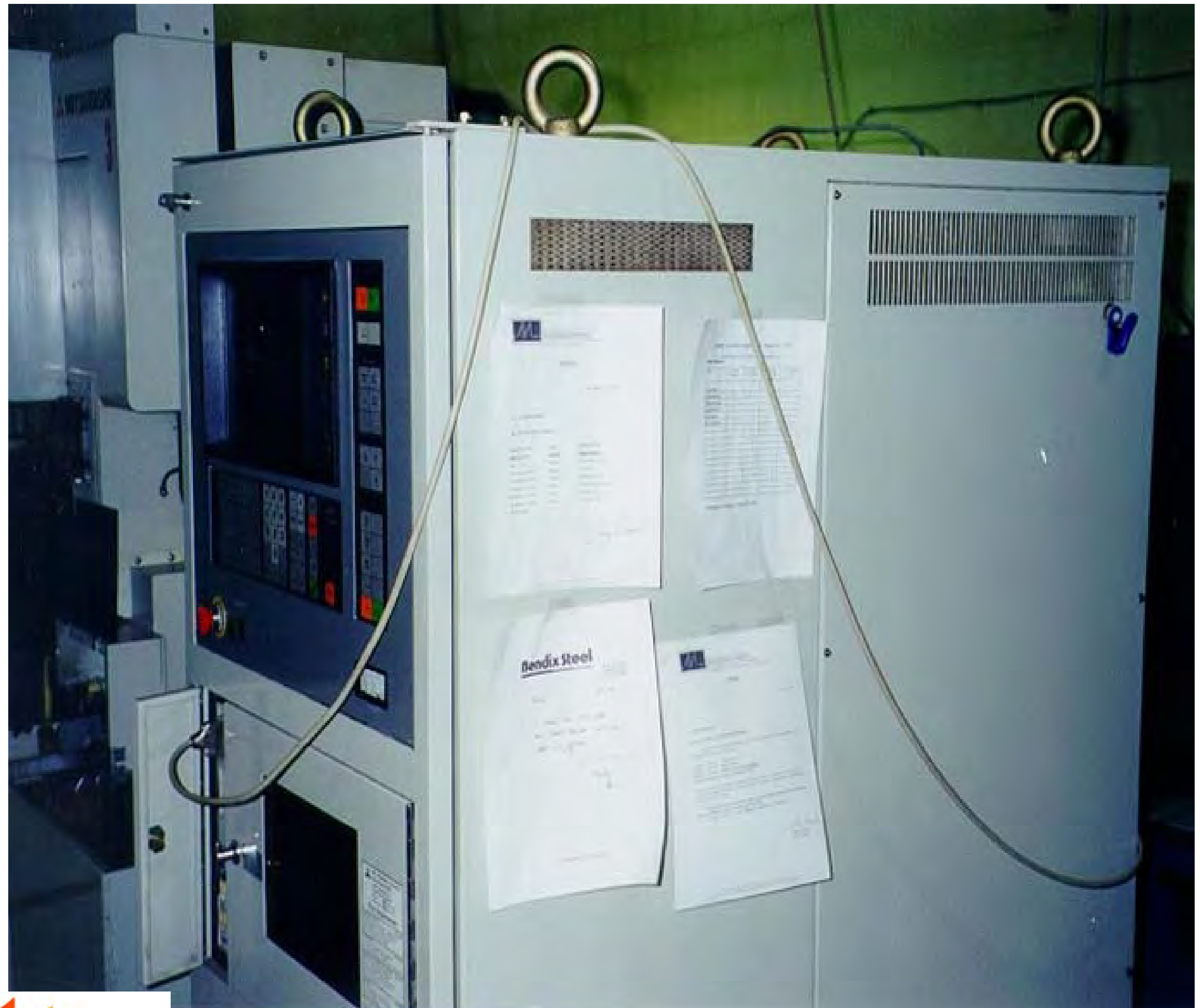
Case Study: McAfee Tool & Die



Note loosely draped comm. cable (antenna)

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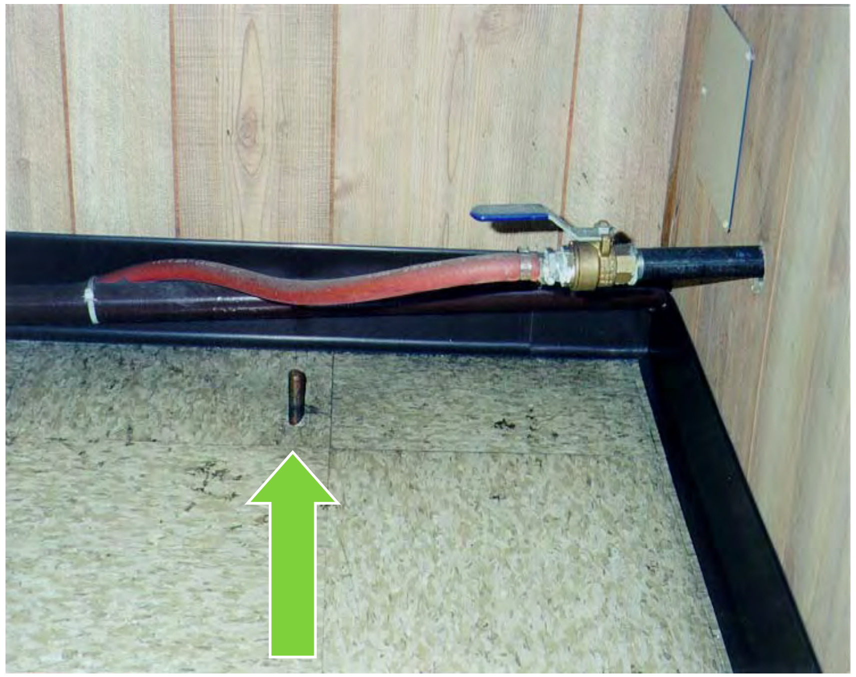
Case Study: McAfee Tool & Die



“Supplemental” electrodes abandoned

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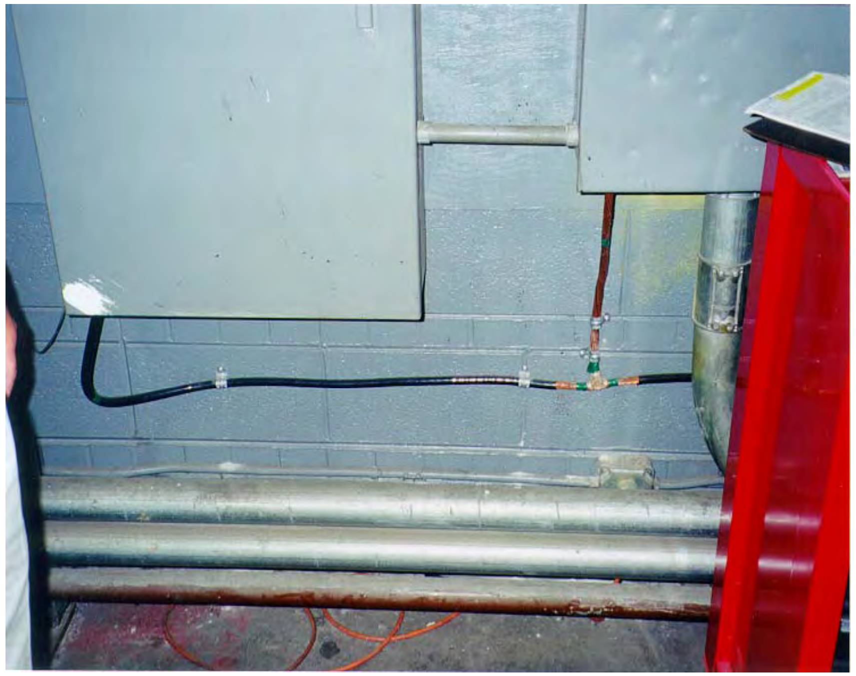
Case Study: McAfee Tool & Die



Cabinets retrofitted with 4/0 copper bonding, aluminum removed

Everything bonded to building steel using 4/0 copper

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Case Study: 911 Center Retrofit

4/0 AWG ring ground completely surrounds building

Source: Power & System Innovations, Inc.

Case Study: 911 Center

Tower on municipal land

Built by Telco

Shared with

emergency services

Source: Power & System Innovations, Inc

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Case Study: 911 Center

Coax braid grounding

Note location on <u>vertical</u> run

Vertical Coax Grounding

29X lightning cable then connects to 4/0 vertical to 4- 50 ft. electrodes under tower

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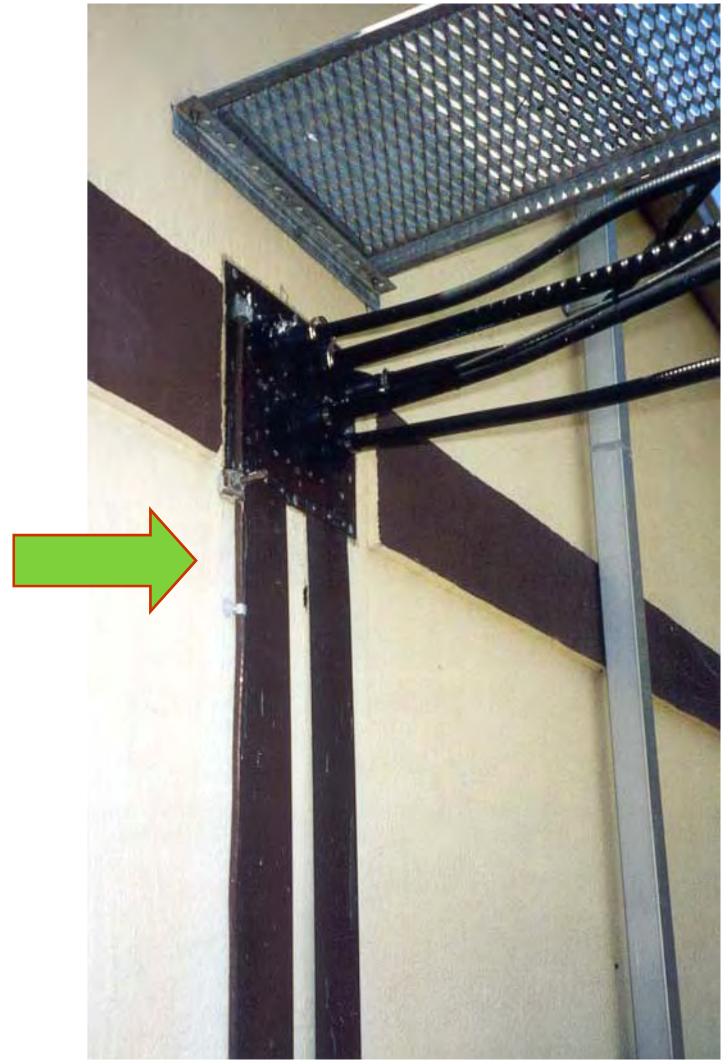
Firewall

Outside copper firewall

4/0 vertical to

ring ground



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Halo Ground

Inside copper firewall

4/0 connects to “halo”

and grounding
electrode system

Note large radii

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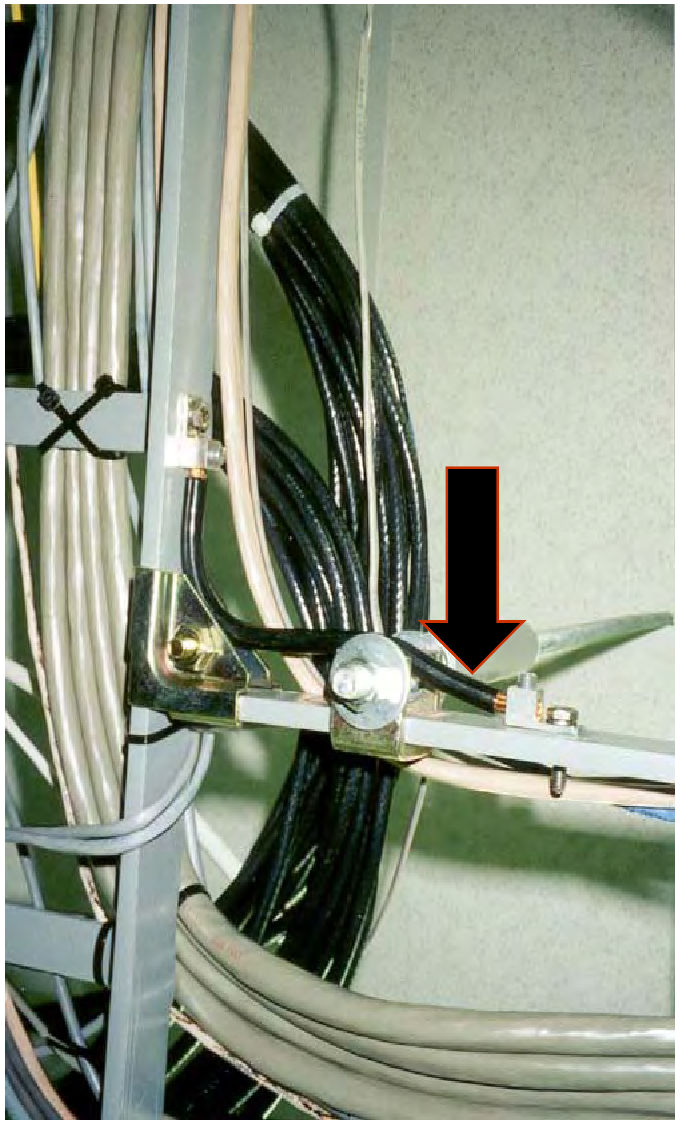
Every Joint Jumpered



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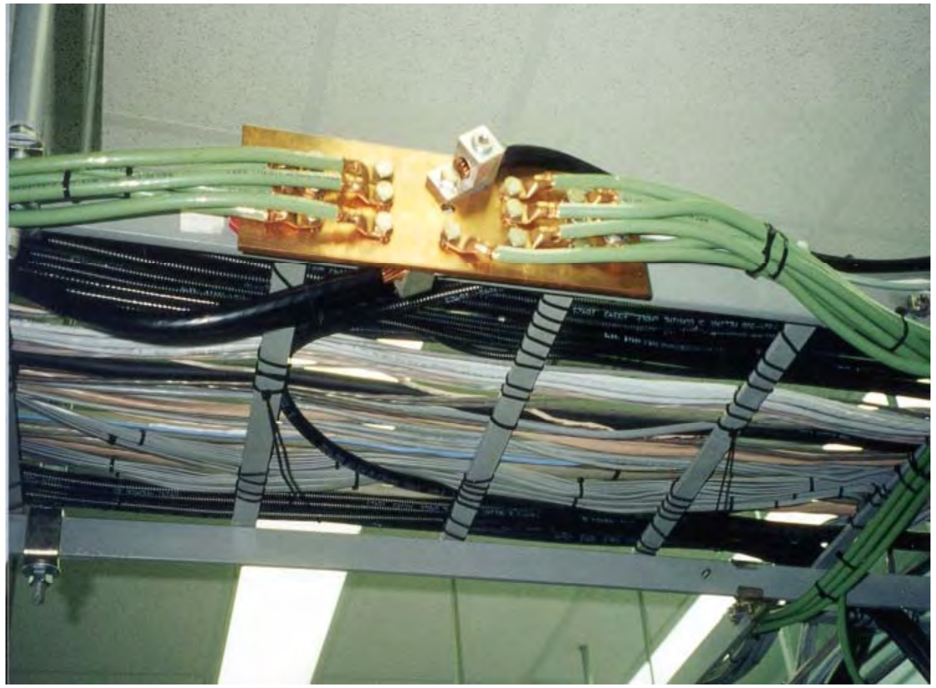
Equipment Grounds

Every joint, tray and cabinet bonded and jumped with #2 to plate, then 4/0 connects to "halo"



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TVSS

- TVSS at the service and all branch panels
- All cabinets bonded with copper jumpers then to ring ground with 4/0 copper

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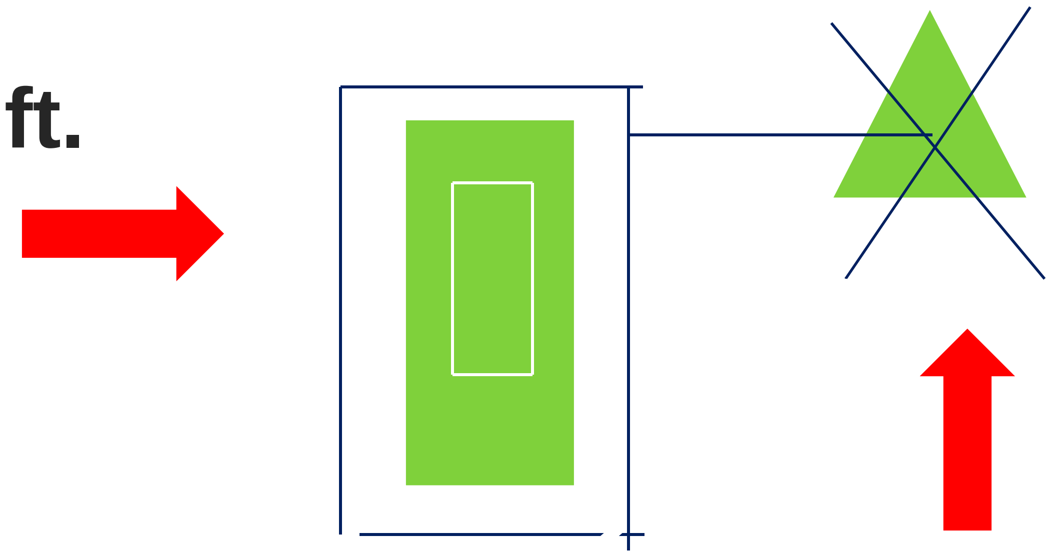
Grounding Layout

Installed 4/0 ring

20 ft rod

every 20 ft.



4- 50’ rods under tower

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Suncoast Schools FCU

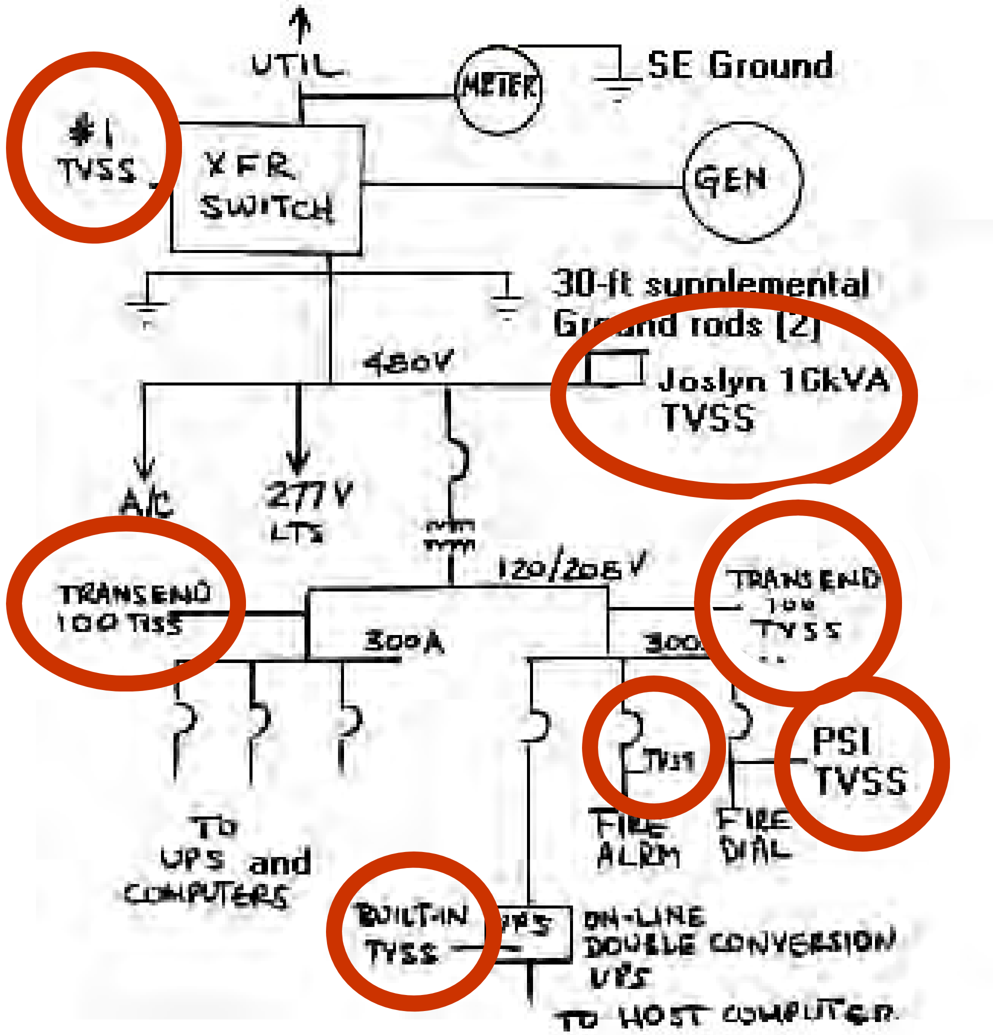
ATM Network

Service Drop

Meter Socket

Electric Meter

TVSS Worked



UTIL
METER
SE Ground
#1 TVSS
XFR SWITCH
GEN
30-ft supplemental Ground rods (2)
480V
Joslyn 10kVA TVSS
A/C
277V LTS
120/208V
TRANSEND 100 TVSS
300A
TRANSEND 100 TVSS
TVSS
PSI TVSS
FIRE ALRM
FIRE DIAL
TO UPS and COMPUTERS
BUILT-IN TVSS
UPS
ON-LINE DOUBLE CONVERSION UPS
TO HOST COMPUTER

Examples of TVSS

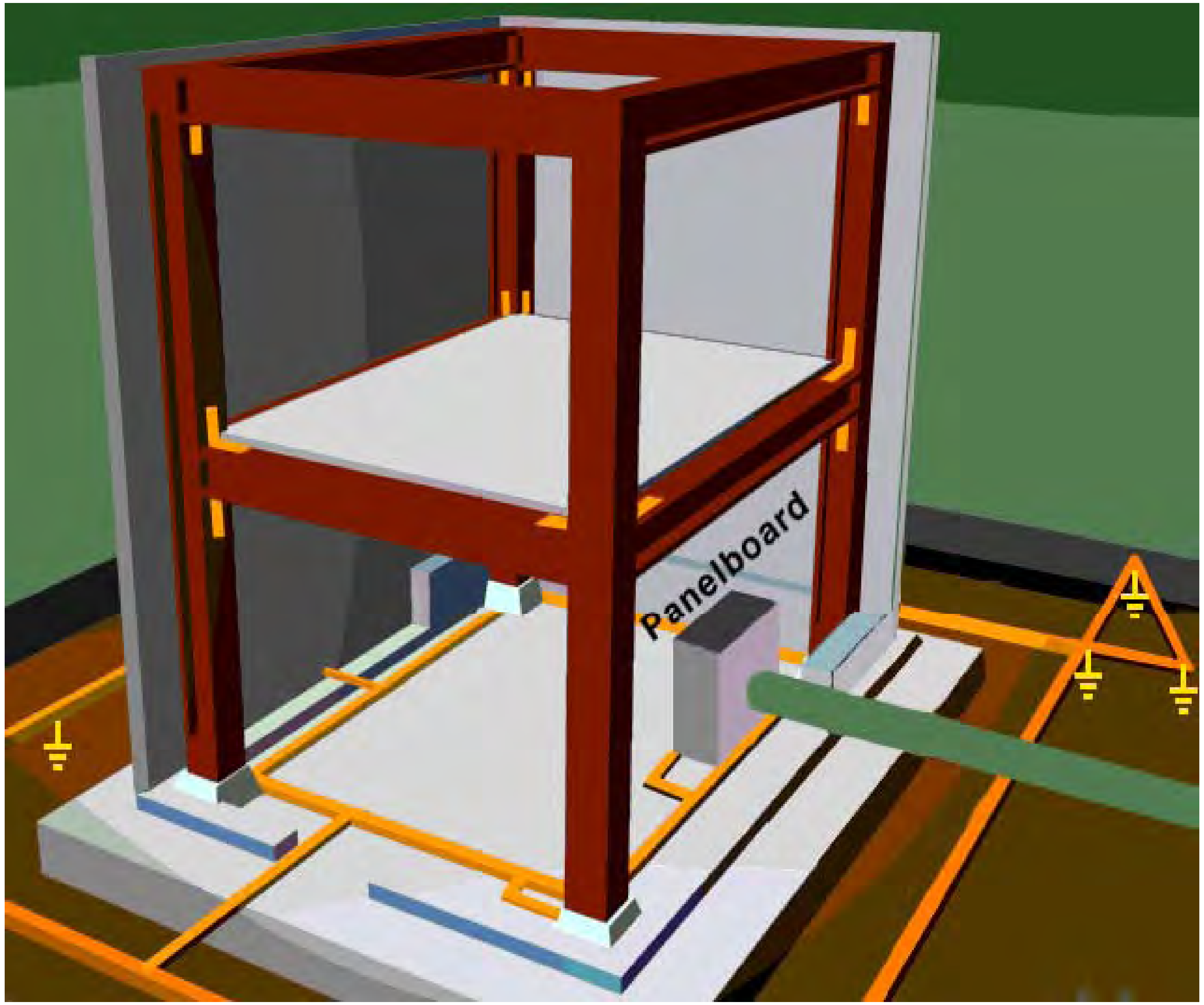
Good Grounding Mandatory

Review

Recommended practices

Getting toward the end

Low R Grounding



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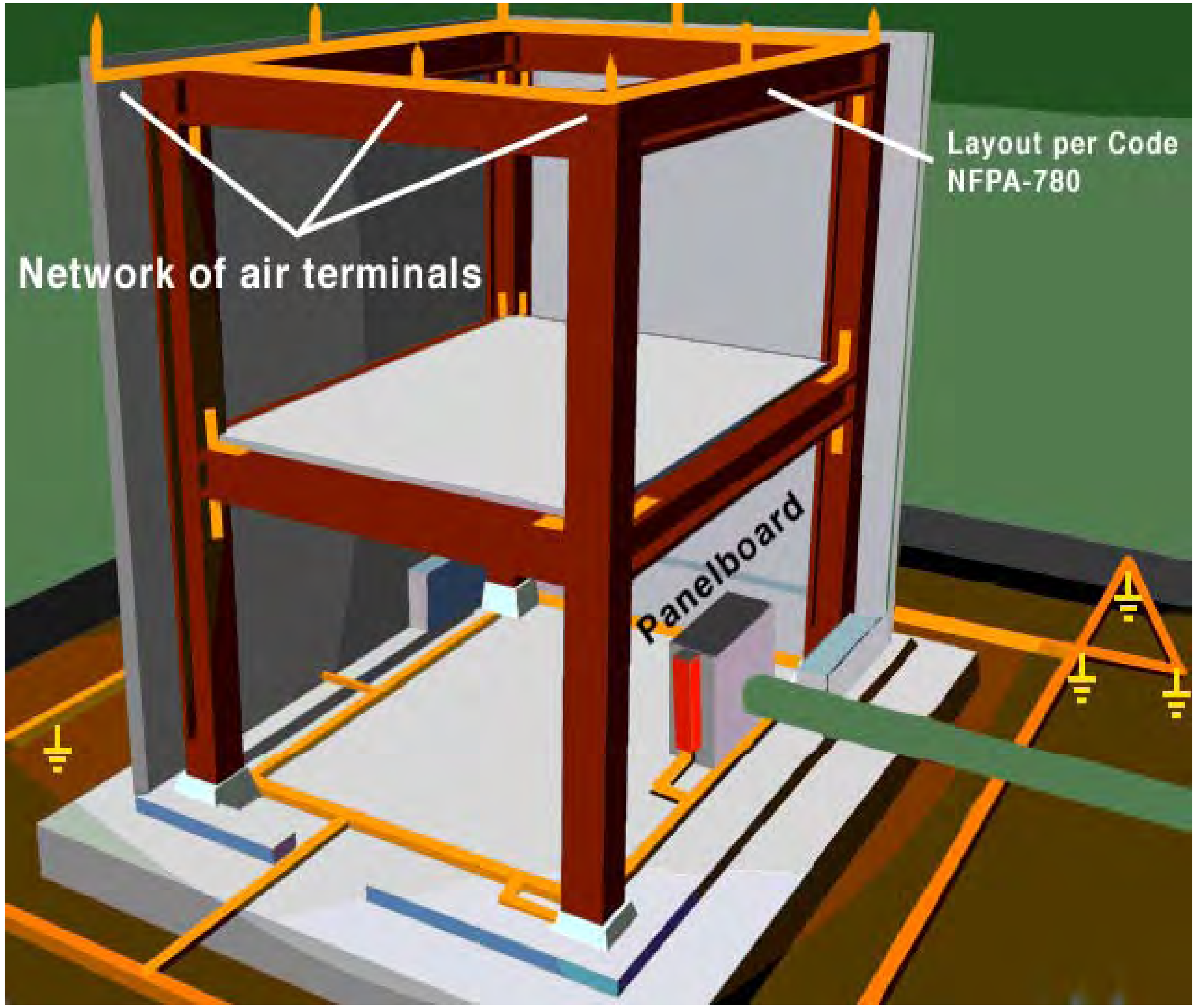
Network of Air Terminals



System Grounding

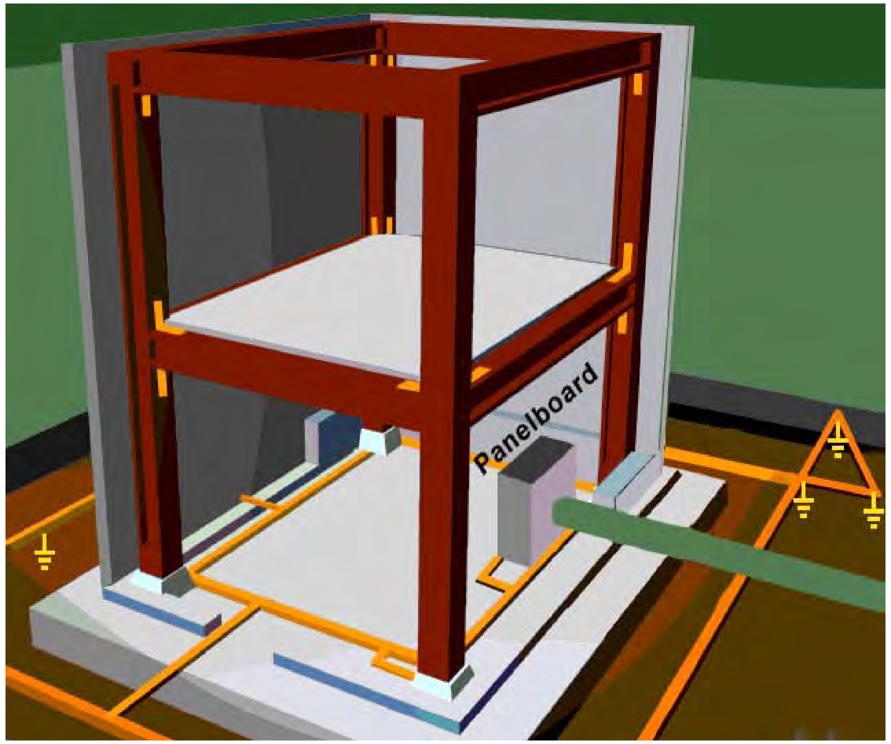
To the Ground Ring:

-multiple ground rods

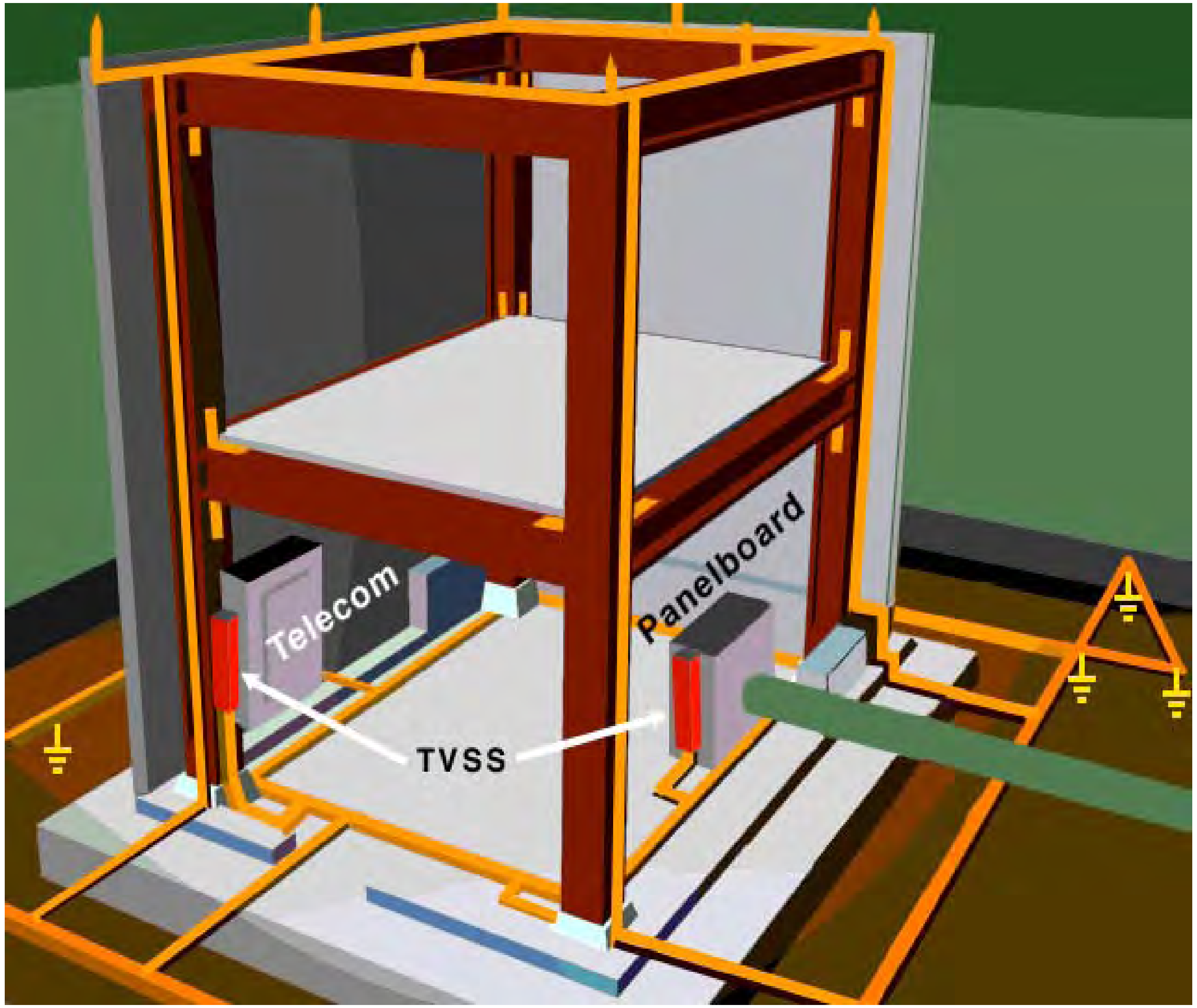
-tie-in building steel

-connect all metallic underground pipes

-lightning protection system

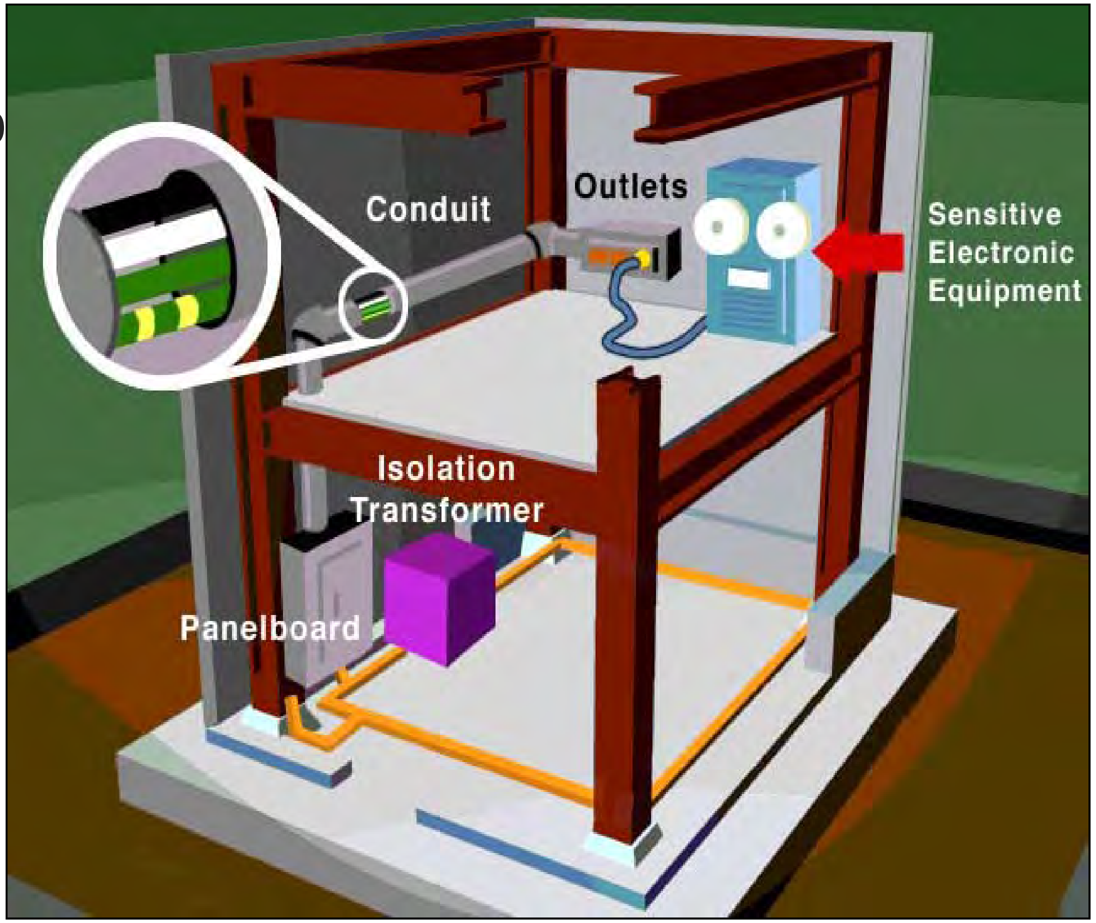


Surge Suppression



Equipment Grounding Conductor

- Use a full-sized EGC and 200% neutral, or separate neutrals
- Don't rely on conduit



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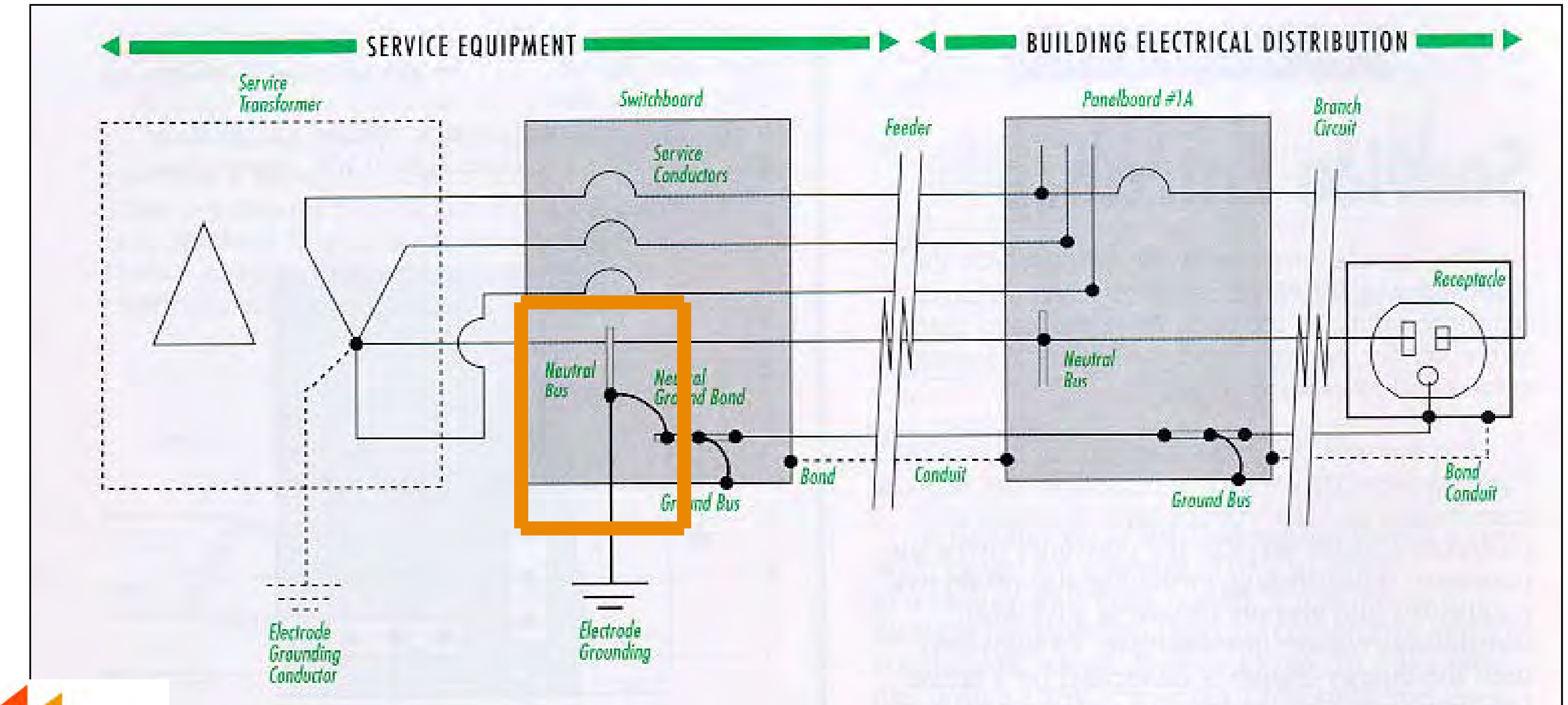
Equipment Grounding

There should be ONE central point connecting the neutral to the ONE exterior grounding electrode <u>system</u>



Source: Dranetz Field Handbook

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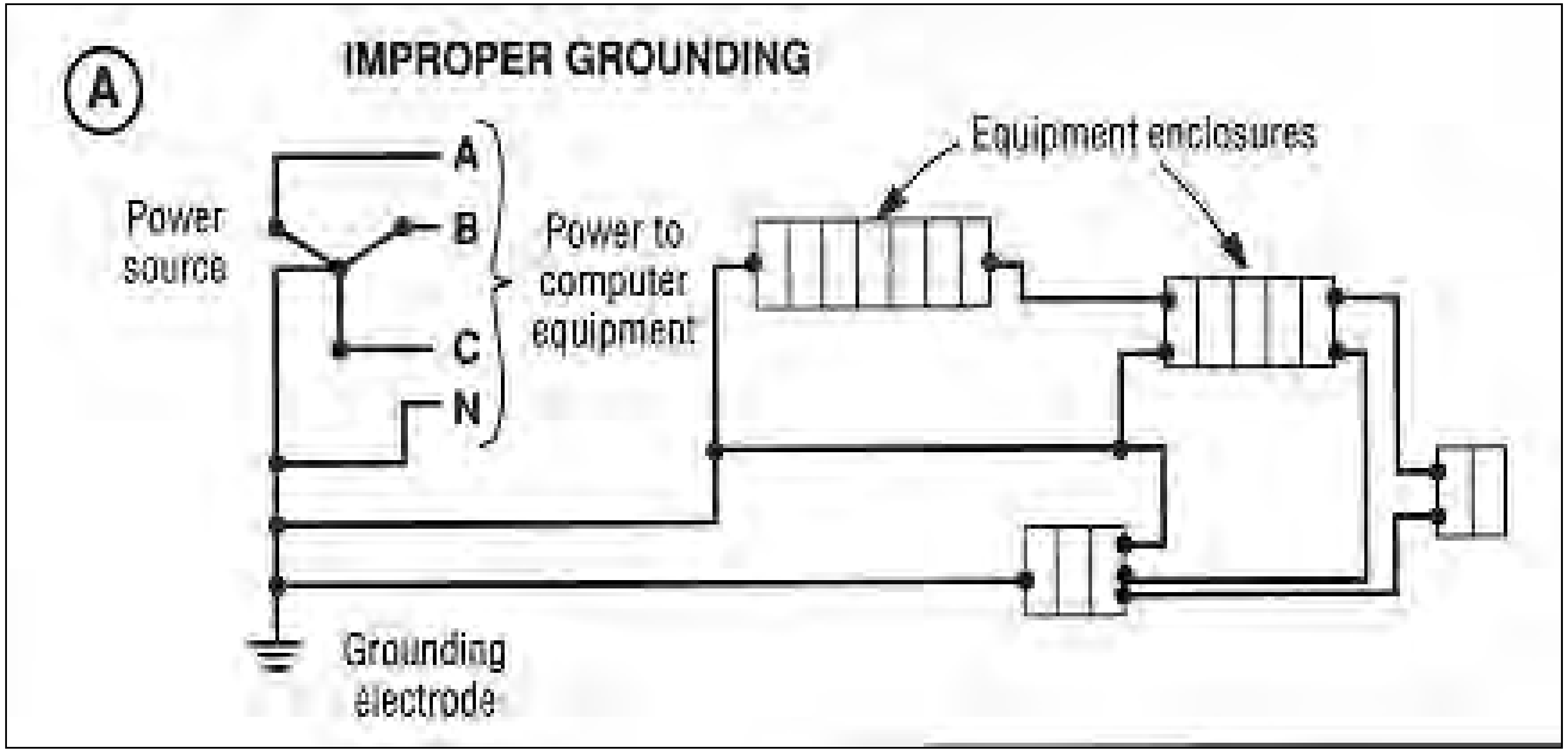
No Ground Loops Allowed



EARTH MUST NEVER BE USED AS A CONDUCTOR

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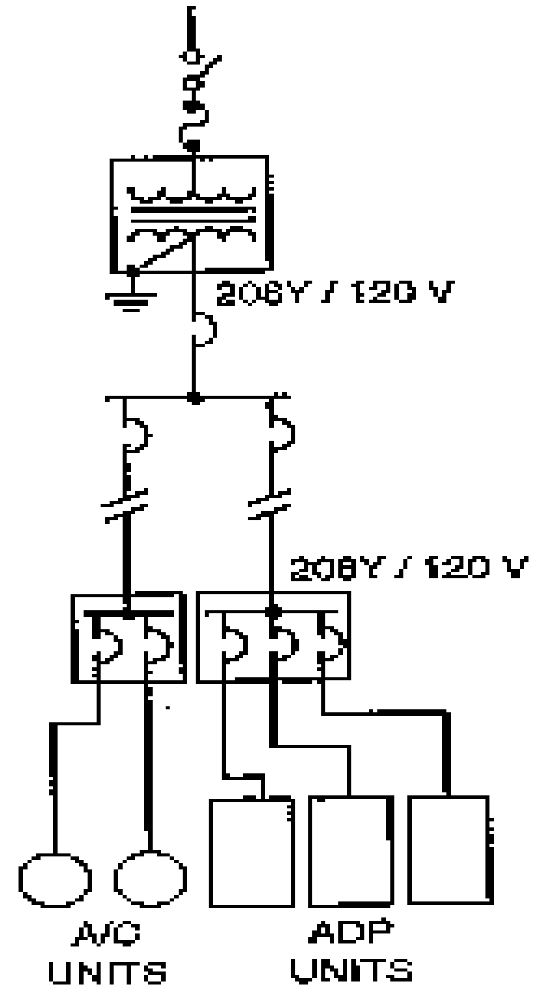
Separate wiring

At least, separate circuits

If possible:

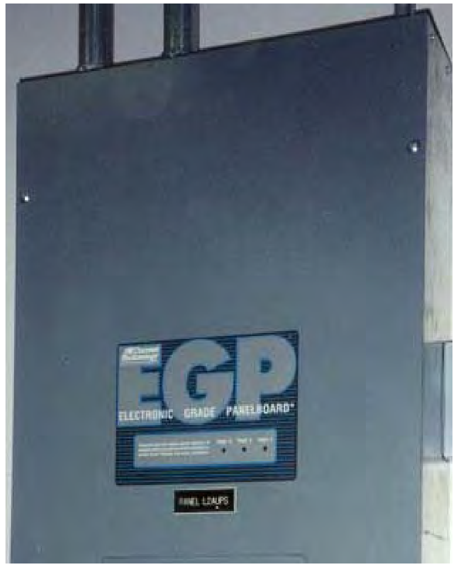
- **separate panels**
- **separate feeders**
- **separate services**
- **shielded isolation trans.**
- **UPS**



Handle Harmonics

Interior:

- Always use a full size copper equipment grounding conductor
- Use a 200% rated neutral
- Use harmonic rated panels



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General Wiring

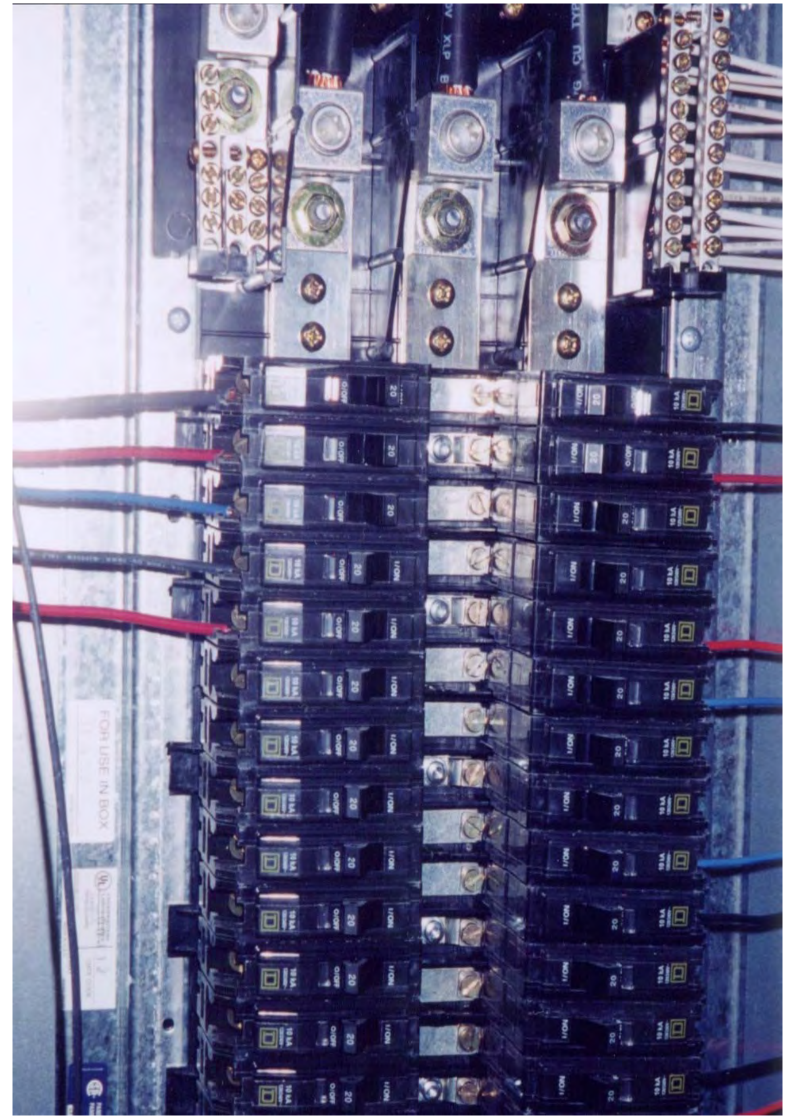
Interior:

- **Limit receptacles to 3-6 per circuit**
- **Limit voltage drop to <3% or less**
  - **wire gage**
  - **circuit length**
- **Check for ground loops**
- **Check for N-G bonds**

General Wiring

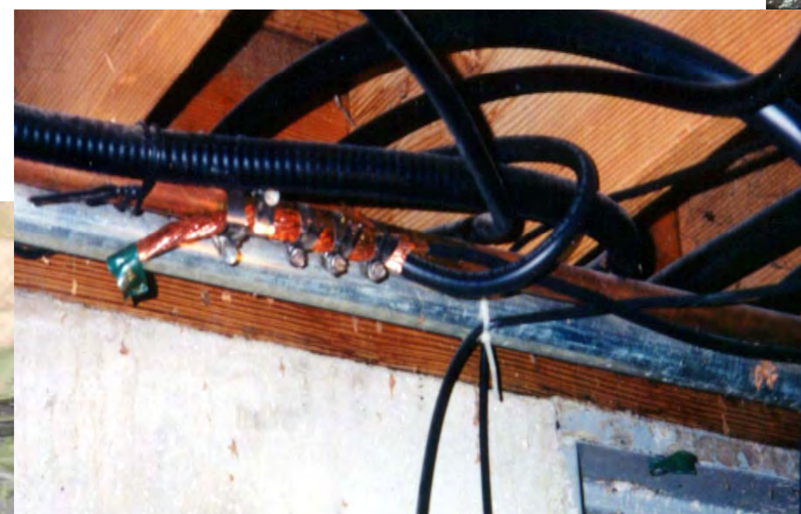
Interior:

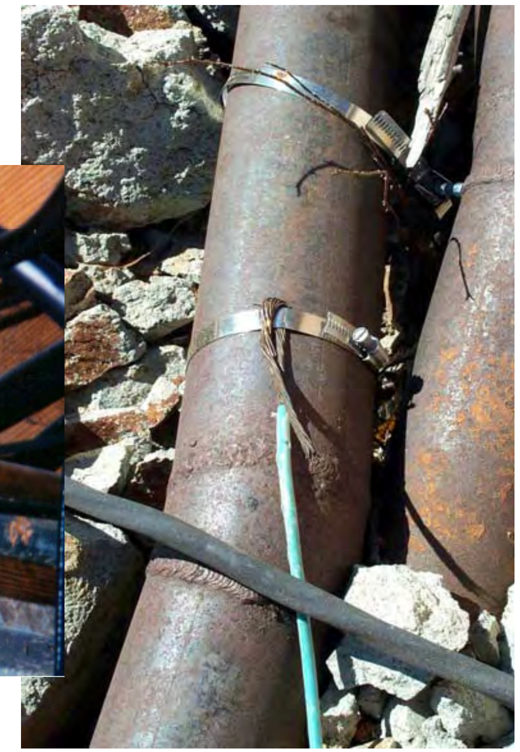
- **Bolt-in circuit breakers**
- **Twist-lock plugs/receptacles**



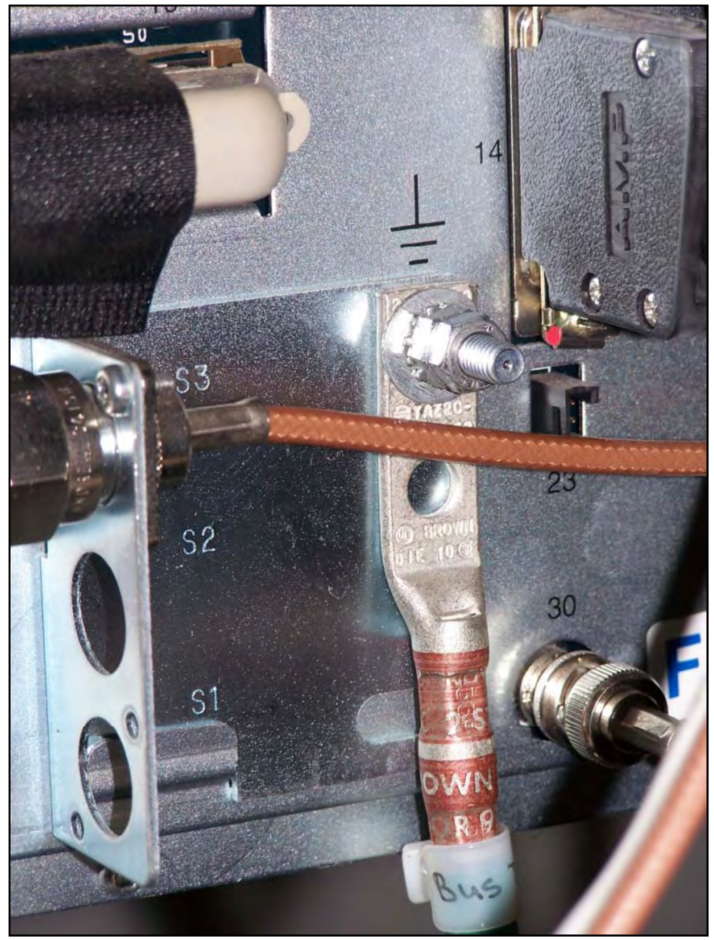
General Wiring

Use proper connections

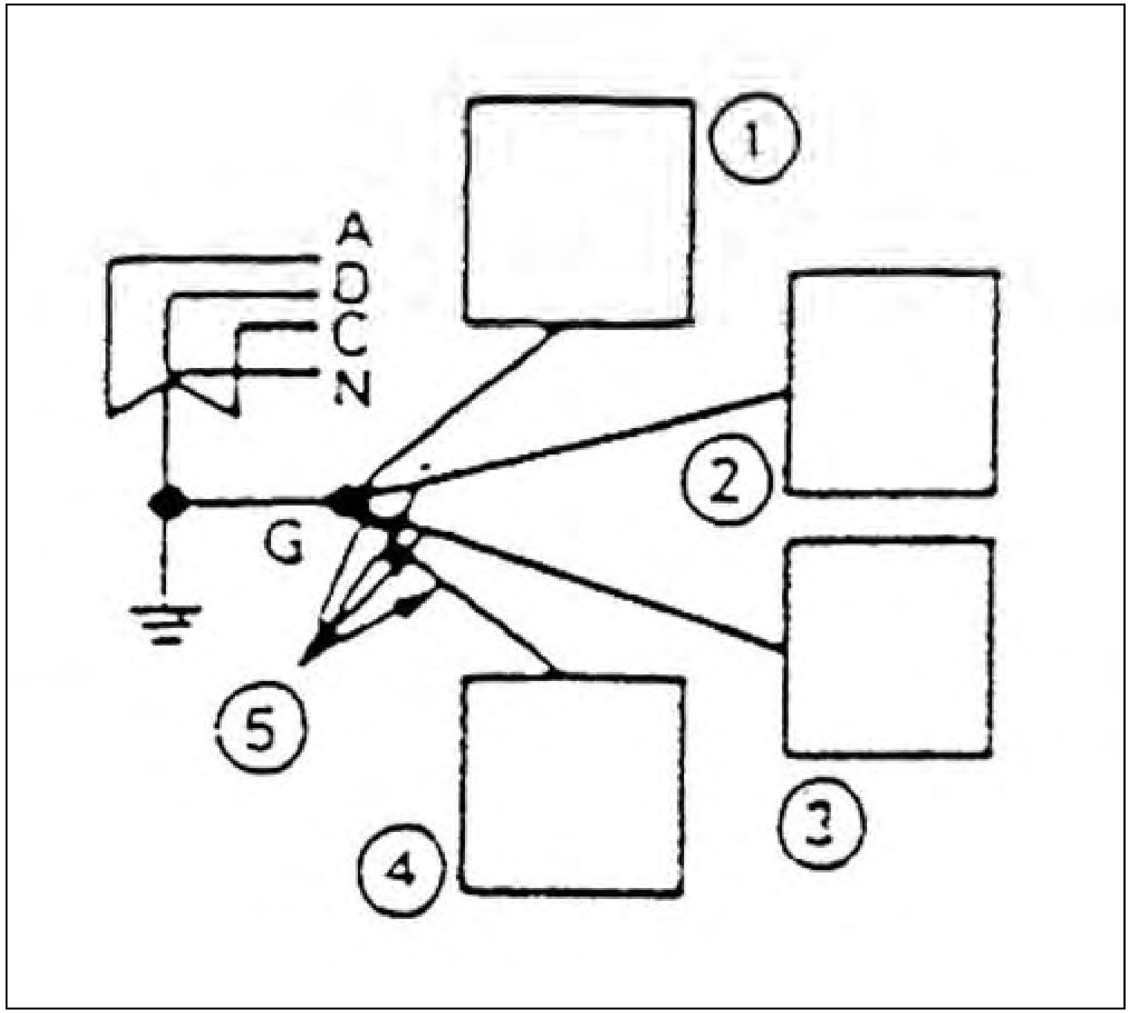




Double Nuts and Lockwashers



Star Pattern



General Wiring

Shielded isolation transformer

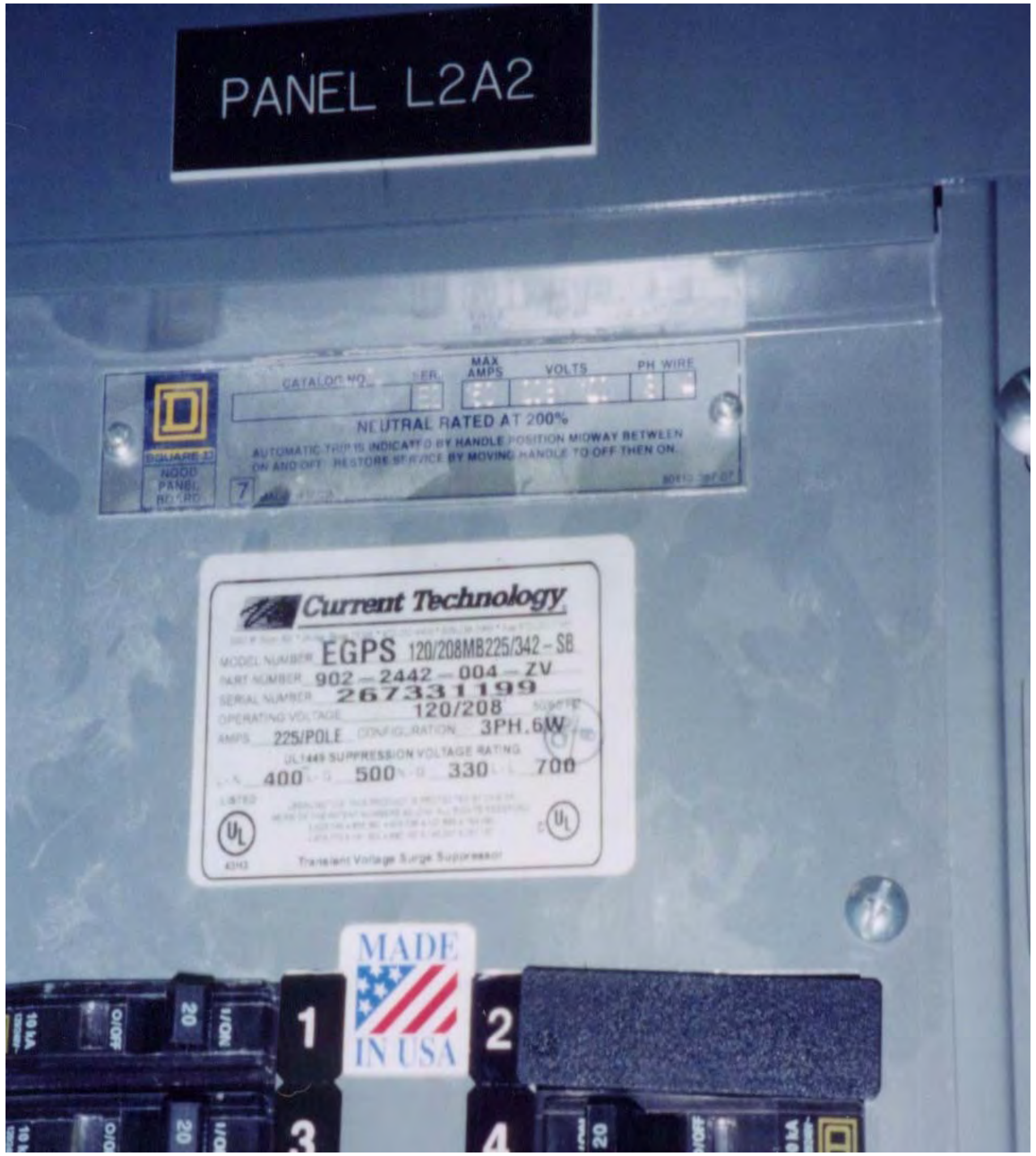
or

K-rated transformer (K-13 or higher)

CDA

General Wiring

Harmonic rated panels



CDA

System Grounding

Bentonite is the only recommended backfill

Be wary of anything containing graphite

Retest System Ground

Retest resistance of grounding electrode system annually (or more often as conditions dictate).

Use fall-of-potential method if possible

CDA

Human Failures

People make changes to the electrical system all the time

They seldom document the changes

Tip

You can exceed the Code,

but don't violate the Code!

"There should be no reason why you cannot design for power quality and still stay within the Code" –

Warren Lewis

CDA

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Before I go….

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Case Histories
Recommendations
Bibliography
CD-ROM

Thanks for your attention.

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