Power Quality
An Ongoing Challenge, Part 1

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Technical Press
March 24, 1999

KPDJ-FM: The Problems Faced

- Facility: 100kW Class C FM station, 20kW transmitter into 10-bay antenna, HAAT 2680ft, power supplier PG&E. Studio site co-located with 5kW AM broadcast station. Studio equipment a mixture of active- and transformer-balanced inputs and outputs, with some unbalanced sources as well.
- Problems: 1) system faults resulting from lightning and utility service disturbances at the transmitter site, 2) crosstalk into audio systems, 3) generally poor overall reliability of solid-state systems.
- Market Data: Eureka, CA, ADI #183, AM station share approaching 50% (18-55), startup FM less than 10%.

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KPDJ-FM Transmitter

Collins/Rockwell 831-G1 FM transmitter. 20 kW TPO into gain of 5 antenna. 100 kW ERP.

Tube final amplifier, solid-state driver stages. SCR-controlled plate voltage supply.

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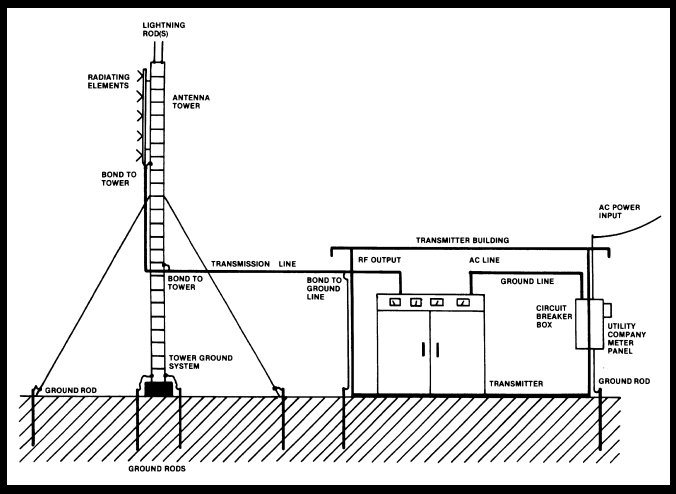
The Transmitter Site



The basic arrangement of the KPDJ-FM transmitter building on Kneeland Mountain.

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The Transmitter Site

The tower for KPDJ-FM at Kneeland Mountain, elevation 2680 ft. Ten bay CP antenna atop a 200 ft. tower.

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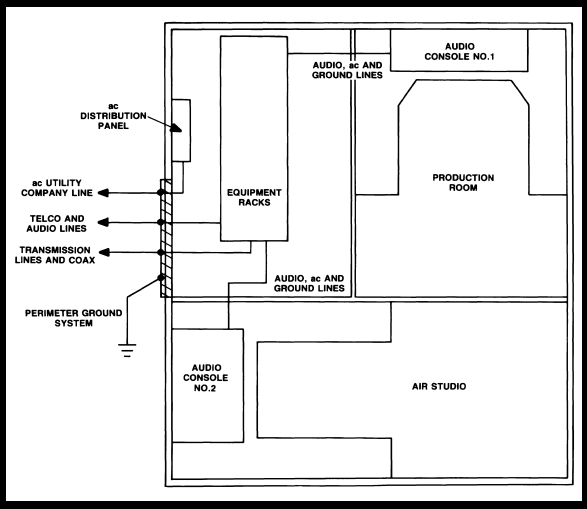
Studio Facility Arrangement



Physical implementation of the KPDJ-FM studio facility.

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Power System Technologies

- Power Electronics: Includes semiconductors, converter circuits, electrical machines, signal electronics, control theory, microcomputers, and CAD.
- AC Theory: Power relationships in ac circuits, ac circuit analysis, inductance and inductive reactance, capacitors and capacitive reactance, and transformers.
- Electro-mechanical Systems: Motors, generators, moving-mass technologies, and other electric machines.
- Atmospheric Energy: Lightning effects, static electricity, and electromagnetic generation.

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Power Quality: Searching for a Paradigm for the Future

- Para-digm (par'e dim') n. 1a) a pattern, example or model, b) an overall concept accepted by most people in an intellectual community, as a science, because of its effectiveness in explaining a complex process, idea or set of data, 2) a nickel short of two bits.

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New Technologies in the Field Today

- Mission-critical LAN and WAN systems for diverse applications in varied industries
- Industrial process control, monitoring, and supervision systems
- Mass data storage for applications ranging from banking to VOD
- Medical diagnosis and support systems

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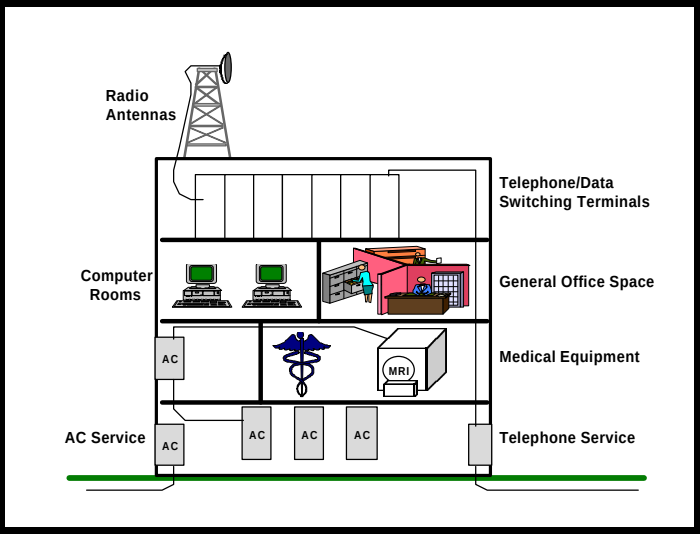
The Environment: New Technologies, New Demands



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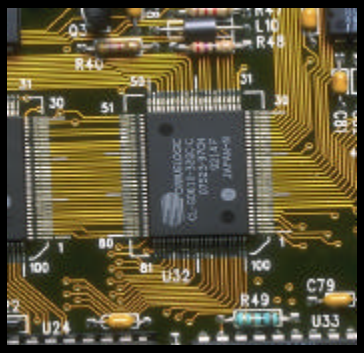
New Technologies for Power Quality Assurance

- Sophisticated power analysis instruments
- Inexpensive UPS systems for point-of-use protection
- Smaller, quieter, more efficient system-wide MG and UPS machines
- Improved component-level protection devices and techniques



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The Role of Management

- Power quality protection hardware is an insurance policy for the facility
- The amount of protection should be dictated by the potential for loss
- Personnel training is just as important as hardware and software
- No facility protection system in entirely fool-proof

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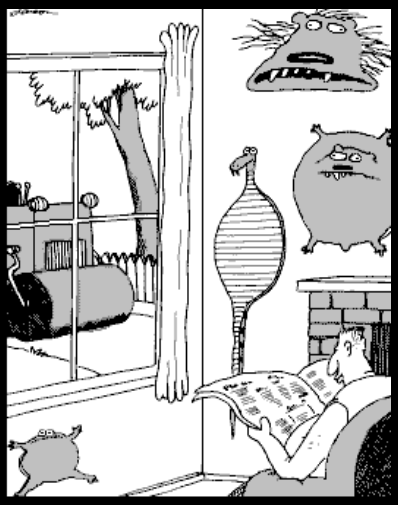
First Rule of Business: You Do What You Know Best



From:
Gary Larson,
The Farside

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Power Disturbance Classifications

- Voltage Surge: An increase of 10 to 35% above nominal line voltage for a period of 16ms to 30s.
- Voltage Sag: A decrease of 10 to 35% below nominal line voltage for a period of 16ms to 30s.
- Transient Disturbance: A voltage pulse of high energy and short duration impressed upon the ac waveform.
- Momentary Power Interruption: A decrease to zero voltage of the ac power line potential, lasting from 33 to 133 ms.
- Power Outage: A decrease to zero voltage of the ac power line potential, lasting more than 133 ms.

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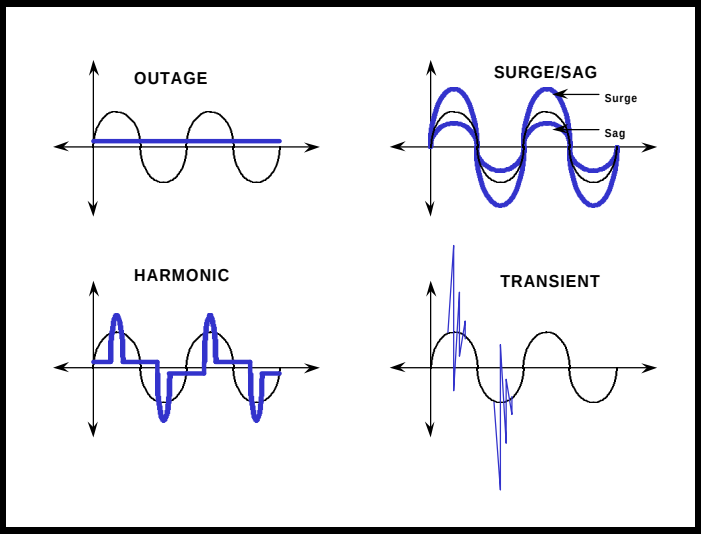
Classifying Power Line Disturbances



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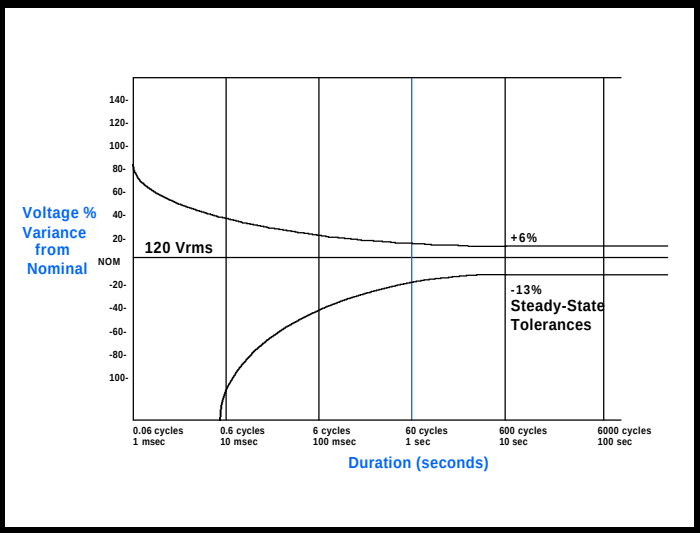
Computer Power Envelope: Established Limits



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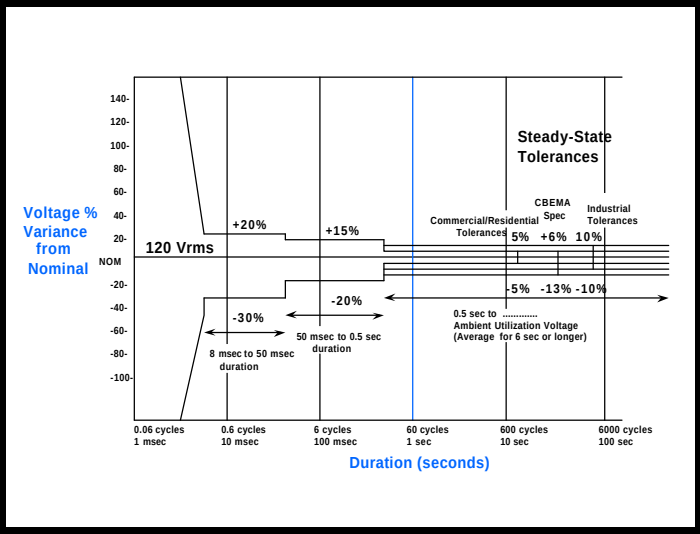
Utility Power Profile: Typical Steady-State Tolerances



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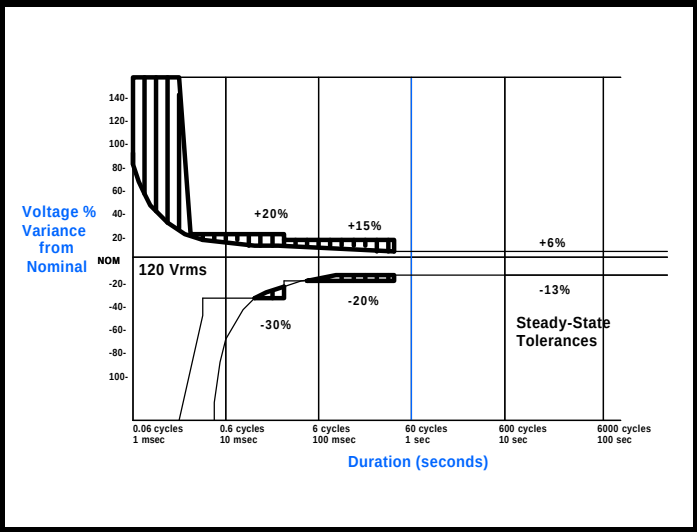
Regions of Non-Overlap: The Problem Zone



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Characteristics of Lightning

- Lightning Effects: Peak current 100kA, energy 5000 J, frequency 10Hz to 40kHz, field at 1 mile 70V/m, rise time 0.5µs to 10µs.
- Thunderstorm Cell Development: Normally negatively-charged on the bottom and positively charged at the top, resulting in a distorted voltage gradient.
- Discharge Waveform: Rise time very fast, slow decay of trailing edge (reciprocal double exponential waveform).
- Lightning Characteristics: Category 1-4, determined by the direction of motion and electric charge of the initiating leader.
- Flash Characteristics. Idealized flash follows a predictable process of specific steps.

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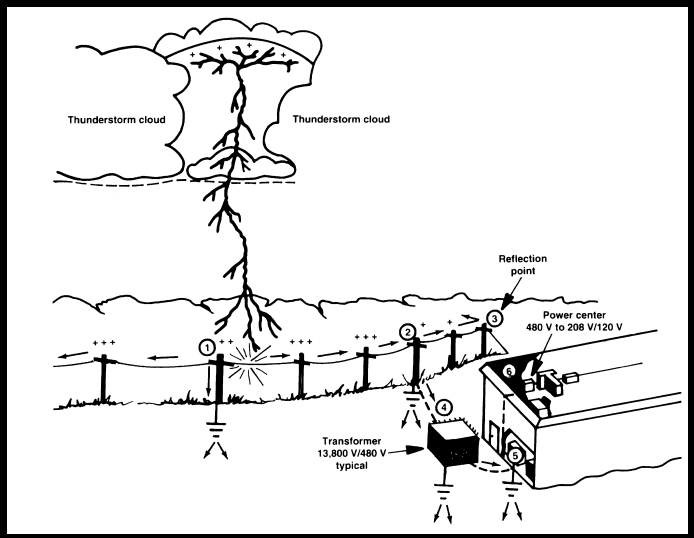
Characteristics of a Lightning Strike



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Lightning Protection Methods

- Point Discharge Theory: Dissipate static charges at a rate sufficient to maintain the charge below the value at which a lightning flash will occur.
- Design Considerations: Radius of dissipator electrode, dissipator construction material, number of electrodes, density of dissipator electrodes, configuration of the dissipator on the tower, and size and deployment of grounding electrodes.
- Numerous Configurations Available: From simple to complex, from basic to exotic.
- Still Controversial: Experience varies from site to site, but worth considering for critical installations.

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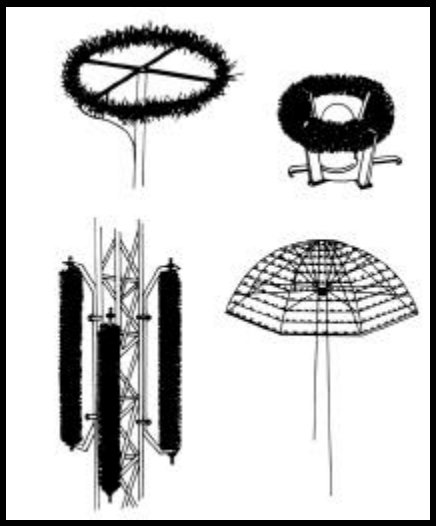
Static Dissipation Arrays



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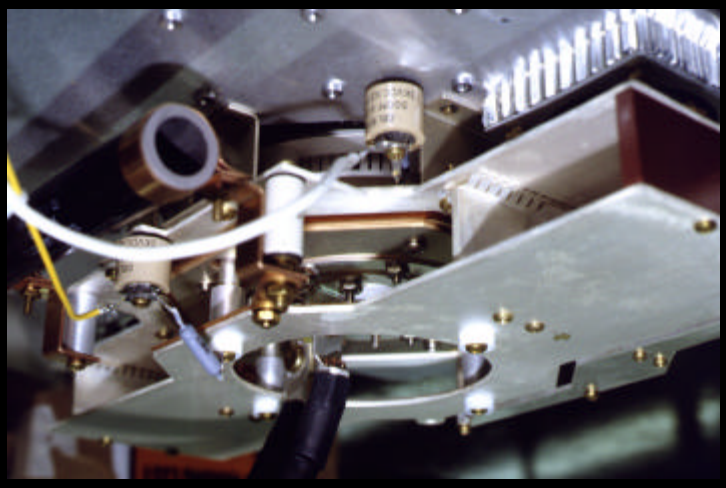
Transmitter PA Grid Compartment



The tight spacing of components in the grid compartment makes arcing a serious concern.

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Power Grid Tube Socket

The screen ring of a 4CX15000 power tube. Note the close spacing of components.

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Arcing Failure Point

Failure of a 4CX5000A resulting from a lightning arc. A crack in the tube ceramic envelope let the device go down to air.

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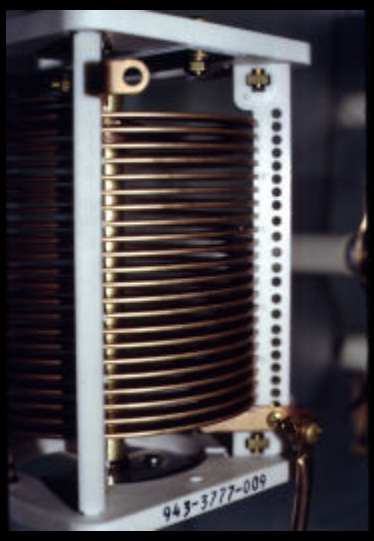
Potential Arcing Failure Point



The windings of PA tank circuits are particularly susceptible to damage and failure as a result of lightning strikes on the RF load.

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Equipment-Caused Disturbances

- Turn-on, Turn-off Spikes: Any inductive load will generate transient energy when power is applied and when it is removed; it is the nature of inductive devices.
- Capacitive Coupling: Transient energy resulting from the inter-winding capacitance of a step-down power transformer.
- Switch Contact Arcing: Showering effects resulting from contact bounce and an imperfect insulating medium.
- Nonlinear Loads: Switching power supplies and solid-state motor controllers are the greatest offenders.
- Utility System Faults: All of the above, and more.

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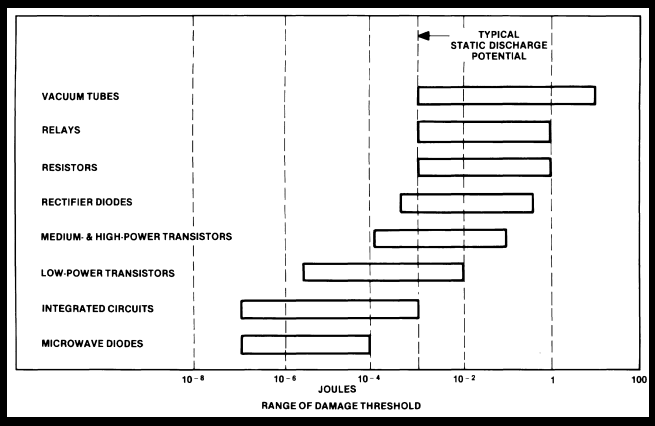
The Damage Threshold



An estimation of the susceptibility of common electric devices to damage from transient disturbances. The vertical line marked “discharge” represents the energy level of a discharge that typically can be generated by a person who touches a piece of equipment after walking across a carpeted floor.

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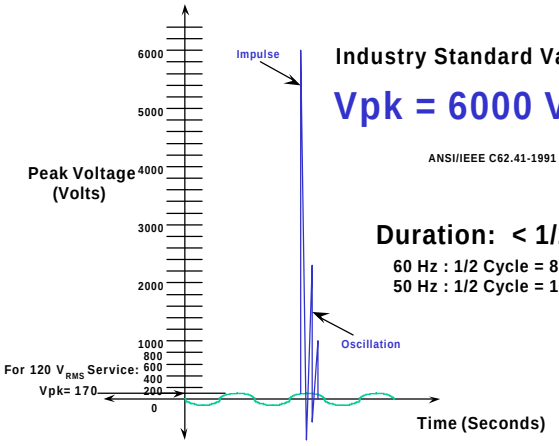
The "Magnitude" of the Problem



Industry Standard Values:

Vpk = 6000 Volts

ANSI/IEEE C62.41-1991

Duration: < 1/2 Cycle

60 Hz : 1/2 Cycle = 8.33 msec
50 Hz : 1/2 Cycle = 10.0 msec

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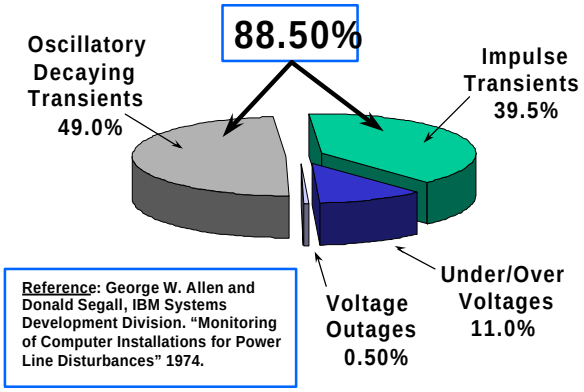
Characterizing Harmful Power Line Disturbances



Reference: George W. Allen and Donald Segall, IBM Systems Development Division. "Monitoring of Computer Installations for Power Line Disturbances" 1974.

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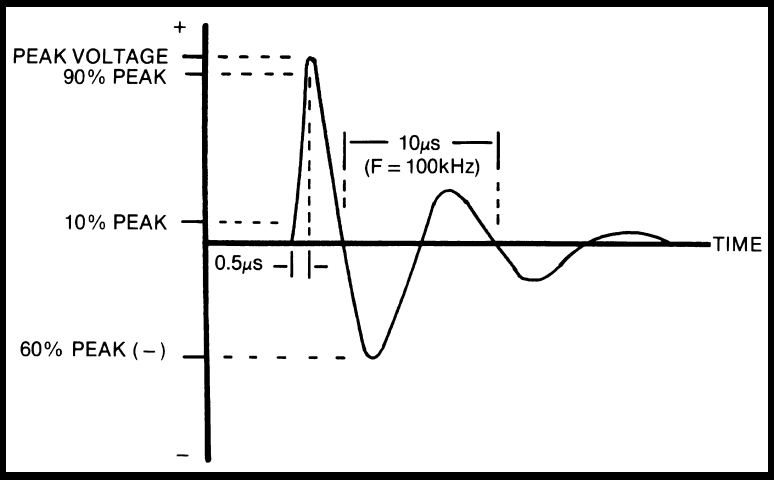
Test Waveform: Ring Wave



The suggested ANSI/IEEE indoor-type transient overvoltage test waveform (0.5 μs - 100 kHz ring wave, open-circuit voltage).

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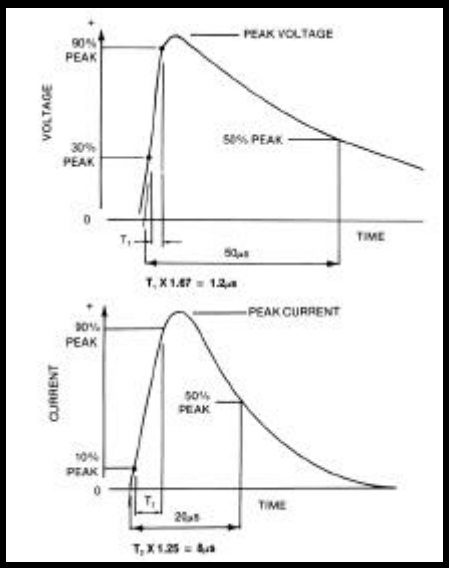
Test Waveform: Combination Wave

The unidirectional waveshape for outdoor-type transient overvoltage test analysis based on ANSI Standard C62.1

Open-circuit waveform

Discharge current waveform



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Problems Caused by Transients: Upsets

- Memory loss in RAM banks
- Corruption of data in local machine and/or file server
- Intermittent system halts
- Peripheral communications failure
- Invalid data from peripheral sensors
- Other types of soft failure requiring rebooting to correct (no permanent damage)

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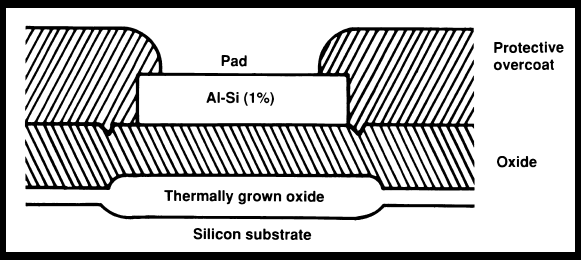
Problems Caused by Transients: Erosion

- Incremental etching down of chips (micro bullets)
- Breakdown of chip internal insulation
- Contact corrosion
- Thermal runaway in transistors
- Other types of soft or hard premature failures



Cutaway view of a semiconductor bonding pad.

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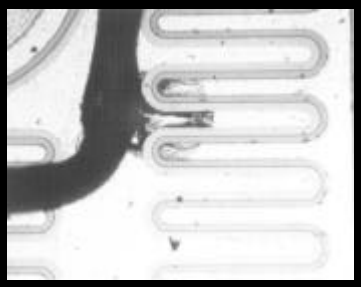
Problems Caused by Transients: Burn-out

- Frequent or unexplained board failures
- System-wide shutdown or failure
- Head crashes on disk drives
- Loss of power supply functionality
- Other types of hard (permanent) failures



Failure of a pass transistor resulting from a transient.

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What to do? Just Add Money

- Hire a Consultant: Authorize a turn-key project involving ac power conditioning, grounding, and lightning protection. *Plan A*.
- Implement Systems Solution: Install a service-entrance power conditioning system. *Plan B*.
- Piecemeal: Install transient suppression components and devices at key points in the transmission system. *Plan C*.
- Do Nothing: Hope for the best. *Plan D*.

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Avoid a Disaster by Planning For Protection

From:
Gary Larson,
The Farside

Group photo disasters

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Power Quality: An Ongoing Challenge

What to do? Film at 11.

Jerry C. Whitaker
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March 24, 1999

Power Quality
An Ongoing Challenge, Part 2

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Transient Protection Alternatives

- Systems approach vs. discrete device approach
- UPS and standby generator
- UPS stand-alone system
- Secondary ac spot network
- Motor-generator set
- Shielded isolation transformer
- Suppressors, filters, and lightning arrestors
- Solid-state line-voltage regulator/filter

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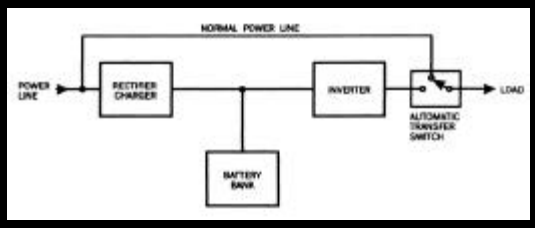
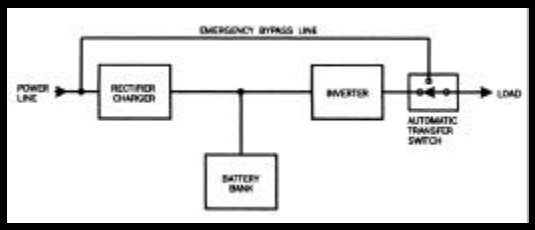
Transfer Mode Options



Forward-transfer mode



Reverse-transfer mode

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Specifying Protection Hardware

- Power Requirements: voltage, current, power factor, harmonic content, and transformer configuration.
- Voltage-regulation requirements of the load.
- Frequency stability required by the load (including the maximum permissible slew rate).
- Effects of unbalanced loading.
- Overload and inrush current capability.
- Bypass capability.
- Primary/standby path transfer time.
- Maximum standby power reserve time.
- System efficiency.

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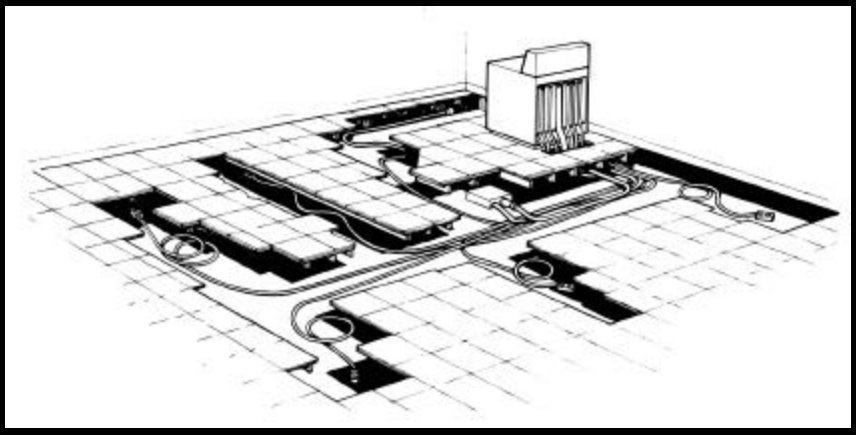
Systems Protection Approach



A dedicated power center offers an efficient method of interconnecting various devices and systems while exercising tight control over voltage excursions. Such systems also can be moved if the facility is later relocated.

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Discrete Device Protection

- Basic Protection: Lightning arrester at service entrance.
- Secondary Protection: MOVs at service drop meter panel.
- Device Staging: Takes advantage of the series resistance and impedance of the ac wiring system.
- Equipment-Level Protection: Identify vulnerable points or elements in critical devices and systems and implement a protection strategy.
- System Design Cautions: Because the typical failure mode of most suppression devices is a short-circuit, the consequences of device failure must be considered.

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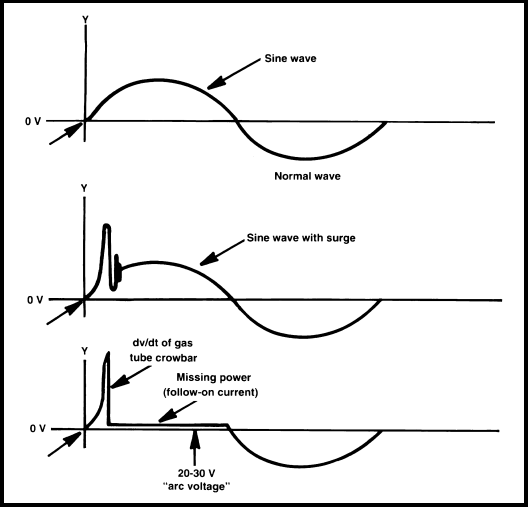
Power-follow Effect



The clamping effect of a crowbar device can result in significant power-follow currents.

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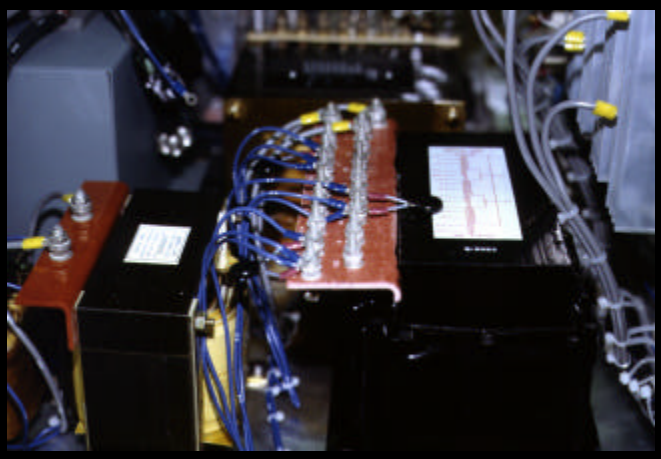
Discrete Device Application



The use of an MOV for transient protection at the input to a power transformer.

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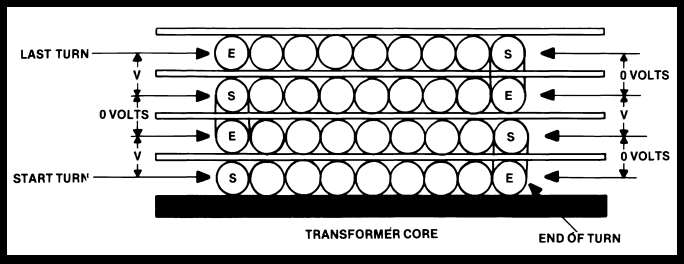
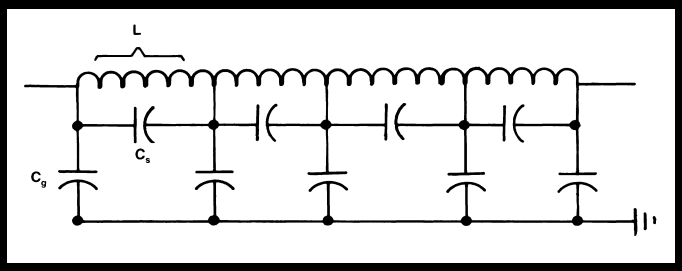
Transformer Failure Modes





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Capacitor Failure Modes

Dielectric breakdown is a major cause of capacitor failure. Arcing between the connection terminals and the case also is a common failure, especially if contaminants are allowed to buildup on the insulating posts.

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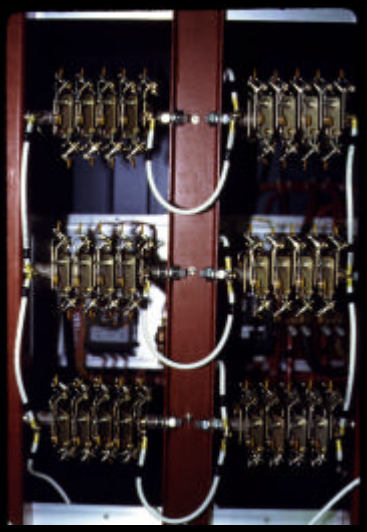
Rectifier Failure Modes



Transient overvoltages are a major cause of rectifier failure. High-energy, steep wavefronts can destroy diode junctions in rectifier stacks unless proper protection is provided. Shown is a 3-phase full-wave bridge assembly.

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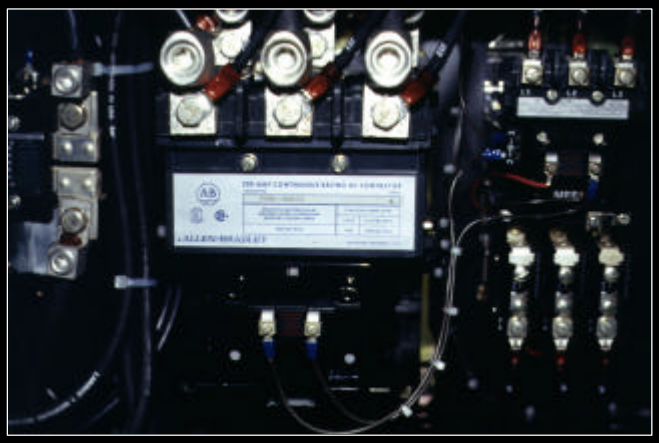
Contactor Failure Modes



Contactor and switch gear failure can result from damage to terminals caused by high-energy arcing, typically from a lightning strike.

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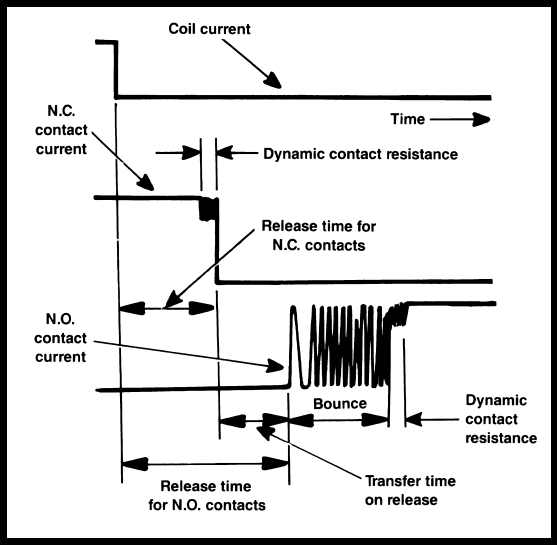
Contact Bounce



The mechanics of contact bounce during the de-energizing period. A similar effect typically is noted during the energizing period.

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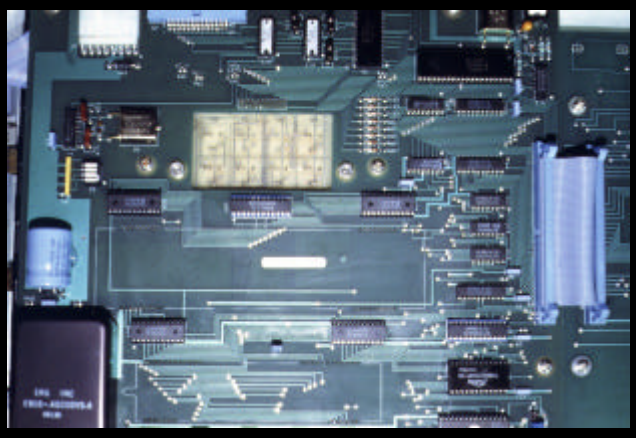
PWB Failure Modes



Dielectric breakdown is a major cause of printed wiring board failure. Arcing between copper traces also is a common failure, especially if the device is exposed to a lightning-prone environment, such as a tower-mounted device.

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Grounding

- Objectives: 1) safety of personnel, 2) prevent catastrophic failures, 3) maintain high level of operational performance, 4) increase overall system reliability.
- Agenda: 1) examine and improve as needed the tower grounding system, 2) examine and improve as needed the studio grounding system, 3) analyze equipment interconnection scheme for ground-loop problems, 4) adjust levels as required for minimum noise and crosstalk.
- Resources: Minimal.
- Expectations: High.

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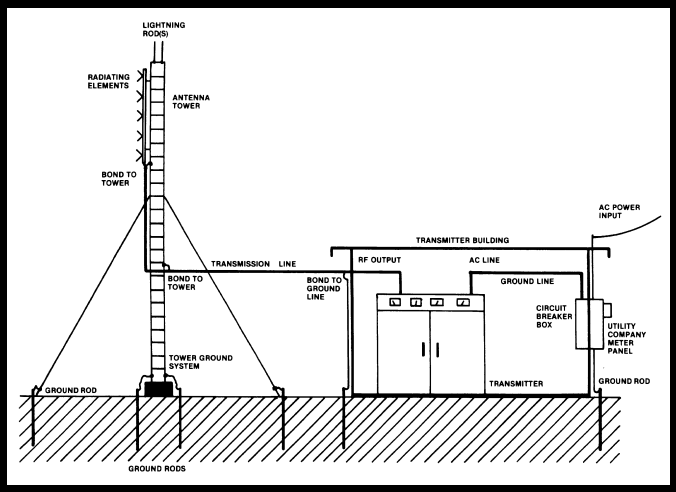
The Transmitter Site



The basic layout of a transmission facility.

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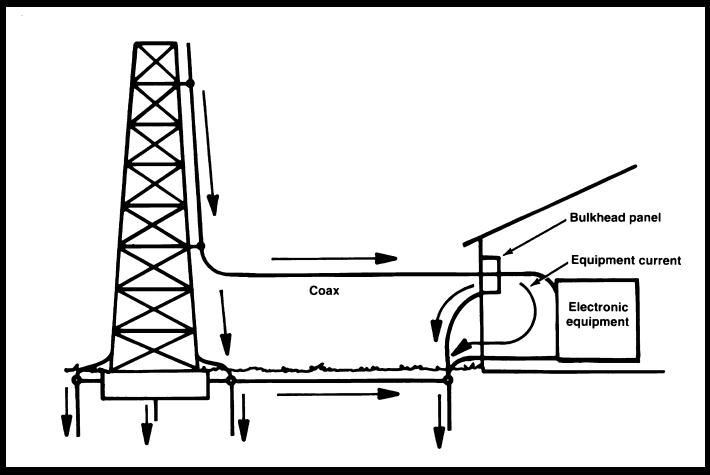
Site Grounding with Separate Service Entry



The equivalent circuit of the original facility design. Note the discharge current path through the electronic equipment.

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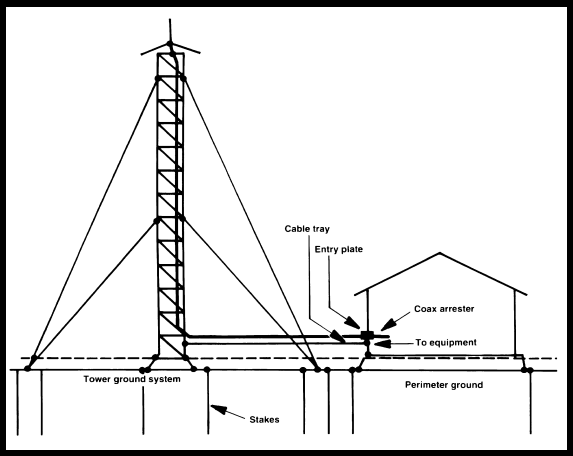
Grounding with Integrated Service Entry



The preferred grounding arrangement for a transmission facility using a bulkhead panel. With this configuration, all damaging transient overvoltages are stripped off the coax, power, and telephone lines before they can enter the equipment building.

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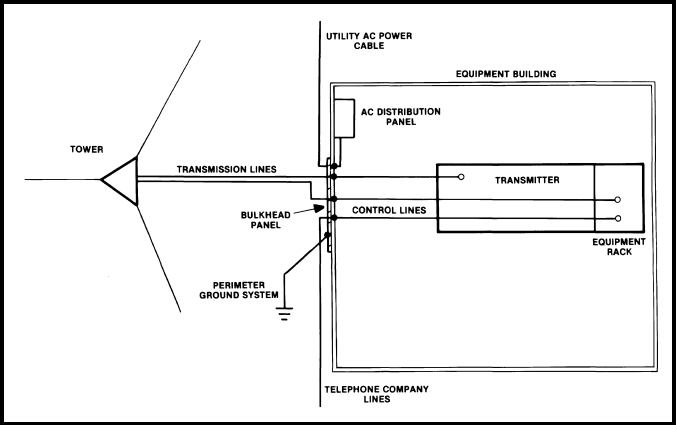
Bulkhead Ground as Reference Point



The basic design of a bulkhead panel for a facility. The bulkhead establishes the grounding reference for the plant.

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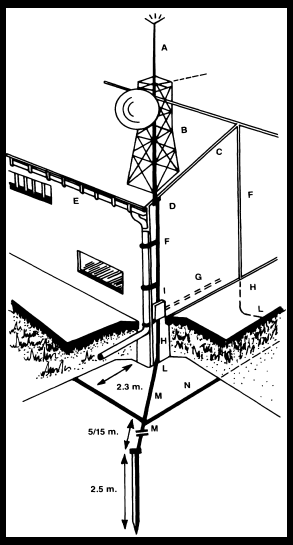
Microwave Tower Grounding

- **A** 5 Point Lightning Rod. It must be so to cover the parabola w/ safety cone
- **B** Receiving Antenna Tower.
- **C** Faraday Shield
- **D** Connecting Clips for Shield
- **E** Connecting Clips for Valleys and/or Gutters
- **F** Faraday Shield Ground Cable
- **G** Grounding of the internal electrical system and ground of the equipment
- **H** Bar Leading to Ground
- **I** Bonding Plates of several conductors
- **L** Bar - Bus Bar Clip
- **M** Zinc Plated Steel Bus Bar or Stranded wire for discharge. Must be buried (in earth).
- **N** Grounding Ring for cable bonding



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Tower Grounding Plan B

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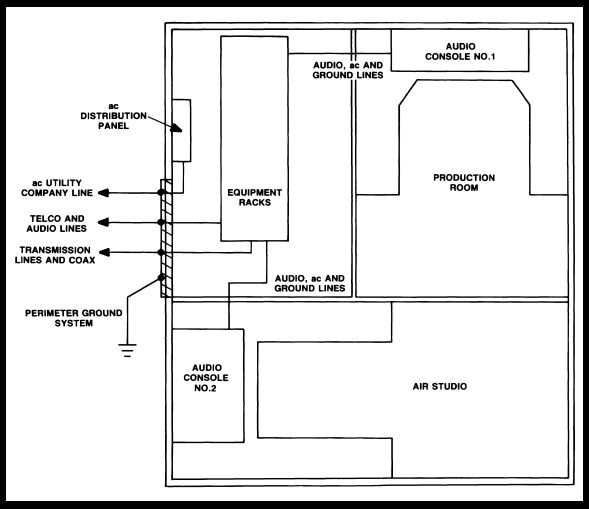
Studio Facility Arrangement



Physical implementation of a studio facility.

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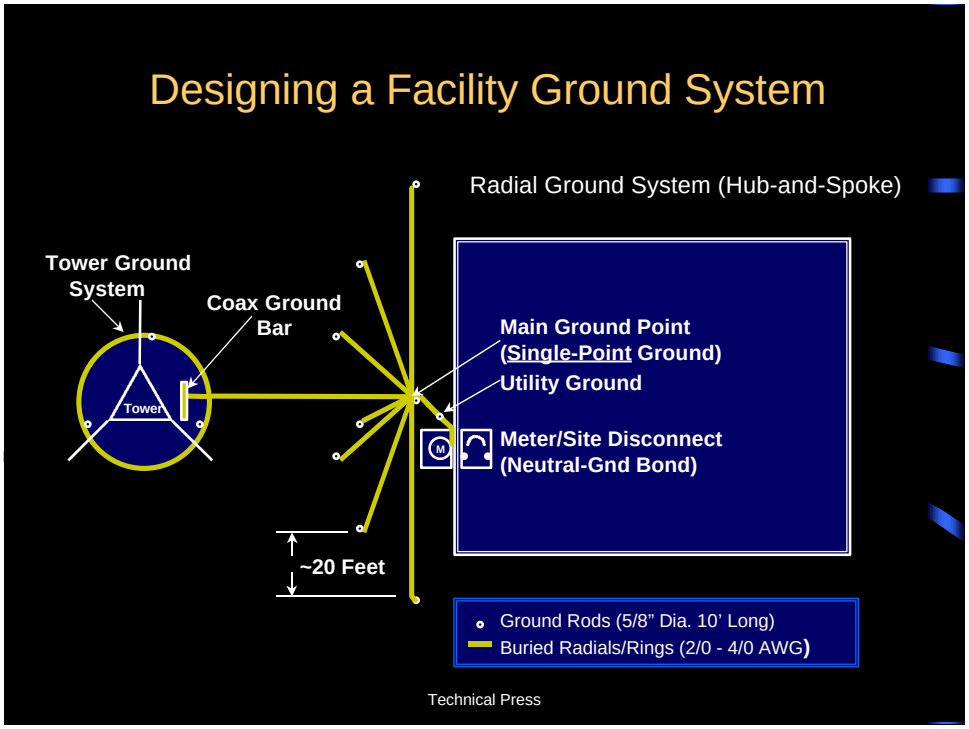
Designing a Facility Ground System
Radial Ground System (Hub-and-Spoke)
Tower Ground System
Coax Ground Bar
Tower
Main Ground Point
(Single-Point Ground)
Utility Ground
Meter/Site Disconnect
(Neutral-Gnd Bond)
~20 Feet
Ground Rods (5/8" Dia. 10' Long)
Buried Radials/Rings (2/0 - 4/0 AWG)
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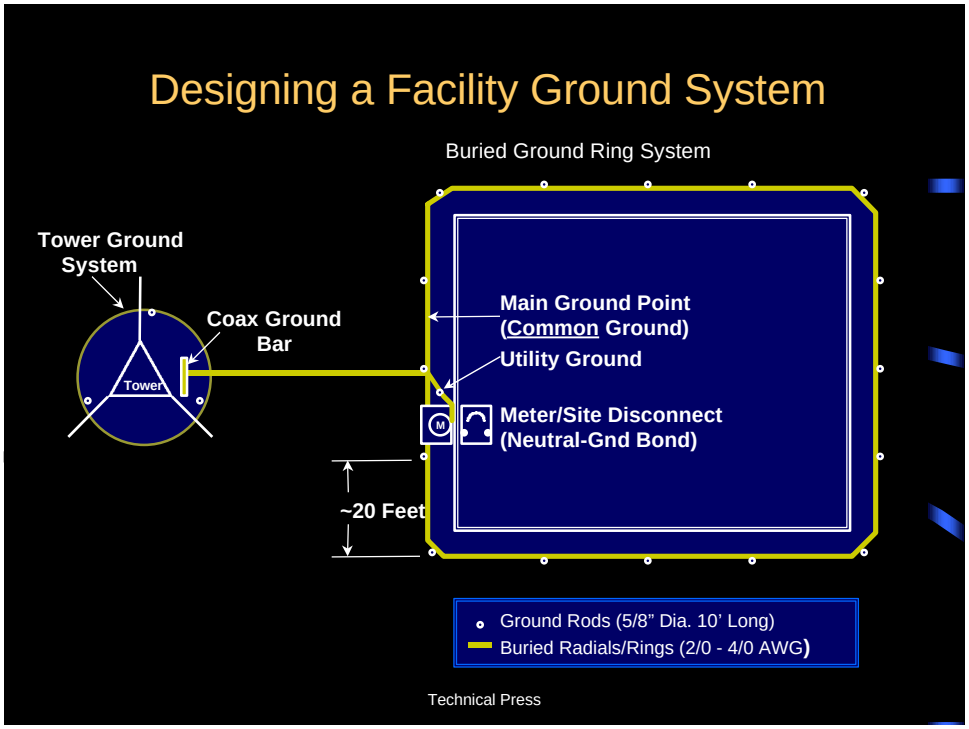
Designing a Facility Ground System
Buried Ground Ring System
Tower Ground System
Coax Ground Bar
Tower
Main Ground Point
(Common Ground)
Utility Ground
Meter/Site Disconnect
(Neutral-Gnd Bond)
~20 Feet
Ground Rods (5/8" Dia. 10' Long)
Buried Radials/Rings (2/0 - 4/0 AWG)
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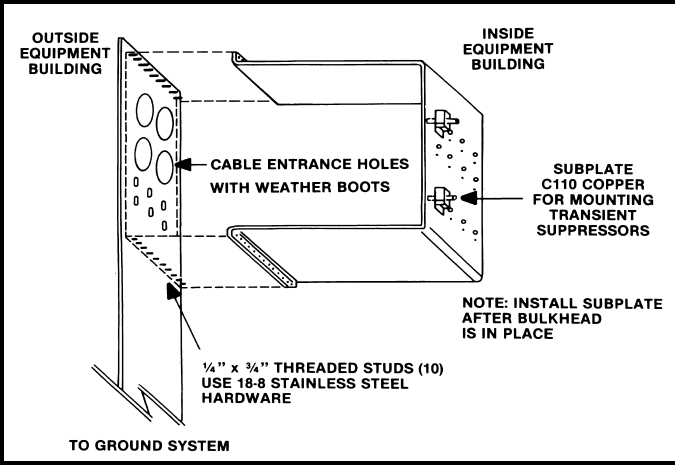
Bulkhead Used as Mount for TVSS



The addition of a subpanel to a bulkhead as a means of providing a mounting surface for transient-suppression components. To ensure that the bulkhead is capable of handling high surge currents, use the hardware shown.

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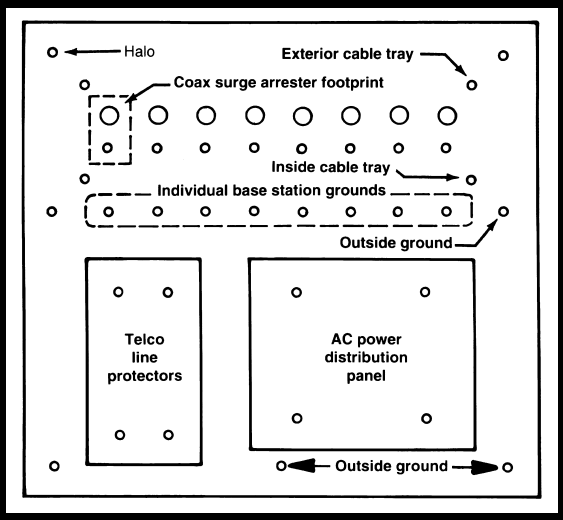
Mounting Layout on Bulkhead



Mounting-hole layout for a communications site bulkhead subpanel.

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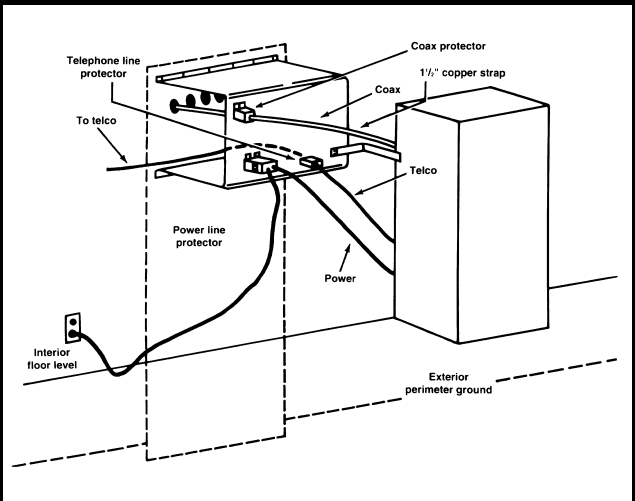
Example of Bulkhead Installation



Bulkhead installation at a small communications site.

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When a Bulkhead is not Used

- Mount a feed-line ground bar on the wall of the building approx. 4” below the feed-line entry point.
- Connect the outer conductor of each feed line to the feed-line ground bar using an appropriate grounding kit.
- Connect a #1/0 AWG cable or 3-6” wide copper strap between the feed-line ground bar and the external ground system. Make a Cadweld or silver-solder connection
- Mount coaxial arrestors on the edge of the bar.
- Weatherproof all connections.

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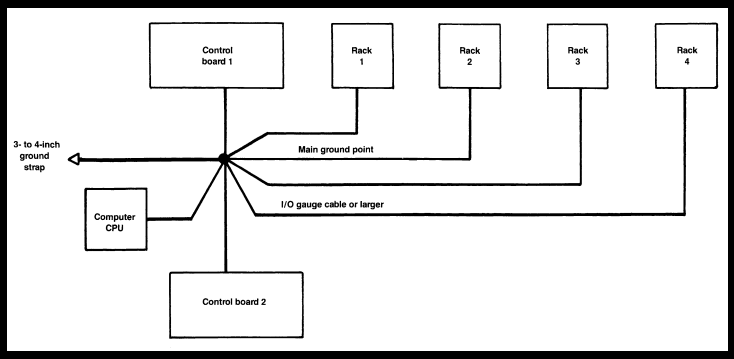
Single Point Grounding Concepts



Typical grounding system. The main facility ground point is the reference from which all grounding is done at the plant. If a bulkhead entrance panel is used, it will function as the main ground point.

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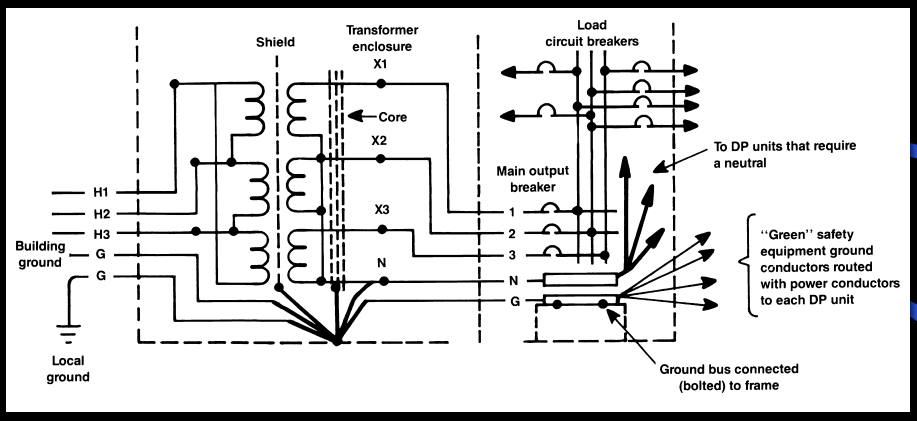
Single Point Grounding Concepts



Single-Point grounding applied to a power-distribution system.

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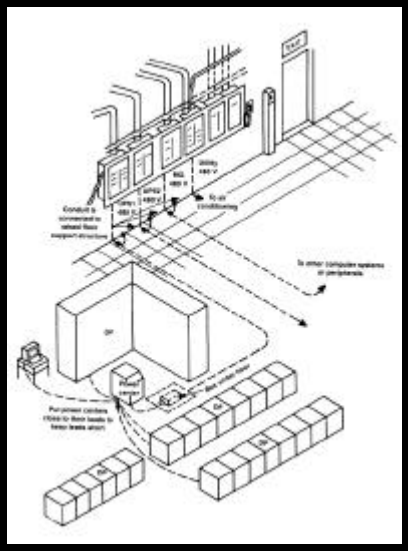
Star-of-stars Configuration Example



Configuration of a star-of-stars grounding system at a data processing facility.

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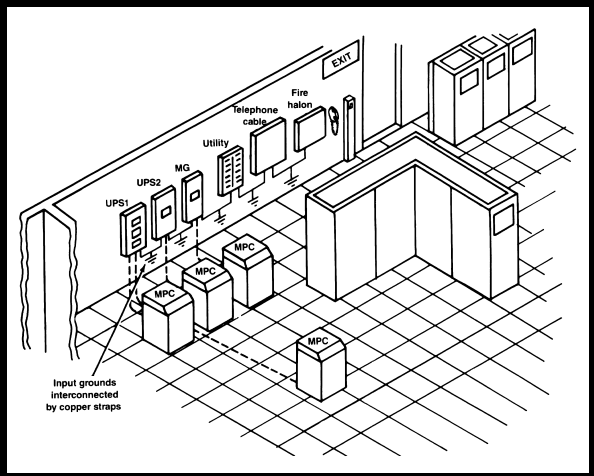
Single Point Grounding Concepts



Establishing a star-based, single-point ground system using multiple modular power centers.

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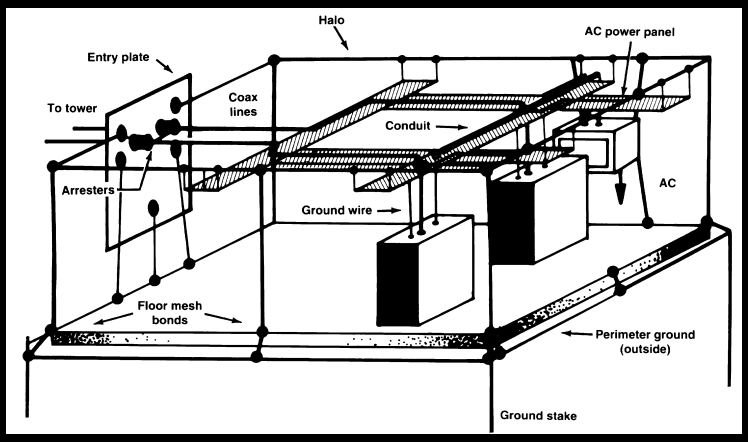
Bulkhead System with Internal Halo



Bulkhead-based ground system including a grounding halo.

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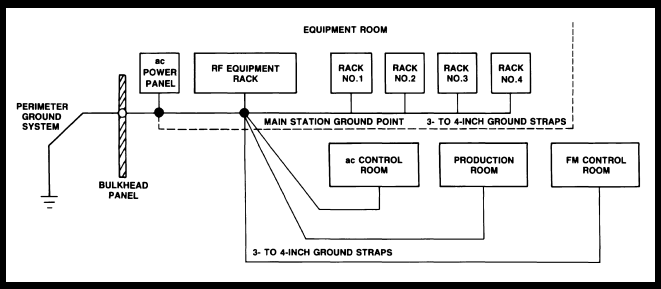
Single Point Grounding for Racks



Typical grounding arrangement for individual equipment rooms at a communications facility. The ground strap from the main ground point establishes a local ground point in each room, to which all electronic equipment is bonded.

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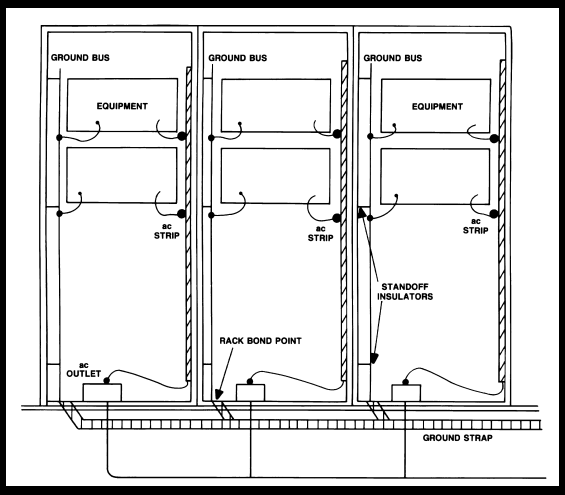
Equipment Rack Grounding



Recommended grounding method for equipment racks. To make assembly of multiple racks easier, position the ground connections and ac receptacles at the same location in all racks.

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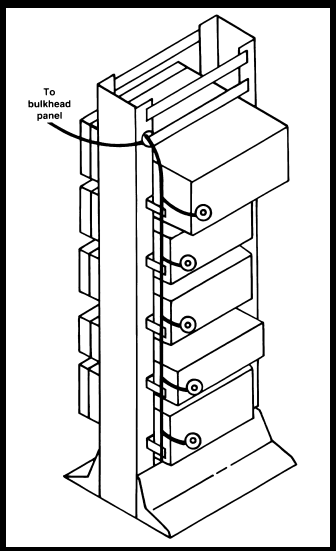
Equipment Rack Grounding



Open frame equipment rack

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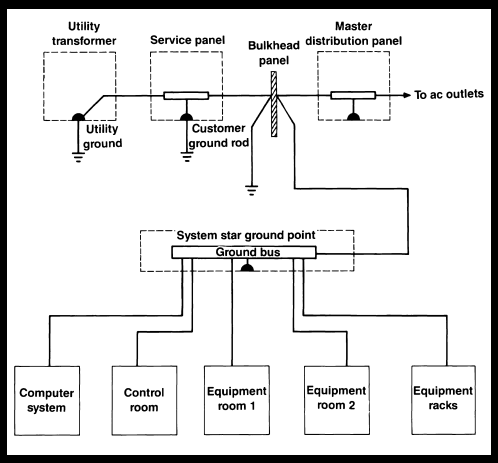
Overall Ground Circuit Schematic



Equivalent ground circuit diagram for a medium-sized commercial/industrial facility.

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Checklist for Proper Grounding

- Install bulkhead to mechanical support, electric grounding, and lightning protection for ac, telco, coax entries.
- Install an internal ground bus using #2 AWG or larger solid-copper wire. Form a star grounding system (star-of-stars at larger sites) and avoid ground loops. Connect following items to the internal ground system:
  - Chassis racks and cabinets of all hardware
  - All auxiliary equipment
  - Battery charger
  - Switchboard
  - Conduit
  - Metal raceway and cable tray
- Install a tower earth ground array by driving rods and laying radials as required to achieve low earth ground impedance.
- Connect outside metal structures to the earth ground array (towers, fences, ice-bridges, etc.)
- Connect power-line ground to array. Follow local codes to the letter.
- Connect bulkhead to the ground array through a low-resistance/inductance bond.
- Use bonds which ensure long-term integrity (CAD-welds, cleaned and prepared surfaces, etc.)

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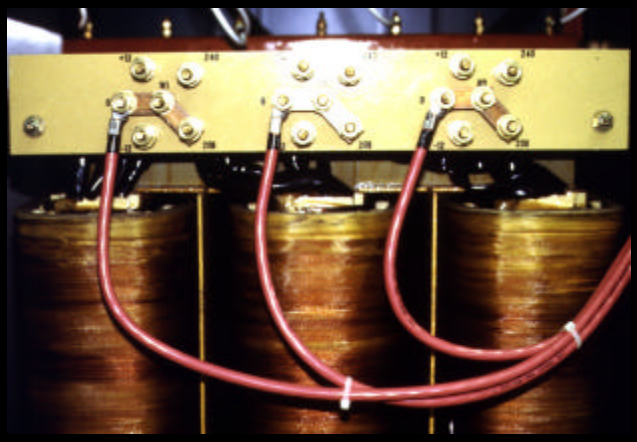
Post Script: Total Failure



A transient disturbance was the apparent cause of a failure of this transformer in the Collins/Rockwell 831-G1. The resulting fire destroyed the transmitter. KPDJ was off the air for two weeks.

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The End

From:
Gary Larson,
The Farside

OK. It's a wrap.

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