AUGUST 2019 TLARC
SURGE SUPPRESSION, ISOLATION, GROUNDING & BONDING (WHEW!)

THANKS TO MANY OTHERS FOR BACKGROUND INFO: DAVID (N1ESK+KF4DKW), GEORGE (N2APB), NEIL (AE1P), AND POLYPHASER CORPORATION

I.E. "PRESENTING THIS TO YOU BY RANDY (WK9M) WITH SEVERAL OTHERS INPUT!"

THIS IS MY 3RD PRESENTATION FOR TLARC

☺

WHAT CONCEPTS ARE WE COVERING TODAY? (+NEXT 4 SLIDES)

- Lightning is the typical concern for most Ham Radio installs and will be the primary topic.
  - "Lightning takes the form of a pulse which typically has about a 2us (2 millionth of a second) rise and a 10 to 45us decay (also millionth) to a 50% level. Presently, the IEEE standard is an 8 by 20us wave-form. The peak current will average 18kA for the first impulse (stroke) and less (about half) for the second and third impulses. Three strokes is the average per lightning strike."
  - "Once ionization occurs, the air becomes a conductive plasma reaching 60,000°F and is luminous. This luminosity level is brighter than the surface of the sun! The resistance of a struck object is of small consequence, except for the power dissipation of the object (I^2R). Fifty percent of all strikes will have a first strike of at least 18kA, ten percent will exceed a 65kA level and only one percent will have over 140kA. The largest strike ever recorded was almost 400kA." [PolyPhaser 1993, Roger Block, p. 1-2]
  - The voltage is between 10kV-120kV depending on where you look online, but isn't as important as current. Voltage is needed to overcome the air space to the ground but is not what causes heat (and damage) as seen above. It is voltage differences that cause problems as we will cover shortly.

RFI

- Any unwanted signal that causes detriment to your receiver or others is interference.
  - Lightning is a form of RFI. Some think of lightning as "static electricity" but it is not.
    - "The main frequency range is DC to about 1MHz." It can go up to as high as 10MHz (half-power point). [PolyPhaser 1993, multiple pages].
    - Most more expensive surge suppressors also have AC power filtering. May still need torroids.
  - Nearby radio/TV stations (AM, FM, TV, etc.)
  - Electronic devices with a switching power supply that lack sufficient filtering
  - Devices that typically generate RF for operation (computers, monitors, etc.)
  - Devices that generate spark gaps (welders, switching relays on motors, Jacobs ladder, etc.)
  - Maybe you can think of some more?

SURGE SUPPRESSION VS. ISOLATION

- Surge suppression is diverting unwanted power to ground to keep it at a safe level while isolation is separating two systems from each other typically with an "air gap".
  - Surge suppression is what most of us will do and is most of this presentation. This ranges from a $10 power strip (probably made in China) to coaxial protection and even whole house protection. Power handling is "virtually unlimited" although suppressors are only really tested to UL standard 1449 (330V let-thru) with no more than 6kV at various current tests. Above 6,000V the surge would arc thru the insulation and not propagate further inside the structure.
  - Isolation is typically used where grounding is not practical for levels around 5kV to 7.5kV. Optoisolators (small LEDs and photodetectors inside an enclosure) and transformers are used for this. Costs typically start at $50 and go up a lot (more on this later).

GROUNDING

- Grounding is a topic that in itself will take several pages to discuss. But some key notes:
  - For the purposes of RF, your house ground is likely not a good ground.
  - Just because a ground rod is in the ground doesn't mean you are grounded.
    - Grounds must be checked initially and periodically to ensure they actually work.
  - Those with good soil conditions will have it easier/cheaper. If you live on top of a granite mountain or in the desert—good luck!
  - Most of us don't need a complex ground rod system unless you are a big DX station or are doing a commercial installation for a tall building. We can do this type of presentation at a later date, but most of us will not be in this category. Especially those with an HOA or POA.

BONDING

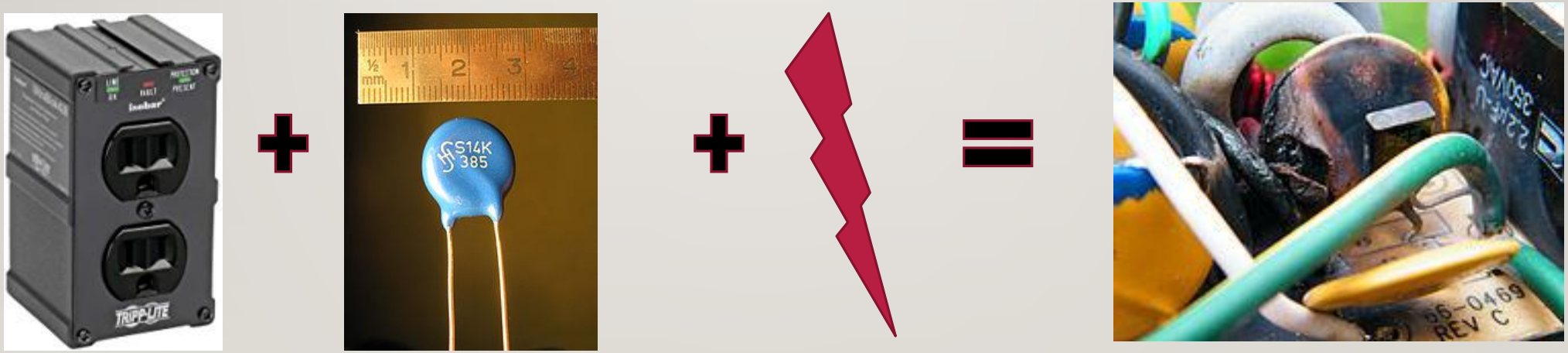
- Bonding is the process of attaching your ground wire to your equipment or system.
  - The 'best' ground is a ground wire, 6AWG (minimum) or larger, that is firmly attached and does not loosen or corrode over time.
  - Commercial systems use an around-the-building 4/0 wire ring, all welded together (aka 'thermite').
  - Copper strap is a good alternative for lightning with 1.5"+. We'll discuss why later on.
  - "Acorns" are fine as well from the local hardware store. Add anti-oxidant and tighten+cover.
  - Please don't use hose clamps unless they are temporary.
  - Hose clamps are for hoses! (Stressed at the Dayton ARRL presentation).

LET'S GET STARTED!

- Throughout this presentation I am pulling resources together from past experience and multiple sources.
  - If you have questions and comments, please raise your hand and I'll keep the response short so we can all learn something new. Or I'll table it until later so we can keep moving. We're not going over the IEEE or Motorola standards for this presentation.
  - I am giving certain tips and features on products but am not selling any particular product or service. You have to look at the equipment you are protecting and decide how much to spend on a solution that will work for you.
    - Don't spend $200 to protect a $50 HT or $10 on a $11k ICOM rig.
  - Be safe! Call digger's hotline if you are unsure where utilities are. Whose fault is it otherwise?

THE ORIGINAL SURGE SUPPRESSOR: MOV

- The original (and cheapest) surge protection is the original Metal Oxide Varistor (MOV). This is a simple design that uses a component connected to the device for when that voltage is exceeded, it causes a the part to short out. And nearly instantaneous heating that can fail over a period time or immediately; it's all a large variable.



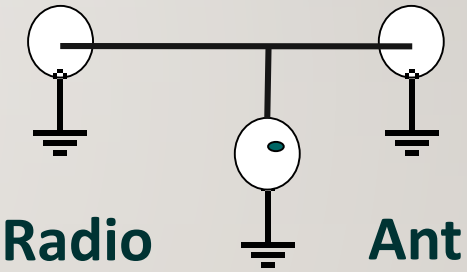
Photos courtesy Amazon and Wikipedia (example photos above).

BUT WAIT!

- My $500 UPS has a $100k CEG "Connected Equipment Guarantee". So it must be a good unit if it's covering me for this high amount no?
  - Insurance such as this is marketing because it might cost them $200 to make the UPS and they spend $1.23/50 on three MOVs. (I checked mouser.com). Most people are not hit with violent surges and even if they pay out $10k every so often they are still way ahead.
  - The CEG covers current market value, i.e. the eBay price. So if your entertainment system was $10k new 10 years ago and goes for $4k now on eBay, they pay $4k.
- MOVs are better than nothing if they extend the life of the connected device, and hopefully have a metal case or heavy plastic case so the fire is contained within.
- Don't spend a lot of $ on a supposed "high end" surge protector that is a MOV.

GDT (GAS DISCHARGE TUBES)

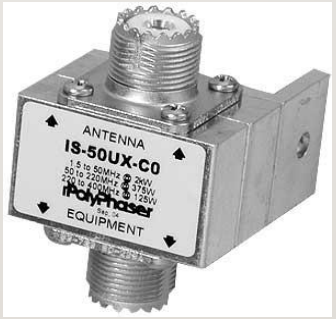
- Next up is the GDT. This is a small gas-filled ceramic plug that is not visible in the circuit (open) until a certain voltage is exceeded; and then the plug becomes a short.
- AC GDT protectors are uncommon
- Coax versions are made by several
- Some can be repaired w/o disassembly
- Simple design; often water resistant

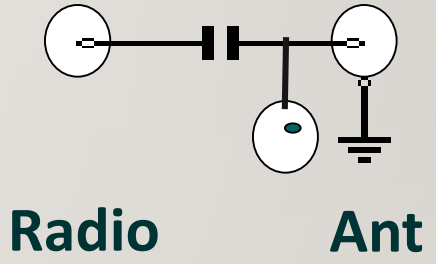


- The Alpha-Delta TTG350 shown above is mil-spec approved and passes DC if needed.

GDT CONT'D (COAX)

- PolyPhaser expanded upon the fact that since lightning is really DC-10MHz (RF), the GDT can take the initial surge voltage and divert that to ground. Anything left over from the arc event would be blocked by a capacitor because the frequency is too low to pass.
- These models are frequency specific
- They block DC due to the capacitor
- The GDT is not user-replaceable…
- (At least not in most models)





- PolyPhaser is used commercially and they are more expensive; still do occasionally fail.

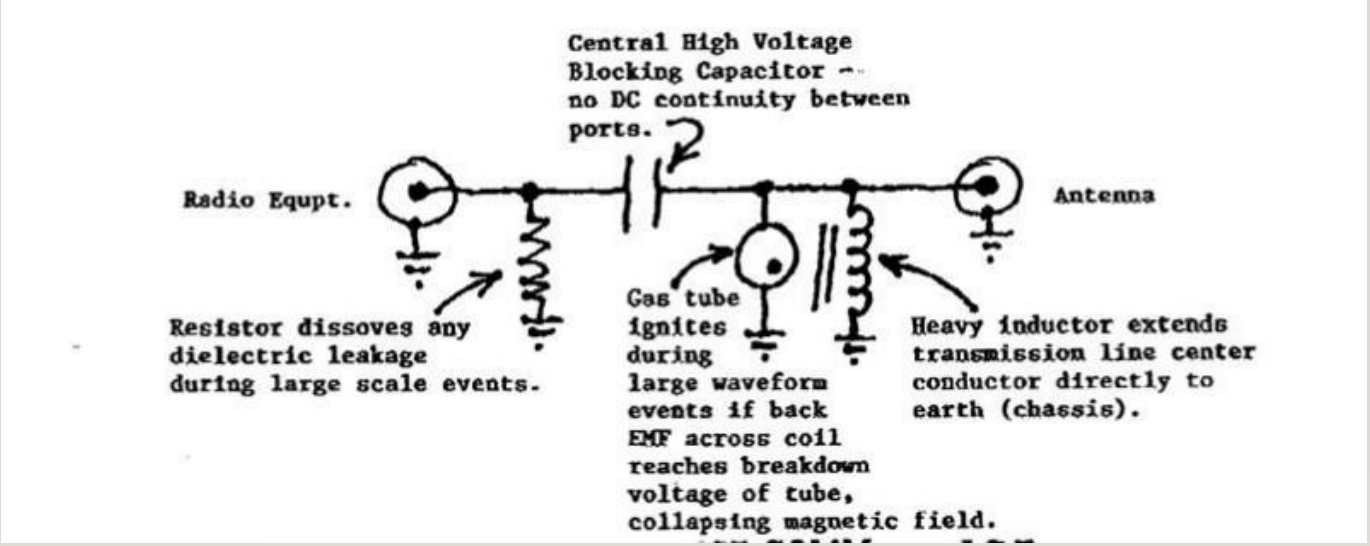
GDT (LATEST DESIGN)

- ICE (Industrial Communications Engineers) has the latest, and perhaps best idea as they use additional components to reduce the surge current before it can propagate farther.
- Array Solutions is now the manufacturer
- This design is not ideal for outdoor use; no seals
- Like PolyPhaser, does not conduct DC
- Constant drain reduces static from storms
- Open one up and it's not a pretty solder job
- See the next page for the schematic…

- Like any suppressor you have to determine what you want and look past the ads. Alpha Delta says the other designs 'have more parts to fail' and others say Alpha Delta is too basic.

ICE DESIGN (COURTESY OF ARRAY SOLUTIONS)

- Here is the schematic of the design that ICE used. It's PolyPhaser+ a few more parts.
- Remember that an inductor is not in the circuit above a given frequency (is open).



SO WHAT ABOUT OTHER AC SURGE SUPPRESSORS?

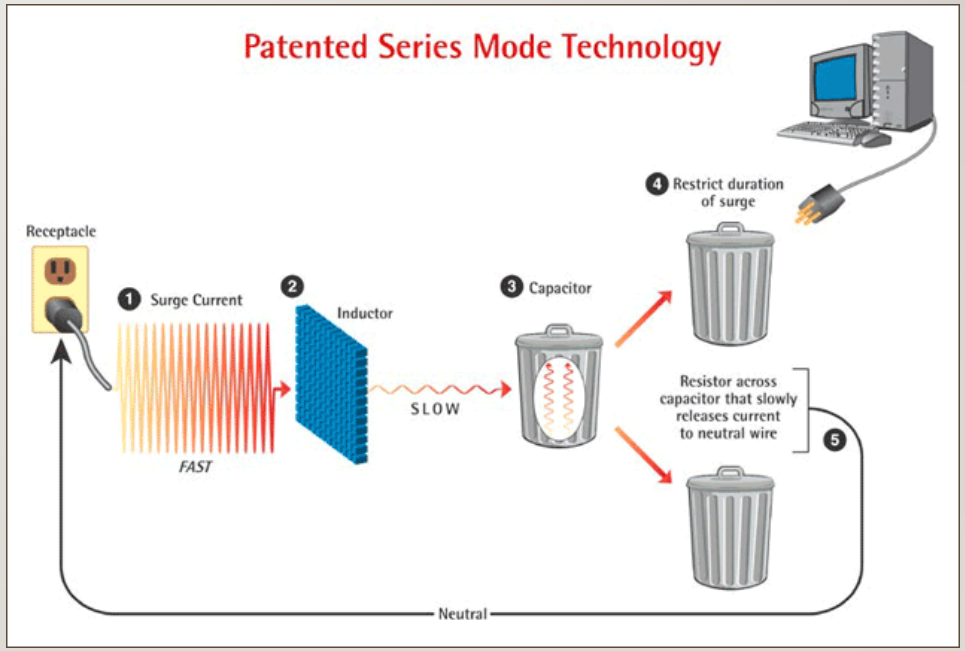
- The other two basic ideas out there are diode based (over a certain voltage the diode becomes a short) and series mode surge protection.
- I won't cover the diode based protectors as they, in the end, do the same thing as the GDT and MOV based designs do—they short a surge to ground over a certain limit.
- The series mode surge protection was initially patented by Zero Surge (www.zerosurge.com) and builds upon the basic idea that since lightning is RF and not static electricity, why not start out with an inductor and block the "high frequency" lightning pulse from going any farther since AC is only 60Hz?
- Zero Surge also exists under some alternate brand names such as "Brick Wall" and "SurgeX" that license their design from 1989. All will do the same; Zero Surge is the cheapest.

ABOUT ZERO SURGE (BEFORE I GO FURTHER)

- If you go to the Zero Surge web site, they have all sorts of online documentation under "EDUCATION" and "RESOURCES".
- A lot of this will go into great detail on why their method of surge suppression is so great and everything else is not. "Why whole building surge protectors don't work" (for sensitive voltage devices). How they can take 1,000 6kV surges at 3kA with no effect.
- And they're right, once you see how they are doing this it is the best idea. Starting at $195 and going up you have to decide if what you are protecting is worth that expense. Even with the 10yr warranty and 50% off rebuild this is an investment. But, time=$.
- I am going over the design and key points on the next page.

THE ZERO SURGE DESIGN

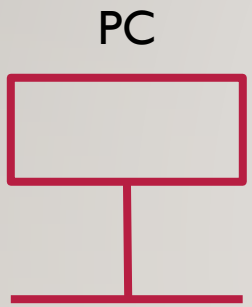
- Zero Surge doesn't show the exact schematic online or what the inside of their suppressor looks like—I'd imagine it is because their patent is over 25yr old. Patent is expired (photo from their web site).
- Overly simplified design shows inductor first
- Remaining voltage charges three caps
- Voltage on caps are released to neutral
- Ground wire is not used so no ground surge
- A Brickwall schematic shows 2V actual limit
- So your max surge with 6kV in is +2V.
- Can be used to protect a high $ UPS too.
- Just don't tell the UPS company. ☺

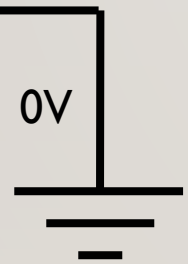


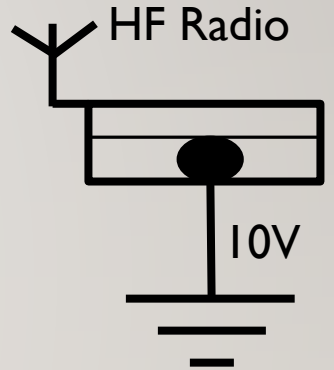
PANEL SURGE PROTECTION

- Panel or "Whole house" surge protection is an option; typically these units are MOV based. They do help protect against serious voltage surges and will prevent a high voltage surge from getting farther down you house wiring.
- As such they have a lifespan like all units of this type
- You must periodically check the indicator(s)
- Consult an electrician if you're not up to the task
- This is a good time to check the house ground!

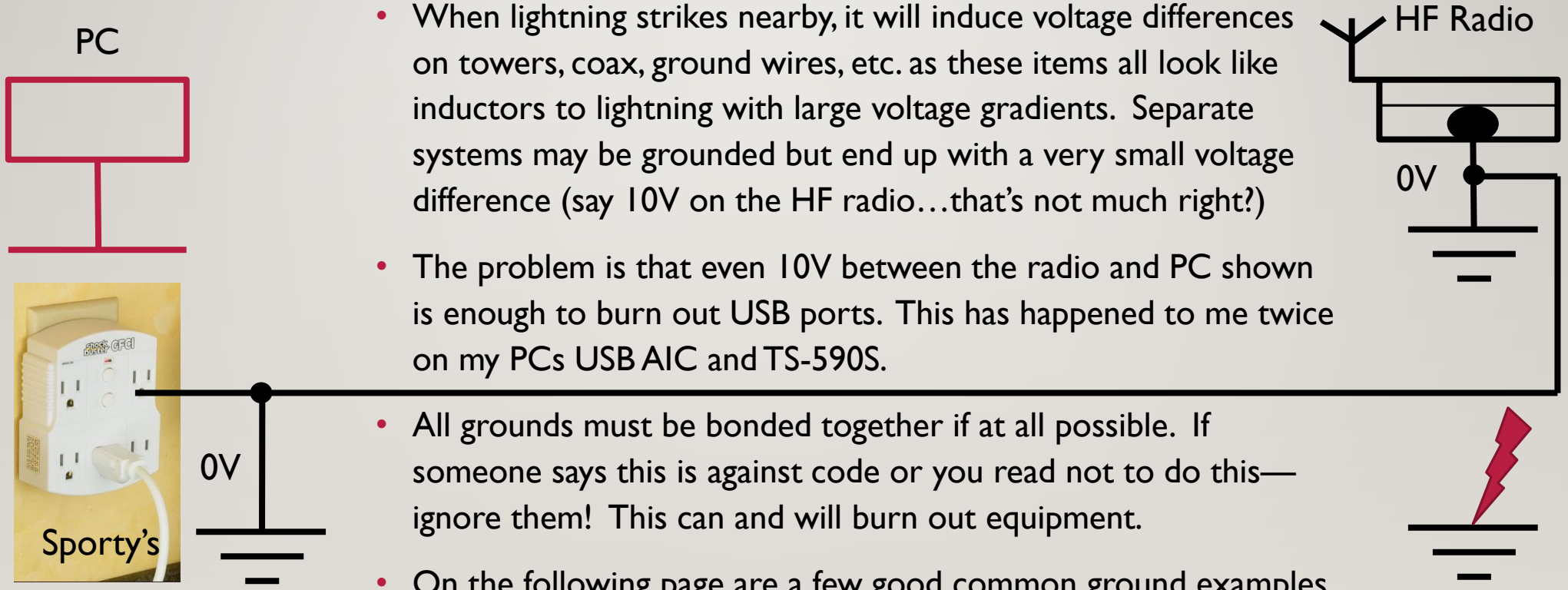
GROUNDING & BONDING
WHAT'S WRONG WITH THIS PICTURE?





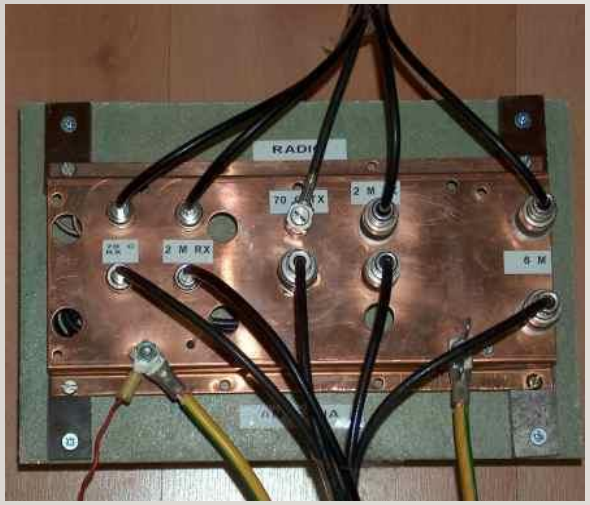


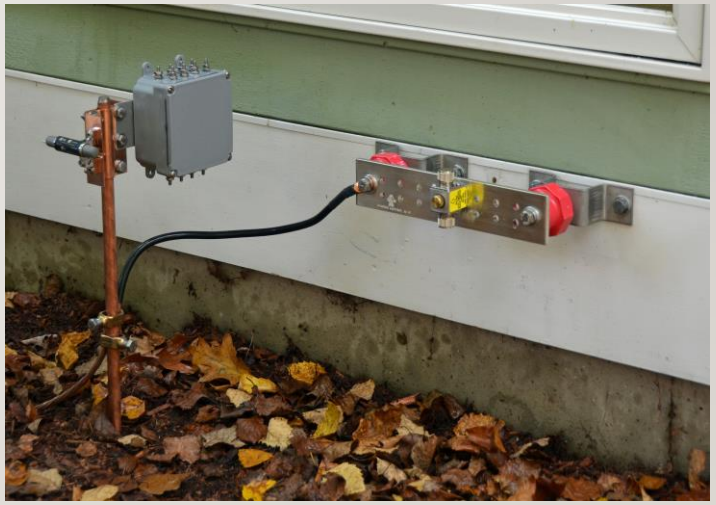
GROUNDING & BONDING
THE GROUNDS SHOWN ARE NOT CONNECTED!



- When lightning strikes nearby, it will induce voltage differences on towers, coax, ground wires, etc. as these items all look like inductors to lightning with large voltage gradients. Separate systems may be grounded but end up with a very small voltage difference (say 10V on the HF radio…that's not much right?)
- The problem is that even 10V between the radio and PC shown is enough to burn out USB ports. This has happened to me twice on my PCs USB AIC and TS-590S.
- All grounds must be bonded together if at all possible. If someone says this is against code or you read not to do this—ignore them! This can and will burn out equipment.
- On the following page are a few good common ground examples.

EXAMPLES OF GOOD COMMON GROUNDS





WHAT IF I CAN'T BOND MY GROUNDS?

- You may be in the situation that the grounds are just too far away; such as on opposite sides of the house. Or it is a building you do not own. Or in a very large building.
- In this case, you'll have to look at using isolators for each connection made between your PC and radio. There can be no direct electrical connection between devices.
  - Think of each USB connection that you have. Do you have a rig control? Serial CW keyer? Ethernet connection? What speed are the USB devices running at…USB 1.1, 2.0, or 3+? There are several programs on the internet such as HWinfo64 (or 32) that will help.
  - For multiple Ethernet connections, you can buy a 12V industrial Ethernet switch and an Ethernet isolator. Then plug the 12V Ethernet switch into the isolator then the other switch.
  - Some devices like the Winkeyer (USB) have an optoisolator for the CW keying. No problems.
- If you are getting the idea this is more complex and expensive; it is. This is what I had to do.

ETHERNET ISOLATOR

- I am only aware of one gigabit Ethernet isolator; it is made by L-Com p/n LC-60601-1.
- This photo is from the l-com web site; currently at $235.
- Typically these are used for medical equipment. So $++.
- I read online that the Ethernet standard isolation is 1kV.
- So you do get some isolation on switch connections.
- 1kV is not enough. I have not opened mine up. ☺
- Maybe after the warranty expires I'll investigate.

USB ISOLATOR

- I initially tried USB 2.0/3.0 isolators on my PC by Coolgear/USBgear. For whatever reason; they had various issues. The IC-7610 is one of those I recall with a USB 3.0 port for DSP use but most radios are still USB1.1 or older.
- This is an example USB1.1 isolator to the right
- 7.5kV isolation; RF immunity too
- Even made in the USA!
- I use two of them; p/n USB402.
- Available on Amazon for $50.
- Last close lightning strike dis/reconnected my mouse.
- So I switched to a wireless mouse and call it airgap fixed. ☺

SO, BACK TO GROUNDING

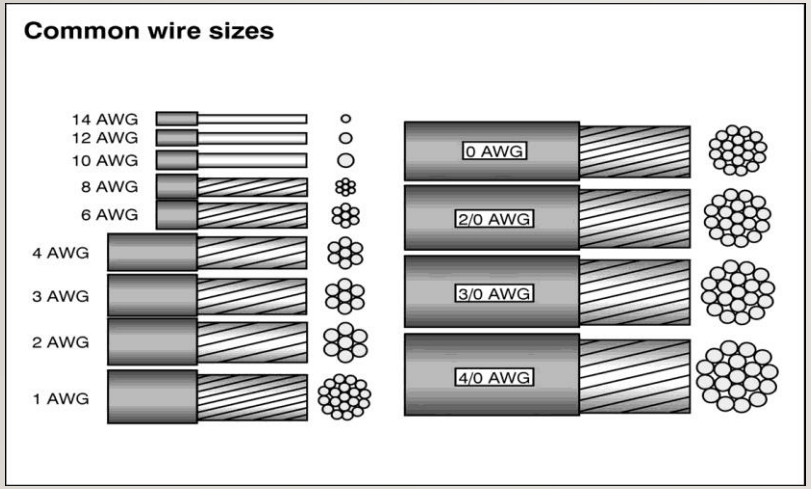
- Most of you will just need to test and possibly improve your ground.
- 6AWG is an old standard and the minimum wire size for lightning protection. Generally it's available at most (if not all) local hardware stores.
- Remember that lightning is RF and therefore subject to the skin effect rule. Most lightning will travel on the outside of a conductor (1-10MHz.) As a result, your "large wire" is not as large anymore when you only use the outer layer. This is why the runs should be kept as short as possible; a long run can act as an antenna in fact.
- An option instead of using wire is to use copper strap. Georgia Copper (www.georgiacopper.com) is a great source for this; you can get free shipping if you find the size you need from other stores such as HRO. Examples are found on the next page; I use the 2" strap myself. (Straps will use more expensive clamps; keep that in mind.)

OTHER TYPES OF GROUND WIRE

- Stranded/braided wire is recommended for wires that need to flex. For example in your vehicle, on a metal door that swings, or on a radio that you move around in the shack.
  - Individual strands will rub against each other and create multiple paths for lightning or RF to travel. This will change with any movement. Higher frequencies can cause PIM.
  - Stranded/braided wire can also create contact problems between the lug and wire. Heavy gauge wire is impractical to solder, will leave gaps, and will not work for lightning (melts).
- Copper strap is ideal because it has a very large surface area. For example, typical 1.5" strap that is .022" thick has a surface area of (1.5+.022)x2=3.044". In order to come close with round wire you'd need at least 2ea 4/0 cables (2.89"). A downside: difficult around corners.
- I have been told that skyscrapers use copper plates stacked & bolted together. Up the center column. (Source: commercial installer I spoke with on a business trip once.)

PHOTOS OF GROUND WIRE

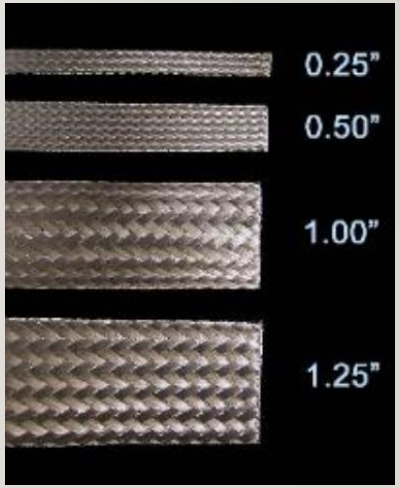
Solid/stranded



www.adventuresindiy.com

Strap

Braided



www.georgiacopper.com (both)

YOUR GROUND IS ONLY AS GOOD AS THE BOND

- There are several good ways to attach the wire to the ground rod.
  - If your installation is permanent, exothermic welding (aka thermite) is the best because the connection cannot loosen itself nor corrode. Kits are available online i.e. from http://www.kf7p.com/KF7P/HargerUniShot.html (thanks KF4DKW) and even places like HRO or DXEngineering.com if you are ordering something else anyway.
  - 2nd best is to use a clamp made for grounds and an anti-oxidant of some type. This is typically called "No-OX" but goes under different brands; it is zinc powder in a grease.
  - Avoid the use of dissimilar metals. Keep copper on copper whenever possible, No-OX is a must if you have to clamp copper grounds to an aluminum tower or mast for example. Dissimilar metals will create a battery with a little bit of acid rain and in a short period of time your ground will have resistance. Any resistance for lightning is bad and will cause arcing.

TYPICAL CLAMPS AND A THERMITE VIDEO AT GEORGE'S PLACE (WITH DAVID ETAL)

Pause here to show the video titled "Ignition (video).mp4" as recorded by George.

Follow with "Ceramic wack-off.mp4" for the end result. I didn't make up that title. ☺

GET THAT GROUND ROD IN

- Getting the ground rod in has never been fun or easy in most cases for the typical 8-10' rods. (Most commercial installs recommend 20'+.) You always run into some unknown it seems.
- There are three common methods that I've seen so far for us hobbyists.
  1. The sledgehammer is the oldest method. It takes a lot of work and you have to have pretty good aim and possibly a ladder to start out. A friend or two helps quite a bit.
  2. Drilling with an impact drill then using a ground rod bit (in impact only mode) can get you halfway started quickly and then the impact driver does the rest with moderate pressure. Commercial installers use jackhammers with a ground rod bit. (More on this one page ahead).
  3. Last method is to solder a garden hose fitting to a copper pipe. Turn on the water and water drill down like an oil well. Supposedly the easiest, but the ground rod starts out loose until the ground presses around the rod (this can take several months to set in fully.) Lookup "ground rod water trick" on Youtube if you'd like to do this method and are not in a big hurry.
- If all else fails, you can always cut the rod off short and go for quantity.

THE IMPACT DRILL/DRIVER METHOD

- What we did out at George's place was to use the impact drill and bit method.
- First start out pre-drilling 3-4' down.
- Then attach the impact bit on the tool and rod.
- The process still takes several minutes.
- The video we took doesn't show much in 10s.
- I'll take a new one and will speed it up later.

TESTING

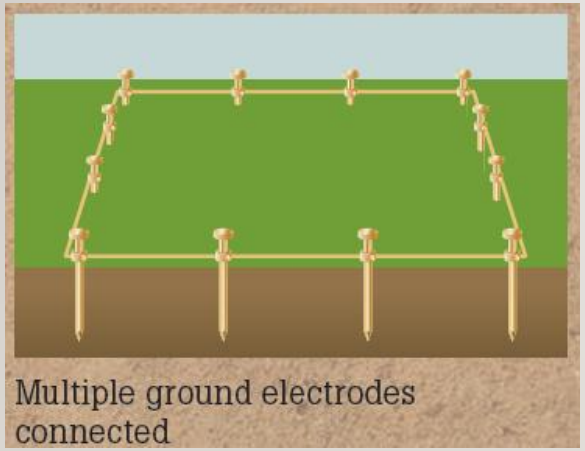
- In order to know that any ground system works, like many things you have to test them.
- The first ground rod I put in at home had a resistance of 820 ohms using a clamp-on tester. I assumed that a ground rod in the ground must be grounded OK; and the end result was that my PC and radio USB ports had been taken out during nearby strikes.
- The NEC for 120V/240V service is 25 ohms with one rod or a second rod must be added. Commercial tower installations specify 5 ohms or less (i.e. Motorola). Many electricians will just pound in one or two rods and call it are good. At my place I test out at around 30 ohms…just a little over.
- If you don't meet spec, it's either more rods or a system that "salts" the ground and makes it more conductive. George's RF ground started out at 61 ohms but…

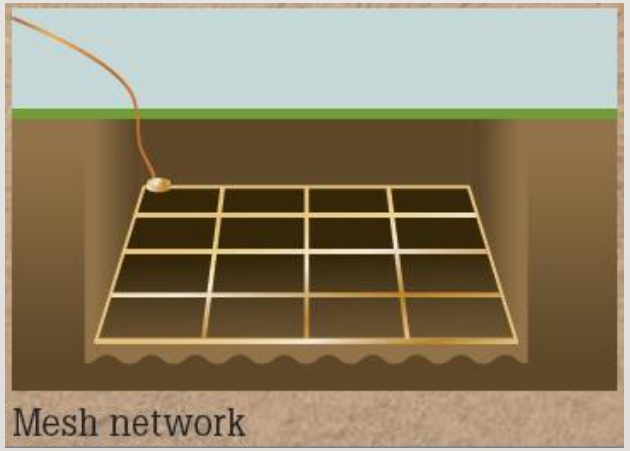
GEORGE'S GROUNDING PROJECT

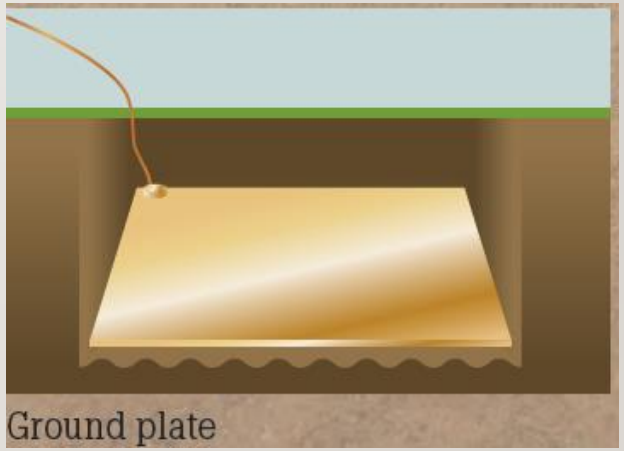
- George lucked out and the two AC electrical ground rods gave him a reading of 13 ohms!
- Since we added a second RF ground in-between the two all four of these were bonded.
- At one point we had a reading of 0.4 ohms. ???
- Once you bond grounds together a loop can form.
- End result is two resistors in parallel: <10.9 ohms.
- 100kV/10.9 ohms = 9,174A. Decent current sink!

LARGER GROUNDING IDEAS IF YOU HAVE A LOT OF SPACE AVAILABLE

- If you have a larger system, there are additional ways to ground and get to 5 ohms.


Multiple ground electrodes connected


Mesh network


Ground plate

AND WHAT ABOUT MAGNETISM?

- Any current through a conductor will also create magnetism. You can put a small current through a wire and deflect a compass needle, or put a large current through a coil and create an electromagnet.
- The large currents created from a lightning strike will create a large magnetic field. It is impractical for most of us to create a Faraday cage for our shack that shields this event using aluminum, copper, or steel (the PolyPhaser book says to use steel for lower frequency magnetism). If you get a very close strike you can still get a magnetic pulse that can move ground wires if they are not secured. Be sure everything is tied down well with cable clamps or zip ties.

EMP

- An ElectroMagnetic Pulse (EMP for short) is typically caused by Nuclear weapons detonated at high altitude and is beyond more than a quick discussion here. Properly grounded and shielded systems can help protect you in this situation. Although there are other things I would be more concerned about at first, EMP is a little like lightning.
- "About 99% of the NEMP is radiated in a broad spectrum between 10kHz and 100MHz. Most of the energy is below 10MHz." (And that's what lightning suppressors already help protect). [PolyPhaser 1993, Richard Block, p. 54].
- The PolyPhaser book goes into greater detail about protecting various devices. We are almost at the end of this presentation and I'll leave this topic for another expert in the future (if they are able to discuss general theory)…

THANKS!!!

- Thanks everyone for attending my 3rd presentation that is a "bit" longer and more technical than my first two.
- Ham Radio by default is a bit of reading along with experimenting to see what works in a given timeframe and budget.
- The PolyPhaser book I referenced is the last printing and when it looked it up was $60 used on Amazon. If you're looking for a good reference, I would go to the ARRL grounding handbook. I may pick one of these up myself to see how the ideas and methods compare to what I've done so far.
- If there are any tips or stories, please stick around for a bit and we can go over additional topics and/or questions. '73, Randy