PolyPhaser CORPORATION

TD1016: An overview of Lightning Protection for Ham Radio Stations.

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Notes:

Proper lightning protection for a ham radio station can involve more variables than any other type of radio site. The antenna location will establish the grounding requirements, while the station location will drive the protection requirements.

The primary rule for surviving a lightning strike is still the same no matter which of the many possible variations you have: all equipment elements must be connected to a single, low impedance ground system. This includes the antenna, the antenna support (pole, tower, etc.), and all of your station's input and output protectors. (I/O's: antenna, power, telephone, rotor, etc.).

Let's examine the significant elements of a good grounding and protection scheme to help you construct an installation that will survive a direct lightning strike.

We begin with choosing the antenna location. This and the antenna type will dictate the size and location of the earth system needed to disperse the strike's energy. The sooner the ground system is able to spread out the energy, the better the chances of preventing it from traveling to your equipment. Almost 90% of strikes will be electrons that, due to like charge, repel and spread out. The antenna ground system provides the interface to the earth body. As we will see later on, the ground system is formed by a set of ground rods interconnected below grade with bare radials.

Also fundamental to a good protection scheme is the creation of a single point ground within the ham shack. This single point ground is used to mount all of the protectors and to provide a ground for all of the equipment chassis. This interior single point ground is connected to an external ground system (composed of radials with ground rods) with a low impedance copper strap. The tower ground system and the single point ground system must be interconnected. This interconnection should be below grade and with a bare low inductance conductor. The coax cable shield must not be the only interconnection between ground systems.

Three Techniques:

Every conductor has measurable inductance. Similarly, ground conductors exhibit normal inductance before they go below grade.

Once in the ground, the inductance of a bare conductor is shunted by the earth's conductivity.

If the soil at the grounding location is not very conductive, three things can be done to help the situation.

- Increase the surface area of the conductor, decreasing its normal inductance.
- “Dope” the soil to increase its conductivity shunting the inductance of the in-ground bare conductors.
- Install additional bare radial lines with ground rods which will effectively parallel the inductance and reduce the overall system inductance.

In some locations it may be necessary to utilize all three of these techniques for the best results. Let's examine each one.

1) Conductor Surface Area:
The most effective material for a ground system conductor is copper strap. Copper as a metal is a good electrical conductor, only moderately attacked by ground and air borne acids, and should have a life span measured in years.

Since lightning has a large portion of its energy in the LF range, it will behave like an RF signal. (See “Lightning Overview” and “Coaxial RF Protectors” for a more detailed discussion) That means the energy will only mostly conducted on the skin of the conductor (skin effect). Thus, the surge current will only ride on the outermost surface of the conductor. Such currents following a round-member conductor will not make extensive use of its large cross sectional area. With a 1-1/2 inch [38.1 mm] or larger flat strap of at least 26 gauge (0.0159 inches) [0.4 mm], both surfaces will conduct the surge.

2) Soil Doping:
Water in its purest form is an insulator. Ionic salts when mixed with water make ions. The earth is a conductor because of the number of ionic salts present in the soil. Therefore, conductivity can be improved by adding more ions to the soil.

Soil doping can be done by either adding water or a saline solution to the soil around the grounding system. If the soil already has a sufficient amount of naturally occurring salts, adding water will free the ions and improve conductivity. The more ions (salts) available, the less water that will be needed to reach a given level of conductivity.

If few natural ions are available, salts, such as Epsom salts, can be added to the soil to increase the conductivity. Depending on the amount of rainfall, doping the ground system radials with 4 pounds of salt per linear foot and 20 pounds per rod may last approximately two years.

3) Ground Radials:
Radials are the most cost effective grounding technique considering system impedance, material cost, and installation labor. If one radial gives "X" resistance, then two will deliver an equivalent "parallel rule" plus 10%. This rule only holds true when the soil has the same conductivity over the entire radial area. After the first two radials, you will need to double the number of radials each time to continue with the parallel-plus rule.

Radials do have a limit on their effective length. If the surge energy has not been launched into the soil within the first 75 feet [22.86 meters), the inductance of the radial will prevent any further effective prorogation. Therefore, as a general rule, all radials should be at least 50 feet 15.24 meters] long and no longer than 75 feet.

Ground rods should be placed along the entire length of each radial. The most cost effective spacing between rods for normal (grassy) soil is two times the length of a rod into the ground. If 8 foot [2.44 meters] rods are used, they should be placed on 16 foot [4.88 meters] centers.

If the soil is not normal (e.g., very dry or sandy), the separation may be reduced in order to minimize the interconnect inductance. It doesn't hurt to have the rods too close, it only costs more in material and labor.

Ground Measurement:
Since most soils are stratified, the best way to determine the effectiveness of a ground system is to measure it. The simplest way to determine the sub-layer conductivity is to measure the first ground rod, one foot at a time, as it is hammered into place. This technique can provide a profile of the lower layers relative to the first foot. Most earth resistance meters measure only dc or low frequency ac

resistance of the ground system. Although the lightning strike is dc, due to the fast rise time to peak current, there is significant RF energy. Since there is a high frequency component, the inductance (effecting transient response) of the ground system is important. Without using very expensive specialized test methods, the only way to ensure a low impedance ground system is to follow the suggestions given for conductors, doping and radials.

Tower Considerations:
No one should consider using a non-conductive structure for an antenna support. Only conductive towers or metal poles should be used for mounting antennas. If the tower or pole has sliding contacts (crank-up or push-up), the joints should be bonded using short sections of copper strap attached with PolyPhaser TK clamps. Normal self - supported and guyed towers will not need such jumpers.

Guyed towers are better from a lightning protection perspective if the guy anchors are grounded properly. Because the anchors are located away from the tower base, at least some of the strike energy will traverse the inductive guy wire to the ground. The more the strike energy is divided, the less there is to go to your equipment.

Dissimilar Metals:
Copper should never touch galvanized material directly without proper joint protection. Water shedding from the copper contains ions that will wash away the galvanized (zinc) tower covering. Stainless steel can be used as a buffer material. However, be aware that stainless steel is not a very good conductor. If it is used as a buffer between copper and galvanized metals, the surface area of the contact should be large and the stainless steel should be thin. Joint compound should also be used to cover the connection so water cannot bridge between the dissimilar metals.

Magnetic Energy:
Lightning has a large magnetic field associated with its typical high current pulse. The magnetic field will couple to all nearby conductive materials. There are two ways to minimize the amount of magnetic energy coupling, shield your equipment or place some distance between the equipment and the likely strike location.

A galvanized steel sheet may be used as a shield to attenuate the magnetic field pulse by 10dB.The steel should be at least 30 gauge

(0.016 inch) [0.41 mm] and should be connected to the ground system.

Distance is the other means to limit magnetic field coupling. The strength of a magnetic field diminishes at the rate of one over the distance squared. Since a moderately high tower is much more likely to be struck than any other nearby structure, the placement of the tower with respect to your equipment deserves significant consideration. Factors that should be considered are not only the magnetic energy which will radiate from the tower, but also the benefit of the distance in terms of the inductive loss provided by the length of the orthogonally run coax. This added inductance of the coax line will buffer the energy entering your equipment area. In addition, the extra distance will provide a little more time for the tower ground system to dissipate the strike energy and thus have less to share with your equipment.

Both of these factors indicate there should be a reasonable >20 feet [>6 meters] separation between the tower and the operating equipment.. For towers already located closer than this, it may be necessary to utilize some shielding to minimize the magnetically induced energy.

Antenna Location:
A ground mounted vertical antenna is very similar to a ground mounted tower. Both have a low impedance connection to the ground system. However, if the antenna or tower is mounted on a roof, the inductance inherent in the conductors to the ground system will be very significant. So significant, that voltages in the order of several hundred thousands volts could be present during a strike. To reduce the inductance in the ground conductors, increase the surface area / circumference of the conductor (wider copper strap) as well as the number of conductors.

For roof mounted antennas and towers, multiple down conductors can be spread over the roof and brought down to ground in multiple locations. This will require a ground system run completely around the building (a perimeter ground). As an added benefit, this multiple down conductor approach will reduce the mutual coupling between down conductors and provide a low, unsaturated perimeter ground to absorb the conducted surge. The magnetic fields will also be divided and could, in theory, cancel in the middle of the building. This will help minimize magnetic energy coupling into the wiring inside the building.

Coax Grounding:

Since the tower is a conductor and is well grounded, all of the coax lines should be grounded (using a grounding kit) at the top of the tower close to the antenna and at the base of the tower before they come toward your equipment.

During the strike event, the tower and the coax lines will mutually share the strike energy. If the coax lines are not grounded as they leave the tower or they are completely isolated from the tower, more energy could traverse the coax toward your equipment than is conducted to the ground system by the tower. Such a large inductive voltage drop may cause arching between the coax lines and the tower that could cause deterioration (pin holes in the coax for moisture to enter) or destruction of the coax lines.

Notice the word "bottom" in this section. Since all towers have some inductance, leaving the tower at a point above ground will allow some of the strike current to continue on the coax line (both the center conductor and shield) toward your equipment. Once at the equipment, the current will follow the chassis to the safety ground. This could elevate the equipment cabinets to deadly voltages, deadly for both people and components.

Even though the inductive properties of the coax cable appear to be beneficial, and extra inductance can be created by adding a few turns to the coax; don't do it. The added turns can also act like an air wound transformer coupling more energy into the line. Make sure coax lines leaving the tower remain at right angles to the magnetic field surrounding the tower.

Control and Coax Line Protection:
Rotor control lines should be protected using a protector at both the top of the tower where the lines go to the control motor and inside the shack at the single point ground panel.

If it is not practical to protect the lines at the single point ground panel, they may be protected at the bottom of the tower. The protected lines should then be placed within EMT (metal) conduit that is grounded only at the tower-base end. The EMT will act as a faraday shield from the tower's magnetic fields and will minimize the amount of induced energy.

Single Point Ground:
The next step in a good protection scheme is to provide a single point ground, a plate where all of your equipment I/O protectors can be located. The panel is best located near the ground to keep the

inductance of the ground conductor low. However, if this requires the plate to be far from your equipment and if the magnetic fields of a nearby tower can easily couple into the interconnecting wires and cables, then the panel should be located close to your equipment.

An alternative to the single point ground plate is to use a rack panel. This is recommended only if all of the I/O protectors are mounted on the panel and the ground connection is directly to the panel and not to any other piece of equipment.

The grounding of the plate or panel is very important. A low impedance path to ground is a necessity and only copper strap should be considered. Since the strap is flat, its susceptibility to magnetic fields is only towards its edges. To prevent coupling, the strap should be oriented with the flat side parallel to the tower (the most likely strike point and magnetic field source). The single point ground plate should also be oriented with its flat side parallel to the tower for the same reason.

In the equipment room, each piece of equipment must be bonded to the single point ground panel with a low inductance strap. This will maintain all chassis at the same potential during the strike event and minimize chassis-to-chassis current flow. The power, telephone and coax line protectors on each of the I/O's must be mounted on the single point plate. This will minimize I/O to-I/O current flow.

Additional protectors may be used to protect the opposite side entrance locations for the power and telephone lines. They will provide added protection for jointly used equipment such as answering machines, appliances and etc. Ideally they should also be grounded and connected by a buried bare conductor to the ground system.

Remember that surge energy can enter your shack in either of two ways: from a strike down the road coming in on the power/telephone lines or from a strike to your tower. In either case, high quality protectors will dump the energy into the ground system. Because of varying propagation times, if the protectors are electrically spread out from each other, they cannot work in unison to keep the voltage levels between the equipment I/O's within a tolerable range for equipment survival.

No Sharp Bends:
Route all ground straps and grounding conductors so they have a gentle bending radius. Bends sharper than 8-inch [203.2 mm] radius

will add unwanted inductance to the desired ground path. Even for conductors buried in the ground, try to prevent sharp bends.

Protectors:
Coax protectors should be units that have dc blocking on the center pin. This serves as a high pass filtering that prevents the lightning's low frequency energy from continuing to your equipment. The strike energy is picked off and diverted into the ground system in a controlled way. The dc blocking ensures the operation of the protector regardless of the input circuitry of the equipment.

Did you know that spark gap protectors with dc continuity will not work on receivers and shunt fed duplexers? The shunt to ground inside a receiver (coil to ground for static draining) prevents the low frequency lightning energy from turning on the dc continuity protector. The coil shunts the energy to ground all right, but it is at the wrong place. If the coil can't handle the energy (half the coax surge energy is on the center pin), the coil will open up and the current will translate to a large open voltage source capable of arcing anywhere within the radio.

Lightning protection can be summed up simply: You have control of the lightning strike energy and not Mother Nature. Once control is lost, all can be lost.

The basement is the best location for the ham shack. It is closest to ground and will have the lowest inductance connection to the grounding system. Because it is below grade, some magnetic shielding may occur. Most basements have concrete floors. Since concrete is a conductor, your equipment must not sit directly on the concrete. Doing so will allow surge energy to enter the shack and find a ground path through your equipment to the floor. Insulate your equipment with material that does not absorb water. Wood is not a good choice. Polypropylene is better than nylon to use as a full footprint sheet insulator. Obviously, you should not be on the concrete floor touching the equipment when a storm is near!

The first floor is the next best location. The magnetic shielding is less than the basement and the inductance to ground is higher than the basement. If your tower is close to the building, the recommended grounding strap, running down the outside wall, may inductively couple some energy from the tower. This is also true for other lines such as coax, tower lights and rotor lines. The longer this parallel run, the more energy will be coupled. Our recommendation is to protect these lines at the tower base then run them in EMT (electrical metal tubing) steel conduit. The conduit should be grounded to the tower base ground point. This will act as a faraday shield for the cables inside. Do not run unprotected lines in the EMT. The protectors must be grounded to each other as well as to the tower ground. The best way to do this is to place the protectors inside a weatherized NEMA type box. Make sure the box is grounded, as well as the inside mounting plate. To do this correctly, remove the paint from the box's outside and inside surfaces at the ground point and use proper joint compounds to weatherize the connections. Stainless hardware may be used. Crimp lugs must be crimped, soldered and weather covered. Solder (60/40) will not hold up to sunlight and ozone without protection. Use a short section of strap to bond between the inside surface of the box and the inside protector mounting plate.

High Rise Buildings:
Our definition of a high rise building is different than the upper stories of a house. The antennas on a high rise are not on a ground mounted tower, but are usually attached to the building structure. Therefore, a single point grounding plan is a must for a high rise equipment room. Grounding both the antenna and the single point ground connection in the equipment room is easy for buildings with structural steel frames - just bond to the building steel. Buildings other than steel construction are not as simple. Some high rise buildings have a fire riser with a straight run to the basement where a super charger pump is usually connected. The riser may be used as a ground path if the pump's power is protected and a strap jumper installed to take the strike energy past the pump's gasket on both its input and output ports. If the riser is over 50 feet away, it may not be the best ground path to use. Check for other paths such as existing building lightning rods with down conductors or large electrical conduits. Do not use drain pipes or vent stacks. If none are available, regardless of the path distance, and it is impossible to run a strap down the side of the building, then the antenna just can't be grounded! When an ungrounded antenna is hit by lightning, the energy will traverse the coax line to your single point equipment ground location. This may be many meters from earth and the inductance/ resistance voltage drop will be very large (hundreds of thousands of volts).

The ideal plan is a single point ground with no sneak paths. Sneak paths are loops that allow lightning current to flow into the equipment room. The easiest sneak paths to miss are the safety ground and the concrete floor (discussed above). The safety ground can be fixed by adding a distribution panel and protector at the single point ground location or, for small sites, a plug-in protector grounded on the single point ground panel. All I/O's (input/output) must be protected at this single point. The next thing to measure is distance. During a strike, distance equates to voltage drop to earth, the entire room of equipment will be elevated. The sharp corners of equipment cabinets can breakdown the air, causing current to flow. This will be a very low current unless another path is found by these streamers. Heater vents and electrical conduits that are not grounded to the single point can become such paths. It is a good idea to bond (ground) all conductive objects within 1 meter of any single point earthed equipment in the room.

Tower mounted equipment is similar to the above high rise situation. The I/O's must be protected and the protectors must be located and bonded together. Single point grounding should be easy to do if the equipment is mounted inside a metal enclosure.

Antenna Support:
Ground mounted vertical antennas require the same type earthing for lightning protection. A vertical antenna's impedance is half of a dipole's. Don't stop short of a good ground plane. The better the ground plane for RF, the better the earthing for lightning. This is assuming that the RF ground plane is in the ground.

If you have a antenna tuner fed long wire and the pole is just supporting the antenna wire, it would be a good idea to have the grounded straps extend higher to intercept a strike or to divert energy to ground if the wire is struck. This can be done by either placing a high voltage gas tube between the long wire and the straps or by making an arc gap between the wire and the ground straps. A gas tube will not be adversely affected by temperature, humidity, pollution, or wind, while the air gap will be affected. It may be difficult to calculate the voltages present at the gas tube and it will change when switching bands. A rule of thumb is for about 7kV. An air gap would be about 0.175" at sea level with 50% humidity and grows larger with elevation/humidity. (Humid air is less dense)

Another gas tube or gap may be added closer to the antenna tuner. For dipole antennas with baluns, use the same gas tube technique. Place gas tubes around the balun. Place one across the balun at the dipole wires and one from each side of the balun to the ground straps. This will protect the balun from a strike to the dipole wires. The more strike energy you can divert to the ground before it

reaches your equipment, the better off you and your equipment will be.

Just a word to those who tell us that they are safe from lightning because they always disconnect the coax from their equipment. When asked what they do with the disconnected line(s), they usually respond that it is placed on the floor. Now if you stop and think about the last few thousand feet that the lightning has jumped, you can see the fallacy of their thinking. In fact, they made it worse since arcing involves ignition temperature plasmas inside your house. True, the radio may still work, if it survives the house fire. Throwing the coax out the window is not a solution, especially if the coax has already entered the house from the antenna or the antenna is roof mounted without a ground path. Grounding switches will not last long with direct hits unless other good ground paths are provided. Grounding the antenna line and not disconnecting the coax shield can still allow strike energy to be shared with the equipment The shield connects to the chassis and if a single point ground is not present with power/telephone protectors, the equipment will be damaged.

Power/Telco entrance:
Full protection for a ham shack must cover not only strikes to your tower, but also hits from down the road to utility lines. By using single point grounding, your ham equipment will survive the hit to your tower. If the outside (tower/perimeter) ground has a low impedance at lightning frequencies, most of the strike energy will be dispersed into the ground and little energy will enter the shack. This is fine, but what if your ground has deteriorated over time or was never very good because of yard size?

The ground system can absorb only so much energy before it becomes saturated. In 90% of the strikes, a traffic jam of electrons will be coming down your tower. If they cannot spread out in a reasonable time frame, the back up pressure (voltage) will find or create another path. The ground system, if too small in area, will cause more energy to traverse the cables and other lines to the shack. The I/0 protectors can keep the voltage levels between the single point ground and the signal line(s) at survivable limits, but the energy is only diverted elsewhere. This could be the house phone lines and power lines.

Other house appliances may be at risk. When the ground system is saturated, the energy is actually coming from the (utility) ground system and can go through your TV, for example, in an effort to leave the area by way of the cable TV drop. Satellite dishes will also have the same problem. The best way to protect the rest of the house is to provide protection at a single point. The easiest single point will be at the power and telephone entrance. The utility ground rod (which should have been already interconnected to your ground system) is used by both the power neutral and the telephone protector installed by the phone company. By placing a power mains protector and a secondary phone line protector at this location, the entire house will be protected. The cable TV or outside antenna coax should be rerouted and a good coaxial protector installed at this point. The cable company installed protector is usually just a grounding block earthing only the outside shield and does nothing to the center conductor energy that can have as much energy as the outside shield! As the ground system rises in potential from a strike, the protectors will take the ground system energy and place it on the power, telephone, and cable TV lines while keeping the voltages between earth and the active lines within the limits of equipment survival.

The utility ground rod for the house should have already been interconnected to your ground system. What if this can't be done? If this is not done, the energy from the tower strike will traverse the house safety ground wires to this rod, causing problems. The reason to interconnect them in the ground using bare conductors was to reduce the inductance of the interconnecting path. It is true that the house wires are a parallel path and there is nothing we can do about it. If the interconnect path is better (lower inductance and resistance) the majority of the current will bypass the house wiring. The only alternative is to provide a copper strap path through the house. This may not be a sufficiently low inductance path and it will radiate to other wires/equipment inside the house.

The power and telephone feeds to your house can be either aerial or underground. Most people think underground is better from a lightning standpoint. Buried underground, it will not be hit directly, but if a nearby tree is hit, the amount of energy coupled through the conductive ground medium can be almost equal to a direct hit. By being underground, the shielding effect to the wires is not great. The buried depth does little when compared to the depth low frequency strike energy penetrates. When you consider the cost of underground utilities, these and the aesthetics must be weighed.

Ground System Materials:
Solid copper wire/strap and copper clad steel rods, makes copper the most commonly used earthing material. Your below grade ground system should be made with the same material throughout.

Mixing of materials, like galvanized rods with bare copper radials, will create a battery action and the zinc of the galvanized rods will become sacrificial, dissolving into the soil. This leaves bare steel to rust and not provide an optimum connection to earth. (Note: when wet, rust can conduct, but not very well.) Using stainless rods in order to prevent corrosion will not provide the best conductivity. Since stainless wire will be required to interconnect the rods, the resistance of the system will increase. An all aluminum ground system should only be considered in very acid soil conditions and even then it should be chemically tested for other attacking soil compounds.

Joints between copper radials and copper clad rods should be made by exothermic welds or by using joint compounds in high compression clamps. Solder connections, even torched silver solder connections will not last as long as the above. An exothermic weld is created when a graphite mold around the connection is filled with copper oxide and aluminum powders. An additional starter powder ignites the exothermic process. The resultant molten copper is deposited into the lower mold cavity where it burns away any oxides and creates a larger fused connection. The larger cross sectional bond decreases the resistance and increases the surface area, reducing the inductance of the joint. Since the materials are all the same, the connection will last as long as the rest of the grounding material. High pressure clamps provide a meshing of copper to copper since the material is soft (malleable). The use of joint compounds further enhances the weather tightness of the bond. The high pressure will need to come from another material stronger than copper.

If you find a rock layer is making the ground rod insertion difficult and you can't remove the rod to start over a few feet away, the best idea is to cut off the rod and connect it to the system. A rock layer will hold water and salts so the conductivity above should be good. Making more connections to areas of higher conductivity will reduce the overall impedance of the ground system (resistance and inductive reactance).

The ground system has a resistance and an inductance value. (It has capacitance too!) The amount and location of the inductance can choke off the effectiveness of radials. When a radial is in poorly conductive soil such as buried in a dry, sandy layer, the radial inductance can be calculated as being in air (a very poor conductor). When the radial runs in highly conductive moist soil (or doped soil), the inductance of the wire is shunted by the soil's conductivity, making it unimportant.

Since copper strap has lower inductance than wire, it is recommended for the radial run. The strap's extra surface area reduces the inductance and the sharp edges allow for a high E field concentration forcing more charge into the soil. Short multi-point (like barbed wire) type grounding systems have been tried and have not been as effective as the sharp edge of copper strap for ground rod interconnecting material or for radial runs without rods. Copper strap radials have been proven successful on bare mountain top solar powered sites where ground rods could not be used. The strap edges helped disperse the strike's deposited charge to the tower by arcing onto the mountain surface, saving the solar powered radio equipment at the site.

Adding ground doping material to your radial trenches and rods can be helpful. Stay away from gels and other chemicals that can shorten conductor life. All add-on conductive earthing materials do little except make your copper conductors larger (more conductive surface area). This gives some percentage of improvement but it still must interconnect to conductive soil where it has both salts and moisture. If the soil is dry around the earthing material, the connection to earth will be poor, regardless of the advertised claims. If the area is not large enough, the earth connection will suffer. By increasing the area of your ground system with the addition of more radials, the same improvements can be obtained for less money.

Longevity:
After doing all this work, Mother Nature still has a way of making anything we do temporary. Once a ground system is in the ground it will start to age. Copper and other metals are attacked by acids, while aluminum is attacked by bases. Other chemicals may be present in the soil causing decreased effectiveness of the grounding materials. This is why maintenance testing is important. While some ground systems last 30 years, others don't even last two years! There are two ways of finding out if your ground system is in need of work. One is after a lightning strike and is too late! The other is to measure the system. An old timer once told me that he tested a ground by disconnecting it from everything and connecting it to power "hot" through a 30 amp fuse. If the ground was good, the fuse would blow. This is not the way to test a ground and it could change the soil conductivity by attempting such a test. The proper way is to use an earth resistance meter providing a fall of potential type test. Be careful when connecting a ground system to your electrical utility ground rod. Depending on ground conductivity, harmonic and other

currents, there could be current flow causing a spark when connected.

Finally!

Most of the above topics are covered in more detail in our other technical documents. Read on! (73, KF4MT)