AM Antenna Systems

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Abstract

Over the years, the collective knowledge of AM antenna systems and the principles behind them has faded somewhat. Most of the tomes used by the last generation of AM consulting engineers date back to the 1940s and are no longer in print.

It is the purpose of this paper to provide the interested reader with a general body of knowledge of AM antenna systems.

1.0 AM Antenna Basics

The purpose of any AM antenna is to radiate the power generated by the transmitter. Some antennas do this better than others, and there are many ways to get a signal into the air.

Non-directional antennas radiate equally in all directions, providing the simplest way to get a signal out in an efficient manner. Directional antennas are used to concentrate signal in some directions (toward population centers, for instance) while suppressing signal in others (toward other stations which must be protected from interference).

The antenna system is the last point in a broadcast system where the broadcaster has any control over the signal. After that point, environmental factors, receiver characteristics and other factors have sway over what the listener hears. The amount of signal received at a given point is dependent on the amount of radiation toward that point from the antenna, the distance to the receiver, the conductivity of the earth between the transmit and receive locations, the character of the terrain between antennas and, sometimes, the ionospheric conditions. Atmospheric noise, natural and manmade, affect the signal-to-noise ratio at the receiver, but it does not affect the level of signal arriving from the transmit antenna.

AM antenna systems are **vertically polarized**. This is done for a number of reasons, including superior groundwave propagation and simplicity of antenna systems. The downside of vertical polarization is that most atmospheric noise is also vertically polarized. Still, vertical polarization is a better choice for AM broadcast than horizontal and virtually all AM radiators are vertical. Not only are horizontal dipole antennas mechanically impractical, their radiation on the horizon is not nearly as good as that of a vertical radiator. Since it is necessary to erect two relatively tall towers to support a horizontal dipole, why not just drive one of the towers directly and forget about the other tower and dipole?

Earlier, we mentioned that several things influence the amount of signal received at a particular point from a given antenna system. The first of these was the amount of radiation toward the receiver. The amount of radiation toward a particular point is influenced by the transmitter power, system losses, antenna efficiency and antenna directivity. Transmitter power is self-explanatory. System losses come in several areas — resistive losses in conductors, ground system and tuning components, and transmission line losses. Antenna **efficiency** is really defined in two ways: One has to do with the vertical radiation characteristics of the antenna; the other has to do with the radiation resistance.

We'll look at both of these in more detail later. The efficiency of a non-directional AM antenna is expressed in millivolts per meter at one kilometer (mV/m/km), and this figure is referred to as the **inverse distance field** or **IDF**.

Another factor that influences the amount of signal received at a particular point is attenuation. Over perfectly conducting earth, the amount of signal received at a distance would be inversely proportional to the distance from the transmit antenna. This relationship is known as the **inverse distance** rule. For example, if at a distance of 1 km a field strength of 100 mV/m is present, at 2 km the field strength would be 50 mV/m. At 4 km, the field strength would be 25 mV/m, and at 8 km it would be 12.5 mV/m. If you were to graph this relationship as field strength versus distance on log-log graph paper, it would plot as a straight diagonal line.

In the real world, the earth is not perfectly conductive. **Ground conductivity** varies from very good (seawater) to very poor (rock and certain soils). The more conductive the ground is, the less a signal from an AM antenna will be attenuated and the more the field strength versus distance plot will resemble the inverse distance line. Over ground that is less conductive, the more a signal from an AM antenna will be attenuated and the more the field strength versus distance plot will curve away from the inverse distance line.

A family of **groundwave curves** is published by the FCC for each group of frequencies, showing the effects of different ground conductivities. These curves are the basis for predicting distance to a field strength and thus the entire US allocation system. A slightly different set of curves is used internationally, the reason for this having to do with treaties that predate the adoption of the current set of US groundwave curves.

We previously mentioned the efficiency expressed as the inverse distance field of a non-directional antenna. You have probably already figured out that the conductivity of the ground in the region between the antenna itself and the receive point 1 km away will cause the field strength at that point to be attenuated below what it would be over perfectly conductive earth. How, then, can one accurately measure the efficiency of an antenna? The answer is with many measurements taken radially, beginning very close to the antenna (usually at the point where the first on-scale reading can be taken). The very close-in measurements establish the unattenuated IDF while measurements farther away from the antenna establish the conductivity of the ground between the antenna and the last point measured.

2.0 Non-Directional Antennas

Non-directional antennas can come in several forms, but by and large these are simple vertical radiators. One type is base insulated and series-fed; the other is grounded base and shunt fed. We'll look at both these types in detail later.

Ideally, the **electrical length** of an AM antenna will be 90 electrical degrees (1/4 wavelength) or more. Antennas of this length provide adequate efficiency and bandwidth. Sometimes, though, aeronautical or structural considerations force broadcasters to use shorter towers. The apparent electrical length of short towers can be increased through the use of **top loading**. Top loading increases the capacitance to ground, and is usually achieved through use of a **top hat** (a flat, horizontal disk attached to the top of the tower) or using bonded guy wires.

Because of mechanical considerations, the use of top hats is not as common as other methods. The top hat must usually support its own weight and withstand wind, ice and other environmental hazards unsupported, so top hat size (and thus effectiveness) is limited.

By far, the most common method of top loading is through use of bonded guy wires. This method uses sections of guy wires bonded to the top of the tower that are usually bonded above the first insulators to adjacent guy wires. Often, other non-structural guys are added and bonded to structural guys to increase the effectiveness of the top loading. It is not unusual to see six or more guy wires bonded together in a “spider web” fashion in a top loading arrangement.

The advantages of top loading are increased base resistance, reduced base capacitive reactance, lower Q and improved bandwidth. While all this sounds very attractive, it is almost always better to achieve these qualities with increased tower height rather than top loading.

Sectionalization is a method of increasing the groundwave efficiency of a vertical radiator, improving groundwave performance and reducing skywave radiation. In a sectionalized tower, an insulator is placed near the center of an electrically long radiator and a network is placed between the sections. In simple terms, the current in the upper section can be adjusted to be in phase with the signal in the lower section, thus focusing the signal radiated toward the horizon and reducing the signal radiated above the horizon. While such an antenna may appear to be more efficient than a shorter, non-sectionalized antenna, the spherical (total) radiation in both antennas will be the same for a given amount of input power, assuming all losses are the same. Sectionalization simply puts the signal where it is needed, toward the horizon, in much the same manner as a multi-bay FM antenna achieves antenna “gain.”

3.0 Current Distribution

An insulated, non-top loaded tower will typically have a **current loop** (or maximum) 90 electrical degrees down from the top of the tower. If the tower is shorter than 90° long, the current loop will occur at the tower base. Current distribution on a single, insulated, uniform cross-section radiator will be more or less sinusoidal in nature and is approximately defined as follows:

$$i_A = I_A \sin(G - y)$$

where: i_A = *current in amperes at height* y
I_A = *Maximum current in amperes*
G = *Tower height in degrees*
y = *height in degrees of current element*

There is always a **current node** (or minimum) and voltage loop at the top of any tower that does not employ top loading. As we move down the tower, the voltage will decrease and the current will increase in an approximately sinusoidal fashion until a current loop and voltage node occur at the point 90° below the top of the tower, if the tower is greater than 90° tall, or at the tower base if it is shorter than 90°. At the point where the voltage or current nodes occur, the voltage or current does not pass through zero but rather reach minimum values and shift approximately 180° in phase in traversing the node region. On a tall tower (greater than 180°), more than one node will occur along the tower's length.

Many things influence current distribution on a tower. Cross-section, uniformity, and nearby conductors are among a few of these. In some cases (which we will explore in detail in the future), there are actually two currents flowing on a particular frequency on a tower — the current that contributes to radiation and the current that is induced from another nearby radiator. This is the norm in directional arrays, where a tower will have current flow from its own excitation and current flow from radiation arriving from other elements in the array. The current distribution on towers such as these is sometimes hard to predict using conventional methods.

For most purposes, we assume sinusoidal current distribution on a radiator, and it usually works fairly well. Modern computer modeling using moment method analysis can, however, do an excellent job of predicting the current flow and distribution on a radiator and this gives the designer a much better picture of what is happening. Knowing the current distribution is important to the vertical radiation characteristics of an antenna. Knowing where the current loop is on an antenna is essential when detuning a radiator for the purpose of eliminating reradiation.

Occasionally, it is beneficial to measure the current distribution on a tower. To do this, a small sample loop is constructed out of copper tubing or aluminum angle and fitted with some sort of insulated bracket/handle so that all measurements can be made with the loop the same distance from the tower leg.

4.0 Vertical Radiation Characteristics

Generally speaking groundwave radiation (and apparent efficiency) from a vertical radiator will increase as the current loop moves up from the base. The optimum electrical length of a vertical radiator is 225° or 5/8 wavelength. At this electrical length, current loops is occur at 45 and 135 degrees above the base. Radiation on the horizon is maximized and radiation above the horizon is minimized.

Shorter towers have more radiation above the horizon and thus produce more skywave radiation and less groundwave radiation. Towers considerably shorter than 90° produce so much radiation above the horizon that much of the power is wasted into space. Nighttime power is usually much more limited when using an electrically short radiator, although considerably more daytime power may be allowed as a result of the reduced groundwave efficiency.

The vertical radiation characteristic of a vertical radiator that is not top loaded or sectionalized, or the **function of theta**, is defined as follows:

$$f(\theta) = \frac{\cos(G\sin\theta) - \cos G}{(1-\cos G)\cos\theta}$$

where:

$f(\theta)$ = function of theta
G = height of the antenna in degrees
θ = vertical angle

This equation returns a multiplier by which the inverse distance field of an antenna is multiplied to find the radiation at a particular vertical angle (θ). For example, if a tower is 90 electrical degrees tall, has an inverse distance field of 300 mV/m at one km and you wish to find the radiation from the antenna at a vertical angle of 20 degrees above the horizon, the above formula gives us a function of theta or multiplier of 0.914. Multiplying this by the antenna's groundwave inverse distance field of 300 mV/m, we find that the radiation at 20 degrees above the horizon is 274.3 mV/m at one km.

This information would be used in engineering a nighttime allocation to determine how much skywave field a particular station would produce at a given location. The design engineer would find the appropriate vertical angle for the distance to the receiver, find the function of theta using this formula, find the **skywave multiplier** from the FCC formula and multiply that by E(∅,θ), or the radiation at the pertinent azimuth and vertical angle from the station. I mention all this now only to show the need to know the function of theta in some circumstances.

One way an electrically short tower can be electrically lengthened is using **top loading**. If a tower employs top loading, the function of theta is computed as follows:

$$f(\theta) = \frac{\cos B \cos(A \sin\theta) - \sin\theta \sin B \sin(A \sin\theta) - \cos(A+B)}{\cos\theta[\cos B - \cos(A+B)]}$$

where:

f(θ) = function of theta

A = the physical height of the tower in degrees

B = the difference, in degrees, between the apparent electrical height (based upon current distribution) and the actual physical height

θ = vertical angle

If, for example, a particular tower is only 60 degrees tall (A) but employs top loading that makes it seem 30 degrees taller (B) based upon current distribution, and we wanted to find the function of theta for a vertical angle of 20 degrees, the above formula yields 0.923. Note that for the same *electrical height* based on current distribution achieved through top loading, the function of theta is higher than the same electrical height achieved without top loading.

Another type of antenna we briefly discussed in Part 1 was the **sectionalized** tower. Sectionalization is used to increase the groundwave efficiency (and reduce skywave radiation) by placing an insulator near the center of an electrically long radiator and controlling the current flow on each section with a network between the sections. For sectionalized towers, there is yet another formula to determine the function of theta:

$$f(\theta) = \frac{\sin\Delta[\cos B\cos(A\sin\theta) - \cos G] + \sin B[\cos D\cos(C\sin\theta) - \sin\theta\sin D\sin(C\sin\theta) - \cos\Delta\cos(A\sin\theta)]}{\cos\theta[\sin\Delta(\cos B - \cos G) + \sin B(\cos D - \cos\Delta)]}$$

where: A = the physical height, in electrical degrees, of the lower section of the tower
B = the difference between the apparent electrical height (based on current distribution) of the lower section of the tower and the physical height of the lower section of the tower
C = the physical height of the entire tower, in electrical degrees
D = the difference between the apparent electrical height of the tower (based on current distribution of the upper section) and the physical height of the entire tower. D will be zero if the sectionalized tower is not top loaded.
G = the sum of A and B (A + B)
H = the sum of C and D (C+D)
Δ *= the difference between H and A (H-A)*

By way of example, if we have a sectionalized tower that has a lower section that is 120 electrical degrees tall (A) and the current distribution makes the lower section seem as if it is 20 degrees taller than that (B), the overall height is 220 electrical degrees tall (C) and top loading of the upper section results in current distribution that makes the tower seem as if it is 15 degrees taller (D) and we want to find the function of theta for a vertical angle of 30 degrees, the above formula yields 0.593. This formula is, obviously, quite cumbersome and difficult to solve using a pocket calculator and paper. However, it lends itself easily to codifying into computer language or a programmable calculator.

5.0 Insulated and Grounded Towers

By and large, the vast majority of AM antennas consist of insulated base towers. Almost all directional arrays use insulated base towers. There are several advantages to using an insulated base tower, chief of which is control of the current distribution on the tower. Insulated base towers are fed across the base insulator. This type of tower is said to be **series fed**, since the excitation is, in essence, fed in series with the tower base.

Occasionally, it is advantageous to use a grounded base tower as an AM radiator. Such circumstances may include mounting of an FM or other antenna on the tower, use of an existing grounded-base tower for AM or, from time to time, proximity of the tower base to a populated building or structure. In these cases, it is possible to use a grounded base tower with good results as an AM radiator if the guy wires are all insulated.

The base impedance of a grounded-base tower is essentially zero, but that impedance rises with height above the base. At some location up the tower (assuming it is of adequate height), a point will exist that will provide an acceptable feed impedance. The easiest way to feed a grounded base tower is with a **slant wire**, which is attached at the aforementioned point and returns to the transmitter building at an angle approaching 45 degrees. This forms what is essentially half of a “delta” match. The location of the best attachment point for the slant wire is usually determined by a cut-and-try method, although experience on the part of the field engineer and modern computer modeling techniques can point to a starting point that should be close to the desired impedance. In most situations, if the feedpoint is properly selected, the only matching needed will be a series capacitor to cancel out the inductive reactance of the slant wire.

Because the excitation in a slant wire fed grounded base tower is shunted across the grounded tower base, this type of antenna is said to be **shunt fed**. The current flow is up the slant wire and then on up the tower to the top, where a current node and voltage loop will exist. Some current, however, also flows down the tower from the slant wire feed point and contributes to radiation. Because there are two radiated fields below the feedpoint (one from the slant wire and the other from the tower below the feedpoint), some suppression of radiation occurs, usually on the side of the tower where the slant wire is located. Seldom is this a problem, however, and the antenna is still considered to be a non-directional radiator.

Another way to feed a grounded base tower is to mount an insulated skirt on it consisting of three or more wires suspended off the tower on insulators and parallel to the length of the tower. The skirt wires are bonded together at the top of the tower and then bonded to the tower itself at a point that produces a desired **driving point impedance**, usually somewhere below the 90 degree point (0.15 wavelengths is a common location for this bond). The skirt wires are also bonded together near the tower base, and this is where the excitation is applied. This type of grounded base antenna is called a **folded monopole**.

The skirt wire conductors form the outer conductor of a transmission line. Were the short located at the quarter-wave point, it would transform the short at that end to an open at the other end, creating a virtual base insulator at the bottom of the tower. By adjusting the location of the short between the skirt wires and the tower, the impedance at the feed point can be adjusted to a favorable value. This arrangement forms what is essentially a “gamma” match.

Current flow in a folded monopole is up on the skirt wires and down on the tower structure. Such antennas perform much like base insulated towers. Radiation current flows up the skirt wires to the tower and then on up to the top of the tower, where a current node and voltage loop will exist.

6.0 Base Impedance

The **base impedance** of an insulated-base tower is determined primarily by the electrical length of the antenna, cross-section, the extent of the ground system and the elevation of the feed point above ground. Short towers have much lower base resistance, and the reactance becomes quite capacitive. When base resistance is quite low, the fixed ground loss of one to three ohms becomes a significant part of the radiation resistance of the antenna. This, in part, is the reason that short towers are less efficient than tall towers.

Taller towers have higher base resistance, and at some point (usually around 80 electrical degrees), the reactance crosses over and becomes inductive. There is some benefit to selecting a radiator with close to a zero reactive component in its base impedance when designing an antenna system. Empirical tower base impedance data is available and published in many places, both in tabular and graph format.

Through the use of moment method computer modeling, the base impedance of many different tower configurations can be accurately predicted. This is particularly useful with tapered or free-standing towers, where the cross-section is great and the parallel capacitance of multiple base insulators is significant.

In grounded-base shunt-fed towers, the feed point impedance is more dependent on feed point location. Since this is usually at least to a degree within the control of the user, a desirable base impedance can often be obtained. This impedance often has a relatively large reactive component; the resulting Q is usually higher and bandwidth lower than that of an insulated tower of the same height.

7.0 Ground Systems

Beneath every AM antenna system is a **ground system** (or at least there is supposed to be). The ground system is every bit as important to the operation of an AM antenna as the tower that is the vertical radiator.

Without a copper (or otherwise conductive) ground system, the losses in a vertical AM antenna are very high. These losses are largely due to the conduction of currents through the earth, which at best has a high resistance. By placing a number of wires in the earth from near the tower base to radial points some distance away, we provide a relatively low resistance path for the ground currents to return to the ground in the vicinity of the tower base. These radial wires make up the classic ground system as is commonly used in one form or another in all AM broadcast antenna systems.

While it is certainly possible to use materials other than copper in a ground system, copper is by far the best compromise for both performance, durability and economy. Copper is used almost exclusively for this application, so for the remainder of this discussion, we will assume bare, soft-drawn copper wire to be the material of choice.

7.1 Ground Currents

Did you ever wonder what was the return path for all that current flowing in your AM tower? These currents leave the antenna as displacement currents, flow through space and finally into the ground, at which point they become conduction currents. Due to skin effect, these currents usually flow very close to the surface as they flow radially back to the antenna base.

With copper ground radials in place, the **ground current** is made up of two parts: One part of this current flows through the earth itself; the remainder flows in the buried wires. This can generally be viewed as a parallel resistive circuit. As the ground current flows inward through the ground or the wire toward the antenna base, it is continually added to by additional displacement currents from the antenna that are flowing into the ground. Because these additional currents differ in phase from the components already flowing in the ground and buried wires, the ground currents do not necessarily increase.

7.2 Ground Losses

It has been established through studies and years of experience with such systems that the ground currents at a distance are proportional to an antenna’s field strength at one kilometer, or the inverse distance field (IDF). In these studies, power was fed to a vertical radiator and the actual current flowing in the buried wires at a distance from the tower base was measured. The results further established that the current flowing in the ground radials at distances greater than 0.3 wavelengths from the tower base remain relatively constant for varying heights of antennas with a constant input power. This indicates that the power lost in the ground at distances greater than 0.3 wavelengths will generally be the same, regardless of the antenna height.

On the other hand, close to the antenna, ground currents of electrically short antennas become quite large. Knowing that the power lost in a conductor is directly proportional to the resistance of that conductor, the importance of maintaining a good array of ground conductors within a quarter wavelength or so of a short antenna is apparent. It may be surprising to you that the losses in a ground system for a 1/4 wavelength tower can easily reach 3 dB or more if many radials are missing, cut or deteriorated. The shorter the tower, the more pronounced the ground system losses will be. This is one reason that electrically longer antennas are more desirable than short ones.

7.3 The “Standard” Ground System

Many years ago, experiments were conducted to determine the effects that the number, size and length of radial ground wires had on the antenna resistance and field strength at a distance (efficiency) of AM antennas of varying heights. Some interesting conclusions were reached as a result of these experiments:

- The distribution of currents depends on the wire size in a logarithmic fashion, making the size of wire used relatively non-critical
- The losses in a ground system are inversely proportional to the number of radial wires used
- The resistance of an antenna of a given height is reduced as the number of radial ground wires is increased
- The reactance of an antenna varies only slightly with differences in the ground system
- The efficiency of an antenna is increased with the number of ground radial wires used, with 120 wires being the optimum balance between cost and efficiency
- The optimum length of a ground system is 140 electrical degrees
- The presence of a ground screen in the vicinity of the antenna base makes no difference in antenna resistance or efficiency
- A buried radial ground system functions equally well as the same number and length of radials installed above the surface of the ground.

It was largely as a result of these experiments that the standard non-directional AM antenna ground system was defined as 120 radials, 90 electrical degrees in length, composed of #10 soft-drawn bare copper wire buried 6" to 8" below the surface. With performance being roughly equal between surface and subterranean systems, it is more desirable to bury the ground system in order to protect it from damage.

The conclusion regarding the ineffectiveness of the copper screen notwithstanding, a copper screen 25' to 50' square (or 120 interspersed 50' radials) in the vicinity of the tower base is also part of the standard ground system. The purpose of the screen or additional short radials is to stabilize the resistance of the antenna and the capacitance across the base insulator with changing ground conditions due to weather, moisture content and the like. Experience has shown that a screen or additional radials close in are very effective at stabilizing an antenna's impedance.

For directional antennas with multiple towers, the same basic ground system elements are used, except that where radials from different towers intersect, they are terminated into and bonded to a **transverse copper strap**. For example, in a two-tower array with 1/4 wavelength spacing, a transverse copper strap would be installed halfway between the two towers and all the radials that would intersect the other tower's radials would terminate onto the transverse strap.

7.4 Current Flow

As was mentioned earlier, in a single-element AM (non-directional) antenna, ground currents return to the tower base radially. In the case of multi-element directional arrays, displacement currents will arrive at every point on the surface of the ground from each element of the array, and all these currents components will all have different phases. The current flow in such a multi-element array will not, then, be entirely radial in nature.

It has been shown in recent experiments that ground currents in multi-element arrays often flow in a spiral fashion toward the individual tower bases. In the early 1990s, a complex rooftop ground system for a five-tower directional array was constructed in grid rather than radial fashion. The resulting efficiency and stability of this unusual and unconventional ground system proved to be quite satisfactory.

7.5 Lightning Protection

A buried copper radial ground system, while very effective as part of a vertical antenna system, is seldom satisfactory as a mechanism to dissipate the energy from lightning that strikes a tower. Individual radials can be burned in two at the point of connection to the tower base strap when large lightning currents flow through them. A separate, large conductor (0 AWG or larger) wire is needed to discharge strike currents. This conductor should be connected to an array of at least four eight-foot copperweld ground rods near the tower base pier.

Insulated-base towers need some method of discharging static across the base insulator, such as a **static drain choke** that has a high impedance at the RF operating frequency but a very low impedance to DC. Towers that use sample loops at tower potential must use sample line iso-coils to isolate the loops from the sample line at the operating RF frequency, and such iso-coils serve well as static drain chokes.

Static drain chokes, while serving to keep dangerous static potentials from building on an insulated tower, are not at all effective at dissipating lightning strike currents. In fact, they present a very high impedance to the ultra-fast rise times of a typical lightning current. A spark gap of some sort is needed directly across the tower base insulator to provide a path for such lightning currents. Gaps of this sort most often consist of two horizontally separated galvanized steel balls, with an air gap between them, located just below the base plate of the tower. “Horn” type gaps are used in other installations, and from time to time, a “needle” gap is used. Both the ball and horn type gaps are of a design where any arc across the elements is self-extinguishing. As the sustained arc climbs farther and farther out on the gap, the spacing gradually increases until a point is reached where the voltage across the gap is less than the breakdown voltage of the air between the points where the arc is occurring. When that point is reached, the arc is extinguished.

Gap spacing is usually set by trial and error, but a starting point can be calculated. The installation, maintenance and adjustment of spark gaps will be dealt with in a later chapter.

7.6 Ground System Installation

Ground radials are usually installed by use of a specially adapted plow. Such implements are equipped with a spindle for the spool of wire and a tube or conduit that conveys the wire from the spool to a point beneath the surface just behind the plow blade. The end of each radial is secured to the copper strap or ring of copper tubing at the tower base and then the plow blade is lowered into the ground at a point ten feet or less from the tower base. It is then pulled radially away from the tower to the desired radial endpoint previously established by survey and marked with a stake. When that point is reached, the plow is raised, the wire is cut and the wire end is pushed back into the furrow.

In this manner, the actual installation of a radial ground system can proceed quite rapidly. A typical crew can install a full 120-radial system for a single tower in about one day, assuming a clean site and that all the surveying/marking of the radial endpoints has been done.

It is important for the engineer in charge of the construction and maintenance of a station to observe the installation of the ground system. As we have previously established, the performance of an AM antenna system is directly related to the condition of the ground system. Mistakes made in the installation process will be around long after the installation crew is gone and the performance of the station will suffer as a result.

The selection of a ground system installation crew should be made carefully and not necessarily be based upon the lowest bid. Choose a reputable contractor with good (and recent) references. Carefully review the amount of materials needed and keep track of the material as it is used in the installation. Copper wire, screen and strap are costly and can disappear quickly from a site. Spot check individual radials by digging into the furrow and locating the wire. More than once, such spot checks have revealed an empty furrow.

At the tower base, the ends of the ground radials are terminated into a copper strap or piece of heavy copper tubing. One method is to build a square frame around the tower base pier out of wooden two-by-fours, then to lay a length of four-inch copper strap over the wood. A galvanized roofing nail is then partially driven into the wood through the copper strap for each radial, and the end of the radial is wrapped around the nail. Once all of the radials are plowed in, the radial ends are silver-soldered to the copper strap and the nails are either removed or driven all the way in. The straps from the underside of the tower base insulator are also silver soldered to this strap.

It is important to insure that silver solder, not tin/lead solder, is used where making bonds in a ground system. It will quickly deteriorate if buried, and the mechanical strength of tin/lead solder joints is inferior to that of silver soldered joints.

Another method calls for a piece of one-inch diameter copper tubing shaped into a circle around the tower base pier with the two ends silver soldered together. The individual radial ends are wrapped one time each around the tubing and silver soldered into place.

If the installation uses short, interspersed radials close in, the ends of these radials are attached to the strap or tubing in the same manner. Where a copper screen is used, the individual pieces are laid out on top of the ground, cut to the proper size and shape and silver soldered together and to the strap or tubing. Where a screen is used, it is best to cover it with large gravel to a depth of at least two inches to protect and secure it. Pea gravel can be used, but a typical copperweld screen is likely to eventually work itself up through small gravel and become exposed in places. Typically, large gravel is less expensive than pea gravel, so it is a better choice for more than one reason.

Where radials intersect a transverse strap, they should be cut to length and bonded to the strap by silver soldering. Strap intersections should be secured mechanically and then silver soldered.

Many installations use a copper strap from every tower to every other tower and to the transmitter building ground system. While there is nothing wrong with doing this, it is generally redundant and unnecessary. The outer jacket of the transmission line feeding each tower serves well as a ground strap between the tower and transmitter building or phasor. There is no real reason to connect the tower bases together with a strap, as the ground currents are carried adequately by the radials and the ground itself.

7.61 Special Circumstances

What happens when a special circumstance exists at a site that does not permit a “conventional” ground system to be installed? Where there is a will, there’s a way, and there are just about as many variations on the basic ground system scheme as there are engineers. Some of these variations are quite creative.

Many AM transmitter sites are located in flood planes or flood prone areas. In these cases, the transmitter building, tuning houses and tower base insulators are often elevated so that the highest predicted level of flood water will not reach the buildings or base insulators. In these circumstances, the buried radial ground system is still used, but the ground screen or interspersed short radials are mounted on a **counterpoise** at base insulator level. A frame of some sort is usually constructed in a hexagon or octagon shape with a 20 - 25 foot radius, and the screen or short radials are installed from a strap or tubing ring below the base insulator to the edges of the counterpoise. The outer edges of the counterpoise are lined with copper strap, and the edges of the screen or the ends of the short radials are silver soldered to this strap. A copper strap is then run down each support leg of the counterpoise to ground level, where it is bonded to the buried ground system, which has been installed in a normal manner below the tower base pier or support pylon. A set of ground straps (usually three or four) is run from the inner ring of the counterpoise down the tower support pylon to join the inner ring of the buried ground system. In the same manner, a number of large gauge wires (0 AWG or larger) should be run from the bottom side of the spark gap to the ground rod array around the base pier or pylon for lightning protection.

It is important to note that if the counterpoise support frame is constructed of a conductive material, **cathodic protection** must be used to protect it. Cathodic protection is a method of inducing a negative DC current into a metal object that is in contact with the ground or another conductive object, thereby preventing corrosion. In the case of a steel frame counterpoise without cathodic protection, corrosion of the frame will eventually take place, both below the ground and at the points where the copper ground material contacts the steel of the frame. If cathodic protection is used, it may be worthwhile to use insulated rather than bare copper wire in the buried portion of the ground system. Were bare wire to be used, a good part of the cathodic protection current would flow in the copper ground radials and not in the steel where it is needed, thus reducing the effectiveness of the cathodic protection.

Should you find that the situation may call for cathodic protection, it is wise to retain an engineering firm that specializes in such systems. The variables and calculations that go into the creation of a successful cathodic protection system are well outside the realm of broadcast engineering.

In other installations, it may be necessary to extend a ground system across a creek, river or canal. Unless the waterway can be lined and capped, it is usually not advisable to string ground radials across the top. Plowing radials in through the bed of the waterway is likewise inadvisable. Flooding, dredging, erosion and the like are prone to displace the radials and damage or destroy that part of the ground system.

A very effective way to cross a small waterway is to install a strap, usually four inches in width, along and parallel to either side of the waterway. All the radials that intersect this strap should be trimmed to length and silver soldered to the strap in the same manner as with a transverse strap. On the side of the waterway opposite from the tower(s), the radials start at the parallel strap and continue to their full length. Then, in at least three evenly spaced locations, a large strap is connected across the waterway to each parallel strap, This strap, which is at least six inches wide, is then buried a safe depth beneath the waterway invert (usually at least three feet).

7.7 Deterioration and Damage

The ground system is often blamed for signal problems. Since it is out of sight and somewhat difficult to observe in place, it is easy for station personnel to assume that there must be something wrong with it when coverage is not what it should be.

The truth of the matter is that a properly installed and buried ground system will last many, many years. Except in the most extreme circumstances, a buried ground system will not deteriorate appreciably in place. Stations that have been in place for fifty or more years have operated with the original ground system without difficulty. Spot checks of radials have revealed them to be in excellent condition.

The biggest dangers to buried ground systems are damage from construction or acts of God and vandalism/theft. A construction company installing a pipeline, sewer, or underground cable across an AM station's site property can cut many radials and cause significant damage. When the ditch is filled back in, it may well become impossible to locate the cut ends of the radials and the more economic fix may be to plow in new radials in those directions. It may be impossible to avoid having the construction work take place across the property, but with careful planning and supervision, the cut radials can be spliced before the ditch is filled in. The result will be no reduction in effectiveness of the system.

Acts of God present a more difficult picture. Erosion, floods, earthquakes and the like are usually beyond our ability to predict accurately, and they can leave a ground system uncovered and exposed. An ounce of prevention is the best medicine in cases where such calamities are likely. Radials can be plowed in deeper, for example, to prevent them from becoming unearthed in a flood or from erosion. At some antenna sites where erosion is a constant problem, a tractor with several implements is kept at the site and used to keep the ground system covered. Constant vigilance is necessary in such cases. Even a short length of radial that becomes exposed can easily be broken or further unearthed by wildlife or livestock.

Following a flood or earthquake, a careful inspection of the antenna site property should be made. The condition and integrity of the ground system should be checked by use of a field strength meter or metal detector if damage is suspected.

It is a good idea to periodically inspect the ends of the radials where they connect to the base strap or ring to be certain that they have not been burned open by lightning. Periodically check the lightning ground wires and connections as well, particularly at the beginning and end of the thunderstorm season.

Vandalism and theft are perhaps the most common dangers to a buried ground system. Copper is valuable, and a determined thief can rip an entire ground system out in a matter of hours. He may not get more than $500 from the scrap value of the copper, but the cost to replace the system can exceed $50,000.

Perhaps the best way to protect a ground system from thieves and vandals is to keep it properly buried. "Out of sight, out of mind" is a maxim to remember in protecting your ground system. If thieves do not know the buried copper is there, they will be unlikely to look underground for it. Good overall site fencing is important, and nothing can substitute for good relations with site neighbors. Keep that in mind when the farmer next door complains about station audio in his telephone. Fix or replace his phone and enlist him to help you keep an eye on the site.

7.8 Shared Site Use

More and more, AM antenna site property is becoming too valuable to use as only an AM antenna site. Open real estate is scarce in many locations, and the big, open field with the tower on it is often very attractive to developers. While an in-depth discourse on shared AM site use is beyond the scope of this discussion, the treatment of ground systems in such situations does bear looking at.

One common shared site use calls for placement of a parking area or roadway across an AM station's site property. There is nothing wrong with paving over a ground system. In fact, this can serve to protect the buried radials from damage and theft or vandalism. The important things to remember are to work carefully with the contractor to insure that the radial wires are not broken during construction, and have a surveyor make an accurate set of as-built drawings. It is easy to break a radial during the paving process, and to prevent this from happening, it is a good idea to place some sand around each radial to give it a cushion . The as-built drawings will allow you or others to accurately locate buried radials during future excavations.

Buildings can be placed on top of a station's ground system, but this may not be a good idea if RF power densities are high or the antenna system is a directional array. If a building must be placed on the ground system, depending upon the size of the building, it may be best to treat the building in the same manner as you would a canal or waterway. Run a copper strap around the outside of the building's foundation, terminating intersecting radials onto the strap. Several straps can then be run under the building's foundation, connecting between the straps along the building sides. Very little in the way of displacement currents will enter the ground through the building, so having radials in place beneath the building is not important. Providing a radial path for currents already flowing in the ground system is important, however, and the use of interconnected perimeter straps serves this purpose nicely.

8.0 Directional Antenna Systems

In an ideal world, all AM antennas would be non-directional (circular radiation pattern). Transmitter site locations would be selected so that all the population to be served would be covered with a strong signal with a minimum waste of signal into unpopulated areas. Population centers would be evenly spaced, with medium and large cities being a good distance apart. In this ideal world, the number of stations would be low enough that all the stations could live together on the band without causing interference to one another.

In the world we live in, though, things just aren't that way. Transmitter site locations are selected as a compromise between cost (land is much cheaper *away* from the city), location and permissible use. As Mr. Murphy usually has it, seldom is a site available where it will work the best for the station. Population centers are often clumped together, as on the east coast, and the number of stations is very high, over 4800 at last count. With only 107 channels on the regular AM band, we all know the band is way overcrowded. Interference between stations is common. All this trouble started when the second AM station signed on the air!

To help overcome some of these problems, when the broadcasting industry was in its infancy, directional antennas were introduced. The very first directional antennas were used to direct the signal into areas where coverage was desirable. Later, directional antennas were used both for directing coverage and for protecting coand adjacent-channel stations from interference. As the band became more and more crowded, directional antennas were used to “shoehorn” new stations in wherever there was a hole. The result... well, the current AM band with all its overcrowding and interference problems is the result. The FCC terms this condition as a “mature” band.

Consider that a 20:1 groundwave protection ratio (26 dB) is required between co-channel stations, and 6 dB is required between first adjacent channel stations. In the middle of the AM band with average values of conductivity, the 0.5 mV/m contour of a typical station transmitting with 1 kW will lie at a distance of about 45 miles from the antenna site. The same or a similar station’s 0.025 mV/m contour (1/20 of 0.5 mV/m) will lie at a distance of about 140 miles from the antenna site. Assuming two typical 1 kW co-channel stations both have non-directional radiation patterns, they cannot, then, be located closer than 185 miles to one another and still maintain the required groundwave protection to one another. If one of these stations uses a directional antenna to reduce its radiation toward the other station, the stations can be located much closer together. The maximum radiation permissible from one station toward another is expressed in mV/m at 1 kilometer at the appropriate azimuth, and engineers call this value the **MPR** (maximum permissible radiation).

Seldom is a groundwave allocation problem so simple as one station protecting just one other co-channel station — usually there are many stations that are entitled to protection. By using a directional antenna and carefully selecting the operating power, a balance can be achieved between coverage and interference protection.

The problem gets even more complex with respect to nighttime allocations. During the day, in most circumstances only the groundwave signal must be considered. At night, however, the skywave signals become a factor. Not only must radiation be limited in the direction of protected stations, but the vertical angle or **theta** (the angle above the horizon that will result in a reflection of the signal off the ionosphere so that it arrives in the protected station’s vicinity) must be considered as well. Limitations on nighttime radiation (still called MPR) are almost always expressed in mV/m at 1 kilometer at a specific value or range of values of theta. For example, the MPR from a particular nighttime facility toward another might be 35 mV/m at 1 km at a theta range of 16 to 24 degrees. That would indicate that the radiation on that azimuth could not exceed 35 mV/m at 1 km for any vertical angle between 16 and 24 degrees. This is where the **function of theta** of the antenna, discussed in Part 2 of this series, comes into play.

From all this, you can see that determining what a directional pattern must look like is a complex affair. Seldom is this process as simple as protecting a single station. Allocation pictures often look like jigsaw puzzles, and with different conductivities Having an effect along the various radials, coming up with a pattern to fit the situation can be very difficult.

8.1 A Simple Two-Tower Pattern

In a directional antenna, the radiation pattern is created by controlling the amplitude and phase of the RF current in each element of the array. The resulting field at any point is the vector sum of the individual element radiation components.

In locations where the fields from the various elements are in phase with one another, the fields add; where they are out of phase, they subtract. In most locations, the fields are not perfectly in or out of phase, and in the case of arrays with more than two elements, there is a combination of addition and cancellation at most points.

Let's consider a simple two-tower directional array. Let's assume our array's elements are spaced 90 degrees apart on a north-south bearing, and that the elements are driven with equal currents (1.0 ratio) with the phase of the current to the southern tower lagging by 90 degrees. If we stand at an observation point some distance from the array on a bearing of zero degrees True (due north), equal fields will arrive at the observation point from each point. Because the elements are spaced 90 degrees apart, the field arriving from the southern element will arrive 90 degrees later than the field from the northern element (90 degree lagging space phasing). Add to that the 90 degree phase delay in the southern element current and the field arriving at our observation point from the southern element is 180 degrees out of phase with the field from the northern tower. This results in complete cancellation of the fields from the two elements.

Now let's consider the same array but move our observation point to a location due south of the array. At this observation point, equal fields will arrive from each of the two elements, but because the southern element is 90 degrees closer, its field will arrive 90 degrees ahead of the field from the northern tower (90 degree leading **space phasing**). Since the current fed to the southern element is delayed by 90 degrees, that cancels the 90 degree leading space phasing, and the resultant field from the southern element arrives in phase with the field from the northern element. The fields completely add, so the resultant field at the observation point is equal to $F_1 + F_2$.

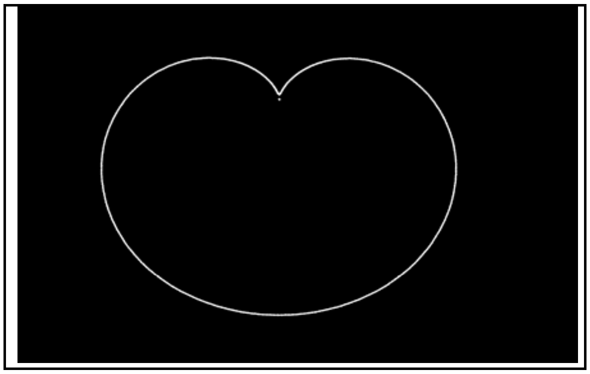
Figure 1

At other points around the array, neither complete addition nor complete cancellation will occur, and vector addition of the arriving fields is used to determine the resultant field. Figure 1 shows the resulting directional pattern of our two tower array.

The theoretical parameters for such an array would normally be listed as follows:

Tower	Ratio	Phase	Spacing	Orient	Height
1	1.000	0.0	0.0	0.0	90.0
2	1.000	-90.0	90.0	180.0	90.0

If the phase of the two elements is reversed (i.e. the phase to the southern element *advanced* 90 degrees rather than retarded), the pattern will be reversed, with complete cancellation to the south and addition to the north.

Now let's consider the same simple two-tower array, but let's increase the spacing to 180 degrees and feed the two elements in phase with one another (0 degree phase shift).At an observation point due east of the array, the equal fields from the two elements will arrive at the same time, since the observation point is equidistant from both elements. Since the phase of the currents in the two elements is the same, the fields from the two elements arrive in phase and thus completely add. The same is true at an observation point on the west side of the array.

If we move to an observation point north of the array, equal fields will arrive from the two elements, but the field from the southern element will arrive 180 degrees behind that of the field from the northern element. Because the currents in the two elements has the same phase, the fields arriving at the observation point will be completely out of phase and will thus cancel. The same is true at an observation point due south of the array. Figure 2 shows the resulting directional pattern of this two-tower array.

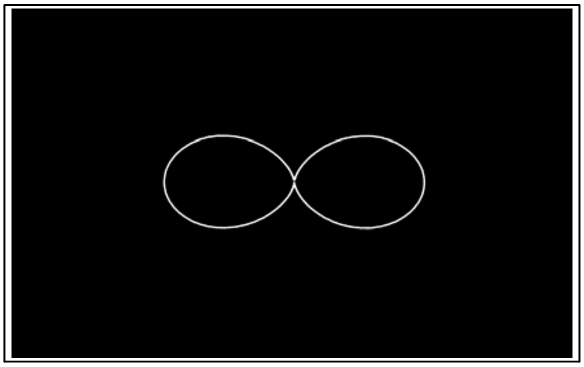
Figure 2

The theoretical parameters for such an array would normally be listed as follows:

Tower	Ratio	Phase	Spacing	Orient	Height
1	1.000	0.0	0.0	0.0	90.0
2	1.000	0.0	180.0	180.0	90.0

By altering the currents in the two elements and making them unequal, there will be neither complete cancellation no complete addition at any point around the array. The result is that nulls are somewhat filled and lobes are not as large.

By altering the phase of the current in the elements, the resulting instantaneous phase of the fields from the elements (current phase plus space phase) will vary, producing patterns of different shapes. The same is true of changing the spacing of the elements.

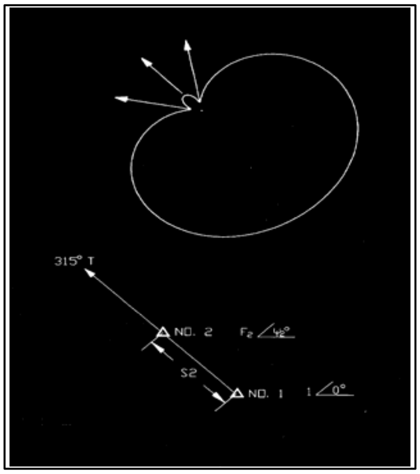

Figure 3

The design engineer can vary all these parameters — current, phase and spacing — in addition to moving the bearing of the line of towers to achieve the desired pattern. If more nulls or broader nulls are needed, additional elements are added to the array. For each additional element, another pair of nulls is created. By placing nulls close together, a broad arc where the radiation is suppressed can be created. The possibilities are limitless.

8.3 Pattern Multiplication

In a more complex example, if we start with a simple two-tower array with a 315-degree tower line, 90-degree spacing and 106 degree phasing, this will result in nulls at 280 and 350 degrees or 35 degrees either side of the tower line (see Figure 3).

Now let's suppose we need additional nulls at 345 and 105 degrees. A two-tower pattern with a 45-degree tower line, 180-degree spacing and 90-degree phasing will produce the pattern shown in Figure 4.

This pattern was selected to show that with a wide-spaced array, maximum radiation does not occur on the azimuth of the tower line. This type of pattern is often useful in daytime protection of a distant station, where radiation toward that station needs to be suppressed without necessarily placing a null in that direction.

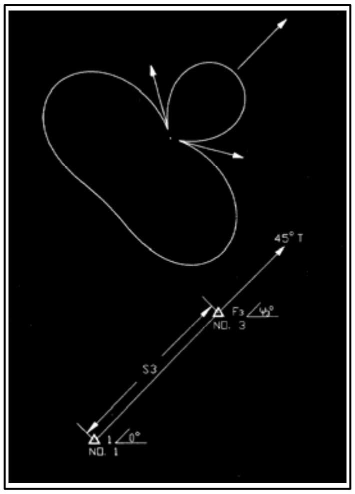

Figure 4

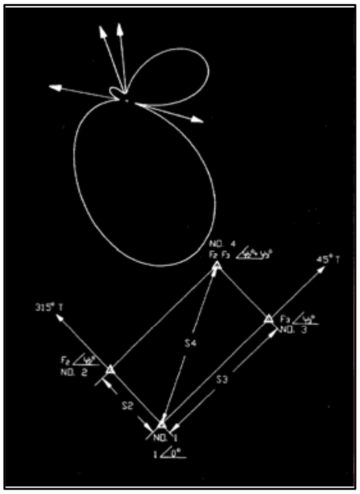

Figure 5

We can combine these two patterns — multiply them, if you will — to achieve a four-tower parallelogram array that produces a pattern with nulls at 280, 345, 350 and 105 degrees (see Figure 5). The nulls at 345 and 350 degrees combine to produce, in effect, a broad single null, which is useful in protecting a large contour or a national border.

We multiply patterns through the use of vector arithmetic. Since we already know what the parameters for both of the two-tower patterns are, we have the parameters for towers 1, 2 and 3. All that remains is to find tower 4's parameters. As shown in Figure 5, simply multiply the field ratios of towers 2 and 3 and add the phases of towers 2 and 3 to find the parameters for tower 4. The parameters for this parallelogram array would then be:

Tower	Ratio	Phase	Spacing	Orient
1	1.000	0.0	0	0
2	1.000	106.0	90	315
3	1.000	90.0	180	45
4	1.000	196.0	201	18

8.4 Pattern Size

So far, for simplicity of illustration, all the patterns shown have equal radiated fields, or field ratios of 1. We can fill the nulls of our patterns by making the currents unequal. As we fill the nulls, we also reduce the size of the pattern major lobe. The amount of energy in a pattern remains the same, regardless of the depth of the nulls or the size of the lobes. The size of a pattern is found by integrating the hemispherical energy flow (the power radiated on and above the horizon in all directions). For a given power input and loss, this will remain the same, regardless of pattern shape. We can liken this to a balloon filled with air. You can squeeze it in the middle, but the ends bulge out. As you reduce pressure in the middle, the ends return to their normal size. Squeeze both ends and the middle bulges out. Still, no matter where or how hard you squeeze, the total size of the balloon does not change.

As a pattern design progresses, it is important to keep an eye on what is going on *above* the horizon. It is easy, particularly with more complex patterns, to wind up with a good bit of energy being radiated above the horizon and into space. This power is, for most intents and purposes, lost, and in the case of most nighttime antennas, it is harmful as it causes skywave interference to other stations. Because the total hemispherical energy in a pattern never changes, by keeping an eye on the size of the horizontal pattern, the designer can generally tell if he has a vertical radiation problem. If the horizontal pattern size or RMS begins to shrink, that power is going somewhere, and that somewhere is up.

Directional pattern design is a complex art that takes years to learn well. While scientific principles govern this art, experience through trial and error is what makes an engineer proficient at pattern design. There are many tricks to the trade that simplify the pattern design process. A novice designer, for example, may take many times longer to produce a desired pattern than an experienced designer using the basic principles we have discussed here. Computer directional antenna design programs are a big help and time saver, but it is entirely possible (and even easy) to design a terrible pattern with one. The computer cannot substitute for knowledge of the craft.

For those building and maintaining directional arrays, it helps to understand the basic principles of array design. Faced with the adjustment of an array, without a good understanding of the designer’s intentions, the adjusting engineer may well find himself in an iterative trial-and-error situation that may *never* produce the proper pattern. A good understanding of vector arithmetic and antenna design principles will speed the process by allowing the engineer charged with adjusting the array to make educated decisions as the tuneup proceeds. In the next part of this series, we will examine in detail the use of vectors in DA adjustment.

8.5 Real World Parameters

Anyone who has ever looked at the FCC license for an AM directional station has probably seen that there are two sets of directional antenna parameters listed. One set is theoretical; the other is operating parameters. There are usually significant differences between them.

The **theoretical parameters** indicate the radiated field ratios and the phases of the radiated fields. If the towers are of equal heights, the theoretical *loop* current ratios will be equal to the radiated field ratios; if the tower heights are different, they will be different.

Assuming sinusoidal current flow, a current maximum or loop will occur 90 electrical degrees below the top of a vertical radiator. If that radiator is less than 90 electrical degrees tall, this loop will exist at the tower base. If the tower heights are the same, the theoretical parameters which are shown on the station license are those the designer used to mathematically create the pattern and they reference this current loop. When the towers are of unequal height, these ratios reference the radiated fields.

The **operating parameters**, on the other hand, indicate the values shown on the antenna monitor when the array is properly adjusted to produce the correct pattern. The operating parameters often deviate significantly from the theoretical parameters, and this is due, in large part, sample system errors and to the mutual coupling between towers.

No matter how careful the installer is, there *will* be errors in the sample system. It is difficult to make all the runs of sample line exactly the same length, and each individual run will have a slightly different characteristic impedance. Differences in the values of antenna monitor terminating resistors, differences in the sample loops or current transformers, even slight differences in the locations of the sample pickups all contribute to sample system error.

Mutual coupling, on the other hand, distorts the assumed sinusoidal characteristics of the current flow on each tower. There are two on-frequency current components in each element of a directional array — the current that contributes to radiation, and the current induced by mutual coupling from other elements. The current that contributes to radiation tends to be sinusoidal, but the effect of the induced current tends to distort that sinusoidal current distribution. The position of the current loop can be quite a distance from where sinusoidal current distribution would place it.

There are many methods of determining the correct operating parameters for a directional array, but all, to one degree or another, rely on trial-and-error adjustments and field measurements. Knowledge of the design, experience, and computer modeling can all help to make each trial an educated trial (rather than a random guess) and shorten the tuneup process.

8.6 Standard Patterns

In all the examples we have used so far in this series, on certain azimuths, the vectors from the array elements completely cancel one another and the resultant radiation on that azimuth is zero. This is difficult to achieve in the real world. Reradiation, scatter and drift in the phasing, coupling and sampling systems limit how close to zero the radiation on a null radial can be adjusted and maintained. In January of 1981, the FCC instituted the **standard pattern**, which increases the size of the **theoretical pattern** (or calculated pattern) by a specific amount. In another part of this series, we will look at how the standard pattern is calculated.

When the standard pattern was instituted, the FCC calculated the standard pattern for all existing stations and authorized them by modification of each station’s license. Today, when the FCC authorizes a directional pattern for a station, it is the standard (and not the theoretical) pattern that is authorized. The FCC proscribes radiation that exceeds the standard pattern value on any azimuth. The designer must use the standard pattern as he designs a pattern to fit a particular application as the FCC requires use of the standard pattern in all calculations of interference and coverage.

8.7 The Directional Antenna Formula

The equation to calculate the pattern shape in the horizontal plane for a directional array of n towers is:

$$E = \sum_{i=1}^{i=n} E_i\, f_i(\theta)\, \beta_i$$

Where: E = total effective field strength vector at unit distance (P) for the antenna array with respect to the voltage vector reference axis.

i = i^{th} tower in the directional antenna array.

n = total number of towers in the array.

E_i = magnitude of the field strength at unit distance in the horizontal plane produced by the i^{th} tower acting alone.

$\beta_i = S_i \cos(\Phi_i - \Phi) + W_i$ (phase relation of the field strength at the observation point (P) for the i^{th} tower taken with respect to the voltage vector reference axis.)

$S_i \cos(\Phi_i - \Phi)$ is the space phasing portion of β_i due to the location of the i^{th} tower and W_i is the electrical phasing portion of β_i.)

Where: S_i = electrical length of spacing of the i^{th} tower in the horizontal plane from the space reference point.

Φ_i = true horizontal azimuth orientation of the i^{th} tower with respect to the space reference axis.

Φ = true horizontal azimuth angle of the direction to the reference point (P) measured clockwise from true north.

W_i = time phasing portion of β_i due to the electrical phase angle of the radiated field of the i^{th} tower taken with respect to the voltage vector reference axis.

This equation, when applied to a directional array, will yield a complex number that represents the field strength and phase of the signal arriving at a particular observation point from each element in the array. This is no more than we were doing in our heads in Part 5 of this series with simple two-tower arrays. With more complex arrays, things get a bit harder, but the basic principle is the same. While this formula may not readily lend itself to working out with pencil and paper, computer types will find that it is easily written into computer code.

8.8 Envision the Vectors

To see the vectors for a particular azimuth, all we really need to know are the theoretical parameters and the following formula:

$$\beta_i = \theta_i + [S_i \cos(\Phi - \Phi_i)]$$

Where: β_i = phase relation of the field from tower *i* on the specified azimuth.

θ_i = phase of tower *i* with respect to the reference tower.

S_i = electrical length spacing of tower *i* from the reference tower.

Φ = true horizontal azimuth angle for which the vector is being calculated.

Φ_i = true horizontal azimuth orientation of tower *i* from the reference tower.

If you look closely, you will see that this is actually the rotational portion of the other formula. At first glance, it looks a lot easier, but what are all those variables? Let's look at a typical set of directional antenna theoretical parameters and see if things start to make sense. Look at Table 1.

Tower	Field	Phase	Spacing	Orientation
1	1.000	0	0	0
2	1.000	90	90	0

These are the theoretical parameters of a typical two-tower directional array, similar to other examples we have used in this series. Let's plug these parameters into our vector formula and see what happens.

θ_i - This is the phase of the tower with respect to the reference tower. In this case, the phase of the reference tower with respect to itself is zero, and the phase of tower #2 with respect to the reference tower is 90°.

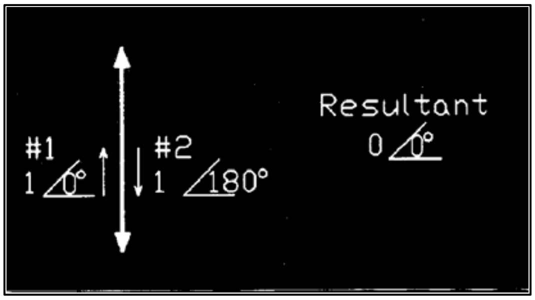

Figure 6

S_i - This is the spacing of the tower, in electrical degrees, from the reference tower. In this case, the spacing of the reference tower with respect to itself is zero, and the spacing of tower #2 with respect to the reference tower is 90°.

Φ_i - This is the orientation of the tower, in electrical degrees, from the reference tower. In this case, the orientation of the reference tower with respect to itself is zero, and the orientation of tower #2 with respect to the reference tower is 0°, or true north.

Φ - This is the <u>azimuth</u> from the center of the array to the observation point. Another way to express this is as the azimuth on which we wish to compute the vectors.

Let's start with $\Phi = 0°$ true. When we plug in all the parameters for tower 1 (the reference tower), we come up with a value of 0°. This is the same as the phase of tower 1, and this will always be true of the reference tower. If the phase of the reference tower had been other than 0°, the formula would have yielded whatever the phase of the reference tower was. In other words, it is not necessary to run the reference tower through the formula — only the other towers in the array. Just know the field and phase of the reference tower. The complex number representing the vector for tower #1 at an azimuth of 0° true, then, is 1.000∠0°.

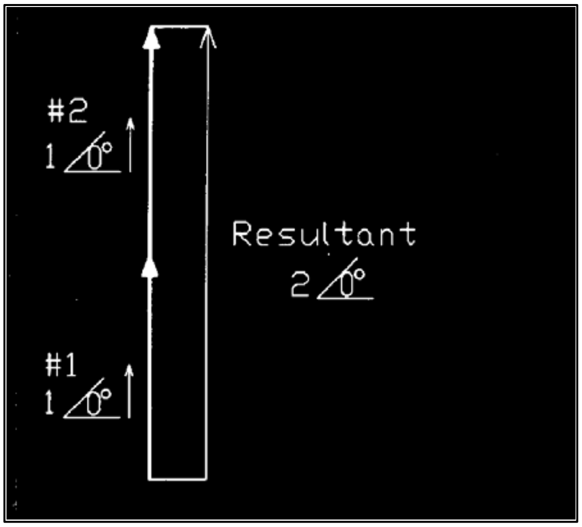

Figure 7

Now, let's run the parameters for tower #2 through the formula. When I did this, I came up with a phase of 180°, so the vector for tower #2 at an azimuth of 0° true is 1.000∠180°.

With these numbers in hand, let's plot them on a piece of paper. You'll need nothing more than a ruler and protractor. The conventional way to plot vectors has zero azimuth at 3 o'clock and angles plotted counterclockwise. For the sake of simplicity and those that have been taught that north is always at the top of the page, the examples here will place zero degrees at 12 o'clock and angles will be plotted clockwise. If you wish to do it the conventional way, do so. It makes no difference in the length of the resultant which way you do it.

Starting near the center of the page, make a dot to represent the starting point. Using the protractor and ruler, draw a line 1.0 inches long at an angle of 0°, or straight up on the page. This represents tower #1's vector. Now, move the protractor to the end of this line (the north end) and draw the vector for tower #2. This line, 1.0 inches long at an angle of 180° (or straight down), will lie back over and completely cover the tower #1 vector, with the end falling back at the starting point. The <u>resultant</u> vector is the distance and angle between the starting point and the end of the tower #2 vector. Since these points coincide in this case, the resultant vector is 0∠0°. This vector diagram for an azimuth of 0° true, shown in Figure 6, shows graphically how at that azimuth the signals from the two towers completely cancel one another.

Now let's try the same thing at an azimuth of 180° true. Remember that the vector for the reference tower is always the same, in this case 1.000∠0°. Plugging tower #2's parameters and a 180° azimuth into our formula, I get a vector of 1.000∠0°. When I draw the two vectors on paper, it is easy to see that the vector from tower #2 completely adds to the vector from tower #1, yielding a resultant vector of 2.000∠0° (see Figure 7).

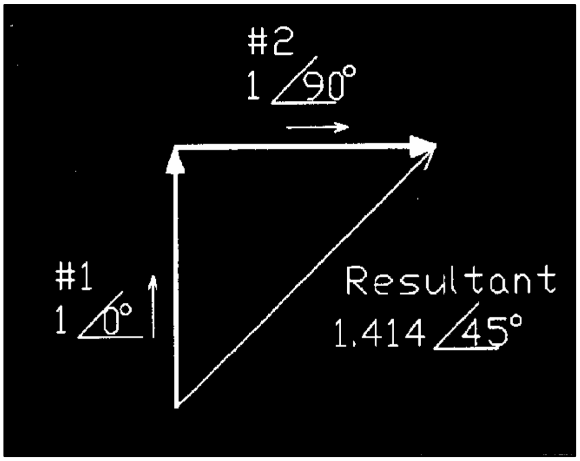

Figure 8

We've seen the extreme cases of complete cancellation and complete addition. Now let's try something in between. Plug in an azimuth of 90° true and tower #2's parameters and you should come up with a tower #2 vector for 90° true of 1.000∠90°. Draw tower #1's vector of 1.0" at an angle of 0°, then draw tower #2's 1", 90° vector onto the end of that. If you measure the resultant vector, you'll find it is 1.414" long at an angle of 45° (see Figure 8). You can see from this graphical representation that the signals from towers 1 and 2 partially add to produce a field that is greater than the field of either one, but less than the sum of the two combined. If you run the same problem for an azimuth of 270° true, you'll find you come up with the same vector. Go ahead and try this at other in-between azimuths. You'll find that when you get closer to 0°, you get more cancellation of the two signals; when you get closer to 180°, you get more addition.

What if you have more than two towers? It's simple. Calculate the vector for each tower and draw it onto the end of the preceding vector. The resultant vector will still be from the starting point to the end of the last vector. When dealing with arrays with more than two towers, it is important to label the vectors as you draw them. If you dn't, it is easy to lose track of which vector belongs to which tower.

Three-tower vectors are fairly easy to draw, but when four or more towers are involved, it becomes more difficult. It should be understood that the angle of the resultant vector is not important. Only the length is important. As you experiment and plot different vectors, don't get hung up on the resultant angle. The field strength meter does not care what the incident phase of the resultant field strength vector is.

If you wish to plot the directional pattern of the array on a piece of polar graph paper, simply plot a dot representing the scaled length of the resultant vector on the azimuth at which the vector was calculated. In the case of the 180-degree azimuth in the example above, you would plot a point at distance from the center of 2 times the scale value at an azimuth of 180 degrees. For the 90-degree radial you would plot a point at a distance from the center of 1.414 times the scale value at an azimuth of 90 degrees. Calculating the length of the resultant and plotting it at five-degree increments all the way around, you can then smoothly join the points together in a graphical representation of the pattern shape.

8.81 Using the Vectors

With the vectors in hand, we have at our disposal a method of graphically depicting what is happening on any given azimuth. This is particularly helpful when setting up an array or working to correct a problem. By plotting the vectors on a given radial, you can see how the different towers interact to create the resultant field on that radial. Many monitor points are on null radials, where some degree of cancellation occurs. By plotting the vectors, you can visualize how towers pair-up on the radial. In parallelogram arrays, pairs of towers often cancel other pairs of towers. Using vectors, you can get a mind picture of the best way to go about adjusting such an array.

9.0 Transmission Lines

Just as the electrician must choose the correct size and type wire for a particular wiring job, and the plumber must select the appropriate pipe, as radio engineers we must choose the right size transmission line. If the wrong line is chosen, the results can be with catastrophic. Proper transmission line selection can make the difference between having a system that is reliable and capable of continued operation under adverse conditions, or having a borderline system that is a time-bomb primed for failure. Sometimes the choice is clear and the differences are obvious; other times the limitations are hidden. In this installment of our AM Antenna series, we'll look at feed lines and explore these limitations.

There are three types of transmission lines commonly used today to feed power from the transmitter to the antenna system. One of these is the open-wire feeder, of which there are several variations.

9.1 Open-Wire Feeders

Transmission lines or feeders created from open (unshielded) wires supported on glass or ceramic insulators are commonly referred to as open-wire feeders. Amateur radio operators often use ladder line, which consists of parallel conductors separated by Plexiglass rods, to provide a balanced feed for high-frequency (HF) antennas. Twin-lead, which used to be the feedline of choice for television receiving antennas, is another variation of the balanced open-wire feeder theme. Neither of these has any practical use in broadcasting because of the relatively low power handling capability, but there are some other types that were commonly used in radio’s early days. Three and six-wire unbalanced systems are the most common of these, and some vestiges of these systems remain today. No new systems have been constructed using open-wire feeders in many years.

Three-wire systems, where two ground conductors supported on telephone pole cross-arms bracket the center RF conductor are one such type. This type of transmission line has a relatively high impedance, can withstand high peak voltages and is relatively easy to maintain. Cracked and broken insulators as well as deteriorated or damaged support structures are the biggest problems with this type of open-wire feeder.

The six-wire feeder consists of four relatively small ground conductors bracketing two parallel center RF conductors in a cubical fashion. In effect, this creates a coaxial cable of sorts. Six-wire systems are typically supported on short creosote poles. The impedance is usually lower than three-wire open feeders. Disadvantages are lower peak voltage capacity, generally lower power handling ability and greater mechanical complexity. With so many more wires — usually 8- or 10-gauge soft-drawn copper — and six glass insulators on each rather complex support structure, there are many points for potential problems. Ice poses a particular hazard for this type of open-wire feeder. One environmental problem that is often caused by this type of feeder occurs when the spacing between ground and center conductors is sufficient to allow small birds to perch on the center conductor wires. When the birds take to flight, their wings can come into contact with the outer wires. The results of this inadvertent shunting of the transmission line are predictable. The feeder survives; the birds do not.

Open-wire feeders were used in the early days of broadcasting for a number of reasons. One was that they could be made on-site out of readily available materials. Another was that they were capable of withstanding large standing wave ratios. In the days before the operating impedance bridge, driving point impedances in multi-element arrays were difficult or impossible to measure with any accuracy. Transmission lines that could withstand the inevitable high VSWR were needed.

9.2 Coaxial Transmission Lines

Coaxial cable is the *de facto* standard transmission line today and it has been for quite some time. As its name implies, coaxial cable is constructed using two concentric conductors on a single axis. Under the broad heading of coaxial cable are several sub-categories. In broadcast transmission applications, we primarily use semi-flexible cable, sometimes referred to by the trade names “Heliax®”or “Flexwell®,” and rigid line, sometimes referred to as "hard line."

9.21 Semi-Flexible Cable

Semi-flexible cable is by far the most common transmission line in use in AM stations. It is ideal for a wide range of low and medium power uses, and its cost is considerably lower than that of comparably rated rigid line. The term "semi-flexible" is used because the bending radius of the line is quite large. For a 1-5/8" line, the minimum bending radius is 20". Anyone who has wrestled line such as this into a tight space or through a conduit will attest that “semi-flexible” is indeed an appropriate moniker.

Under the heading of semi-flexible cable are both foam- and air-dielectric lines. Foam lines are designed for applications that do not require a pressurization path to the antenna. Their average power handling capability is lower, and loss is higher than the same size air-dielectric line, but their peak power ratings are higher. This is primarily due to the higher losses of foam as a dielectric. Foam-dielectric cable is available in sizes up to 1-5/8".

Air-dielectric lines utilize a spiral polyethylene spacer to keep a constant spacing between the inner and outer conductors. To maintain safe operation, this type of line must be kept under constant pressurization with dry air or nitrogen. Usually, a dehydrator or nitrogen regulator is connected to the line at the transmitter building end of the run to provide pressurization. Weekly checks of the amount of pressure in the line should be part of the engineer's routine inspection. Leaks that develop are a sure sign of impending trouble and should be investigated quickly.

Air is, by far, a superior dielectric to foam. It does ionize more easily than foam, however, and this results in the lower peak power ratings. Because air does not heat up as foam does with power applied, air dielectric lines can handle higher average power than foam lines of the same size. Copper heating becomes the primary average power limiting factor in air dielectric lines.

9.22 Rigid Lines

Rigid lines are available in sizes from 7/8" to 9-3/16". They have inherent low losses and high power handling capability. Rigid lines are normally made in 20-foot lengths with flanges on each end. Inner conductors are made of high-conductivity oxygen-free copper that are supported inside the outer conductor by peg or disk insulators with a low dielectric constant (usually ceramic or Teflon).

If you have ever experienced a catastrophic failure of a transmission line, you will appreciate the repairability of rigid line. Often, when a burnout occurs, it is confined to a relatively small area. The affected section(s) can be easily replaced and the remainder of the line cleaned thoroughly to remove soot particles. For a fraction of the cost of replacing the entire transmission line run, a station can often have its rigid line repaired and be back on the air in a very short period of time. Many stations using rigid lines keep a spare section or two on hand along with spare connectors, flanges and hardware for just such an occasion.

9.3 Characteristics

Several properties determine the suitability of a given line for a particular application. These properties are published in charts and graphs provided by the manufacturers of such lines. Every engineer should keep several transmission line catalogs handy. In addition to line ratings, they contain all kinds of other useful engineering information.

9.31 Impedance

Impedance is one of the most important properties of a transmission line. The value of a transmission line's impedance is determined by the size and spacing of the inner and outer conductors as well as the dielectric constant of the dielectric material between the conductors. Most lines in use today are rated at 50Ω, although I have measured the impedance of such lines to ±10% of the nominal rated value. 75Ω is a common impedance value in older systems, particularly AM systems. Occasionally, transmission lines with characteristic impedances of 51½Ω, 52Ω, 63Ω and even odder values can be found in older installations. For all practical purposes, unless you are replacing an older line and there is some compelling reason to use an odd-impedance line, 50Ω is likely to be the desired impedance of any line purchased today.

9.32 Power Rating

The power handling capability of a transmission line is absolutely critical to its proper selection and safe use. It is limited by either the maximum peak power (determined by the electric field strength and dielectric constant) or the maximum average power (determined by the allowed temperature rise of the inner conductor).

Using the manufacturer's supplied ratings, you can tell at a glance what the average and peak power capabilities of a given line are. What takes more than a glance to determine is whether a given line size is suitable for a given application. A look at just about any manufacturer's power rating graph will also show that the peak and average power ratings tend to converge at lower frequencies so that at AM frequencies, where skin effect is minimal, they are the same.

9.33 Derating

Consider an AM station that needs to replace the transmission line to one of its directional array elements. Let's assume that there is normally 10 kW of power flowing to that particular element. According to the manufacturer's published ratings, 7/8" foam dielectric line is capable of safely handling 44 kW. That should be *plenty* of safety margin, shouldn't it? Let's look closer.

If we're going to modulate the power being fed to the DA element 100% positive, the peak power will be equal to 40 kW. That's getting pretty close to our 44 kW rating. If we allow for 125% positive modulation, our peak power is over 50 kW, well above the peak power handling capability of the transmission line.

Another variable that we need to allow for is VSWR. In any real world situation, even in the best matched system, there will be times when the VSWR on a transmission line will be higher than 1.0:1. This can be due to ice, changing ground conductivity, defective ATU components or a number of other factors. In choosing a transmission line, always allow for 2:1 VSWR. This will provide an adequate safety margin in most cases.

The formula for derating a transmission line for VSWR and modulation is as follows:

$$P_D = \frac{P_{PK}}{(1+M)^2\,VSWR}$$

Where: P_D = Transmission line derated power

P_{PK} = Transmission line rated peak power

M = Modulation percentage as a decimal

Using this formula, you can compute that our 7/8" foam line, rated at 44 kW peak power, is only good for a little over 4 kW! Take my word for it; at a station here in Dallas, this very scenario played out with the result being a burned up, brand new transmission line. If I had my way, manufacturers would overlay this formula in red on their power rating tables and graphs!

9.34 Attenuation

Attenuation is another important line characteristic. It is caused by a combination of the I^2R losses of the copper and the dielectric losses of the dielectric material. The losses in the dielectric material tend to be directly proportional to the frequency. Conductor losses are related to the dimensions, permeability and conductivity of the material and tend to vary with the square root of the frequency.

While the rated attenuation of a

transmission line is very significant at FM and TV frequencies, it is seldom significant at AM frequencies. Line losses are so low in a typical AM system that they can be ignored altogether, provided that the transmission lines are otherwise adequately rated.

9.4 Fittings

Many types of fittings and terminations are available to allow us to make the transition between the coaxial transmission line and RF sources and terminations. The *end terminal adaptor* is in common use at AM frequencies. This device creates an airtight seal to the transmission line and provides a brass stud connection for the center conductor. The body of the fitting is equipped with threads and a nut for the ground connection. On air-dielectric lines, a gas port is provided on the fitting to facilitate pressurization or purging. By far, this is one of the easiest means of connecting the tubing in a phasor or antenna tuning unit to the transmission line.

LC-type connectors were once popular at lower power levels for lines up to 1" in diameter. This is a coaxial screw-on fitting very similar to the PL-259 connectors used on RG-8 cable.

EIA flange connections are very popular means of line termination. The outer conductor of the flange bolts onto the chassis of the equipment, and the center conductor is attached with a “bullet”, which is a spring-loaded expansion connector that fits inside the center conductor. EIA flange terminations for air dielectric lines provide a gas port. None is needed on foam line terminations. Rigid transmission lines almost always terminate in EIA flanges, although adaptors to end terminals and other types of fitting are available.

When choosing the fitting to use on a transmission line, the connection provided by the equipment manufacturer should be considered. Obviously, the two have to match. In high altitude situations, the end terminal adaptor may be a better choice than the EIA flange because of the larger spacing between the stud at the end of the terminal and the body of the connector. EIA flanged connections are prone to arc over in high power situations at high altitude, where the air ionized more easily.

10.0 RF Ammeters

To maintain proper operating parameters in an antenna system, it is necessary to have a means of accurately measuring the antenna current. We have several tools available to us to measure this parameter, and in this part of our AM antennas series, we will examine the different types and look at their advantages and limitations.

10.1 The Thermocouple RF Ammeter

The most popular RF current measuring device has long been the thermocouple ammeter. This device consists of a DC meter movement connected to a thermocouple through which RF current flows. When the thermocouple is heated, a proportional current flows through the meter winding, causing deflection of the meter.

Thermocouple RF ammeters have the advantage of simplicity. They are typically manufactured with stud-type connections by which they are connected into the RF circuit under test. To prevent damage due to lightning currents or static discharges, a make-before-break switch is typically provided in permanent metering circuits to allow the meter to be placed into the circuit for measurement and removed from the circuit for normal operation, all without disturbing the continuity of the RF current path.

Some metering circuits are manufactured with a “hot jack,” which is a make-before-break receptacle into which a removable meter is plugged. The meter itself is usually mounted on a phenolic handle to permit it to be safely plugged into the RF circuit without causing RF burns to the user. The advantage of this plug-in type of meter is that the thermocouple meter itself is stored in the transmitter building, out of the elements that can affect its calibration.

Thermocouple RF ammeters have the advantages of relatively low cost, simplicity, accuracy and broad frequency range. The disadvantages are susceptibility to damage. Lightning currents and static discharges through a thermocouple meter are usually fatal. Nearby lightning discharges can cause magnetization of the meter movement, resulting in inaccurate readings. This type of damage is particularly troublesome, since it may not be readily apparent, as a catastrophic failure would be.

It is easy to check the calibration of a thermocouple RF ammeter, because of its wide frequency range. Simply connect the meter being checked in series with a calibrated AC ammeter across the secondary of a variac. By adjusting the amount of current flowing with the variac, the indications of the two ammeters can be compared. If it is discovered that the RF ammeter is in error, repairs can be attempted or a calibration chart can be made to validate the meter’s indications.

In a directional array, where base current RF ammeters are used to maintain base current ratios, it may be desirable during the construction and tuneup process to calibrate the RF ammeters against one another. If one meter in the set is at significant variance with the others, it can then be replaced with one that tracks the other meters or a calibration chart can be made. Likewise, if the base currents in an array are found to be out of tolerance but all the other array parameters and monitor point field strengths are normal, it is a good idea to check the calibration of the thermocouple RF ammeters before doing anything else.

If the inaccuracy of a thermocouple meter is believed to be caused by a magnetized meter movement, a degaussing coil can be used to demagnetize it. In most cases, the meter’s accuracy will return when the residual magnetism has been removed.

10.2 The Toroidal RF Ammeter

The other type of RF ammeter that is becoming very popular is the toroidal-type, which consists of a shielded, toroidal current transformer connected to a rectifier/filter that in turn drives a meter. This type of RF ammeter employs a separate, shielded current transformer which produces a fixed voltage per ampere of RF current flowing in the circuit being measured. The meter is housed in a separate unit and contains the rectifier, filter and a switch that removes the meter itself from the circuit. A relay that allows remote activation of the meter is optional on some units. The current transformer is connected to the meter unit with a piece of coaxial cable. At the factory, the meter, transformer and cable are calibrated as a system. In the field, using a different coaxial cable or switching metering units between transformers will result in inaccurate current readings.

One of the biggest advantages of this type of RF ammeter is that there is no direct connection to the circuit under test. This has a twofold effect: one, it does not introduce a new component into the circuit's impedance; and two, the propensity for damage by lightning strikes and static discharges is decreased by a large factor.

Another advantage is that with a single pickup transformer, a meter with multiple, switchable scales can be used. Many radio stations operate with significantly different power day and night. Some of those that operate with similar powers operate different directional patterns where the current in a particular element may be large in one configuration and very small in another. It is difficult to measure such diverse values of current with a meter using a single scale. Using a multiple, switchable scale toroidal RF ammeter, a current of 25 amperes can be accurately measured on one scale while a current of less than 5 amperes can be measured on another. Optional relay switching within the ammeter allows remote base current metering on the appropriate scale. This can be tied into the pattern switching logic of the array and the correct scale will always be selected for the current mode of operation.

One manufacturer is now offering a toroidal RF ammeter package on an insulated carry-around, plug-in frame. This package offers the same advantages as the plug-in thermocouple RF ammeter — it allows the meter to be stored in the controlled environment of the transmitter building, out of harms way. Another advantage is that base current ratios can be read much more accurately using a single meter than they can using multiple meters with varying amounts of error in their calibration.

About the only disadvantage to the toroidal RF ammeter is initial cost. They are more expensive than their thermocouple counterparts. Long term, however, their cost is lower than that of thermocouple meters. Their better durability, stability and accuracy will more than compensate for their higher initial cost. In some cases where multiple scales are needed to accommodate different patterns or current values, a single switchable-scale toroidal meter may be less expensive than two thermocouple meters with all the requisite switching hardware.

11.0 Sampling Systems

At the heart of every directional antenna is a sampling system that provides indication of the relative currents and phases in the elements of the array. The key to a successful sampling system is stability. A stable sampling system will make true changes in array operating parameters evident so that they can be compensated for and the array kept in adjustment. A sampling system that is not stable will provide false indications of array drift that the engineer will then "chase" with phasor controls, unknowingly cranking the array out of proper adjustment with no clear way back!

A directional antenna sampling system is made up of three elements: a sample loop or sample transformer for each element, an antenna monitor that measures the relative amplitude and phase of each sample, and transmission lines that connect the samples to the antenna monitor.

11.1 Sample Loops

A sample loop is just what its name implies — a one-turn metallic loop that is permanently attached to the tower. A typical loop is made of galvanized or stainless steel angle iron. Some loops are made of large-diameter copper tubing, but these are not as durable as steel loops. As a rule, a sample loop must be mounted 10 - 15 feet above the ground, except on tall towers, where the loop is positioned 90 electrical degrees below the top of the tower. If the towers in the array are all the same height, the sample loops should all be located at the same height above the base insulator.

Sample loops can be either insulated from the tower and kept at ground potential, or operated at tower potential. The latter method is more common. In such cases, the sample line itself is wound into an isolation coil that presents a high impedance at the carrier frequency to carry the current sample across the base insulator without significantly affecting the impedance of the tower or disturbing the sample itself. This iso-coil provides a convenient static drain for the tower, and a capacitor can be used across part of the winding to achieve a parallel resonance and "float" the tower for modes where that element is not used (such as non-directional operation).

Sample loops have the advantage of being mounted above the base insulator, on the radiating element itself. As such, they tend to provide a superior sample and give a relatively good indication of the current and phase at the loop location. The disadvantage is that they are exposed to the elements all the time and subject to deterioration and damage. When the antenna monitor suddenly shows array parameters at variance, particularly when only one element seems to be affected, check the sample loops first.

11.2 Sample Transformers

Sample transformers consist of a shielded toroidal loop through which a conductor carrying RF current to the tower is passed. Such transformers are essentially the same as those used in toroidal RF ammeters. A given RF voltage is produced per RF ampere flowing through the conductor being sampled, e.g. one or two volts per amp.

Sample transformers are typically mounted inside the tuning house or ATU enclosure and as such, have the advantage of being out of the elements. Such pickups are very stable and sampling systems that employ them seldom exhibit drift. In addition, no iso-coil is needed. The disadvantage of sample transformers is that they sample the current below the base insulator as opposed to the actual radiation current. The sample taken at that point will include a small component that flows to ground through the base insulator capacitance. In addition, sample transformers become unreliable is the element being driven is more than 130 or so electrical degrees tall.

When ordering a set of sample transformers, the manufacturer can provide a set that is matched as closely as possible. Voltage output within 1% and phase tracking within 0.5° are attainable, and when using sample transformers to set up an array, it is best to be as accurate as possible.

By way of comparison, it is usually easier to set up a new directional antenna using sample loops than using sample transformers. From an operational standpoint, sample transformers are better to work with because of their stability and reliability. Ideally, one would use sample loops to set up an array and sample transformers to monitor it. The expense of using both kinds of sample is too great, however, so this is seldom (if ever) done.

11.3 Sample Lines

The transmission lines used in a sampling system are a critical element. In a typical system, all lines are of the same electrical length, exhibiting the same amount of phase shift. Typically, _" or ½ " foam coaxial cable is used for sample lines. When installing the system, the line to the farthest element in the array is laid out and cut. Then, the remaining lines are cut to match the longest line. To achieve equal phase shifts in all the lines, it is then necessary to measure the electrical length of the lines, either with a time domain reflectometer (TDR) or by measuring the resonant frequency of the transmission line. Through careful measurement and trimming, it should be possible to achieve phase shifts within 0.1° from line to line.

When installing sampling transmission lines, it is important to install all of each of the lines in similar environmental conditions. For example, if one line is buried underground, all the lines should be buried underground. If the last 20 feet of one line is above ground in the transmitter building, the last 20 feet of all the lines should be similarly installed. Excess lengths of line, such as that of lines that run to the nearer towers in the array, should be stored in the same conditions as the rest of the lines. Typically, if the sample lines are buried underground, the excess line is also buried. The purpose of this is to maintain a uniform phase shift from line to line. Were all of one line buried and another line half buried and half in direct sunlight, considerable variation in phase shift between the two lines would be expected. This is unacceptable in a directional antenna sampling system.

In choosing a sampling system transmission line, there is both normal and phase-stabilized line. Phase-stabilized transmission line has been temperature treated to achieve a repetitive phase-temperature characteristic for reliable tracking. This is achieved through heat cycling at the factory that relieves the mechanical stresses that are part of the manufacturing process. Phase-stabilized transmission line is considerably more expensive than normal line, and its value is questionable. After a few weeks or months in service, a normal transmission line becomes naturally phase-stabilized, and if the lines are all installed in the same environmental conditions, the phase shifts of all the sample lines in the system will change by the same amount with temperature variations anyway.

11.4 Antenna Monitors

The final element in a directional antenna sampling system is the antenna monitor. This device terminates the sample lines and electronically compares the relative currents and phases of the samples. One tower for each mode of operation is selected as the reference tower, or the tower to which the other tower samples are referenced. The indicated phase of the reference tower is usually zero, and the current ratio is 1.000.

The phases of the other towers in the array are displayed as leading or lagging that of the reference tower. For example, if one tower in the array indicates -80° on the antenna monitor, that means that the current in that sample is lagging 80° behind the current in the reference tower sample.

The currents in the other towers in the array are displayed as a ratio, or a percentage of the current in the reference tower. For example, if one tower in the array indicates a ratio of 0.650 on the antenna monitor, the current in that element is 65% of that in the reference tower.

Older antenna monitors could only select and monitor one tower at a time. The loop reference, or calibration of the reference tower current sample, had to be adjusted each time before the remaining ratios were read in order to insure accuracy. This type of antenna monitor was difficult (but not impossible) to accommodate with a remote control system.

Modern antenna monitors simultaneously monitor all tower samples at once. The loop reference is continuously and automatically set. An analog voltage sample representing each tower's ratio and phase is continuously available, making remote monitoring of the antenna monitor easy. These modern antenna monitors also have an amplitude mode, where the actual RMS voltage of the sample is displayed. If the loss of the transmission line and the volts per amp output of the sample transformer (if used) are known, this display can be used to remotely monitor base currents, a very handy feature indeed!

11.5 Accuracy

Because of distortions in the sinusoidal current distribution in the towers of a directional array that are caused by mutual coupling between the elements, it is just about impossible to obtain a sample that resembles the theoretical phases and ratios of the properly adjusted array — no matter how carefully the sampling system is calibrated. With modern moment method computer modeling, however, it is possible to closely predict what the actual driving point ratios and phases should be. With an accurate sampling system and this computer model in hand, it is much easier to set up an array.

More important than accuracy, however, is stability. Since a directional array is set up and the proper indicated phases and ratios are determined by field strength measurements, it is more important that a sampling system indicate changes from the properly adjusted indications than it is that it accurately resemble the actual currents and phases in the system.

12.0 Control Systems

An important part of most directional antenna systems is the control circuitry. The majority of stations operating with a directional antenna have more than one mode of operation. Some stations operate non-directional daytime and directional at night. There are a few that operate just the opposite — directional day and ND at night. Others operate directional day and night, but with different patterns. Some stations have yet a third mode or pattern for critical hours. Some means of switching between patterns and modes is needed.

12.1 Why switch?

A station that operates non-directional part of the time and directional during other times must have a means of detuning the unused towers. The same is true of multiple pattern directional arrays where some towers in the array are not used in some modes. The method used to detune the unused towers differs with the situation, and some engineers prefer one method over others. Whatever method is used, however, to implement the detuning it is necessary to switch out that tower's directional network and switch in a detuning network at the tower.

When operating with different directional modes, it is often necessary to switch in different components in the antenna tuning unit (ATU) for the different modes. For example, the daytime directional pattern may require a 90-degree lagging network at one tower, while the nighttime pattern may require an 80-degree leading network. Two separate tee-networks would be required, and a means of switching between them would be needed.

12.2 RF Contactors

Switching of components and networks in an AM antenna system is usually accomplished using different variations of the RF contactor. This device uses sturdy, plated finger-stock and plated shorting bars to create a high-current capacity switch. Several individual SPST switches are typically arranged on an insulated frame with a rocker-type armature to create SPDT and DPDT switch arrangements. 110/220-volt AC solenoids or electric motors are used to actuate the armature. Solenoid-driven switches are very fast and provide almost instantaneous transition between switch states, but the current draw of the solenoids is high and the rather violent mechanical action produces significant wear and tear. Motorized RF contactors are much gentler and they typically require very little current to operate, but they are mechanically more complex and are quite slow to operate, taking a full second or more to transition between states.

Another type of RF switch that is sometimes seen in situations where lower power levels are involved is the vacuum relay. Depending upon the impedance of the RF circuit where the relay is inserted, this type of switch can be a very economical alternative. Vacuum relay coils draw very little current, their operation is very fast, and there is generally only one moving part. At higher power levels or in circuits where RF voltages or currents are high, a vacuum relay may not work.

While RF contactors are generally ruggedly designed, they can easily be damaged by lightning, arcing contacts and the like. Lightning, if not properly shunted, may jump from the RF conductors over to the motor or solenoid as it seeks ground through the AC neutral. The results are predictable — a burned out solenoid or motor. Limit switches are frequent casualties of lightning as well.

RF arcs can occur if the excitation is not completely removed before the contactor goes into motion. An improperly designed or operating control system may allow this condition to occur. When it does happen, arcs develop between the finger stock and the shorting bar. The plating is destroyed at this point, and eventually the shorting bar may become spot-welded to the finger stock or the supporting frame, preventing the switch from moving. Another effect is that the points which have arced tend to be poor connections and heat builds up there as current flows. This heat can destroy the switch in a short period of time.

12.3 A Proper Control System

At the heart of any multi-mode AM antenna system is a control system to manage the operation of all the RF switches and transmitters. The job of this system is to properly sequence all the events that must take place as a mode change occurs and to prevent excitation of the system without all the switches in the proper position.

As an example, let’s consider a multi-tower directional array that must switch between DA-day and DA-night modes. When the command is received from the local pushbutton or the remote control to switch patterns, first the controller must mute the excitation. This is achieved either by opening an interlock, disabling the drive or inhibiting the plate circuit of the transmitter in use at the time. After a preset amount of time has passed (usually a tenth to a quarter of a second or so to allow the transmitter excitation to shut down completely), a command to move all the RF switches in each of the antenna tuning units and phasor is initiated. Once a tally is received from all the switches showing that they have successfully moved to the new position and another preset amount of time has passed, the transmitter excitation is reenabled. From pattern selection to successful completion of the switch, if everything is properly adjusted, should be less than a half second — well within the recovery time of most AM receiver AGCs. In a properly designed, properly adjusted system, listeners will notice little more than a pop when the switch is made.

If something goes awry during the switch, say a contactor does not move, the control system should sense this and prevent the excitation from coming back on. Phasor and ATU components, including transmission lines, can be seriously damaged or destroyed if excitation is allowed to come on feeding an incorrectly configured system. Should, for example, a 50 kW daytime transmitter be allowed to come on feeding a system with one ATU still configured for the 1 kW nighttime pattern, in all likelihood the capacitors in the ATU will be destroyed, and the transmission line is at serious risk of being damaged as well.

12.4 Safety Functions

Operator safety functions should also be incorporated into an antenna control system. In the systems I design, I always insist in fully interlocked phasor cabinet doors so that opening any door or cover plate on the phasor will remove the RF excitation from the system. I also incorporate a key-switch operated interlock bypass circuit which will allow operation of either transmitter into the dummy load while the main is on the air. We have all been in situations, some stressful, where we get in a hurry and perhaps forget to turn the transmitter off before opening an equipment access door. It is important that we protect ourselves and other workers from these situations with safety features.

12.5 Relays vs. Logic

Over the years, antenna control systems have traditionally been designed using relay logic. Throughout my career, I have often thought that these same functions could be achieved easily and more economically using logic circuits instead of mechanically latching relays and time-delay relays. That is true, but with the control system indirectly connected to all that steel sticking up into the air, the mean time between failures could be measured as the time span between the last repair and the next thunderstorm! Relays are fairly immune to the large surges that are bound to come in when lightning strikes, and they can handle large amounts of current.

Only recently, however, one manufacturer has come out with a PCL (Programmable Logic Controller) based antenna switching controller. This controller is completely programmable to operate a set of RF switches and transmitter interfaces in any combination that can be imagined. The interface to the outside world has been ruggedized to give the system good surge/lightning immunity.

Whether relay controlled or logic controlled, the fact remains that either motors or solenoids that run on either 110 or 220 volts AC must be actuated by the control system. There are two ways to do this: One involves running a constant AC power feed to each tower and using low voltage slave relays to actually apply the AC power to the solenoids or motors. The advantage with this method is that a single run of AC power cable can be run to each tower and other AC powered loads — tower lights, ATU lighting, utility outlets, etc. — can be operated from that same source. The down side is the added components (relays, sockets and wiring) necessary.

The other method involves switching the AC current to the motors or solenoids directly from the controller. If solenoids are used, this involves running a rather large (#10 or better) conductor to each side of each solenoid plus a neutral. If motors are used, smaller conductors can usually be used. A separate source of AC power must then be run to each tower for the ancillary loads.

12.6 Care and Feeding

Most modern antenna control systems are built to be fail safe. That means that the system power supply must be on and all the relays/switches in the proper position for the selected mode before the transmitter will be allowed to come on. Redundant power supplies are common, since the failure of the controller supply will prevent the transmitter from coming on, even if all the RF circuitry is correctly configured!

Because the control system is so central to the transmitter site's operation, periodic checks of the power supply voltage are important. Also, it has been said that cleanliness is next to godliness. This is especially true when it comes to relay-based control systems. A dirty relay here can keep the station off the air.

The limit and travel switches on contactor motors or solenoids are especially prone to give trouble. Because of the rather violent action of solenoid operated contactors, these switches really get slammed open and shut. Proper adjustment of limit switches and actuating hardware is critical.

For some reason, in those areas that are plagued with them, fire ants seem to be attracted to AC power (you guys in the north, get ready — they're coming!).I have seen fire ants completely pack solenoid mechanisms to the point where the contactor could not move. Periodic cleaning out of these areas with a vacuum or high pressure air is necessary to keep the mechanisms moving freely. Also, a few moth balls in a cup left in the ATU will go a long way toward keeping ants, wasps and other pests away.

Finally, it is important to periodically test all the interlock and safety circuits in the system. If the transmitter excitation is not being completely killed before any contactor starts to move, arcing and arc damage will occur. An improperly working interlock can get you killed. Test these features at least once a year.

The antenna control system should be invisible if it is working properly. By starting with a good design and continuing with good maintenance, you can achieve trouble-free operation for many years.

13.0 Troubleshooting

From time to time, things go wrong with all antenna systems. Things are bad enough when it happens with a simple non-directional antenna. When a multi-element directional array goes haywire, it can be maddening!

Rule number one in this situation is *DON'T PANIC!* The tendency is to grab phasor controls and try to correct the situation immediately; this is the wrong thing to do! *Don't touch anything* until you have enough information to make an educated decision of *what* to do.

13.1 Incorrect Antenna Monitor Parameters

Let's assume that one or more of the parameters as shown on the antenna monitor are at variance with their proper values. Start by making a note of the proper values on a piece of paper with the values as read on the monitor alongside. In this way you can quickly see what parameters are at variance. If only one or two values are out of whack while all the others are normal, there is a good chance that the problem is with the sampling system or monitor and the array is functioning normally. As a rule, when something changes in an array due to a component malfunction, all the parameters are affected to some degree. This is because of the mutual coupling between the array elements.

You have probably noticed that if you crank the phase of one tower out a couple of degrees and touch nothing else, there is a change in all the other phases, ratios and base currents in the system in addition to a change in the common point resistance/reactance. The same thing generally holds true no matter what the cause of the original change, be it a phasor control being adjusted or a component changing value.

When an engineer calls me saying that something is wrong with his array, I always start by asking him if the common point impedance has changed. If it hasn't, we start with the antenna monitor.

A good next step is to check the antenna monitor by swapping its inputs around. A common failure mode in some antenna monitors is a stuck or open relay. The mercury-wetted relays in these units should be trouble-free and long-lived but they tend to wear out over time. I have replaced scores of them over the years. When a relay sticks, it may cause all the tower readings other than the reference tower readings to be incorrect. To check for this, disconnect all inputs but the reference tower, then connect one of the other tower sample lines to each of the other inputs in turn. You should see the normal indication of phase and ratio for the sample line being used as it is moved from input to input. When you come to a channel where you do not get the correct readings, that is the one with the bad relay. If there is a stuck relay, it tends to load the other channels so while the phase readings may be normal during this procedure, the ratio readings will often be low for all but the channel with the defective relay.

Occasionally, antenna monitor sample line terminating resistors can become damaged by arcs or lightning strikes. The symptom will be a very high ratio on one of the antenna monitor channels. Check these resistors with an ohmmeter while the sample lines are disconnected. They should all be very close to the same value.

The detector diode in your antenna monitor is one of those "future failure components" to watch out for. Usually this diode is a germanium type, very prone to damage from lightning. If this happens, hopefully it will open completely. I have seen them become non-linear, however, giving incorrect readings on all towers. The symptom of this condition will be a significantly changed loop reference setting on the reference tower. If you have to crank that control more than half a turn to get 100% on the loop meter, suspect the detector diode. Another failure mode occurs when a resistance develops in the detector diode. The symptom in this case is excessive ratio meter wiggle with modulation, and all the ratios tend to be incorrect.

Another possibility is the faulty sample line. You can check your sample lines by running an open circuit/short circuit impedance test on them. This will give you the characteristic impedance and approximate electrical length of each of the lines. You can also bridge the sample lines open-circuit at an odd quarter-wavelength resonant frequency to determine exactly the electrical length. The best way to check sample lines is with a time-domain reflectometer (TDR). These devices are generally available for rent, and many tower riggers now have TDRs in their shops.

Sample loops can cause trouble, with welds and insulators breaking. Sometimes high winds can blow loops around so that they are no longer properly oriented. A sample loop should be positioned so that it is perpendicular to the tower face behind it. A good way to check loop alignment is to stand at the tower base and look up at the loop — if positioned properly, the loop should line up with the guy wire. Inspect the loops up close, looking for corrosion, loose connections and hardware, etc. Most loops attach to the sample line with an N- or UHF-connector of some sort. Check these connectors for water, corrosion, etc. There may be a copper strap or braid used to jumper from the connector to the open end of the loop. This strap can easily break loose from the loop. Be sure that it is well bonded to the metal of the loop.

Toroidal transformers can, from time to time, cause problems when used in a sampling system. Some are prone to arc internally when their output is unloaded. While sample lines should always be terminated in the load resistors in the antenna monitor, it is possible that enough voltage could develop at the tower end of a long sample line to allow an arc to occur. If a transformer is suspect, swap it with one from another tower (any but the reference tower) and see if the problem disappears.

13.2 Incorrect Base Currents

The most suspect indicating instrument in any radio station is the base current ammeter. They lie like a slick politician. From the moment they leave the factory their calibration becomes suspect. Vibration, magnetic anomalies, temperature, humidity, insects, moisture — everything — affects their accuracy. Toroidal current meters can also lie, but they are more reliable than thermocouple meters. If everything else is okay (antenna monitor parameters and monitor points), suspect one of the meters. The very best way to keep base current meters accurate is to use one meter at all the towers, carrying it to the towers and plugging it in when needed and storing it in the controlled environment of the transmitter building when not in use. This can be done with either type of meter.

13.3 High Monitor Point

A likely cause of a high monitor point reading is an anomaly at or in the vicinity of the point itself. Reradiators and other factors beyond the station's control can influence the field strength at a monitor point. If you find a point high, don't adjust anything. Measure five or six points on the radial and see how they compare to the last full or partial proof. If they are in, you can assume the array is in adjustment and the monitor point itself has become unusable. §73.158 specifies the procedure for changing the monitor point on a radial.

If the entire radial is high, the array may be out of adjustment, even though the array parameters are all within tolerance. This can easily occur in arrays with very tight nulls. Before you start cranking, though, it is a good idea to put the array in the non-directional mode and look at five or six points along the radial both ND and DA. Compare the ratios with those in the last full proof. It could be that a conductivity change is responsible for the high readings and the array is in adjustment.

13.4 Faulty Component

From time to time, parts do fail in directional antennas. The most common failure component is the mica capacitor. I always suspect them first, but they aren't always the problem.

A symptom common to component failure is heat. Shut the system down and immediately but carefully feel of all the components in the phasor and ATUs. Some components may be warm but none should run hot. Suspect any hot component. Look at all the coils for discoloration caused by heating. Loose hardware can get red hot under current, causing oxidation and an intermittent connection. Look for leaking capacitors as well.

If you have an RF bridge on hand, use it to measure the reactance of any suspect components. If you aren't fortunate enough to have a bridge at your disposal, you can use a capacitor checker. Many stations have the old-style "magic eye" capacitor checkers lying about. Use a capacitor of known value to test the checker before testing the suspect cap. Take lead inductance into consideration when reading capacitor value on the checker. If you don't have a bridge or capacitor checker, many of the better digital multimeters (some in the under-$100 range) have a built-in capacitor check function. It might be worthwhile to invest in one.

There are many things that can go wrong with a directional array and there is usually a ready fix for each type of problem. Seldom, however, will cranking on the phasor repair a problem. You may be chasing a bad antenna monitor or sample line, or compensating for a component with a changing value. When trouble comes, stop, think and troubleshoot the problem through thorough investigation and logical thinking. Crank on the array only after the problem has been diagnosed and fixed.

14.0 Regulatory Requirements

The FCC regulates broadcast stations, and in the past, there were many and more specific regulations than there are now. In the age of deregulation, the rules are full of the seemingly harmless phrase, "as often as necessary to insure compliance". This phrase took the place of specific intervals for various readings, calibrations and the like that were once in the rules. Now, although we have the freedom to make these measurements on our own schedule, the monkey is clearly on our backs to keep all the parameters within the terms of our station licenses. If you are caught with a parameter out of tolerance, you are likely to not only receive a Notice of Apparent Liability (NAL) for the parameter violation but for not having measured it as often as necessary to insure that it is within compliance as well! That may not seem fair, but it goes to show that deregulation may not be such a good thing after all.

We will begin in the transmitter building and take a walk through the regulatory requirements pertaining to every part of an AM antenna system.

14.1 Antenna Current

An often misunderstood provision of the FCC's rules pertaining to operating power in directional antenna systems says that the authorized input power shall exceed the nominal power by 8% for stations authorized 5 kW or less, and by 5.3% for stations authorized more than 5 kW (see §73.51). That means a 5 kW station employing a directional antenna will employ an antenna input power of 5.4 kW. The station license should reflect the correct input power (and is, in any case, the final authority as to the proper input power), so be sure you use the common point current value specified there rather than one calculated for the station's nominal power.

§73.1215 lists the requirements for indicating instruments, including common point and base current ammeters. Their accuracy must be within 2% of the full scale reading, and the full scale value must not be more than five times the nominal reading. Further, the meter must not read off-scale during modulation. There are certain other requirements pertaining to scale divisions and the like contained in that section. If you are employing a meter manufactured or supplied by one of the mainstream broadcast equipment manufacturers, you can be reasonably sure that these minor requirements have been met.

You should be sure, however, that the normal reading is greater than one-fifth full scale, and that the meter does not exceed full scale under modulation. Many times, following a lightning strike or some other incident, an RF ammeter is replaced with whatever is currently available. Particularly in the case of low power operation, sometimes the replacement meter will not be of the proper scale.

If you find yourself in this position and you are using a toroidal RF ammeter (such as those manufactured by Delta Electronics), you can increase the sensitivity of the meter by running multiple turns of the RF feed through the toroid pickup. The reading will be proportional to the number of turns through the donut (i.e. two turns will double the reading, three turns will triple it, etc.). For example, suppose your low power nighttime operation has a licensed common point current of 0.2 amperes and the lowest scale meter you can find is five amperes. By wrapping five turns through the toroid, the 0.2 ampere reading will appear as a 1.0 amp indication, which is in compliance with the rules. If you do this, however, you will need to file a form 302 (license application) with the FCC to modify the station license to show the new indicated current.

The requirements for remote reading ammeters are contained in §73.57. Remote reading ammeters must be accurate to within 2% of the reading on the regular (local) RF ammeter. The sensors or pickups for remote reading RF ammeters must be located on the transmitter side of the local RF ammeter. If your site employs remote reading RF ammeters, it should be part of your regular routine to compare the readings between the local and remote meters.

RF ammeters, particularly thermocouple meters, are the most likely indicating instruments in an AM antenna system to give incorrect readings or trouble. It is an excellent idea to keep a new, factory-calibrated meter (preferably a plug-in type meter) in the transmitter building. From time to time (at least annually), all the meters in the system can be calibrated against this reference meter.

14.2 Antenna Resistance

Periodic checks should be made of the resistance at the common point or non-directional antenna base. The frequency of this resistance check will vary from station to station, and will probably be determined by the nature of the environment around the antenna. Areas with poor ground conductivity or sites with poor or deteriorated ground systems may see a considerable shift in base or common point resistance with changes in the amount of water in the soil. Similar (and sometimes more dramatic) changes can occur when the ground freezes. If you have a common point bridge built into your phasor, you are all set to make a resistance measurement every time you visit the site. Otherwise you will have to use an operating impedance bridge to make the measurement from time to time as required. If the resistance has changed more than 2% from the value specified in the license, you will need to file an application for modification of license.

14.3 Sample Systems

In directional systems, next to RF ammeters, the sampling system is the most likely element to produce false indications. The FCC rules contain specifications for sampling systems, and specifically contain the requirements for “approved” sampling systems. The basic requirement for an “approved” sampling system is that the transmission lines exhibit uniform phase shift (less than 0.5° difference from the shortest line to the longest line with normal temperature variations).

Should some component in the sample system become damaged or malfunction, it is permissible to operate for up to 120 days without notifying the FCC as long as all other parameters (base current ratios, monitor points and common point current) are maintained. Should the outage exceed 120 days, the FCC must be notified and special temporary authority requested. If portions of the system above the base insulator are replaced, a partial proof of performance will be required. Sample system rules are contained in §73.68.

14.4 Monitor Points

Field strength measurements at the

monitor points (MPs) of directional stations must be made “as often as necessary to ensure that the field at those points does not exceed the values specified in the station authorization”(§73.61). This is one of those instances where it doesn’t matter if you read the MPs yesterday and they were correct, if the FCC inspector finds one or more of them higher than the licensed limit today – you are likely to get dinged both for the high MP and for not measuring the points often enough. If you do not have an approved sample system, the same requirement applies, but the interval between measurements must not exceed 120 days.

14.5 Directional Operating Parameters

On the antenna monitor, the indicated ratios must be maintained within 5% of the values specified in the station license. Phases must likewise be maintained within 3°of their licensed values. At the tower bases, base current ratios must be maintained within 5% of their licensed values. Note that it is not the base current values themselves that are licensed, it is the ratios.

Should an instance arise where the parameters cannot be maintained within the prescribed values, you must measure the field strength at each of the MPs. If they are all below the licensed values, you may continue to operate at full power for up to 30 days without further authority from the FCC while the problem is being corrected. If one or more of the MP field strengths exceeds the licensed maximum, you must reduce power to a level that brings the high MP field strength below the maximum. The rules pertaining to directional antenna system tolerances and procedures for operating at variance are contained in §73.62.

14.6 Fencing

§73.49 requires AM sites using series-fed, folded unipole and insulated base antennas to enclose the base of each tower within a locked fence. The size of the enclosing fence is determined by the E- and H-field present in the vicinity of each tower base. The safe thing to do is fence each element in the array at the radius specified in the FCC’s OET Bulletin No. 65 for the nominal power of the station. By doing this, you can be assured that if something should go wrong and all the transmitter power is fed to any one element, no person can enter into a field that exceeds the ANSI limit. Of course, you can fence the entire perimeter of the property and forego fencing of the individual elements, but in that case you must otherwise delineate the areas where the RF radiation exceeds the ANSI limit.

14.7 Proof Documents

Finally, there is a requirement in §73.154 that the results of the most recent set of directional partial proof of performance measurements be kept in the station records and available to the FCC for inspection. Many stations, however, do not have a copy of their last proof on hand. If you find that you do not have this document, you can order it from one of the copy services in Washington. Not only will having this document on hand comply with the rules, it will provide you with a benchmark for your directional system. Present readings can be compared to those in the proof to determine if a perceived problem actually exists.