DIRECTIONAL ANTENNAS MADE SIMPLE

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How this book will help you understand the inner workings of AM directional antenna systems

Without a doubt, AM directional antenna systems are probably one of the most misunderstood pieces of equipment in a radio station. Many who are masters at manipulating computers and dealing competently with other aspects of the state-of-the-art radio station keep an arms length when it comes to a DA system.

This is a "how to" book. It is not intended to be a treatise on the design of directional antennas. Mathematics have been kept to a minimum. It is not intended to be a replacement for an experienced consultant. There is no substitute for experience!

The pages that follow are intended to give chief engineers, technical directors and technically minded owners a window into the inner workings of these systems. They have been written in a manner that is easy to understand taking the reader on a journey from basic concepts to finished project. It assumes that the reader knows little about the subject. For those with some experience under their belts it hopefully will serve as a reference book on the "how tos" of tasks not performed on a routine basis.

To start, the first chapter covers the basics of the vertical antenna system. Directional antenna systems are made up of two or more vertical radiators. It is essential that the reader have a good working knowledge of the single vertical element before they attempt to understand how it fits into a more complex system. The concepts of ground conductivity, measured field strength and inverse field strength are covered.

Chapter two incorporates the single vertical element into the more complex directional antenna system. Mutual impedance, driving point impedance, phase and the addition and subtraction of RF signals are covered in a manner that is easy to grasp and understand.

Chapters three, four and five take the reader by the hand and guides them through the construction, adjustment and proof-of-performance measurements of a two pattern directional antenna system. The intricacies of measuring driving point impedances and converting measured field strength to inverse field strength are covered in their entirety.

Chapter six contains a wealth of preventative and corrective maintenance tips. It also contains detailed information on hanging other antennas on a DA radiator and making the required partial proof-of-performance measurements.

Comments and suggestions on this publication are welcomed. It is always interesting to know when one's efforts contribute to the knowledge of another. It, too, is always helpful to add to one's own knowledge.

Jack Layton

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Chapter One

Understanding the Vertical Antenna

1.01 The vertical antenna: The standard of the broadcast industry

The antenna used by all AM broadcast stations in the United States is the vertical radiator. It comes in a variety of sizes and shapes. Most vertical antennas used for broadcasting are insulated at the base. These are called *series fed.* A minority have no base insulator but are fed with a parallel wire or slant wire. These are called *shunt fed.* Still others, grounded at their base, have three or more skirt wires running down to the base. These wires are tied together and form the feed point for this type of system. Various names are attached to these skirted towers. The Unipole™ and the Tunapole™ are trade names marketed by two such manufacturers.

Uniform cross section guyed towers and self-supporting towers are other variations. They vary in height from 150 feet to 500 or more feet. All have a ground system buried under them. All radiate a vertically polarized signal.

A broadcast station is interested in covering the city to which it is licensed and its suburban area with as much signal as possible. Thus, there is a need for maximum energy to be radiated along the surface of the earth. Energy radiated up at high vertical angles during hours of daylight is wasted by absorption in the D-layer of the ionosphere. During hours of darkness this energy is reflected back to the surface of the earth several hundred, or even several thousand miles away by the F2-layer of the ionosphere. The radiator that best fills this requirement is the vertical antenna.

When a single vertical antenna is used as a radiator, energy from the broadcast station is radiated in equal amounts in all directions or azimuths. This is called a *non-directional antenna* (NON-D) system. When it is desired to distort this circular pattern, providing less signal strength in some directions and more in others, two or more vertical radiators are used. This is called a *directional antenna* (DA) system. Each radiator is energized via its own transmission line with RF energy from the transmitter. By carefully adjusting the ratio of the current amplitudes in each element and the electrical phase relationship of the current in each element to each of the others the shape of the radiation pattern produced by the system can be accurately predicted and controlled.

This book is intended to primarily describe the "how tos" of building and maintaining directional antenna systems. However, the operation of the DA system is directly related to how each element in the system performs individually. Therefore, a logical place to start would be to examine some of the characteristics of the vertical radiator operating as a non-directional system. Indeed, we will do just that. But, before we begin, it is necessary to review some basic laws of physics and revisit some common antenna terminology.

1.02 The Relationship Between Frequency and Wavelength

Let's generate some energy at 1 *hertz* (Hz) or *one cycle per second* (CPS). For a moment let's imagine we have 3-D glasses that will allow us to see this signal as it travels through space! We press the spring loaded push button switch and start the generator; precisely one second later we let go of the switch. In that one second the leading edge of our one cycle of energy travelled 186,000 miles. This happened just as the the end of that one cycle of energy was leaving the generator. By observation, the length of that one cycle of energy, from beginning to end, was 186,000 miles. Therefore, we can say that the wavelength of one cycle of energy at a frequency of one Hz is 186,000 miles.

THE SPEED OF LIGHT

Centuries ago Galileo looked through his telescope and observed the moons of Jupiter casting a shadow on the surface of the planet. He came up with a formula to predict exactly when the shadows of these moons would darken the edge of our solar system's largest planet. Six months later he again looked through his telescope expecting to find order and compliance with the laws of physics. Much to his dismay everything had gone haywire. The shadow of the moons crossing the edge of Jupiter's visible disc was some many minutes behind schedule. His formula and what he now observed were at odds! Galileo scratched his head. Ah ha, he reasoned, the earth is now on the other side of the sun from Jupiter, some 180 million miles further away! From this information galileo calculated the speed of light. He came up with a figure that isn't very far off what we accept today as the speed of electromagnetic energy (light and radio waves) through free space - 186,000 miles per second or 300,000 kilometers per second.

If we double the frequency to 2 Hz we have to squeeze 2 cycles into the same 186,000 miles in one second. The distance between the beginning and end of one cycle of this energy will be 93,000 miles - half the 186,000 miles. If we go to 4 Hz then 4 cycles must occupy the same 186,000 miles. The distance from beginning to end of one cycle at this frequency is 186,000/4 - 46,500 miles. From this we can conclude that every time we double the frequency we halve the wavelength - the distance between the beginning and the end of one cycle. From this information we can also develop the following formula:

$$\text{(\#1)} \qquad \text{one wavelength in free space(in miles)} = \frac{186{,}000}{\text{f Hz}}$$

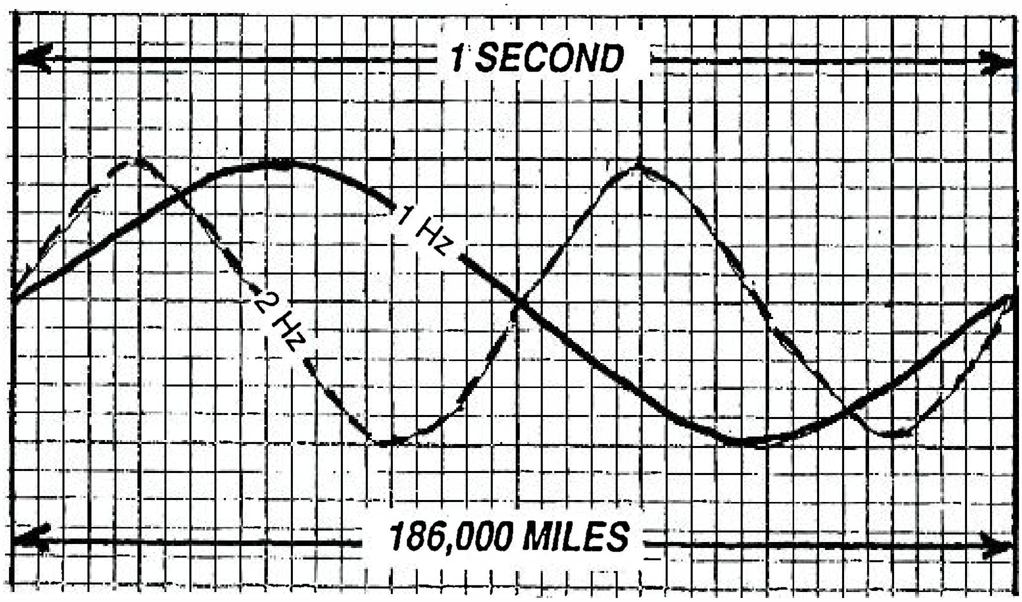


Figure 1-1

A graphical representation of the relationship between frequency and wavelength

This formula, using these units of measure, wavelength in miles and frequency in hertz, isn't of too much use to us. We have to reduce the units of measure to feet or meters and the frequency to *kilohertz* (kHz) or *megahertz* (mHz).

(#2)

$$\text{one wavelength in free space (in feet)} = \frac{186}{\text{frequency in kHz}} \times 5280$$

or

(#3)

$$\text{one wavelength in free space (in feet)} = \frac{982}{\text{frequency in mHz}}$$

or

(#4)

$$\text{one wavelength in free space(in meters)} = \frac{300}{\text{frequency in mHz}}$$

1.03 Angular Measure

In broadcast antenna terminology wavelength, including the length of transmission lines, the height of towers (symbolized by the use of the letter G) and the spacing between antenna elements (symbolized by the use of the letter S) is noted in angular measure or *electrical degrees.* One wavelength is 360 degrees; a half wavelength 180 degrees; a quarter wavelength 90 degrees, etc.

(#5)

$$\text{electrical degrees} = .366 \times \text{frequency in mHz} \times \text{length in feet}$$

For example: a 250 foot tower, at a frequency of 950 kHz, is 86.9 degrees tall.

(#6)

$$\text{one electrical degree in feet} = \frac{2.73}{\text{freq. mHz}}$$

For example: One electrical degree at 950 kHz is 2.87 feet.

(#7)

$$\text{electrical degrees} = 1.20 \times \text{frequency in mHz} \times \text{length in meters}$$

For example: A tower 75 meters tall is 85.5 degrees tall at 950 kHz.

(#8)

$$\text{one electrical degree in meters} = \frac{0.83}{\text{freq. mHz}}$$

For example: One electrical degree at 950 kHz is .87 meters.

METRIC CONVERSION

meters to inches - multiply by 39.37

inches to meters - divide by 39.37

meters to feet - multiply by 3.28

feet to meters - divide by 3.28

miles to kilometers - multiply by .62

kilometers to miles - divide by .62

1.04 The Ground System

Before looking at the actual antenna, which is above ground, let's first take a look at the part of the antenna system which is underground. When using a base fed vertical antenna, whether it is series fed or shunt fed, RF energy is introduced between the radiator and ground; to be more specific, RF energy is introduced between the radiator and the *ground system.* The ground system plays a very important role in the performance of the entire antenna system. An inadequate ground system or a deteriorated ground system will adversely affect the performance of the vertical radiator.

Standards of good engineering practice dictate that the minimum ground system under a tower used for AM broadcasting should consist of at least 120 radial wires (commonly called radials) that extend out at least 90 degrees from the base of the tower. This is one wire, every 3 degrees of arc, fanning out from the base of the tower. The ground radials should be terminated on a copper strap ring encircling the concrete tower foundation. In addition, the ground system will usually consist of a ground screen, 24' X 24', and/or 120 short radials, 50 feet or so in length, interspersed with the longer ones.

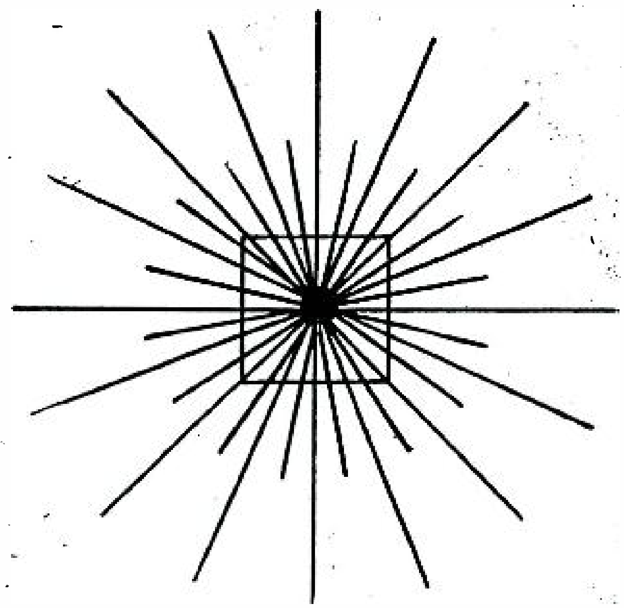


Figure 1-2

Layout of the typical ground system with 120 90 degree radials, a 24 x 24 foot ground screen and short radials interspersed between the longer ones

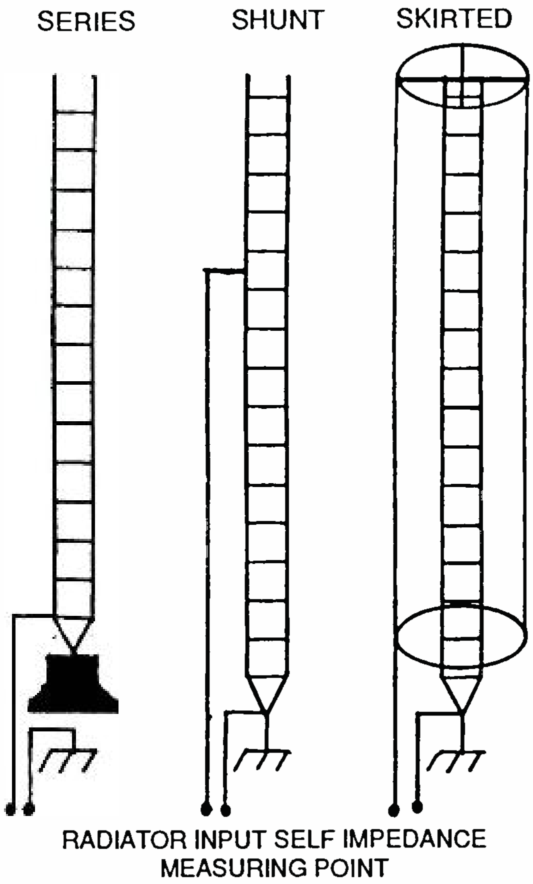
In unusual circumstances, the ground system may be elevated above ground. It can also be laid on the surface of the ground. Normally, it is buried a few inches below the surface of the earth for protection.

A 2 inch, or larger, copper strap is connected to the radial termination at the base of the tower. The strap is buried and taken into the transmitter building for grounding the transmitter and associated equipment racks.

1.05 The Self Impedance of the Radiator

Figure 1-3

Illustration of the measuring point of the self impedance of series fed, shunt fed and skirted radiators



The *self impedance* of a vertical antenna, also called the *base impedance*, is the resistance and reactance present at the input point of the radiator. This is the point where the base current RF ammeter is located and power in a non-directional antenna system is determined by using Ohms Law: $I^2 R$. The impedance is measured at the operating frequency, between the antenna side of the RF ammeter connection (with the meter removed) and the ground system. The only shunt or series element permitted on the antenna side of the measuring point is a *lighting choke* or a *static drain choke.*

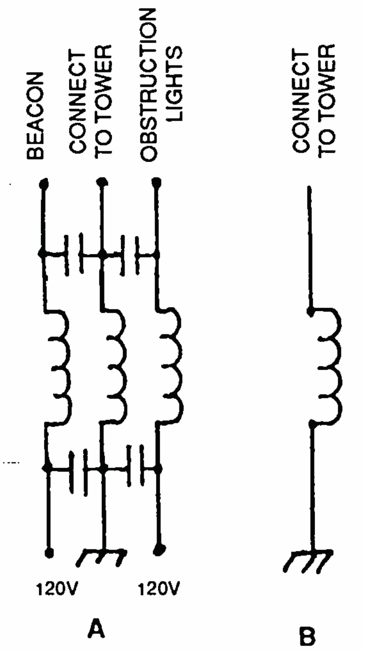
The lighting choke is a bifilar or trifilar wound coil used installed across the base insulator of a series fed tower. AC power for the tower obstruction lights and beacon lights is fed through this coil. It prevents the AC wiring from shorting the RF energy to ground.

The purpose of the static drain choke is to place a DC connection to ground, while preventing an RF short to ground, on a series fed tower. Static electricity generated by nearby lightning storms, dust storms, blizzards and other forms of air ionization is conducted to ground. When a lighting choke is used it will serve double duty as a static drain. In the absence of such a device, static discharges are apt to occur across ball gaps or horn gaps at the tower base or across or through capacitors in the matching network. Both conditions will cause DC overload and/or VSWR protection circuits in the transmitter to trip. Such discharges can destroy components in the antenna matching network.

Figure 1-4

A - typical lighting choke arrangement - minimum inductance of each coil should be 300 microhenries as they are in parallel across the base insulator

B- static drain choke



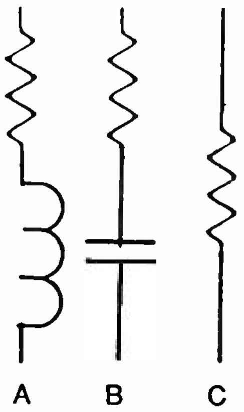


Figure 1-5

The input impedance of an antenna system can consist of A - resistance and inductive reactance +j B - resistance and capacitive reactance -j C - when at resonance resistance only

Coils and capacitors that are part of the antenna matching network, and devices used to measure antenna current remotely, should be located on the matching network side of the base current RF ammeter. In a series excited radiator this input point or measuring point is essentially directly across the base insulator.

The input impedance or self impedance of the series excited tower will be determined primarily by its physical height, by its physical construction (uniform cross section guyed, self supporting, etc.) and the dimensions of the faces of the tower. It will also be influenced by nearby objects (metal fences, other towers, etc.) and the size and condition of the ground system installed under it.

The input impedance will consist of resistance and reactance - symbolized R and X respectively. The reactance in antenna terminology is expressed as plus or minus **j**. Inductive reactance is positive **+j** and capacitive reactance is negative **-j**. The reactance of coils and capacitors used in matching networks is expressed as X_L and X_C respectively.

Table 1-1 shows representative values of various physical heights of self-supporting and uniform cross-section vertical radiators. A typical uniform cross-section guyed tower, with a physical height of 90 degrees, as shown in the table, might be expected to have a self impedance of 50 +j68 - 50 ohms resistance and 68 ohms of inductive reactance. The exact impedance at the operating frequency must be determined by measurement with an RF bridge.

When the antenna is shunt fed there is no base insulator. In older installations where a series feed antenna has been converted to a shunt feed system, the base insulator should be strapped out with four pieces of copper strap running directly from the tower to the ground system. In the case of a self-supporting tower the base insulator on each leg should be strapped to ground in a like manner.

The fencing around the tower, if metallic, must be bonded to the ground system at intervals of 8 to 10 feet.

SELF IMPEDANCE OF TYPICAL SERIES FED VERTICAL RADIATORS

Physical Height Degrees	Self-Supporting Tower		Uniform Cross Section Guyed Tower	
G	R	X	R	X
50	7	-j100	9	-j170
60	9	-j 70	14	-j108
70	14	-j 25	21	-j 46
80	20	+j 11	34	±j 0
90	60	+j 35	50	+j 68
100	90	+j 80	83	+j136
110	130	+j 90	133	+j 210
120	175	+j 80	240	+j285
130	190	+j 15	425	+j310
140	165	-j 70	760	± 0
150	130	-j 85	430	-j280
160	82	-j 55	360	-j380
170	60	-j 25	210	-j340
180	40	-j 5	132	-j283
190	28	+j 25	86	-j225
200	23	+ j 50	60	-j170
210	20	+j 80	50	-j130

TABLE 1-1 Representative values of self impedance for various physical heights of self-supporting and uniform cross section guyed series fed towers as measured between the base of the tower and a ground system consisting of 120 radials.

AC power for the tower lights can be introduced directly onto the grounded tower. Power wiring running up the tower should be bypassed to the tower at its base with .001 uf or larger, high quality mica capacitors. This reduces the possibility of RF being carried back into the transmitter building on the AC wiring. Likewise, any coaxial cables for STL antennas or RPU antennas that come down the tower face should have their shields bonded to the tower at its base. This not only assures an RF free cable at its termination on the STL or RPU receiver but prevents a large difference in potential from developing between the cable and the tower in the event of a lightning strike. The ground system should also be bonded to the tower at its base. A skirt will usually consist of three or more wires, evenly spaced around the tower, dropping down parallel to the tower, spaced out from it anywhere from one foot to six or more feet. The skirt is electrically tied to the tower either at the top or at some point down from the top. In some installations the shorting stub to the tower is adjusted for zero reactance - resonance - or optimum input resistance. From this point on down the tower it is suspended on insulators to a point a few feet above ground level where all of the skirt wires are tied together. This becomes the feed point of the radiator. Input impedance is measured between there and the ground system. A shunt fed antenna, of a given height, can usually be adjusted to exhibit a higher input resistance than a series fed tower of comparable height.

The input resistance of the shunt excited radiator will be determined by its physical height, by its construction, the dimension of the faces of the tower, the configuration of the skirt installed upon it, and the location of a shorting connection to the tower (if any). It too will be influenced by nearby objects (metal fences, other towers, etc.) and the size and condition of the ground system under it.

1.06 Reactance +j or -j and Resonance

From Table 1-1 note that the reactive component of a vertical radiator is capacitive for very short heights, less than 90 degrees, inductive for heights between 90 and 180 degrees and capacitive for heights over 180 degrees. If this is carried out farther you would see that the sign of the reactance changes every 90 degrees from plus to minus.

Both capacitive and inductive reactances simultaneously are present at the feed point to the radiator. When the capacitive reactance predominates **-j** will be indicated on the RF bridge. When the inductive reactance predominates **+j** will be indicated on the RF bridge.

When the capacitive and inductive reactances are equal only resistance will be indicated by the bridge. This condition is known as *resonance*. Examples of this are the 80 degree and 140 degree uniform cross-section radiators shown in Table 1-1. The input impedance of these radiators consist of resistance only, no reactance. Also note that the reactance at the input to the self-supporting tower shown in the table passes through zero somewhere between 70 and 80, 130 and 140, 180 and 190 degrees in height. This is evidenced by the change in sign of the reactance.

1.07 Velocity Factor

Logic says that these vertical radiators, shown in Table 1-1, should be resonant at intervals of 90 degrees. In fact the resonant heights are at 80 and 140 degrees - a little less than a quarter wavelength and considerably less than a half wavelength.

Let's jump back a few sections to our discussion on wavelength vs frequency. We developed our formulae (#1,. 2, 3 & 4) for wavelength based on the fact that the speed of electromagnetic energy through free space is 186,000 miles or 300,000 kilometers per second. However, in a wire, a steel tower or an RF transmission line its speed is considerably slower. This is the cause of the apparent anomaly. The figures in column #1 of the table are physical heights. Resonance occurs when the electrical height of the radiator is a multiple of 90 degrees.

Also note that the physical resonance heights for the self-supporting tower shown in the table are considerably shorter than those for the uniform cross section tower. A three leg self-supporting tower will exhibit a different input impedance and different physical resonance height than a same height four leg self-supporting tower. Additionally, the distance between legs of self-supporting radiators will have an effect on these parameters.

Velocity factor will be revisited when we discuss coaxial cable used for transmission lines in the DA system.

1.08 Resistance: R

Figure 1-6

R_R is the R in Ohms Law that represents power radiated; R_L is the R in Ohms Law that represents power lost

Again looking at Table 1-1: The input resistance of a short uniform cross-section tower is very low. It increases as the height of the radiator is increased. It passes through a theoretical value of 36 ohms at 90 electrical degrees and continues to increase until it reaches 760 ohms at the 180 electrical degree point then begins to come back down. The self supporting structure exhibits similar behavior but the maximum values of both R and X don't go as high. If we were dealing with a wire radiator, who's diameter is small, the values of R and X would be much higher around the 180 degree height than those shown for the uniform cross-section tower.

As a model, let's go back to our 90 degree tower with an input impedance of 50 +j68. The 50 ohms resistance is made up of radiation resistance and loss resistance. We will call these R_R and R_L respectively. R_R in our power formula - $I^2 R_R$ - represents power radiated by the antenna; $I^2 R_L$ represents power dissipated as heat in ground system losses and ohmic losses in the tower itself. If we put an RF ammeter in the feed point of this radiator and energize it with 1000 watts of RF energy the meter will read 4.48 amperes $(I)^2 \times (R_R + R_L) = P$ $(4.48)^2 \times 50 = 1003$ watts).

The actual loss resistance is difficult to accurately determine. If care has been taken to install an adequate ground system and there are no excessive losses in tower joints, it is reasonable to assume an R_L figure of 3 to 4 ohms. Using the 50 ohms in our model, let's assume we have 46 ohms of radiation resistance and 4 ohms of loss resistance. This represents 923 watts of radiated power [$(4.48)^2 \times 46 = 923$ watts] and 80 watts of loss. [$(4.48)^2 \times 4 = 80$ watts].

To illustrate why it is not good practice to use a very short radiator let's examine a 50 degree uniform cross section radiator. When the height of a tower is decreased below 90 degrees the input resistance will also decrease.
The losses remain substantially the same but become a larger part of the total input resistance.

Figure 1-7

Among other losses, R_L is made up of R_J, the resistance in joints between tower sections; R_S, the resistance of the steel of which the tower is constructed; R_B, losses across the base insulator; R_G, losses in the copper of the ground system and also joints between parts of the ground system

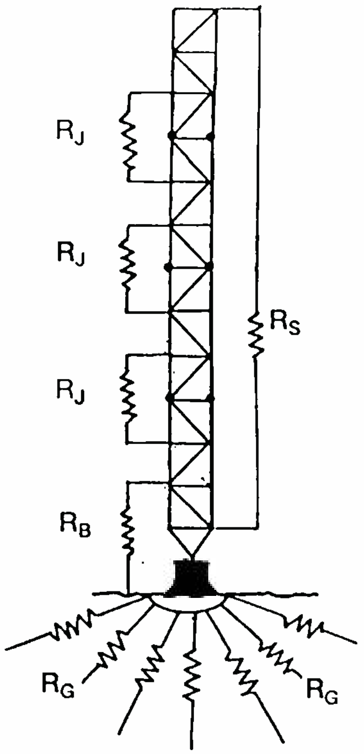


Table #1 tells us to expect an input impedance of 9 -j170. When we energize this system with 1000 watts the RF ammeter will read 10.54 amperes $[(10.54)^2 \times 9 = 1000$ watts]. The losses haven't changed. They are still the result of 4 ohms R_L; therefore, by ohms law 444 watts goes up in heat $[(10.54)^2 \times 4 = 444$ watts]. If the loss resistance is 4 ohms then the remaining 5 ohms of the total R in the input impedance is the radiation resistance. Expect 556 watts to be radiated $[(10.54)^2 \times 5 = 556$ watts].

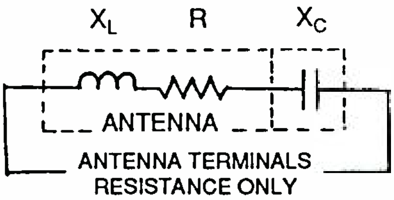
So far in our discussion we have without any effort energized various radiators with RF energy generated by a transmitter. The transmitter is usually located some distance from the base of the antenna. It requires a length of coaxial transmission line to connect it to the radiator.

The transmission line typically is 50 ohms characteristic impedance. We can't just tie it to the transmitter on one end and the input to the radiator on the other end. The output of today's solid state transmitters is 50 ohms. Tying the 50 ohm line to the transmitter is fine. However, the other end of the line must be terminated in a 50 ohm resistive load to make the transmitter comfortable.

1.09 Tuning Out Reactance

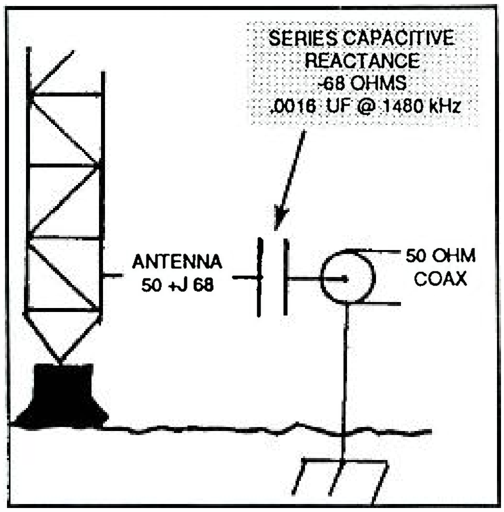
Figure 1-8

The external series X_C equals the X_L, when only R remains



Jumping back to our 90 degree uniform cross-section radiator, the solution to our dilemma is quite simple. The base impedance is 50 +j 68. If 68 ohms of capacitive reactance is added in series with the feed point the only thing remaining is 50 ohms of resistance.

Figure 1-9 Radio station XYZ operates on 1480 kHz. The base impedance of this tower is 50 +j68. A match to the line can be effected by placing a .0016 uf capacitor in series with the feed.



The value of the capacitor needed to produce 68 ohms of reactance is calculated by:

$$C = \frac{1}{2 \pi f X_c} \quad (\#9)$$

where: $\pi = 3.14$

f = frequency in mHz

C = capacitance in uf

If our radio station is operating on 1480 kHz the value of capacitor needed in series with the tower feed to cancel out the 68 ohms of inductive reactance would be:

$$\frac{1}{2(3.14)(1.48)(68)} = .0016 \text{ uf}$$

For the sake of discussion, let's consider the case of a radiator whose input impedance is 50 -j68. We can use the same approach, except in this case we must tune out 68 ohms of capacitive reactance. This calls for a series inductor. The value of inductance needed to produce 68 ohms of reactance is calculated by :

(#10) $$L = \frac{X_L}{2\pi f}$$

where:
$\pi = 3.14$
f = frequency in mHz
L = inductance in microhenries
X_L = inductive reactance in ohms

If our radio station is operating on 1480 kHz the value of inductance needed in series with the tower feed to cancel out the 68 ohms of capacitive reactance is 7.32 microhenries:

$$\frac{68}{2(3.14)(1.48)} = 7.32 \text{ uh}$$

1.10 Matching Networks

That was easy. However, what if the radiator was 110 degrees in height? Table 1-1 indicates that a base impedance of 133 +j210 would be expected. We could pull the trick just described and insert 210 ohms of capacitive reactance in series with the feed. However, we would end up with 133 ohms of R. If we terminated the transmission line on this load the VSWR would be about 2.5:1. Line losses would increase and higher than normal RF voltages would exist at various points along the coaxial transmission line between the center conductor and shield. In addition, the solid state transmitter at the other end of the transmission line would be very unhappy! The VSWR protective circuitry would probably reduce its power considerably or take the transmitter off the air.

An 80 ohm resistor connected across the end of the line in parallel with the 133 ohm antenna feed point would give us a 50 ohm match! The transmitter would be happy. The VSWR on the line would be close to 1:1. However, in the process we would burn up more than half of the transmitter power in the resistor. That's not very practical.

This situation calls for a network made up of inductors and capacitors to match the 133 ohm tower base resistance to the 50 ohm coaxial line. A pi-network could be used; an L-network could be used; or a Tee-network could be used. Any one of these, plus other methods, would yield satisfactory results in this application. Rarely will you find a pi-network in an AM antenna system. Therefore, we will leave it undiscussed.

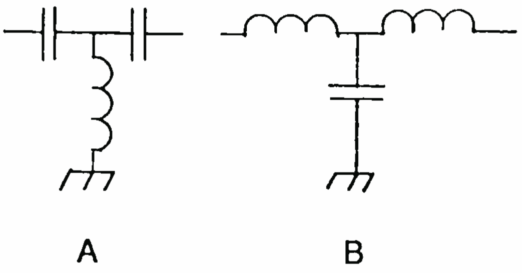
L-networks are frequently used for matching a non-directional radiator to a coaxial transmission line but not too often seen in directional antenna systems. The drawback to the L-network in directional antenna systems is that both the Q and the phase shift through it is determined solely by the ratio of resistances to be matched. The matching network of preference in the directional antenna system is the T-network. Q and phase shift can be chosen independently of the resistances to be matched.

Figure 1-10

T-networks

A - current through A will be advanced

B - current through B will be delayed



Matching networks will match only pure resistances. The reactive part of the load must first be dealt with before attempting to use an L-network or a T-network. As we calculate the values of the components needed in the matching network you will see that sometimes it is possible to use the load reactance as part or all of the output leg.

Whenever we insert capacitors and inductors in the path of RF currents we create a phase lag or a phase advance; that is the current will either lag or lead the voltage. In this application - that of the non-directional radiator - within reason, this is of little consequence. When we progress on to the directional antenna feeder system it becomes very important.

Matching networks come in two configurations: lagging and leading. A lagging network delays the phase of the current through it. A leading network advances the phase of the current through it. Figure 1-10 shows the configuration of Leading and lagging, phase advance and phase retard, T-networks. Figure 1-11 shows the configuration of leading and lagging, phase advance and phase retard, L-networks. When the series elements of the network are capacitors there is phase lead or advance. When the series elements are inductors there is a phase lag or delay.

ELI THE ICE MAN

Voltage leads current in an inductor; current leads voltage in a capacitor. An easy way to remember is to recall ELI the ICE man! E voltage leads I current in an L inductor; I current leads E voltage in a C capacitor.

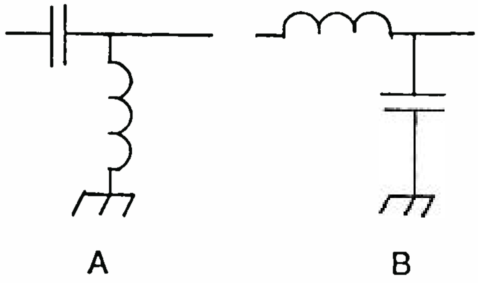
The phase advance configuration forms a high pass filter attenuating frequencies lower than the operating frequency. The phase delay configuration forms a low pass filter attenuating frequencies higher than the operating frequency.

This can sometimes be used to good advantage in a non-directional matching network to keep unwanted RF out of the transmitter, and the resultant generation of intermodulation products, when another broadcast station is close by. If it is higher in frequency use the lagging low pass network; if it is lower in frequency use the leading high pass network.

Figure 1-11
L-networks

A - current through A will be advanced

B - current through B will be delayed



In a directional antenna system phase advance or phase lag introduced by matching networks must be carefully chosen and controlled to produce the proper phase relationships between the various elements in the array.

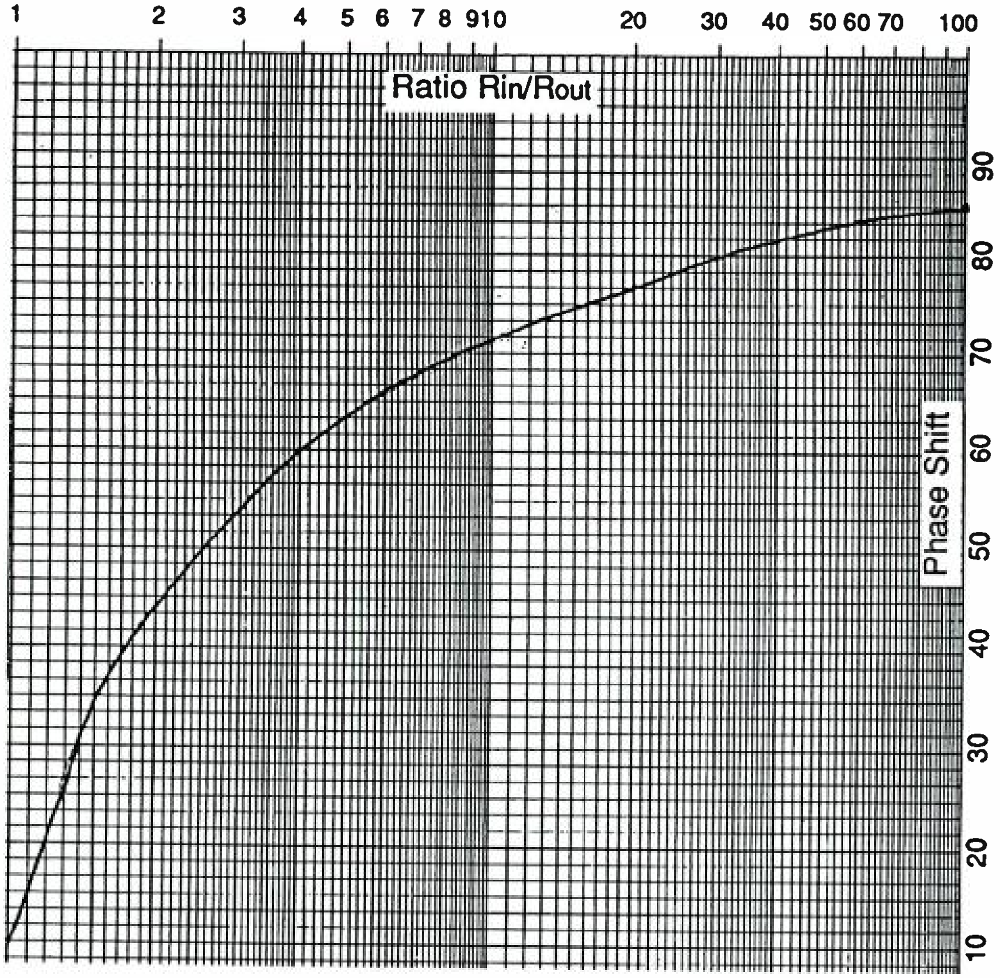
1.11 L-Networks

Meanwhile, back to the antenna matching problem at hand: To refresh our memories: We are attempting to match a 110 degree tall (G=110°) uniform cross section tower to a 50 ohm coaxial transmission line. From Table 1-1 we assume the base impedance to be 133 +j210. We will assume only because we have no way of confirming fact. Once the tower is constructed we will measure its actual value of resistance and reactance.

Figure 1-12

Graphical presentation of the phase shift through an L-network

R_1/R_2 is the ratio of the resistances being matched



As mentioned in the previous section: The value of phase shift through the L-network and the Q of the network is determined solely by the ratio of resistances to be matched. We are matching a 50 ohm transmission line to a 133 ohm radiator. The ratio of these resistances is 2.7 (133/50). The phase shift through an L-network used to match this ratio of resistances is determined to be 52 degrees by the graph shown in Figure 1-12.

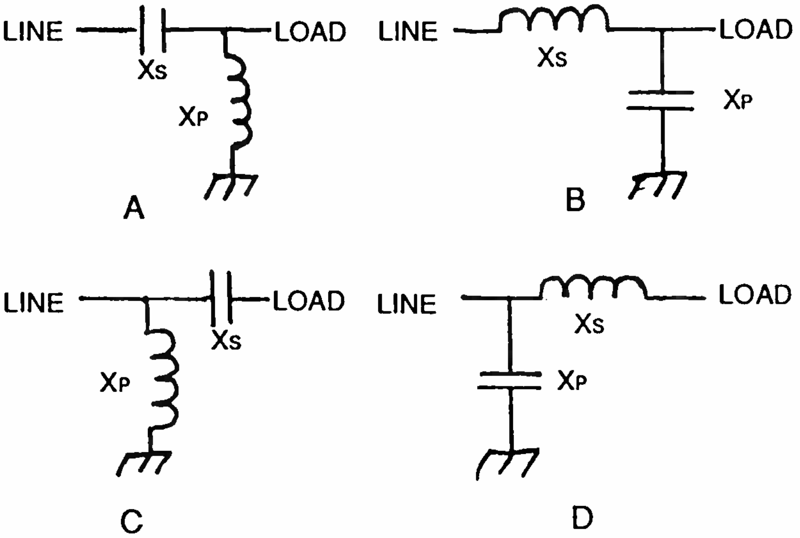
When using an L-network the parallel reactance, denoted as Xp, always goes on the side of the network connected to the higher resistance. Figure 1-13 shows four possible configurations of L-networks. In 1-13A & B the load resistance is higher than the line resistance. In 1-13C & D the line resistance is higher than the load resistance. A and C are phase advance or high pass networks; B and D are phase retard or low pass networks.

Figure 1-13

L-network configurations

A & B the load resistance is greater than the line resistance

C & D the line resistance is greater than the load resistance



The actual values of reactances are calculated using the following formulae:

(#11)

$$X_P = \frac{R_1}{\sqrt{\frac{R_1}{R_2} - 1}}$$

$$X_S = R_2 \sqrt{\frac{R_1}{R_2} - 1}$$

where: R_1 is always the larger of the resistances to be matched
R_2 is always the smaller of the resistances to be matched
X_P is the parallel or shunt reactance in ohms
X_S is the series reactance in ohms

Now, once again, back to the business of matching the 50 ohm line to the 133 ohm tower at 1480 kHz: Configurations A or B will work. Substituting actual resistances into our formulae #11:

$$X_P = \frac{133}{\sqrt{\frac{133}{50} - 1}} = \frac{133}{\sqrt{1.66}} = \frac{133}{1.29} = 103.1 \text{ ohms} = X_P$$

$$X_S = 50\sqrt{\frac{133}{50} - 1} = 50\sqrt{1.66} = 50\,(1.29) = 64.5 \text{ ohms} = X_S$$

Remembering that matching networks will match only pure resistances we first must cancel out the +j210 component of the antenna. To do this we connect a capacitor with 210 ohms reactance in series with the tower feed. At 1480 kHz, we calculate the value of capacitance needed using formula #9, on page 10:

$$C = \frac{1}{2(3.14)(1.48)(210)} = \frac{1}{1952} = .000512 \text{ uf}$$

The capacitance and inductance needed to supply X_P and X_s are now calculated. Figure 1-13A details the phase advance or high pass configuration. The values of series capacitance and parallel inductance are calculated using formulae #9 and #10, on pages 10 and 11 respectively:

$$C = \frac{1}{2(3.14)(1.48)(64.5)} = \frac{1}{599} = .001668 \text{ uf} = X_s$$

$$L = \frac{103.1}{2(3.14)(1.48)} = \frac{103.1}{9.29} = 11.1\text{uh} = X_P$$

Figure 1-13B details the phase retard or low pass configuration. Again, using formulae #9 and #10, the values of parallel capacitance and series inductance are calculated:

$$C = \frac{1}{2(3.14)(1.48)(103.1)} = \frac{1}{958.3} = .001044 \text{ uf} = X_P$$

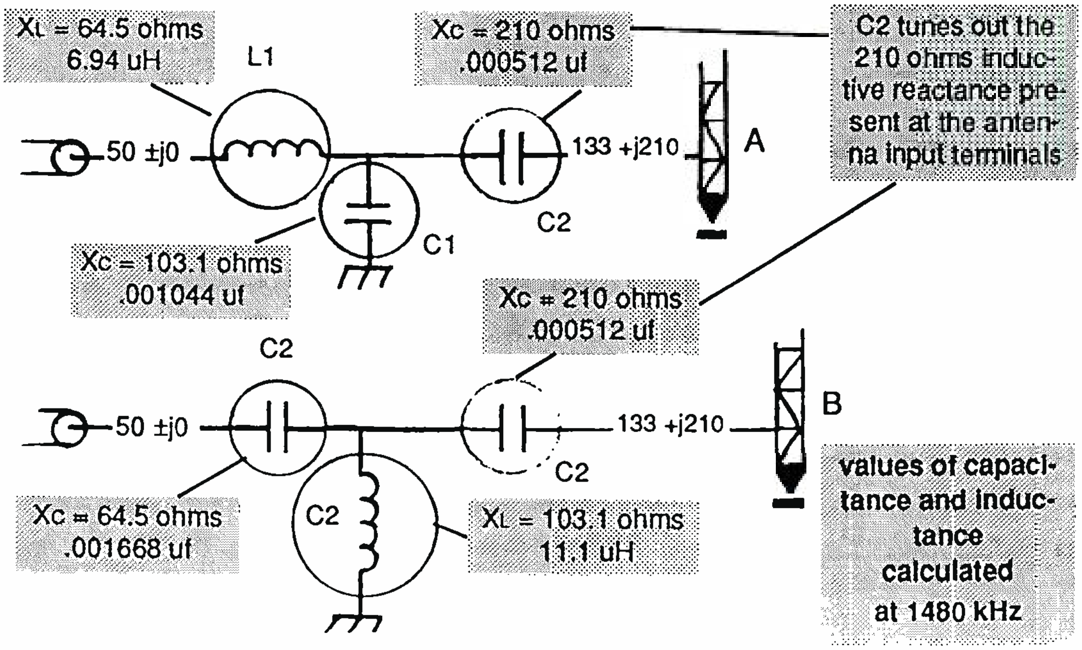
$$L = \frac{64.5}{2(3.14)(1.48)} = \frac{64.5}{9.29} = 6.94 \text{ uh} = X_s$$

Figure 1-14

L-networks used to match a 50 ohm feed line to a tower impedance of 133 +j210

A - phase retard low pass

B- phase advance high pass



Air variable capacitors are never used in antenna matching networks. Spiders, reptiles and birds find them convenient places to nest or roost! Their use makes for instability and arcing problems. You won't find the values of fixed capacitors needed for this network on your radio supplier's shelf. One solution is to use vacuum variable capacitors. They are an excellent choice but are expensive. An alternative is to use fixed mica transmitting capacitors with reactance values slightly higher than what is required. A small adjustable coil - either with a roller or adjustable tap - is placed is series with the fixed capacitor. It can now be adjusted to the required reactance value. Figure 1-15A & B details such arrangements.

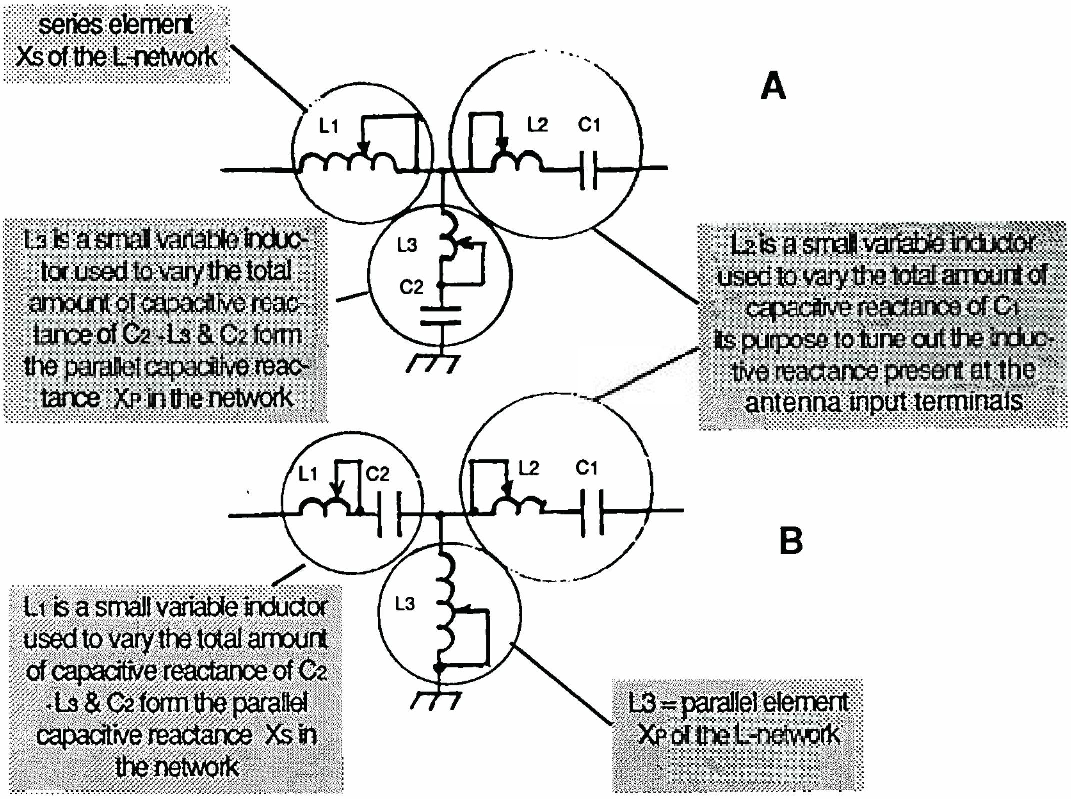


Figure 1-15

Practical L-networks using a small tapped or roller inductance in series with a fixed capacitor to adjust Xc

For example: A .0004 uf capacitor has a reactance of 268 ohms at 1480 kHz. A 10 uh inductor has a reactance of 93 ohms at 1480 kHz. This combination in series - using a tapped or roller inductor - will give us a variable capacitive reactance from 175 ohms to 268 ohms - an Xc of -175 ohms (93 - 268) ohms with all of the inductor in the circuit and an Xc of - 268 ohms with all of the inductor shorted out. By adjustment of the inductance tap or roller we can tune out the +j 210 reactance portion of the antenna input impedance.

To review, before moving on: The amount of phase advance or phase retard through an L-network is determined solely by the ratio of resistances to be matched. Likewise, the Q of an L-network is determined solely by the ratio of resistances to be matched. When the series element is an inductor there will be phase retard. When the series element is a capacitor there will be phase advance. The shunt or parallel element always goes on the side of the network where the higher resistance is present.

1.12 T-networks with a ±90° phase shift

The matching network most commonly seen in the directional antenna system is the T-network. Phase shift can be set independent of all other parameters. Not only are these networks used for matching but are widely used for phase control in DA systems. By varying the series elements in a T-network phase advance or delay can be varied over 20 or more degrees, almost, but not quite, independent of the input and output impedance. T-networks are also widely used as matching networks in non-directional systems.

Like the L-network, a T-network can be used in a low pass, phase retard configuration, or high pass, phase advance configuration. When the phase delay or advance through the T-network is chosen to be ±90 degrees the calculation of reactance values is very simple: All three legs of the network are equal and can be determined by the formula:

$$(\#11) \quad X_1 = X_2 = X_3 = \sqrt{R_{IN} R_{OUT}}$$

where: X_1, X_2, X_3 **reactance in ohms of the series and shunt elements**
R_{IN} **is the characteristic impedance of the transmission line**
R_{OUT} **is the base resistance of the input to the vertical radiator**

For our model, which presents an input resistance of 133 ohms, to be matched to a 50 ohm coaxial transmission line, the value of X_1, X_2 and X_3 are all 81.5 ohms.

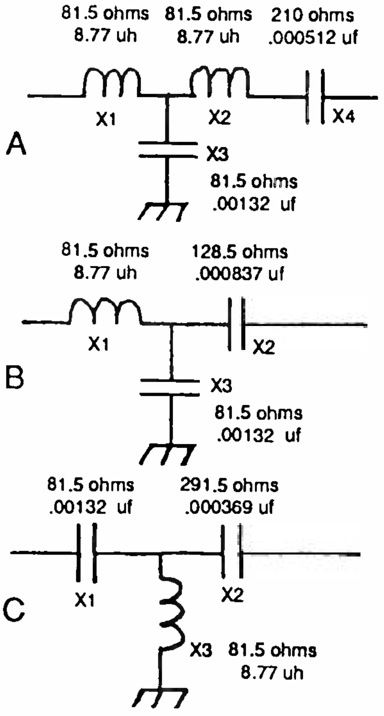
$$X = \sqrt{(133)(50)} = \sqrt{6650} = 81.5 \text{ ohms reactance in each leg}$$

For a radio station on 1480 kHz, using formulae #9 and #10, the values of C and L are, 8.77 uh and .00132 uf.

Figure 1-16

Three configurations of T-networks used to match a 50 ohm line to an antenna with a Z of 133 +j210

L and C values shown are calculated for 1480 kHz



$$C = \frac{1}{2(3.14)(1.48)(81.5)} = \frac{1}{757.5} = .00132 \text{ uf}$$

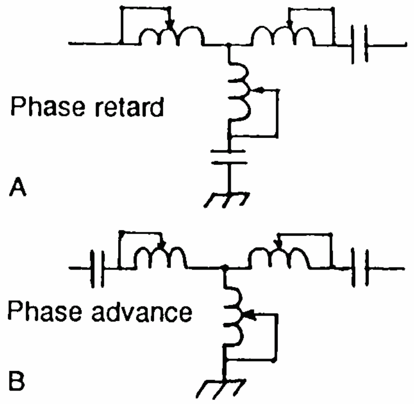
$$L = \frac{81.5}{2(3.14)(1.48)} = \frac{81.5}{9.29} = 8.77 \text{ uh}$$

But wait, we already have 210 ohms of inductive reactance present as part of the radiator input impedance. We could cancel it with a capacitor then construct the T-network with equal 81.5 ohm legs, as shown in Figure 1-16A. A more practical approach would be to use the 210 ohms inductive reactance as part of the output leg of the phase lag matching network. Capacitive reactance X2 would then be 128.5 ohms. (210 - 81.5 = 128.5)

If we use a phase advance network, as shown in Figure 1-16B, the output leg of the network, X2, would be 291.5 ohms of capacitive reactance - the 81.5 ohms needed to effect a match and the 210 ohms needed to can cancel the inductive reactance of the radiator's input impedance.

Figure 1-17

The practical configuration of the T-networks shown in 1-16 using small inductors in series with fixed value mica capacitors



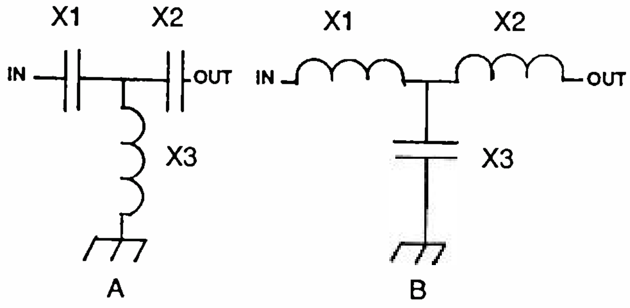
As with the L-networks discussed in the previous section, when not using vacuum variable capacitors variable tapped or roller inductors are inserted in series with fixed mica capacitors to vary capacitive reactance. Figure 1-17 details the practical construction of the T-networks shown in Figure 1-16. Care should be taken when using this technique to use only a minimum amount of inductance. The capacitor used should have no more than 130 percent of the reactance required in the circuit. When these limits are exceed the L-C combination will form a high Q circuit limiting the bandwidth of the network.

1.13 T-networks with other than ±90° phase shift

It is often desirable or necessary - especially in the directional antenna feeder system - to utilize a T-network with a phase shift other than ±90 degrees. Unlike the L-network, phase shift through a T-network can be chosen independently of the resistances to be matched. The configurations of the networks shown in Figure 1-17 and Figure 1-18 remain the same but the values of X1, X2 and X3 will not be equal as they were when the phase shift was ±90 degrees.

Figure 1-18

The three elements of the T-network referenced to formulae 13



For values of phase shift other than ±90 degrees:

(#12)

$$X1 = -\frac{\sqrt{R_{IN} R_{OUT}}\,(1 - [R_{IN}/R_{OUT}\ \cos\beta])}{\sin\beta}$$

$$X2 = -\frac{\sqrt{R_{IN} R_{OUT}}\,(1 - [R_{OUT}/R_{IN}\ \cos\beta])}{\sin\beta}$$

$$X3 = \frac{\sqrt{R_{IN} R_{OUT}}}{\sin\beta}$$

where: **R_{IN} is the characteristic impedance of the transmission line**
R_{OUT} is the base resistance of the input to the vertical radiator
β is the desired phase shift through the network
$\cos\beta$ is the cosine of the angle of desired phase shift through the network
$\sin\beta$ is the sine of the angle of desired phase shift through the network

Let's take the tower we have been using as a model and go through the arithmetic calculations in designing a T- network to match it to a 50 ohm transmission line. Its base impedance is 133 +j210. Substituting real figures into the #12 formulae:

where: $R_1 = 50$ ohms
$R_2 = 133$ ohms
$\beta = -75°$
$\cos\beta = .259$
$\sin\beta = .966$

$$X1 = -\ \frac{\sqrt{50\,(133)}\,(1 - [50 / 133 \times .259])}{-.966}$$

$$X1 = -\ \frac{\sqrt{6650}\ (1 - [\,.376 \times .259])}{-.966}$$

$$X1 = -\ \frac{81.5\,(1 - [.097])}{-.966} = -\ \frac{81.5\,(.903)}{-.966}$$

$$X1 = -\ \frac{73.59}{-.966} = 76.2 \text{ ohms}$$

$$X2 = -\ \frac{\sqrt{50\,(133)}\,(1 - [133 / 50 \times .259])}{-.966}$$

$$X2 = -\ \frac{\sqrt{6650}\ (1 - [\,2.66 \times .259])}{-.966}$$

$$X2 = -\ \frac{81.5\,(1 - [.689])}{-.966} = \frac{81.5\,(.311)}{-.966}$$

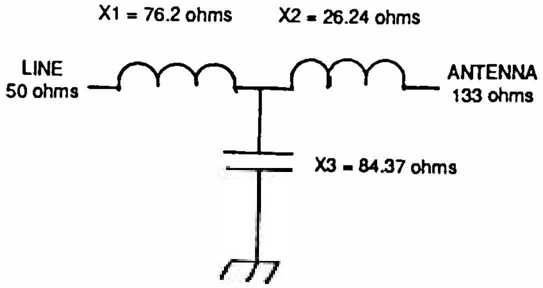
$$X2 = -\ \frac{25.35}{-.966} = 26.24 \text{ ohms}$$

$$X3 = \frac{\sqrt{50\,(133)}}{-.966} = \frac{\sqrt{6650}}{-.966} = \frac{81.5}{-.966} = -84.37 \text{ ohms}$$

A 75° phase retarding T-network designed to match 50 ohms to 133 ohms is shown below:

Figure 1-19

The 75° phase retard T-network for matching a 50 ohm line to an antenna impedance of 133 +j210



At 1480 kHz the values are:

X_1 = 8.20 uh

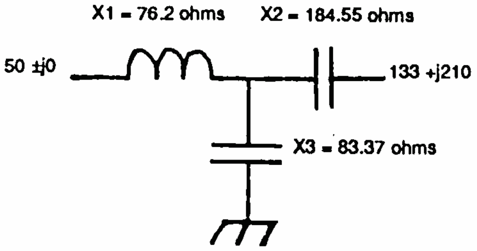
X_2 = 2.82 uh

X_3 = .001275 uf

The load impedance is not purely resistive, therefore we must take steps to cancel out the 210 ohms of inductive reactance - the +j210. Again, a capacitor with a reactance of 210 ohms could be inserted between the T-network and the tower and the values shown in Figure #1-19 could be used. An alternative, and preferred method, is to use the +j210 as the output inductance in the network. As a matter of fact we have more than enough inductance in the antenna load and must still cancel 183.76 ohms of inductance with a capacitor in the output leg of the T-network (210 - 26.24 = 184.55). The finished product is shown in Figure 1-20.

Figure 1-20

Note that the +j210 of the load is used in the output leg - capacitor X2 cancels out the remaining 184.55 ohms of inductive reactance



At 1480 kHz the values are:

X1 = 8.19 uh

X2 = .000585 uf

X3 = .001290 uf

As previously discussed, if fixed mica capacitors are used a small tapped or roller inductance will be inserted in series with X_2 and X_3 to arrive at the required values.

1.14 Current and Voltage Rating of Capacitors

When an AM carrier is modulated the power swings down to zero at a 100% negative peak and instantaneously up to 4 times the unmodulated carrier on a 100% positive peak. A positive peak of this magnitude represents an instantaneous doubling of both current and voltage through and across components in the RF feeder system.

When the voltage rating of a capacitor is exceeded, the dielectric is apt to break down and the plates of the capacitor will become shorted together. A high peak voltage from a lightning strike can radically change the value of a mica capacitor. Vacuum capacitors are sometimes self healing when an inside arc occurs. Care should be taken to keep the outside of glass vacuum capacitors free of dirt. An arc can develop from terminal to terminal, across the glass, on the outside of the capacitor. This can burn a hole through the glass releasing the vacuum and destroying the capacitor.

When the current rating of a capacitor is exceeded it will become hot. Mica capacitors will change value or drift in value when this occurs. Excessive heating of a vacuum capacitor can cause the glass or ceramic envelope to crack.

The current rating of a capacitor is specified at 1 mHz. You can convert this to your operating frequency by the following formula:

$$I_O = I_R \sqrt{f_O} \qquad (\#13)$$

where: I_O **= current rating at operating frequency**
I_R **= current rating at 1 mHz**
f_O **= operating frequency in mHz**

1.15 Field Strength vs Power

Let's go back to our first model, the 90 degree tower with a 50 ohm input resistance. It is energized with 4.48 amperes of RF current. By ohms law, $I^2 R$, we verify that the power being delivered to it is very close to 1000 watts. Our next step is to take a *field strength meter* (FSM) and go out to a point that is beyond the induction field of the antenna. The induction field of a radiator is generally considered to extend out to a distance 5 times the height of the radiator. For the sake of our discussion, we drive out to a distance of 1.6 kM or 1 mile. We calibrate the field strength meter and take a measurement. It indicates 100 *millivolts per meter*, abbreviated 100 mV/m.

The basic unit of measurement of field strength or field intensity is volts per meter, abbreviated V/m. The typical field strength meter will measure signals from 10 microvolts per meter (10uV/m) to 10 volts per meter (10 V/m). It will have six full scale ranges, each covering 20 dB.

Now, reduce power to 500 watts. The RF ammeter reading drops to 3.45 amperes. The field strength meter now reads 70.7 mV/m. Next, raise the power to 2000 watts. The RF ammeter indicates 6.32 amperes and the measured field strength is 141 mV/m.

The current in the radiator and the measured field strength behaved in the same manner: When the power was halved they both dropped to .707 their previous value; when the power was doubled they both rose to 1.41 their previous value. From this observation we can draw the conclusion that antenna current and radiated field increase or decrease in relation to the square root of the power change.

(#14) $$\text{change in measured field} = \sqrt{P_1/P_2}$$

where: P_1 = new power
P_2 = reference power

This mini-experiment demonstrates a concept that will be important in understanding how a directional antenna system produces gain over a single element non-directional system.

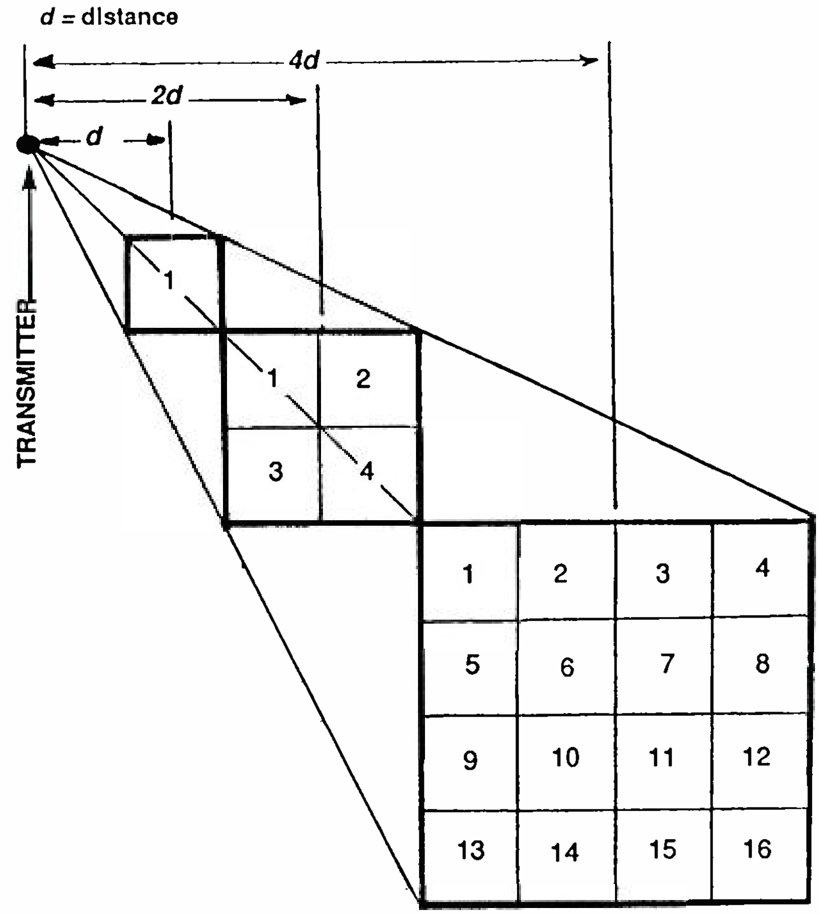
1.16 The Inverse Distance Law

The laws of physics mandate that when distance is doubled the field strength is halved. Your attention is called to Figure 1-21. Note that as the distance is doubled away from the transmitter the area covered is squared. At d = 1 one square is covered; at d = 2 four squares are covered; as d = 4 sixteen squares are covered. If the paper was large enough we could carry this on and on. At d = 8 sixty-four squares, at d = 16 two-hundred-fifty-six, etc.

For a moment let us assume that the field strength in the square where d = 1 is 100 mV/m. In the last section, FIELD STRENGTH vs POWER, we learned that the measured field drops to half when the power is decreased by a factor of 4. At d = 2 the power density has fallen by a factor of four as the area to be covered has gone from one to four units. At a power density of 0.25 the field strength drops to 0.5 its previous value - the square root of 0.25. Thus, we will measure 50 mV/m.

Figure 1-21

As the distance is doubled, the area covered increases by the square of the distance



As the distance from the transmitter is again doubled to four miles, the area covered increases again by a factor of four, to 16 squares. The .25X watts is now diluted once again by a factor of 4 to .0625X watts. The field strength is halved and we measure 25 mV/m at the 4 mile marker.

This phenomena is explained by the inverse distance law. Over a perfectly conducting earth, with no external influences, the signal radiated from our vertical antenna would behave in this manner; when distance is doubled the measured field is halved. Unfortunately, as the radio signal travels away from the antenna is moves over an earth that is far from a perfect conductor. About the closest we will find to perfect is a signal propagated over sea water. For a distance out to 100 kilometers or more the signal will behave exactly as predicted. Then, it too not being perfect and due to the curvature of the earth, falls off drastically.

Inverse field strength, sometimes called *unattenuated field* or *inverse distance field*, is the standard used in all antenna calculations. When an antenna pattern is spewed out of the computer its values of field strengths at various azimuths is in millivolts per meter of inverse field at one kilometer (or at one mile). As you will see in the next section, inverse field can not be measured directly. Many measurements of actual field strengths must be made. They are then converted to inverse field at one km or one mile.

1.17 Measured Field, Ground Conductivity and Inverse Field

Let's jump back again to FIELD STRENGTH vs POWER and pick up where we left off with our imaginary radio station on 1480 kHz. At 1 mile, 1.6 km, the measured field from our 90 degree radiator, energized by 1000 watts of RF power was 100 mV/m. At 2 miles, 3.2 km, from the antenna and take another reading on our field strength meter. It indicates 16 mV/m - not the 25 mV/m we expected. At 4 miles, 6.4 kM, the meter indicates 4.6 mV/m - not 12.5 mV/m. If the signal was in strict compliance with the inverse distance law our measurements would have decreased in a straight - 50 mV/m at 1.6 km, 25 mV/m at 3.2 km, and 12.5 mV/m at 6.4 km. Something else must be influencing the signal. That something else is ground conductivity!

Figure 1-22 on the next page is a reproduction of Graph #18, from the FCC Rules and Regulations. This particular graph covers the frequency range of 1430 kHz to 1490 kHz. There are 18 others that cover the other sections of the AM broadcast band from 540 kHz to 1610 kHz. They can be found in Section 73.184(f) of the FCC Rules. These are officially known as *Ground Wave Field Strength versus Distance Curves.* This family of graphs is used to convert the real world of measured field strength to the perfect and theoretical world of *inverse field strength,* sometimes also referred to as *unattenuated field.*

Across the top of the graph is distance in kilometers from the antenna from 0.1 to 50 km; down the left side of the graph is field strength in millivolts per meter, mV/m. On the right side of the graph the various curves are labeled 5000, 40, 30, 20 . . . etc. These are ground conductivities in millisiemens per meter.

The lower set of curves are for distances from 10 km to 5000 km from the antenna. Distance is labeled on the bottom of the graph and ground conductivities shown by the denoting numbers in the graph grid.

Note the straight line marked INVERSE DISTANCE 100 MV/M AT 1 KM. It shows signal strength falling off exactly as predicted by the inverse distance law - 100 mv/m at 1 km, 50 mV/m at 2 km, 25 mV/m at 4 km, ... The curves indicate the expected actual field intensity at specific distances from the antenna, over paths with various ground conductivities, when the inverse field is 100 mV/m at one km.

Sea water has a conductivity of 5000, far better than any soil we will ever encounter. By the curves you can see that if our imaginary radio station was located on the beach of an ocean we could jump into a boat with our field strength meter, sail away from the transmitter, and get measurements just as the inverse distance law predicts out to a distance of about 100 km.

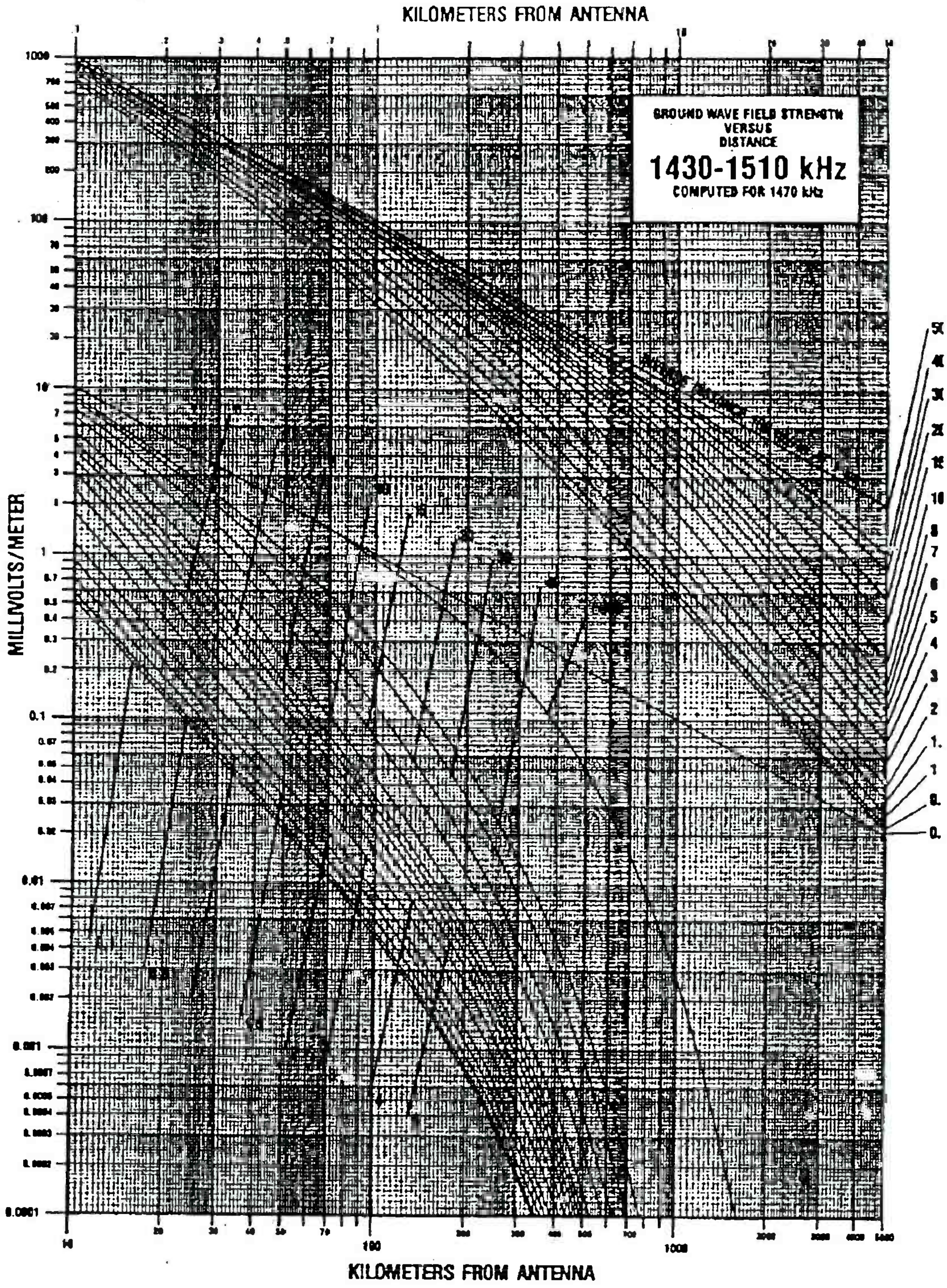
Using the values of field strength measured in the first paragraph of this section, with a pencil dot, plot the 1.6 km reading of 50 mV/m on the graph - 1.6 km on the top scale, 50 mV/m on the scale to the left. Do the same for the 16 mV/m at 3.2 km and the 4.6 mv/m measurement at 6.4 km. Note that these 3 pencil marks lie approximately on the ground conductivity curve marked 4 on the right side of the graph.

In order to accurately determine inverse field in a specific direction, many measurements, 40 or more, are made on a straight line out from the antenna to a distance of 32 or more kilometers (20 miles). These measured azimuths are known as *radials.* Mr. Webster defines the term "radial" as "radiating from or converging to a common center." Don't confuse the use of this term with the same term used to describe the wires radiating out from the tower in the ground system. This data is displayed on log-log coordinate graph paper similar to the paper on which these FCC curves are plotted. Using a light table, the plotted data is compared to the FCC graph. It is fitted to the conductivity curve that most closely matches the plotted data. The inverse field is determined by the point at which the straight line - the inverse distance curve - crosses the 1 km distance mark.

Figure 1-22

Ground wave field intensity vs distance for the family of frequencies 1430 to 1510 kHz

Distance is read at the top or bottom of the graph - field intensity on the left side - ground conductivity curves are labeled at the right side and labeled for the bottom set of curves on the graph itself



GRAPH 18

Figure 1-23

Data plotted from an actual proof of performance - note the change in ground conductivity from 4 to 7 at a distance of 5 miles

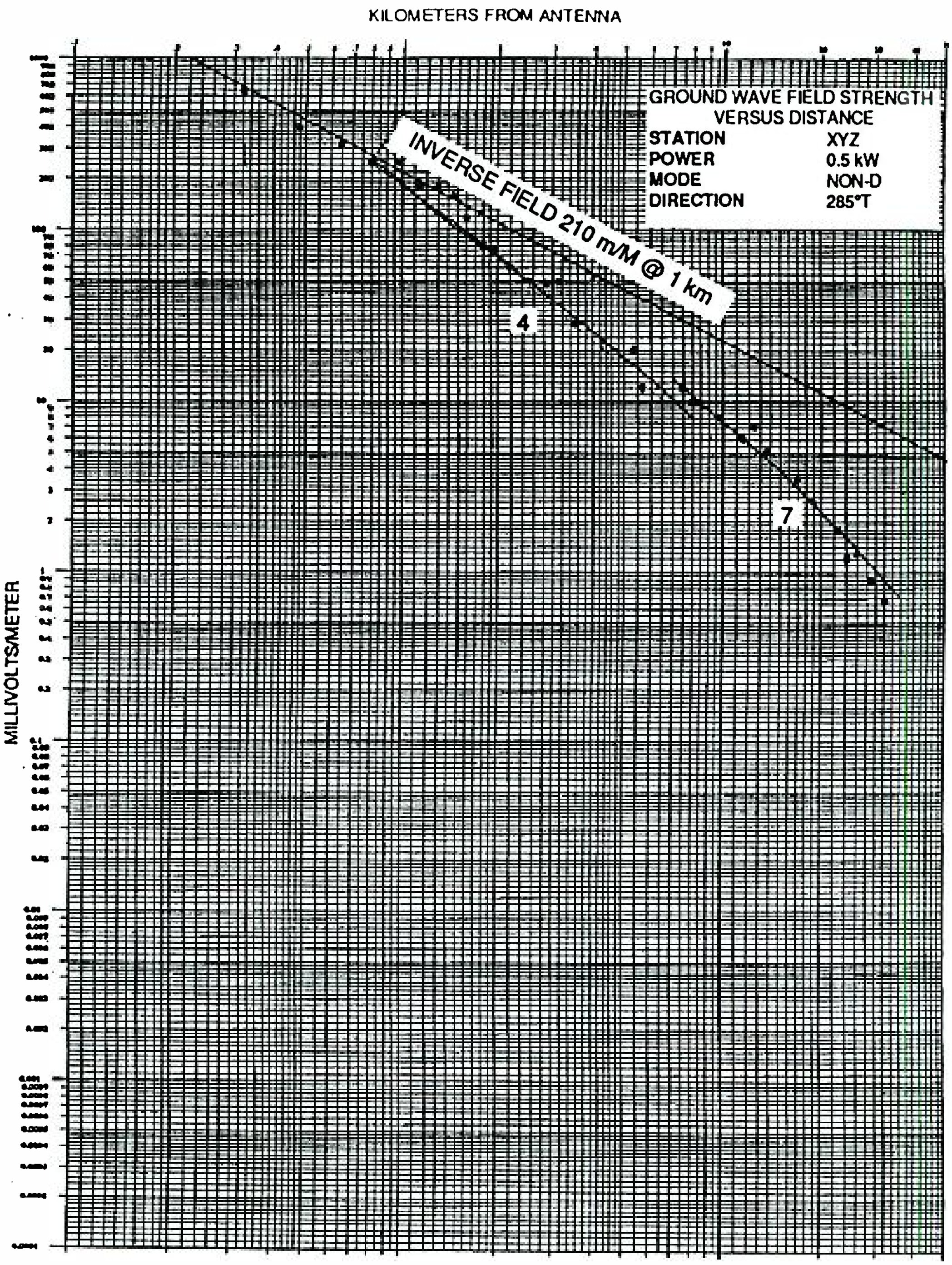


Figure 1-24

Ground wave field intensity vs distance for the family of frequencies 540 to 560 kHz

Distance is read at the top or bottom of the graph - field intensity on the left side - ground conductivity curves are labeled at the right side and labeled for the bottom set of curves on the graph itself

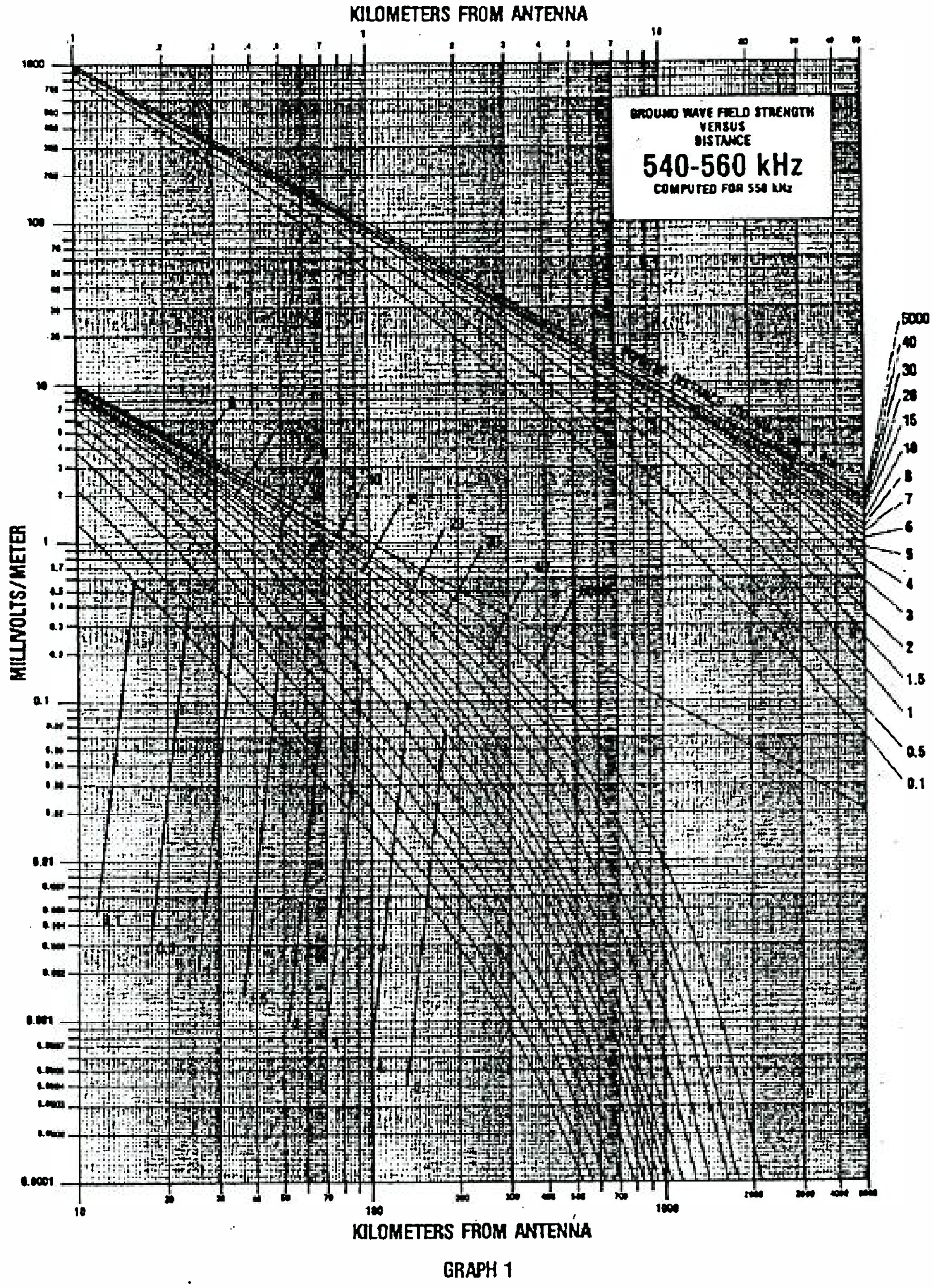


Figure 1-24 is a reproduction of Graph #1 from Section 73.184(f) of the FCC Rules. It covers the frequency range of 540 to 560 kHz. It, like the others, is drawn to a scale of 100 mV/m at one km. Note that the amount of signal expected to be delivered to a point 50 km from the antenna, when the inverse field is 100 mV/m at one km, over a ground conductivity of 5, is 0.9 mV/m. (Use the curve labeled 5 at the right side of the graph, distance of 50 km labeled at the top of the graph and the expected field intensity of 0.9 mV/m labeled at the left side of the graph.) At this distance you can also use the lower set of curves and the distances indicated at the bottom of the graph.

Now, flip back one page and perform the same exercise for 1480 kHz, using the graph shown in Figure 1-22. Note that the amount of signal expected to be delivered to a point 50 km from the antenna, when the inverse field is 100 mV/m at one km, over a ground conductivity of 5, is but 0.1 mV/m. From this we can draw the conclusion that as we go higher in frequency in the AM broadcast band we can expect a given ground conductivity to cause a faster drop off of the ground wave signal. Thus the reason for the 1 kW station on 540 kHz having a greater coverage area than the same 1 kW facility on 1600 kHz.

Figure 1-25

From Section 73.190 of the FCC Rules - Ground conductivities in the continental US

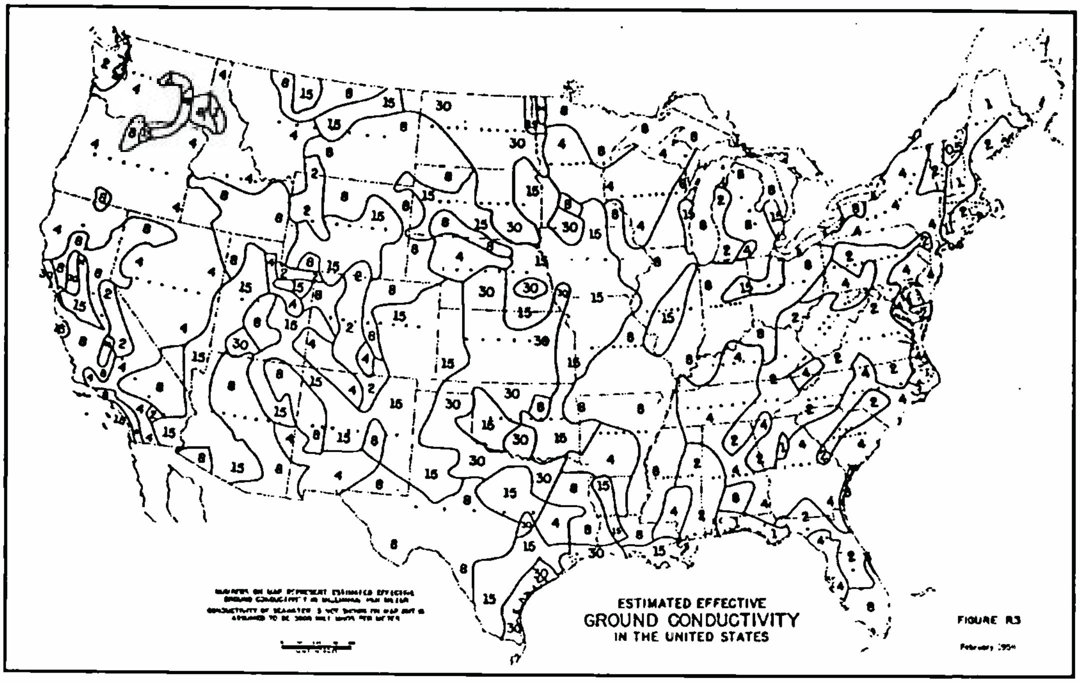


Figure 1-25 is a reproduction of Figure R3 contained in Section 73.190 of the FCC Rules. It shows estimated ground conductivities in the continental United States. From this we can draw the conclusion that a 1 kW facility on 540 kHz in Kansas, with a ground conductivity of 30, will have considerably more ground wave coverage that the same facility located in Maine, with a ground conductivity of 1. If we assume a value of inverse field intensity of 100 mV/m at 1 km, the scale to which the charts are drawn, with a conductivity of 1 the distance to the 0.5 mV/m contour is 30 km; with a conductivity of 30 the distance to the 0.5 mVm contour is about 150 km. Remember, this figure shows estimated conductivities. Actual ground conductivities can be and are measured using the procedure just described in this section.

1.18 Radiator Height vs Ground Wave Inverse Field Strength

Thus far we have only considered the effect of power and ground conductivity on the inverse field strength and the amount of signal strength actually delivered to a point distant from the vertical antenna. This book is not intended to be a course on antenna theory but for a moment I'll bend that rule! An *isotropic radiator* is an imaginary antenna used only for comparison purposes. If you could construct one it would look like a sphere - a ball - suspended in outer space. If you could energize it with 1 kW of RF power it would radiate an inverse field strength of 173.5 mV/m at one km - 107.6 mV/m at one mile. This same radiated field would exist in every direction away from the sphere. This is the total amount of radiation available from our 1 kW spread out in every possible direction.

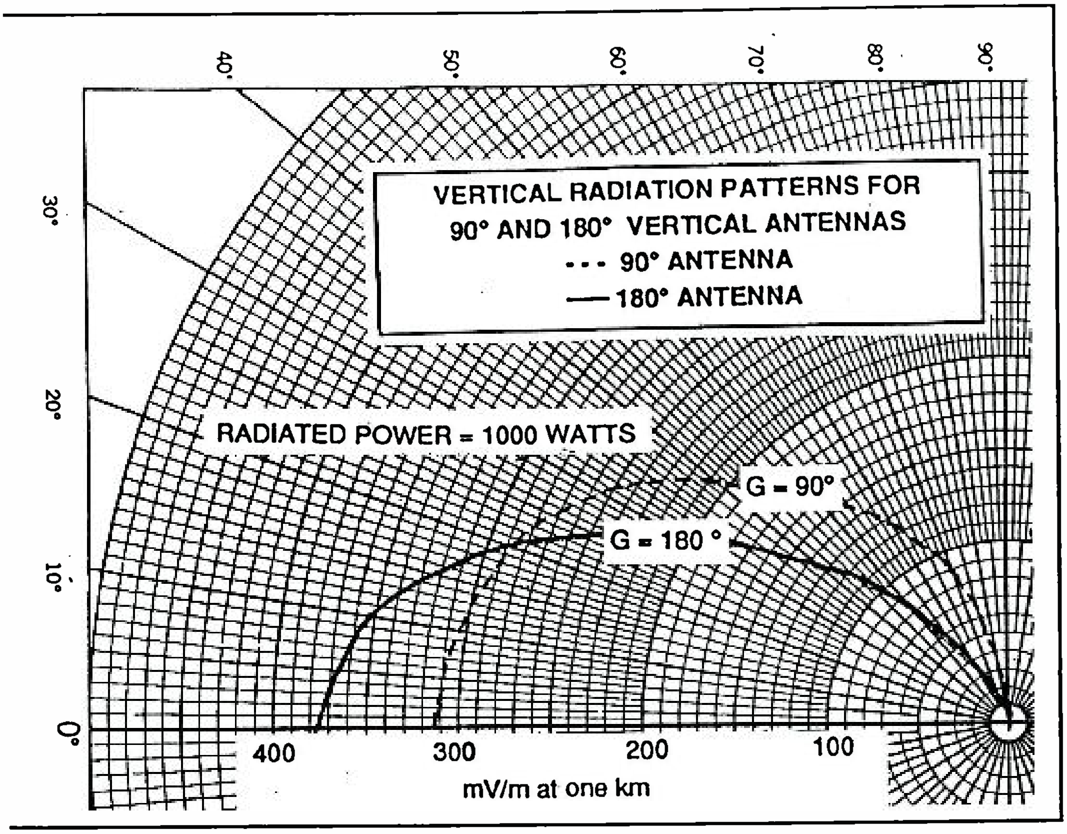
Figure 1-26

Vertical radiation patterns for 90° and 180° vertical antennas

90° radiator pattern shown with dotted line

180° radiator shown with solid line

0° elevation is ground level 90° elevation is directly up toward the zenith



Now, if we cut the imaginary ball antenna in half and sit it on the face of the earth it would be called upon to radiate the 1 kW of power only over half the area as the other half would be blocked by the earth. This imaginary antenna is called a *hemispherical radiator*. Thus, the power density has been effectively doubled. Our 1 kW of energy has to cover only half the space. As we learned in the section 1.15, when power is doubled the field intensity increases by a factor of 1.41. Therefore, we might rightly expect that the inverse field at 1 km would increase by a factor of 1.41; indeed it does to 243.9 mV/m - 151.7 mV/m at one mile.

Let's move one step farther and examine a radiator 90 degrees in height. The radiation from this antenna does not equally cover an entire hemisphere. If it could be seen it would appear much like a doughnut sliced the long way through and placed on a table. The same amount of energy that was radiated by the 1 kW when it energized the isotropic antenna and the hemispheric antenna is now radiated by the vertical antenna. However, rather than it being spread over one or two hemispheres it is more concentrated along the surface of the earth; at high angles there is little radiation; off the end, straight up, there is no radiation. When the mathematics of trigonometry and geometry are applied this 90 degree tall vertical antenna - over a perfectly conducting earth - is found to produce an inverse field strength of 314.5 mV/m at one km - 195 mV/m at one mile - when energized with 1 kW.

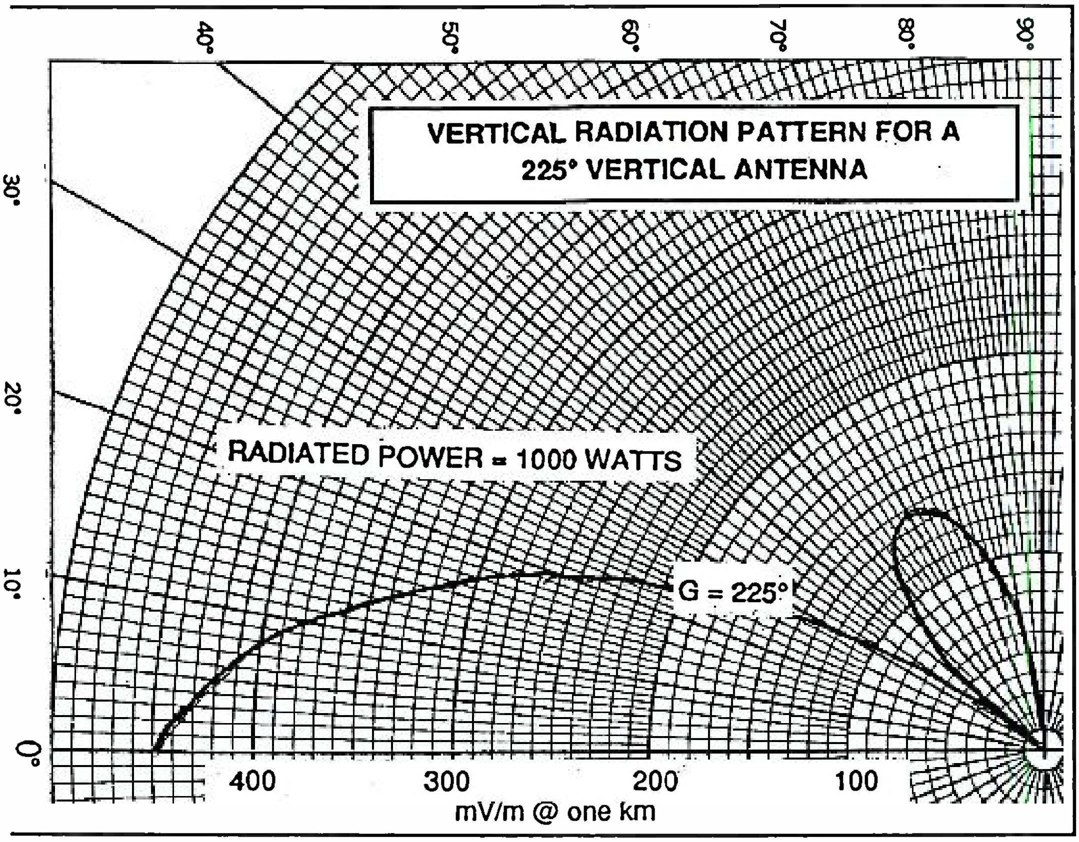
What happens if we use an antenna taller than 90 degrees? Figure 1-26 is a portion of a graph redrawn from Section 73.190 of the FCC Rules. It shows the vertical radiation pattern and expected inverse field intensities for 90 and 180 degree radiators at angles from the horizontal along the surface of the earth up to 90 degrees - straight up off the top end of the tower. In the drawing shown, these radiators are energized with 1 kW of power. Note that the 0.25 wavelength - 90 degree - radiator produces 312 mV/m of inverse field at one km - 195 mV/m at one mile - on the surface of the earth. If we look at up at an angle of 45 degrees we see that only 192 mV/m at 1 km - 120 mV/m at one mile - is produced by the same antenna.

A 180 degree antenna will produce an inverse field of 235 mV/m at one mile - 376 mV/m at one km - along the surface of the earth. At 45 degrees up it produces less than the 90 degree antenna - only about 60 mV/m - 96 mV/m at one km. The added energy radiated at ground level comes from reduced radiation at high angles.

FIGURE 1-27

Vertical radiation pattern for A 225° vertical antenna

0° elevation is ground level 90° elevation is directly up toward the zenith



Now, examine Figure 1-27. It details the vertical radiation pattern of the 225 degree radiator - 5/8 wave length. When energized with 1 kW it produces 275 mV/m of inverse field at one mile - 440 mV/m at one km. This is 3 dB more than the 90 degree antenna. As you can see from the graph, it too comes from reduced radiation at high angles. Note, however, that this 225 degree radiator also produces a minor lobe, with about 85 mV/m of of inverse field, at a vertical angle of 60 degrees. For daytime use we are interested in ground wave coverage. This minor lobe is of no concern. However, during hours of darkness, it can be troublesome. Energy from this lobe can be reflected back into the ground wave coverage area of the radio station by the ionosphere. When this energy arrives in phase with the ground wave signal the field intensity will increase; when it arrives out of phase the signal will fade. This phenomena is known as *selective fading*. It is apt to cause receivers with envelope detectors to produce distorted audio as it can cause one sideband to be out of phase with the other. High angle radiation can also cause severe interference to other co-channel and adjacent channel stations thousands of miles away.

Well, so far so good. It would appear that the taller the radiator the more signal there will be radiated along the surface of the earth. This is exactly what is desired for AM radio coverage. So why not use a tower that is 270 or 360 degrees tall?

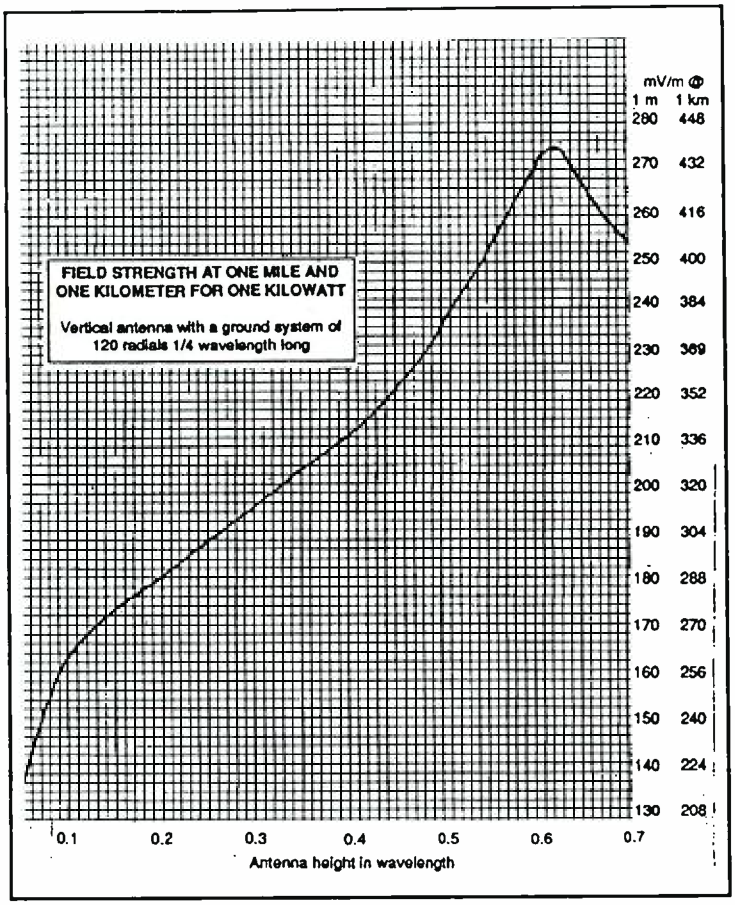


Figure 1-28

Inverse ground wave field strength at one mile and one kilometer for various height vertical radiators

Figure 1-28 is redrawn from Figure 8 Section 73.190 of the FCC Rules. Shown is ground wave inverse field intensity for various heights of radiators up to 250 degrees. It shatters our assumption that radiators taller than 225 degrees will produce higher values of ground wave field intensity. As you can see, ground wave field intensity begins to drop off rapidly as the height of the radiator is increased beyond 225 degrees. Energy radiated along the ground begins to feed the minor lobe that we saw in Figure 1-27. Eventually the ground wave signal will diminish to near zero and all of the energy radiated from the tower will be concentrated at high angles. For this reason, simple base fed towers with heights greater than 225 degrees are not useful for AM broadcasting.

Table 1-2

Vertical radiation pattern shape for towers from 70 to 225 degrees in height

VERTICAL RADIATION PATTERN SHAPE

HEIGHT OF TOWER IN DEGREES	Elevation Angle f(O)									
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
70	1.00	0.98	0.93	0.84	0.72	0.59	0.45	0.30	0.15	0.00
80	1.00	0.98	0.92	0.83	0.71	0.58	0.44	0.29	0.15	0.00
90	1.00	0.98	0.91	0.82	0.69	0.56	0.42	0.28	0.14	0.00
100	1.00	0.98	0.91	0.81	0.68	0.54	0.40	0.26	0.13	0.00
110	1.00	0.97	0.90	0.79	0.65	0.51	0.37	0.24	0.12	0.00
120	1.00	0.97	0.89	0.77	0.64	0.50	0.36	0.23	0.11	0.00
130	1.00	0.97	0.88	0.75	0.60	0.45	0.32	0.20	0.09	0.00
140	1.00	0.96	0.87	0.72	0.57	0.41	0.28	0.17	0.08	0.00
150	1.00	0.96	0.85	0.70	0.53	0.37	0.24	0.14	0.06	0.00
160	1.00	0.96	0.83	0.66	0.48	0.32	0.20	0.11	0.05	0.00
170	1.00	0.95	0.81	0.62	0.43	0.27	0.15	0.07	0.03	0.00
180	1.00	0.94	0.79	0.58	0.37	0.20	0.09	0.03	0.00	0.00
190	1.00	0.93	0.75	0.52	0.30	0.13	0.02	-0.02	-0.02	0.00
200	1.00	0.92	0.74	0.49	0.26	0.04	-0.06	-0.08	-0.05	0.00
210	1.00	0.91	0.67	0.38	0.11	-0.07	-0.14	-0.14	-0.08	0.00
220	1.00	0.89	0.61	0.28	-0.01	-0.19	-0.25	-0.21	-0.12	0.00
225	1.00	0.88	0.58	0.22	-0.08	-0.26	-0.30	-0.25	-0.14	0.00

The shape of the vertical radiation pattern, sometimes called the *vertical radiation characteristic*, for towers of practical heights is shown in Table 1-2. To use this table, multiply the inverse field strength at ground level by the decimal figure at the appropriate elevation angle. Figures 1-26 and 1-27 are drawn from this table. The negative numbers indicate a reversal of phase in the minor high angle lobe that appears when the radiator height is above 180 degrees.

● ● ● ●

Chapter Two

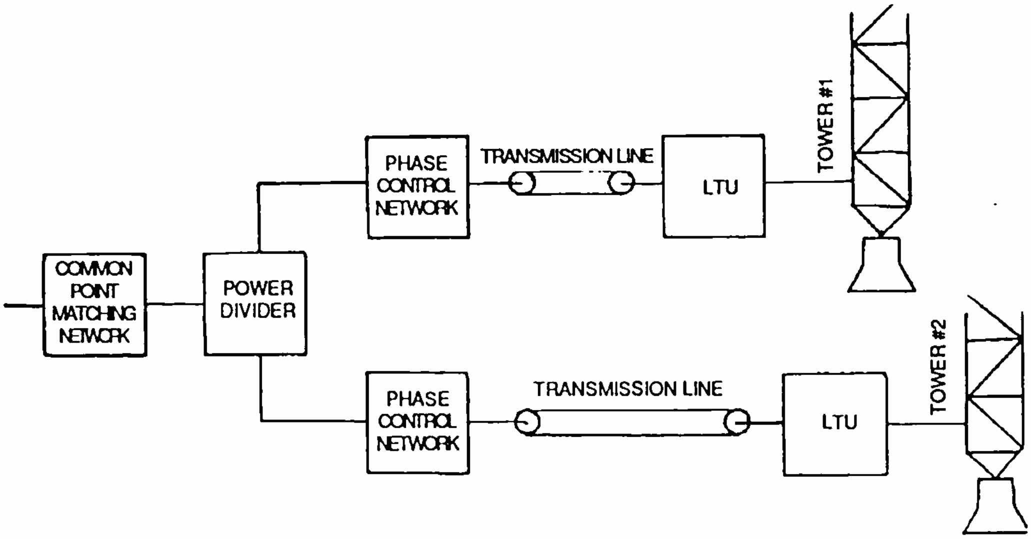
Understanding the Directional Antenna System

2.01 The Purpose of the Directional Antenna System

When it is desired to increase the radiated signal in some directions and reduce it in others two or more vertical radiators are used. These configurations of multi-tower vertical antenna systems are commonly called directional antenna systems - sometimes abbreviated DA system. The size and the shape of the radiation pattern produced by these systems is controlled by their physical construction (tower heights, spacing between towers, orientation, etc.) and the electrical parameters of the currents (current phase, current ratio and RF power) which energize the system.

Figure 2-1

Block diagram of a simple 2 tower directional antenna system



A particular facility might use one DA pattern for both night and day operation; different DA patterns for night and day operation, a daytime DA pattern, a DA pattern for critical hours (sunrise until 2 hours after sunrise and 2 hours before sunset until sunset) and yet another DA pattern for night operation. Another combination commonly found is non-directional day operation and a DA pattern for night operation. There are even a few stations around that operate directional day and non-directional night. It is not uncommon for a facility to utilize different output powers for day and night and sometimes critical hours operation.

Directional antenna systems used for AM broadcasting utilize radiators that are individually excited with RF energy from the transmitter through a feeder system. Control of the RF current and the phase of the RF current in each element in relationship to the other elements in the system lends itself to precise control of the radiation pattern produced by the array. By exciting the radiators with different current ratios and current phase relationships the radiation pattern can be changed for day and night operation.

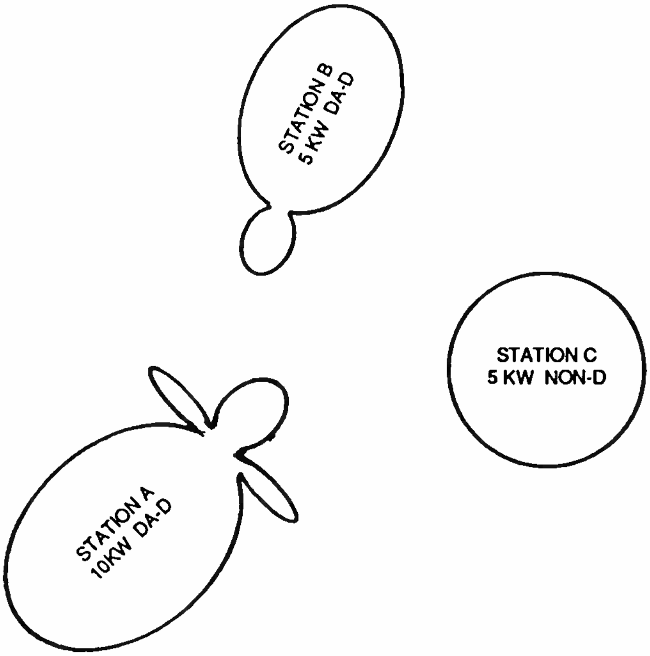


Figure 2-2

Contour map showing a combination of directional and non-directional antenna patterns detailing how stations A & B protect each other by using directional antenna systems and how both protect non-directional station C

Each directional antenna system is custom designed for a particular situation to fit an AM radio station into a particular location. Radiated signal is reduced in the direction of other stations on the same frequency (co-channel) and adjacent frequencies (adjacent channel) to protect them from interference. At the same time, the transmitter site is located to place the city and suburban areas in directions where the signal is increased by the use of the directional antenna system. There are even a few stations in the U.S. that have no protection requirements but use a DA system solely to increase signal over the city of license. Each is designed, located and built to satisfy a particular need. No two systems are identical in all aspects; physical and electrical. The one thing all of these systems do have in common is that they all use vertical radiators.

DIRECTIONAL ANTENNA TERMINOLOGY

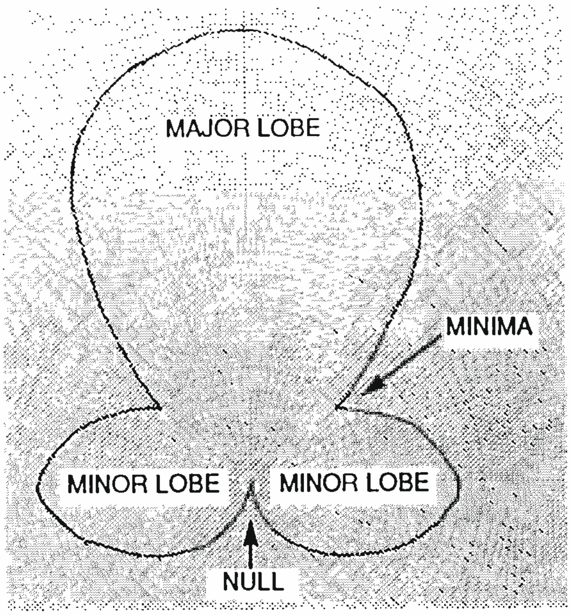
DA-D = directional antenna daytime
DA-N = directional antenna nighttime
DA-CH = directional antenna critical hours
(critical hours = 2 hours after sunrise
and 2 hours before sunset)
NON-D or no designation = non-directional
LS = local sunset

2.02 Major Lobes, Minor Lobes, Nulls and Minimas

A good analogy of a DA system is a round balloon. Fill the balloon up with air. Let this air represent the RF energy with which the system is energized. You have essentially a round envelope containing a given amount of air. Let the shape of this envelope represent the shape of the radiation pattern of the non-directional antenna. Pinch the balloon in at its middle. There now exists a bow tie shaped balloon with two bulges and two pinched areas. The actual volume of air in the balloon has not been increased or decreased. The number of cubic inches of space occupied by the balloon is the same as it was before it was pinched. Only the shape of the containing envelope itself has changed from round to a bow-tie configuration.

Figure 2-3

Major lobes, minor lobes, nulls and minimas



In directional antenna terminology the bulges are called *lobes*. The pinched areas are called *nulls* or *minimas*. Strictly speaking, a null is an azimuth on the radiation pattern where radiated field is zero. A minima is an azimuth on the radiation pattern where radiated field is low but not zero. In the nulls or minimas values of inverse field will be lower than what would be radiated utilizing the same power non-directionally. Each directional antenna radiation pattern will contain at least one, and usually more than one, null or minima.

Lobes are categorized as major lobes and minor lobes. In the center of a major lobe of the radiation pattern values of inverse field will be higher than what could be realized utilizing the same power non-directionally. Some radiation patterns contain two or more major lobes.

A minor lobe is a bulge in the radiation pattern that contains maximum values of inverse field that are less than the field radiated in the major lobe and less than what would be realized by a non-directional pattern energized with the same power. In more complex systems utilizing three or more towers there will be at least one or more major lobes, several smaller minor lobes and many nulls or minimas.

The term *radiation pattern* has several different meanings. We should have a grasp of those meanings. The size and shape of the *theoretical radiation pattern* is calculated using pure mathematics. It takes into consideration height of the radiators, the spacing of the radiators one to another, the power fed to the DA system, the relative ratios of the currents energizing each radiator, and the relative electrical phase of the current energizing each radiator.

The *standard radiation pattern* is based on the size and shape of the theoretical radiation pattern. It is the square root of the square of the theoretical radiation pattern, plus the square of what is known as Q, multiplied by 1.05. What a mouthful! Suffice it to say, for our purposes, the standard radiation pattern is always somewhat larger than the theoretical radiation pattern. In addition, where a true null (zero radiation) occurs in the theoretical radiation pattern there is always some radiation fill-in in the standard pattern as 1.05(Q) will remain. When such a null (now a minima) occurs it is sometimes called a Q-null. The standard pattern leaves some room for maneuvering when adjusting the DA system. The standard radiation pattern is the pattern used for allocation and interference determination purposes. It is shown in the calculations and polar plot(s) submitted in the application for the CP. In older DA systems (before 1980) you will find the polar plot pattern surrounded with a dotted line. This dotted line represented what was known as the MEOV (maximum expected operating value). It too defined a pattern that was somewhat larger than the theoretical radiation pattern. The standard radiation pattern has replaced the MEOV.

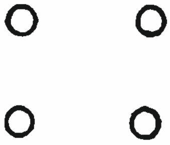
Figure 2-4

Different configurations of tower layouts for directional antenna systems

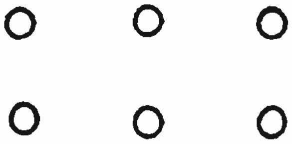
TWO TOWER IN-LINE

THREE TOWER IN-LINE

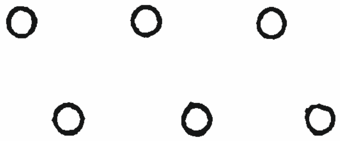
THREE TOWER DOG LEG



FOUR TOWER PARALLEL-O-GRAM



SIX TOWER PARALLEL-O-GRAM



SIX TOWER PARALLEL-O-GRAM

The *measured radiation pattern* is the pattern determined by the inverse field strengths produced by the directional antenna system as adjusted, at various azimuths. These inverse fields are determined by analyzing the measured data collected in the directional proof-of-performance.

Under some circumstances, a *modified standard radiation pattern* is specified. If after construction and adjustment of a directional antenna system is complete it is found that measured inverse fields in one or more directions exceed the field shown in the standard radiation pattern an application for a modified standard radiation pattern is filed. In other words; when the directional antenna system can not be adjusted to produce a radiation pattern contained within the confines of the standard radiation pattern one can apply for a modified standard pattern. Among the causes of such a problem are structures that cause excessive re-radiation of the signal and distort the directional pattern and in rugged terrain where the elevation of the measuring points along a radial, or part of a radial, are at drastic variance to the elevation of the antenna system. In these situations one might be looking up or down 20 or 30 degrees from the measuring point(s) to the antenna system. A modified standard radiation pattern is calculated and constructed either by lowering the power input to the antenna system to reduce all of the the inverse fields, by adding a correction factor that will cause the entire radiation pattern to be larger than what was applied for in the CP or by applying an augmentation factor to part of the pattern to raise the permitted inverse fields in certain directions. Of course, if either of the latter two solutions are chosen, it must be shown that the increased radiation toward other co-channel and adjacent channel radio stations will not cause interference to them.

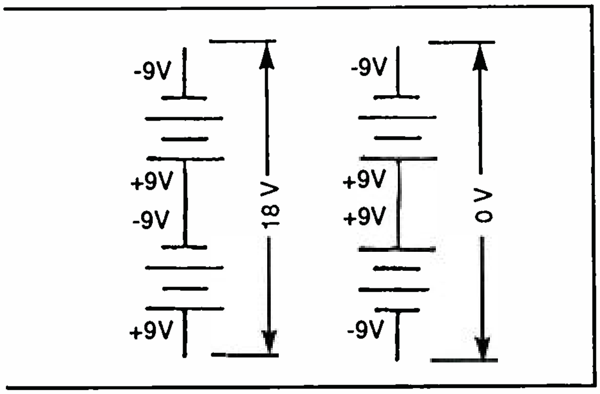
The complexity of these systems grows as the number of radiators increases. Directional antenna systems come in many configurations and sizes: An in-line array, as its name implies, will have three or more towers, all in line with each other. A dog leg array is a directional antenna system with three or more towers where one tower is off set from the line of the others. A parallelogram array will have four, six, eight, nine or twelve towers arranged as a square or parallelogram. Arrays with a large number of towers are used to produce radiation patterns that suppress radiation over wide horizontal angles, sometimes 270 degrees or more.

2.03 Phase: The Addition and Subtraction of AC Voltages

When two batteries are connected in series, with the positive terminal of one connected to the negative terminal of the other, the resultant voltage produced is the sum of the two. If both batteries were producing the same voltage the resultant would be twice that of either one alone. These two generators of DC voltage might be said to be connected in phase.

Figure 2-5

Batteries adding and subtracting



If one battery is reversed, the positive terminal of it connected to the positive terminal of the other, the resultant voltage will be the difference of the two. If both batteries were producing the same voltage the resultant would be zero. These two generators of DC voltage might be said now to be connected 180 degrees out of phase.

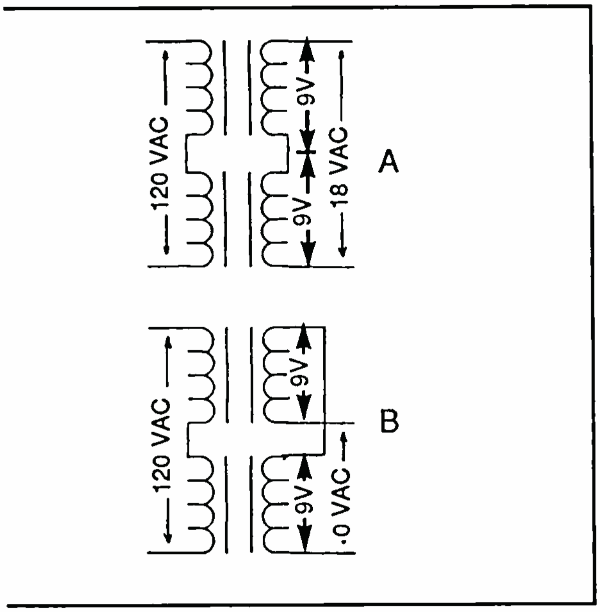
AC voltages behave in a similar manner. Figure 2-6 shows two 9 volt transformers connected together. In A they are connected in phase. The resultant output voltage is the sum of the two - 18 volts. In B they are connected out of phase. The resultant output voltage is the difference of the two - in this case zero volts. Had one transformer's secondary winding been delivering 9 volts and the other 15 volts the output of the two in phase would have been the sum - 24 volts AC - and when out of phase the difference - 6 volts AC.

Figure 2-6

Transformers connected in-phase and out of phase

A - in-phase addition of voltages take place

B - out of phase subtraction takes place

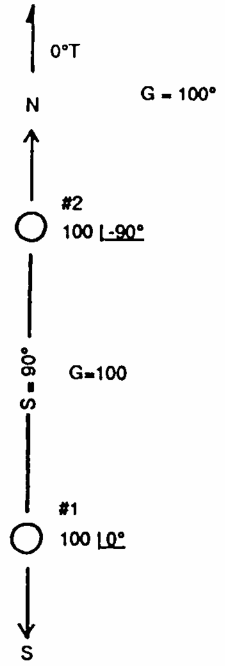


2.04 Phase: The Addition and Subtraction of RF Signals

Now, let's put two towers in place of the batteries and transformers: Figure 2-7 shows a model of just such an arrangement. The line of towers is on a bearing of 0° - true north. The **bearing of the line of towers is denoted by the half arrow point line. This is always referenced to true north,** <u>never to magnetic north</u>. The spacing between the towers is 90 electrical degrees. Tower #1 is the south tower and tower #2 is the north tower. Each tower is of the same height and is energized with equal amounts of RF current. The current ratio is then 1:1. The figures shown to the right of the towers 100 $\underline{|0^\circ}$ and 100 $\underline{|-90^\circ}$ denote vector quantities. The 100 denotes the RF field radiated by the towers. In this case each tower is radiating an inverse field intensity of 100 mV/m at 1 kM. Seeing that both towers are of the same heights RF current and RF field ratios are interchangeable. When different height towers are used, one must stick with RF field ratios. The 0° and the -90° inside the box denote the timing or phase of the RF current energizing each

Figure 2-7

Layout of a 2 tower array with equal field ratios showing electrical and physical parameters



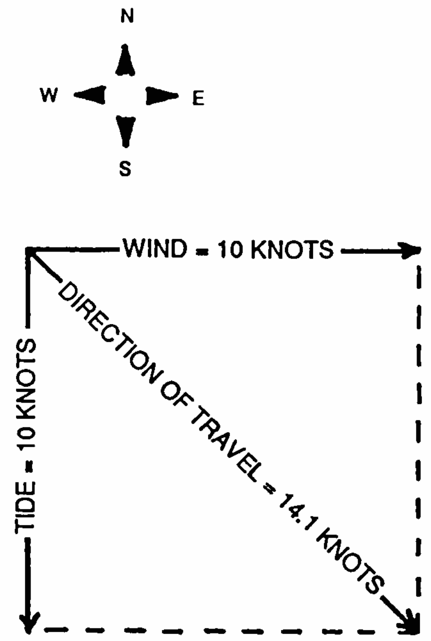
tower. In this case the current phase of tower #2 lags the current phase in tower #1 by 90°. By using current ratios as the magnitudes of the tower vectors the operating parameters - current ratio and phase - of tower #1 could be rewritten 1.0 ∟0° and tower #2 1.0 ∟-90°

For a moment let's stop and examine vectors. A vector has magnitude and direction. They can be added, subtracted, divided and multiplied. The wind is a vector. It has magnitude - a certain speed - and direction. The tidal effect on the sea is also a vector - magnitude or speed and direction. A sailboat propelled by a 10 knot wind from the west will travel in an easterly direction at 10 knots. This vector could be written 10 ∟E . If there is no wind but just tide from the north at 10 knots the boat will be propelled in a southerly direction at 10 knots. This vector could be written 10∟S. If there is both wind and tide the sail boat will neither travel due east nor due south. The two vectors have added to form a third: In this case the vessel would travel at a speed of about 14.1 knots in a southeasterly direction. This vector could be written 14.1 ∟SE. If the tide was running from the east at 10 knots the sailboat would stand dead in the water. The tide would cancel the effect of the wind.

Meanwhile, back to our two tower array. The S=90° denotes the electrical spacing between towers. The arrow with the 0°T next to it at the top of the drawing denotes the true bearing on which the line of towers lays. In this case the line through the towers is due north. Although not germane to our immediate discussion, the G=100° denotes that each tower is 100 electrical degrees in height.

Figure 2-8

Vector diagram of the sail boat influenced by wind and tide



Let's position ourselves with a field intensity meter at a measuring point 1 kM due north of the array. Tower #1 is individually energized. The meter indicates 100 mv/m. It is shut down and tower #2 is individually energized. The meter again indicates 100 mV/m. Now both towers are energized with the phase and field ratios shown in Figure 2-7. The RF signal from tower #1 leaves the radiator at 0°. As it travels north toward tower #2 is is delayed by 90° due to the time it takes to travel the 90° tower spacing. When it reaches tower #2 its electrical phase is now -90° - the same as that of tower #2. The 100 mV/m from each tower are in phase and add together toward true north. The field intensity meter indicates 200 mV/m.

Let's now position ourselves, with the meter, 1 kM due south of the array. We begin our experiment in a similar manner by energizing each tower individually. Each delivers a 100 mV/m signal to our south measuring point. The signal from tower #2 begins the journey toward our measuring point with its phase already delayed by 90° reference tower #1. When it reaches tower #1 it has been further delayed by 90° due to the spacing between towers. Its phase is (-90°) + (-90°) or -180° and the signal from tower #1 is 0°. Two AC voltages equal in magnitude and 180 out of phase cancel out to zero. The field intensity meter at our southerly measuring point reads zero.

DIRECTIONAL ANTENNA SYMBOLS

Ø = the azimuth in degrees referenced true north from the center of a DA system
Ψ = phase of the current in degrees exciting a radiator
S = spacing in electrical degrees between radiators
G = height of a radiator in electrical degrees
Z = impedance made up of resistance and reactance
R = resistance part of Z
+j =inductive reactance part of Z
-j = capacitive reactance part of Z

If we were to walk around the array, starting at our southerly point, keeping our distance at 1 kM, we would see the meter move off zero. Eventually when we reached our point north of the array it would once again read 200 mV/m. The signals from the two towers, at these intermediate points on our 1 kM radius circle, are neither completely out of phase nor totally in phase. Therefore, neither total cancellation nor total addition takes place.

2.05 The Effect of Unequal Field Ratio on Pattern

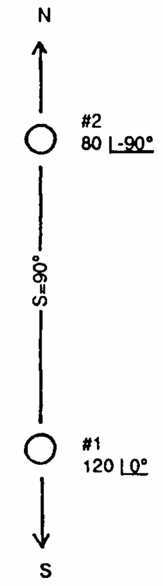


Figure 2-9

The two tower array with unequal fields from each tower

So much for the case of equal current or field ratios. Let's examine what happens if we set up the array as shown in Figure 2-9. Tower #1 will radiate 120 mV/m of inverse field at 1 kM and tower #2 will radiate only 80 mV/m. Again we go to the measuring point due north of the array and verify that indeed the towers individually are radiating the proper amount of signal. When the array is energized with these new electrical parameters we will once again measure 200 mV/m. The 120 mV/m from tower #1 arrives in phase with the 80 mV/m from tower #2.

Then it's back to our southern measuring point. Here, once again, we verify the performance of the radiators individually; 120 mV/m from tower #1 and 80 mV/m from tower #2. When the array is energized the two signals still arrive 180 degrees out of phase but being of unequal amplitudes total cancellation does not occur. The meter reads 40 mV/m - the difference between 120 mV/m and 80 mV/m. The null has now become a minima.

As we lower the radiated field from tower #2 the null once created in the due south direction when the radiated field strengths from each tower was equal continues to fill in. Eventually when the current in this radiator goes to zero we are back to non-directional operation. Tower #1 does all the radiating.

Field intensity gain from a DA System

It's relatively easy to visualize how signals from towers in a directiona antenna system cancel or add to form the pattern. However, what is behind the gain in field strength over a single element? A 90° tower energized with 1 kW will produce an inverse field of 312 mV/m at 1 kM. This same tower energized with 500 watts will produce .707 of this value - or 220.5 mV/m at 1 kM. Now, take the two towers in a 1 kW DA system, each energized with 500 watts. On azimuths where the individual signals are totally in phase and add together the inverse field will be 441 mV/m. In a four tower array, where each are energized with 250 watts, each element produces 156 mV/m at 1 kM. On azimuths where the individual signals are totally in phase and add together the inverse field will be 624 mV/m.

2.06 The Effect of Phase on Pattern

Thus far, we have examined an array and a radiation pattern that is fairly simple to visualize. Rarely, if ever, would such a pattern with one null or minima from a two tower array be used. The norm is to adjust the phase angle of the #2 radiator so that two nulls or minimas are formed positioned either side of the line of towers. They will always be equally spaced about the tower line. For example: If one null lies 25 degrees clockwise from the line of towers at 25° true the other null will lay 25 degrees counter clockwise from the line of towers at 335° true. As the phase angle of the #2 tower is moved in a more negative direction, past -90°, two nulls or minimas form. The more negative we adjust the phase in the #2 tower the farther from the center line of the towers will the nulls (minimas) appear. In line with the towers, to the south, a minor lobe will now appear. It will continue to grow in intensity as the nulls move away from the tower line. At the same time, the major lobe centered on the tower line to the north diminishes in intensity. Eventually, when the phase angle between towers is -180° the two nulls will lie in an east west direction, perpendicular to the line of towers. The two lobes, the minor lobe that formed to the south and the major lobe to the north, will be of equal size, but less than the 200 mV/m when there was but one lobe. The total amount of energy in the radiation pattern hasn't changed, it has only been redistributed.

If we continue to retard the phase in the #2 tower, the lobe to the north becomes smaller while the lobe to the south increases in intensity. When the phase angle is brought to -270° the two nulls will once again converge, the minor lobe will disappear, and there will be one null in line with the towers. However, the radiation pattern will be totally reversed. There will be a null or minima to the north and the major lobe will now be directed to the south. Note: The phase angle of -270° is the same as a phase angle of +90. The positioning of the nulls are dependent on a combination of tower spacing and phase.

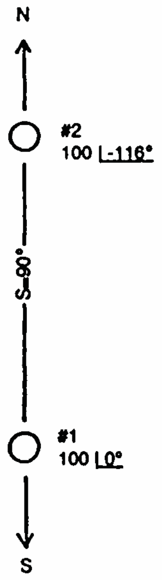


Figure 2-10

Electrical and physical parameters of a two tower array producing nulls at approximately ±45° off the line of towers

When the tower line runs north south, tower #2 lies due north of tower #1 and the radiated field from each tower is equal, the formula for adding the vectors is simplified. Taking spacing and electrical phase into account, the shape of the pattern can be calculated by the following formula:

(#14) $$Ed = 2E \text{ cosine } (S/2 \text{ cosine } \varnothing + \Psi/2)$$

where: S = spacing between towers in electrical degrees
Ψ = electrical phase of tower #2 reference tower #1
Ø = azimuth from center of the array to measuring point
E = inverse field intensity radiated from each tower individually
Ed = inverse field radiated by the directional antenna system

For the model shown in Figure 2-10, Table 2-1 defines the shape of the radiation pattern. The nulls lie approximately ±45° either side of the line of towers at 135° true and 225° true. Calculations for an in-line array need only be done for half the pattern as it will always be symmetrical about the line of towers.

TABLE 2-1 PATTERN CALCULATION FOR THE 2 TOWER ARRAY SHOWN IN FIGURE 2-10

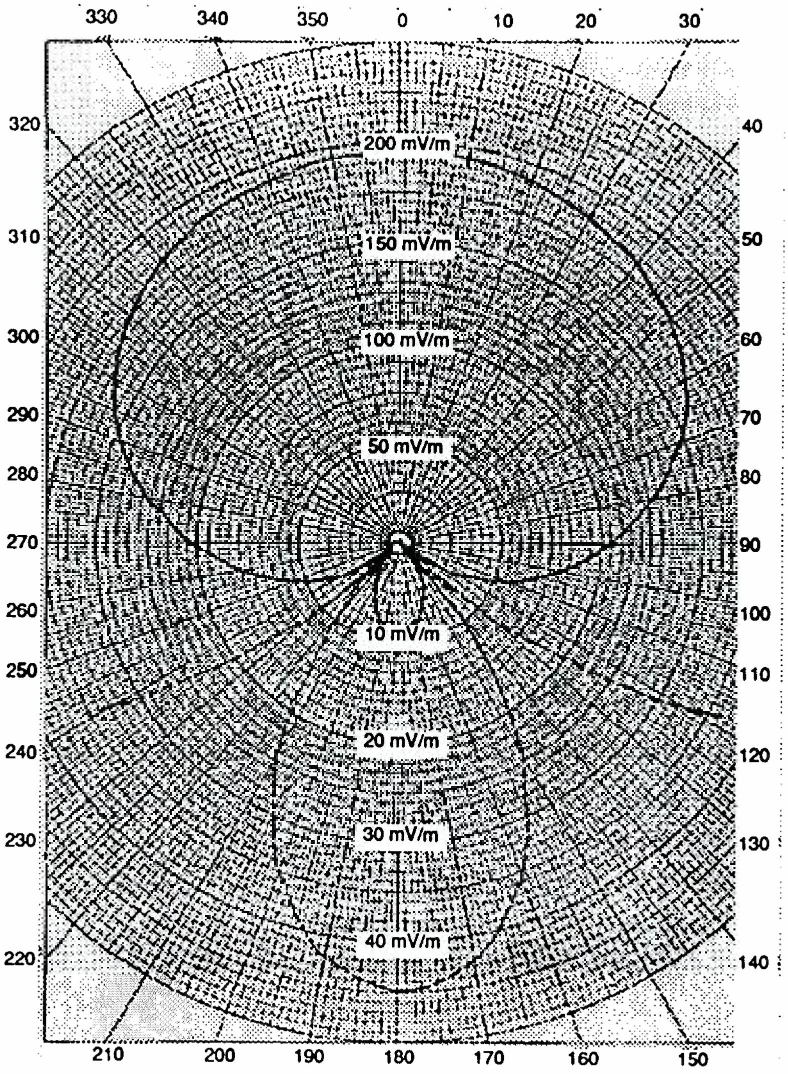
A	B	C	D	E	F
Ø	cos Ø	B x 45	C+(-58)	cos D	200 x E
000	1.000	45.00	-13.00	0.97	194.87
010	0.985	44.30	-13.70	0.97	194.87
020	0.940	42.30	-15.70	0.96	192.54
030	0.866	38.97	-19.03	0.95	189.07
040	0.766	34.47	-23.53	0.92	183.37
050	0.643	28.94	-29.06	0.87	174.82
060	0.500	22.50	-35.50	0.81	162.82
070	0.342	15.39	-42.61	0.74	147.20
080	0.174	7.83	-50.17	0.64	128.10
090	0.000	0.00	-58.00	0.53	105.98
100	-0.174	-7.83	-65.83	0.41	81.89
110	-0.342	-15.39	-73.39	0.29	57.17
120	-0.500	-22.50	-80.50	0.17	33.01
130	-0.643	-28.94	-86.94	0.05	10.68
135	**-0.707**	**-31.82**	**-89.82**	**0.00**	**0.00**
140	-0.766	-34.47	-92.47	-0.04	-8.62
150	-0.866	-38.97	-96.97	-0.12	-24.27
160	-0.940	-42.30	-100.30	-0.18	-35.76
170	-0.985	-44.30	-102.30	-0.21	-42.61
180	-1.000	-45.00	-103.00	-0.22	-44.99

Table 2-1 shows the pattern calculations using formula #14 for the two tower array shown in Figure 2-10. Column A is the azimuth. Note that calculations are done for only 180 degrees of azimuth as the pattern on the other side of the line of towers will be identical. The calculated field strength at 340 degrees true will be the same as that calculated for 20 degrees. Column B is the cosine of Ø, azimuth. Column C is column B x S/2. Column D is column C + Ψ/2.

Figure 2-11

Plot of the pattern produced by the two tower array shown in Figure #2-10 and calculated in the matrix Table #2-1

Note the expanded 5X view of the null areas and minor lobe shown as a dotted line



Column E is the cosine of column D. Column F is column E times the sum of the inverse field strengths from each tower or 2E; in this case 200 mV/m Column F is the inverse field strength at one kilometer to be expected at azimuth 0.

Electrical phase in a two tower directional antenna system can be adjusted to produce 1 or 2 nulls (or minimas) for tower spacings up to 180 degrees. If there is only 1 null (or minima) it will be in line with the towers. For spacings between 180 and 360 degrees electrical phase can be adjusted to produce 2, 3 or 4 nulls (or minimas).

2.07 Driving Point Impedance

Before we can move on to a discussion of the feeder system we must first understand the fundamentals of *driving point impedance*. This subject is the cause much confusion for the uninitiated. It's one of the phenomena that some say is part of the black magic of directional antenna systems!

Back in Section 1.05 we examined the subject of The Self Impedance of the Radiator; the electrical characteristics of the input to a stand alone tower used for non-directional operation. To review: The self impedance of a vertical antenna, sometimes called the base impedance, is the resistance and reactance present at the input point of the radiator. The input impedance or self impedance of the series excited tower will be determined primarily by its physical height, by its physical construction (uniform cross section guyed, self supporting, etc.) and the dimensions of the faces of the tower. It will also be influenced by nearby objects (metal fences, other towers, etc.) and the size and condition of the ground system installed under it. When the tower is energized the input impedance remains constant.

The driving point impedance of an element in a directional antenna system is the electrical characteristics of its input when the system is adjusted to the proper electrical operating parameters of current ratio and current phase. The driving point impedance of each element in the DA system will be determined by its self impedance, the current phase and current ratio with which it is excited, the electrical operating parameters, the current ratio and current phase which excite each of the other radiators in the system, its spacing from other radiators in the system, and the mutual impedance between radiators

Let's introduce some black magic into the domain of directional antennas! This will give us something to dispel a few paragraphs further on: **The driving point impedance of a radiator in a DA system will always be different than its self impedance.** Even though each element in a DA system might have the same self impedance each will more than likely have different driving point impedances. This is a very important concept to grasp. Unless you have an understanding of this, many of the other parts of the DA puzzle will not fit into place.

Now, with that said, let's examine the ramifications of those words! Two or more towers in close proximity to one another will exhibit *mutual coupling* much the same as two inductors placed near each other. When each individual tower is excited with RF energy, some of the energy from each one will be induced into each of the others and vice versa. The magnitude or amount of energy induced is dependent on the distance between the towers and the magnitude or amount of signal radiated by each of the other towers. The phase angle at which the energy is induced is also dependent upon its spacing to the other towers in the system and the phase angle of the current which excites each of the other towers. All of this will have an effect on the input impedance or driving point impedance of each radiator.

From a practical standpoint, we are confronted with the fact that we can not measure the driving point impedances until the entire array is constructed and adjusted to produce the proper phases and current ratios in each element. Therefore, we can't design the feeder system necessary to produce these current ratios and phases until we know the driving point impedances of each radiator. It sounds like a catch- 22!

Calculations to the rescue! If we have the design parameters - spacing, current ratios, phases, heights of the towers, etc. - we can, using tables of assumed or empirical values, calculate individual driving point impedances. The feeder system for the array can be designed using these values of driving point impedances. As a starting point, for adjustment of the array, these values are also used. When the directional antenna system is adjusted to produce proper current ratios and phases and the desired radiation pattern, driving point impedances can be measured using an in-line RF bridge. Readjustment is then made to correct for any substantial variations from the calculated values.

While the calculation of driving point impedances is a necessity for the design engineer, the "ways and hows" of these calculations should also be known by those wishing to become proficient in the set-up, adjustment and maintenance of directional antenna systems. Therefore, we will go through the arithmetic necessary to calculate the driving point values of the radiators in our two tower array. It's not terribly difficult; it looks harder than it is in reality!

The formula for the driving point impedance for the #1 tower:

(#15) $Z_1 = Z_{11} + Z_{12}\,(I_2/I_1)$

where: **Z_1 is the driving point Z of the #1 tower**
Z_{11} (pronounced Z one-one) is the self impedance of the #1 tower
Z_{12} (pronounced Z one-two) is the mutual impedance between the #1 and #2 towers (a vector quantity - phase and magnitude)
I_1 is the current which energizes tower #1 (a vector quantity - phase and magnitude)
I_2 is the current which energizes tower #2 (a vector quantity - phase and magnitude)

The formula for the driving point impedance for the #2 tower:

(#16) $Z_2 = Z_{22} + Z_{21}\,(I_1/I_2)$

where: **Z_2 is the driving point Z of the #2 tower**
Z_{22} (pronounced Z one-one) is the self impedance of the #1 tower
Z_{21} (pronounced Z two-one) is the mutual impedance between the #2 and #1 towers (a vector quantity - phase and magnitude)
I_1 is the current which energizes tower #1 (a vector quantity - phase and magnitude)
I_2 is the current which energizes tower #2 (a vector quantity - phase and magnitude)

For more than two towers terms for each additional tower are added. For example:

$Z_1 = Z_{11} + Z_{12}\,(I_2/I_1) + Z_{13}\,(I_3/I_1) + Z_{14}\,(I_4/I_1) \ldots\ldots + Z_{1n}\,(I_n/I_1)$
$Z_2 = Z_{22} + Z_{21}\,(I_1/I_2) + Z_{23}\,(I_3/I_2) + Z_{24}\,(I_4/I_2) \ldots\ldots + Z_{2n}\,(I_n/I_2)$
$Z_3 = Z_{33} + Z_{31}\,(I_1/I_3) + Z_{32}\,(I_2/I_3) + Z_{34}\,(I_4/I_3) \ldots\ldots + Z_{3n}\,(I_n/I_3)$

Let's follow through on the calculations for the driving point impedances of the directional antenna with the parameters shown in Figure 2-10.

Z_{11} and Z_{22} are the self impedances of towers #1 and 2 respectively. Each radiator is a 110° high uniform cross section guyed tower. This self impedance data is obtained from Table 1-1 on page #7. It is found to be 133 +j210.

Z_{12} and Z_{21} is the mutual impedance between towers #1 and #2. On the following page, Figure 2-12 is a graph of mutual impedance between 110° radiators for various spacings. Tables containing mutual impedances for radiators of various heights and spacings can be found in Appendix II. Our spacing is 90°. The graph shows the mutual impedance to be magnitude 47 and phase -35°; expressed in polar notation $47\ \underline{|-35^\circ}$. In this case Z_{12} and Z_{21} are the same value as each radiator is spaced 90° from the other. If there was a third radiator spaced 90° beyond tower #2 its spacing to tower #1 would be 180°. The mutual impedance, or Z_{13} term, taken from the graph in Figure 2-12, is $33\ \underline{|-115^\circ}$. Read tower spacing on the top and magnitude and phase on the right side.

Using formula #15 the driving point impedance of tower #1 - noted Z_1 - is then calculated:

$Z_1 = (133 + j210) + (47 \underline{|-35^\circ}\ [1 \underline{|-116^\circ} / 1 \underline{|0^\circ}])$

dividing first the terms inside the [ ] brackets

$Z_1 = (133 + j210) + (47 \underline{|-35^\circ}\ [1 \underline{|-116^\circ}])$

next multiplying the right hand terms

$Z_1 = (133 + j210) + (47 \underline{|-151})$

then changing the right hand terms to rectangular form

$Z_1 = (133 + j210) + (-41.1\ -j22.8)$

finally adding the two rectangular terms

$Z_1 = 91.9 + j187.2$

Using formula #16 the driving point impedance of tower #2 - noted Z_2 - is then calculated:

$Z_2 = (133 + j210) + (47 \underline{|-35^\circ}\ [1 \underline{|0^\circ} / 1 \underline{|-116^\circ}])$

dividing first the terms inside the [ ] brackets

$Z_2 = (133 + j210) + (47 \underline{|-35^\circ}\ [1 \underline{|+116^\circ}])$

next multiplying the right hand terms

$Z_2 = (133 + j210) + (47 \underline{|81^\circ})$

then changing the right hand terms to rectangular form

$Z_2 = (133 + j210) + (7.4 + j46.4)$

finally adding the two rectangular terms

$Z_2 = 140.4 + j256.4$

A review of the process for converting vectors from polar to rectangular form and vice versa is presented in Appendix I. A review of the process of for adding, subtracting, multiplying and dividing vectors is also presented in Appendix I.

The driving point impedance - the impedance at the base - of tower #1 in our array, when the system is adjusted for proper phase and current ratio, is 91.9 +j187.2. The driving point impedance - the impedance at the base - of tower #2 in our array, when the system is adjusted for proper phase and current ratio, will be 140.4 +j256.4.

If your calculator is still handy, change the #2 tower phase to -90° and recalculate the driving point impedances. With these new operating parameters, $Z_1 = 106.04 + j\ 171.5$ and $Z_2 = 159.96 + j248.5$. For those who have ever adjusted a directional array, this radical change in driving point impedances sheds some light on why current ratio is apt to change when phase is adjusted, and vice versa. When phase is adjusted, this change in resistance and reactance will cause a change in current. Note that not only did the driving point Z of the tower that was adjusted change but the driving point Z in the other radiator as well. In multi-element arrays every one of the driving point values change whenever any adjustment - phase or current ratio - is made!

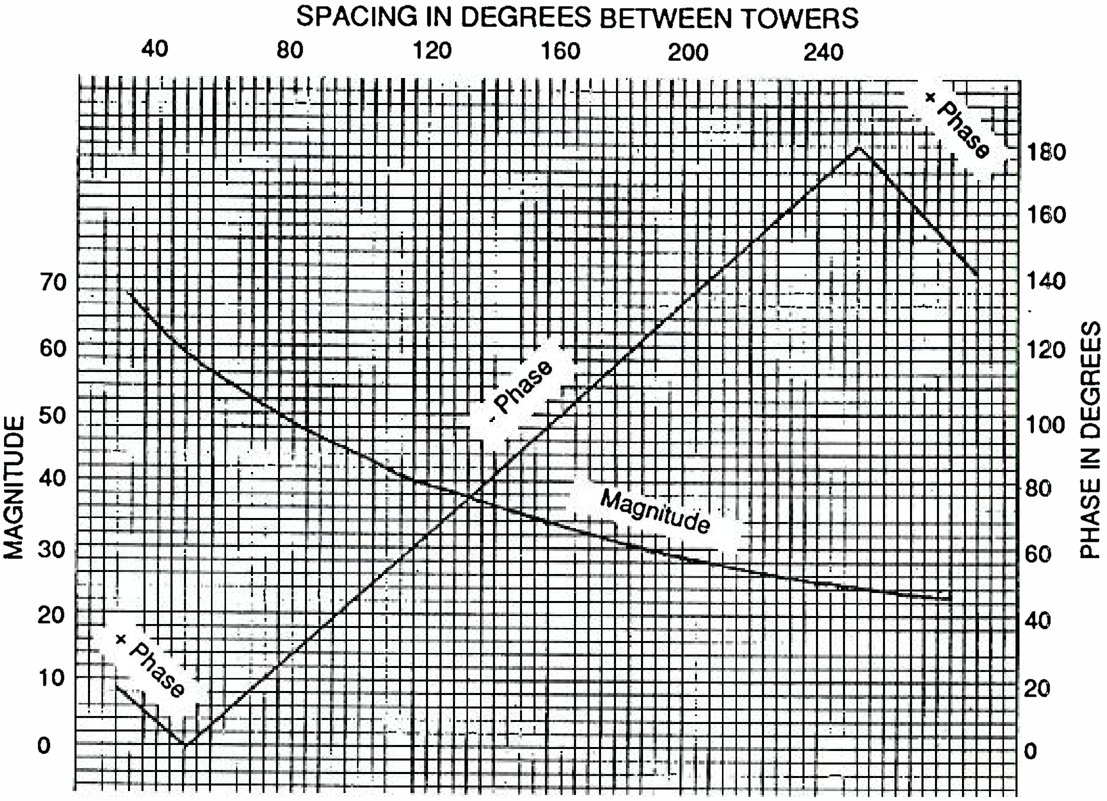
During the design phase of the system careful attention must be paid to driving point impedances. As we saw when discussing the non-directional radiator, when radiation resistance is low the losses can be high. Very low values of resistance where there are high RF currents make for much loss.

These calculated values of driving point impedances will also be used to design the feeder system for the directional antenna. These figures are required for the design phase of the matching networks and also to determine how much RF power must be delivered to each tower to achieve our required base current ratio. Once the array has been tuned to the design parameters of current ratio and phase we will be able to measure the actual driving point impedances with an inline RF bridge. At this point we will readjust for any discrepancies between calculated and actual values of driving point R and X.

Figure 2-12

Graph showing mutual impedance for110° towers for spacings up to 280°

Note how the magnitude of coupling decreases as spacing is increased



Appendix #2 contains mutual impedance data tables for radiators from 70° to 180 ° in height.

2.08 Power Distribution Among the Elements in the Array

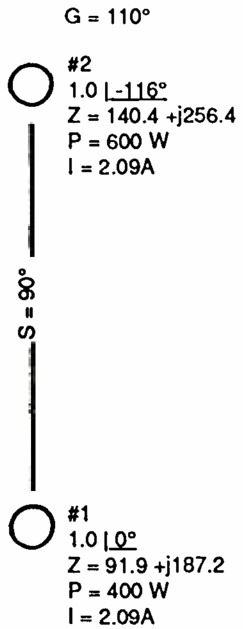


Figure 2-13

The two tower array pictured in Figure #2-10 showing all calculated electrical operating parameters for a power of 1.0 kW

A cursory glance at the system in Figure 2-10 could easily lead one to conclude that equal amounts of power are delivered to each radiator. After all, the base current in each element is the same. As we saw in our experiment, when the radiators were energized individually with the same amounts of power, they both radiated equal amounts of signal.

But wait! Even though the currents are equal, the driving point resistances are not. The resistance of the #1 tower is 91.9 ohms. When it is excited with 1 ampere of RF current Ohms Law - I^2R - indicates that it is energized with 91.9 watts. The driving point resistance of the #2 tower is 140.4 ohms. When it is excited with 1 ampere of RF current Ohms Law - I^2R - indicates that it is energized with 140.4 watts. Have we somehow broken Ohms Law?

Carrying this one step farther, the total power in this example is 232.3 watts (91.9 + 140.4). Tower # 1 is energized with 40 percent of the total power (91.9 / 232.3) and tower #2 with 60 percent of the total power (140.4 / 232.8). If our station is licensed for 1.0 kW, when the array is in adjustment, power distribution will be 400 watts to tower #1 and 600 watts to tower #2. Each tower will have a base current of 2.09 amperes.

Why this anomaly? Both towers are radiating the same amount of signal; Why the different powers? Exit now another directional antenna mystifying occurrence: 100 watts of power from tower #2 is coupled into tower #1, added to the 400 watts delivered to the radiator via the feeder system, and re-radiated by it!

A simple way of determining power distribution in the system is once driving point impedances are known, imaginarily energize each radiator with 1 unit of RF current. If the current ratio of tower A is 1.0 then it gets 1.0 ampere. If the current ration of tower B is 2.5 then it gets 2.5 amperes, and so forth. Using ohms law, square the current and multiply it by the driving point resistance. This will give you watts. Do this for each radiator. Add up all the powers and then divide the power in each element by the total. You will now have a percentage of total power to be distributed to each element.

2.09 Radiators With a Negative Driving Point Resistance

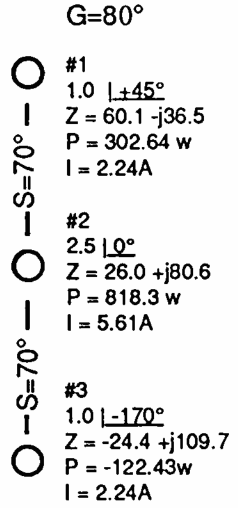


Figure 2-14

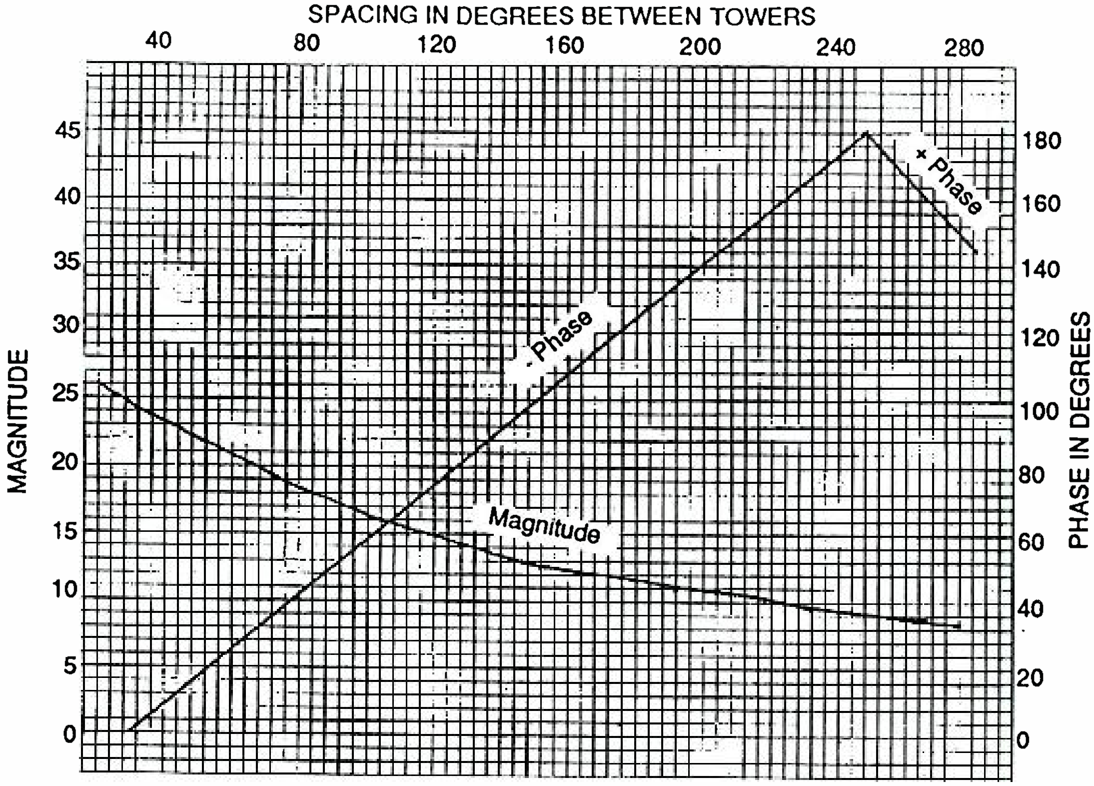
A three tower array with a tower that has a negative driving point resistance

Take a close look at the 3 tower array pictured in Figure 2-14. By what you have learned in previous sections of this book you can see that the radiators are 80° in height (G = 80). The spacing between elements is 70° (S = 70). In Table 1-1 you will find the self impedance of an 80° uniform cross section tower to be 30 ±j0. For those who wish to go through the mathematics of calculating the driving point impedances, power distribution and expected base currents, Figure 2-14 is a graph showing mutual impedance data for 80° towers.

However, already shown in the drawing of the array are the driving point values, power distribution and actual expected base currents for 1 kilowatt operation. Take a close look at tower #3's driving point impedance. It's not a typo; its driving point Z is -24.4 +j109.5. And yes, the power delivered to the radiator is shown to be -122.43 watts. And yes, the power delivered to the other two radiators add up to more than 1.0 kW! No wonder it has been said that directional antennas involve "black magic!" What does all of this mean?

Figure 2-15

Mutual Impedance between two 80° towers This data used to calculate the driving point impedances of the array shown in Figure 2-13



In the last section we saw how 100 watts from one tower was coupled into the other and re-radiated. In this model 122.43 watts more than required to maintain the proper base current ratios and field rations has been coupled into tower #3 from the other two radiators. It must be efficiently removed! Envision the tower as transmitter. Instead of connecting the tuning network to the transmission line we could terminate the tower in a resistor to dissipate the 122.43 watts. Pattern shape could be achieved by this method. However, pattern size will suffer. The 122.43 watts would not be radiated. It would be converted to heat in the resistor. This condition would destroy the efficiency of the system. Standards of good engineering practice dictate that this power should be returned back into the system, in phase, so that it is not lost. In a properly designed and adjusted directional antenna system, a radiator with a negative value of driving point resistance is matched to the feed line and the power is delivered back to the common junction of feed lines in the phasor.

A radiator with a negative resistance, carrying a considerable portion of the overall RF power, is an open invitation to low efficiency if it is not properly handled. Energy dissipated or lost through high mismatches causes the size of the radiation pattern to shrink. In addition, it can be the source of instability in the system.

In the design phase of a DA system it is sometimes possible to avoid this condition. Examine the formulae for driving point impedance (#15 and #16). It is evident that the higher the self impedance of the tower the better chance of avoiding a radiator with a negative resistance. Taller towers can sometimes be incorporated. However, the taller the towers the higher the mutual impedances between them for a given spacing. Top loading of towers is another resource available to the design engineer. Also, the use of skirt fed towers in directional antenna systems has become increasingly popular. They exhibit a higher self impedance. Sometimes it is possible to increase the spacing between towers and maintain a satisfactory pattern shape. As you can see by the graph of mutual impedance, as spacing is increased the magnitude of the mutual impedance decreases.

2.10 The Directional Antenna Feeder System

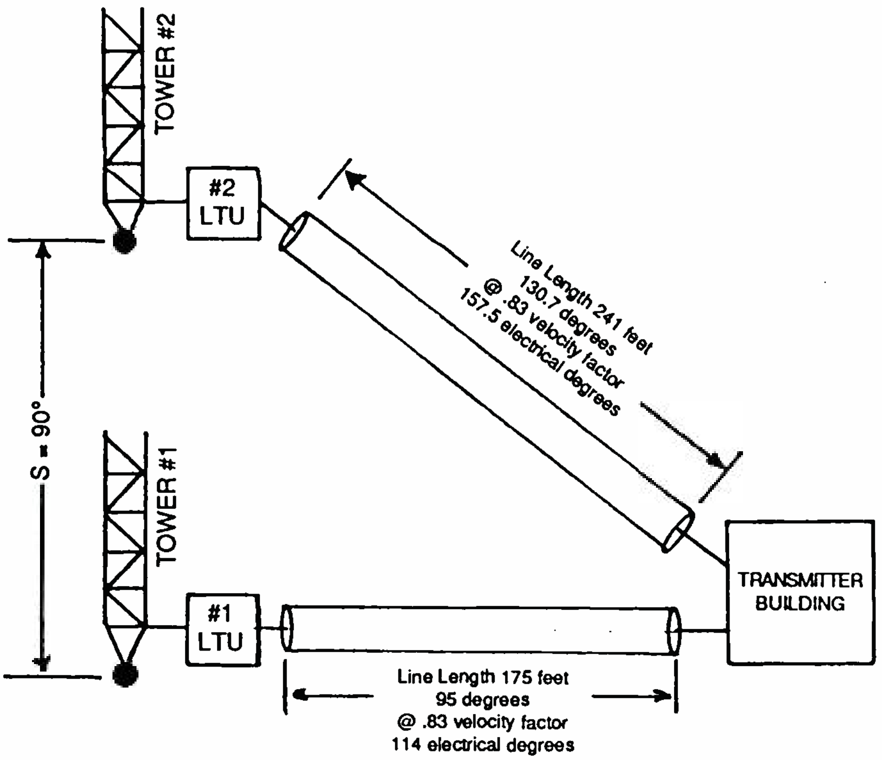
Meanwhile, back to our two tower array shown in Figure 2-13: The purpose of the feeder system of a directional antenna is to efficiently deliver the RF energy from the transmitter to each radiator in the proper quantity (watts) and proper timing (phase): In this case 400 watts to tower #1 and 600 watts to tower #2. The current delivered to tower #2 must lag that delivered to tower #1 by 116 degrees. In the process, a load of 50 ±0 must be maintained on the transmitter and the terminating impedance on each of the transmission lines must be close to 50 ohms resistive.

Figure 2-16 is a physical block diagram of the physical layout of the feeder system. Its design must take into account the locations of the towers in relation to the transmitter building. This will determine the length of the coaxial feed lines. Feed lines produce phase delay. Their approximate length must be known before the feeder system can be designed. The velocity factor of the transmission line to be used must be known if phase delay is to be accurately predicted. The coaxial cable chosen must be capable of handling not only carrier power but a 100% modulated AM signal.

In our model, the line to the #1 radiator is 175 feet in length. The #2 line is 241 feet. Using formula #6 on page#4 we determine one electrical degree at 1480 kHz to be 1.84 feet [2.73 / 1.48 = 1.84]. The 175 foot line is 95 electrical degrees in length (175 / 1.84). Typical air dielectric coax cable has a velocity factor of 0.83. Using this figure, the electrical length of the #1 coaxial transmission line is determined to be 114 degrees [95 / 0.83]. Using the same procedure, the physical length of the #2 transmission line is 131 degrees (241 / 1.48). Its electrical length is 157.5 degrees (131 / 1.84). (For the sake of simplicity these figures have been rounded off. Some adjustment is provided in the system so absolute lengths are not necessary.) Therefore, the #1 transmission line will contribute 114 degrees of phase lag in the system and the #2 line will contribute 157.5 degrees of phase lag. Once the positioning of the building in reference to the radiators is set, we have little control over the line length, and the phase lag introduced by them. A change in the specified type of line with a different velocity factor or the lengthening of one or both lines are the only variables that possibly could be introduced.

Figure 2-16

Physical layout of the system showing the location of the transmitter building in relation to the towers



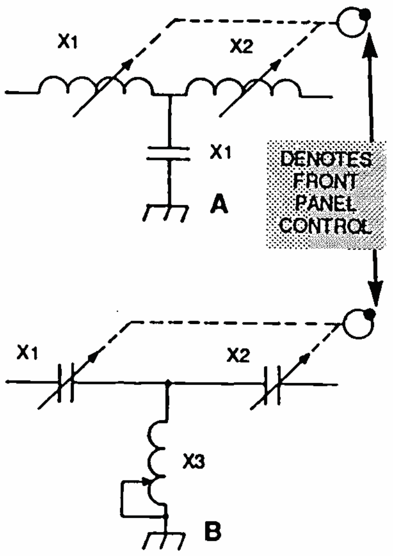
Working back from the radiators themselves; the *line terminating units* (LTUs), sometimes called *antenna terminating units* (ATUs) and at other times *antenna coupling units* (ACUs), are an integral part of the feeder system. The terms LTU, ATU and ACU are synonymous. These matching networks provide the interface between the coaxial transmission lines and the feed points of the radiators. They will match the 50 ohm coaxial feed line to the driving point impedance of the radiator. Depending on their design, they will also contribute phase advance or phase lag. When T-networks are used, a great deal of phase shift options become available during the design phase of the feeder system. Phase shifts from ±50 degrees to ±130 degrees are easily obtainable with reasonable size values of reactances.

Figure 2-17

A - 50 ohm in - 50 ohm out -90° phase control T-network

B- 50 ohm in - 50 ohm out +90° phase control T-network

All reactances are 50 ohms



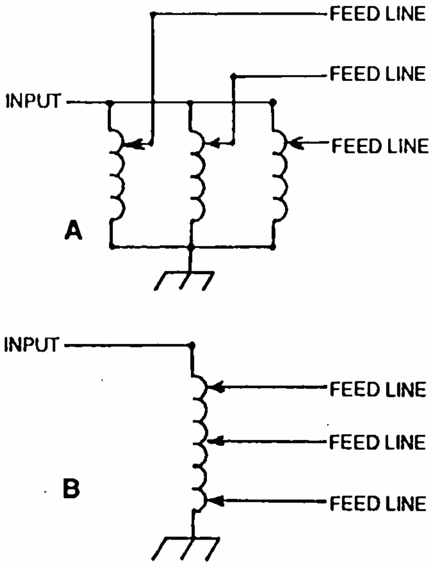
The phasor, the hub of the DA system, will contain phase control networks for front panel adjustment of the phase and the magnitude of the current driving each element in the system. In a simple two element directional antenna, such as we are modeling here, it is only necessary to have front panel control of phase and power for one element in the system. In our case we will provide it for tower #1.

T-networks are usually incorporated for front panel phase adjustment. If the design of the phase adjustment network is around a 90 degree phase shift T-network, 50 ohms in and 50 ohms out, ganging the series arms and making them adjustable from the front panel, we can expect almost pure phase shift as we adjust ±20 degrees. This means a minimal shift in power/current ratio as a by-product of phase adjustment as the input and output impedances will remain fairly constant.

Figure 2-18

A - shunt type power divider

B- series type power



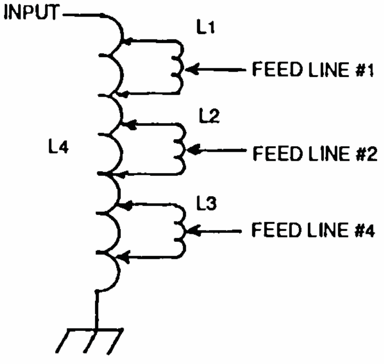
Next in line, looking back toward the transmitter, is the power divider. As its name implies, its purpose is to distribute transmitter energy in the proper amounts to the various elements in the directional antenna system. The power divider provides for front panel adjustment of power. A well designed power divider will allow one to vary current / power to an element with a minimal amount of accompanying phase change.

Power distribution is typically accomplished by a shunt or series divider. Shunt dividers are common for two and three tower systems. As you can see from Figure 2-18A, a shunt power divider parallels the loads presented by the transmission lines. These coils have front panel adjustable rollers. The feed lines are connected at these points. When four or more feed lines are in parallel a very low resistance will result. This makes for high current at the input to the divider.

Figure 2-18B is a series divider. Large arrays will utilize this type of system. Figure 2-19 details a practical series power divider. Small coils, L1, L2 and L3, are tapped across a portion of a larger coil, L4. The small coils have a front panel adjustable rollers. The tower requiring the highest amount of power may or may not be fed directly from the top of the large coil, with no adjustment. The others are adjustable reference to this one. The tower requiring the second highest power is next on the large coil. The tower requiring the lowest amount of power is nearest to ground.

Figure 2-19

A practical series power divider



Two other types of power divider are worth mentioning (see Figure 2-20): the unequal resistance type and the transformer type. Seldom is either used in new directional antenna design. The unequal resistance divider parallels the inputs to two T-networks or L-networks. By varying the input resistance power division can be controlled. The transformer type divider inductively couples RF energy to a coil that has a grounded variable center tap. This arrangement is useful only in two tower arrays. Power in the respective elements can be controlled by moving the position of the ground tap on the coil. The current at each end of the coil is 180° out of phase.

Next, inside the phasor cabinet, we come to the *common point matching network.* The impedance at the input to the power divider will not be 50 ±j0. Transmitters are designed to deliver RF power to a load with electrical characteristics close to this value. The common point matching network's sole purpose is to transform the input impedance of the power divider to 50 ±j0. It can be an L-network or a T-network. The series and shunt elements of the common point matching network may or may not be adjustable from the front panel.

Figure 2-20

A - unequal resistance power divider

B - transformer type power divider

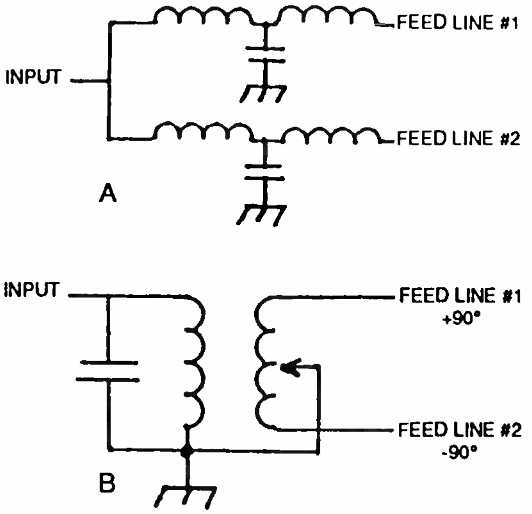


Figure 2-21 details the layout of the feeder system. The full transmitter power - 1000 watts in our model - is delivered to the power divider input. Here it is split two ways: 400 watts to tower #1 and 600 watts to tower #2. The typical shunt or series power divider should introduce little or no phase shift.

The energy to be delivered to tower #1 is fed through a 90 degree phase lag T-network. Its input and output impedance is 50 ohms. Its series arms are ganged and adjustable from the front panel to provide for phase adjustment. At the output of this network the phase has been delayed by 90 degrees reference the input to the power divider. The transmission line introduces another 144 degrees of phase lag. At the input to the #2 LTU the phase has been delayed 204 degrees (-90+[-114]). The #2 LTU is a 90 degree phase advance T-network. It advances the phase by 90 degrees. The current driving tower #2 lags what was fed to the power divider input by 114 degrees (+90° in the LTU + [-114° in the transmission line - 90° in the phase control network]).

The transmission line to tower #2 is fed directly from the output of the divider. When the RF energy arrives at the input to the #2 LTU is has been delayed by 157.5 degrees reference the input to the power divider. The LTU delays it by another 72.5 degrees. The current driving tower #2 lags what was fed to the power divider input by 230 degrees (-157.5° in the transmission line + [-72.5° in the LTU]).

Now, the phase of the current in tower #2 must lag the phase of the current in tower #1 by 116 degrees. Indeed it does. The difference between -230° and -114° is -116! If we subtract 114 degrees from phase we come up with a phase angle of 0° for tower #1 and -116° for tower #2.

Figure 2-21 Block diagram of the feeder system for the two-tower array

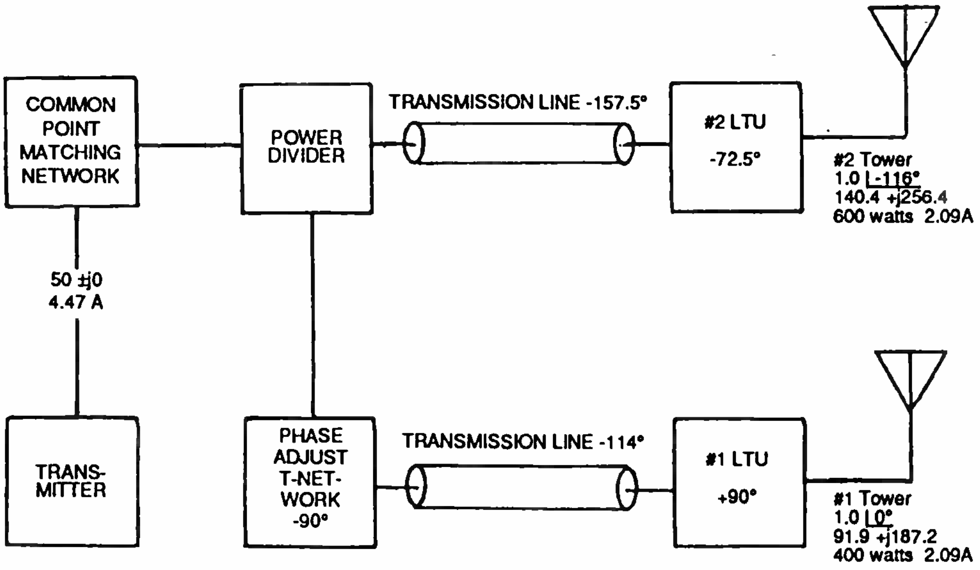
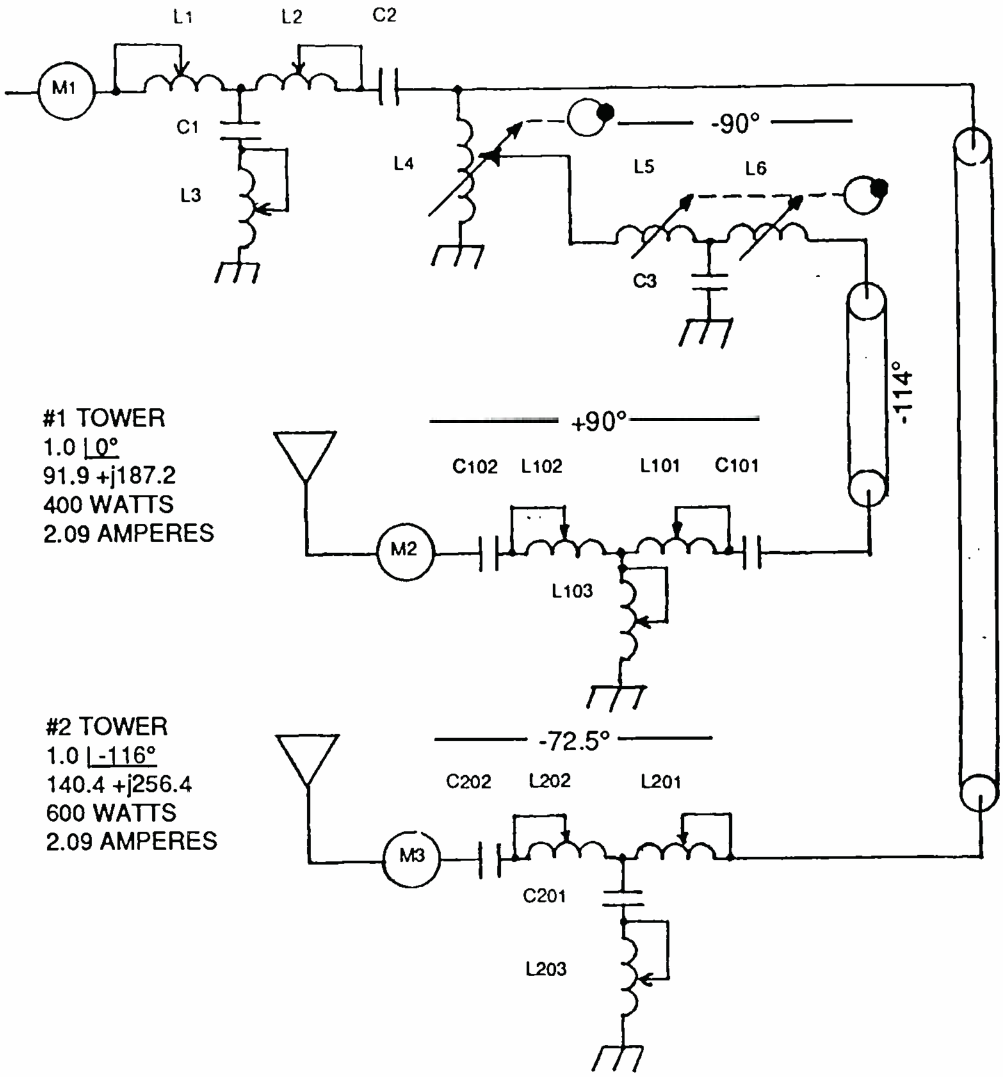


Figure 2-22

Details of the feeder system for the two tower array

L4 is adjustable from the front panel of the phasor - it varies current/power to tower #1

L5 and L6 are ganged together and adjustable from the front panel - This control provides for adjustment of the phase in tower #1



So much for the block diagram layout; now on to the actual nuts and bolts of coils and capacitors. We will start at the radiator ends of the system.

The LTU at the base of tower #1 must match the drive point impedance of 91.9 +j187.2 to the 50 ohm coaxial transmission line. It must do this while contributing 90 degrees of phase advance to this part of the feeder system. Back in Section 1.12, on page 17, T-networks with ±90° of phase shift were discussed. The configuration of this network, for advancing of phase, is shown in Figure #1-10A on page #12. It consists of capacitors in the series arms and an inductor in the shunt arm. C101 and C102 make up the capacitive reactance of the series arms. L101 and L102 are small tapped indictors that will give us adjustment of the capacitive reactance.

Using formulae #12, on page 17, for ±90° T-networks, we calculate the value of each leg of the network to be 67.79 ohms. At 1480 kHz this is .002151 uf and 7.28 uh.

First, calculating the input arm: A .001 uf capacitor has a reactance of 107.5 ohms at this frequency. An inductive reactance of 39.7 ohms - 4.27 uh - in series will give us the 67.79 ohms of capacitive reactance needed. To make the combination of C101 and L101 adjustable through the needed value of capacitive reactance should be larger than 4.27 uh.

The shunt arm is simple: L103 is 67.79 ohms. At 1480 kHz we need a 7.28 uh inductor. An somewhat larger tapped inductor will allow us to adjust to this value.

The output leg becomes a little trickier: We need 67.79 ohms of capacitive reactance in this leg. We already have 187.2 ohms of inductive reactance present in the tower load. It must be cancelled. A capacitor with a reactance of 254.99 ohms (67.79 + 187.2) will satisfy our need. At 1480 kHz this is .000422 uf. A .0004 uf capacitor will give us 268 ohms. That doesn't leave much room for adjustment. If we use a .00035 uf capacitor for C102 we will have 307.25 ohms of reactance. An inductive reactance of 52.06 ohms in series for L102 will give us the 254.99 ohms . An 5.59 uh inductor satisfies this need. It should be larger and tapped to arrive at the precise value of reactance.

For the tower #2 LTU: Using formulae 13, on page 17, we first calculate the value of inductance needed in the input leg L201 for a -72.5 degree T-network. It works out to be 78.75 ohms of inductive reactance. At 1480 kHz this is 8.47 uh. A tapped coil of a larger value will be used.

For the shunt leg C201 and L203: Using formula #12 on page #19 we calculate 87.85 ohms of capacitive reactance. A .001 uf capacitor is 107.5 ohms. This in series with 19.65 ohms of inductance - 2.1 uh - gives us the required reactance value. Again, the inductor will be made larger and provide for a tap on it.

Now the output leg C202 and L202: Calculations, again using formulae #12, show that we need 13.67 ohms of inductive reactance. We have 256.4 ohms of inductive reactance in the tower load impedance. If we cancel 242.73 ohms our need is satisfied. This is .000443 pf. A .00035 pf capacitor is 307.25 ohms. This in series with 64.52 ohms of inductance - 6.94 uh - again adjustable - will satisfy the requirements of the output leg of our -72.5 degree T-network.

Inside the phasor, for the tower #1 phase control network, L5, L6 and C3: Using formula 11, on page 17, it's easy to see that all three legs of this network will be 50 ohms. At 1480 kHz this is .002151 uf and 5.38 uh.

For the series legs two 10 uh roller variable inductors will be ganged together. These should be adjustable from the front panel for phase adjustment.

For the shunt leg: A .002 uf capacitor is 53.78 ohms. This value is very close to what is needed. A series coil is probably not necessary but can be included to provide a method for adjustment.

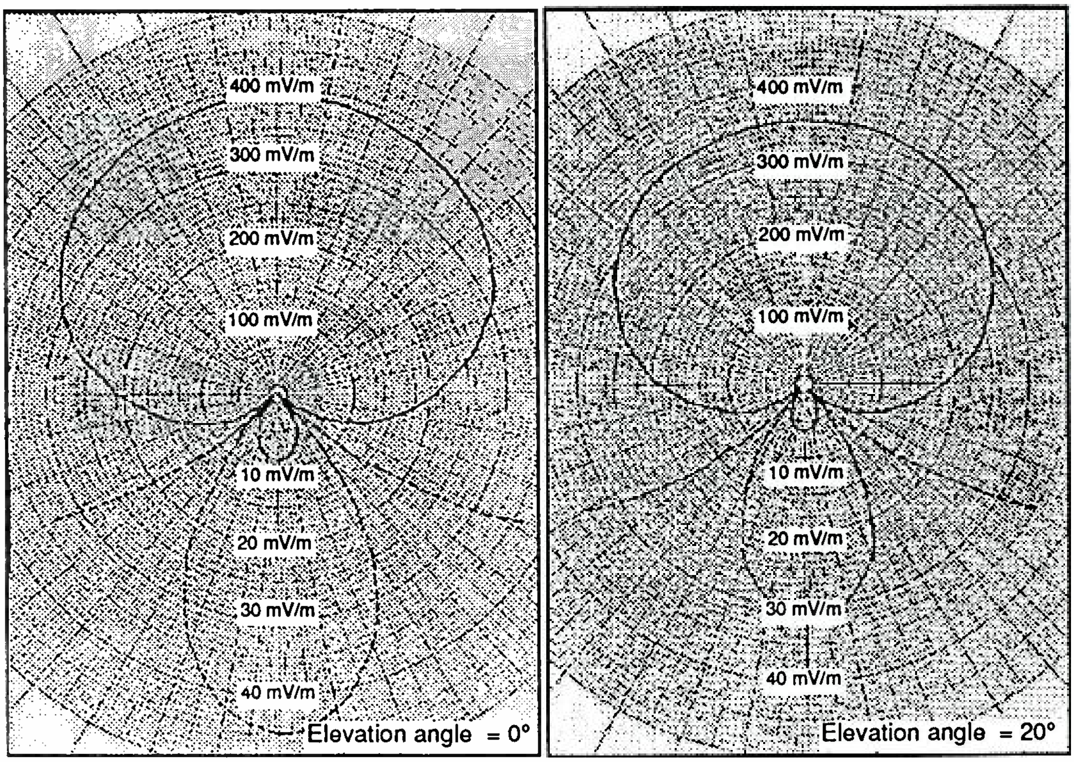
The power divider network consists of L4. A 10 uh front panel adjustable inductor will shunt about 93 ohms of reactance to ground. The tower requiring the lower amount of power - in this case tower #1 - will be fed from the roller tap on L4. Tower #2 - the tower requiring the greater amount of power - is fed directly off the output of the common point matching network. In a two tower array it is only necessary to have phase and power control on one of the towers as its current and phase are referenced by the other tower. Some feeder designs, however, will provide for control of phase and power in both radiators.

The common point matching network assures that the transmitter sees a 50 ±j0 load. It is the interface between the directional antenna feeder system and the transmitter. If both transmission lines are exactly matched, the input will be about 25 ohms with some inductive reactance due to L4. It is not uncommon to see some serious mismatches in DA systems. When this occurs the resistance and reactance present at the power divider input can be far from what is predicted. The components in the common point matching network should provide for handling a wide range of resistance and reactance.

In large arrays, where many transmission lines are tied together in the power divider, its input resistance can be quite low. The entire power output of the transmitter is present at this point. Low resistances and high power can result in some very high currents.

In our model, C2 is provided to tune out the inductive reactance present at the input to the power divider. It can be eliminated if the reactance does not exceed what is needed in the output leg of the common point matching T-network. The values of L1, L2, L3 and C1 can be calculated using the formulae and methods previously discussed in this section.

2.11 The Radiation Pattern Above the Surface of the Earth



Figures 2-23 and 2-24

The radiation patterns of the two tower array with parameters shown in Figure 2-10

The pattern on the left is at 0° elevation - ground level

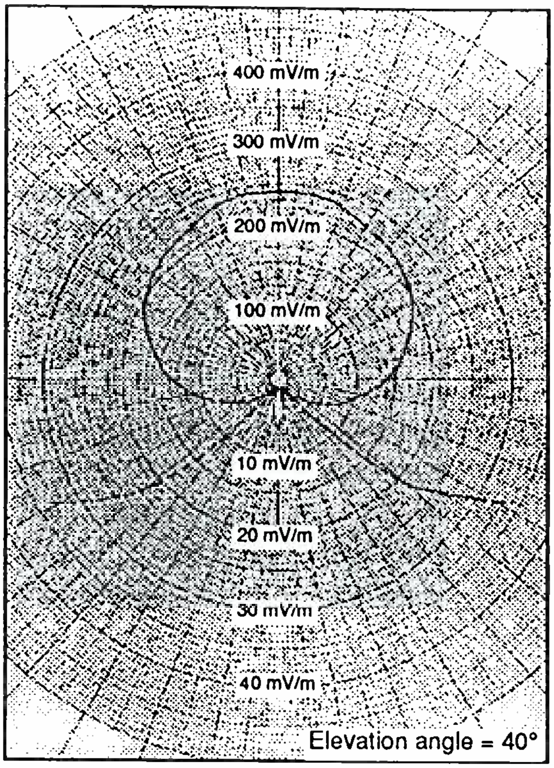
The pattern on the right is at 20° above the surface of the earth

Now that we have our directional antenna system working - well at least laid out on paper - let's investigate some other phenomena that begs for an explanation. Thus far we have calculated and have concerned ourselves with the radiation pattern - and how it is formed - at ground level. This is called the *horizontal radiation pattern* - the pattern formed at 0° elevation.

When a directional antenna system is used for daytime operation the radiation pattern formed along the surface of the earth is all that is of concern to us. However, once the sun has set, the D-layer of the ionosphere disappears. Energy at AM broadcast frequencies that was absorbed in this layer of the ionosphere now travels upward to the F-2 layer. Here some of it is reflected back to the surface of the earth. Now, if the antenna system radiated energy <u>only</u> along the surface of the earth we would have no concern. However, that is not the case. Energy is also radiated up toward the ionosphere. This energy is reflected back to the earth at the same angle as it strikes the ionosphere. If we know how much energy is radiated, at what azimuth and at what elevation angle we can then calculate how much will be reflected back down to the surface of the earth, and where! We won't delve into interference considerations as that is an allocation problem. The purpose of this chapter is to familiarize you with how and why the directional antenna system works.

Figure 2-25

The radiation pattern at 40° elevation of the two tower array with parameters shown in Figure 2-10



To complicate matters, the directional antenna pattern formed along the surface of the earth changes radically at elevation angles above the horizontal. Where there were total nulls at ground level at certain azimuths, the azimuths of the nulls at elevations above ground will change. Indeed, at times the nulls can totally disappear at elevation angles above the horizontal. Figures 2-23 through 2-26 show what happens to the radiation pattern formed by our two-tower array as we lift our observation point off the surface of the earth.

These patterns are all drawn to the same scale. In addition to the size of the pattern shrinking, note how the positioning of the nulls move as we move our observation point toward the zenith. At 60° the minor lobe has disappeared, and the nulls have deteriorated and converged to form but a dent in the pattern.

The shape of the radiation pattern at any elevation above ground level can be calculated by adding two terms to formula #14 as shown on page 40:

(#15)

$$ED = 2E\,fO\,(S/2 \text{ cosine } Ø \text{ cosine } O + \Psi/2)$$

where:

S = spacing between towers in electrical degrees

Ψ = electrical phase in degrees of tower #2 reference tower #1

Ø = azimuth from center of array to measuring point

E = inverse field intensity radiated from each tower individually

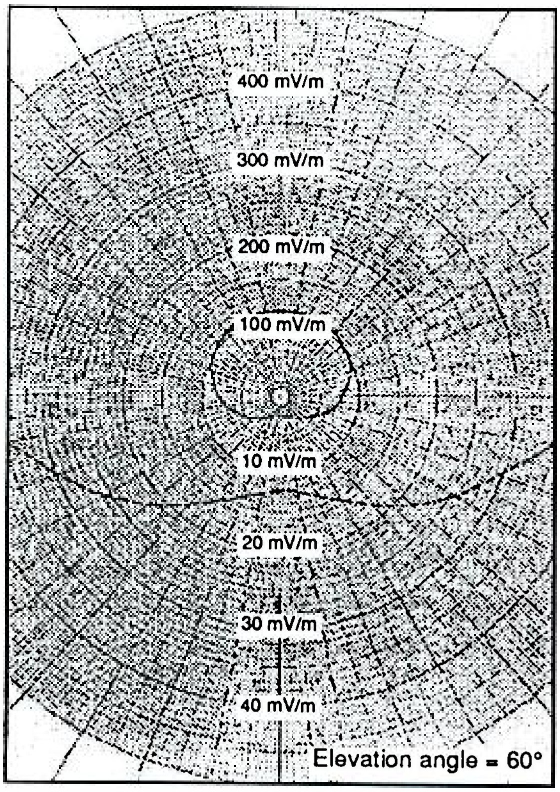
ED = field radiated by the directional antenna system

fO = vertical radiation characteristic of the height towers

O = elevation angle in degrees above ground level

Figure 2-26

The radiation pattern at 60° elevation of the two tower array with parameters shown in Figure 2-10



The term fO is the vertical radiation characteristic discussed in Section 1.18. It defines the vertical radiation pattern shape of a single vertical radiator. At ground level it is 1.00. For elevations above ground, as the radiated signal decreases for a given distance, it is a decimal. When you get to the zenith - a point directly above the radiator - it becomes 0.00. As you might expect the value of E - the radiation from each tower individually - is multiplied by the vertical radiation characteristic. This accounts for the pattern produced by the directional antenna system becoming smaller as the elevation angle is increased.

The other new term in our formula is cosine O. The elevation angle above ground is denoted O. As we saw in Section 2.04, Phase: The Addition and Subtraction of RF Signals, the timing or phase of each signal changes constantly as it travels through space. This is directly related to the distance travelled. At any given point away from the array the signals will add or subtract in proportion to their phase relationship.

Figure 2-27

An illustration of how the distance - thus the phase relationship - changes when the observation point is lifted off the surface of the earth

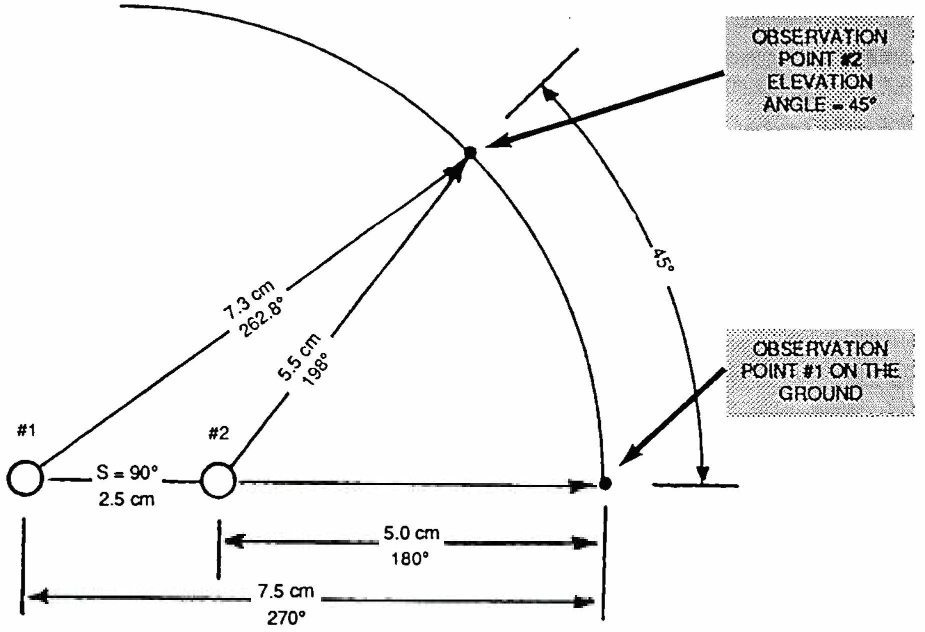


Figure 2-27 shows two field measuring points: Point #1 is on the ground; point #2 is at the same distance away from the center of the array but up at an elevation angle of 45°. The spacing between the two elements in our model is 2.5 cm. The distance to our ground based measuring point #1 is 7.5 cm from tower #1 and 5.0 cm from tower #2. We can say our distance ratio is 1.5:1.0. The distance to our 45° elevated measuring point #2 is 7.3 cm from tower #1 and 5.5 cm from tower. This distance ratio is 1.33:1.0.

Another way of looking at this relationship is to allow the 2.5 cm between radiators to be our 90° spacing between towers. This makes 1 cm = 36 electrical degrees. Tower #1 is then 270 degrees (7.5 x 36) from measuring point #1 and tower #2 180 degrees (5.0 x 36) distant. The difference is still 90° (270 - 180) - the spacing between towers.

Now, let's try the same experiment for the #2 measuring point at 45° elevation. Tower #1 is 262.8 degrees distant (7.3 x 36). Tower #2 is 198 degrees distant (5.5 x 36). The difference in phase is now 64.8° (262.8 - 198).

Needless to say, radiation patterns at angles above ground level are not easily measured or verified - although some have resorted to using helicopters! During the design phase of a DA system that is to be used for night time operation, pattern shape and size at every 5° above ground level must be calculated and submitted with the application for a construction permit. It must be shown that this energy leaving the array above ground level at critical azimuths will not cause harmful interference to distant stations on the same or adjacent channels. When the pattern shape and size produced at ground level is measured and found to be in accord with what had been calculated, it is then assumed that the pattern shape and size at vertical angles is also in conformity.

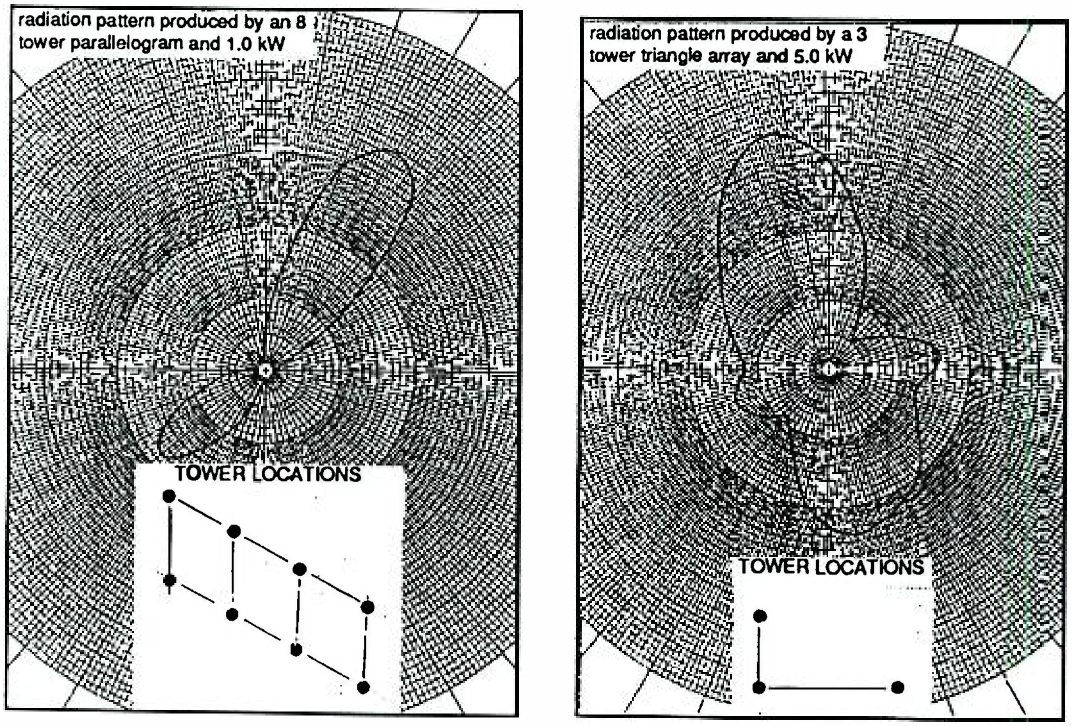
2.12 Arrays With More than Two Elements

Two tower arrays have their limitations. Quite frequently it is necessary to suppress radiation over a wide angle. Three or more elements will be required to produce such a pattern. Sometimes a non-symmetrical or lopsided pattern is required. In this case an in-line array will not suffice. Figure 2-28 is a sampling of radiation patterns produced by various arrangements and numbers of towers.

The principles described in the design and operation of the two tower array also apply to these larger systems. As a matter of fact, one design approach adds or multiplies two or more two tower radiation patterns to come up with what will be produced by the final configuration of towers, phases and current ratios. As you can well realize, the math involved in calculating such radiation patterns becomes much more complex. The complexity of the design of the feeder system and the adjustment of these larger arrays probably increases by the square of the number of radiators! Most directional antenna design is today done by computers.

Figure 2-28

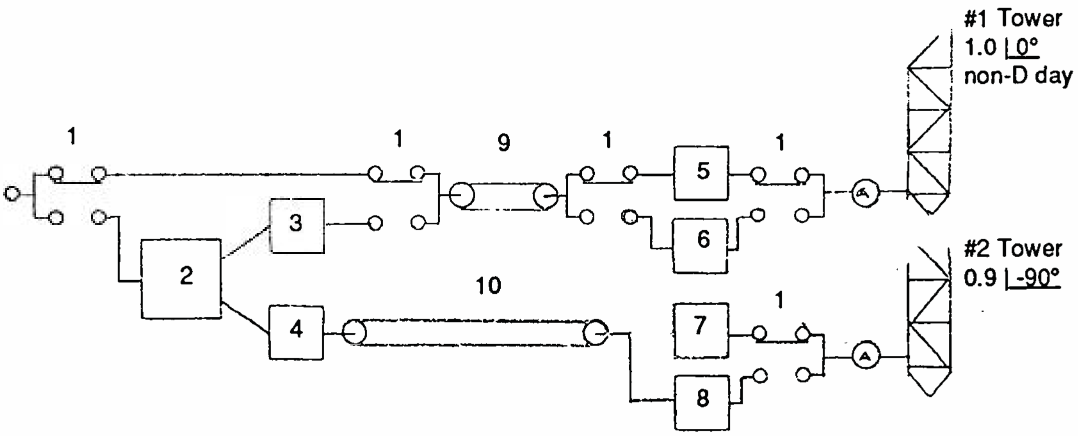
radiation patterns produced by various tower configurations



2.13 Antenna Systems that Produce Two Radiation Patterns

It is frequently necessary for a radio station to use one radiation pattern during daytime hours and another during nighttime hours. In some cases a daytime only station on the same or adjacent frequency will have to be protected during day hours. When this station goes off the air at sunset, due to it no longer being necessary to generate a minima in its direction, it sometimes is possible to change the night time radiation pattern to allow more signal in the daytime limited direction. More than likely, however, when the sun disappears from the sky is becomes necessary to limit radiation in some directions, particularly at vertical angles, as energy is now reflected off the D-layer of the ionosphere. This reflected energy can arrive at ground level in the primary coverage area of other stations causing interference. The commonly seen arrangements of different operating modes is non-directional day/directional night or directional day with a different directional pattern for night time operation. Sometimes powers will also change day to night. In very rare cases a third pattern will be used for critical hours operation - from sunrise until two hours after sunrise and from two hours before sunset until sunset. In a few instances, a station will use a different transmitter site for day and night operation. An example of when this is desirable is when radiation must be limited to the north during the day. This would call for a transmitter site north of the city. At night it might be necessary to limit radiation to the south. If the same site were to be used, the city of license and its suburban area will lie in the direction of the nulls. A different site, located to the south of the city, would be desirable Figure 2-29 shows the block diagram of a feeder system for a station that operates non-directional day and directional night.

Figure 2-29 block diagram of a non-directional day/two-tower directional night antenna system



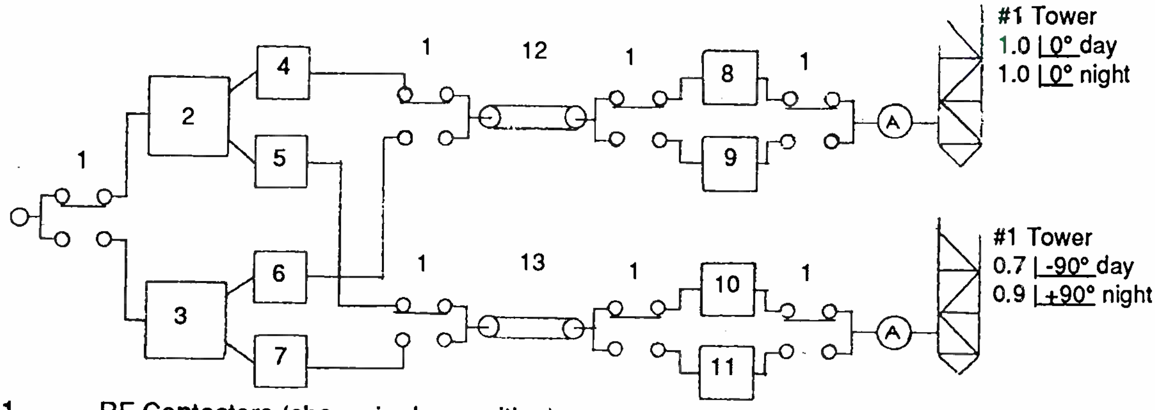
1	RF Contactors (shown in day position)
2	Power Divider
3	#1 Phase control -90°
4	#2 Phase control -90°
5	non-directional line terminating unit -90°
6	#1 tower DA line terminating unit -90°
7	detuning network for #2 tower when system is operating non-directional
8	#2 tower DA line terminating unit -90°
9	#1 transmission line -90°
10	#2 transmission line -180°

A station operating non-directional day and DA-N at the same transmitter site will use one tower of the array for non-directional operation. The other towers will be detuned to render them ineffective radiators. This is necessary so as to not distort the non-directional pattern. When two different patterns are used there are occasions when not all of the towers are needed to produce both radiation patterns. Perhaps a two tower array will suffice for day time operation and four towers will be necessary for night operation. All of the unused towers in the day operation must be detuned. More on dutuning unused towers in Chapter #4.

As we have learned in our discussions in this chapter, the shape of the radiation pattern and the direction of the lobes and nulls is formed by the physical configuration of the towers and by the electrical current ratio and phase of the energy driving each. Once the system is built the orientation of the array and the spacing between radiators can not be changed. However, the phase and current ratio in each of the elements is variable. Thus, it is possible to use the same radiators, in the same physical configuration, to produce radically different radiation patterns.

Complex switching of components and/or entire coupling networks are needed to effect such changes. Careful consideration must be given to the side effects that occur when such changes are made. The most obvious effect is that the driving point impedance of each radiator will change when the radiators are driven with new values of electrical current ratios and phase relationships. This means new values of inductance and capacity in the LTU networks will be required. In order to produce a second set of electrical operating parameters, phase delay and/or advance requirements will be different. Power division will also change from one mode to the other. Many well designed two pattern directional antenna systems use only transmission lines and towers in common for both patterns. Different LTUs, phase control networks, power dividers and common point matching networks are used for day and night operation. In essence, there are two feeder networks standing side by side sharing only a few components. Figure 2-30 is a block diagram of such a system.

Figure 2-30 block diagram of a two-tower DA-2 antenna system



1	RF Contactors (shown in day position)
2	Day Power Divider
3	Night Power Divider
4	#1 Day Phase control -90°
5	#2 Day Phase control -90°
6	#1 Night Phase control -90°
7	#2 Night Phase control +90°
8	#1 Day DA line terminating unit
9	#1 Night DA line terminating unit
10	#2 Day DA line terminating unit
11	#2 Night DA line terminating unit
12	#1 Transmission line -90°
13	#2 Transmission line -180°

In the system shown in Figure 2-30, if the towers are spaced 90°, switching from one mode to the other will reverse the direction of the major lobe 180°. Separate line terminating units are used for each mode as the driving point impedances will change when the elements are energized with new values of current ratio and phase.

RF contactors are used to effect these changes. A contactor is a locking type relay with two sets of coils. The coils are designed to operate from either 120 volts or 240 volts AC. One coil pulls a spring loaded armature into position where it locks into place. The power is then removed from the coil. To change positions the other coil is momentarily energized. The armature is pulled into position number two and locked. Typically, RF contactors come in SPDT and DPDT configurations capable of handling RF voltages up to 30 kV and RF currents of 100 amperes.

RF contactors are equipped with two or four micro switches mechanically activated by the position of the armature. These switches can be used to activate tally lights and/or interlock with the transmitter. This prevents the application of RF power to a system where one of the contactors has failed to properly position itself. The tally lights immediately identify the faulty contactor.

● ● ● ●

Chapter Three

Building the Directional Antenna System

3.01 Developing Your Plan

The construction of a directional antenna system and its associated transmitter plant - even a small low power system - is a mammoth task. There's myriad of details that must be dealt with in the proper way and in the proper sequence. The more thought given to this phase of the project, the easier it will be to pull it together in an orderly manner. There will always be the unexpected; those situations will require on site, sometimes spur of the moment, decisions. However, if you cover all of the expected, it is a lot easier to deal with the unexpected. Eventually, the antenna system will have to produce the radiation pattern specified in the construction permit. You will have to prove it by making hundreds of field intensity measurements. Five years down the road the antenna system will still be required to produce the same radiation pattern. A lot of what you do now, and how you do it, will determine the built-in stability of the array. If you have a plan and do the right things right the first time, the need for headache medication and Maalox later on will be minimal!

Jot down your thoughts. Start looking for and talking with some of the contractors, service providers and vendors you will need. For starters:

- ✓ Have the site surveyed
- ✓ Have surveyor layout the base locations of the the towers
- ✓ Contact local power company
- ✓ Contact local telephone company
- ✓ Look for a company to do clearing and grading of the site
- ✓ Look for a building contractor
- ✓ Look for an electrical contractor
- ✓ Start preparing an equipment list
- ✓ Give some thought as to how you will (off load) the transmitter and phasor
- ✓ Give some thought to the requirements of your transmitter building
- ✓ Give some thought to the physical construction of the phasor and LTUs
- ✓ Who will erect the towers

Before any contractor is permitted to work at the site he should be made to produce evidence of workman's compensation and liability insurance. His insurance agent will issue a certificate stating the limits of coverage. The certificate should be dated and made out to the broadcaster. Should the insurance lapse or be cancelled, the agent is bound to notify those to whom certificates have been issued. Check with your own insurance company as to what insurance coverage limits the contractors should be required to carry.

The sections that follow will help you fill in the blanks and also give you some more food for thought to add to your list.

3.02 Site Selection

Before an application for a construction permit can be filed with the Commission the prospective permittee must have access to a suitable transmitter site. This means that it must be owned by the applicant or the applicant must have a reasonable expectation of buying, leasing or otherwise constructing the proposed transmitter and antenna facilities on the site.

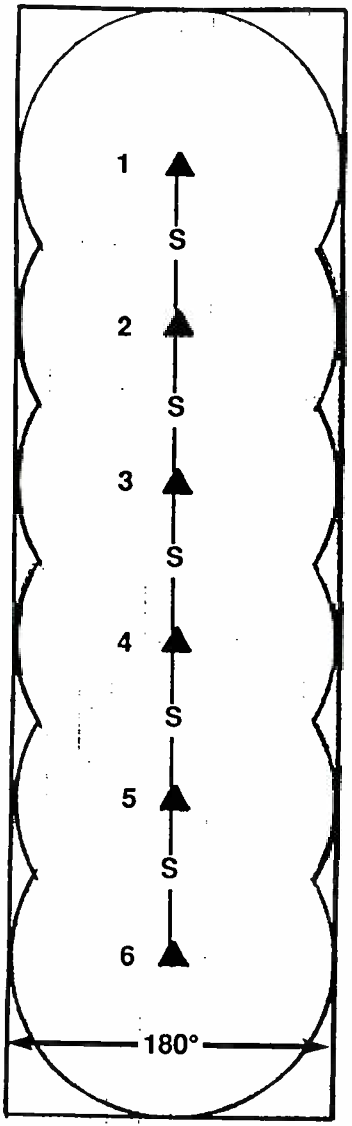


Figure 3-1
Plot plan for a six-tower in-line array - at 540 kHz this plot would be about 900 feet wide by 3150 long - at 1600 kHz about 300 feet wide by 1050 feet long

Once the consultant has determined protection requirements and the number of towers required, their spacing, orientation and their configuration (in-line, parallelogram, etc.), the required land area necessary for towers, guy anchors and ground system can be calculated. When site hunting, one must keep in mind that it isn't just X number of acres needed. The land area for the site must be oriented to accommodate the array. Figure 3-1 shows the plot layout of a typical six tower in-line array. At 540 kHz, with 90° spacing between towers, it requires about 65 acres to accommodate towers and ground system. In practice, a piece of land approximately 900 feet wide and 3150 feet long running in exactly the direction of the tower line, is unlikely to be available. The site will probably end up being much larger than 65 acres.

The site must be at least two miles distant, and in some cases farther, from any tall structures including other towers and water tanks. Re-radiation can cause much grief when it comes time to adjust the array and prove by field intensity measurements that it is working properly. A tower or tank that is an eight-wavelength or more in height can cause trouble. Detuning of such structures can be both expensive and time consuming.

In rural areas, the task of finding such a plot is usually not too difficult. Several suitable sites might be available. In close proximity to a big city it might be impossible to find a suitable piece of land. Such a parcel in an urban or suburban area, in all probability, will be worth much more than the entire value of the radio station, if developed as residential property. As a matter of fact, in recent times AM radio stations have been known to go silent and sell the transmitter site land for more than the radio station could bring in a sale!

Once a suitable site is located you must investigate what restrictions you will encounter in putting up towers. Again, in rural locations limitations will be few if any. The author recently discovered, in a small town, that there were no tower restrictions what-so-ever; not even a building permit was required to erect them! This came as a pleasant surprise to one who has become accustomed to much bureaucratic red tape when seeking a permit for a tower. In or near a big city be prepared for a lengthy process of zoning hearings and perhaps litigation. The big cry today is "RF hazard." Listen carefully and you will really hear the locals saying, "Not in my back yard!"

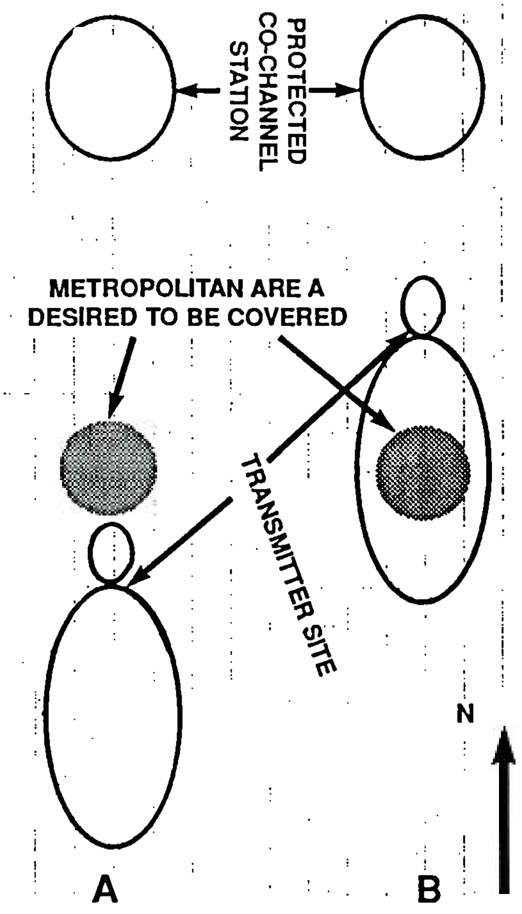
The location of the site relative to the city of license and high population areas to be covered will play a role in its selection. Where there are critical protection requirements to the north obviously the transmitter site would have to be located somewhere other than to the south of the city. As illustrated in Figure 3-2, a site to the south of the metro area would put little signal over it.

In addition, the site must be reasonably level. The elevations of the tower bases *above mean sea level* (AMSL) at the top surface of the concrete foundation piers of adjacent towers should be within a few feet of each other. In order to meet this requirement some grading might be required. When this is done, however, it might then become necessary to use oversized tower foundations and guy anchors seeing that they will be located in fill.

Figure 3-2

transmitter site A will not work - in protecting the co-channel station to the north a minima is created over the metropolitan area

transmitter site B allows the major lobe to lie over the metropolitan area

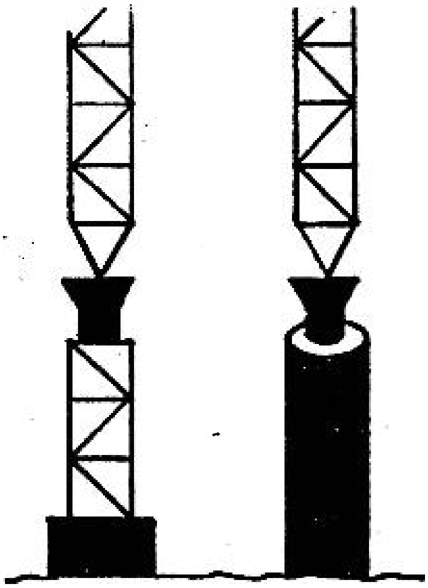


Another way of meeting this requirement is to install a taller foundation for a tower that lays at a lower elevation. This should not be carried to extremes - i.e. beyond 15 feet of elevation. Figure 3-3 shows two ways of accomplishing this: by raising the base on a tall concrete pier or adding a steel section of tower below the base insulator.

In swampy areas care should be exercised to make sure the tower bases and the LTU housings remain above the high water mark. Bases and tuning houses can be elevated on concrete piers to accomplish this end. The WIND transmitter site in northwestern Indiana is an example of such construction. It is located on flood plain of the Little Calumet River. The four tower bases and tuning houses are elevated about 15 feet above ground level. In the spring time a boat is required to get to the tower bases as 6 to 8 feet of water floods the area. The array is very stable with little change in radiation pattern from normal to flooded conditions. This type of environment runs up the cost of the installation considerably. This transmitter plant and directional antenna system was built in the mid-70s. It might be very difficult to accomplish this today due to environmental restrictions. However, when looking for a suitable site in a large metropolitan area, this is one solution. A site as just described certainly is not suitable for building houses.

Figure 3-3

two methods of raising the base insulator



The terrain surrounding the towers on which the ground system will be installed should be perfectly flat in the area of the ground screen - i.e. out to 25 or 30 feet from the tower base. Many arrays have been installed and function satisfactorily with ground systems beyond the area of the ground screen that drop off in elevation rather rapidly. A good rule of thumb is to limit the change in elevation of out to the end of the ground system to a grade of 1.5:1. This means ±15 feet of elevation for every 100 feet of horizontal distance.

If the site is wooded the expense of clearing it must be budgeted. If its for the six-tower 540 kHz array just described, 65 acres of clearing will be expensive. Keep in mind that a considerable amount of copper wire for the radial system must be buried. Large roots or rocks near the surface can make this task difficult.

Commercial AC power must be available at the site. State of the art AM transmitters of up to 10 kW will operate on single phase power. Larger transmitters, and those of vintage age, will require 208/240 or 480 volts 3 phase power. A long distance between the nearest available commercial power and your proposed building can also be expensive. Poles and wire, and the labor to install, are not low in cost! There are some areas where the power company will pick up part of the cost provided you can guarantee them a return on their investment. In the case of a transmitter site, you will probably be there for a long time and you can very closely estimate how much power you will use on a monthly basis.

Unless you are planning to remote control the transmitter on the STL and provide for delivering operating parameters to the control point via a TSL, telephone service must be available. A dial up business line is all that will be required. Dial up remote control systems are the norm today. This is far less expensive than bringing power from a distance to the site, but it is a consideration and a necessity.

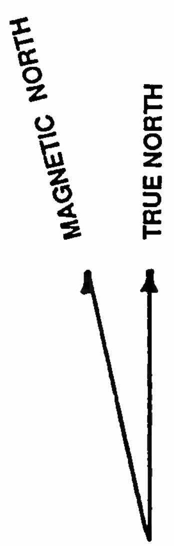
3.03 Locating the Tower Bases

When the directional antenna system is designed on paper, careful attention is paid to protecting other stations on the same and adjacent frequencies from interference. This requires that minimas be produced in specific directions - on specific azimuths. In order for this to occur, each radiator must be energized with the proper current ratio and current phase. We have control over these electrical parameters. They can be changed with relative ease. However, in addition to electrical parameters, certain physical parameters must be fulfilled; namely the spacing and the orientation of the radiators. These parameters are not adjustable. They become fixed once the towers are erected. If a mistake is made in locating the tower bases, there's a good chance that you will not be able to produce the required radiation pattern. It might very well require dismantling of one or more towers, pouring a new foundation for the tower base and guy anchors, and perhaps even tearing up the ground system and relocating it! Needless to say, this type of error will be very expensive to correct. It can not be done in-house. There is no room for approximations or guess work. Laying out the base locations for the towers in a directional antenna system is a job for a registered surveyor.

Figure 3-4

True north is referenced by an arrow with both sides of the tip

magnetic north is indicated by a single tip on the arrow

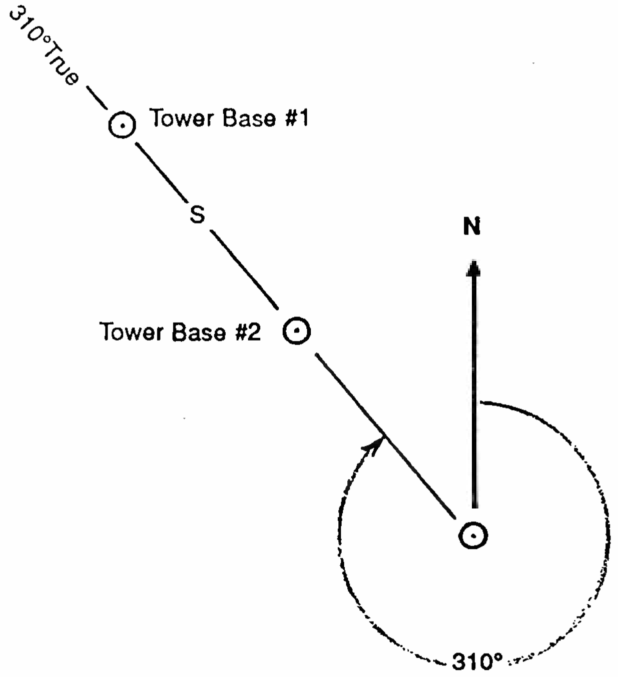


Surveyors usually reference azimuths to **magnetic north**. The reference on which the tower line or lines are specified for a DA system is **true north**. On a map or plot plan, true north is distinguished from magnetic north by the tip on the arrow used to designate the direction north. A full tip on the arrow indicates true north. A half tip magnetic north. The difference between these reference points can be ±10 degrees or more. Magnetic north can be determined with a compass. True north is most easily determined by observing Polaris - the north star. However, Polaris is not always in the direction of true north. From any point on the earth it appears to move in a small circle of about 2 degrees around the axis of the earth's rotation. The actual mechanics of determining how and when to observe Polaris for laying out a true north line are left to the expertise of the surveyor. Suffice it to say, it means an after dark field trip to the proposed transmitter site!

Figure 3-5

diagram shows proper tower base location for an array orientation of 310° true

the surveyor should mark the exact location of each tower base



Armed with the layout of the array supplied by the consultant who designed it, he surveyor should be commissioned to indicate the precise location of each tower base with a substantial marker driven into the ground 24 inches or more, exposing only an inch or two. This deters vandals or browsers from moving or removing the marker. For ease of locating it, the tip can be spray painted red. In addition, a second more visible wood stake can be set along side marker for the purpose of later locating it.

Have the surveyor also mark a plot plan showing tower base locations. It's not a bad idea to have him also mark the center of the array on a typographic map. This will save you the trouble of later locating it on a typo map .

It is cheap insurance to have the surveyor come back and recheck the positioning of the tower bases once the foundations have been poured. The cost of abandoning a foundation is much less than later having to move a tower.

3.04 The Feeder System: Physical and Electrical Considerations

Obtain several copies of the plot plan of the site from the surveyor. If the surveyor hasn't already marked the locations of the tower bases, using a protractor and ruler roughly lay out their locations and that of the transmitter building on one of the copies. From this you can determine the approximate lengths of transmission lines. It will also come in handy when dealing with the electric and telephone company. With the approximate line length information in hand the feeder system can be designed.

If your consultant is to design the feeder system for the array, supply him with this information. Once you have the design in hand, put it out to bid with several reputable phasor manufacturers. If you go directly to a manufacturer and have him design the feeder system, get it approved by the consultant before you or anyone else signs on the dotted line! For any array there are several configurations of feeder systems that will work. Some will work better than others; some will be satisfactory; others will be less than satisfactory.

Mica vs vacuum capacitors: In lower power installations you will have a choice. Vacuum capacitors are far more expensive than micas. However, vacuum capacitors are more stable in value and less prone to catastrophic failure. In high power applications there will be less of a choice. Voltage and current requirements will mandate the use of vacuum capacitors in many places in the feeder system. Price the system both ways. If the price of vacuums can be plugged into the budget, they will probably pay for themselves in the long run. The system will no doubt be more stable and suffer from less lightning damage over the years. Chapter #1 covers how to rate the current carrying capability of capacitors.

The coupling units at the base of the towers; the LTUs: Will they be built in metal boxes or will they be located in concrete block houses? If you were to take a close look at a good sampling of the directional antenna systems in operation today, there is no doubt that you would find that the most stable and most reliable are those where the LTUs are mounted on open steel panels inside concrete block houses. One of the reasons is that the construction of the T-networks on a rigid steel panel, bolted to the concrete block wall of a shelter, is mechanically more stable than the same network components mounted in a metal box supported by 4 X 4s. In addition, these installations are much easier to maintain. It is impossible to set up an impedance bridge, null detector and generator out in the open in the rain or snow. Inside a 6 foot square concrete block house; well it's not impossible under the just described conditions, only inconvenient! Corrective and preventive maintenance is much easier when you can get in out of the elements. It is also easier to perform a visual inspection of the components when they are spread out mounted on a wall rather than crammed into a metal box. The size? Minimally a 6 foot by 6 foot shelter for a single mode low power installation will do. For higher powered operation the components in the line terminating unit will be larger thus necessitating a larger mounting panel and a larger wall on which to mount it. If you have a phase sampling line isolation coil to house make sure to allow room for it.

If it is a multi-mode DA system (DA-D & DA-N) two LTUs will have to call the concrete block house home. Occasionally, in lieu of two LTUs, an RF contactor will be used to switch taps on coils on a single LTU. If your budget can stand the gaff, insist on two separate LTUs. When disaster strikes in the form of lightning or some other catastrophic failure only one mode of operation has been disrupted, not two! At any rate, be aware of the construction of the system before having concrete slabs poured and bricks mortared into place.

Base current and common point RF ammeters: Each LTU must be equipped with a device to measure the amount of RF current energizing its associated element. Since day one, thermocouple ammeters have been used for this purpose. The major draw back to these devices is that they follow the increase in RF current under modulation. In order to get an accurate measurement the meter must be read without modulation. There must also be a make before break switch or insertion plug so that they can be removed from service when not being read. If left in the circuit, a lightning strike will not only take out the meter but, in the process, open the feed between the LTU and the tower. To say the least; not a good situation!

Today there is another choice: the transformer coupled ammeter. It consists of a toroidal pick up transformer through which the RF feed to the tower is passed. The transformer is connected to an analog indicating instrument by a piece of shielded cable. The meter does not respond to the increase in RF current under symmetrical modulation. Also, it is not necessary to remove it from the circuit when not in use. A toggle switch is provided to take the indicating instrument out of the circuit to prevent it from being damaged during electrical storms.

When reading base currents in a high power directional antenna system, the meter reader can easily be exposed to RF fields in excess of those recommended or allowed by law. The indicating instrument on a transformer coupled ammeter can be located in a weather proof box in a location near the base of the tower, but removed from the area of high exposure. Base currents then can be safely read. Price the feeder system both ways. Again, if the budget can withstand the gaff of this luxury, the job of reading and ratioing base currents will be much easier.

The transformer coupled ammeter, rather than the thermocouple type, is recommended for use at the input to the directional antenna system: the common point. This is the instrument that will determine transmitter output power. Reading this type of instrument, in this application, without having to cut audio to the transmitter or wait for a natural pause, is well worth its extra cost.

Another option to be considered, as the design of the feeder system starts to take place, is the installation of a common point impedance bridge at the input to the directional antenna system. This is an operating impedance bridge permanently mounted in the phasor cabinet. It enables one to continuously monitor the common point resistance and reactance. The transmitter is the signal generator and a built in meter serves as the null detector. The instrument has two calibrated dials calibrated in resistance and reactance. Models are available that will handle up to 50kW of power fully modulated.

Transmission lines: Will they be foam dielectric or air dielectric? What size? This will have to be factored in as part of the design of the feeder system. Velocity factor and power handling capability are considerations to be taken into account. If the transmission lines are to be air dielectric, a dehydrator which pumps dry air into the lines to pressurize them should be part of the equipment package. The lines need be pressurized only to 2 or 3 pounds per square inch (psi). The purpose is to eliminate condensation in the void between the center conductor and the shield. A few drops of water and a lot of RF power can cause a very bright light - other wise known as an arc - inside the line. The consequences are immediate and devastating! Make provisions for the dehydrator to be located near the point where the transmission lines leave the phasor cabinet.

An alternative is to use nitrogen to pressurize the transmission lines. Nitrogen is available from welding supply vendors. If the seals on the lines have a minimal amount of leakage, a tank will last for several months. Dry nitrogen is suppled in tanks that are pressurized, when full, to 2200 psi. Even though nitrogen will not burn and is not explosive, they are bombs waiting to explode! At a pressure of 2200 psi the valve on the top of the tank, if broken off, can be propelled through several inches of concrete! Always replace the protective cap over the valve. OSHA regulations, and common sense, dictate that nitrogen tanks, be they full or empty, be secured by a chain to the wall to prevent them from accidentally being tipped over. The tanks themselves are constructed from steel and are very durable. The weak point is the valve on the top of the tank. Never, attempt to connect a tank of nitrogen directly to the transmission line. A regulator between the tank and the line is necessary to reduce pressure to 2 or 3 psi. Care should be exercised when connecting a fully pressurized tank to the regulator. Do not use excessive force on the wrenches.

How will the transmission lines leave the phasor cabinet? The lines to each of the towers will be buried but - do you want then to come out the bottom of the phasor cabinet into a duct to make their way outside or exit the top of the cabinet to make their way across a ceiling to an outside wall? How about the line from the transmitter to the phasor and from the phasor cabinet to the dummy load? Will they come out the top or the bottom of the cabinets? The manufacturer will need to have this information in hand to complete their design.

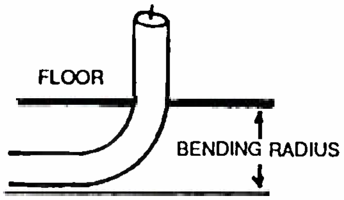


Figure 3-6

If the coax cables exit through the bottom of the phasing cabinet allow a sufficient bending radius

If you plan on having the transmission lines exit the building through a duct in the floor, make sure you provide for adequate depth below the phasor cabinet to accommodate the bending radius of the lines. The minimum bending radius for 7/8" coax is 10 inches, for 1 5/8" cable 20 inches and for 3 1/8" cable 30 inches. This means duct depths of 10 inches, 20 inches and 30 inches respectively.

Should you incorporate automatic switching to non-directional operation? Even when a station is not licensed for non-directional operation there are good reasons to incorporate RF contactor switching to the non-D mode. When a new directional antenna system is put into service, a complete non-directional proof-of-performance is required. One tower of the array is operated in the non-directional mode while field intensity measurements are made. These measurements are later compared to the directional measurements. Automatic switching requires 2 or more RF contactors in the system. The transmission line to the non-directional tower must be switched from the power divider to the output of the transmitter. Either components and/or coil taps in the DA LTU must be switched to match the self impedance of the tower to the line. An alternative is to switch a separate LTU network into the RF path at the tower end of the transmission line. More on this in Chapter #4. Automatic switching from DA to non-D allows this mode of operation to be left intact to be used in an emergency situation should the directional system fail. Section 73.1680(b)(1) of the FCC Rules allows for emergency operation with one element of a directional antenna system at 25% of the station's authorized power. With DA/non-D switching you have a built-in back up.

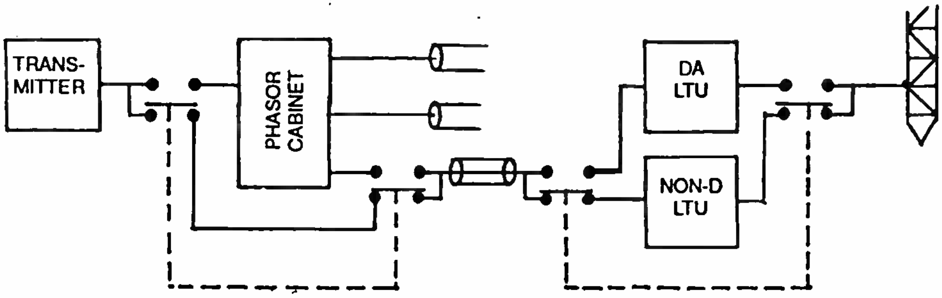


Figure 3-7

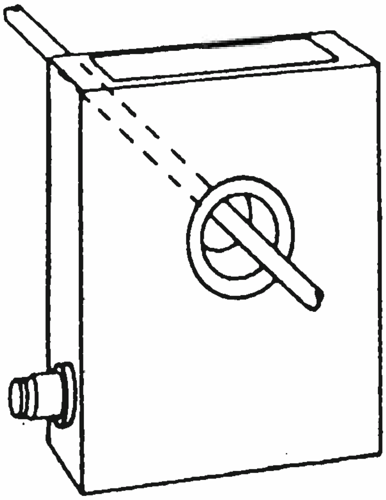
block diagram of DA/non-D switching

3.05 The Phase Sampling System: Its Individual Components

The sampling system is a system within a system! It is the eyes of the directional antenna system. As we discussed in Chapter #2, the current energizing each element in the directional antenna system is a vector quantity; it has magnitude and phase. The ratio of the magnitude and the phase of each of these vectors - the current in each tower - will determine the size and shape of the radiation pattern the system will produce. We must be able to continuously monitor these quantities while the system is in operation. This is necessary not only to make the initial adjustments to the array but also to observe its day to day performance. Section 73.68 and 73.69 of the FCC Rules lays out minimum standards for directional antenna sampling systems.

Figure 3-8

toroidal current transformer for extracting an RF sample from the tower feed



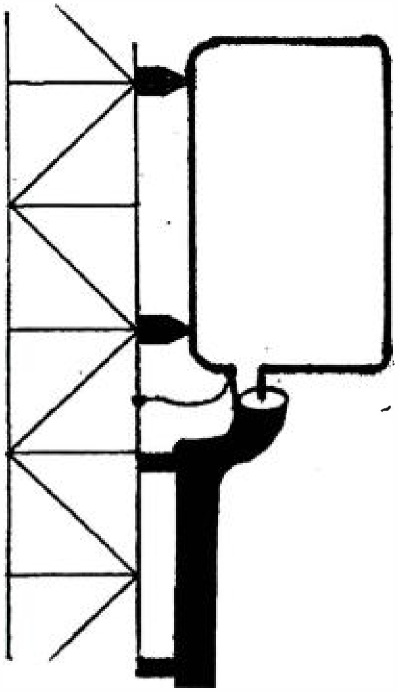
In order to measure current magnitude and current phase in each element of the system it is necessary to extract a sample of the RF current that energizes each. Where the radiators are less than 120 electrical degrees in height the sample device is a toroidal current transformer. It consists of a toroid coil through which the RF feed to the tower is passed. The current transformer is part of the LTU and is located in its housing. An N connector or a UHF type coaxial connector delivers the sample of RF energy to the sampling line. When installing toroidal current transformers the arrow on the device should always point away from the LTU and toward the tower. Also, the device must be tied to the ground strap on the LTU panel or cabinet.

Where taller towers are used, a non-rotatable loop is mounted on the tower 90 degrees down from the top. For half wave towers this means the loop should be located half way up the tower. Typically, the loop will be about 48" by 12". Its actual size is not important. The use of identical size loops on each of the towers is important. One side of the loop, along with the shield of the coaxial phase sample line, is tied to the tower. The center conductor of the sample line is connected to the other side of the loop. The loops must be oriented toward the towers in an identical manner. (i.e. All of the shield connected sides toward the face of the towers.)The sample line is hung on the tower with cable hangers at 3 foot intervals. At the base of the tower, above the base insulator, the shield is again bonded to the tower. An inductor made from coaxial cable brings the RF sample across the base insulator with out shorting the tower to ground. At the bottom end of the inductor the shield is bonded to the ground system.

Loops should be mounted on towers to minimize unwanted RF pickup from other towers in the system. Maximum pickup occurs in line with the two sides of the loop. In an in-line array the loops should be mounted so that maximum pickup is at right angles to the other elements in the system. In a parallelogram this is easier said than done! Figure 3-10 shows correct positioning of loops on an in-line array, and suggested positioning for a parallelogram. It's also shown in this figure.

Figure 3-9

non-insulated phase sampling loop mounted on a tower - the coax shield should be bonded to the tower at the loop and again at the tower base

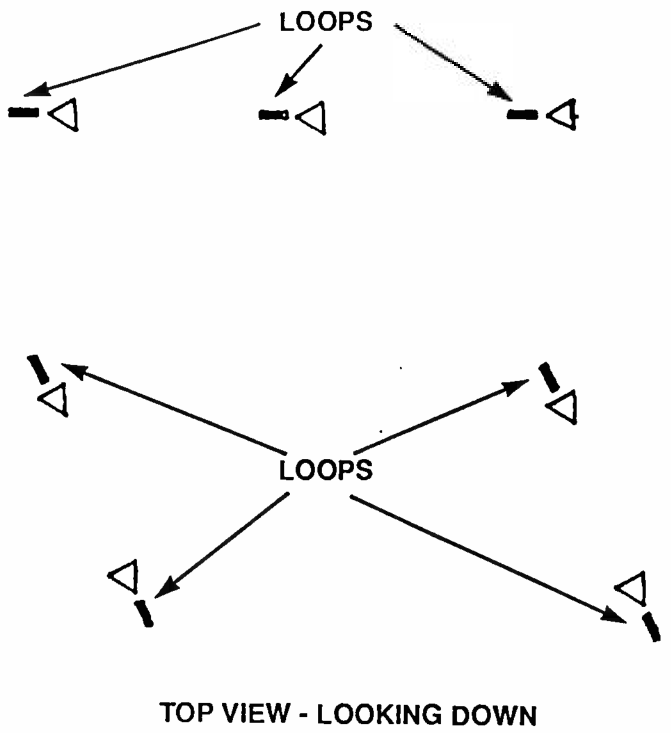


The coaxial sample lines carry the RF samples extracted by the transformers or loops back to the antenna monitor in the transmitter building. These lines should be equal lengths of either 3/8" or 1/2" solid shield foam dielectric (braided shield not acceptable) phase stabilized cable with a polyethylene jacket. Cable of this type is suitable for direct burial applications.

As temperature changes, the physical length of the sample line will expand or contract. This changes the time delay encountered by the RF sample between the

Figure 3-10

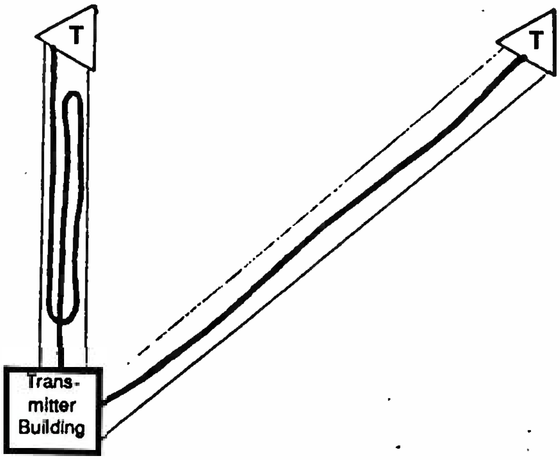
the loops should be oriented to minimize RF pickup from adjacent towers



pick up device and the antenna monitor. In addition, temperature change will cause the dielectric constant of the dielectric insulating material to vary. This changes the velocity of propagation in the cable. Both phenomena will cause phase instability in the sample of RF current delivered to the antenna monitor. What appears to be changes in operating parameters in fact is instability in the monitoring system. When foam dielectric coaxial cable is subjected to temperature changes, it undergoes a change in electrical length that can not be removed by restoring it to the initial temperature. This effect is eliminated by temperature cycling the line until it returns to the same electrical length after each cycle. Temperature cycling is used to produce phase stabilized coaxial sampling lines. When a sampling loop is mounted on a tower, phase stabilized line must also be used for the run down the tower as well as for the run from the tower base to the antenna monitor in the transmitter building. The cables should be exposed to similar environmental conditions - i.e. temperature variations. This means, if one tower is 200 feet from the transmitter building and another 300 feet, the excess 100 feet of line from the closer tower should be looped back on itself and buried in the trench. Coiling it up in the LTU cabinet or house or the basement of the transmitter building is not acceptable. Environmental conditions (i.e. temperature and humidity) will not have the same effect on it as on the portion buried 3 feet underground. If these specifications are followed you will have an accurate and stable sample of the RF current from each tower available back in the transmitter building.

Figure 3-11

excess sampling line should be coiled up and buried so that it is exposed to the same environmental conditions as the other line(s)



Let's for a moment say that the 200 foot lines represent an electrical length of 90 degrees at our operating frequency. The phase from each element in the system will be delayed by 90 degrees from what it was at the sample pick up transformer or loop. Relative to each other, the samples will have the same phase relationship to each other as they did at the pickup device. Being of equal lengths, the losses in each cable will be the same and the magnitudes of the samples will have the same relationship as they did at the terminals of the pickup devices.

When the temperature goes from 100° on a hot summer day down to -20° on a cold winter night the velocity factor - thus the phase delay - of the cable might change. Seeing that both lengths of cable are exposed to the same environment, however, they will change by an equal amount. The phase relationship of the two samples delivered to the input of the antenna monitor will remain the same.

The device used to measure these quantities of magnitude and phase is called an *antenna monitor.* It will have two analog or two digital readouts available; one for current magnitude called *loop current*, and the other for current phase called *phase angle*..

We will eventually choose one element in the array against which all of the other elements will be referenced. This element will be known as the *reference tower.* This will be the tower energized with the highest amount of RF power or RF current. From it we will reference the loop current and the phase angle of all the other towers.

The loop current control on the antenna monitor will be adjusted so that the indication from this tower, with normal operating power, will read 100.0. The currents of all the other elements in the system will be referenced against it. For example: If element #2 reads 45 and element #3 reads 65 the loop current ratio between the reference tower and tower #2 is 0.45 and between the reference tower and tower #3 is 0.65. FCC Rules require loop current ratios to be maintained within ±5% of their licensed values.

The phase angle of the reference tower as displayed on the antenna monitor will be zero. The phase angles of the currents in all the other elements in the system will be referenced against it. For example: If element #2 reads +85° and element #3 reads -30° the phase between the reference tower and tower #2 is 85° and between the reference tower and tower #3 is -30°. FCC Rules require that phases be maintained within ±3° of their licensed values.

While no longer prohibited by the rules, the use of toroidal current transformers as pick up devices on towers taller than 120° is not recommended. Ideally, the current sample should be taken near the point on the tower where the current is maximum. This is 90 degrees from the top. On a 90° tower this is at or near its base. On a 150° or 160° or taller tower this is obviously far from the base. One is apt to get erroneous antenna monitor indications when current transformers are used as sampling devices on tall towers. This makes initial adjustment of the array more difficult and prone to error.

3.06 The Transmitter Building

The two largest pieces of equipment that will call the transmitter building home are the transmitter itself and the phasor cabinet or cabinets. One equipment rack will usually suffice. If you don't plan on a backup transmitter leave room for one anyway. It might be in the cards for sometime in the future. Take a piece of graph paper and layout to scale where each major piece of equipment will be located. From this you can determine the size building you will need.

Several manufacturers offer custom pre-built equipment shelters in sizes up to 30' X 60'. Options include computer floors, overhead wire ladders, electrical wiring and HVAC. This is one viable alternative to building your own. These shelters are air tight and rodent proof and come in a variety of sizes. A local contractor prepares the foundation and the shelter is off loaded at the site right onto it.

Concrete slabs with concrete or cinder block walls are probably the basis of the great majority of broadcast transmitter buildings in use today. Glass block windows allow light in while keeping out vandals. Plan to locate the building on the high ground end of the plot. Cleaning mud from wire ducts, transmitters and phasor cabinets after a flood is no fun! In a flood plain the transmitter building should be located on pilings above the 100 year high water mark.

What ever your choice, carefully plan for duct work in the floor and/or wire ladders suspended from the ceiling to facilitate the wiring from and to various pieces of equipment. Don't forget to provide for the entrance of transmission lines, copper ground strap, AC power for tower lights, phase sample lines and control circuit wiring for changing patterns or mode of operation.

We have all heard the story of the guy who built a boat in his basement and then couldn't get it through the door! Make sure you don't have a building with doors too small to bring the transmitter and phasor cabinets through. Double three foot steel doors are advisable.

Provide for at least a small work bench. There will always be a need to repair and maintain equipment. A piece of 3/4 inch plywood and some 2 X 4s will go a long way toward making your job a bit easier when the audio processor or modulation monitor dies and needs to be resurrected!

How about a dummy load. If it will be air cooled make provisions for it to be located in a place where the heat it generates can be safely dissipated. The transmitter should be interlocked to the air flow in this type of dummy. No air - no RF! Dissipating RF in the dummy without the benefit of air flow has been known to cause fires in transmitter buildings.

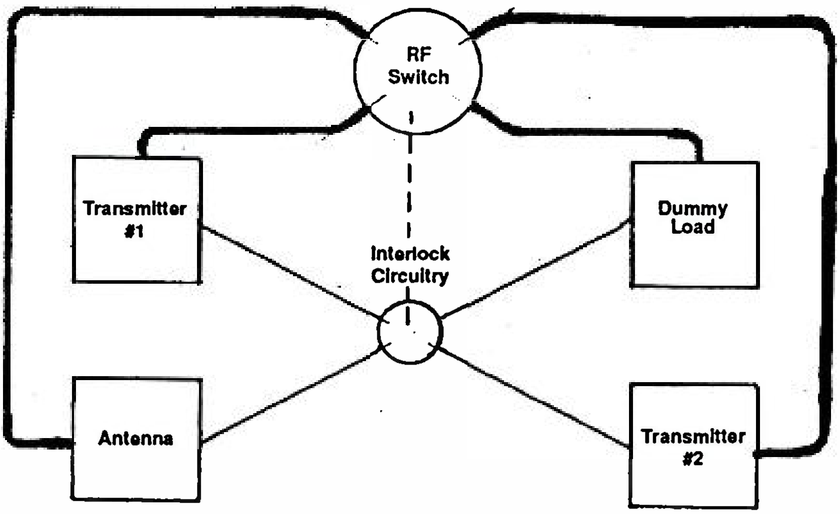
If there's running water at the transmitter site you can use a water cooled load. Be prepared to furnish a water supply of any where from 1 to 25 gallons per minute - depending on the RF power output of the transmitter. Also make provisions for getting rid of the water. Again, the transmitter must be interlocked to water flow - not water pressure. The resistive elements in a 50 kW water cooled load are about as big around as your little finger. A second or two of RF without water will destroy them.

A device called a Moduload® is marketed by Bird. Similar devices are available through other manufacturers. Depending on the power level, this load is cooled by circulating anywhere from 2.5 quarts to 10 gallons of liquid coolant - ethylene glycol and water - in a closed system. Interlock the transmitter to coolant flow in the load.

Figure 3-12

block diagram of a typical interlock arrangement for dummy load coolant

In addition, the phasor cabinet door(s) should be interlocked to the transmitter that is on-the-air



Plan on space for this piece of equipment. For air cooled dummy loads, locate them well away from combustible material. Always provide for transmitter to be interlocked to coolant flow - be it air, oil or water.

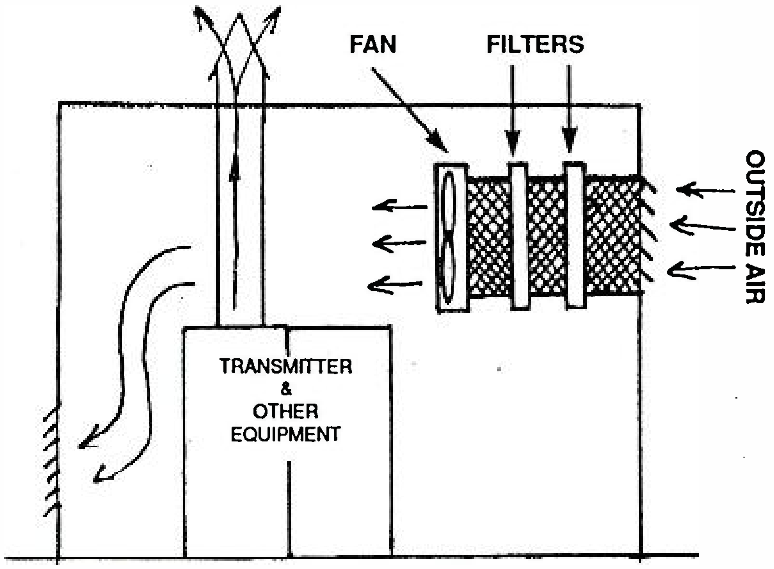


Figure 3-13

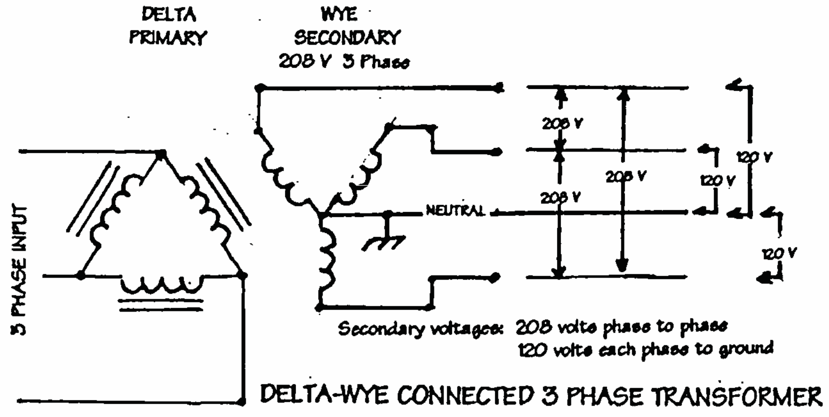
keeping the building at a positive pressure with filtered air keeps the inside of the transmitter and other equipment cleaner

How about cooling the building? If it is only serving as an unmanned transmitter building, air conditioning in most climates probably isn't necessary. A large volume of air flow, however, is a must. Rather than exhausting air out of the building with one or more fans, give some thought to pulling air into the building through at least 2 sets of filters. The building is then under a slight positive pressure. This arrangement won't draw in dirt from under doors or through wall cracks. If your pre-fan filtering is made air tight you will have an almost dust free environment inside the building. High voltage attracts dirt and dust. If your transmitter is an older tube type, there will be little dust and dirt to be attracted. Even the continuous volume of air flow in a solid state transmitter with no more than 200 or 300 volts on the output stages, eventually causes it to become filthy. With pre-filtering and positive pressure, the transmitter will still look like it just came from the factory even when it has been in use for 5 years or more.

How about AC power to, into and through the building? State-of-the-art 5 kW and smaller transmitters, will operate on single phase 240 volt AC power. Some higher powered transmitters can, as an option, be ordered to operate with single phase power. Typically, a 5 kW solid state transmitter will consume about 13 kW of power under 100 percent tone modulation. A heavy duty 150 or 200 amp version of what is used for residential service will suffice. The transmitter, and any other equipment that operates from 240 volts, is connected across the hot wires. Equipment and devices that require 120 volts are connected from one side to the neutral ground.

Figure 3-14

In a wye connected 208 volt 3 phase service 120 volts can be obtained from any phase to neutral

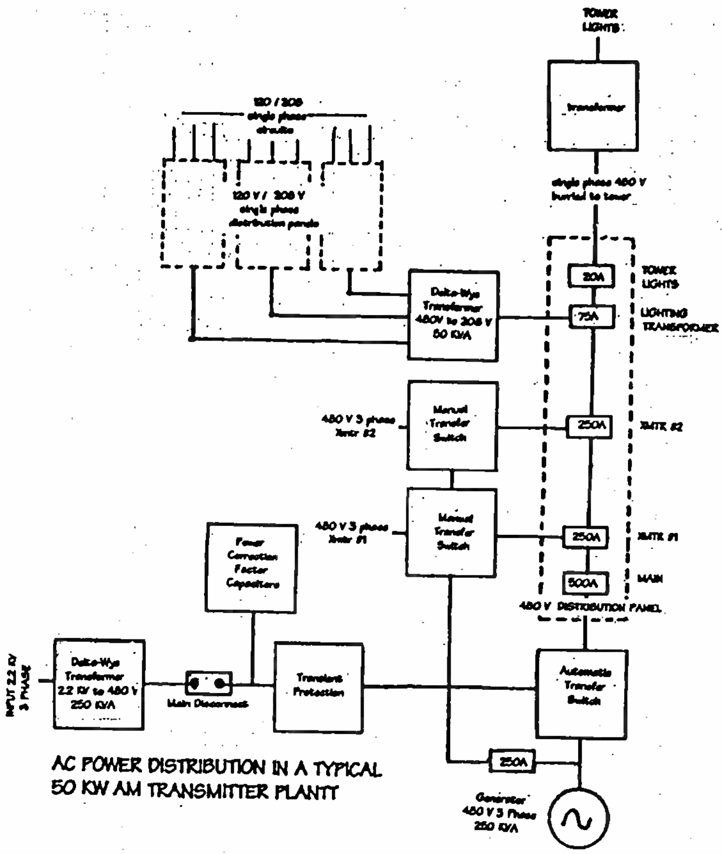


Where 3 phase service is required it is provided at 208 or 240 volts. A 50 kW transmitter will usually require 480 volts 3 phase service. It is normal practice to bring 2200 or 4160 volts, or higher, up to the building. Then, using a concrete pad mounted transformer, in a delta-wye configuration, step it down to 208/240 or 480 volts. When power is delivered to the transmitter building at 208 volts, 120 volt equipment can be powered from any phase to neutral. When 240 volt 3 phase power is delivered, a 240 volt primary/120 volt secondary transformer is connected across each phase to power 120 volt equipment. Where 480 volts 3 phase power is delivered to the building for a 50 kW installation, a transformer connected in a delta-wye step down configuration provides 208 volts 3 phase. Single phase 208 volts can be obtained across any of the 3 phases and 120 volts single phase can be obtained from any phase to neutral. Figure 3-14 details these configurations.

Figure 3-15

the AC power wiring layout for a typical 50kW AM transmitter plant

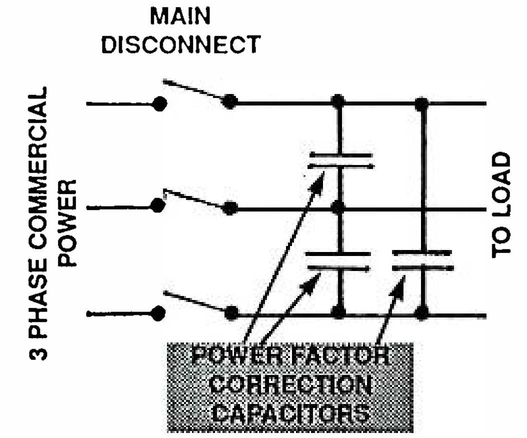
manual transfer switches for each transmitter allow for the running of the off-air transmitter from the diesel generator keeping the power demand at its normal level



Power lines and their support poles or the ground wires running down the wooden support poles, can be sources of re-radiation. This source of radiation can make it impossible, or at least very difficult, to adjust the array to produce very deep minimas. Ideally, the power feed will be via underground service. Never run above ground electrical service between towers!

The electrical AC power layout of a typical 50 KW transmitter plant is shown in Figure 3-15. The monthly invoice that you receive from the electric company is based on both consumption and demand. Consumption is measured in kilowatt hours. Demand is based on the maximum demand in KVA during any 15 minute interval of the billing period. A 50 kW transmitter plant, running 24 hours a day, will present a fairly constant demand. However, when you test the 50 KW alternate main transmitter into the dummy load for a half hour, the demand will will almost double. You will pay dearly for the privilege of requiring this extra 70 or 80 KVA for only a 30-minute period. The system shown here allows the alternate transmitter to be run directly off the emergency generator by-passing the power company demand meter. In addition, it serves as a convenient load into which you can test the generator.

Note too the method used to supply power to the tower lights: Where the tower light load is heavy - many obstruction lights and several beacons - and the run from the building to the tower base long, it is sometimes advantageous to supply a higher voltage to the base of the tower - in this case 480 volts single phase - and then step it down to 120 or 240 volts as needed.



Real power is measured in watts - volts times amperes. Apparent power is measured in volt-amperes - volts times amperes. When the figure is large it is expressed in KVA - kilovolt amperes. When there is only resistance in the circuit real power and apparent power are the same. The power factor is said to be 1.00. When a circuit has resistance and reactance the apparent power will be greater than the real power. This difference is expressed as a percentage and is called *power factor.* The typical transmitter plant will have many transformers and motors connected across the power line. These are inductive reactances. Your bill is based on volts times amperes times hours. You will be paying for more electricity than you really consumed. In order to converge real power and apparent power, a bank of capacitors is placed across the power line. These are called *power factor correction capacitors.* Note their positioning just beyond the main disconnect on the 480 volt 3 phase feed.

Note also the transient protection between the 480 volt feeder and the distribution system. In this day and age of solid state equipment the incorporation of such a device is worth its weight in gold! Spikes of several thousand volts generated by lightning hits and other disturbances can cause havoc, damage and off air time!

3.07 Tower Lighting

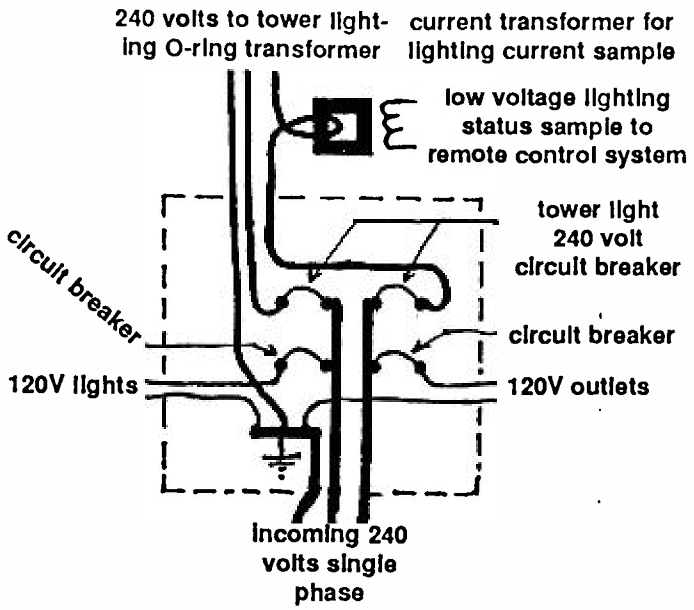
Where obstruction lights and beacons require 120 volts, make provisions for a 240 volt tower lighting circuit for each tower. Each should have a separate circuit breaker. The size of the breaker will be determined by the number of lights required. Each beacon will have two 620 watt bulbs in it; each obstruction light a 120 watt bulb.

Immediately adjacent to the breaker box mount another electrical box. This will house the current transformers that enable the status and condition of the tower lights to be observed via the remote control system. The wires to each tower should run out of the breaker box into the sampling device box. From there they can begin their run to the tower bases. You will more than likely run afoul of the electrical inspector if you loop one wire from the connection on the breaker into the box that houses the sampling device, through the current transformer and then back to the breaker box to be wire nut connected to the tower feed! At the tower end of the run, power the tower lights from the sampled leg to neutral. The other hot wire to neutral is used for a light and a 120 volt outlet in the tuning house or tuning cabinet. When the lights are illuminated the current transformer and associated rectifier and filter will supply a few volts DC to the remote control system for status monitoring.

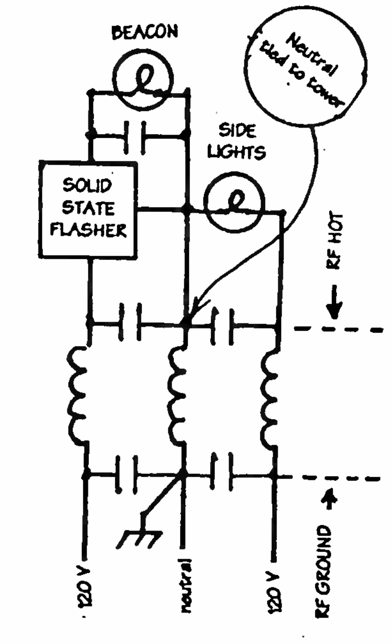
Where 240 volts is required for tower lights, run two hot wires and a neutral to the LTU. Locate a 4-circuit breaker box inside the tuning house or cabinet. The tower lights are wired through an appropriately sized circuit breaker across the two hot wires. In this situation, the cur-

Figure 3-17

when 240 volts are required for lighting when using an O-ring isolation transformer this arrangement works well



rent transformer for remotely monitoring the status of tower lights is mounted in the LTU shelter. One of these wires is looped through the current sampling device for monitoring tower light status. The sample is returned to the transmitter building and eventually the remote control system via an extra pair of wires in the multi-paired control cable. Tuning house lights and electrical outlets are wired from either hot side to neutral through separate breakers.



Center winding used as static drain

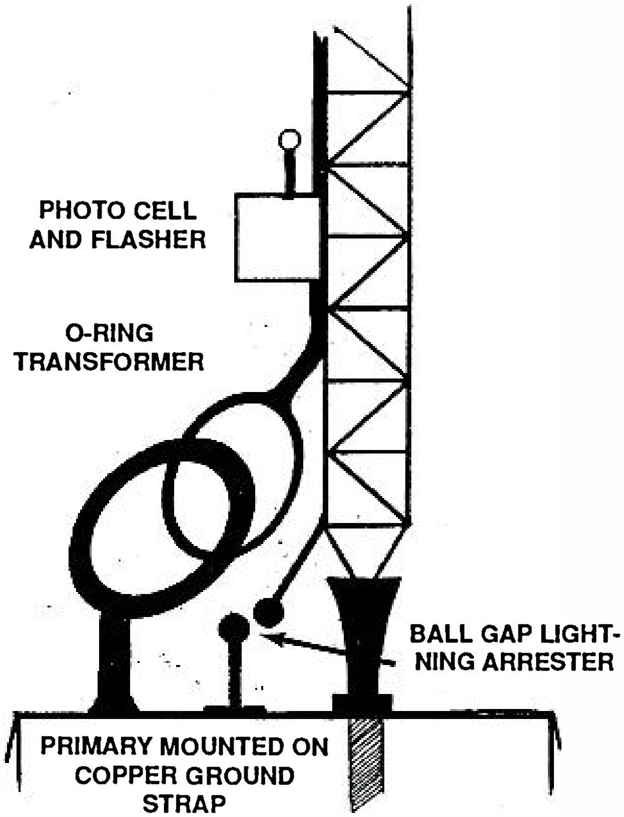
There are two ways to bring the AC power for the tower lights across the base insulator of a series fed tower. The most commonly used, and least expensive method, is a lighting choke. Reference was made to this method in chapter #1. The AC voltage for the lights is delivered across the base insulator via bifilar or trifilar wound choke coil. The photo cell that controls the on/off function of the lights, and the solid state flashing device for the beacon, can be located on either side of a trifilar choke. Where the lighting current is small, a bifilar choke can be used to bring 120 volts onto the tower. The photocell and flasher are then located on the tower.

The lighting chokes provide for bypassing each hot wire to neutral on each side of the coil. In addition, in the interest of keeping RF from being brought back into the AC power wiring in the building, it is advisable to provide for bypass capacitors from each hot wire to ground at the building end of the run.

In high power installations, 10 kW and above, when tall towers with high base impedances are used, or when the operating frequency is at the low end of the band - below 800 kHz - lighting chokes can cause serious side effects! At high powers there can exist very high voltages across the base insulator. Tall towers and high impedance also cause high voltages, in addition, the choke in parallel across this high impedance can increase losses. Last, but not least, the limited inductance of the choke can cause inadequate isolation allowing RF to flow into the transmitter building via the AC wiring. In these situations O-ring transformers are used.

Figure 3-20

details of the O-ring lighting isolation transformer



The O-ring transformer resembles two interlaced doughnuts. They are weather proof and are usually installed right at the tower base. The primary is supported on a pipe and flange bolted to the concrete tower foundation. The secondary is bolted to the tower. It is imperative to ground the supporting hardware of the primary with a 2" or larger size copper strap. Silver solder or braze the strap to the flange and to the ground system. It's not a bad idea to connect a strap from the secondary housing to the tower. Any intermittent contact can cause intermittent changes in the base impedance of the tower. This shows up as unexplained intermittent changes in current ratio and phase. Ultimately the stability of the radiation pattern is affected.

Inside the primary doughnut the primary coil is wound in toroidal fashion. The secondary consists of a many loops of wire. The air gap between primary and secondary provides only a small amount of capacity across the base insulator.

O-ring transformers are available in many different power ratings. Most have primary jumpers available that will allow you to connect it for 240 volts in and 120 volts out.

The flasher device for the beacons must go on the tower when using an O-ring transformer for isolation. The high initial surge current that occurs when a transformer is initially energized will quickly destroy a solid state flasher if you attempt to have it interrupt primary power.

Use rigid or EMT conduit in and around the LTU and to the O-ring transformer. Greenfield conduit - flexible conduit that resembles BX wire - even though it is available with a weather proof jacket - will corrode over a period of time. It then starts to look like an inductor, in a high RF field, between the primary of the O-ring and the LTU cabinet. It too can cause unexplained changes in base impedance.

If the radiators for the DA system are skirted towers, where the tower is at ground potential, the lighting circuit can be introduced directly onto the tower. Each of the wires should be bypassed to ground with a .005 uF, or larger, mica capacitor at the bottom of the tower. This will provide reasonable assurance that RF is not carried back into the building on the AC power wiring.

Make sure all conduit connections are tight. It's not a bad idea to braze the conduit to metal panels and cabinets on which the LTU components are mounted. Loose connections in high

RF fields - besides causing instability - can get hot - very hot! From personal experience, the author can attest to the fact that nearby combustible materials can be ignited where loose conduit connections to cabinets exist in high RF fields.

When a lighting choke is used, the neutral wire of the AC circuit is tied to the tower on the RF hot side of the circuit. It will also serve as a static drain. During electrical storms and other atmospheric disturbances a high potential of static electricity can build up on the tower. If it is not drained off to ground it will cause the ball gaps on the tower to arc. This in turn will trip the transmitter off the air due to a plate/collector current overload or through the VSWR protection circuit. When an O-ring transformer is used a static drain must be installed from the tower feed to ground. Install the static drain choke in the LTU, connected from the tower feed to the ground strap.

Figure 3-21

by pass AC wiring running up a grounded tower - also bond the shield of any coaxial cables running up the tower to the structure at its base

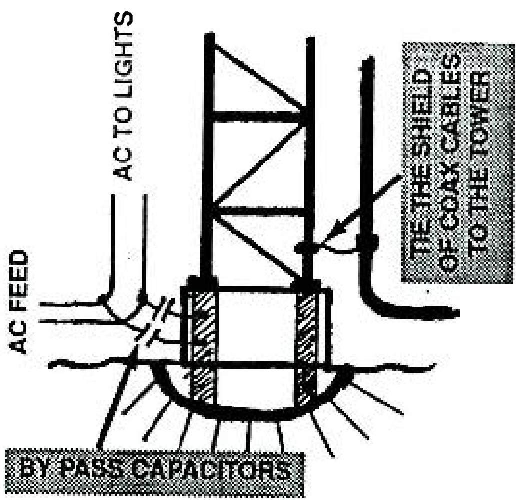
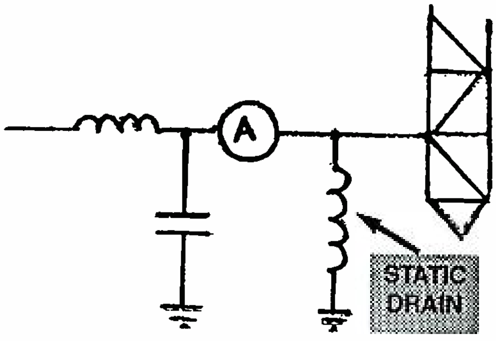


Figure 3-22

the static drain should be connected directly from the tower RF feed to the LTU ground strap



3.08 The Installation of the Towers

Before arriving at the installation phase of the project it will pay you to do a little homework on your own, especially if the tower erection crew does not work for the tower manufacturer. Obtain a set of specifications for the tower base and guy wire anchor foundations. Be familiar with what is required in the way of size and depth. These specifications are for foundations installed in undisturbed earth. If the site is on fill, the size of the foundation - and sometimes its configuration - will have to be larger or different than specified. In some situations, test borings might be advisable. The results of a boring might indicate that pilings may have to be driven to support the downward weight of the tower. In addition to the weight of the steel, there is a considerable weight imposed by the downward pull of the guy wires. When in doubt, consult with the manufacturer. Its far better to discover and investigate these "flies in the ointment" before moving on.

The site must be accessible. Read the fine print in the errector's agreement. If a road has to be built into the site it's your responsibility. The tower erector should be able to move heavy machinery to each tower base and each guy anchor.

It's also your responsibility to obtain the necessary permits for construction. It will normally be necessary to supply the building inspector with one or more sets of prints and specifications of the towers. The legwork on this phase of the project should be done long before the tower crew arrives on site.

For the foundation pier, the installation crew will dig the hole and then fasten a form in place on top of the excavation. Make sure the center of the excavation is as close to the spot marked by the surveyor as possible. Reinforcing rods should be positioned inside the form and either wired or welded to keep them in place. The purpose of the reinforcing bars - called rebar - is to distribute the stress throughout the concrete block that forms the foundation. Concrete should fill the hole and then the form to the top. The anchor bolts for the tower base plate should be positioned in the top of the pier and extend well into the concrete - 12 to 18 inches.

The locations of the guy anchor foundations are determined by the erection crew using a transit. They should be precisely at 120 degree angles from one another at the distance from the base as called for by the tower manufacturer. For towers taller than 275 feet there might be an inner and outer anchor. These should be inline with one another - not skewed. Follow the manufacturers instructions on the amount of concrete required for each anchor.

After the holes for the guy anchors have been dug, the steel anchor rod will be placed in the excavation. Holes are provided in the anchor rods for the installation of steel reinforcing rod. Several pieces of rebar should be installed and wired into place. When concrete is poured this will assure that the anchor rod and concrete form one solid block. Before concrete is poured take a look at the vertical and horizontal position of the anchor rod. When the guy wires are installed the pull should be nearly in line - vertically and horizontally - with the rod. Any side pull is to be avoided. Again, if there are unusual conditions - marshy ground, fill dirt, sandy soil, etc. - check with the tower manufacturer on the size and configuration of anchor foundations.

It takes time for the concrete to cure. A period of 10 days to 2 weeks is the minimum that should elapse between pouring of concrete and the erection of towers.

The tower base plates will be installed on the foundation pier using the bolts imbedded into the concrete. Two pieces of 2 inch or larger copper strap should cross each other under the base plate. One piece will come down each side of the pier and eventually be silver soldered or brazed to the ground system. The other piece of copper strap will be handled in similar fashion. It's advisable to braze the straps to the base plate. Corrosion can take place and what was thought to be a good electrical ground connection to the base plate will become intermittent. This can be the cause of a change in base impedance that ultimately is reflected as a change in current and/or phase. In addition, the ground side of the ball gap lightning protection device is bolted to the base plate. A bad ground connection will compromise this protection.

If metallic guy wires are used, they are cut and assembled during this waiting period. Porcelain guy strain insulators - commonly called "johnny ball" insulators - should break the guys up at 50 to 100 foot intervals - 50 feet if the operating frequency is at the high end of the band and 100 feet if below 1000 kHz. This is to render them ineffective parasitic radiators. Three sets of insulators - or large fiberglass insulators - should isolate metallic contact where the guys attach to the tower.

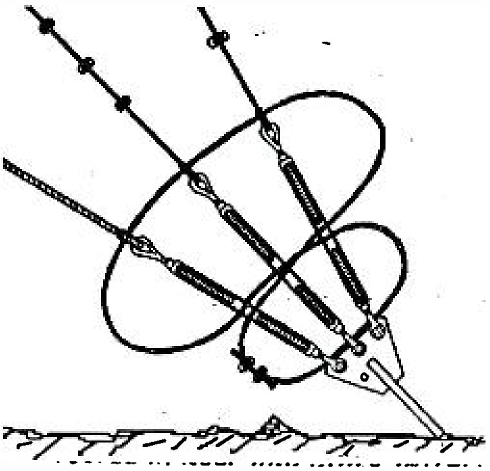
A source of momentary transmitter outages is static discharge arcing across guy wire insulators. This can happen during electrical storms, snow storms and at other times when the atmosphere is highly charged. This phenomena causes the driving point of the tower(s) to radically change. Overload relays or VSWR protection in the transmitter will cause it to cough - trip on and off. A cure for this is to use fiberglass guy lines. When metallic guys are used a specially designed weather proof choke across each insulator on the top set of guy wires will eliminate this problem. The static is drained off through the choke rather than arcing across the insulator.

Top loading of a tower is sometimes specified to increase the base impedance - thus the drive point impedance - where radiator height in a DA system must be limited for one reason or another. The top set of guy wires is sometimes used to accomplish top loading. The consultant will specify how much top loading will be used. The top set of guy wire insulators is eliminated. The guy wires are electrically connected - usually brazed - to the top of the tower. The insulators are then inserted in the guy wires down 30 or 40 feet as specified by the consultant. When this is done 24 inch fiberglass insulators are used at the end of the guy wires used for loading. A wire is sometimes specified to tie all the guys together just above the insulators on the tower side. Needless to say, any top loading employed, be it a top cap or guy wire loading, must be both physically and electrically stable. Any electrical intermittents or physical movement will cause instability in the radiation pattern.

About 60 feet of tower - enough to include the first set of guys - will be assembled on the ground. Included will be the bottom section and the base insulator. This is called a "stub." The erection crew will then use a crane to set it into place. The guys will be connected to the anchors and tensioned to pull the stub into plumb. An erection fixture - sometimes called a gyn pole - is pulled up into place and bolted to the top of the stub. This fixture is used to haul the next tower section up into place. When it has been secured the fixture is moved to the top of this section and the process is repeated until the tower is complete. As each set of guys is attached to the anchors, the turnbuckles must be adjusted for proper tensioning and the tower checked to assure that it is plum.

Figure 3-23

turnbuckles must be secured with a safety wire to prevent accidental unwinding



The FAA requires that the tower under construction be illuminated after it exceeds 150 feet. A temporary red light, continuously burning during hours of darkness, is to be positioned at the uppermost point. As an alternative, the permanent lighting, as required by the construction permit, can be installed an made operational as construction progresses.

Once the towers have been erected each joint, on one leg must be spot welded to assure electrical continuity. Failure to do this will make for another source of future trouble.

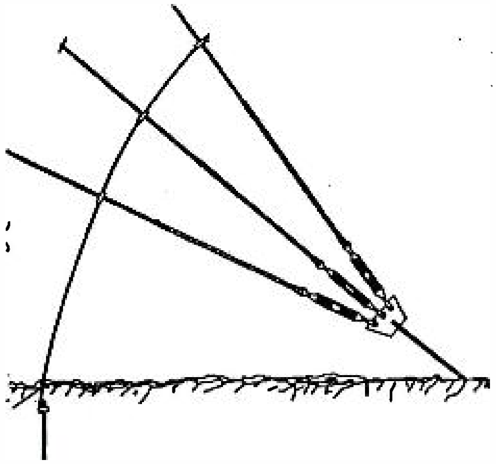
If the towers were not painted before erection, now is the time. If they were painted before erection the paint should be touched up. There will be many scratch and scrape marks.

After final plumbing and tensioning is complete, a safety wire should be threaded through the turnbuckles and secured with two cable clamps to prevent accidental unwinding and failure of a guy wire.

A ground wire should be attached to the guy wires above each anchor. This wire should then be terminated in an 8 foot ground rod. This minimizes the amount of current that will flow through the anchor rod during a lightning strike.

Figure 3-24

the bottom of each set of guys should be tied to an 8 foot ground rod to prevent lightning discharge through the anchor



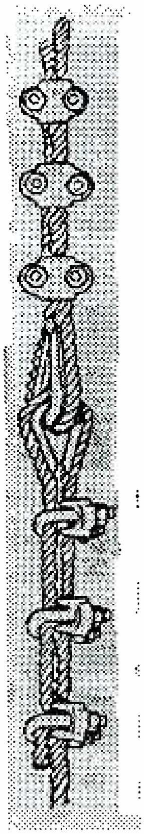


Figure 3-25

the proper way of installing cable clamps with the U-bolt over the short end of the guy

Typically, the lighting circuits on the tower are installed in conduit. It is wrap-locked to the tower. WrapLock is a brand name for stainless steel strap used to hold conduit and transmission lines to a tower. If the flasher and photocell are located on the tower, the electrical box housing these components must be water tight. At each level where there is an obstruction light or beacon there will be a junction box. The AC neutral should be tied to the tower inside these boxes. They, too, must have gaskets installed between the cover and box to keep water out. A conduit breather should be installed in the bottom of each junction box. This is an open 1/2" connector to preclude the formation of condensation inside the sealed electrical system. The breather is a 1/2" connector with a screen inserted in it to keep bugs and other varmints out.

When the tower work is complete, the man in-charge will present you with an acceptance form to sign! Before signing, and surely before the tower crew leaves, hire an outside contractor to climb each tower and inspect it. Give him or her a polaroid camera. Have them take pictures of any evident problems or suspected problems. The check should include the mechanical joints between tower sections. Are all bolts in place and tight? The weld between each section must be checked. Do all electrical boxes have covers and gaskets in place? Do all of the lights work? On the ground; check all towers for plumb. Are gaskets in place on the beacon lenses, obstruction light lenses and obstruction light lenses? These ideas are but a starting point for your checklist.

3.09 The Installation of the Transmission Lines

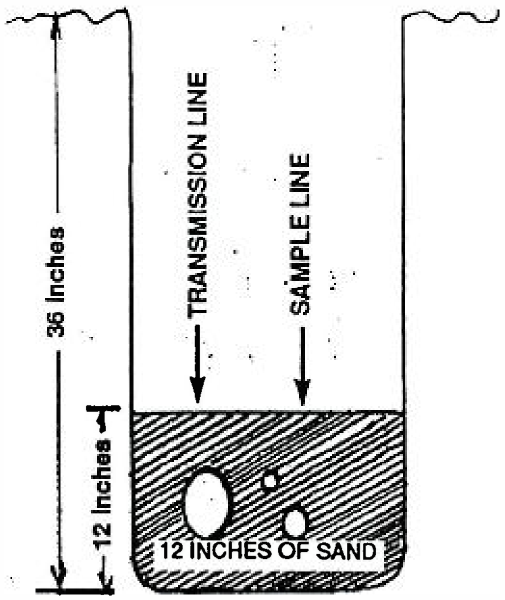
Next in the order of events comes the installation of transmission lines. Will they be installed above ground or buried? Unless there is some over riding reason, the first choice of installation is underground - rigid line being the exception. However, rigid line is rarely used in new directional antenna installations. This places the lines out of gun shot range and out of the reach of vandals! The installation of transmission lines, power lines for the tower lights and phase sample lines above ground also opens the door to unwanted radiation and/or re-radiation or RF pick up on the lines. If transmission lines must be installed above ground the outer shield of coaxial cables should be bonded to the ground system at intervals of no more than 40 feet.

The normal choice if transmission lines is foam dielectric or air dielectric coaxial cable with a polyethylene jacket. This type of cable is water proof and suitable for direct burial applications. Phase sampling lines - as previously discussed - should be of similar construction. AC power cables as well as any other cables, should be suitable for direct burial.

The transmission lines, the phase sample lines, the tower lighting cable and the multi-conductor cable needed for mode switching (DA-D to DA-N, etc.), if required, may be buried in the same trench. The minimum acceptable depth for protection is 36 inches. It is desirable to bury these cables below the frost line to prevent their being subjected to heaving due to the freeze-thaw cycle. In some cases, this might require a depth greater than 36 inches. Before the cables are installed in the trench, a 6-inch bed of sand should be placed in the excavation. Once the cables are in place a 6 inch covering of sand should be poured. This will help to protect the lines from heaving. It also

Figure 3-26

details of the cable trench with the cables encased in sand



offers some protection from sharp rocks causing abrasions or puncture. Before the trench is backfilled, a 3-inch piece of red or yellow mylar warning ribbon should be placed on top of the sand cover. This will offer a visual buffer to anyone who, years later, might have reason to excavate (i.e. installation of additional lines) in this area. The trench should be over filled to compensate for settling.

In the interest of being kind to those who will follow you, make a copy of the plot plan on which the tower bases and building have been marked and pencil in the locations of the trenches. At the same time mark the locations of any other underground water lines, sewer lines or electrical feeds.

Plastic PVC pipe is sometimes installed in the trench. Sample lines, AC lines and multiconductor cable is then pulled in the pipe. Coaxial line larger than 1/2" can not be pulled through such conduit. The beauty of this arrangement is that if there is a line failure it can be replaced without digging up the ground system. Even if the lines are directly buried, a length of empty 6" or 8" PVC pipe buried in the trench will allow for the installation of replacement cable or additional cables should the need later arise.

Large quantities of coaxial line - even the 1/2" line used for the sampling system - will be shipped on cable reels - either disposable or returnable. The reel must be put on cable jacks to unroll it. Never attempt this task by uncoiling the cable while the reel sits on the ground. Kinking or other damage to the line is a real possibility. The job of unreeling and installing transmission lines that are 7/8" or larger is best left to a contractor with the right equipment. A 500 foot roll of 7/8" cable will weigh approximately 250 pounds; a 500 foot roll of 1 5/8" cable about 500 pounds and a 500 foot roll of 3" cable nearly 900 pounds - not including the weight of the reel!

Always use a tubing cutter to cut air dielectric lines. A hacksaw will allow metal filings to drop down into the line opening up the possibility of disaster when power is applied. In addition, immediately cover the end of air and foam dielectric lines after cutting them to prevent dirt or moisture from entering them.

The shield of the transmission lines should be tied to the ground system with a 2" or larger copper strap in the phasor cabinet and also at the LTU. This is usually provided for in both places by a bracket that will both ground the line and hold it mechanically in place.

Once the connectors or end seals are installed on air dielectric lines, open the gas plug at the LTU end of the line. Attach a dehydrator or a tank of nitrogen equipped with a regulator. Allow the air or gas to blow through each line for an hour or so to purge it of any accumulated moisture. After replacing the plug, pressurize the lines to 2 or 3 PSI. Use soapy water applied with a small paint brush to check for leaks at all connectors and end seals. It's not a bad idea to order an extra gasket and O-ring or two as they are easily damaged during installation. Now is the time to replace them, if necessary.

3.10 The Installation of the Ground System

There's an old saying: "Out of sight; out of mind." The ground system is the other half of the directional antenna system! The towers stick out like a sore thumb. The ground system is their silent partner. Without a ground system the directional antenna will not work. When some of it is missing or improperly installed, the system will not work properly. It is imperative that a qualified representative of the radio station, or the contract engineering company responsible for project management be on site at all times during this phase of the project. Once the radials, copper strap and screen that make up the system is buried, the opportunity to easily determine its integrity is gone forever.

The construction permit will specify the exact form of the ground system. This information is taken from what the consultant specified in the application. It will say 120 buried radials, so many feet in length (usually 90 degrees, sometimes longer), about the base of each tower, terminated and bonded where they will intersect between towers. Perhaps it will allow for the radial system to be truncated where limited by property boundaries. It probably will specify a ground screen of a specific size (usually 24 X 24 feet or 48 X 48 feet) and/or 120 short radials, again the length will be specified, to be interspersed with the long ones. On some construction permits the size of wire used for the radials system may also be specified, again taken from the application data. For the radial system #10 soft drawn copper wire is most often used. It is very flexible and certainly easier to handle than copperweld wire.

The ground system should not be installed until the towers have been erected. Cranes, winch trucks and other heavy equipment can break radials and tear up copper strap.

The ground system for even the simple two tower array shown in Figure 3- 27, for use at the high end of the broadcast band, will call for about 30,000 feet of wire. If 120 short radials 50 feet in length are also part of the design this will require another 12,000 feet of buried wire. The radial system for the 6 tower in-line array shown in Figure 3-1 on page 63, for operation on 540 kHz, will require about 300,000 feet of buried radials, not counting short radials that might be part of the design.

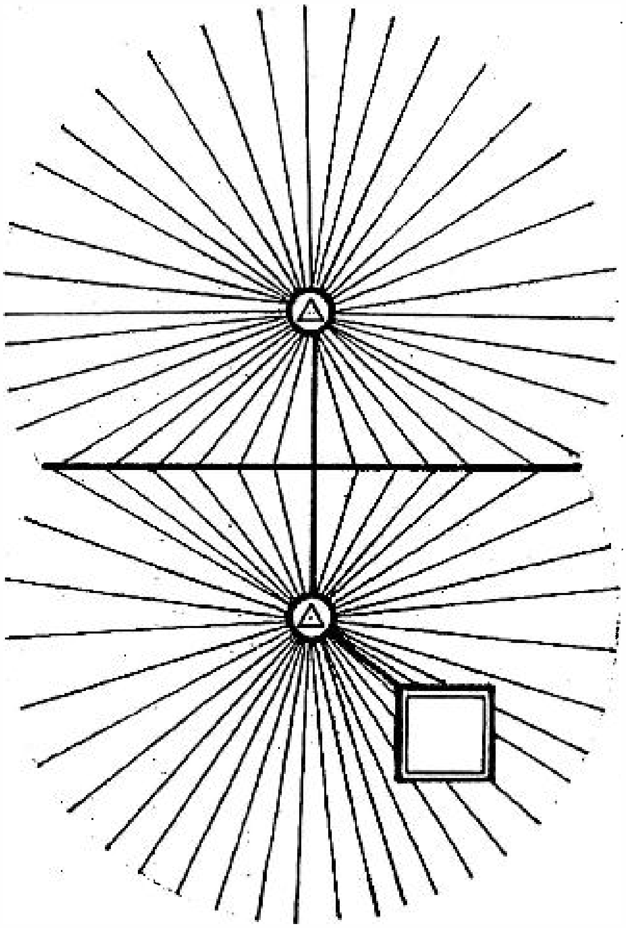
Expanded copper mesh ground screens are available in 8' X 24' lengths. Where a 24' X 24' screen is specified 3 will be brazed or silver

Figure 3-27

the ground system for a two tower directional antenna system

note the copper strap between towers, the strap that terminates the radials where they would overlap, the strap running out to the transmitter building and the strap around the building to which all terminated radials are bonded

the ground screens and/or short radials are not shown in this drawing



soldered together. Where a 48' X 48' screen is specified, 12 screens silver soldered or brazed together will be required at the base of each tower.

A 2 inch or larger copper strap should run between tower bases. Where radials from adjoining towers intersect they will be terminated and brazed or silver soldered to a buried copper strap. If spacing between adjoining towers is greater than 180 degrees the consultant will usually specify that radials that would intersect be extended and bonded to the strap. In addition, a buried copper strap should run from either the the base of one of the towers or one of the pieces of strap that terminate intersecting radials, into the transmitter building for grounding the transmitter, phasor and other equipment. If the transmitter building is in the radial field, a copper strap should ring the building. Terminated radials should be bonded to it. Terminated radials should be bonded to the strap on the far side of the building and continued out to the specified length.

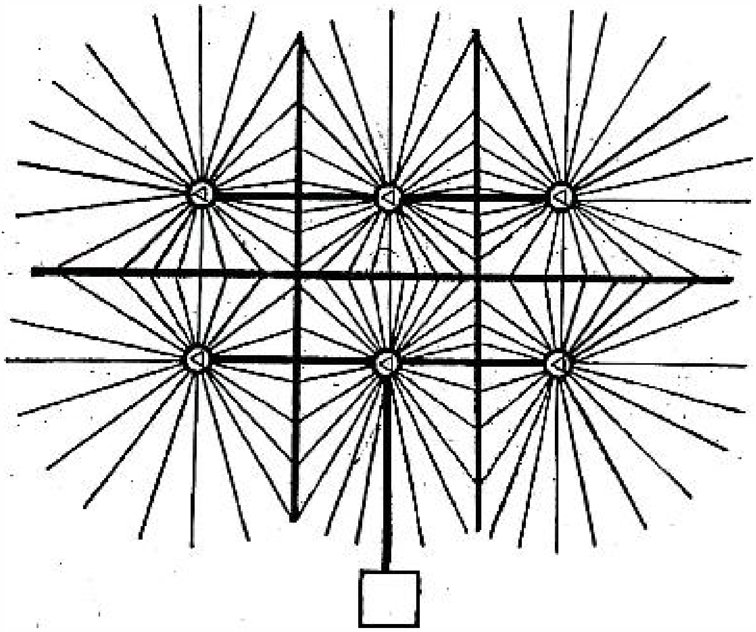
Copper strap in 2", 3" and 4" widths, comes in .032" thickness suitable for use in ground systems. The two tower array shown in Figure 3-27, on 1600 kHz, minimally will require about 300 feet of strap. The large six tower array on 540 kHz, shown in Figure 3-1, about 4000 feet.

All bonding that is done on the ground system must be made with silver solder or by brazing. Never use soft solder. Connections made with it will deteriorate when exposed to the elements. It is also likely to melt when the ground system is called upon to dissipate the energy produced by a lightning strike. The melting point of soft solder, depending on its blend of tin and lead, is in the 400°F range. Silver solder and brazing rod have melting points of near 1000°F. The flame produced by a propane torch is not hot enough for this job. A torch that combines acetylene and oxygen will be required.

As you can see, there will be miles of radial wire, hundreds of feet of copper strap and perhaps 13,000 square feet or more of ground screen to be installed. Order must prevail or we will have a real mess on our hands! Therefore, the first order of business is to lay out the ground system using a transit and tape measure. First, determine the mid-points between towers where the radials will be terminated. Mark each end with wooden stakes. Stretch a string or rope between the stakes. A small trough a foot wide and about 6 inches deep should be dug along this line. Likewise, a similar trough should be dug between tower bases. Copper strap will eventually be installed in these excavations.

Figure 3-28

the ground system for a six tower parallelogram array

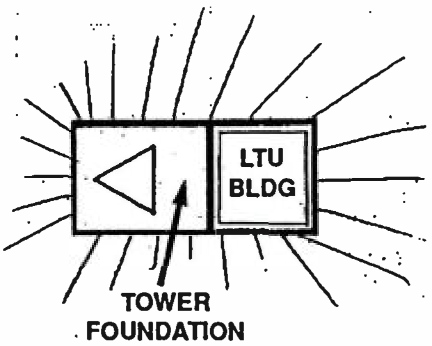


A piece of copper strap or a bundle of 6 or 8 pieces of radial wire twisted together should be installed as a ring around each tower foundation. Each radial wire will be bonded to this ring along with the straps that criscross the foundation and runs under the base insulator, the strap that runs between towers and the strap that will ground the LTU cabinet or panel.

If the LTUs are to be housed in concrete block buildings, the slab for these enclosures should be poured before any of the ground system is installed. The building should be within a few feet of the tower base. The copper strap around the tower foundation pier should extend around the slab as shown in Figure 3-29. The transmission line, AC lighting lines, phase sample line and any multi-conductor cable for pattern or mode change should come through the concrete slab in the appropriate place.

Figure 3-29

the strap should surround both the tower foundation and the slab for the LTU shelter

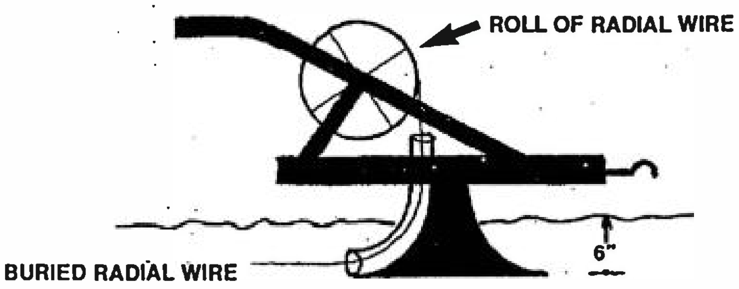


Next, using a rope cut to the specified length of the radials, with a plow or other pronged device, mark the outer edge of the radial field. Once your circle is marked, use a transit, set up at the base of the tower, to mark the end of each long radial. Drive a wooden stake into the ground for each.

Normal installation procedure for radial wires is to plow them in using a wire plow. Figure 3-30 is a rough drawing of such a piece of equipment. Tower errectors, who usually do the ground system installations, more than likely will have such a device in their cache of equipment. A farm equipment dealer can easily fabricate a wire plow by bending a piece of pipe and then welding it onto a triangular pronged plow. Using a tractor or other piece of heavy equipment, each radial is plowed into the ground, starting at the tower base, ending at the wooden stake. Soft drawn copper doesn't always come on a reel. It is sometimes necessary for someone to handle the roll of wire while walking alongside the plow.

Figure 3-30

a wire plow, pulled by a tractor, is the standard piece of machinery for radial installation



A method that will also work is to use a single pronged plow. Loop the wire around the spike on the prong. Plow it into the ground to a depth of 4 to 6 inches, pulling the wire in the furrow as you go. Make sure the wire lays in the furrow. The wire handler stays put at the tower base and unrolls it as needed. If short radials are specified, the same procedure is followed for their installation.

Wrap each radial around the wire or strap ring at the base of the tower. Radials plowed into the field and left unconnected are useless. Where radials will be terminated between towers, leave 12 inches or so visible in the trough. Also, with either method, don't worry about backfilling the furrows. The first rain will do the job for you.

If a ground screen is specified, the radials should be left above ground out to where the edge of the ground screen will eventually lie. Each radial will then be bonded to the edge of the ground screen. The screen will be installed on top of them.

Copper strap can now be laid in the trench between towers and in the trenches where the radials are terminated at the mid-point between towers. If the transmitter building is in the radial field, the strap around it can now be installed. Bond the terminated radials to the mid-point straps; bond all radials and the straps that criscross the foundation pier to the ring of strap around the tower foundation; bond any interrupted radials at the transmitter building to the strap that runs around it; bond continued radials on the other side of the building to the strap; bond the mid-point strap(s) to the strap that runs between towers; bond the strap that runs into the transmitter building either to one of the mid-point straps, the strap ring around one of the towers or the strap that runs between adjacent towers. Any place that radials or straps run near enough to each other to touch they should be brazed or silver soldered. Intermittent connectivity can cause instability problems. When all is complete back fill the mid-point trenches and the one that contains the strap that runs between towers.

Using heavy work gloves, carefully unroll the screens. Extruded copper ground screen has very sharp edges. Cut the center piece to center it on the tower foundation pier. Lay one parallel to the next. You will probably have to drive a wooden stake through each corner to hold it down. Having been wound up in a roll it tends to behave more like a spring than a mat! The edges must be silver soldered or brazed together at intervals of 2 or 3 inches. Once the screens have been joined together, the radials will be bonded to the outer edge of the ground screen.

The fence around the tower can now be installed. Question number one: How tall should the fence be? The FCC Rules do not specify a height. That question is probably best answered by the radio station's insurance company. Six foot would seem to be a minimum. Contact with a tower energized with 50 kW of RF can kill! Ten feet would be a more comfortable height.

Question number two: How far away from the tower should the fence be installed? Again, the FCC Rules do not specify a distance. From a practical standpoint, it must be far enough away from the tower to prevent kids from poking objects through the fence and touching the tower. At the time of this writing, exposure to RF fields in excess of 100 milliwatts per square centimeter at AM frequencies (100 mW/cm^2) violates ANSI standards. When new standards are adopted the exposure level will probably be lowered. If the installation is in an area to which the public has access, the fence should limit accessibility. The only way to be certain you are in compliance is to measure the RF voltage (E) field and magnetic (H) field after the system is in operation. Of course, by then the fence is in place and might have to be moved!

The type of fence/distance will influence exposure level. Chain link fence is an effective shield at AM frequencies. Experience has shown that RF radiation exposure from a 90 degree tower energized with 50 kW is considerably below 100 mw/cm^2 outside a chain link fence just 15 feet from the tower. When the pickup probe was taken inside the fence, the exposure level was far above 100 mw/cm^2. When the probe was raised above the top of the 10 foot chain link fence, the exposure again exceeded 100 mw/cm^2. This suggests that a distance of 15 feet for a chain link fence is adequate for a 90 degree tower energized with 50 kW. It also suggests that the distance should be considerably farther out when a wooden stockade fence is used. Remember too, the full transmitter output power is split up between the elements in the array. In addition, these measurements were made on a 90 degree tower. For taller towers the E field will increase and the H field will decrease. A telephone conference call with your consultant and insurance company can best answer this question.

If a metallic fence is installed, it must be bonded to the ground system at intervals of ten feet or less. The base impedance of the tower can change by 10 percent or more between its bonded to unbonded state. When the fence is left floating to a perchance of being grounded today and ungrounded tomorrow, one invites instability in the radiation pattern produced by the directional antenna system.

3.11 The Installation of the Line Terminating Units

If the line terminating units at the base of each tower are to be installed in concrete block buildings, the slab for the enclosure should have been poured before the ground system was installed. A copper ground strap, tied to the strap around the circumference of the pier and enclosure, will be brought into the shelter between the slab and the first row of bricks on the wall where the panel containing the LTU components will be mounted. A steel door should be used. Make provisions for running a piece of the copper strap on the wall up the hinge side of the door frame. Bond a piece of braided ground strap to the door and the strap at the top and bottom of the door. In a high power installation the door can be RF hot if you neglect to do this. In any installation, an ungrounded door that might have a reasonable path to ground today and no path to ground tomorrow is another invitation to instability in the array.

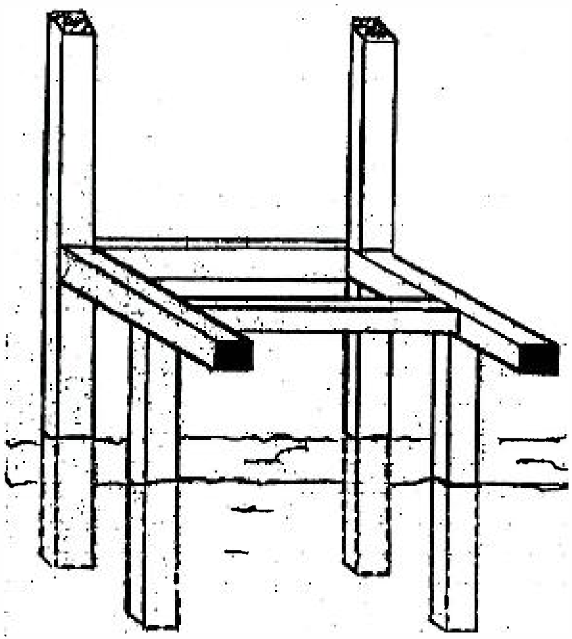
The transmission line, phase sampling line, AC power and any control circuit lines should enter the shelter through the concrete slab near where they will eventually be connected to the LTU. Provisions must be made for a bowl type feed through insulator to be mounted in the appropriate place for feeding RF from the coupling network to the tower. If a lighting choke is used, it is typically mounted on the panel that also holds the inductors and capacitors that make up the coupling network. The AC for the lights will be routed either inside the tubing that forms the RF feed to the tower or tied to it. At this point the lighting feed is RF hot and must be treated as such. If sampling loops are used, the sample line coming down the tower is also RF hot. It too must be brought through the concrete block in the appropriate manner. The isolation coil for the sampling line will be made of 3/8" or 1/2" coaxial cable. It should be mounted immediately adjacent to the panel which holds the LTU components. The coax shield of the sample line should be tied to the tower at the bottom. On the RF cold side of the isolation coil the shield should be tied to the mounting panel and then, via copper strap, to the ground strap on the LTU component mounting panel.

The RF feed connection between the coupling network and the tower should be made of 1/2" or larger tubing. It should be formed in a one or two turn loop of 12 to 18 inches in diameter. The AC lighting wire and the phase sampling line should be tied to the tubing or inside of it. A lighting discharge can cause as much as 200,000 amperes to flow. Needless to say, the inductors and capacitors that make up the matching network in the LTU are not capable of handling this enormous amount of current. The voltage to ground present in the lightning strike has a very fast rise time - typically about 2µs. It can be visualized as a short burst of high frequency RF energy. Current flow caused by lightning behaves like all electrical currents. It seeks the path of least resistance/impedance to ground. The one or two turn inductor appears as a high value of inductive reactance to this energy. Most of it will be dissipated across the ball gap at the base of the tower and through the copper strap to the ground system rather than through the components of the matching network.

The tubing should be welded or brazed to the tower. Obviously, if the AC wiring and/or sample line is to be inside the tubing, the bonding of it to the tower should be done before the cable is pulled in.

Figure 3-31

a mounting frame, fabricated from treated 4X4 timebers, that will hold a several hundred pound LTU cabinet



One way of mounting LTUs that are housed in weather proof cabinets is to use treated 4 X 4 lumber. A suggested frame is shown in Figure 3- 31. This allows the cabinet to rest on the frame, exerting only downward weight, rather than being hung from just 2 supports. The cabinets and their contents are apt to weigh 200 pounds or more. The horizontal force exerted by the cabinet when hung on just support poles will eventually cause the supports to sag forward. Note that the tops of the back support poles are cut at an angle. This provides for water to run off them rather than soak in. It's not a bad idea to cut a square of 1 by lumber and make a cap for these grain-end exposed timbers. Use lag bolts - not nails - to hold the frame together. Lumber yards and home building supply stores sell steel brackets for deck construction to tie 4 X 4 lumber together. Also note the extended horizontal timbers between the vertical supports on the short side of the frame. This will allow you to put a board in place, right in front of the LTU cabinet, for setting up an impedance bridge, signal generator and null detector.

Four holes with a minimum depth of 3 feet should be dug in the appropriate places for the legs. Dump about 3 or 4 inches of coarse stone into each hole. This will provide for drainage and also allow for leveling the frame. Drop the frame into the holes. Using a carpenter's level check the vertical supports for plumb and the horizontal supports for level. Add a few stones into the appropriate hole(s) to bring the supports into plumb and level if necessary. When you are satisfied with your handiwork, mix an 80 pound bag of ready mix concrete for each hole. Pour it in slowly using a stick to tamp it down. This will assure the absence of large voids in the poured cement.

Allow a few days for the concrete to cure and then you are ready to set the cabinets in place. Six lag bolts should be sufficient to hold the cabinet to the mount - four through the back of the cabinet into the support posts and one through each side of the bottom of the cabinet into the horizontal supports. The coaxial transmission line and phase sampling line can be brought up to the surface of the earth directly under the cabinet. If knockouts are not already provided, a Greenlee punch of the appropriate size is used to provide access through the bottom of the cabinet. AC wiring for tower lights, and any multi-conductor cable for pattern switching, should be protected in a conduit between ground level and the cabinet. At least one 2 inch or larger copper strap should be silver soldered or brazed to the radial ring around th tower foundation, tacked to one of the 4 X 4 vertical supports, and silver soldered or brazed to the ground strap that will be provided on the LTU cabinet. When the installation is complete seal openings around cable entrances with electrical putty that is available at building supply stores and electrical supply houses. This discourages mice, snakes and other undersirables from setting up housekeeping among the coils and capacitors that make up the matching network!

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Chapter Four

The Non-Directional Proof-of-Performance

4.01 The Purpose of the Non-Directional Proof

The *construction permit* (CP) for a broadcast facility, issued by the FCC), is an agreement between that agency and the holder of the permit. In essence the agreement states: If you, the permittee, construct the facilities as proposed in your application for the CP, they, the governmental agency, will issue you a license to operate this broadcast facility. That sounds reasonable and straight forward. Submit information showing that the facility has been constructed as specified in your application for the permit and a license will be issued to you to operate it. In the case of a construction permit for an AM broadcast facility using a directional antenna system, proof must also be submitted with the application for a license to show that the antenna system as adjusted is producing the radiation pattern specified in the application. Part 73 of the FCC Rules and Regulations, specifically sections 73.151 and 73.186, detail the procedure of gathering, analyzing and documenting this information.

The radiation pattern specified in the application for a construction permit is the standard radiation pattern (see page 34). In addition to it being shown in tabular form at every 5 degrees of azimuth at ground level, it is also plotted on polar coordinate graph paper. If the array is to be used for nighttime operation, the size and shape of the radiation pattern is calculated and tabulated for every 5° of vertical elevation up to 60°. For measurements purposes, we are interested in the horizontal radiation pattern - the pattern at 0° elevation. When the radiation pattern at ground level has been measured and proved to be in conformance with what has been submitted in the application, a reasonable assumption can be made that the size and shape of the radiation pattern at elevations above ground level will be as calculated.

The calculated radiation values at each azimuth in mV/m of inverse field at one kM cannot be exceeded. As discussed in Section 1.17 on page 23, we can not go out and make just one field intensity measurement at one kM from the antenna system, in each direction of interest, and call it quits! It will take perhaps as many as 40 field intensity measurements along each azimuth of interest, starting in very close to the array and then measuring on out to 20 or more miles. These measurements will be tabulated and plotted on log-log graph paper and compared to the graphs published in the FCC Rules. From this plotted data we can determine the inverse field. These measured azimuths are called *radials.*

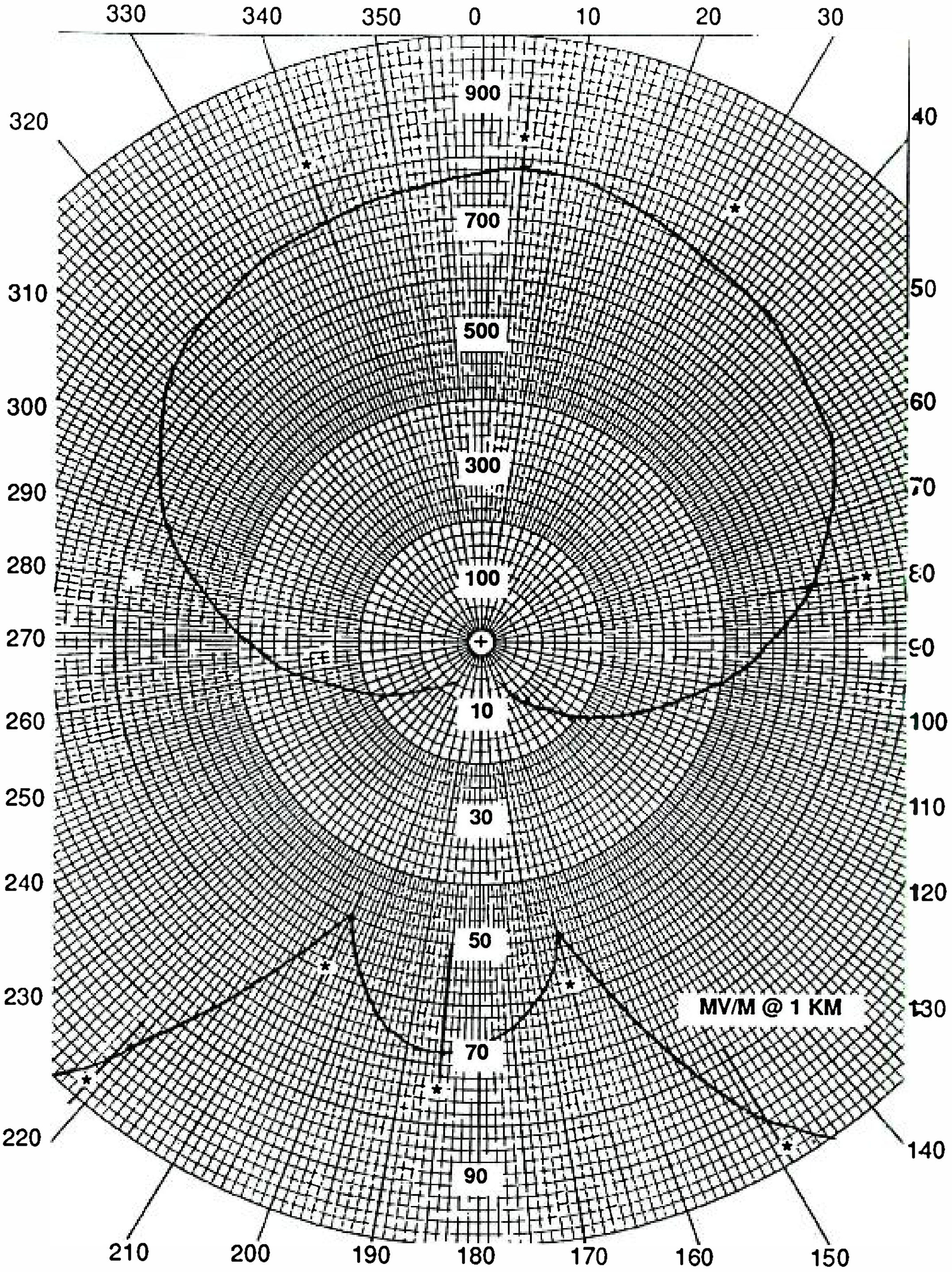
For the non-directional proof, just one tower of the system will be energized. The others will be detuned to make them ineffective radiators. The self impedance of the energized tower will be measured so that power into the radiator can be accurately determined. Then we will do what is known as a *non-directional proof-of-performance* - commonly called a non-directional proof (non-D proof).

Why the non-D proof? From antenna theory and empirical data we can make a close approximation of what the inverse field from a non-directional radiator will be when tower height and power is known. When the measured data taken along a radial is plotted and compared with the published graph, an accurate determination of both ground conductivity and inverse field can be made. After the directional antenna is adjusted, these very same points will be remeasured. The values of measured field strength for directional operation will be plotted and compared to the published graph. The non-D proof will have already determined ground conductivity (or conductivities). along this path, in this direction. It now becomes a relatively easy task to determine inverse field for directional operation by fitting the plotted data to the known conductivity curve.

Figure 4-1

Polar plot of two-tower array DA-D 2.5 kW

azimuths to be measured are marked with *



In addition, the measured non-directional field strength and the directional field strength at each point will be will be ratioed. Either the arithmetic average or the logarithmic average of all the ratios of the measured points along the radial will be calculated. The non-directional inverse field will be multiplied by this average. The product will be the inverse field produced by the directional antenna system in this particular direction.

Sounds complicated? Not really! We will take this step by step as we move along and put into operation our imaginary directional antenna system.

What azimuths do we measure? How many azimuths must we measure to reasonably determine that the radiation pattern is in conformance with what has been submitted in the application? There are 360 degrees on the compass. Obviously it is not necessary or feasible to measure all 360 to accurately determine the size and shape of the pattern! Section 73.151 of the Rules outlines what is required:

1) those specified in the CP

2) at least three radials to identify the major lobe; additional radials may be required

3) along a sufficient number of other radials to establish the effective field. In the case of a relatively simple directional antenna pattern five more radials in addition to those in 1) and 2). In the case of a complex pattern as many radials must be measured as necessary to establish the pattern's size and shape.

The CP will specify one or more azimuths on which a monitor point must be established. These azimuths are usually in critical directions toward stations that are protected from interference by the directional antenna system. At least three radials will be measured to identify the major lobe. Section 73.151(a)(1)(iii) of the rules calls for at least an additional five radials to be measured. For a simple two tower array this minimally adds up to at least nine radials. Figure 4-1 shows such a pattern plot and identifies the ten radials that will be measured. In the case of a more complex array many more radials will have to be measured to adequately prove that the radiation pattern is in conformance with what was calculated and submitted in the application for the CP.

RADIALS TO BE MEASURED ON THE TWO-TOWER PATTERN

5°	Major Lobe ID
30°	Major Lobe ID
80°	Additional Radial
131°	Additional Radial
165°	Required by CP
185°	Required by CP
205°	Additional Radial
239°	Additional Radial
290°	Additional Radial
340•	Major Lobe ID

Table 4-1

RADIALS TO BE MEASURED ON THE FOUR-TOWER PATTERN

5°	Major Lobe ID
30°	Major Lobe ID
80°	Required by CP
92°	Required by CP
106.5°	Required by CP
131°	Additional Radial
149°	Additional Radial
185°	Required by CP
221°	Required by CP
239°	Additional Radial
263.5°	Required by CP
278°	Additional Radial
290°	Additional Radial
340•	Major Lobe ID

Figure 4-2 shows the plot of a pattern produced by a four tower in-line array. Fourteen radials will have to be measured to prove this pattern. They are identified on the plot: Six on azimuths where the establishment of a monitor point is required; three to identify the major lobe; five additional to identify nulls and minor lobes in the pattern.

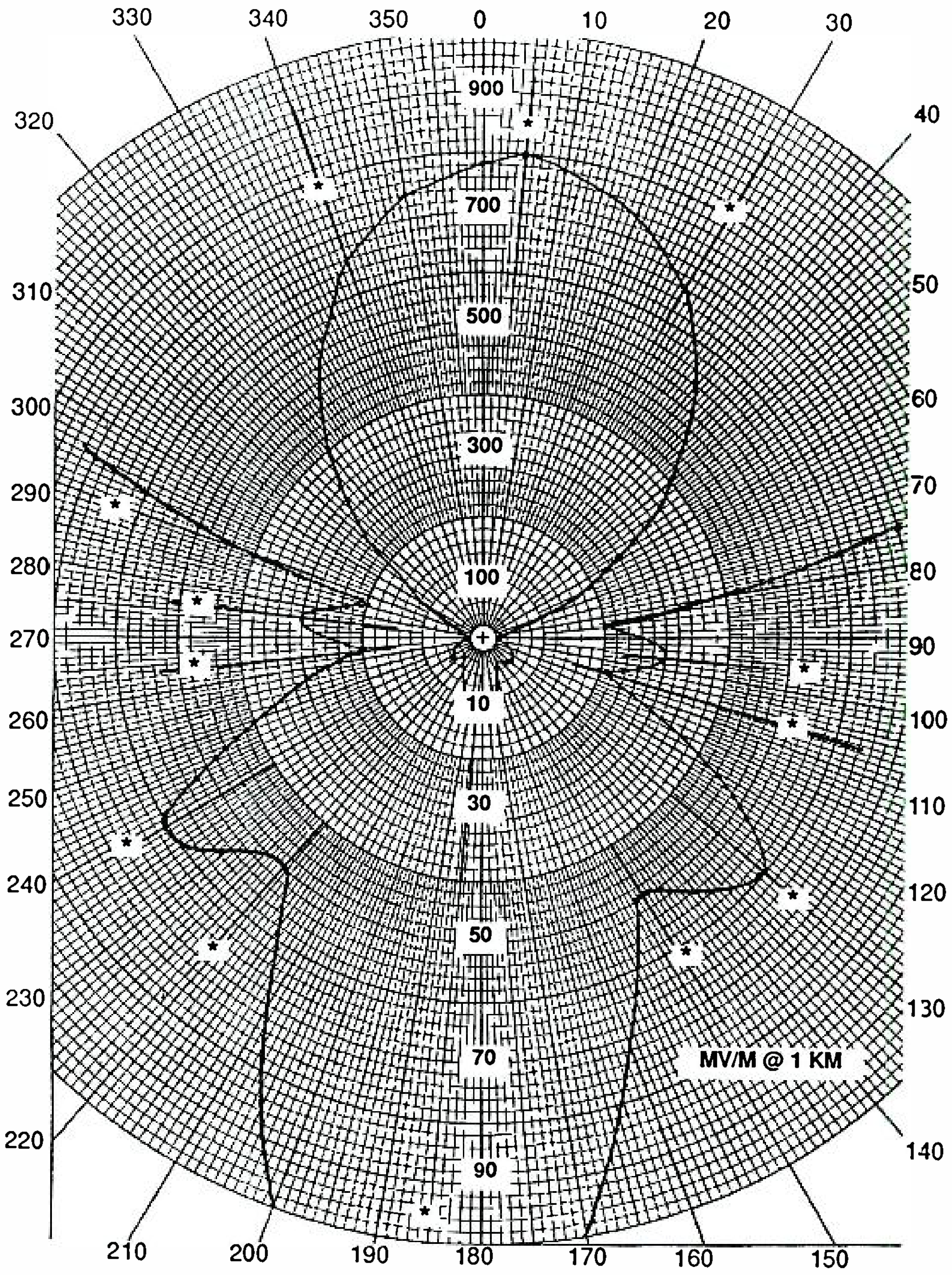
When the array is to produce two patterns (i.e day and night) a non-D proof and two directional proofs will have to be done. The radials measured in the non-D proof should include those on which day monitor points are required, those on which night monitor points are required, those required to identify the major lobes of each pattern and the additional required five. Some radials can be common to both patterns.

For the purpose of illustration in this chapter, and those following, we will take these two patterns and use

Figure 4-2

Polar plot of two-tower array DA-N 1.0 kW

azimuths to be measured are marked with *

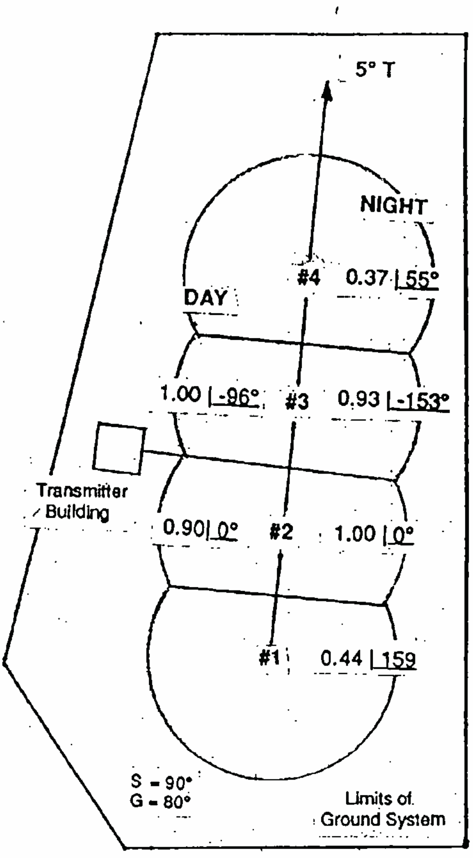


them as examples for our imaginary radio station, XYZ, on 1480 kHz. The two-tower pattern - using towers #2 and #3 - will be used with 2.5 kW for day time operation. With it we are protecting an adjacent channel daytime station in the direction of 185° true. The four-tower pattern is used with 1.0 kW for night time operation. With it we are protecting co-channel and adjacent-channel stations in the directions of 106.5° true and 239° true. The city of license lays north of the transmitter site. The line of towers is 5° true - 5° east of true north. Both major lobes - day and night - are centered on 5° true. The towers are 80° tall - 150 feet - and the spacing between them 90° - 166 feet.

Figure 4-3 is a plot plan of this directional antenna system. It shows a scale layout of the towers, ground system and the property boundaries. The electrical operating parameters for both night and day operation are also shown..

Figure 4-3

plot plan of the two-tower DA-D / four-tower DA-N directional antenna system



Note that the energy in the center of the major lobe for night operation with 1.0 kW approximates that in the day pattern when 2.5 kW is used. In the night pattern the major lobe is fairly narrow. In the day pattern the lobe is wider. A considerable amount of energy is radiated off the sides of the array in the day pattern. Also, the inverse field radiated toward the day time adjacent channel station, in the direction of 185° true, is limited to 68 mV/m at 1 kM. At night, when the day timer has signed off, this restriction is relaxed. The energy in the minor lobe centered on 185° is 120 mV/m at 1 kM. However, to the east and west the radiated sky wave signal must be limited toward other stations. Inverse field intensities of less than 60 mV/m at one kM are produced by the night time array over an angle of more than 70 degrees on each side of the line of towers.

So, how many radials will we have to measure as part of our non-directional proof-of-performance? There are 14 on the night pattern and 10 on the day pattern. Examination shows that some of these are common to both patterns. Eight of the night radials are common to the day pattern proof. There are only two that are unique to the day pattern. Therefore, a total of 16 radials - 14 for the night pattern plus the 2 unique to the day pattern - will be required to be measured.

Before applying power to a new system it is necessary to notify the FCC, in Washington, of your intention to conduct Equipment Tests. Section 73.1610 of the Rules covers such operation. Directional and non-D proof-of-performance measurements required by a CP may be conducted during daytime hours provided that the antenna system is substantially tuned during the experimental period. The rules provide for the non-D proof to be conducted with power adjusted to 25% of that specified in the permit for the directional facilities, or a higher power that might be authorized in the same CP for non-D facilities. Thus, we could use 625 watts of power for the non-D proof. We will use 500 watts.

By following this procedure, in both modes of operation - day and night - we will bring the patterns into substantial adjustment during the experimental period. Interference to the daytime station will be minimal - if not non-existent - in the DA-D mode. The proofs will be conducted with the carrier unmodulated except for station identification at the beginning and end of such operation and hourly during operation.

There are situations where non-directional operation with even a small amount of power would cause objectionable interference to a co-channel or adjacent channel station even with the carrier unmodulated. When this is apt to occur, arrangements have been made to conduct the non-D proof on another frequency - a channel or two removed from the operating frequency. When such an unusual situation occurs the frequency chosen should be on the same family of GROUND WAVE FIELD STRENGTH VERSUS DISTANCE FCC graph as the operating frequency. For example: For an operating frequency of 1480 kHz the proof frequency should be between 1430 and 1510 kHz; in other words, it should be on graph #18. This allows us to use the same set of ground conductivity curves to compare the non-D and DA proof measurements. Unusual arrangements such as these should be made well in advance. The bureaucracy likely to be encountered will make this more than an overnight process!

The frequency of state of the art transmitters are PLL controlled. It is an easy matter to change it by 10 Khz in the field. Older transmitters will require a crystal for the non-D proof frequency.

As one makes field intensity measurements out toward the end of a radial, interference from a station on the same frequency can be encountered. Interference from a co-channel station will manifest itself as an unstable reading on the field strength meter. The measured field will vary as the two signals beat together. The repetition of the movement on the indicating meter will be determined by the frequency offset between the two carriers. A one hertz offset will cause the interval between maximums on the meter to be at one second intervals; two hertz, two seconds, etc. The intensity of the beat will be determined by the ratio of the amount of signal of the two carriers. About the best one can do under these conditions is to note the minimum and the maximum amounts of signal observed on the meter. Later, before analyzing the measurements, the two should be averaged. The averaged figure will be used. In the proof data submitted, the minimum/maximum and average should be noted.

When the interference comes from an adjacent channel station the indicating instrument will jump around under modulation of the interfering station. Under these conditions wait for a programming pause to get an accurate reading.

4.02 Procuring and Preparing Maps

The proof-of-performance on an antenna system requires us to actually get out into the field and measure the amount of signal being radiated from the antenna system. If our measurements are to be meaningful, in addition to knowing the exact amount of field strength present at a given location, we must accurately know where the measuring location is in relation to the directional antenna system - both in distance and direction. Therefore, large-scale accurate maps are a necessity.

The United States Department of the Interior (USGS Information Services - Box 25286 - Denver, CO 80225-9916) publishes topographic maps suitable for doing directional antenna proofs-of-performance. A topographic map accurately represents the natural and man made features of the land. The shape and the elevation of the terrain are portrayed by contour lines and specific features such as roads, towns, water areas and some buildings are shown on these maps. This makes them ideal for accomplishing the task that lays ahead of us.

The largest scale topographic maps available should be used. These are the 7.5 Minute Series Maps. Each of these maps covers an area 7.5 by 7.5 minutes of longitude and latitude. The map scale is 1:24,000. One inch on the map represents 2000 feet on the ground. The size of the individual maps is approximately 22 by 27 inches. Depending on the area of the country, a 7.5 minute quadrangle map - as they are commonly called - will cover an area of about 50 to 70 square miles. USGS topographic maps are usually named after the most prominent city, town or natural landmark shown on it.

An alternative is to use the 7.5 by 15 Minute Series Maps. Their scale is slightly smaller, but still acceptable: 1:25,000. One inch on the map represents 2083 feet on the ground. The land area covered varies from about 200 to 275 square miles. The major drawback to these maps is their size: 24 by 40 inches. Trying to handle an assortment of 7.5 by 7.5 minute maps while navigating and piloting a car is a chore in itself. The 7.5 by 15 minute maps make life even more interesting!

Smaller scale maps are to be avoided as it is necessary to accurately know where you are when making proof-of-performance field strength measurements. (Currently, the largest USGS Map available for Alaska is 1:50,000.) These maps will have a lesser amount of detail making it more difficult to pinpoint your location.

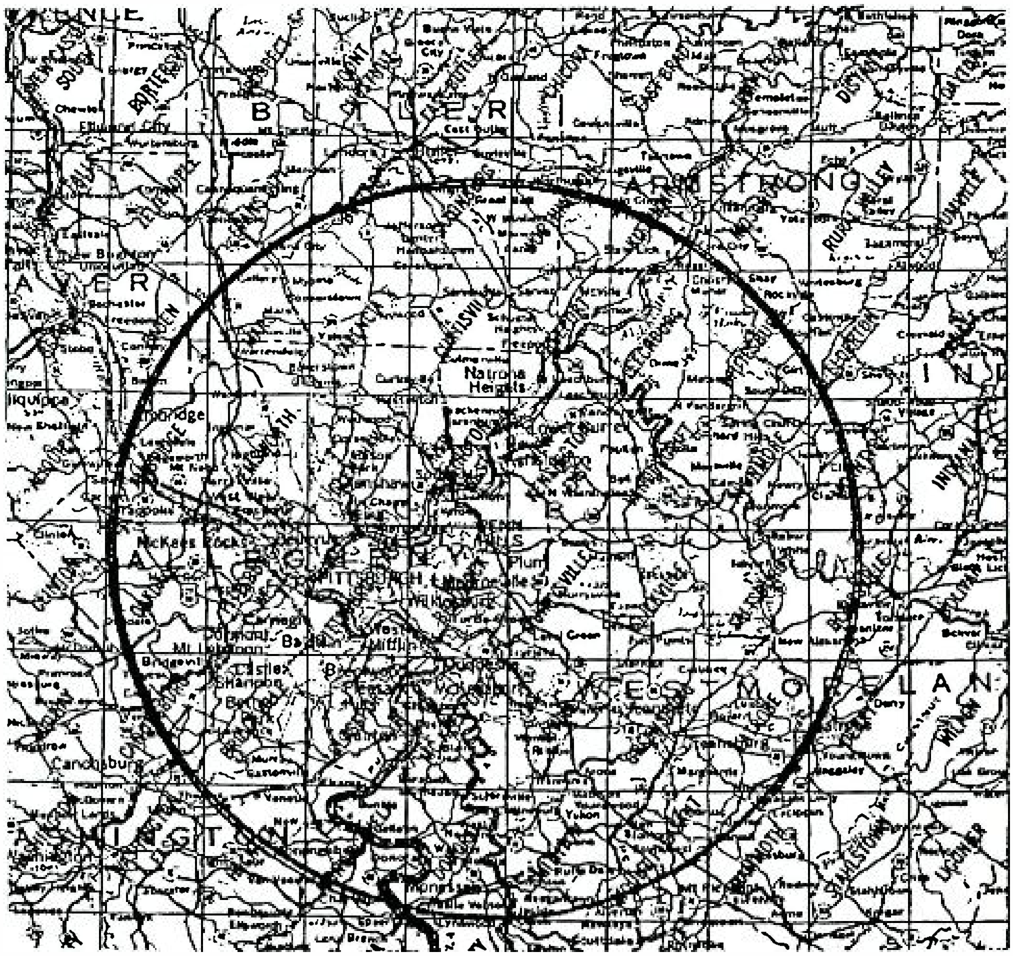


Figure 4-4

the topographic map index is a necessity for determining what maps are necessary for the proof

obtain all maps within a 25 to 30 miles radius of the transmitter site

Which maps do I buy? An Index *to Topographic and Other Map Coverage* is available for each state. The large index map is blocked off showing every USGS map by name that is available for that state. Mark the approximate location of the transmitter site on the index map. With a compass draw a circle with a radius of approximately 25 to 30 miles centered on the site as shown in Figure 4-4. Order every map encompassed by any part of the circle. Order at least two maps of the quadrangle on which the transmitter site is located and two copies of any maps within 3 kM of the site.This could be as many as fifty or more 7.5 by 7.5 minute maps.

USGS topographic maps, catalogs and indexes are available in most large cities from commercial map dealers. Consult the yellow pages of the telephone directory. They also may be purchased by mail from: USGS Map Sales, Box 25286, Federal Center, Building 810, Denver, CO 80225.

If the surveyor has not already located the center of the array on the topo map, now is the time to do it. Take the map on which the transmitter site is located. Using landmarks, locate the center of the array. Using the geographic coordinates on the construction permit, double check your work.

On your 7.5 by 7.5 minute 1:24,000 scale map, lay a ruler marked off in cm on the side of the map closest to the transmitter site. The map is marked in 2.5 minute increments - 150 seconds of latitude. The distance between two of these 2.5 minute marks is 19.4 cm. Therefore, 1 second of latitude is 0.129 cm on the map (19.4 / 150). A second of latitude, anywhere on the surface of the earth, is approximately 101.11 feet - 0.129 cm on a 1:24,000 scale map.

Longitude is a different story. A second will vary from approximately 101.45 feet at the equator to zero at the poles. All lines of longitude converge at both the north and south pole. The approximate length of one second of longitude at any point on the surface of the earth can be calculated by the following formula:

(#16) **cos latitude (101.45) = one second of longitude in feet**

For example: At 40.5 degrees latitude one second of longitude is
cos 40.5 (101.45) =
(0.760) (101.45) = 77.1 feet

Lay the ruler across the top or the bottom of the map - the edge closest to the transmitter site. The map is also marked in 2.5 minute increments of longitude - 150 seconds. In the example shown in Figure 4-5, 150 seconds is 14.7 cm. Therefore, 1 second of longitude, on this map, at 40° 30" 00' latitude, is 0.098 cm (14.7/150).

Now, using a square, carry the line of latitude from the center of the array as you have identified on the map to the vertical edge. Do the same for the line of longitude out to the top or the bottom of the map.

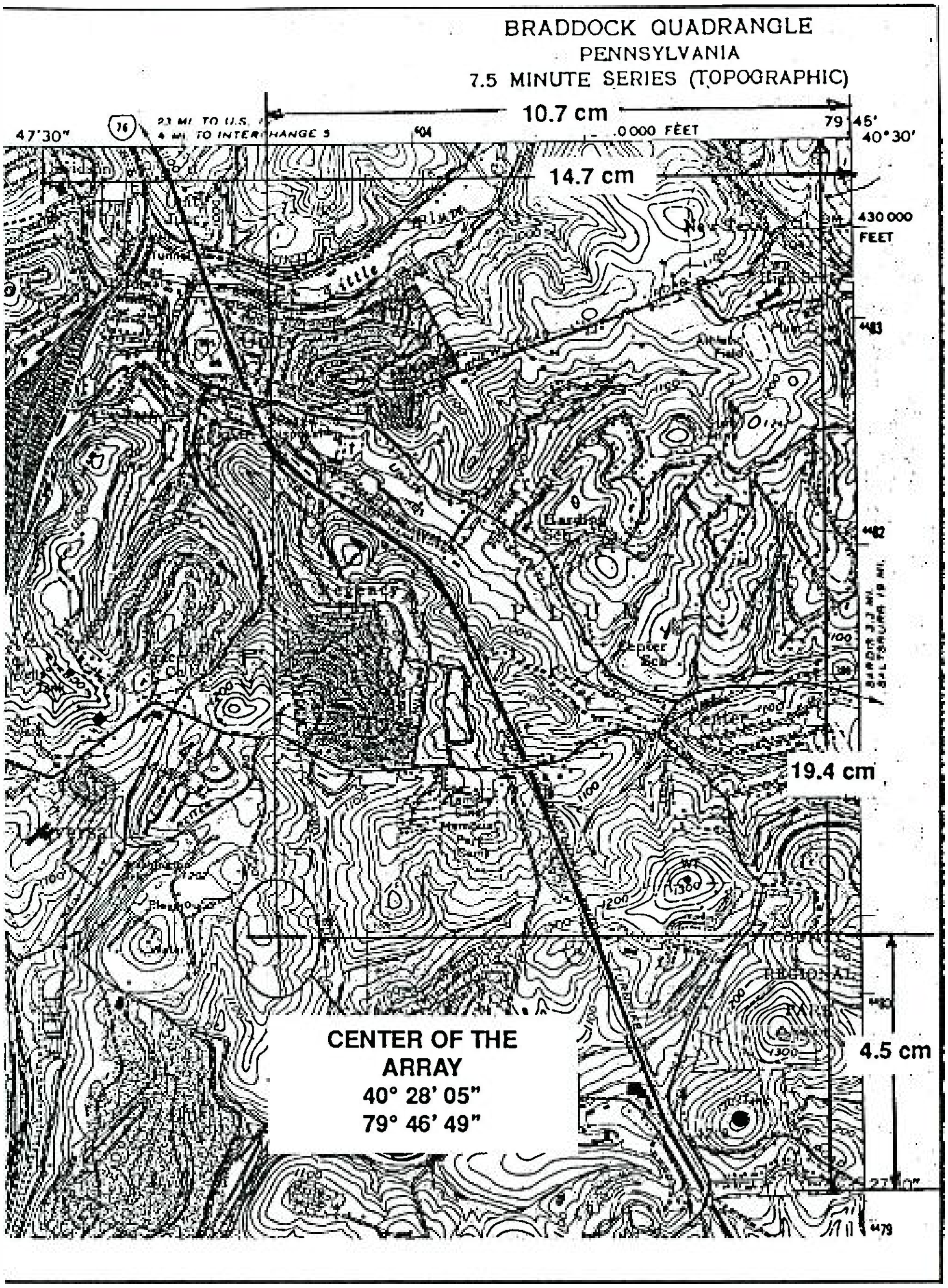
In Figure 4-5, our horizontal line is 4.5 cm north of the 40° 27" 30'line of latitude. Seeing that 0.129 cm = one second of latitude, the transmitter site as marked on the map is 35 seconds (4.5 / 0.129) north of 40° 27" 30" - at 40° 28" 05' north latitude.

Our line on the top of the map is 10.7 cm west of the 79° 45" 00' line of longitude. Seeing that 0.098 cm = 1 second of longitude, the transmitter site as marked on the map is 109 seconds (10.7 / 0.098) west of 79° 45" 00' at 79° 45" 109' - or 79° 46" 49' (109 seconds is 1 minute 49 seconds).

Thus, the transmitter site as marked on the map is at 40° 28" 05' north, 79° 46" 49' west. Does it agree with the coordinates on the CP? If not work backward, plot the site using the coordinates listed on the CP. If you can't get coordinates and land marks to agree, go back to the surveyor who located the tower bases. Have him locate and mark the center of the array on your map.

Figure 4-5

determine the location of the center of the array and mark it on the map



CENTER OF THE ARRAY
40° 28' 05"
79° 46' 49"

Section 73.186 of the Rules requires field intensity measurements to be made at intervals of 0.2 kilometers (655 feet) out to a distance of 3 kilometers (1.87 miles) from the antenna. Measurements made in the induction field of the antenna are meaningless. Therefore, our measurements will start at 5 times the height of the tower. Our imaginary radio station, being used as a model, is on 1480 kHz. The towers are 90° in height - 166 feet - 50.46 meters. Meaningful measurements for our non-D proof can be made no closer than 252 meters from the tower - .25 kM - approximately 825 feet.

Using the scale at the bottom of the map and a compass, draw concentric rings around the marked center of the array. The first will be 0.3 km out. The next will be 0.5 km, the next 0.7 km, and so on every 0.2 km on out to 3 km (1.87 miles). This procedure is illustrated in Figure 4-6. As we do the non-D proof, we will strive to measure every point where a radial line crosses one of these concentric lines. This means 14 close in points on each radial. A small error in distance or azimuth close in to the antenna system is large in percentage. When we remeasure these points during the DA proof, 200 feet off the radial can be many degrees of error. Accuracy is a must!

Figure 4-6

a measurement should be made at each point where the radial crosses a concentric linbe

The next task is to lay out on the maps each of the radials we will measure. Starting with the map on which the transmitter site is located, with the aid of a protractor, carefully mark the direction of the first radial, which is 5°. Draw a line out to the edge of the map. Next do the 30° radial, then the 80° radial, and so on until all 16 radials that are to be measured in our non-D proof have been marked on the quadrangle where the transmitter site is located. Do the same for the second transmitter site map. Take care and time. Accuracy is important.

Using scotch tape or other tape that is easily removed, fold back the outside edge of the adjoining maps to conceal the white perimeter frame. The fold must be right on the edge of the map portion of the paper. Tape one adjoining map at a time to the central map. Make sure adjoining roads and other landmarks line up as illustrated in Figure 4-7. Using a yard stick or other long straight edge extend all radials that cross the map on to it and then out to the its far edge. Repeat the same procedure for the next adjoining map. If you use care, errors can be kept down to one degree or less. Accuracy is important. We will use the drawn-in radial lines to locate measuring points on the maps. If we get too far off the desired azimuth, our collected data will be meaningless. It will become impossible to prove that the array is in adjustment - even if it is producing the specified radiation pattern.

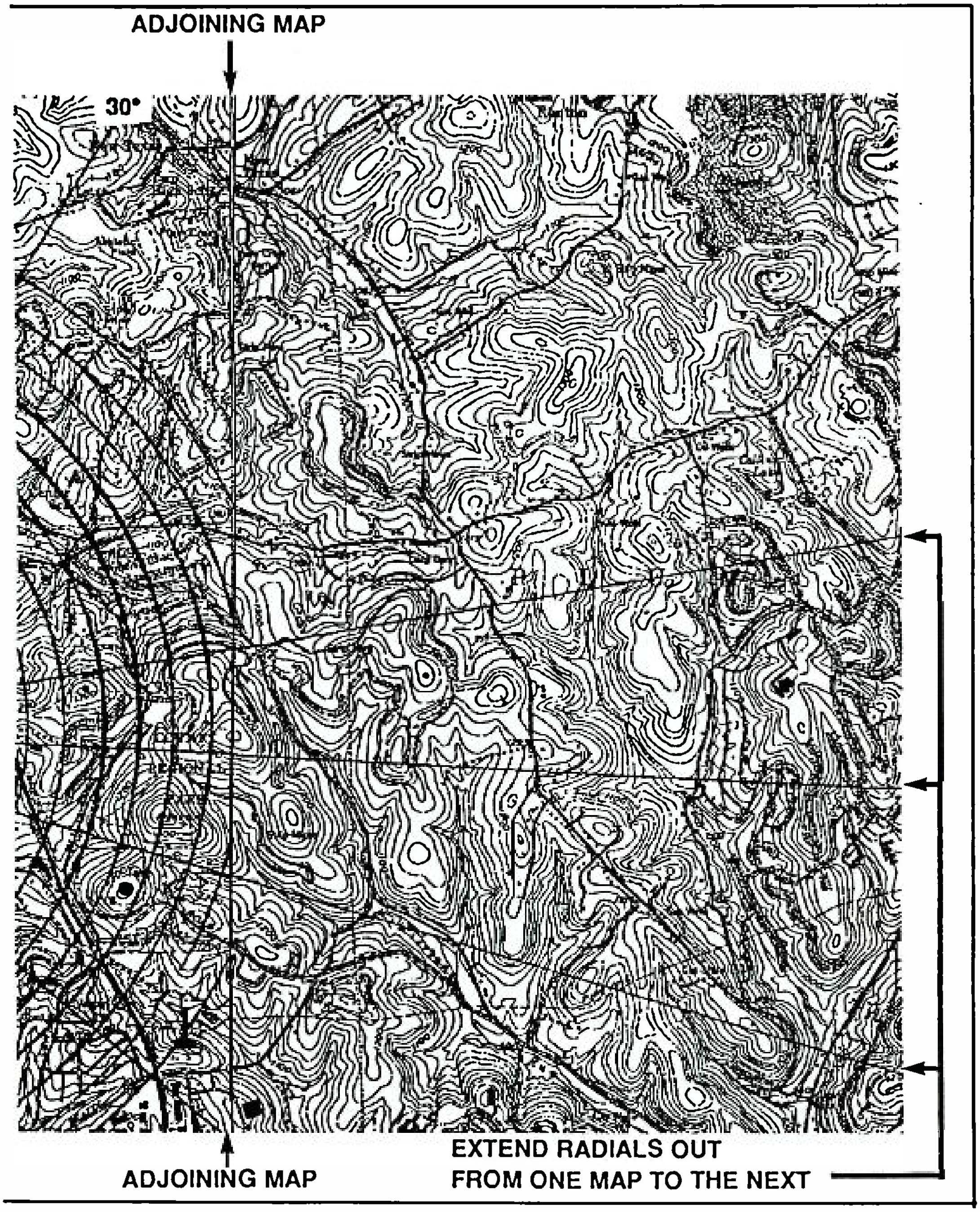


Figure 4-7

fold back the edge of one map and tape it to the next

extend radials out to far corner and then continue process on the next map

4.03 Setting Up the Non-Directional Tower

Table 4-3 lists the operating parameters for each radiator for both patterns: current ratio and phase, driving point impedance, power energizing the tower, and the expected base current. The tower used for making non-D proof measurements is the tower which will be energized with the most power for directional operation. In our model, XYZ Radio, it is tower #2 in both the day and night patterns. Had it been tower #2 for night operation and tower #3 for day operation, either could have been used.

DIRECTIONAL ANTENNA OPERATING PARAMETERS

DAY PATTERN - 2.5 KW (2700 watts)

Tower	Ratio/Phase	Driving Point Z	Power Watts	Current Amperes
#1	------------	----------------	----------	-----
#2	0.90 ∠0°	43.99 -j17.30	1636.7	6.10
#3	1.00 ∠-96°	23.17 -j12.03	1065.3	6.78
#4	------------	----------------	----------	------

NIGHT PATTERN - 1.0 KW (1080 watts)

Tower	Ratio/Phase	Driving Point Z	Power Watts	Current Amperes
#1	0.44 ∠159°	4.94 -j3.30	59.83	3.48
#2	1.00 ∠0°	12.38 +j0.70	774.59	7.91
#3	0.93 ∠-153°	8.04 +j12.80	435.52	7.36
#4	0.37 ∠55°	-23.00 +j28.00	-197.45	2.93

Table 4-3

Figure 4-8, on the next page, is a schematic of the feeder system for this array. We will be referencing it during this chapter and the next. Every component is marked for identification.

In order to energize tower #2 for non-directional operation, we will have to jerry-rig some connections! The RF contactors (K1, 2K1, 2K2, 3K1 and 3K2) are shown in the night position. The system should be switched to day operation. The strap or copper tubing that connects tower #3 to 3K1B should be temporary disconnected at the RF contactor. Care should be taken to see that it does not touch any components or ground. Tower #3 should be floating.

J1 and 2J1 are jumpers called J-plugs. They are jacks where RF ammeters can be inserted. When the plug jumper is removed it will open up the circuit. Pull both jumpers and connect a piece of copper tube or strap between the transmission line side of 2J1 and meter side of J1. This feeds the transmitter output directly to transmission line #2. RF contactor 2K1A and B are now in the day position - opposite what is shown on the print. The day t-network consisting of 2L10, 2L11, 2L12 and 2C6 is now in the circuit between the transmission line and tower #2.

Measure the self impedance of tower #2. 2J3 is not a simple j-plug. It is a make before break plug designed to facilitate the insertion of an RF ammeter in series with the tower without opening the circuit. This arrangement is necessary to allow one to measure base current while the system is in operation. An RF meter mounted on an insulated plug can be inserted into the jack making connection between the LTU and antenna feed before the spring loaded jack connections are broken. An alternate arrangement is to use a make before break RF switch. The strap or tubing connection between 2J3 and the tower should be opened. The impedance bridge will be connected between the tower feed and the ground strap on the LTU.

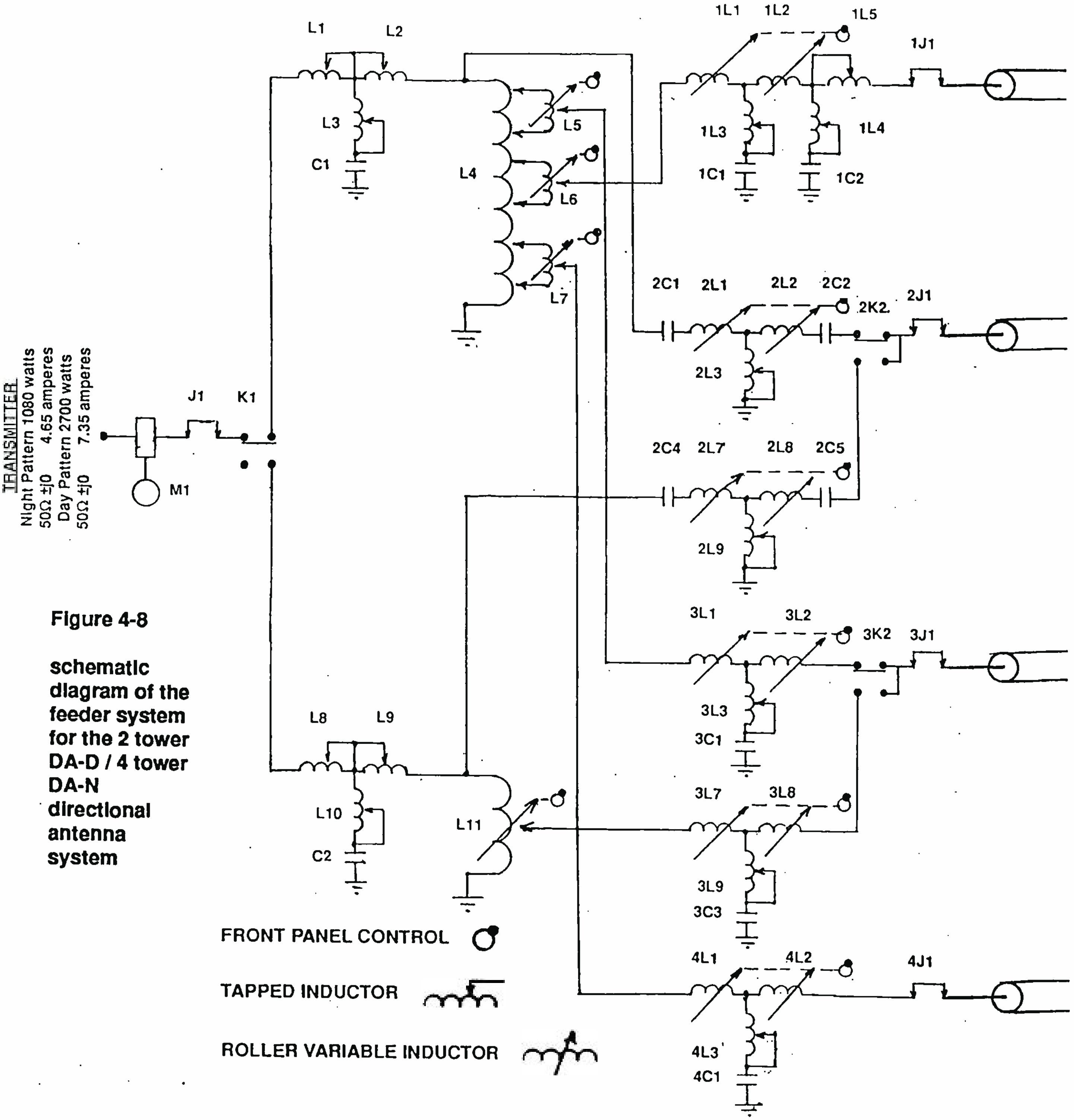
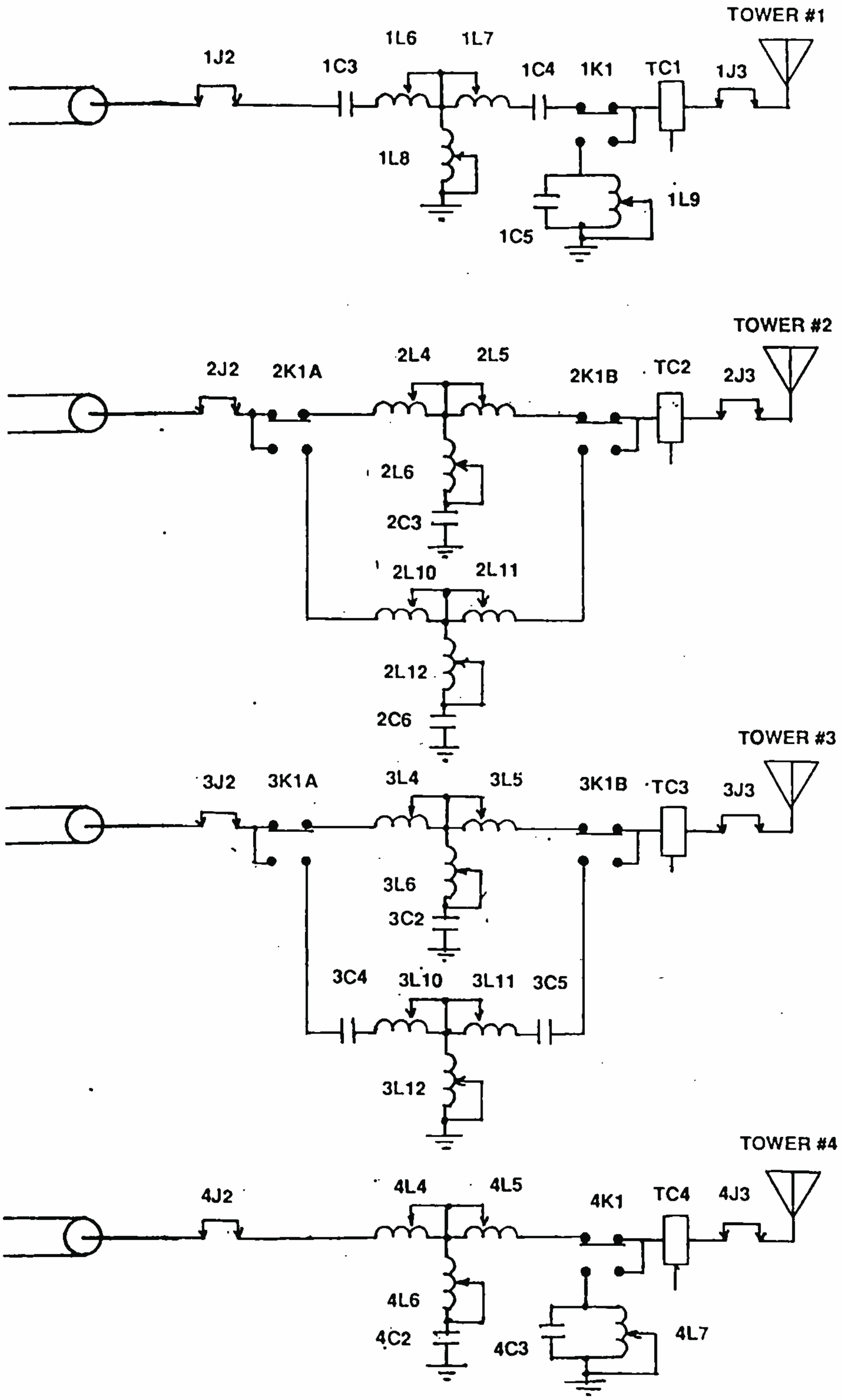


Figure 4-8

schematic diagram of the feeder system for the 2 tower DA-D / 4 tower DA-N directional antenna system



#1 NIGHT

0.44 ∠159°
4.94 -j 3.3
59.83 watts
3.48 amperes

#2 NIGHT

1.00 ∠0°
12.38 -j 0.7
774.59 watts
7.91 amperes

#2 DAY

0.90 ∠0°
43.99 -j 17.3
1636.08 watts
6.10 amperes

#3 NIGHT

0.93 ∠-153°
8.04 +j 12.8
435.52 watts
7.36 amperes

#3 DAY

1.00 ∠-96°
23.17 -j 12.0
1063.93 watts
6.78 amperes

#4 NIGHT

0.37 ∠55°
-23.0 +j 28.0
-197.45 watts
2.93 amperes

Table 1-1, on page 6, gives a nominal value of 34 ±j0 for the self impedance of an 80° tower. The measured value will be close to this but more than likely not exactly this value. Chain link fences and other nearby objects will have an effect on the self impedance of the tower. For our discussion, we will assume that we measure 34 ±j0 at 1480 kHz.

Using formula #11 in Section 1.12, we now calculate the values of a t-network to match the 50 ohm transmission line to the input of the tower 34 ±j0. For the sake of simplicity we will use a -90°phase shift. It needn't be 90 degrees but the math is simple! All components are of the same reactance.

$$X1 = X2 = X3 = \sqrt{Rin \times Rout} = \sqrt{50 \times 34} = \sqrt{1700} = 41.2 \text{ ohms}$$

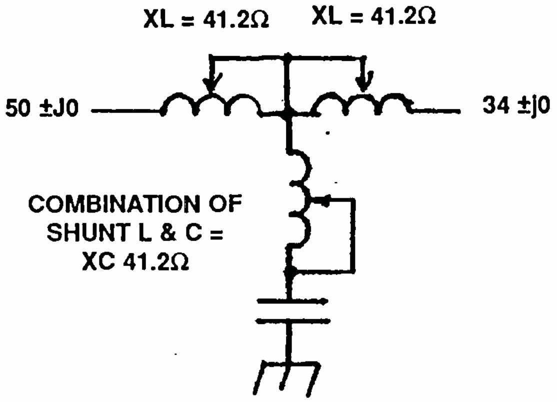


Figure 4-9

the T-network used to match the 50 ohm transmission line to the self impedance of the non-directional tower

In view of the fact that the input impedance to the tower is purely resistive we need make no provisions for altering the value of the series output leg of the network to tune out reactance. Each leg of the t-network can be set to 41.2Ω using the bridge.

When this is complete, reconnect the tower. Open 2J2 and measure the input to the t-network. It should be 50 ±j0. If it's close - within an ohm or two - it is satisfactory. We will revisit the self impedance of the tower and this t-network after detuning the unused towers.

Before applying power, make sure that all of the current transformers - TC-1, TC-2, TC-3 and TC-4 - are terminated. This means connected via the sampling line to the antenna monitor, or terminated with a 50 ohm resistor. A current transformer can be damaged or destroyed if left in the circuit, without a termination, when power is applied. Turn the loop current controls - both day and night - on the antenna monitor all the way down. Plug the base current meter into 2J3.

Transmitter power can now be applied. If the transmitter has a variable power control, turn it all the way down and gradually bring it up. If there's no smoke, bring it up to the 500 watt level. The base current should read 3.83 amperes for 500 watts ($I^2R=P$). The RF power amplifier operating parameters - plate or collector current and voltage - should be near what the manufacturer has specified for this power of operation.

4.04 Detuning the Unused Towers

Vertical structures in the high RF field of an AM station will re-radiate energy. This re-radiation will combine in some directions in phase with the radiation from the energized tower and in other directions out of phase with the radiation from the energized tower. The end result is distortion of the circular non-directional pattern we are about to measure. Towers #1, #3 and #4 are sitting there within a half wavelength of the energized tower, unenergized but just waiting to cause trouble by acting as parasitic radiators!

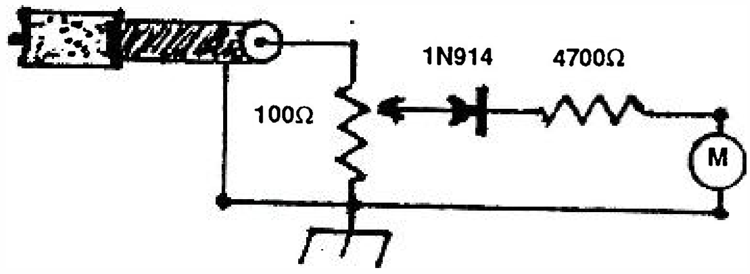
Towers #1 and #4 - the two not used in the day pattern - have provisions incorporated in the LTU for detuning them. 1C5 and 1L9 form a parallel resonant circuit between the tower #1 feed and ground when the system is in the day mode of operation. 4C3 and 4L7 form a similar arrangement in the tower #4 LTU. You will have to raid your junk box or temporarily borrow some components from the T-networks in the #3 LTU to make a detuning network for tower #3. Open the feed to this tower at 3J3 and connect the LC network between it and ground. If junk box parts are used they needn't be large. A piece of B&W coil stock and a variable capacitor - the type used in higher powered ham transmitters - will suffice.

Various methods can be used to indicate when the tower has been rendered an ineffective radiator. We are looking to reduce current flow in the tower to ground to the lowest possible value. This is the condition where re-radiation from the unenergized tower will be close to zero. The indicator must be able to be read down to a very low value.

A 100 mA RF ammeter plugged into 1J3 (or its counter part in the other LTUs) will work. The loop current indication on the antenna monitor can be used for this purpose. The draw back is that it is in the transmitter building and your are moving a tap on a coil in the LTU during this process. It can work with a pair of walkie-talkies for communication.

Figure 4-10

simple detector circuit that can be used in conjunction with the toroidal current transformer or sampling loop to indicate proper adjustment of the detuning network



The circuit shown in Figure 4-10 is a simple diode detector with a 100 uA indicator. meter. It can be made in a small mini-box with an N-type male RF connector on the end of a piece of RG58 coax. The indicator is fed from the phase sampling current transformer TC-1 (or its counter part in the other LTUs). Disconnect the phase sampling line and connect the detector.

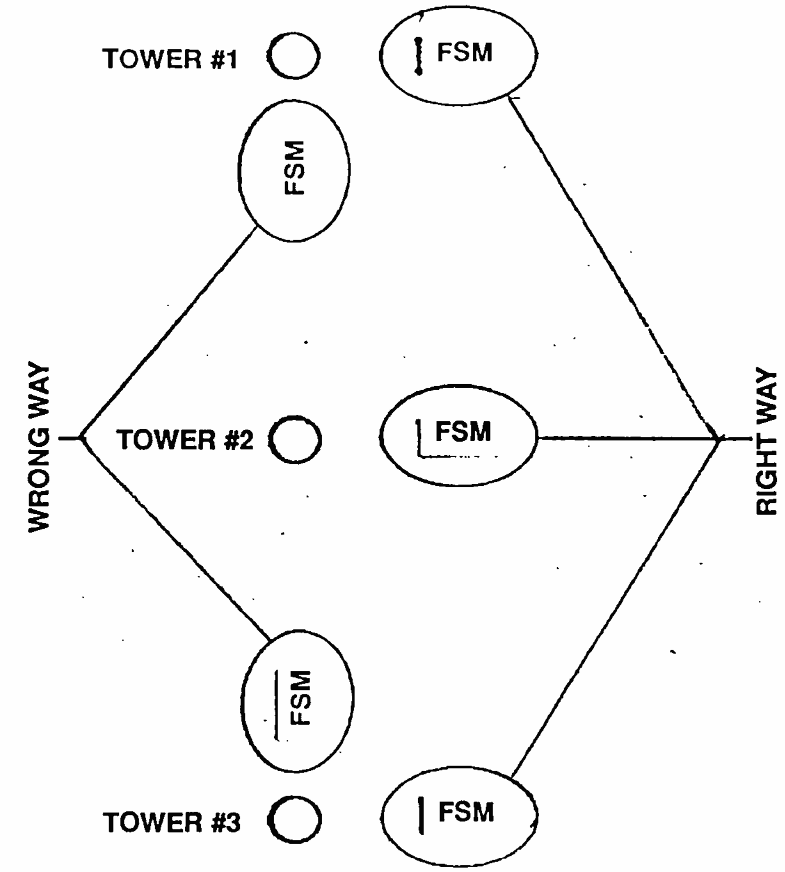
A field intensity meter also makes an excellent detuning indicator. Set it up on the tripod in the location as shown in Figure 4-1. Don't try it with the meter between towers. Orient the meter for a maximum indication in the direction of the tower to be detuned. The loop antenna is very directional and if set up as shown will primarily indicate radiation from the tower you are attempting to detune. The distance between the tower being detuned and the meter should be about 25 feet.

With the non-D tower energized, no matter which method is used, the object is to move the tap on 1L9 (or 4L7) to bring the indication on the meter as low as possible. Move the tap about a quarter turn at a time. Go through resonance then move the tap back. Be careful: Even with only 500 watts energizing the non-D tower you can get a nasty RF burn from the unenergized tower by induced RF voltage. Lower the transmitter power to be safe. If the strap connected to the tap is at ground potential as shown on the print, you will be OK. If the strap is connected to the hot end of the coil, beware!

Once you are satisfied that tower #1 is detuned go on to tower #3 and complete the same procedure. On this tower, if you use the phase sampling torroidal transformer and detector or the antenna monitor loop current indication, remove the connecting strap on 3K1. Connect the temporary detuning circuit between the disconnected strap (or tubing) and ground.

Figure 4-11

when using the field strength meter as an indicator for detuning towers, it should be positioned so that it is oriented at a right angle toward the other towers in the system



Once you are satisfied that tower #3 is detuned, go on to tower #4 and complete the same procedure.

When you complete tower #4, it is advisable to go back and recheck the #1, #2 and #3 detuning networks. Mutual coupling between towers can upset the resonance in an adjoining tower when it is detuned. This is most likely to happen when the towers are taller than 90° and the spacing less than 90°.

4.05 Non-Directional Base Impedance Measurements

TOWER #2 BASE IMPEDANCE DATA
(for non-D proof-of-performance measurements)

Frequency kHz	Resistance Ohms	Reactance Ohms
1450	31.0	-3.6
1455	30.0	-2.9
1460	30.5	-2.2
1465	31.0	-1.6
1470	32.5	-0.9
1475	32.5	-0.1
1480	34.0	0.0
1485	34.0	+0.8
1490	35.0	+5.2
1495	36.5	+3.5
1500	37.0	+3.5
1505	36.0	+4.8
1510	40.0	+4.2

Table 4-3

It is necessary to know the exact amount of power with which the non-D tower is energized. Therefore, we are now going to turn the transmitter off and go back and remeasure the input impedance to tower #2. It may have changed slightly during the detuning process as there is mutual coupling between it and the other towers. Also, we will now not only measure input impedance at the operating frequency, but at 5 kHz intervals out to 25 kHz below the operating frequency, and at 5 kHz intervals out to 25 kHz above the operating frequency as specified in 73.54(c)(1) of the Rules.

These measurements should be made on the antenna side of 2J3 - with the circuit open. The results of these measurements will be tabulated as shown in Table 4-3 and graphed as shown in Figure 4-12A and 4-12B. They will become part of the package of data submitted with the non-D and DA proof-of-performance measurements to the Commission.

Figure 4-12A

graph of the base resistance of the radiator used for the non-directional proof measurements

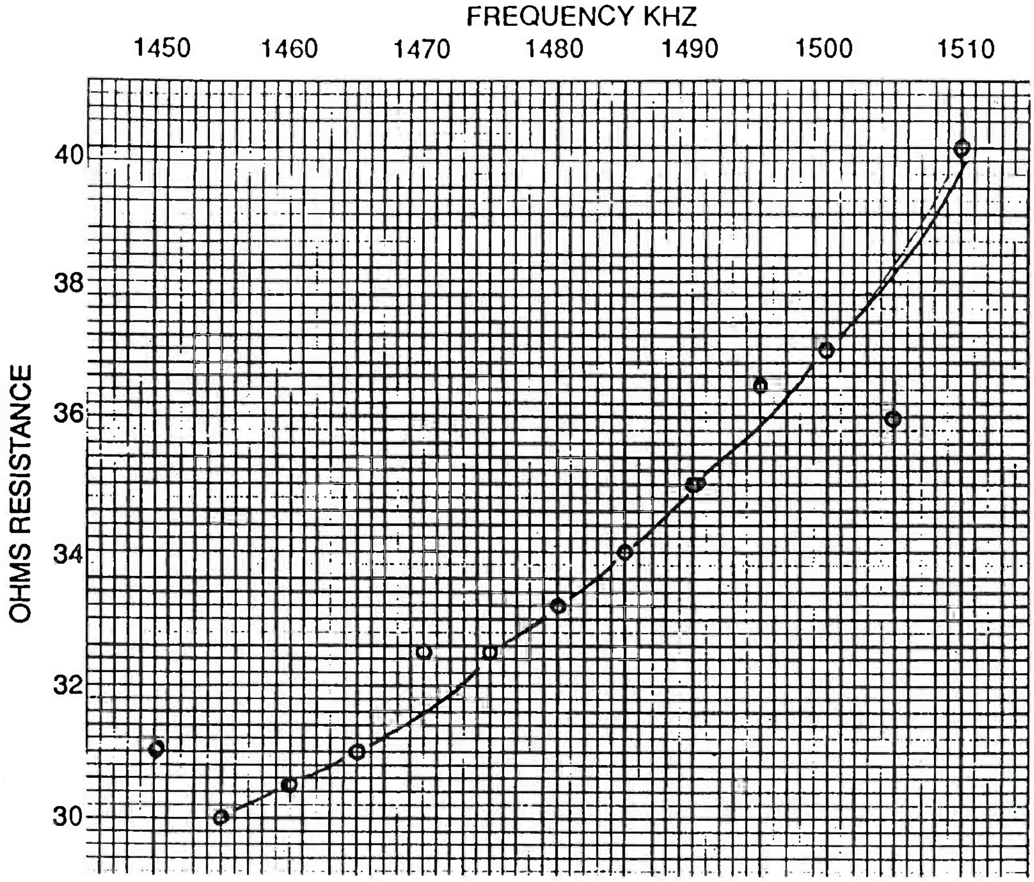
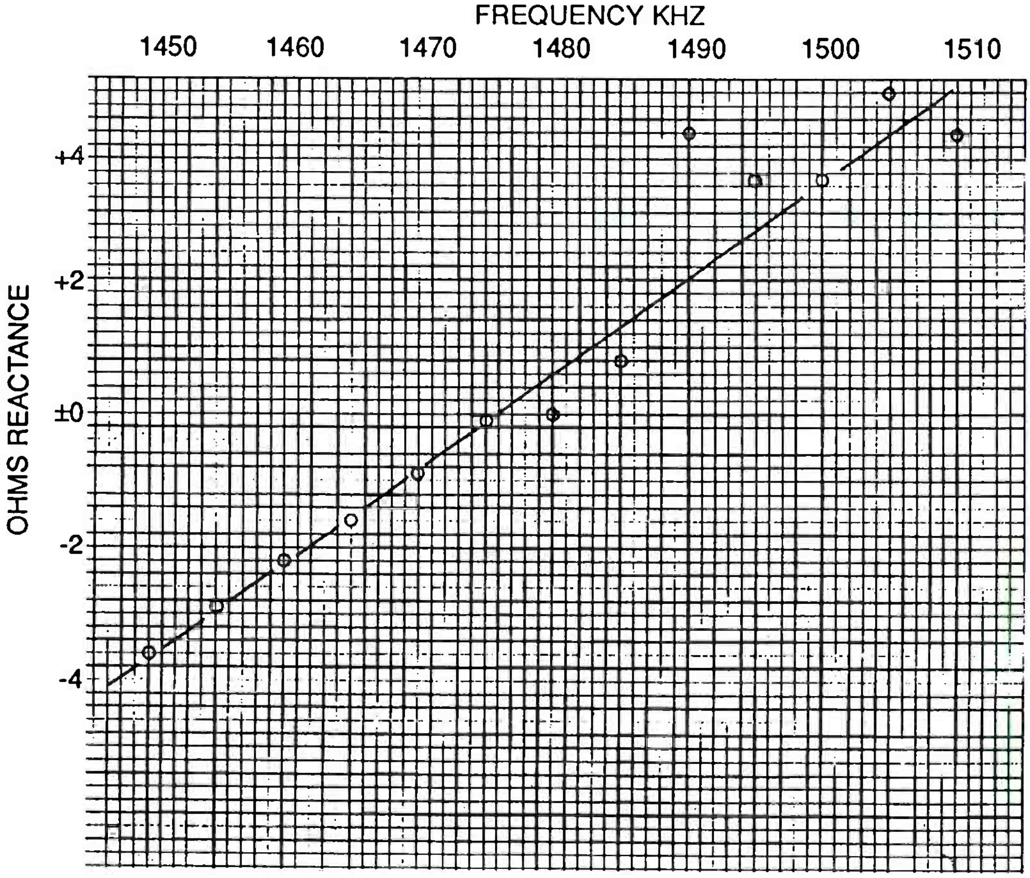


Figure 4-12A

graph of the base reactance of the radiator used for the non-directional proof measurements



4.06 Making the Non-Directional Proof-of-Performance Measurements

The collecting of measurement data for an antenna proof-of-performance is a mammoth, time consuming, expensive proposition. Therefore, be as certain as possible that everything is in order before you begin. Double check as you move along on this task.

The field intensity meter being used should carry a current calibration seal - within the last 18 months. If more than one field intensity meter is used, they should all be checked for substantial agreement. Take the meters to a point out away from the antenna where the field intensity is between 10 and 100 mV/m. Standing in the same spot, one at a time, measure the radiated field. Do not be calibrating one meter while taking a measurement with another. You might very well end up reading signal radiated by the oscillator of the meter being calibrated! All meters should agree to within 2 percent. Discrepancies must be investigated before starting measurements. It's not a bad idea to carry out this same exercise each morning before setting out to make measurements.

Check the RF ammeter that you are using to measure the current of the #2 tower. Try another meter from one of the other towers. They should agree. Our measured data can be meaningless if the measured power in the non-D tower is in error.

Section 73.186(a)(1) of the Rules lay out the requirements for making AM field intensity measurements for determining inverse or effective field strength:

- Beginning as near to the antenna as possible, but not less than 5 times the vertical height of the radiator, or in the case of a directional antenna, 10 times the spacing between the farthest elements in the system, measurements shall be made at intervals of approximately 0.2 km out to 3.0 km (1.87 miles) distance.
- From 3.0 km out to a distance of 10 kM (6.2 miles), measurements shall be made at intervals of approximately 1.0 kM (0.62 miles).
- From 10.0 km out to a distance of 25 to 34 kM (15.5 miles to 20.0 miles)), measurements shall be made at intervals of approximately 3.0 kM (1.87 miles).
- Additional measurements shall be made, if needed, beyond 34 kM (20 miles).
- Where the antenna is rurally located, up to 18 measurements on each radial shall be made.
- Where the antenna is located in a city, where unobstructed measurements are difficult to make, measurements shall be meade on each radial at as many unobstructed locations as possible, even though intervals are considerably less than stated above, particularly within 3.0 kM of the antenna.
- In cases where it is not possible to obtain accurate measurements at the closer distances (even out to 8 or 10 kM due to the character of the intervening terrain), the measurements at greater distances shall be made at closer intervals.

There are 16 radials to be measured in this non-D proof. If we measure every 0.2 kM as required in the Rules, from .3kM out to 3.0 kM, we will make over 200 close-in measurements. For the most part, these must be made on foot. Minimally this will require 48 kM - 30 miles - of walking! The easiest way to accomplish these measurements is to make them using 3 man teams: Two persons to handle the rope distance measuring device described in the next paragraph and a third person to make the measurements, handle the map and record the data. Two or more teams will make the job go much faster. As a matter of fact, for a proof of this size two teams could work on the close-in measurements while a third person could begin the measurements, using an automobile, beyond 3.0 kM - 1.87 miles.

Each team should be equipped with a length of clothes line 100 meters - 328 feet in length. This will become the basic standard of distance for our close -in measurements. A field intensity measurement will be made every two lengths - every 0.2 kM - 200 meters. The team should also be equipped with one of the maps marked off every 0.2 kM, a magnetic compass, a hammer and a supply of wooden stakes.

Close-in measurements will begin beyond the induction field of the radiator - no closer than 5 times the tower height - 750 feet. To keep matters simple, we will start at 0.3 kM. Set up a transit at the center point of the array - midway between towers #2 and #3. Using the line of towers as an azimuth reference for the transit and the rope to determine distance, have the team walk off 300 meters - 3 rope lengths - and drive a stake into the ground. Do each of the 16 radials in this same manner.

Before beginning, place a vehicle out near the end of the radial on which you are about to make close-in measurements. This will save the team from having to walk back to the transmitter site!

After making sure the antenna input power is as close to 500 watts as practical - 3.82 amperes - we are ready to begin the non-D proof. The first measurement will be at the stake marking 0.3 kM. The two persons manning the rope - with the aid of the map and the compass to keep on azimuth - should pull off two rope lengths and drive another stake. Take note of the compass bearing while facing away from the array. The direction will be referenced magnetic north - not true north - but it can be used to help keep you on course for the close-in measurements. Also, you will come near to or cross landmarks. Use them to note and/or correct your direction as necessary.

The meter person follows behind and makes and records the data, noting the point number, both on the log and on the map, azimuth, distance, date, time, field intensity and any physical land marks that might enable one to easily identify the point for remeasurement during the DA proof. Figure 4-14 is a typical field log used for non-D proof measurements. The log should indicate the radial and the point number along with the date, time and measured field intensity. Where the distance is easily noted from the concentric lines around the transmitter site, note it on the log. Where the measuring point is between concentric lines, or in the case of the farther out measurements, leave the distance column blank. Distances can be measured later using the map scale. The important thing is to make sure you are accurate in noting the location of the measuring point on the map.

Leave the stakes in place beyond this point. It will be necessary to remeasure these points during the directional proof. Describe the measuring point on the field log where you can reference it to a landmark. Leaving the stakes behind is no guarantee that they will be there when it's time to remeasure during the DA proof.

If you are unable to make the measurement right on the 0.2 kM interval due to the topography - i.e. a lake, a ravine, etc. - make a measurement on either side of the obstruction. The important thing is to accurately mark the location of the measuring point on the map. When measurements are complete, the distance from the center of the array to the measuring point can be determined with the map scale.

A point where the radial crosses a road is a good location for making a measurement. It is also a good place to double check distance and azimuth. Make corrections if necessary.

Global Positioning Satellites (GPS) are being extensively used by surveyors and navigators to determine exact positioning. This technology is relatively inexpensive. Receivers are now on the market for less than $200. There's no reason why it could not be used to good advantage for making close in antenna proof of performance measurements.

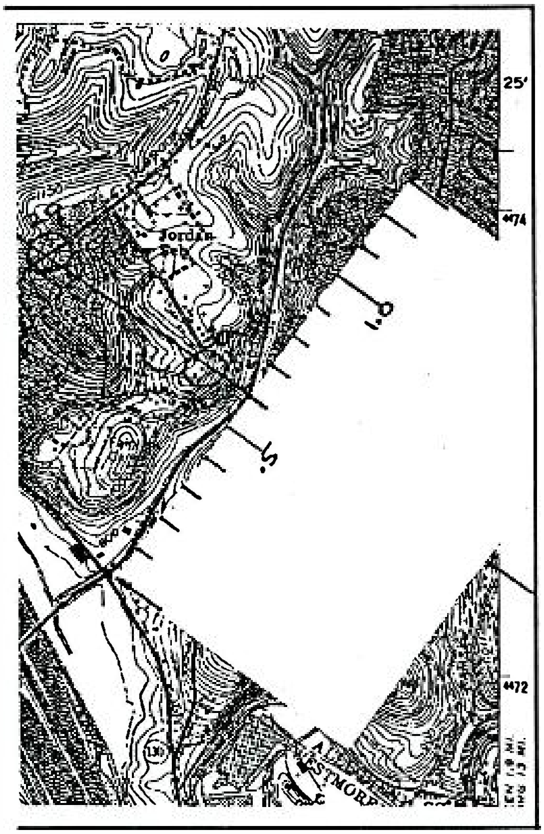
The task of making close-in field strength measurements is certainly simplified and less prone to error by using this technology. In addition, any guess work in returning to the same point to make the DA measurement would be eliminated.

Where measurements must be made across a lake or river - or worse yet, where the radial runs down the center of the river for several miles - it would seem that a GPS receiver would be a must! Prior to the availability of this technology, it was necessary for one to do a lot of guess work and approximate positioning using shore based landmarks as a reference while taking measurements from a boat.

Where the close-in measurements go through a populated area, a vehicle can be used. For all of the measurements beyond 2.87 kM, 2 miles, we will use a vehicle. Take a business card and turn it over to the unprinted side. Using the map scale, mark off tenths of a mile on it. You should be able to get 1.2 or 1.3 miles on it. Use the scale on the card and the car's odometer to determine distance from a land mark (i.e. an intersection) to a measuring point where the radial crosses a road.

Figure 4-13

using the map scale, mark mileage on a business card, use it in conjunction with the vehicle odometer to determine location



Measuring points should be free from overhead wires. Also, measuring points in close proximity to steel light poles or other metallic structures should be avoided. This is sometimes easier said than done when making measurements in densely populated areas. After the field intensity meter has been calibrated, turn it 360 degrees. The indicated field strength should drop to at least one tenth the maximum indicated value at minimum. A poorly defined null off the side of the meter's loop antenna more than likely indicates re-radiation from a nearby object. Measuring points that exhibit this problem should be avoided.

Try to make more measurements than necessary. On most radials you will find a point or two that is way off the curve on either the high or low side. If you have made enough measurements you can toss out those that obviously are influenced by external circumstances.

Following the guidelines of Section 73.186, we will make a minimum of 7 or 8 measurements on each radial between 3.0kM (1.87 miles) and 10 kM (6.2 miles). These should be made at intervals of approximately 0.5 to 0.75 miles.

From 10 kM - 6.2 miles - to 34 kM - 20 miles - we will make another 7 or 8 measurements. These should be made at intervals of approximately 2.0 miles. The exact point on the radial where the measurements are made must be accurately marked and numbered on the map for later identification. This is of the utmost importance as distance from the array will be determined using this data and the map scale.

Take a road map or atlas with you in addition to the topographic maps. When trying to find your way back to the transmitter site, or to the end of another radial to begin measuring backwards toward the site, the topo maps, as detailed as they are, leave something to be desired. As a matter of fact, they are too detailed for over the road driving!

It's not a bad idea to draw the radials on the road map for navigation purposes. Back tracking your measuring path - even though you thought it was a straight line, isn't always the shortest and quickest way back!

Figure 4-14 is the format of a typical field log used for recording measurement data. The point number should correspond to the marked number on the map. Where you know the distance - as is the case for the close-in measurements - record it in miles or kilometers in the appropriate column. For the farther out measurements leave the distance column blank. You will later determine it using the map scale. Date and time are a necessity. To avoid the possibility of inadvertently measuring a sky wave signal, do not begin making measurements until 2 hours after sunrise. Quit 2 hours before sunset.

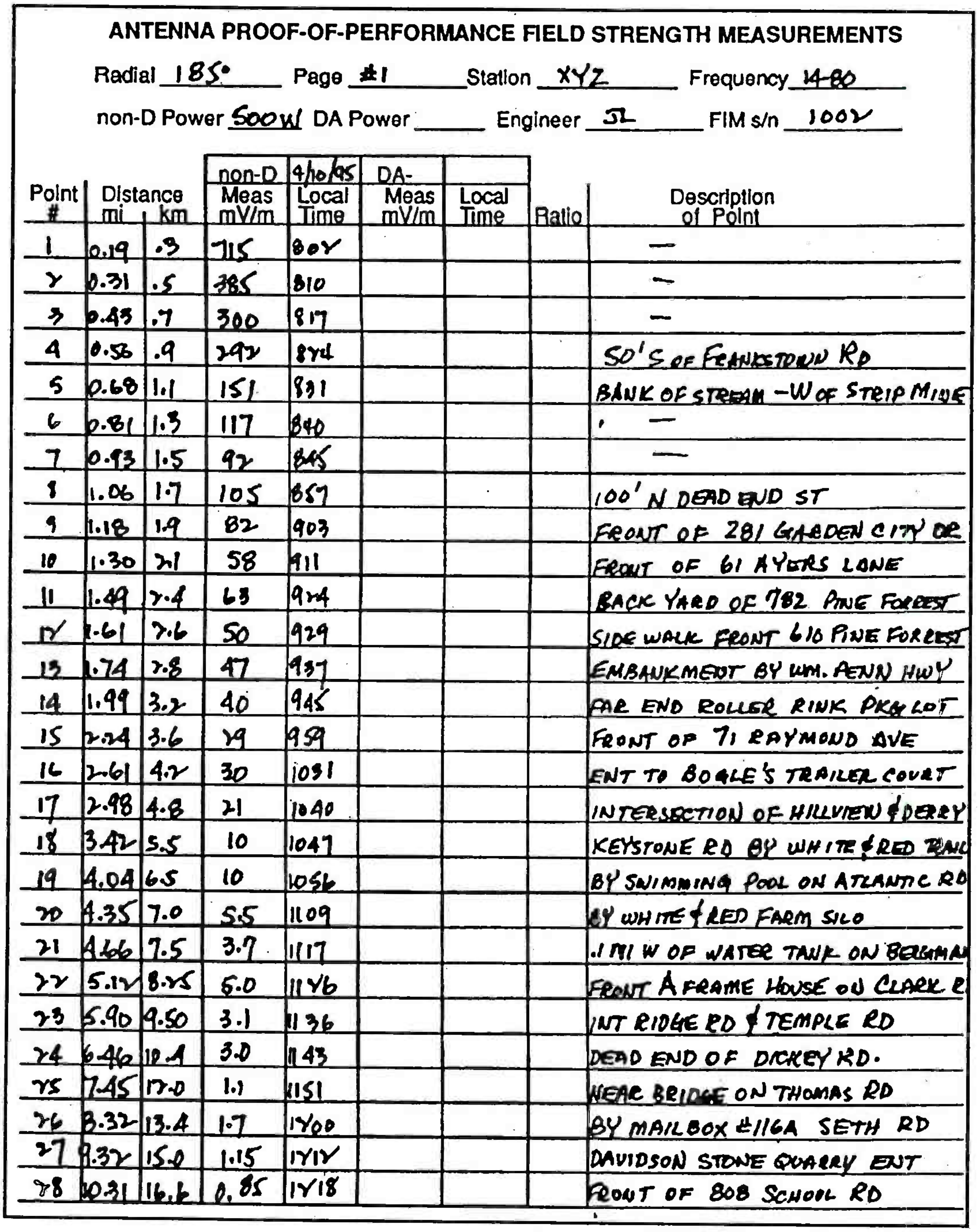


Figure 4-14A

field log format for recording antenna proof-of-performance measurements

Non-D measurements recorded are those for the 185° radial

they will be analyzed in the next section

ANTENNA PROOF-OF-PERFORMANCE FIELD STRENGTH MEASUREMENTS

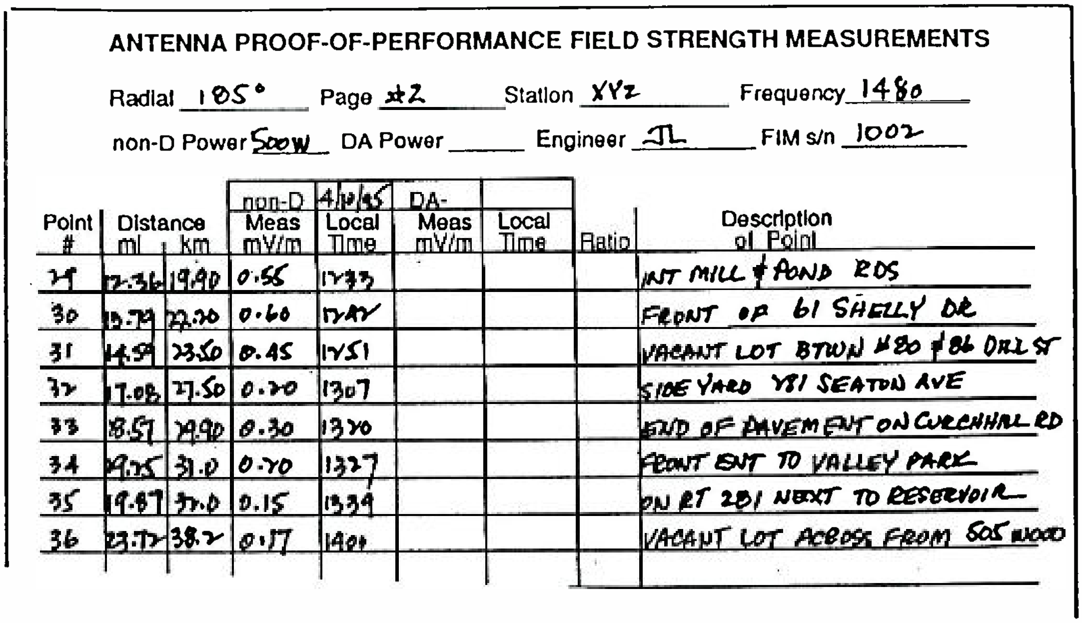
Radial 185° Page #1 Station XYZ Frequency 1480

non-D Power 500W DA Power ______ Engineer SL FIM s/n 1002

Point #	Distance mi	Distance km	non-D Meas mV/m	4/10/95 Local Time	DA- Meas mV/m	Local Time	Ratio	Description of Point
1	0.19	.3	715	802				—
2	0.31	.5	385	810				—
3	0.43	.7	300	817				—
4	0.56	.9	292	824				50' S OF FRANKSTOWN RD
5	0.68	1.1	151	831				BANK OF STREAM - W OF STRIP MINE
6	0.81	1.3	117	840				—
7	0.93	1.5	92	845				—
8	1.06	1.7	105	857				100' N DEAD END ST
9	1.18	1.9	82	903				FRONT OF 281 GARDEN CITY DR
10	1.30	2.1	58	911				FRONT OF 61 AYERS LANE
11	1.49	2.4	63	924				BACK YARD OF 782 PINE FORREST
12	1.61	2.6	50	929				SIDE WALK FRONT 610 PINE FORREST
13	1.74	2.8	47	937				EMBANKMENT BY WM. PENN HWY
14	1.99	3.2	40	945				FAR END ROLLER RINK PKG LOT
15	2.24	3.6	29	959				FRONT OF 71 RAYMOND AVE
16	2.61	4.2	30	1031				ENT TO BOGLE'S TRAILER COURT
17	2.98	4.8	21	1040				INTERSECTION OF HILLVIEW & DERRY
18	3.42	5.5	10	1047				KEYSTONE RD BY WHITE & RED TANK
19	4.04	6.5	10	1056				BY SWIMMING POOL ON ATLANTIC RD
20	4.35	7.0	5.5	1109				BY WHITE & RED FARM SILO
21	4.66	7.5	3.7	1117				.1 MI W OF WATER TANK ON BERGMAN
22	5.12	8.25	6.0	1126				FRONT A FRAME HOUSE ON CLARK
23	5.90	9.50	3.1	1136				INT RIDGE RD & TEMPLE RD
24	6.46	10.4	3.0	1143				DEAD END OF DICKEY RD.
25	7.45	12.0	1.1	1151				NEAR BRIDGE ON THOMAS RD
26	8.32	13.4	1.7	1200				BY MAILBOX #116A SETH RD
27	9.32	15.0	1.15	1212				DAVIDSON STONE QUARRY ENT
28	10.31	16.6	0.85	1218				FRONT OF 808 SCHOOL RD

Figure 4-14B

second page of the 185° field log



ANTENNA PROOF-OF-PERFORMANCE FIELD STRENGTH MEASUREMENTS

Radial 185° Page #2 Station XYZ Frequency 1480

non-D Power 500W DA Power _____ Engineer JL FIM s/n 1002

Point #	Distance mi	Distance km	non-D Meas mV/m	4/10/95 Local Time	DA-Meas mV/m	Local Time	Ratio	Description of Point
29	12.36	19.90	0.55	1233				INT MILL & POND RDS
30	13.79	22.20	0.60	1242				FRONT OF 61 SHELLY DR
31	14.59	23.50	0.45	1251				VACANT LOT BTWN #80 & 86 DALE ST
32	17.08	27.50	0.20	1307				SIDE YARD 281 SEATON AVE
33	18.57	29.90	0.30	1320				END OF PAVEMENT ON CHURCHHILL RD
34	19.25	31.0	0.20	1327				FRONT ENT TO VALLEY PARK
35	19.87	32.0	0.15	1339				ON RT 281 NEXT TO RESERVOIR
36	23.72	38.2	0.17	1401				VACANT LOT ACROSS FROM 505 WOOD

Describe each measuring point. This will aid you in going back and remeasuring the directional pattern. Also, a few years down the road it might be necessary to do a partial proof-of-performance on the DA system. You will then be comparing those measurements to the data collected during this original proof. A description of measuring points as well as the availability of the original copies of the topo maps will be worth their weight in gold!

Each morning, before going out into the field, check the transmitter operating parameters (plate/collector voltage and current) and the antenna base current. A component failure or change in value in the LTU network caused by an over night electrical storm, or other occurrence, could render a day of collecting measurement data worthless.

While making the non-D proof, look for a suitable monitor point on the radials where such a point must be established. It should be no closer than 1.62 kM (1 mile) and no farther than 6.48 kM (4 miles) from the array. The monitor point should be at a location that is likely to remain usable for a long period of time. Cemeteries, golf courses and parks are likely candidates. The point must be accessible all year around. It should be free of overhead power and telephone lines. Periodic measurement of these points is one of the ways we will determine the long term stability of the array.

The closer the monitor point is the center of the array the better. In climates where the ground freezes during the winter months, changes in ground conductivity between summer and winter can cause large seasonal variations in measured field strength. The percentage of change in measured field at a point only 1 mile from the array will be less than that which is apt to occur 4 miles distant.

The idea of a monitoring point is to establish a system where we can sample field strength at one point on a radial and relate it to inverse field strength on that azimuth. For example: After the measurements are analyzed, on a certain azimuth we determine that the inverse field strength is 75 mV/m. At a particular point on this radial we actually measured 7.5 mV/m. It's reasonable to assume that if the field strength at this point rises by 33% to 10 mV/m, the inverse field strength on this azimuth will also rise by 33% to 100 mV/m. That's alright for a basic assumption but is not always the case. Without a better method, monitor point maximums are based on this premise. More on monitor points in the next chapter.

Figure 4-15

each measuring point should be identified and numbered on the topographic map

make sure the map number and the field log number agree

4.07 Analyzing the Non-Directional Proof-of-Performance Measurements

We should now have 30 or more field intensity measurements made on each radial. All of the antenna pattern calculations and the allocation/interference assumptions were based on inverse field strength at one kM. The task is now to translate this measured data that we have collected on each radial into inverse field strength at one kilometer. In addition, the process we will use determines ground conductivities along the 34 kM path from the center of the array to the end of the radial.

The distance from the center of the array to each measuring point must be determined. On the 1:24,000 scale maps, 4.2 cm on the map = one km on the ground. Again, use care in determining distance. Where the radial crosses from one map to the next, mark the distance from the center of the array to the end of the radial on one map. Where you pick it up on the next, again mark distance. Using the ruler, determine distance to the next measuring point from the edge of the map and then add the distance to the center of the array. Enter the distance in km on the field log.

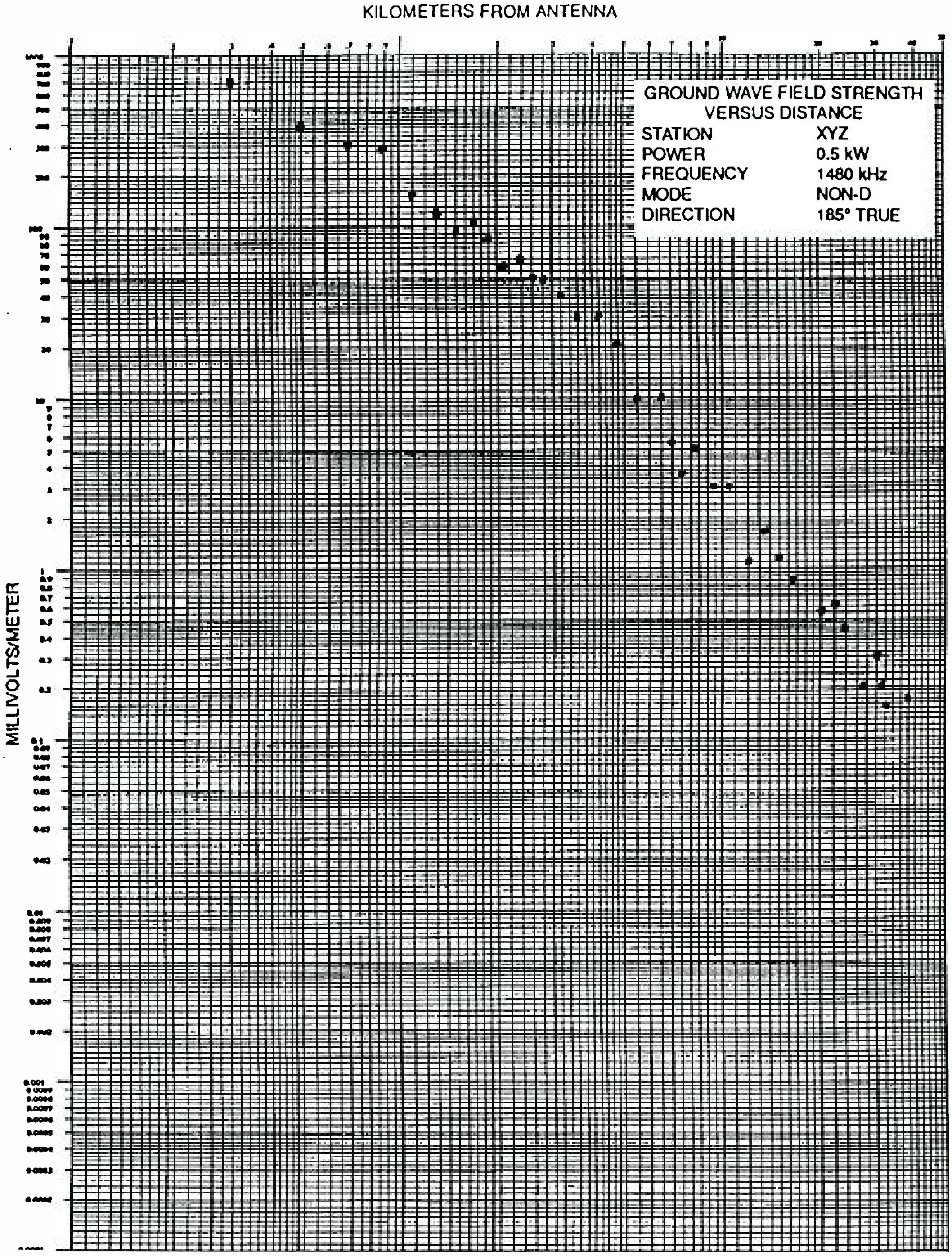


Figure 4-16

Non-directional field strength data taken from the field log for the 185° radial shown in Figure 4-14 plotted on Ground wave Field Strength vs Distance log-log paper

The next step is to plot each measurement on log-log graph paper. This special paper is the same paper on which the graphs in Section 73.184 of the FCC Rules are drawn. It is available from International Transcription Service, 2100 M Street NW, #140, Washington, DC 20037 - telephone 202-857-3800.

Using a separate sheet of paper for each radial, plot each measurement taking care to observe distance in km noted on the top of the paper and absolute values of field strength using the scale on the left side of the paper. Figure 4-16 shows the plotted data that was tabulated in Figure 4-14 .

Now take the graph for the appropriate frequency from Section 73.184 of the Rules and place it on a light table.Graph #18, covering 1480 kHz, is shown in Figure 1-22 On page 24. Place your plotted material on top of it. Keep the vertical edges aligned while shifting the paper with your plotted measurements vertically. We are looking for the best fit of our plotted measured data to one or more of the conductivity curves. Rarely, if ever, is all of the data a perfect fit. Some scattering of data will occur due to external influences other than ground conductivity being present. This is usually more noticeable when values of inverse fields are very low.

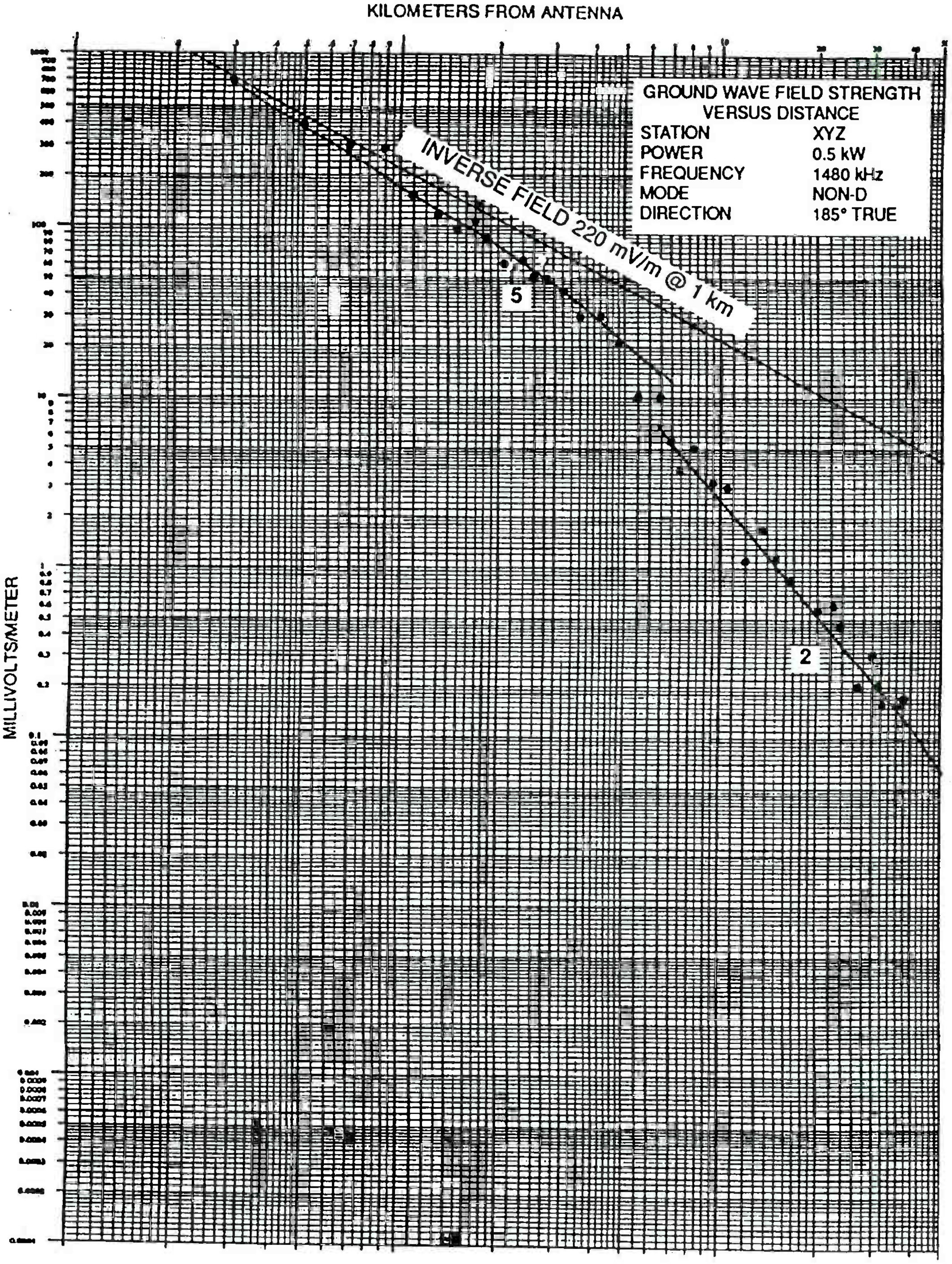


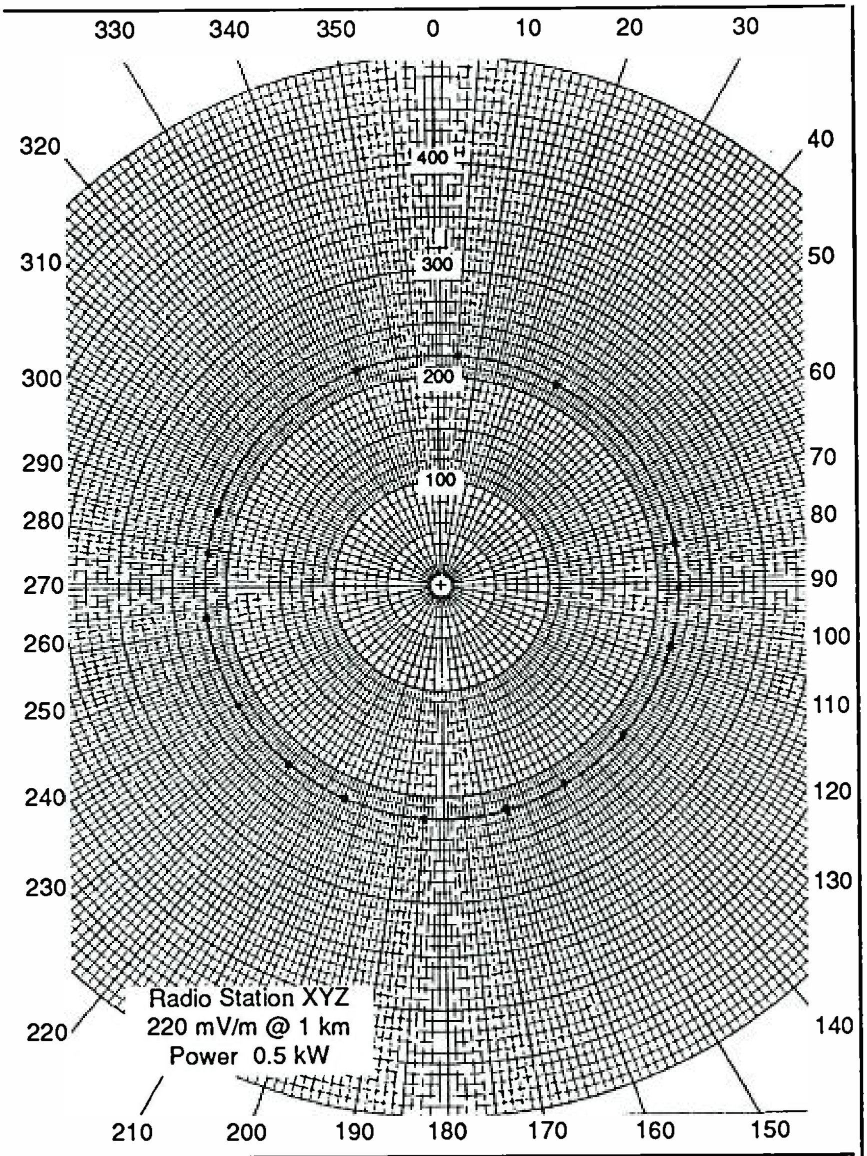
Figure 4-17

ground conductivity curves and inverse distace line drawn in for the data plotted in Figure 4-16

On the plotted data for our 185 degree radial shown in Figure 4-18, the curve for a ground conductivity of 5 out to about 5.0 kM is the best fit. The curve for a conductivity of 2 from this point to 34 kM is the best fit. These curves are traced onto our plotted data and appropriately marked. Without moving the paper the straight inverse distance line is also traced in. The point at which this line crosses the 1 kM distance line is the value of inverse field at 1 km on this radial. The value in mV/m is read on the scale at the left edge of the paper. On this particular radial, for the data shown, the line crosses the 1 km point (read on the top) at 220 mV/m (read on the left side) - and the 1 mile point at 136 mV/m.

Figure 4-18

non-directional proof measurements plotted on polar coordinate graph paper



There can be 3 or 4 or more values of conductivity along a 34 kM path. When this occurs, it can be difficult to delineate between changes in ground conductivity and scattering of the measured data.

This same procedure is repeated for each of the other measured radials. Not all non-directional patterns are circular. The influence of other towers not completely detuned, or other nearby re-radiating structures, can distort a circular pattern. In an in-line array, the influence of a larger ground system along the line of towers can also cause the pattern to be other than circular. However, in our imaginary radio station XYZ, the inverse fields on all 16 measured radials have been analyzed to be 220 mV/m for 500 watts of power. The circular pattern is shown in Figure 4-18. This information is necessary when we attempt to determine the directional inverse field strengths.

Once all of the non-D measurements are complete, the temporary arrangements that were made to feed tower #2 can be dismantled. The temporary detuning network for tower #3 can be disassembled. The tower can be re-connected to the LTU. The entire feeder system should be once again connected for directional operation.

Chapter Five

Producing and Measuring the Directional Antenna Pattern

5.01 Introduction to Directional Antenna Adjustment

Up to this point, we have just been laying the ground work for our final objective. If the foundation as now built is on solid ground, we should have little trouble accomplishing our ultimate goal of producing the radiation pattern as set forth in the application for a construction permit. Of equal importance is having the pattern stay put over a long period of time.

A word to the wise: The non-directional and directional proofs-of-performances measurements must be made under the same seasonal conditions. In other words, if you make the non-D measurements during August you can not make the directional measurements during February! Ideally, these sets of measurements will be made within a month or two of each other. Ground conductivities, especially in parts of the country where they are low to begin with, will change from summer to winter. Where the ground freezes the change can be radical! You will *never* get the directional measured data to fit the non-D curves.

Our immediate task is to produce the design parameters of phase and current ratio in the various elements of the system. Once we have accomplished that, we will sample radiation at a point or two on some of the radials we have measured on the non-D proof. By ratioing these values of field strength against those measured in the non-D proof, we will get a rough idea of the depth of the minimas and the size of the minor lobe(s) being produced by the array. It will probably be necessary to make some fine adjustments to phase and current ratio - especially on the night pattern - while observing field intensity at these selected points. Once we are reasonably certain that the pattern is in conformance with what was specified in our construction permit, we will make a full directional proof-of-performance. This requires remeasuring the points on the radials that we originally measured in the non-D proof. We will first start with the two tower day pattern. Once it has been adjusted and the proof completed and analyzed, we will then go on to the night pattern.

Before beginning the adjustment procedure, there are some housekeeping chores to which we must attend: The base impedance of each tower should be measured. The other towers must be detuned or floating. The resistance and reactance of each should be similar provided the towers are of similar construction (cross section, height, etc.). With the impedance bridge nulled, have someone go to each guy anchor and pull on the guy wires to vibrate the tower. The impedance should remain constant. Any variation is an indication of something loose or broken. The towers will be subject to movement and vibration under windy conditions. In some climates they might be covered with ice several times a year. Take a hammer and tap on the RF feed from the LTU to the tower. Pull on all of the ground strap connections. If you note variations in base impedance when doing any of these things, you are sure to note instability of the array during wind storms and icing. Now is the time to track down the source of the problem and fix it.

Go back and check to make sure all chain link fences are tied to the ground system at 10 foot intervals. If you find problems, correct them now. If you wait until after the array is adjusted, you might have to go back to ground zero and start the adjustment process from scratch. Worse yet, if you have a fence that has a good connection to ground today, and no connection tomorrow, you will pull your hair out looking for the instability. This type of situation can easily cause a jump of several degrees in phase and several percent in current ratio.

Take all of the RF ammeters - base current meters and common point meter - out of their respective circuits. String them in series with the dummy load and apply enough RF power to have the lowest scale meter deflect about 80% of full scale. It's better to find a bad meter now than later. Base current ratio values will eventually be noted on the station license. While a meter discrepancy will cause no immediate problem if you ever have to replace an erroneous meter you will have a problem. The new meter will be reading correctly and you will have a base current ratio that does not agree with what is listed on the license. This will more than likely mean a partial directional antenna proof-of-performance to show the array to be in tune before the Commission will correct the license.

Check all RF connections - straps and tubing - in each of the LTUs and inside the phasor cabinet. They should be tight. There should be a lock washer under each nut. Check the operation of all pattern changing RF contactors. The shorting fingers should seat properly in the finger contacts.

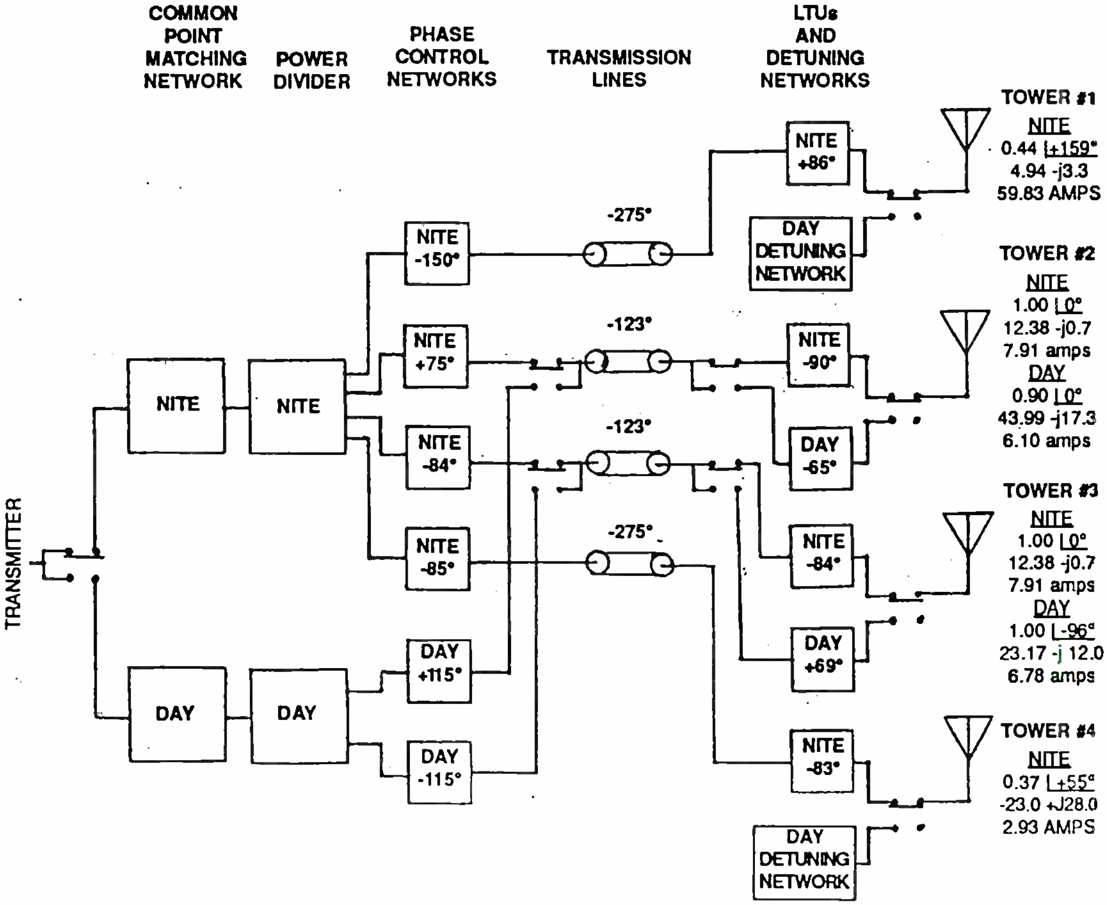
5.02 Initial Set Up of the System

Figure 5-1 indicates the phase shift required through each branch of the feeder in the directional antenna system. The first task we will tackle is to set up the day pattern LTU networks for the for the proper match and phase shift between the transmission line and driving point impedance of each tower. Then we will adjust the phase control networks, inside the phasor cabinet(s), for 50 ohms in and out with the phase shift called for in the feeder design information.

Life is made a lot easier if we first calculate the values of reactance needed in each of the three legs of the networks - series input, series output and shunt - before actually moving taps on coils!

Figure 5-1

block diagram of the DA feeder system showing the phase shifts through the various networks for day and nite operation



Back in Chapter #1 - Section 1.12 and 1.13 - we discussed T-networks. It's now time to revisit them: When the desired phase shift through a T-network is ±90 degrees the reactance of each leg of the network is equal. For a ±90 degree phase shift the formula (#12) is:

$$\mathbf{X = \sqrt{Rin\ Rout}}$$

where X is the reactance of each leg of the network
R1or Rin is the characteristic impedance of the transmission line
R2 or Rout is the resistance part of the driving point impedance.

If the phase shift is other then ±90 degrees the formula (#13) is:

$$\mathbf{X1 = -\frac{\sqrt{Rin\ Rout}\,[1-(Rin/Rout)\,(\cos\beta)]}{\sin\beta}}$$

$$\mathbf{X2 = -\frac{\sqrt{Rin\ Rout}\,[1-(Rout/Rin)\,(\cos\beta)]}{\sin\beta}}$$

$$\mathbf{X3 = +\frac{\sqrt{Rin\ Rout}}{\sin\beta}}$$

where: X1, X2 and X3 are the input, output and shunt reactances respectively
R1or Rin is the characteristic impedance of the transmission line
R2 or Rout is the resistance part of the driving point impedance.
β is the desired phase shift through the network

For the #2 day pattern LTU where Rin = 50 ohms, Rout = 43.99 -j17.3 and β = -65°:

$$X1 = -\frac{\sqrt{50(43.99)}\,[1-(50/43.99)(.423)]}{-.906} =$$

$$X1 = -\frac{\sqrt{2199.5}\,[1-(1.137)(.423)]}{-.906} = \frac{46.9\,[1-(.481)]}{-.906} =$$

$$X1 = -\frac{46.9\,(.519)}{-.906} = \frac{24.34}{-.906} = 26.87 = X1$$

$$X2 = -\frac{\sqrt{50(43.99)}\,[1-(43.99/50)(.423)]}{-.906} =$$

$$X2 = -\frac{\sqrt{2199.5}\,[1-(.880)(.423)]}{-.906} = \frac{46.9\,[1-(.372)]}{-.906} =$$

$$X2 = -\frac{46.9\,[.628]}{-.906} = \frac{29.45}{-.906} = 32.5 = X2$$

Now, the driving point impedance of this tower already consists of 17.3 ohms of capacitive reactance. It must be cancelled by adding 17.3 ohms of inductance to the output leg of the T-network. Therefore X2 becomes (32.5 + 17.3) 49.8 ohms.

$$X3 = \frac{\sqrt{50\,(43.99)}}{-.906} = \frac{46.9}{-.906} = -51.77 = X3$$

Performing the same arithmetic for the #2 phase control network where both the input and output resistances are 50 ohms the formulae for the T-network simplify to:

(#17) $$X1 = X2 = -\frac{R\,[1-(\cos\beta)]}{\sin\beta}$$

$$X3 = \frac{R}{\sin\beta}$$

where: R = input and output resistance
β = desired phase shift of the network

$$X1 = X2 = -\frac{50\,[1-(-.423)]}{-.906} = \frac{50(1.423)}{-.906} = \frac{71.75}{-.906} = 78.53 \text{ ohms} = X1 = X2$$

$$X3 = \frac{50}{-.906} = -55.18 \text{ ohms} = X3$$

Using the same formulae, the calculations are made for the tower #3 LTU day T-network and the #3 day phase control network. Table 5-1 shows all of the calculated values for the day pattern LTU and phase control networks.

Component Reactances for the Day Pattern LTUs and Phase Control T-networks
(all Input Z = 50 ±j0)

	Input Leg	Output Leg	Shunt Leg	Phase	Out Z
#2 phase control network	- 78.53 Ω	- 78.53 Ω	+ 55.18Ω	+115°	50 ±j0
#2 line terminating unit	+26.87 Ω	+49.80 Ω	- 51.77 Ω	- 65°	43.99 -j17.3
#3 phase control network	+78.53 Ω	+ 78.53Ω	- 55.18 Ω	-115°	50 ±j0
#3 line terminating unit	- 8.29 Ω	- 18.36 Ω	+ 36.44 Ω	+69°	23.17 -j12.03

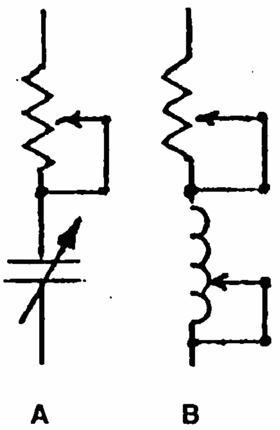
Table 5-1

We next set up the impedance bridge, signal generator and null detector at the base of tower #2. With one end grounded and the other end open, adjust 2L10 for 26.87 ohms at 1480 kHz. Next comes 2L11. Again, with one end open and the other grounded, adjust it for 49.8 ohms. Disconnect the top end of 2L12 from the series legs of the network. By moving the tap on the inductor, adjust the combination of 2L12 and 2C6 for 51.77 ohms at the operating frequency.

Figure 5-2

variable impedance dummy load used to simulate driving point impedance of the radiator

use A for R -j
use B for R +j



It's now time to raid the junk box! We need components to make up a variable impedance dummy load to simulate the driving point impedance of the tower. We will only subject these components to the power of the signal generator so they need not be large. A 100 ohm 2 watt pot will be fine. It can be carbon or wire wound. A large value air variable capacitor is next on our shopping list. (Hosfelt Electronics part #15-797 - three section - 570 pf per section). An assortment of fixed value capacitors will also be needed to parallel with the variable. Last, but not least, in this application, we will need a 5 or 10 uh air wound inductor physically large enough to get an allegator clip tap on it. If your junk box is well stocked, a roller inductor of 5uh to 10uh total inductance will do fine.

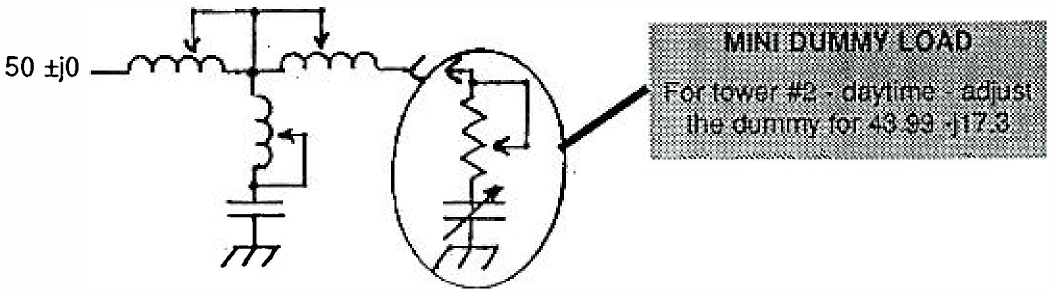
In the day pattern the reactive part of the driving point impedance of both radiators is capacitive. The dummy load should be arranged as shown in Figure 5-2A. Where the driving point impedance consists of inductive reactance, as it will in 3 of the radiators when energized to produce the night pattern, the components should be arranged as shown in Figure 5-2B.

The driving point impedance of tower #2 when energized for day pattern operation is 43.99 -j17.3. At 1480 kHz we will need approximately .006 uf of capacity for 17 ohms reactance. It will be necessary to parallel a .005 uf capacitor with our (3 X 570 pf) variable. With the impedance bridge connected across the mini-dummy set the R dial to approximately 44 ohms and the X dial to 25.6 ohms. The direct reading on the X dial is X/f mHz. Therefore, the actual indication on the reactance dial should be 17.3 x 1.48 or approximately 25.6 ohms to indicate a value 17.3 ohms at 1480 kHz. Alternately adjust the pot and the capacitor to obtain a null on the detector.

Connect the dummy load as now adjusted from the output of the LTU network to ground. Connect the impedance bridge to look into the network from the transmission line end. You should read very close to 50 ±j0. If you are far off go back and recalculate your values of inductance and capacitance needed in the network. Also, double check the mini-dummy to make sure it is set to simulate the correct value of driving point impedance. Do not indiscriminately start moving taps on the inductors. While you might effect a match you will change the phase shift through the network. This could prevent you from bringing the array into tune with the design parameters of current ratio and phase.

Figure 5-3

connection of the mini-dummy to the T-network in the LTU to simulate the driving point impedance of the radiator



Once this step is accomplished, disconnect the mini-dummy. Reconnect the tower and the feed line to the LTU network. Perform the same procedure for tower #3, first setting the individual reactances, then hanging the readjusted mini-dummy on the output side of the network and measuring the impedance at its input.

Once the LTU components have been adjusted to the correct reactance values, move on to the day pattern phase control networks in the phasor cabinet. Take a good look at the two ganged inductors - 2L7 and 2L8 - while having someone rotate the control shaft. Make sure both increase in value when the phase adjustment control is turned in one direction and decrease as it is turned in the other direction. It is possible through a construction error to have the inductors connected so that one increases in value as the other decreases while the shaft is turned in the same direction. When this happens, you will get nowhere fast while trying to adust operating parameters!

Open the #2 day pattern phase control network at 2C4 and 2C5. Connect the bridge across the 2C4 - 2L7 circuit putting the ground connection of the bridge at the junction of 2L7 and 2L9. We are now about to adjust the combination of 2C4 and 2L7 to the value shown in Table 5-1. Set the bridge for R0 -j78.5. Remember to actually set the X dial to approximately 116 ohms as you must apply the correction factor of X/fmHz. Rotate the adjustment shaft that drives the coils until a null is obtained. Now check value of reactance for the combination of 2L8 and 2C5, again keeping the bridge ground connection at the junction of 2L8 and 2L9. Without any further adjustment it should read close to 78.5 ohms of capacitive reactance.

With the ends of the network still open at 2C4 and 2C5, move the ground connection of the bridge to ground. Place the hot lead at the junction of 2L7, 2L8 and 2L9. Set the bridge of R0 +j55. The X dial setting for 1480 kHz should be 81.4 (55 X 1.48). Adjust the tap on this inductor for a null on the bridge.

Connect the mini-dummy to the bridge. Set it up for 50 ±j0. Hang it across the output of the network. Read the impedance at the input to the network. It should read close to 50 ±j0. Connect the network back into the feeder circuit. Repeat the procedure for the #3 day pattern phase control network using the values of XL and XC as previously determined..

With the #3 day pattern power adjust control set the tap on L11 about midway. This will need some cut and try later on.

Make sure all of the feeder system networks are reconnected, all towers connected and all RF j-plugs reinserted. The system should be switched to the day pattern. Open J1. Disconnect L9 from L11. Measure the impedance at the top of L11 with both day pattern phase control networks (#2 and #3) connected. It should be in the neighborhood of 25 ohms resistance with some inductive reactance. Using the formulae for 90 degree T-networks, adjust L8 and the combination of L10 and C2 for 35 ohms ($\sqrt{50 \times 25}$). Adjust L9 for 35 ohms reactance less whatever reactance was measured looking into L11. Reconnect L9 to L11.

Now, measure the impedance of the input to the feeder system on the antenna side of J1. Adjust L8 and L10 for 50 ±j0. L10 will have the most effect on resistance. L8 will effect reactance. When complete, reinstall J1.

5.03 Adjustment of the Energized Feeder System

We are now ready to apply power to the system. Preliminary adjustment must be made during the experimental period - between midnight and sunrise local time - as provided for in Section 73.1610 of the FCC Rules. This is to minimize the chance of causing harmful interference to other operating facilities. Once the array has been brought into substantial adjustment, operation during day time hours is permitted to accomplish final adjustment for the purpose of making the directional proof of performance measurements.

Before proceeding: Check to make sure the antenna monitor is configured to use the #2 tower in both the day and night pattern configuration as the reference tower. If the monitor was ordered this way it will be configured in this fashion. If it is a used monitor check the instruction book for details of how to configure it in this manner.

Turn the power output on the transmitter down to minimum. A couple of hundred watts will be sufficient. Put the antenna monitor in the DAY monitoring configuration. Turn the loop current pots all the way down. Select the #2 tower for observation - DAY REFERENCE.

The original design parameters for the antenna system may appear wildly different than the 1.0 ∠-96° and 0.9 ∠0° shown. The designer might very well have used the center point of the array as a reference point. These theoretical parameters would appear as 1.0 ∠-48° and 0.9 ∠+48°. Our antenna monitor will reference the phase angle and current of the #3 tower to the #2 tower. The #2 tower will always read 0° phase on the monitor. By adding -48° to both phase angles we come up with 1.0 ∠-96° and 0.9 ∠0° without really changing anything!

In addition, the current ratio might be expressed differently: 1.11 ∠-96° and 1.0 ∠0°. Likewise, both ratios can be divided by 1.11 to reduce the magnitudes to 1.0 and 0.9 respectively. These are the parameters we will read on the monitor and to which we will initially adjust the day pattern.

Now comes the moment of truth! Turn the transmitter ON! Slowly turn the power output control up. The common point RF ammeter should indicate 2 amperes for 200 watts of power. When you reach this level turn the DAY LOOP CURRENT control up. When you reach 90 on the loop current meter on the monitor - stop. If you can't get an indication of 90 with the loop current control turned all the way up, increase the transmitter output power.

At this point perform any necessary calibration procedures on the monitor. Follow the manufacturer's instructions for the antenna monitor in use.

Now, with the #2 tower loop current at 90, press the switch on the monitor to select tower #3. If we lived in a perfect world the monitor would read -96 degrees phase and 100 for loop current. Hopefully it won't be terribly far off. Adjust the #3 power control on the phasor - while juggling back and forth between tower #2 and #3 on the monitor. Adjustment of the #3 power will not only vary the #3 loop current but the #2 loop current as well. When you get close to the right loop current ratio, adjust the #3 phase control as necessary to bring the phase indication to -96°.

By now you have found out that the power and phase controls are not totally independent of each other. The power control will have an effect on phase and vice versa. Not only will the phase control change the load on the power divider but as the phase of the current in the tower is changed, the driving point impedance of both towers will change. Thus, interaction is compounded!

When you have arrived at the design values of phase and current ratio it's time to go back and remeasure the common point impedance. Any adjustment to any operating parameter - current or phase - will be reflected as a change in the input impedance to the system.

If your phasor has a built in operating impedance bridge and L8 and L10 are adjustable from the front panel, you can check the impedance and adjust it back to 50 ±j0 with power applied. If the phasor is as shown in Figure 4-8 you will have to shut the transmitter down, open J1 and remeasure and readjust to 50 ±j0 by moving taps on L8 and L10.

When this is complete, re-energize the system and bring the transmitter power output up to 2700 watts as indicated by 7.35 amperes of common point current.

Power output in a directional system is measured at its input. In order to compensate for losses in the feeder system, the FCC Rules allow for power to be 8% above nominal licensed powers of up to, and including, 5 kilowatts. For powers above 5 kilowatts, the rules call for power input to the directional antenna system to be 5% above nominal licensed power. For our day pattern, licensed for a nominal power of 2500 watts, the actual antenna input power will be 2700 watts.

5.04 Preliminary Check of the Radiation Pattern

Now that the theoretical electrical phase and current ratio is being produced in the day time DA system, we will make a spot check of the radiation pattern. For starters we will make two or three field strength measurements on points previously measured on the 165°, 185° and 205° radials. These are the two minimas and the tip of the minor lobe. See Figure 4-1. On the 165° and the 185° radials, one of these points should be the one you intend to select as a permanent monitor point. If the inverse field along these azimuths are within the limitations of the theoretical pattern more than likely the other seven will fall into place.

Refer to Figure 4-14A and 4-14B on pages 113 and 114: On the 185° radial, we will remeasure pints #14, #15 and #16. For each of these points, divide the DA field strength by the non-D field strength. Add the 3 ratios together and divide the result by 3 as shown in Table 5-2.

The non-D inverse field strength along the 185° radial was determined to be 220 mV/m at 1 km. Multiply 220 by the average ratio. This will give you a rough idea of the DA inverse field in the direction of 185° = 220 X .268 = 58.96 mV/m at 1 km.

A examination of the polar plot of the day time standard pattern, as shown in Figure 4-1, indicates that the inverse field at 185° can not exceed 68 mV/m at one km. The construction permit will also specify this maximum. The idea is to adjust the array so that the actual inverse field is 10 to 15 percent below this value. A monitor point will be established on this radial. The maximum limitation on measured field strength at this point that will be specified in the station license will depend not only on the field strength at this location during the DA proof but also on how far the measured inverse field is below the inverse field indicated in the standard pattern.

185° Radial

Point #	Non-D mV/m	DA mV/m	Ratio
14	40	11.0	.275
15	29	7.6	.262
16	30	8.0	.267
			.804

.804 / 3 = .268 = AVERAGE RATIO

TABLE 5-2

If the inverse field is measured to be 68 mV/m in this direction there would be room for no tolerance on the monitor point maximum specified on the license. It is doubtful that the FCC would license the array if adjusted in this manner. Our sampled value of 58.96 mV/m falls within these guidelines.

The same procedure should now be carried out for the 165° and the 205° radials. The standard pattern indicates a value of 50 mV/m of inverse field at one km for each of these azimuths. The CP specifies a monitor point on the 165° radial. The CP will also specify an inverse field maximum of 50 mV/m in this direction. The average ratio times the non-directional inverse field should fall somewhere between 40 and 45 mV/m. Again, this leaves room for some tolerance on the monitor point measured field before the maximum allowable inverse field is exceeded. The average ratio times the non-directional inverse field on the 205° radial should be below 50 mV/m.

Keep in mind, we are only sampling radiation to make an estimation of inverse field. The actual inverse field will be determined by measuring many more points on these radials. It is possible that once we start measuring farther out on the radial we will find values to be too high and have to come back for more fine adjustment. However, if all three radials appear to be within the ball park we can proceed.

If field strength ratios are too high or way too low some fine adjustment must be made. Bringing the current ratio closer to 1:1 will lower the value of radiated field in the minimas - 165° and 205°. This will also lower the value of radiation in the minor lobe at 185°. Adjusting it from 0.9 toward 0.8 will do the opposite. Moving the phase toward 90 degrees will move the position of the minimas toward one another. This will raise the value of radiation on the 165° and 205° radials but will pinch off the minor lobe and decrease radiation at 185°. With a simple two tower pattern, one can make an adjustment, then drive to the prospective monitor points, measure field strength, then come back and adjust if necessary. A pattern such as this one can usually be brought into adjustment by one person, within a few hours using this method. A larger array, producing a more complex pattern, might take several people equipped with field intensity meters and two-way radios (or cellular telephones), stationed on critical azimuths. This will be discussed in more detail when we adjust the night pattern.

5.05 Measuring the Driving Point Impedances

Up to this point we have been depending on calculated values of driving point impedances. It's not unusual for actual driving point impedances to be somewhat different from those that were calculated. Now that the array is in adjustment - or at least very close to being in adjustment - the actual values of driving point impedances can be measured.

The instrument needed for this measurement is an *operating impedance bridge* (OIB). Before turning the transmitter off, carefully note the indicated loop currents and phase. In addition, read and note the base current in each radiator. Insertion of the bridge in the feed point to the tower(s) is apt to cause a slight shift in phase and/or current ratio.

Now, shut the transmitter down. Open 2J3 - the feed to the base of tower #2. Insert the OIB in the feed to the tower. Turn the transmitter ON. Check the phase and current ratio. If they have shifted adjust them back to where they were before insertion of the bridge.

At this point it is wise to reduce power. The driving point impedance will remain constant no matter what power level is used to energize the array. Only a few watts is needed to drive the null detector instrument in the bridge. High power increases the RF field to which you are exposed while using the bridge and also increases the likelihood of serious injury should you accidentally come into contact with a component in the energized LTU.

Adjust the bridge for a null. The indicated value of R is the driving point resistance of tower #2. Remember, the value of X must be corrected for frequency X as read on the bridge. This divided by the frequency in mHz, will give you the value of the reactive component of the driving point impedance. Turn the transmitter OFF, remove the bridge and reinsert the plug into 2J3.

Turn the transmitter back on. Adjust the phase and current ratio back to the values you originally wrote down. Repeat the procedure for tower #3.

If the measured values of resistance and reactance vary appreciably from what was calculated and to which the LTUs were adjusted, it will be necessary to recalculate the values of the series and shunt reactances, then jump back to Section 5-2. Each of the reactance arms in the LTU T-networks will have to be readjusted to the new values. Some adjustment to phase and current ratio will have to be made when the feeder system is re-energized. The array is then adjusted to the previous phase and current ratio that produced the proper field strengths. Remeasure and readjust the common point impedance to 50 ±j0. Make sure the common point current is correct - in this case 7.35 amperes for 2700 watts. Field strength measurements with transmitter power output very low or high are useless. The three points on each radial in the minimas and on the tip of the minor lobe on the 165°, 185° and 205 degree radials should be remeasured. Field strengths should be close to the previous values. If so, leave well enough alone! If some fine readjustment is needed now is the time to do it.

5.06 Directional Antenna Common Point Impedance Measurements

TABULATION OF COMMON POINT IMPEDANCE DATA
(for day time directional antenna operation)

Frequency kHz	Resistance Ohms	Reactance Ohms
1450	40.0	+15.0
1455	41.0	+14.0
1460	40.0	+13.1
1465	43.1	+11.0
1470	45.0	+7.9
1475	47.0	+4.0
1480	50.0	±0.0
1485	52.9	-4.0
1490	55.9	-6.9
1495	58.9	-10.0
1500	61.8	-12.0
1505	64.0	-11.9
1510	65.0	-9.9

Table 5-3

Power when using a directional antenna system is measured at the common point input to the system. The common point impedance must be measured just as we did the non-directional antenna base impedance. Section 73.54 of the Rules require that resistance and reactance be measured at 5 kHz intervals out to 25 kHz above and below the operating frequency. These measurements will be made looking into the system at J1 with the plug removed. The results of these measurements will be tabulated as shown in Table 5-1 and graphed as shown in Figure 5-3A and 5-3B on the next page. They will become part of the package of data submitted with the non-D and DA proof-of-performance measurements to the Commission.

Figure 5-4A

graph of the common point resistance for the day pattern

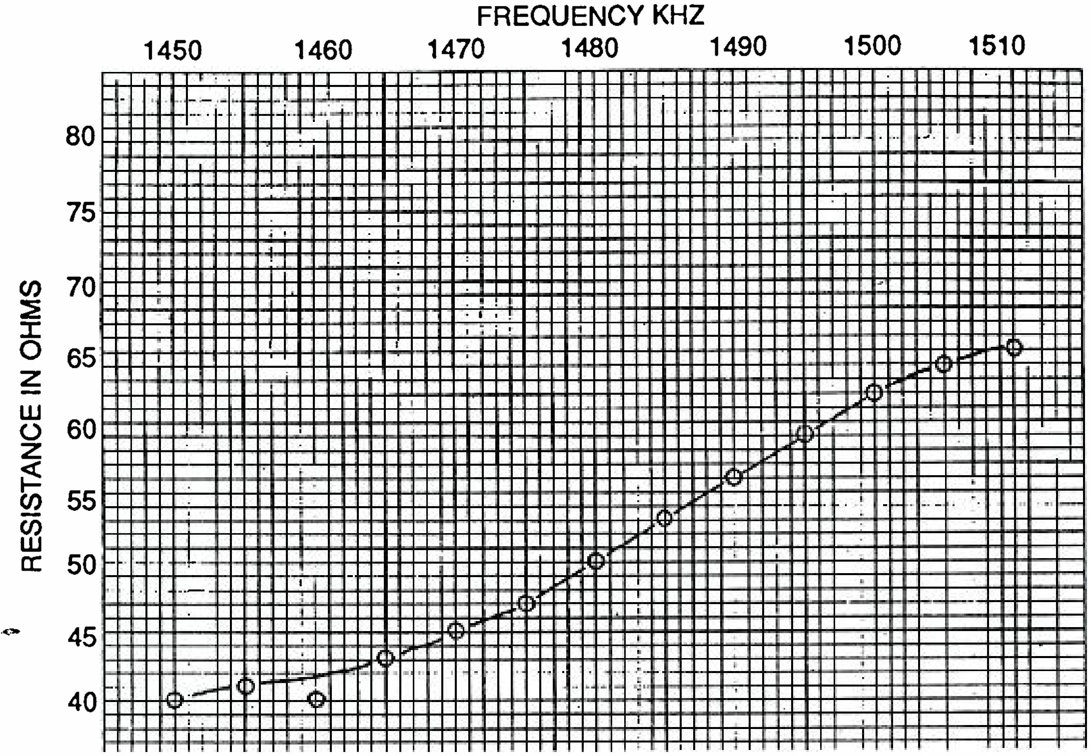
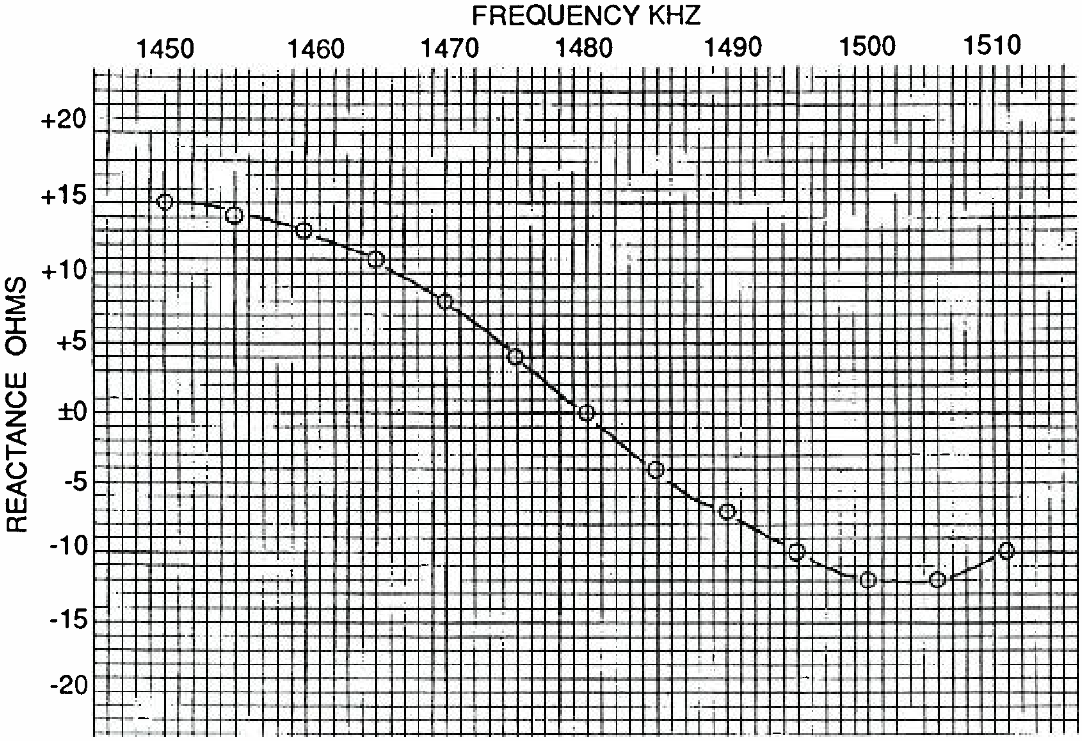


Figure 5-4B

graph of the common point reactance for the day pattern



5.07 Making and Analyzing the Directional Proof-of-Performance Measurements

Starting at a distance of 10 times the distance between the farthest radiators in the system, each point measured in the non-directional proof will be re-measured during the directional proof. At distances which are closer, we run the risk of erroneously measuring radiation from individual towers. The pattern is not fully formed until we are out this far. The distance between tower #2 and tower #3 is 166 feet. Therefore our DA measurements will begin no closer than 0.5 km - 1660 feet from the center of the array. The measured value of directional field strength will be ratioed to the non-directional measured value as we did in the sample points. Either the arithmetic average or the logarithmic average of the ratios at each measuring point may be used to establish the DA inverse field on each radial. An individual point ratio that is above or below the overall average will tend to have less effect on the result when the logarimithic method is used.

Scattering of data on radials where the inverse field strength is low is quite common. Scattering is where the measured field strength is far higher or lower than might be expected. It is caused by reradiation from nearby wires or structures. When this effect is extreme, the logarithmic method of ratio averaging will give a better picture of actual inverse field strength.

The 165°, 185° and 205° radials should be the first to be measured. The inverse field on a radial can not be determined until the data for every point along the radial is ratioed and the average computed. If we find the inverse field strength in these minimas or in the minor lobe to be above what is called for in the standard pattern, it's back to square one on adjustment. Therefore, if there is a problem, it's prudent to find out before we invest too much time in the DA proof measurements.

The next logical measurements on the day radiation pattern will be made on the 149° and 239° radials. The polar plot of the radiation pattern, and the calculations submitted as part of the application for the construction permit, indicate that the inverse field strengths in these directions should not exceed 92 mV/m at one km. From there we will proceed to do the five remaining radials in the major lobe.

For a field log, use copies (put the originals in a safe place) of the log first used for the non-directional measurements. Figures 5-5A and 5-5B show the 185 degree radial measured directional data entered in the log. Each directional measurement is ratioed to its non-directional counterpart. Adding the 34 individual ratios (the first two of the 36 non-D measurement locations were not measured in the DA mode as they were too close to the array) we get 9.230. Diving by 34 (the number of points measured) the average comes out to 0.272. The non-directional inverse field strength along this radial was 220 mV/m at one km. Multiplying 220 by .272 will give us the directional inverse field 59.84 mV/m of on the 185° radial.

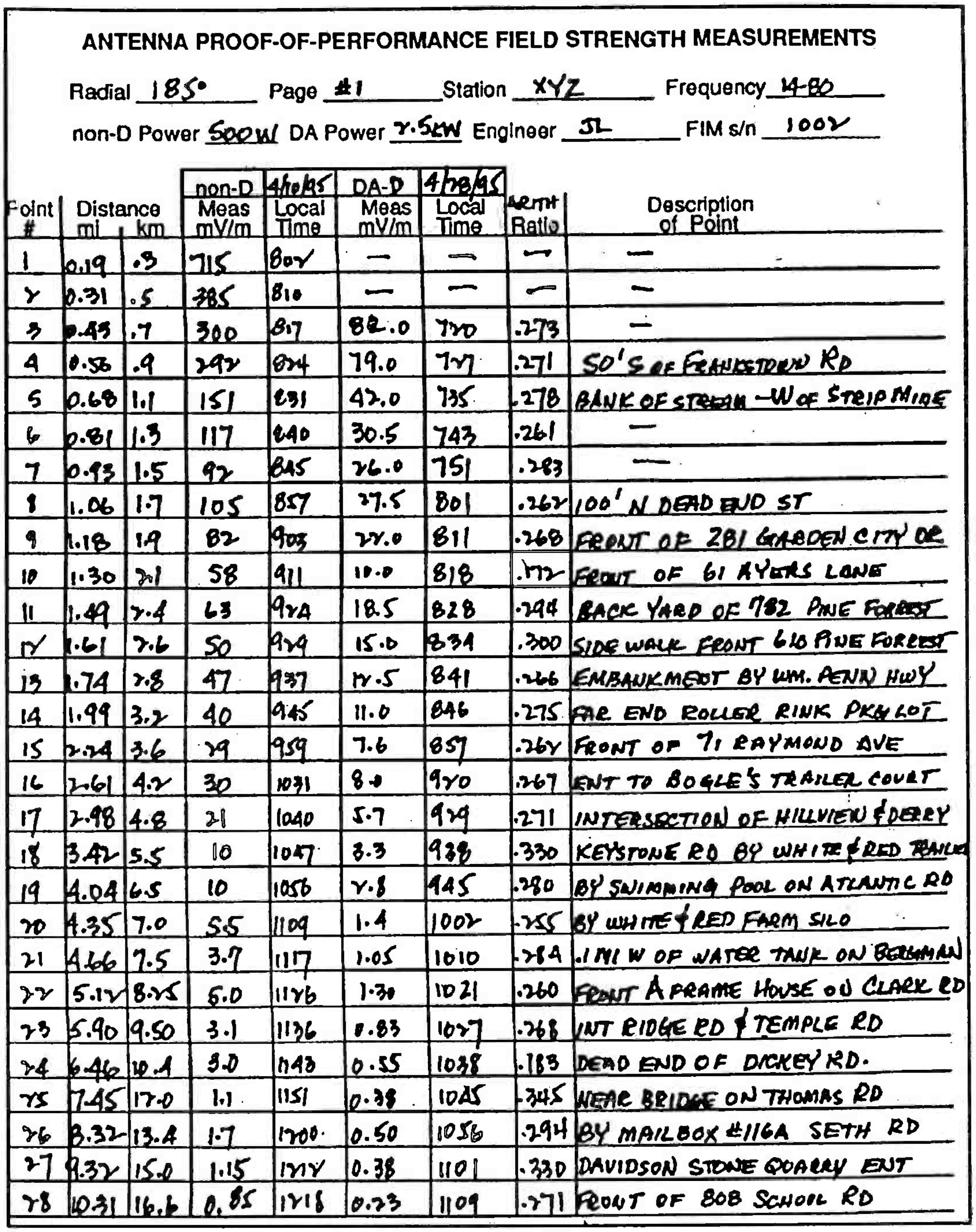
If we used the log ratio, the logarithm of each individual arithemetic ratio would be entered in the ratio column. To obtain the average, the 34 log ratios are added together then divided by 34. Using a hand calculator, determine the antilog of this average. The non-directional inverse field strength -220 mVm at 1 km - is multiplied by the antilog. When we analyze the 263.5 radial on the night pattern, the log method will be illustrated.

Figure 5-5A

tabulation of directional antenna field strength measurements for the day pattern 2.5 kW on the 185° radial

the non-directional measurements were gathered and presented in Figure 4-14

the figure in the ratio column is the arithmetic ratio of the directional measured field divided by the non-directional measured field



ANTENNA PROOF-OF-PERFORMANCE FIELD STRENGTH MEASUREMENTS

Radial 185° Page #1 Station XYZ Frequency 1480

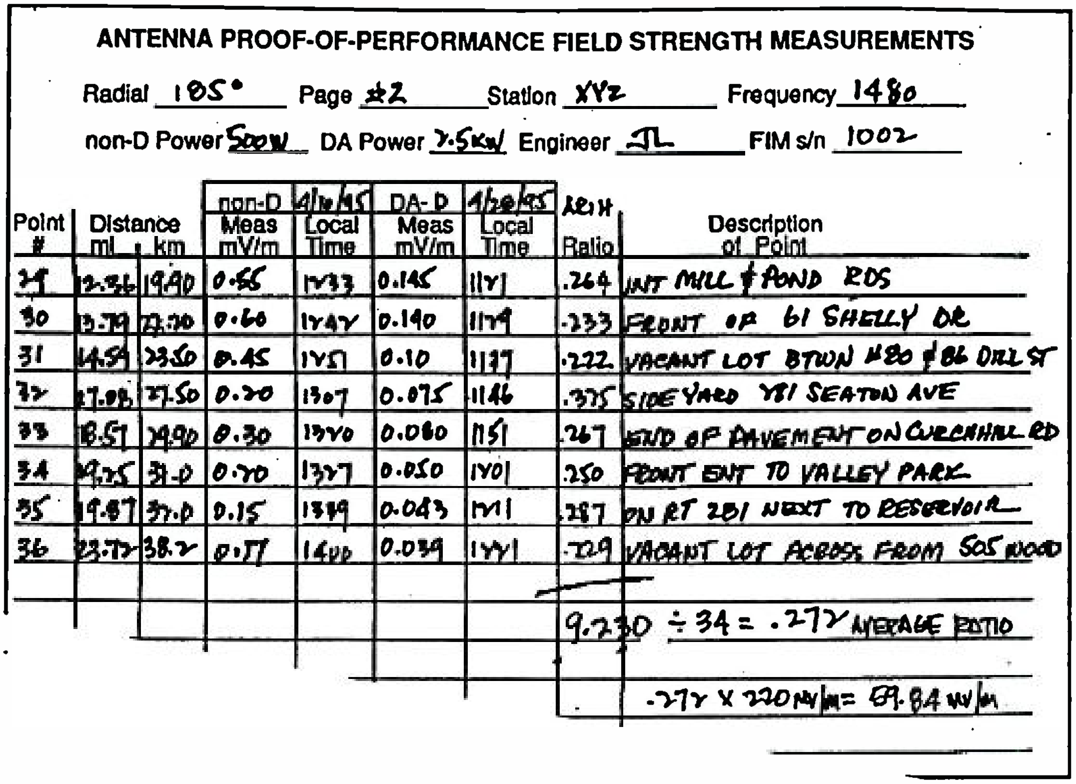
non-D Power 500W DA Power 2.5KW Engineer JL FIM s/n 1002

Point #	Distance mi	Distance km	non-D Meas mV/m	4/10/95 Local Time	DA-D Meas mV/m	4/28/95 Local Time	Arith Ratio	Description of Point
1	0.19	.3	715	802	—	—	—	—
2	0.31	.5	385	810	—	—	—	—
3	0.43	.7	300	817	82.0	720	.273	—
4	0.56	.9	292	824	79.0	727	.271	50'S OF FRANKSTOWN RD
5	0.68	1.1	151	831	42.0	735	.278	BANK OF STREAM — W OF STRIP MINE
6	0.81	1.3	117	840	30.5	743	.261	—
7	0.93	1.5	92	845	26.0	751	.283	—
8	1.06	1.7	105	857	27.5	801	.262	100' N DEAD END ST
9	1.18	1.9	82	903	22.0	811	.268	FRONT OF 281 GARDEN CITY DR
10	1.30	2.1	58	911	10.0	818	.172	FRONT OF 61 AYERS LANE
11	1.49	2.4	63	924	18.5	828	.294	BACK YARD OF 782 PINE FORREST
12	1.61	2.6	50	929	15.0	834	.300	SIDE WALK FRONT 610 PINE FORREST
13	1.74	2.8	47	937	12.5	841	.266	EMBANKMENT BY WM. PENN HWY
14	1.99	3.2	40	945	11.0	846	.275	FAR END ROLLER RINK PKG LOT
15	2.24	3.6	29	959	7.6	851	.262	FRONT OF 71 RAYMOND AVE
16	2.61	4.2	30	1031	8.0	920	.267	ENT TO BOGLE'S TRAILER COURT
17	2.98	4.8	21	1040	5.7	929	.271	INTERSECTION OF HILLVIEW & DERRY
18	3.42	5.5	10	1047	3.3	938	.330	KEYSTONE RD BY WHITE & RED TRAIL
19	4.04	6.5	10	1056	2.8	945	.280	BY SWIMMING POOL ON ATLANTIC RD
20	4.35	7.0	5.5	1109	1.4	1002	.255	BY WHITE & RED FARM SILO
21	4.66	7.5	3.7	1117	1.05	1010	.284	.1 MI W OF WATER TANK ON BERGMAN
22	5.12	8.25	5.0	1126	1.30	1021	.260	FRONT A FRAME HOUSE ON CLARK RD
23	5.90	9.50	3.1	1136	0.83	1027	.268	INT RIDGE RD & TEMPLE RD
24	6.46	10.4	3.0	1143	0.55	1038	.183	DEAD END OF DICKEY RD.
25	7.45	12.0	1.1	1151	0.38	1045	.345	NEAR BRIDGE ON THOMAS RD
26	8.32	13.4	1.7	1200	0.50	1056	.294	BY MAILBOX #116A SETH RD
27	9.32	15.0	1.15	1212	0.38	1101	.330	DAVIDSON STONE QUARRY ENT
28	10.31	16.6	0.85	1218	0.23	1109	.271	FRONT OF 808 SCHOOL RD

This same procedure will be carried out for each of the other radials. Start at 0.5 km and re-measure each point. Ratio each, calculate the average and determine the directional inverse field strength as just described. On the 5°, 30°, 80°, 290° and 340° radials the average ratio will be greater than 1.00 as those inverse field strengths will exceed the 500 watt non-directional inverse field strength of 220 mV/m at 1 km. All DA inverse fields - both those in the minimas and in the lobes - must be below those indicated on the polar plot of the standard radiation pattern shown in Figure 4-1.

Figure 5-5B

page #2 of the 185 degree radial measurements



ANTENNA PROOF-OF-PERFORMANCE FIELD STRENGTH MEASUREMENTS

Radial 185° Page #2 Station XYZ Frequency 1480

non-D Power 500W DA Power 2.5KW Engineer JL FIM s/n 1002

Point #	Distance mi	Distance km	non-D 4/12/85 Meas mV/m	Local Time	DA-D 4/20/85 Meas mV/m	Local Time	RELH Ratio	Description of Point
29	12.36	19.90	0.55	1233	0.145	1121	.264	INT MILL & POND RDS
30	13.79	22.20	0.60	1242	0.140	1129	.233	FRONT OF 61 SHELLY DR
31	14.59	23.50	0.45	1251	0.10	1137	.222	VACANT LOT BTWN #80 & 86 DILL ST
32	17.08	27.50	0.20	1307	0.075	1146	.375	SIDE YARD 281 SEATON AVE
33	18.57	29.90	0.30	1320	0.080	1151	.267	END OF PAVEMENT ON CHURCHILL RD
34	19.25	31.0	0.20	1327	0.050	1201	.250	FRONT ENT TO VALLEY PARK
35	19.87	32.0	0.15	1349	0.043	1211	.287	ON RT 201 NEXT TO RESERVOIR
36	23.72	38.2	0.17	1400	0.039	1221	.229	VACANT LOT ACROSS FROM 505 WOOD
							9.230	÷ 34 = .272 AVERAGE RATIO
								.272 X 220 mV/m = 59.84 mV/m

Where one is unable to bring, by adjustment of the array, the measured inverse field strengths, on all radials, down to or below those calculated and submitted in the application for the construction permit, other measures must be taken. If no interference to other co-channel or adjacent channel facilities will result from this increased radiation an application for a modified standard pattern can be submitted to the FCC. The modified standard pattern is computed either by making the entire pattern larger than what had previously been specified or by expanding sectors (portions) of the pattern where the excessive inverse field exists.

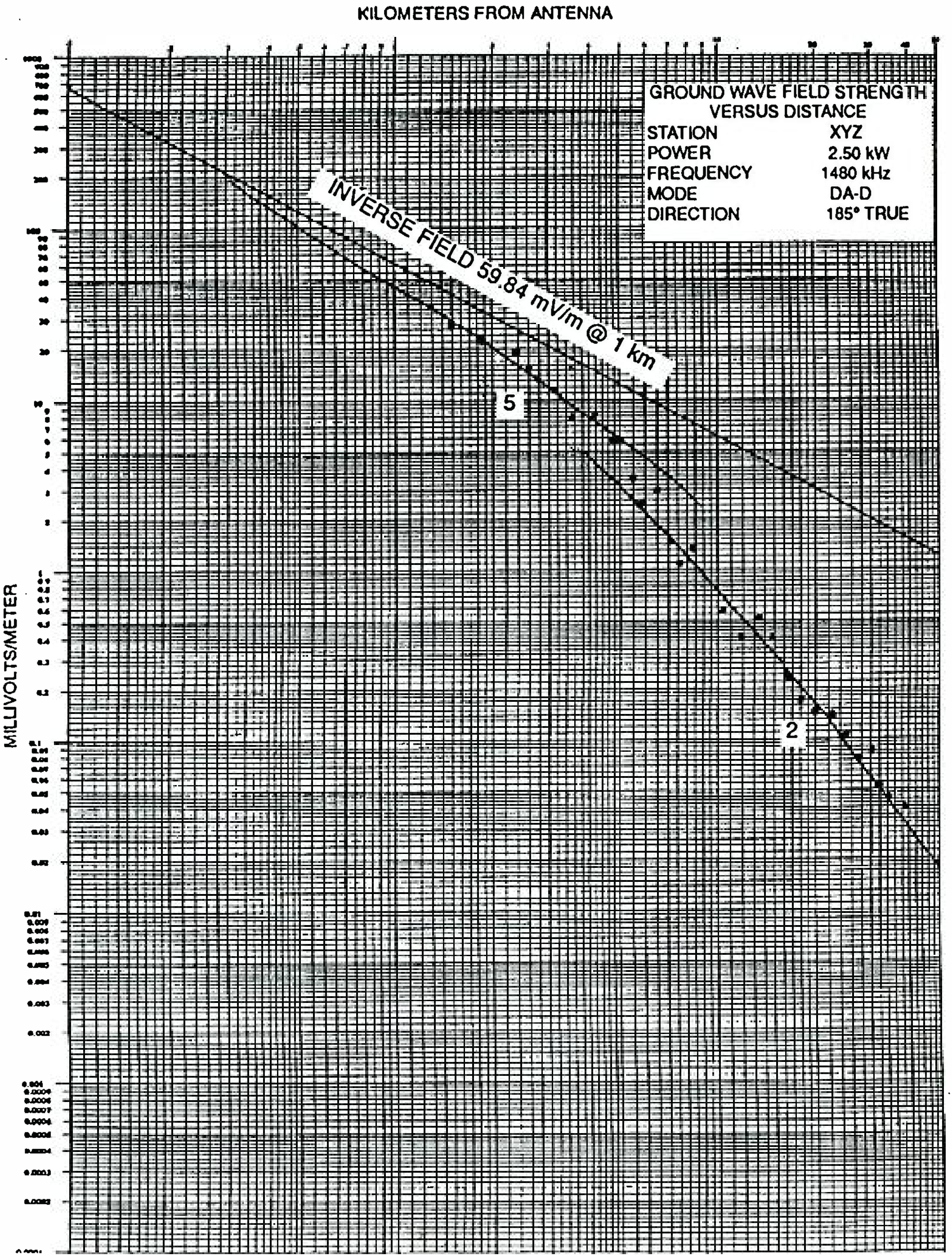
If this is not possible, due to objectionable interference being caused to another facility, the size of the radiation pattern must be reduced to bring all inverse field strengths, on all radials, below that specified in the application for the construction permit. This is accomplished by reducing the power input to the system. In the past this was accomplished by inserting a resistor in the feeder system to burn up power. With modern day state of the art transmitters power levels from almost zero to the maximum capability of the transmitter are easily accomplished by turning a small pot up or down!

Each measurement must be plotted on the log-log graph paper as was done for the non-directional measurements. This is illustrated in Figure 5-6. The ground conductivity curves of 5 out to about 5 km and 2 from there to 40 km, as determined in the non-D proof are used. Note where the straight inverse distance line crosses the one km point - right at 60 mV/m (to be exact 59.8 mVm).

Figure 5-6

the plotted daytime directional field strength measurements

ground conductivities are taken from the non-directional plotted measurements for this radial - Figure 4-17 on page 117



5.08 Summarizing Your Collected Data

Now that all nine radials have been measured, all data tabulated, each point ratioed against the non-D measurement at the same point and the average ratio determined (either arithmetically or logarithmically) and the directional inverse field strength determined by multiplying the non-directional inverse field by the average ratio, it's time to summarize all of our efforts. Table 5-2 is such a summation. Note that all DA inverse field strengths are below those specified in the standard radiation pattern. In addition, all those on which a monitor point is required to be established are at least 10% below the maximum specified in the standard radiation pattern. This will allow for some tolerance on the maximum specified field strength at that point. This information will be noted on the station license.

SUMMATION OF MEASURED DA--D DATA
mV/M @ 1KM

AZIMUTH	DA/NON-D AVERAGE	NON-D INV FIELD	DA INV FIELD	MAX ALLOWED STD PATTERN
05	3.492	220	768.2	780
30	3.200	220	704.0	730
80	2.401	220	528.2	550
149	0.401	220	88.2	92
165	0.190	220	41.8	50
185	0.269	220	59.8	68
205	0.210	220	46.2	50
221	0.380	220	83.6	92
290	2.470	220	543.0	550
340	3.251	220	715.2	730

TABLE 5-4

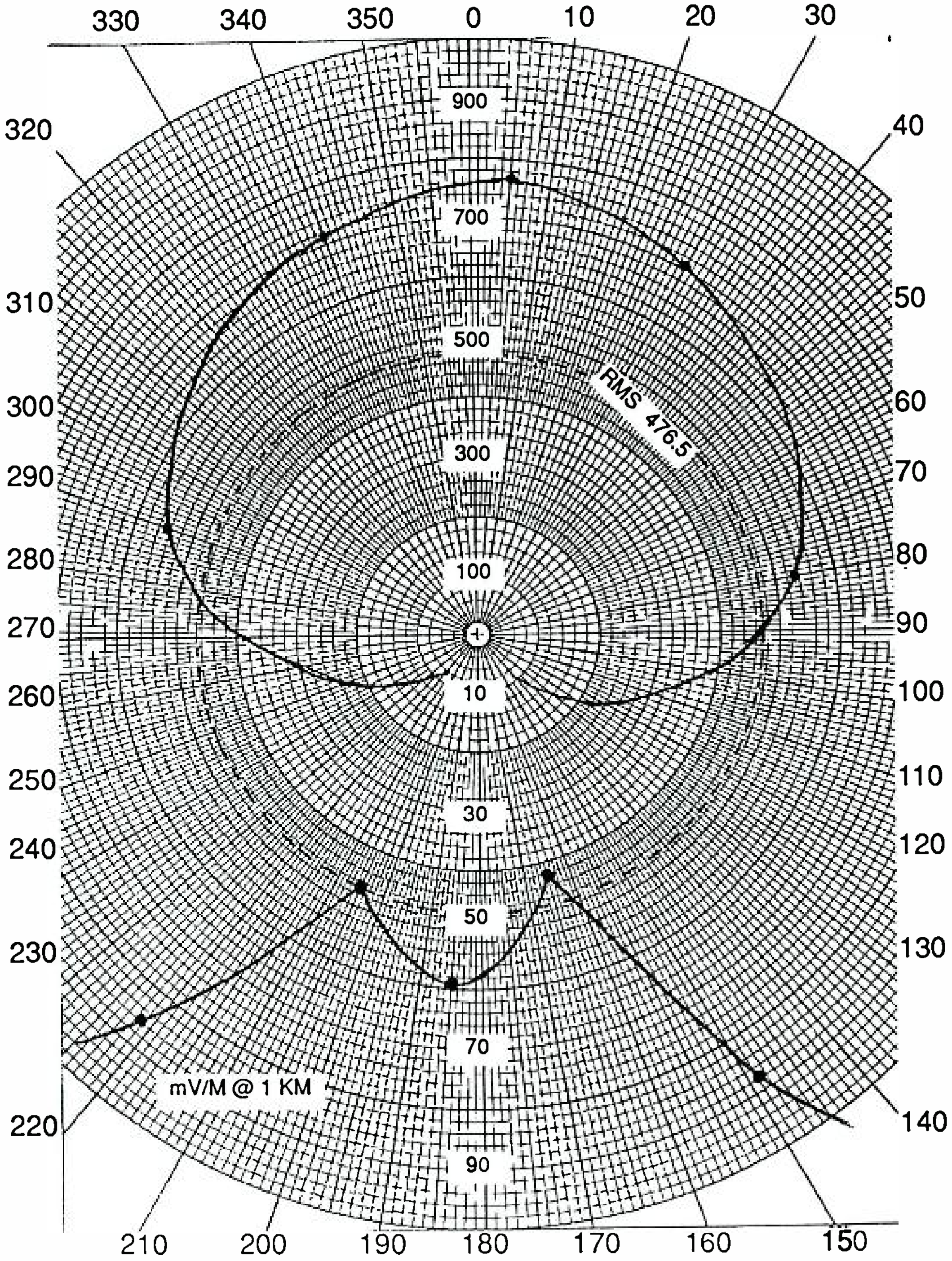
From the measured inverse field strength data we can now draw the actual radiation pattern being produced by the array as now adjusted. The inverse field strength on the nine azimuths we measured are plotted on polar coordinate graph paper. The polar plot of the measured radiation pattern is drawn and shown in Figure 5-7. The dots mark the plotted data. Values of inverse field strength for azimuths not measured are interpolated. Note that the actual measured pattern is slightly smaller than the standard pattern shown in Figure 4-1. This is to be expected as the measured inverse field strengths must be contained within the envelope of the standard pattern. The pattern also appears to be a bit lopsided. This is especially evident in the area of the two minimas. There is nothing unusual about this. The dotted circle is the RMS of the pattern. We are about to discuss this in the next section.

Figure 5-7

polar plot of measured inverse distance field strengths

RMS is discussed in the next section

the area of the RMS circular pattern is the same as the area encompassed by the directional radiation pattern



5.09 Determining the RMS of the Radiation Pattern

The RMS, *root mean square*, of antenna pattern refers to its size. Section 73.189 of the Rules specifies minimum field strength requirements for the various classes of AM radio stations. In lieu of actually having to measure the pattern size of a non-directional AM station, a minimum height and minimum size of the ground system for the non-directional radiator is specified in the Rules. If these height and ground system sizes are not met, a non-directional proof might be required to show that the installation indeed complies with this section of the rules. The RMS, or pattern size, for an AM station using a non-directional antenna system is easily determined. The pattern should be circular and if the inverse field strength at one km in a particular direction is determined, the size, or the RMS, of the radiation pattern has been determined.

FCC Rules refer to the size of the pattern - the RMS - in mV/m at one km for one kW. Unless the operating power is 1 kW we must adjust these figures. Back in Chapter 1 we saw the effect of power on radiated field. Field strength changes in direct proportion to the square root of the power change. For example: If power is doubled the field strength will change by a factor of 1.41 ($\sqrt{2.0} = 1.41$). If the power is halved the field strength will change by a factor of 0.707 ($\sqrt{0.5} = .707$). To adjust the figures shown in Table 5-1 to a specific power, multiply what is shown by the square root of the actual power in kW.

For example: A 50 kW Class A station must produce a minimum inverse field strength of 2559 mV/m at one km. ($362 \times \sqrt{50} = 362 \times 7.07 = 2559$).

These same minimums apply to stations operating with a directional antenna system. The size of the radiation pattern must meet the RMS specified in section 73.189 of the Rules. Our imaginary Class B station operating on 1480 kHz must produce 282 mV/m per kilowatt at one km. Our operating power is 2.5 kW. That means the RMS of the pattern must be at least 445.6 mV/m ($282 \times \sqrt{2.5} = 282 \times 1.58 = 445.6$).

Let's look at this another way: In Figure 5-7, along with the measured DA pattern, is the polar plot of a non-directional radiation pattern with an RMS of 476.5 mV/m. It is indicated by the dotted line and it is drawn to the same scale as our measured DA-D pattern. The area on the paper covered by the directional pattern is the same size as the area covered by the circular non-D pattern. We can therefore conclude that the measured directional pattern has an RMS of 476.5 mV/m.

A polar plainimeter is a device used for determining the area of an irregular 2 dimensional figure. It can determine the area encompassed by the DA-D pattern. Once area is determined, a circle can be drawn on polar coordinate paper with the same area. This is one method of determining RMS.

The RMS of the directional pattern can also be calculated from figures taken from the measured pattern. At one time this was a laborious process. Now, however, with the aid of a hand held calculator it can be accomplished in just a few minutes.

The formula for determining the RMS of the DA pattern, with data taken from the plotted pattern, is:

(#18) $$\text{RMS} = \sqrt{\frac{E_0^2 + E_{10}^2 + E_{20}^2 + \ldots . E_n^2}{n}}$$

where: RMS = the root mean square or size of the radiation pattern in mV/m
E_0, E_{10}, E_{20} etc. = the inverse field values for each azimuth
n = the total number of azimuths

Values of inverse field at every ten degrees are taken from the pattern plot. The value of n then becomes 36 (360 / 10). These values are squared then added together. An average is then taken (divide by 36). The square root of this figure is the RMS or size of the pattern.

Table 5-5 shows the arithmetic for the measured pattern shown in Figure 5-7. If you jump back to Figure 4-1 - the standard pattern - and calculate its RMS you will find it to be close to 489 mV/m.

DETERMINING RMS OF THE DA-D PATTERN

Azimuth	EmV/m	E^2
000	760	577600
010	760	577600
020	720	518400
030	704	495616
040	675	455625
050	640	409600
060	618	381924
070	575	330625
080	528	278784
090	470	220900
100	390	152100
110	302	91204
120	240	57600
130	170	28900
140	100	10000
150	88	7744
160	50	2500
170	48	2304
180	58	3364
190	58	3364
200	51	2601
210	56	3136
220	84	7056
230	120	14400
240	180	32400
250	240	57600
260	300	90000
270	385	148225
280	475	225625
290	543	294849
300	580	336400
310	620	384400
320	660	435600
330	690	476100
340	715	511225
350	740	547600
		SUM = 8172971

$$\sqrt{\frac{8172971}{36}} = \sqrt{227027} = 476.5 = \text{RMS}$$

Table 5-5

5.10 Selecting Permanent Monitor Points

The construction permit for a directional antenna system will specify that a permanent monitor point be established on one or more azimuths. In the CP for day operation there are two azimuths on which it specifies a monitor point: 165 degrees and 185 degrees. A monitor point should be no closer than 1.0 mile from the center of the array - 1.62 km - or farther than 4.0 miles - 6.5 km. As mentioned previously, the closer to the array the better. Seasonal changes in ground conductivity will have less effect on measured field intensity on points closer to the array.

The purpose of the monitor point is to give those responsible for the maintenance of the DA system a means of taking a meaningful sample of field strength at one point on a radial to determine if the system is in proper adjustment. The rationale is: If this one point, previously measured along with all of the other points on a radial, is within a certain tolerance, it can reasonably be assumed that the other points along this radial are also reasonably close in value to what they were when the DA proof was made. If the measured field strength at the monitor point goes up 10% it can reasonably be assumed that the inverse field along this radial also increased by 10%. Although this is a reasonable assumption, it is not always valid. The ground conductivity can change season to season. This will cause the measured value of field strength to fluctuate while the inverse field remains constant.

Let's look at the data we collected along the 185° radial. It is shown in Figure 5-5 . Points 8 through 18 fall within the required distance. Point #14 is in the parking lot of a roller rink. It is clear of overhead wires and metallic structures (metal light poles, etc.). It's accessible year around (no fenced in area that might be locked at times). In all probability, it will be there for a long time (no construction on it). There should be no hassle from the land owner to your visiting this point on a regular basis. It would probably make a good monitor point.

There is also one other consideration: The point data, when plotted on the field strength versus distance graph, should fall reasonably close to the ground conductivity curve. Its ratio DA/non-D should be close to the average ratio. This would indicate that there are probably no influences other than distance and ground conductivity on the measured field at this point. The DA/non-D ratio on point #14 is 0.275. The average ratio on this radial is 0.272. This would appear to be an excellent monitor point candidate!

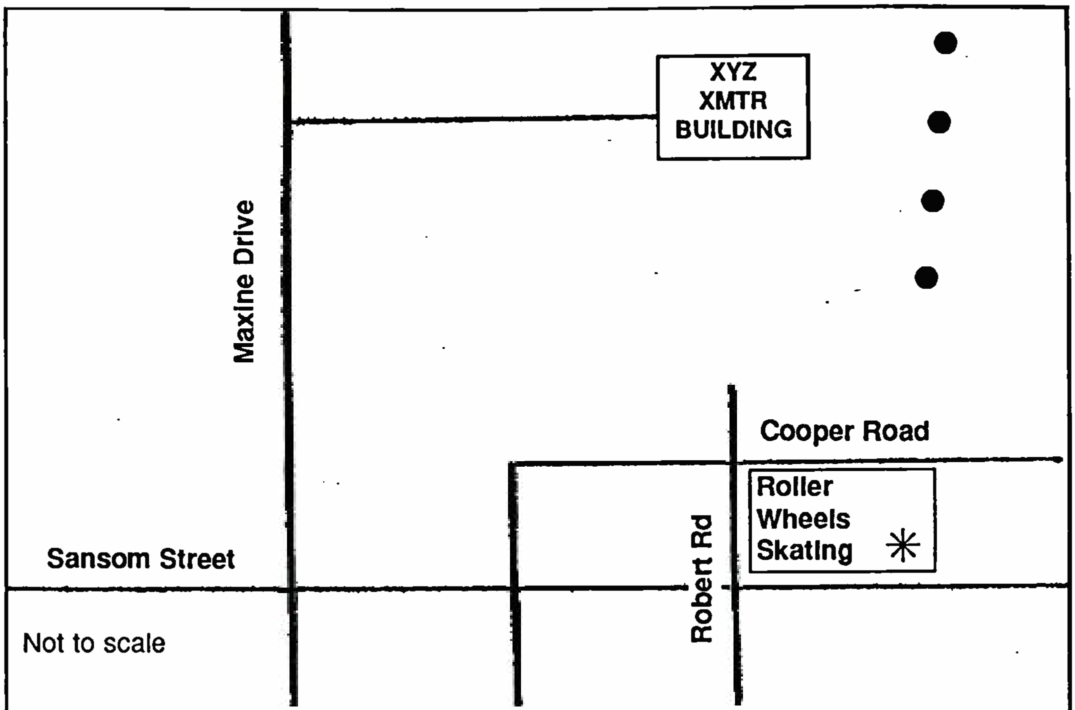
A map of how to get to this point from the transmitter will be made part of the engineering exhibit on the application for a license. A description of how to get to the monitor point must accompany the map. Figure 5-7 is a model. Take along another person and a camera to the point. While holding the field strength meter as you would to take a measurement, have your accomplice take a picture of you. The picture should include as many permanent land marks as possible (houses, mail boxes, etc.). This will all become part of your application to be submitted to the FCC for a license. Follow this procedure for each radial on which a monitor point is specified. In the case of our imaginary station XYZ, a point is also specified on the 165 degree radial for the day pattern.

The Station License will contain a description of the point along with instructions on how to get to the monitor point. It will also specify a maximum value of field strength permitted at the point. This maximum is determined by the field strength measured at the monitor point during the DA proof and the measured inverse field vs the maximum allowed inverse field on the radial.

Figure 5-8

map and written description of how to get to the 185° MP

a photograph of the point, with as many permanent land marks as possible included, with the field strength meter in place, must accompany the map and description as part of the license application exhibit



Directions to the 185° Monitor Point

Proceed out the XYZ access road - turn left on Maxine Drive for 2.4 miles - turn left on Sansom Street for 0.5 miles - turn left on Robert Road for one block - turn right on Cooper Road - take second entrance into Roller Wheels Skating and go to the southeast corner of the parking lot - reading is taken in the corner of the paved area. This is Point #14 on the 185° radial 1.99 miles from the center of the XYZ array

The following formula can be used to determine the maximum value that could be assigned to a monitor point:

(#18) $$E_{max} = \frac{\text{Maximum inverse}}{\text{Measured inverse}} \times E_{mp}$$

where: E_{max} = maximum value of field strength permitted at monitor point
Maximum inverse = maximum value of inverse field shown in standard pattern
Measured inverse = inverse field measured during the DA proof
E_{mp} = value of field strength measured at the monitor point during the DA proof

In the case of our chosen monitor point - point #14 on the 185° radial:
$E_{max} = 68 \times 11.0 = 12.5 \text{ mV/m} = 59.84 = E_{max}$

If the measured field strength at the monitor point increases by 13.5%, from 11.0 to 12.5 mV/m, it is assumed that the inverse field strength will increase by 13.5% from 59.84 mV/m to 68.0 mVm. In practice, the FCC does not always follow this rule of thumb.

5.11 The Adjustment of Multi-Element Directional Antenna Systems

Now that the array producing the day pattern has been tamed and conquered we can move on to the more complex night time array! All of the basics remain the same. In the day array we had the phase of one tower and one current ratio to handle. In the 4 tower night array there will be three phases and three current ratios. In the day pattern there were two minimas and one minor lobe. In the night pattern there are six minimas and five minor lobes. This night time array will suppress radiation below that which would be delivered non-directionally over about 270 degrees of azimuth. In four of the minimas radiation is limited to about six percent of what would be delivered non-directionally with a kilowatt of power.

To avoid being repetitious, we will not go back over every detail of the "how tos." Rather, the important steps of the procedure will be outlined.

Figure 5-1, on page 121 indicates the phase shift required through each of the networks in the night array's feeder system. As we did for the day pattern, each LTU network and phase control network must be set up for the proper phase shift and match. This is accomplished by setting each reactive leg, in each network, to its proper value as we did for the 2 tower array. The reactance required in each leg must first be calculated.

Your attention is called to the overall schematic diagram of the feeder system - Figure 4-8. The phase control network for the #1 tower, consisting of 1L1, 1L2, 1L3, 1L4 and 1L5 along with 1C12 and 1C2, looks a bit different than what we have encountered thus far. This network is really two T-networks in series. A total phase shift of -150 degrees is required at this point. Attempting to accomplish this much phase lag with a single network is not advisable. Both T-networks are identical - 50 ohms in and 50 ohms out, each having a phase shift of -75 degrees. Inductor 1L2 is the sum of the series output inductance of the first network and the series input inductance of the second.

After setting all of the network legs to their proper values, put the network back together by reinstalling all the straps and tubing. Then check each with the mini-dummy just as we did on the day feeder system.

The power divider for the night pattern is somewhat more complex than what we encountered in the day system. The reference tower - tower #2 - which receives about 70 percent of the total power is tapped directly on the the output of the common point matching network. Small roller inductor coils are tapped on L4. Normally these taps would be located in the order of power distribution - the lowest power required being closest to ground on L4. However, tower #4 is a negative tower. Power is flowing from the radiator back to the common point of the system. The roller capability of L5, L6 and L7 allow for front panel fine control of power. Taps on L4 will probably have to be changed as the tuning process progresses.

With the RF contactors in the night position, measure the input to, and adjust as necessary, the night common point matching network which consists of L1, L2, L3 and C1. The input to this network, with all jumpers and components in place, should be adjusted to 50 ±j0.

As in the day pattern, the theoretical operating parameters may be wildly different than what we can read on the antenna monitor. They might look thus:

#1	$1.00\ \underline{|0^\circ}$
#2	$2.27\ \underline{|201^\circ}$
#3	$2.11\ \underline{|48^\circ}$
#4	$0.85\ \underline{|256^\circ}$

We must reduce these ratios and phases to something that we can read on the antenna monitor. Tower #2 is the reference tower. If we divide the magnitudes by 2.27 and subtract 201° from each phase we will have:

#1	$0.44\ \underline{|-201}$
#2	$1.00\ \underline{|0^\circ}$
#3	$0.93\ \underline{|-153^\circ}$
#4	$0.37\ \underline{|54^\circ}$

All is now well except the #1 phase. We can read -201° on the antenna monitor but it is more convenient and less confusing to read values less than 180°. If we add 360 degrees to -201 degrees we get +159 degrees. This is easily read on the monitor. The new parameters are exactly the same as the old - just expressed differently.

Check the antenna monitor to ascertain if it configured to use the #2 tower as the reference tower. Energize the system with a few hundred watts of power.

Once you begin the process of adjusting the phases and current ratios to their theoretical values you will soon find out how interactive one control is on the other. In the two tower system we had only the interaction of one power and one phase control. By now you have found that changing the #1 phase changes all phases and all current ratios! Not only does the driving point impedance of each tower change when any adjustment is made, causing a shift in the other operating parameters, but the load reflected back to the power divider also changes.

A method that I call "half-correction" has proved helpful when adjusting a multi-element array. If the phase of the #1 tower must be corrected by 40 degrees move it in the right direction 20 degrees. More than likely, all of the other parameters will change. Return these phases and current ratios to their previous values. Repeat this process until all parameters are as desired. This usually minimizes the possibility of a "catch 22" situation!

When you arrive at the theoretical phases and current ratios, recheck and readjust as necessary the common point impedance. When this is done energize the system with 1080 watts - 108% of the nominal power of 1000 watts - 4.65 amperes.

The next step is to calculate what we might expect in the way of measured field strength at several points on some of the critical radials. This time we should look at all of the radials on which we are required to have a monitor point. These are 80°, 106.5°, 185° 221° and 263.5°. (See table 4-2 on page 94) Table 5-7 shows the maximum average ratios between non-D measured and DA measured field strengths permitted on each of these radials.

MAXIMUM ALLOWABLE DA / NON-D AVERAGE RATIO ON THE DA-N RADIALS
mV/m @ 1 km

Azimuth	Meas Non-D Inverse Field	Max Allowable DA Inverse Field	Max Average DA/non-D Ratio
005	220 mV/m	800 mV/m	3.636
030	220 mV/m	665 mV/m	3.023
080	220 mV/m	44 mV/m	0.200
096	220 mVm	30 mV/m	0.136
106.5	220 mV/m	20 mV/m	0.091
131	220 mVm	60 mV/m	0.273
149	220 mVm	50 mV/m	0.227
185	220 mVm	120 mV/m	0.545
221	220 mVm	50 mV/m	0.227
239	220 mVm	60 mV/m	0.273
263.5	220 mV/m	20 mV/m	0.091
278	220 mV/m	30 mV/m	0.136
290	220 mV/m	44 mV/m	0.200
340	220 mVm	665 mV/m	3.023

TABLE 5-7

We now measure 3 points on these five radials, remembering that we must not be closer than 10 times the distance between the farthest radiators in the DA system. For the night time DA system this is 4980 feet (3 X 166) - .94 mile or 1.5 km. Just as we did with the day pattern, these points will be ratioed against the non-D measured field strength at the same locations. The average of these three points on each radial should fall below those shown in table 5-7. Remember, we are only sampling. The actual ratio, when all 30 plus measurements are made, may be higher or lower than this sample. Unless you really live a good life, some or all of these averages will be above what is desired!

One kW radiated non-directionally from one of these towers will produce an inverse field in excess of 300 mV/m at one km. The directional antenna must suppress this field to 20 mV/m at some azimuths. The radiation in these directions is only about 6% of these non-directional values. This is equivalent to just a few watts radiated non-directionally. In an array that produces many minimas and suppression values of this magnitude the easiest way of fine tuning is to put several folks out in the field with two-way radios (or cellular phones) and field intensity meters. For convenience, the meters should be set up on tri-pods. Making adjustments and then driving to these points to measure is an exhausting if not futile task!

For starters, we will place a person/field strength meter/two-way radio at a point on the 106.5° radial, one on the 149° radial and a third on the 278° radial. The choice of these azimuths was not arbitrary. An in-line array should produce a pattern that is symmetrical on either side of the line of towers. A minima should be located at 106.5°. If radiation in this direction is within tolerance it is reasonable to expect that the radiation in the corresponding minima at 263.5° will fall into place. If there is re-radiation from another structure (tower, water tank, etc.) this expectation might not be realized. However, for starters we will make this assumption. The mirror image of the minima at 149°is the one at 221°. The depth of these two minimas will have a large effect on the radiation in the minor lobe centered at 185° off the back of the line of towers.

By fine tuning a degree or so of phase at a time and a half percent or so of current ratio, while keeping notes on the effects of adjustments on the field strengths at these three points, it won't take too long to get a feel for what adjustment affects which points in which direction. Once you have brought these three points into what appears to be reasonable values of measured field strength it's time to go back and re-sample three points on each of the 5 radials.

Once the average ratio of the 3 fall below what has been calculated in Table 5-7 it's time to measure the driving point impedances. The same procedure as outlined in section 5.05 is used. Note the values of phase and loop current ratios before inserting the bridge into the feed point of the towers. Adjust for any variations caused by the inductance/capacitance of the bridge. If the measured values are close to the calculated values to which the networks were adjusted, leave well enough alone. If they are not, the individual reactances of the series and shunt legs of the networks should be recalculated. Each should be reset to the new values as set forth in section 5.05. If you carefully noted the values of phase and current ratio in each element before starting this procedure the task of retuning to these values should be simplified.

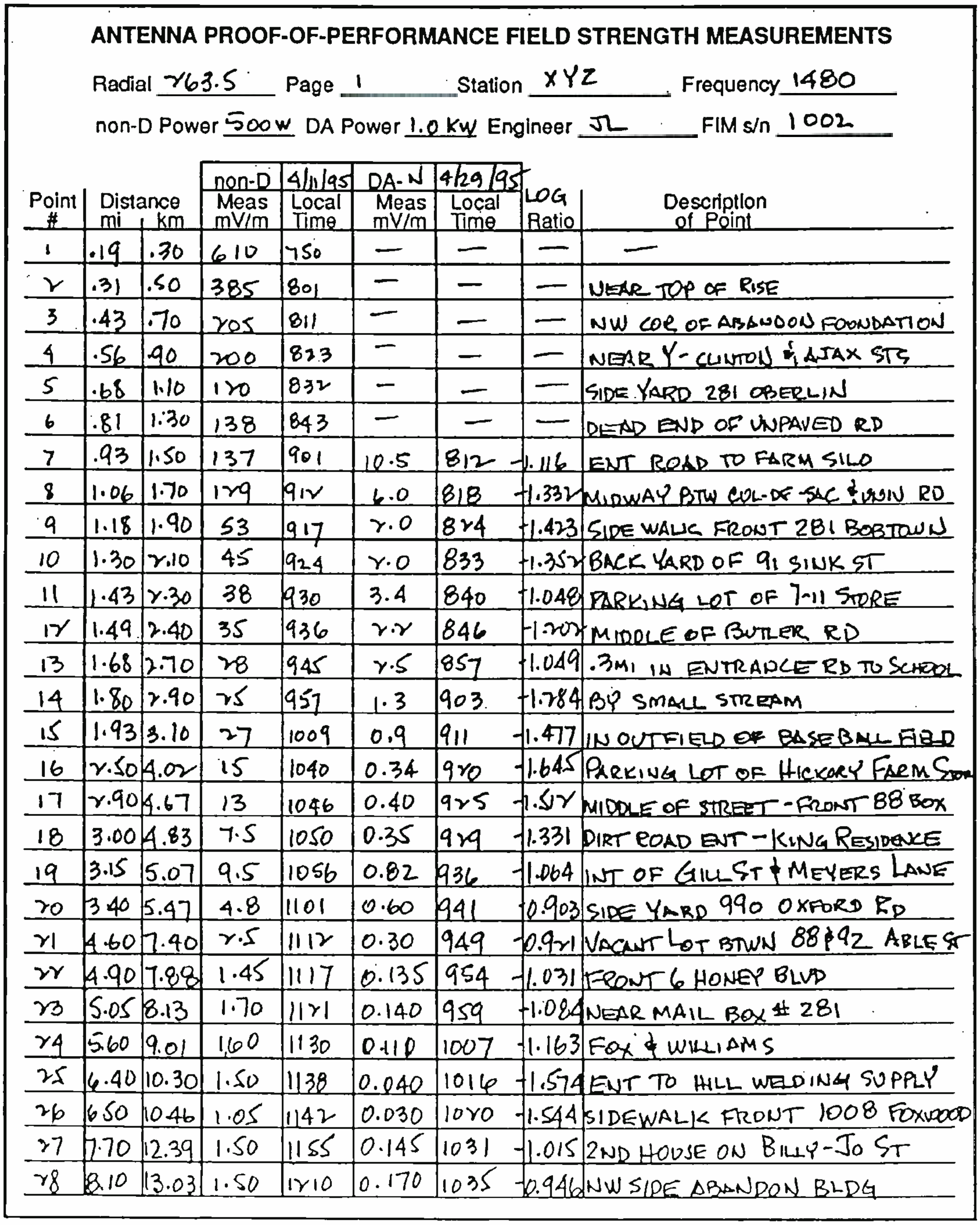


Figure 5-9A

field log showing the collected non-D and DA-N field strength measurement data for the 263.5 radial

the DA-N / non-D log ratio is shown

ANTENNA PROOF-OF-PERFORMANCE FIELD STRENGTH MEASUREMENTS

Radial 263.5 Page 1 Station XYZ Frequency 1480

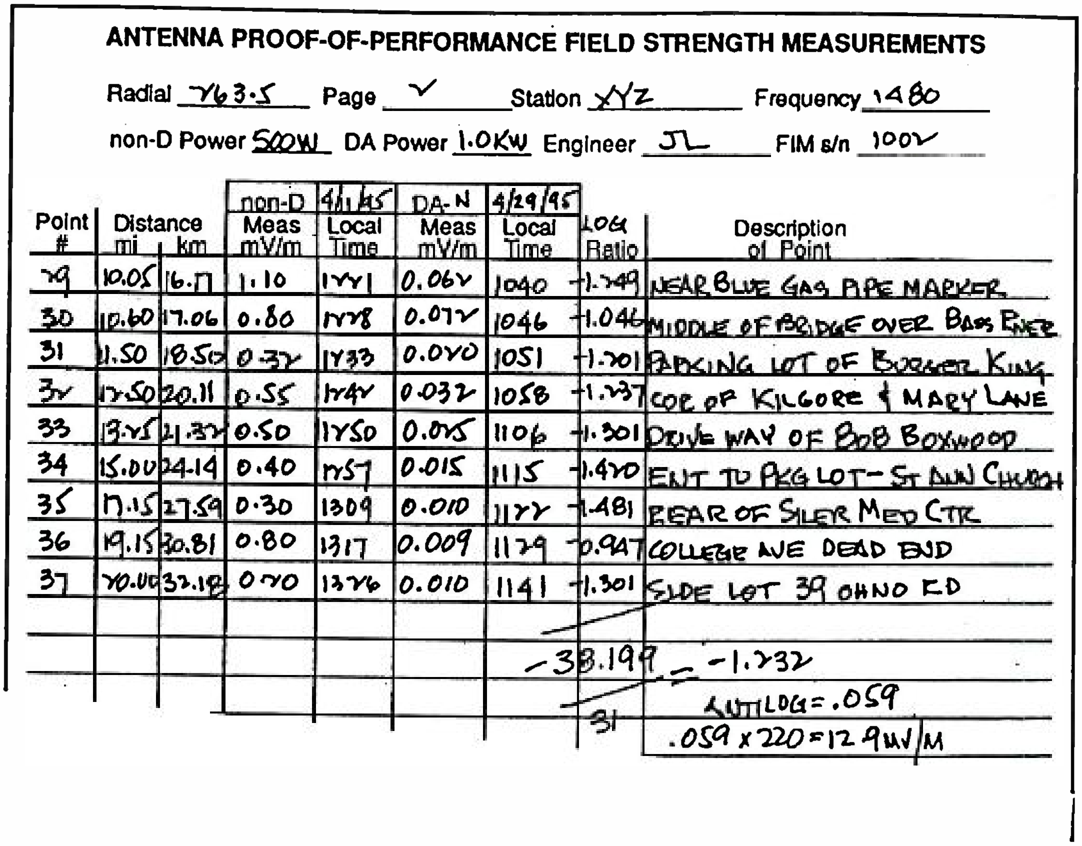
non-D Power 500w DA Power 1.0 Kw Engineer JL FIM s/n 1002

Point #	Distance mi	Distance km	non-D Meas mV/m	4/11/95 Local Time	DA-N Meas mV/m	4/29/95 Local Time	LOG Ratio	Description of Point
1	.19	.30	610	750	—	—	—	—
2	.31	.50	385	801	—	—	—	NEAR TOP OF RISE
3	.43	.70	205	811	—	—	—	NW COR OF ABANDON FOUNDATION
4	.56	.90	200	823	—	—	—	NEAR Y- CLINTON & AJAX STS
5	.68	1.10	120	832	—	—	—	SIDE YARD 281 OBERLIN
6	.81	1.30	138	843	—	—	—	DEAD END OF UNPAVED RD
7	.93	1.50	137	901	10.5	812	-1.116	ENT ROAD TO FARM SILO
8	1.06	1.70	129	912	6.0	818	-1.332	MIDWAY BTW CUL-DE-SAC & MAIN RD
9	1.18	1.90	53	917	2.0	824	-1.423	SIDE WALK FRONT 281 BOBTOWN
10	1.30	2.10	45	924	2.0	833	-1.352	BACK YARD OF 91 SINK ST
11	1.43	2.30	38	930	3.4	840	-1.048	PARKING LOT OF 7-11 STORE
12	1.49	2.40	35	936	2.2	846	-1.202	MIDDLE OF BUTLER RD
13	1.68	2.70	28	945	2.5	857	-1.049	.3MI IN ENTRANCE RD TO SCHOOL
14	1.80	2.90	25	957	1.3	903	-1.284	BY SMALL STREAM
15	1.93	3.10	27	1009	0.9	911	-1.477	IN OUTFIELD OF BASEBALL FIELD
16	2.50	4.02	15	1040	0.34	920	-1.645	PARKING LOT OF HICKORY FARM STOR
17	2.90	4.67	13	1046	0.40	925	-1.512	MIDDLE OF STREET - FRONT 88 BOX
18	3.00	4.83	7.5	1050	0.35	929	-1.331	DIRT ROAD ENT - KING RESIDENCE
19	3.15	5.07	9.5	1056	0.82	936	-1.064	INT OF GILL ST & MEYERS LANE
20	3.40	5.47	4.8	1101	0.60	941	-0.903	SIDE YARD 990 OXFORD RD
21	4.60	7.40	2.5	1112	0.30	949	-0.921	VACANT LOT BTWN 88 & 92 ABLE ST
22	4.90	7.88	1.45	1117	0.135	954	-1.031	FRONT 6 HONEY BLVD
23	5.05	8.13	1.70	1121	0.140	959	-1.084	NEAR MAIL BOX # 281
24	5.60	9.01	1.60	1130	0.110	1007	-1.163	FOX & WILLIAMS
25	6.40	10.30	1.50	1138	0.040	1016	-1.574	ENT TO HILL WELDING SUPPLY
26	6.50	10.46	1.05	1142	0.030	1020	-1.544	SIDEWALK FRONT 1008 FOXWOOD
27	7.70	12.39	1.50	1155	0.145	1031	-1.015	2ND HOUSE ON BILLY-JO ST
28	8.10	13.03	1.50	1210	0.170	1035	-0.946	NW SIDE ABANDON BLDG

Figure 5-9B

page #2 of the field log showing the collected non-D and DA-N field strength measurement data for the 263.5 radial

to determine the DA-N inverse field strength on this radial, the non-D inverse field is multiplied by the anti-log of the average log ratio



ANTENNA PROOF-OF-PERFORMANCE FIELD STRENGTH MEASUREMENTS

Radial 263.5 Page 2 Station XYZ Frequency 1480

non-D Power 500W DA Power 1.0KW Engineer JL FIM s/n 1002

Point #	Distance mi	Distance km	non-D 4/1/95 Meas mV/m	Local Time	DA-N 4/29/95 Meas mV/m	Local Time	Log Ratio	Description of Point
29	10.05	16.17	1.10	1221	0.062	1040	-1.249	NEAR BLUE GAS PIPE MARKER
30	10.60	17.06	0.80	1228	0.072	1046	-1.046	MIDDLE OF BRIDGE OVER BASS RIVER
31	11.50	18.50	0.32	1233	0.020	1051	-1.201	PARKING LOT OF BURGER KING
32	12.50	20.11	0.55	1242	0.032	1058	-1.237	COR OF KILGORE & MARY LANE
33	13.25	21.32	0.50	1250	0.025	1106	-1.301	DRIVE WAY OF BOB BOXWOOD
34	15.00	24.14	0.40	1257	0.015	1115	-1.420	ENT TO PKG LOT - ST ANN CHURCH
35	17.15	27.59	0.30	1309	0.010	1122	-1.481	REAR OF SILER MED CTR
36	19.15	30.81	0.80	1317	0.009	1129	-0.947	COLLEGE AVE DEAD END
37	20.00	32.18	0.20	1326	0.010	1141	-1.301	SIDE LOT 39 OHNO RD

$\frac{-38.199}{31} = -1.232$

ANTILOG = .059

.059 x 220 = 12.9 mV/M

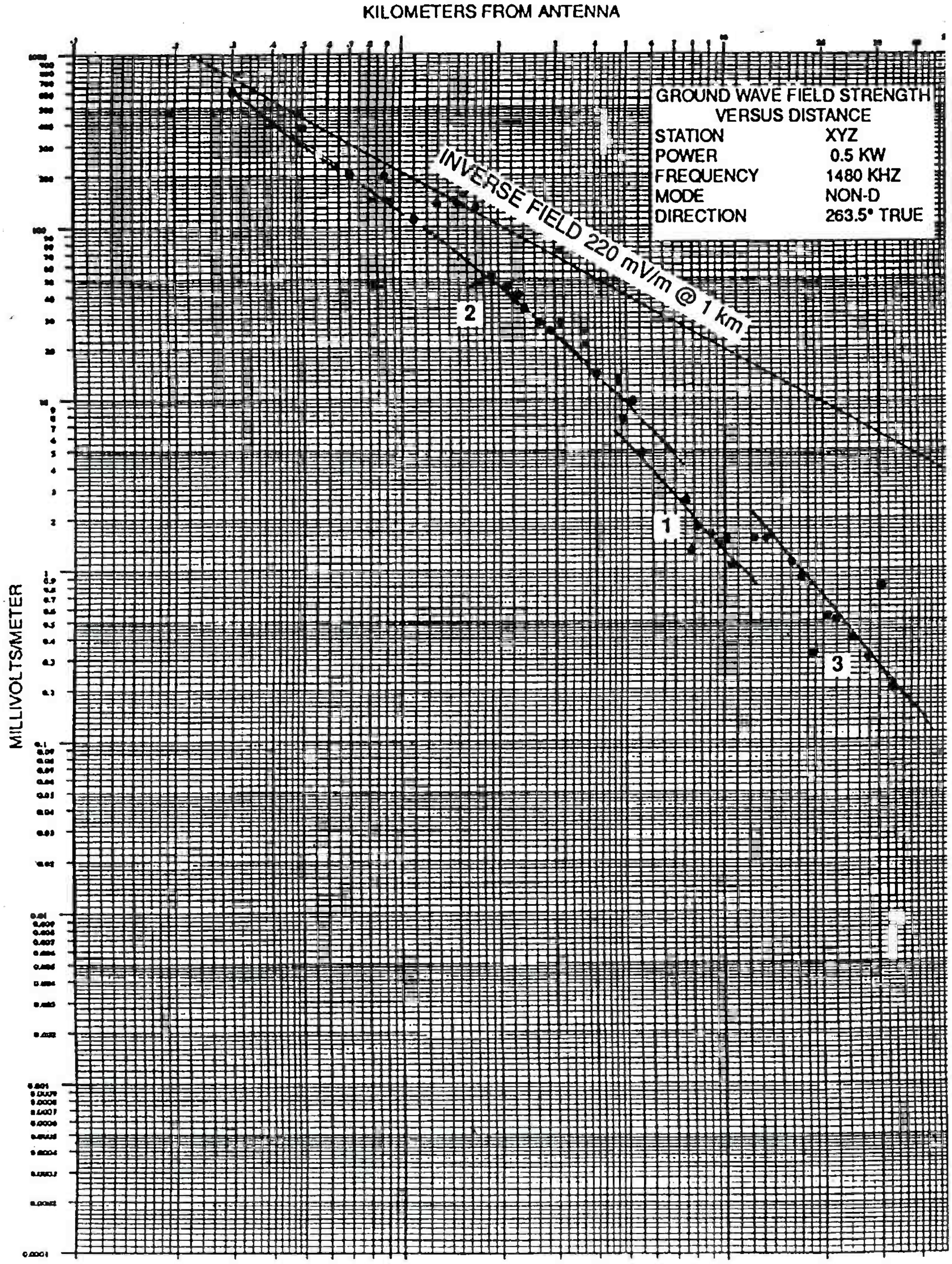
Remeasure the common point impedance and readjust the common point network as required. It is important to make sure the correct amount of power is being delivered to the input of the antenna system. Now is a good time to make your resistance and reactance measurements every 5 kHz either side of the operating frequency as required.

With that accomplished, recheck your field sample points. If they are back to field strength values close to what they were before the driving point measurements and any readjustment, it's time to begin the directional proof. Start by measuring the minimas at 106.5°, 149°, 221°, and 263.5°. If these inverse fields are within the envelope of the standard pattern, then the probability is good that the minor lobes at 92°, 131°, 185°, 239° and 278°will be within specifications. The 5 remaining radials in the major lobe should be the last to be measured.

Ratio the DA measurements to those collected in the non-D proof. They are also to be plotted. Figures 5-9A and 5-9B show the tabulated data on the field log for the 263.5° radial. The ratio of DA to non-D measurements has been done using the logarithmic method. The non-directional inverse field along this azimuth, using 500 watts of power, has been determined to be 220 mV/m. The log average of the 31 ratios is -1.232. The antilog of this number is 0.059. Therefore, the DA-N inverse field along this radial is 12.9 mV/m (220 X .059).

Figure 5-10 shows the plotted non-D data. Note that the ground conductivity is 2 out to about 5 kilometers. At that point there is a break and the conductivity is 1 out to approximately 11 km. From that point it fits well to the ground conductivity curve of 3. Figure 5-10 shows the plotted directional data. Note that there is a considerable amount of scatter in the plotted data. This is not at all unusual when the inverse field is very low. A power of just a few watts radiated non-directionally on one of these towers would produce an inverse field of 12.9 mVm.

Figure 5-10



the non-D measured field strengths along the 263.5° radial

with a power of 500 watts the inverse field is determined to be 220 mV/m @ 1 km

the ground conductivities are 2 out to about 5 km - 1 from 5 to 11 km - and 3 from 11 km to 34 km

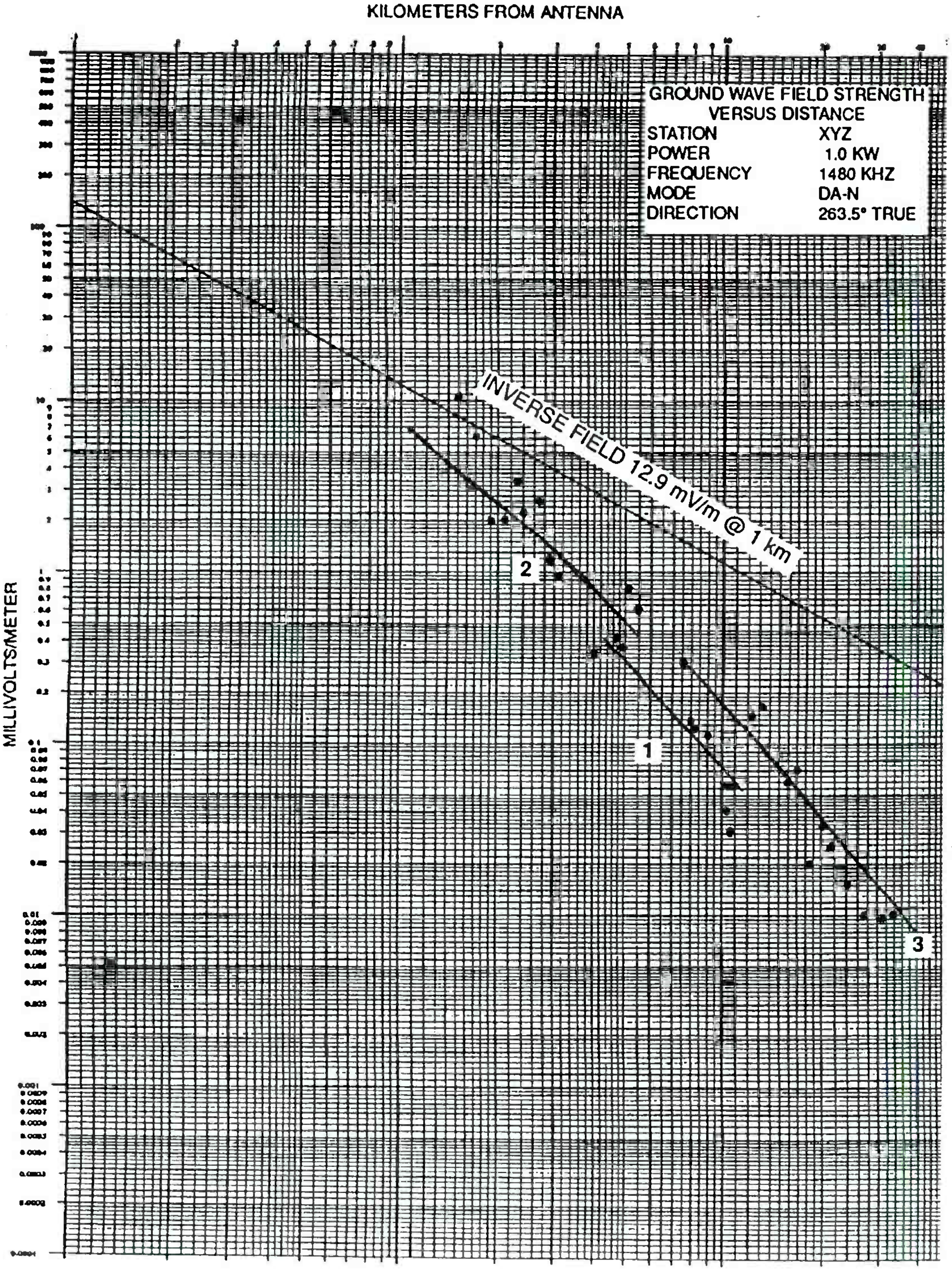
As you near the end of this radial, measured DA-N signal strengths will be very low. You may experience interference from co-channel stations. A beat between carriers will occur - evidenced by the rapid swing of the meter pointer. Note the maximum and the minimum reading of the meter. When you complete your measurements along the radial, average the two readings. Record the average in your data log. Use it to compute the average ratio for the radial. Also, make a note of this to be included in the engineering report.

Figure 5-10

the1.0 kW DA-N measured field strength along the 263.5° radial

the inverse field is determined to be 12.9 mV/m @ 1 km

the ground conductivities are 2 out to about 5 km - 1 from 5 to 11 km - and 3 from 11 km to 34 km were determined when the non-D proof measurements were plotted and analyzed



In addition, when you take field strength measurements in a deep minima you are apt to see the indicating instrument jump around with modulation. This is not an unusual occurrance. When you listen to the signal along such a radial it sounds like it is distorted and over modulated. This condition is due to the antenna system attenuating the carrier more than the sidebands.

Once you have completed all of the measurements, and find all of the directional inverse field strengths contained within the envelope of the standard radiation pattern, you can summarize your data, determine the RMS of the pattern and select permanent monitor points on the radials where required.

All of our tabulated measurement data for the non-directional proof, the day time directional proof and the night time directional proof will become part of the engineering exhibit to be submitted to the FCC as part of the application for a license. The measured non-D and DA impedance data, the descriptions and maps of how to get to the monitor points, a photograph of each monitor point, along with the topographic maps used in making the proofs with measuring point locations marked on them, and an FCC 302 form also become part of the license application

With the installation and adjustment of the systems complete, let's move on to the problem of keeping the patterns in adjustment and repairing the system when - and if - disaster strikes.

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Chapter Six

Directional Antenna Maintenance

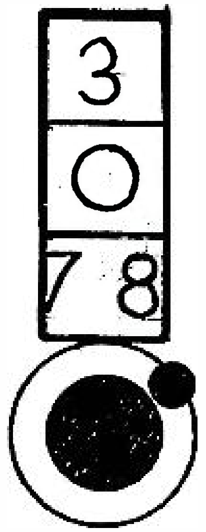
6.01 Preventative Maintenance

While the array is working, there are several things you can do to make life easier later on. First: Put all of the maps and descriptions of the measuring points in a safe place. If and when you have to do a partial proof-of-performance on the system, you won't have to buy new maps, reconstruct the radials and guess as to where the actual point of measurement was located. Time dulls memories!

Write down the exact position of every adjustment on the front panel of the phasor. Use the method shown in Figure 6-1. Mark down the exact positioning of the counter. You will be able to come back very close to the original point should a disgruntled employee or a Mr. Fix-it decide to take it upon himself to make some adjustments to the array! Take some hobby paint - two different colors if you have two patterns - and mark the position of every tap on every inductor. Also mark the position of each roller on adjustable inductors because couplings have been known to slip thus making your notations of counter setting useless! Use one color for the day pattern components and one for the night pattern components. The two colors are especially important if coils are shared between patterns

Figure 6-1

make a note of the exact positioning of each counter on the front panel of the phasing cabinet



Make a permanent record of all the measured - not calculated - driving point impedances. If you inherited the array, and there is no record, measure and record these values. Measure and record the self impedance of each radiator with the others floating. It's not a bad idea to mark these on the schematic of the directional antenna feeder system. Measure and mark on the schematic the reactance values of each leg of every matching and phase control network.

With the aid of an impedance bridge, measure the resonant frequency of each transmission line, first opened at the LTU end, then shorted. In the event of a suspected transmission line problem this information makes for easy verification or elimination. Record this data on the DA feeder schematic. All of this may seem like a lot of work but can pay dividends later when there is a failure.

Open each phase sampling line at the LTU. Measure its resonant frequency both open and shorted. This can help you later isolate antenna problems from sampling system problems.

If your system uses thermocouple ammeters for measuring base currents and common point current, mark each as to its proper location, then take them out of the circuit, string them in series with the feed to your dummy load and apply enough RF power to have the lowest scale meter read about 80% of full scale. Compare the readings of each. It's better to know about a discrepancy before there is a problem than to pull your hair out trying to correct an out of tolerance problem should you ever have to replace the meter.

Roller inductors tend to become welded in place when they are not exercised on a regular basis. After sign off, every three months or so, exercise each phasor control by turning it one full turn clockwise then one full turn counter clockwise from its normal position. If it's too hard to turn, stop. Forcing it will break the shaft or the gear in the vernier drive. Investigate the cause of binding. It can usually be traced to corrosion in a bushing through which the shaft travels, corrosion of the roller where it moves along the shaft when adjusted, or the roller becoming welded to the coil due to arcing. It's not a bad idea to keep spare roller contacts for the inductors in stock. Clean the coil where the weld has taken place and/or the shaft along which the roller moves. Use a very fine emery cloth. Replace the roller contact. It's far better to find and correct this type of problem before an adjustment must be made. At that point, you could have two problems on your hands!

Periodically check the contacts on the pattern change relays. There should be some play in them so that any slight misalignment of the fingers does not put undue stress on the stationary contact. Also check the contacts for any signs of arcing or heat. An open feed to a tower will cause panic at pattern change time!

Make sure that J-plugs are well seated into the jack. Some phasors are constructed with the plugs hanging down. Constant vibration caused by the twice a day movement and seating of RF contactors will eventually cause upside-down plugs to fall out of the jack. This is just as bad as an open tower feed! Take a vinyl tie wrap and fasten the plug into the jack so it can't fall out. Cut the tie if you must remove the plug.

Loose RF connections can be a cause of intermittent problems. Periodically check the feed between the LTUs and the towers. Each 1/4-20 bolt connecting strap or copper tubing to a component should have a split type lock washer under the nut. If it doesn't it is apt to come loose and become the source of a problem. Check connections for tightness on a regular schedule.

The tubing that passes through a toroidal sampling transformer or an RF meter pickup transformer should be centered in the pass hole. Tubing that touches one side of the pickup device can be the source of an arc during an electrical storm. This can damage or destroy the sampling transformer.

Clean the LTU cabinets or shelters on a regular basis. Rodent and other wildlife find these places to be attractive homes. It's amazing what a mouse nest or a birds nest inside an inductor can do to operating parameters. Ideally the cabinets or shelters will be rodent proof. That's the ideal; most are not! Clean the surfaces of mica and vacuum capacitors on a regular basis. A heavy accumulation of dirt across the face of a capacitor - especially a vacuum capacitor with a glass envelope - can be the invitation to disaster. Where high RF voltages exist, an arc across the face of the capacitor - between terminals - can crack the glass and release the vacuum. That means the end of the useful life of the capacitor!

Check all ball and horn gaps on a regular basis. Ball gaps separated by six inches aren't apt to do much good in an electrical storm. They should be separated by about a half inch wider than the spacing where they will arc under 100% modulation.

The static drain on each tower should be visually checked during each inspection of the system. In addition, an ohm meter will verify that it is still capable of doing its job. A static drain choke is useless if it is open. An open choke usually has no effect on operating parameters, thus is can easily go unnoticed. The only noticeable effect might be an unusual amount of static discharges tripping the transmitter VSWR circuitry. An open drain is an open invitation to component damage in the LTU network.

Measure the monitor points on a quarterly basis. Abrupt changes might indicate a system problem. A change in common point impedance - manifesting itself as an apparent change in transmitter efficiency - can be an indication of a component drifting in value.

6.02 Corrective Maintenance

Sooner or later there will be a sudden change in the operating parameters of the antenna system. The operator of almost every directional antenna system will experience this - it's just a matter of WHEN. This frequently comes during nature's display of fireworks - an electrical storm! Any radical change in a component value, be it an inductor or a capacitor, will be accompanied by a large change in antenna phase indications and current ratios. In addition, the common point impedance will radically shift in value. Solid state transmitters do not work well into unusual loads. In many cases the transmitter VSWR circuitry will keep it off the air when this happens.

The first step is to make a complete visual inspection of the system. Carefully look at each component in each LTU. When lightning is the culprit the LTU, being the first line of defense, usually takes the brunt of the punishment.

Inductors are a favorite target. There may be no evidence of overheating or burn marks but there are occasions when coil windings jump off the form on which they are wound. This type of damage is very visible. It is caused by a very fast rise time of an enormous amount of lightning current through the inductor. The rapid buildup of a magnetic field causes the mechanical damage. A temporary cure is to pry the windings back on to the form. They usually can be made to stay in place until a replacement coil becomes available. Also, look for signs of heating or arcing. Coil windings have been known to be burned open by a lightning hit. Check the roller contacts on variable inductors.

Capacitor failure can be another result of a lighting hit. See if the transmitter will come up under low power. This will be enough to give you some indications on the antenna monitor. Look at loop current ratios and phases. They will be way off base but careful scrutiny and comparison to normal parameters will usually reveal one tower's parameters to be farther out of line than the others. This is the likely place to start. Measure each capacitor in that tower's LTU network with a bridge. You are not looking for a small variation from normal value. More than likely the reactance will have changed by 50 percent or more. If you don't find it in the first LTU measure the capacitors in the others.

On occasion, the large currents and high voltages present during a lightning strike are able to find their way into the phasor. If all of the inductors appear to be intact, start measuring the value of capacitors in the phase control networks.

If there is a tower in the array that has STL antennas, RPU antennas or an FM antenna on it check its self impedance. Where an insulated 90 degree section of transmission line is used to isolate the line from the tower, the shorting strap(s) at the quarter wavelength point should be checked by a competent tower climber. They have been known to burn off. This causes the self impedance of the tower to change, sometimes radically. In turn the driving point impedance is affected.

Where the feed line for antennas on a tower is brought across the base insulator with an isocoupler, check it with an ohm meter for a short. A problem in this area usually will also cause the auxiliary system (STL, FM or RPU) to become inoperative.

strap that comes disconnected can cause a shift of 10% or more in the self impedance of the tower. When you repair damage of this nature make sure you add more ground straps to the fence.

A broken guy wire insulator can cause a change in the self impedance of the tower. If it's one right at the tower the change can be radical. If it's out in the middle of the guy wire the change in operating parameters and self impedance will be more subtle. The guy wire can, however, act as a parasitic radiator.A pair of binoculars is a good maintenance tool for locating this kind of trouble.

Section 73.62 of the Rules sets out certain tolerances for directional antenna operating parameters: Base current and antenna monitor loop current ratios must be maintained within ±5% of their licensed values. Phase relationship between elements in the array must be within ±3° of the licensed values. Drifting operating parameters can usually be traced to a capacitor slowly changing value. However, before jumping to conclusions, first check the monitor points. If they remain stable, the change in parameters you are observing might be caused by a problem in the sampling system. Section 6.07 gives some hints on dealing with this type of problem. After a sampling system problem has been ruled out, immediately after sign off check each capacitor in the system for heating. Warm is OK - especially in a high power system. Too hot to touch makes the capacitor a prime suspect. If you measured the reactance of each leg of each LTU and phase control network, as suggested under preventive maintenance, remeasure and compare them to previous values.

A large change in one operating parameter of a directional antenna system (i.e. one phase or one loop current) will always be accompanied by a change in the other operating parameters. If this is not the case you more than likely have a sampling system problem.

The operator of a directional antenna system should have a supply of spare transmitting capacitors on hand. A few mica caps of selected values are worth their weight in gold when a system failure occurs. A multitude of reactances can be obtained by hooking the spares in series or parallel, or even series-parallel arrangements. This will enable you to resume operation with some sense of normalcy even if it is at reduced power. These capacitors need not be new. Hamfests are a source of inexpensive shelf spares that serve well in an emergency.

Section 73.1680(b)(1) of the rules authorizes non-directional operation in an emergency situation. Generally, this must be at no more than 25% of the authorized directional operation. Such operation is subject to termination in the event of an interference complaint.

Some DA systems are equipped to switch to non-D operation with the push of a button even when this is not a normal mode of operation. Operation under 73.1680 is simplified when such provisions are available. The LTUs are set up to match the driving point impedances of the radiators. Any non-directional operation will require a match between the transmission line and the self impedance of a tower. It is prudent for the operator of a system not so equipped to give some advance thought as to how emergency non-directional operation might be accomplished should the need arise. A seasoned engineer would probably consider it prudent to set up one of the LTUs for non-D operation one evening after sign off. The straps necessary to connect the transmitter directly to the feed line might be fabricated and stored in a safe place for the day they are needed. With taps marked and jumper straps available, it's a simple operation to quickly get back on the air in this mode when/if the need arises.

6.03 How to Make a Partial Proof-of-Performance

After a directional antenna system has been licensed and operating, there are situations where it will become necessary to show that the radiation pattern it is producing is still in compliance with what was authorized in the original construction permit. The nearby construction of cellular telephone or other type of structure, changes in the sampling system, changes in measured field strength at a monitor point, replacement of a tower, the hanging of an FM or STL antenna on one of the radiators; these are all situations that call for partial proof-of-performance measurements on an existing directional antenna system.

The methods to be employed for making and analyzing partial proof-of-performance measurements on a directional antenna system are detailed in Section 73.154 of the FCC Rules. Field strength measurements must be made on at least 10 points on each of the radials measured during the last complete proof-of-performance. The measurements are to be made within 3 to 16 kilometers (2 to 10 miles) from the center of the array. If a monitoring point is located on the radial it is one of the points that must be measured.

The results of the measurements may be analyzed in either of two methods: Either the arithmetic average or the logarithmic average of the ratios of the field strength at at each measurement point along each radial to the corresponding field strength in the most recent complete proof-of-performance may be used to establish inverse distance fields.

In essence: We are going to make an effort to measure all of the points on each radial, between 3 and 16 km (2 to 10 miles) that were measured when the last complete proof was done. There should be at least 10 points on each radial located within this distance. If there are not, then we will measure a previously measured point or two at a distance less than 3 km distance and/or a point or two beyond 16 km. Some previously measured points may not be accessible or identifiable due to changes that come with time. A recently constructed interstate highway along a radial might make new measurements in several locations impractical or impossible. Again, if there are less than 10 accessible points within the prescribed distance, then do a point or two before or beyond. Try to include more than the minimum of ten. If you have a measured point that is far above or below what was previously measured it can be discarded.

A year after our 2 tower day/4 tower night array is put into operation an STL antenna is to be installed on tower #3. Before starting construction/installation a partial proof will be done on both the day and the night patterns. You will have to measure 24 radials - the original 10 for the day pattern and the original 14 for the night pattern. Time and date are necessary when this data will be submitted as part of an application. Question 11 on the 313 Form for a license to operate the STL system asks if the STL antenna is mounted on an AM radiator. Your YES answer to this question will alert the Commission to look for supporting information and documentation about the operation of the broadcast antenna. They will be most interested in what effect the mounting of the dish, transmission line and isocoupler had on the operation of the directional antenna system. The big question will be, "is the directional antenna system still producing a radiation pattern that falls within the envelope of the standard pattern?" You may also have to submit a 302 Form for direct measurement of power if the operating parameters of the array, as adjusted to produce the radiation pattern after the installation, are substantially different than the previously licensed values.

To begin, you will need a copy of the last complete proof-of-performance measurements. They should be part of the files available in the event of an official inspection. If you can't find these documents and know the name of the consultant who worked on the system, they might have a copy available. If you strike out there you can have International Transcription Service, 2100 M Street NW, #140, Washington, DC 20037 - telephone 202-857-3800 - make a copy of the data filed with the Commission. They will do this for a nominal fee.

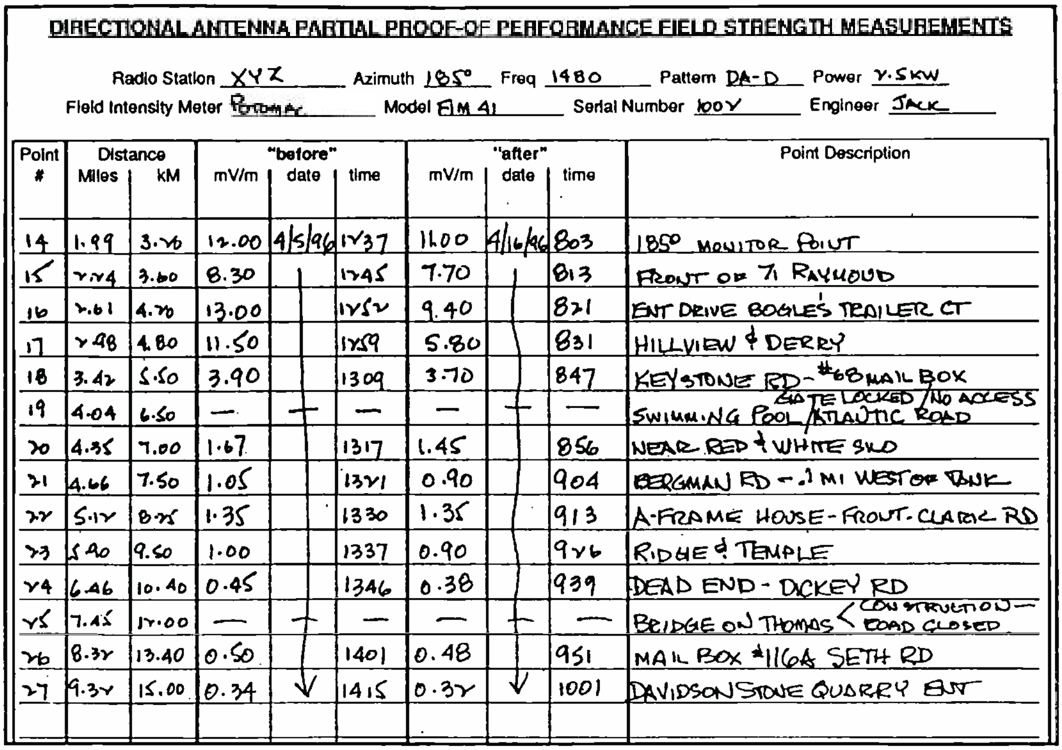
If the topographic maps used to make the last proof are in your possession, your job will be made a lot easier. Reduced size copies of the maps are part of the engineering report submitted with the application for a license. These are not suitable for finding the original measuring locations. The scale is too small and their reproduction is usually of poor quality. In this case, you will have to acquire new maps (see section 4.02, page 97). Draw the radials on them as described in Section 4.02. With the aid of the map copies in the engineering report and the original tabulated measurement data, which includes point numbers and distance from the center of the array, mark the measurement points on the new maps. Identify each by the number assigned in the complete proof. This is not as difficult as it might appear. When you measure the distance recorded in the tabulation on the map you will usually find a road intersection with the radial at the correct place. If you have the original point descriptions, all the better. When you arrive in the area of the point, chances are you will be able to identify the exact location where the measurement was previously made. If lady luck isn't with you, and the descriptions are not available, make the measurement based on your identification of the point by the map. This time write your own point descriptions should it be necessary to someday return for another partial proof!

The same general rules for making field strength measurements discussed in section 4.06 should be observed. Measurements made directly below overhead wires or in close proximity to a new water tank or two-way tower will probably be far from what was measured at this distance in the last proof. It's better to move a couple of hundred feet or so away from such a structure and be slightly off the radial than to utilize what surely will be suspect measurement data. If you have more than the minimum required 10 points this one can be eliminated from the average.

The field-log form for making a partial proof is shown in Figure 6-1. Note that it contains columns for "before" and "after" measurements. Frequently it is advisable to do a partial proof before modifications to a system take place (i.e. hanging an FM antenna on a radiator in an existing array, construction of a nearby cellular tower, etc.) and after modification and readjustment is complete. This scenario puts all the cards on the table! If the array is in adjustment before changes are made, the measurements prove it. If there are existing problems, you will be well aware of them before introducing another variable.

Prior to trotting off with the field intensity meter, prepare the logs. Enter the data at the top. (There's not much point in having ten measurements and not knowing which radial or pattern they came from!) Enter point number, distance and point descriptions if they are available.

Be careful in recording your data. It is easy, especially if you skip a point for one reason or another, to record the measured field strength data and identify it by the wrong point number.



DIRECTIONAL ANTENNA PARTIAL PROOF-OF PERFORMANCE FIELD STRENGTH MEASUREMENTS

Radio Station XYZ Azimuth 185° Freq 1480 Pattern DA-D Power 2.5KW
Field Intensity Meter Potomac Model FIM 41 Serial Number 1002 Engineer JACK

Point #	Distance Miles	Distance kM	"before" mV/m	"before" date	"before" time	"after" mV/m	"after" date	"after" time	Point Description
14	1.99	3.20	12.00	4/5/96	1237	11.00	4/16/96	803	185° MONITOR POINT
15	2.24	3.60	8.30		1245	7.70		813	FRONT OF 71 RAYMOND
16	2.61	4.20	13.00		1252	9.40		821	ENT DRIVE BOGLE'S TRAILER CT
17	2.98	4.80	11.50		1259	5.80		831	HILLVIEW & DERRY
18	3.42	5.50	3.90		1309	3.70		847	KEYSTONE RD - #68 MAIL BOX
19	4.04	6.50	—		—	—		—	GATE LOCKED / NO ACCESS SWIMMING POOL / ATLANTIC ROAD
20	4.35	7.00	1.67		1317	1.45		856	NEAR RED & WHITE SILO
21	4.66	7.50	1.05		1321	0.90		904	BERGMAN RD - .1 MI WEST OF TANK
22	5.12	8.25	1.35		1330	1.35		913	A-FRAME HOUSE - FRONT - CLARK RD
23	5.90	9.50	1.00		1337	0.90		926	RIDGE & TEMPLE
24	6.46	10.40	0.45		1346	0.38		939	DEAD END - DICKEY RD
25	7.45	12.00	—		—	—		—	BRIDGE ON THOMAS < CONSTRUCTION — ROAD CLOSED
26	8.32	13.40	0.50		1401	0.48		951	MAIL BOX #116A SETH RD
27	9.32	15.00	0.34		1415	0.32		1001	DAVIDSON STONE QUARRY ENT

Figure 6-2

a suggested partial proof field log for recording "before" and "after" field strength measurement data

Remember, we are going to compare new measurements with previous measurements. If we are comparing apples to oranges it's meaningless. Where you skip a point on your log immediately draw a line through it. This helps prevent this kind of error.

When you have completed measurements along a radial the measurement data should be transferred to another sheet to be analyzed. The form illustrated in Figure 6-3 works well. Here we have taken all of the measured data from our field log and have transferred it to the worksheet. Each new measurement it ratioed to the original DA measurement made at the same location. The new measured value of field strength at each point is divided by the field strength at that location recorded in the last complete proof. Enter the ratio in the appropriate column. Call up the logarithm of the ratio on your calculator and enter it in the log column. When you have completed your partial proof a quick glance at these work sheets will tell you which method best fits the data you have collected.

Add up all the ratios and divide the result by the total number of measurements recorded on the worksheet. This is the average arithmetic average ratio. Add all of the figures in the log column. Again, divide the result by the total number of measurements recorded on the worksheet. Call up the antilog of this number on your calculator. It is the logarithmic average.

Going back to the complete proof, find the inverse field produced on this radial for day time operation. It is 59.20 mV/m. Enter it in the space provided at the top of the worksheet. Also enter the arithmetic and log averages in the spaces provided. Now, multiply the original inverse field of 59.20mV/m by these averages. Using the arithmetic method, we calculate the new inverse field to be 69.86 mV/m. Using the log method, 67.84 mV/m. Follow the same procedure for each radial on each pattern. Remember, the "after" inverse fields must fall within the envelope of the standard radiation pattern to be acceptable.

Figure 6-3

a convenient worksheet for analyzing the field strength collected data in the "before" and "after" partial proofs of performance

PARTIAL PROOF-OF-PERFORMANCE MEASUREMENTS
WORK SHEET

Radial 185° Station XYZ Pattern DA-D Power 2.5KW

Original DA inverse field mVm 59.20

"before" Arithmetic Average Ratio	1.180	"before DA inverse field mV/m	69.86
"before" Logarithmic Average Ratio	1.146	"before DA inverse field mV/m	67.84
"after" Arithmetic Average Ratio	0.986	"after DA inverse field mV/m	58.37
"after" Logarithmic Average Ratio	1.073	"after DA inverse field mV/m	60.56

Point	Distance		Orig DA	"before"			"after"		
#	Miles	KM	mV/m	mV/m	ratio	log ratio	mV/m	ratio	log ratio
*14	1.99	3.20	11.00	12.00	1.091	.038	11.00	1.000	.000
15	2.24	3.60	7.60	8.30	1.092	.038	7.70	1.013	.006
16	2.61	4.20	8.00	13.00	1.625	.211	9.40	1.175	.070
17	2.98	4.80	5.70	11.50	2.018	.305	5.80	1.018	.008
18	3.42	5.50	3.30	3.90	1.182	.073	3.70	1.121	.050
20	4.35	7.00	1.40	1.67	1.193	.077	1.45	1.036	.015
21	4.66	7.50	1.05	1.05	1.000	.000	0.90	0.857	-.067
22	5.12	8.25	1.30	1.35	1.038	.016	1.35	1.038	.016
23	5.90	9.50	0.83	1.00	1.205	.081	0.90	1.084	.035
24	6.46	10.40	0.55	0.45	0.818	-.087	0.38	0.691	-.161
26	8.32	13.40	0.50	0.50	1.000	.000	0.48	0.960	-.018
27	9.32	15.00	0.38	0.34	0.895	-.048	0.32	0.842	-.075
Average Ratio					1.180	.059		0.986	-.010
Antilog						1.146			1.073

* = monitor point

Note that the "before" inverse field, as calculated by the arithmetic method, falls slightly above the 68 mV/m field specified for this radial in the original CP. The same data when analyzed using the log method falls slightly below the limit. The "after" field strength measurements analyzed both ways show the inverse field strength to be well within limits.

Prepare a summary sheet showing, for each radial, the "before" and "after" ratios, the "before" and "after" inverse field strengths and the standard pattern value of inverse field.

6.04 Relocating a Monitor Point

Monitor points are meant to provide an easy means of sampling the radiation pattern to ascertain if the directional antenna system is in proper adjustment. Specific monitor points will be specified on the station license. Each will have a maximum value of permitted measured field strength assigned. If the field strength at the monitor point is only influenced by a rise or fall of the inverse field along the radial on which it is located, it will be a reliable indication of the operation of the DA system.

Sometimes a monitor point becomes unsuitable. Construction on or nearby the point might make the measured field strength go way high or fall to a very low value. A point might become inaccessible due to construction or removal of a bridge. At other times a point might just become bad where the measured field increases for no apparent reason.

When the latter occurs you should make sure that the measured field strength at the point is all that has changed and not the field strength at all the points along the radial. Measure a previously measured point or two either side of the monitor point. If they have increased then you probably are faced with an increased inverse field on the radial. This is corrected by readjustment of the array. If the measurement at the monitor point is all that has increased then the point itself is suspect.

Section 73.158 of the Rules provide for the relocation of the point:

1) A partial proof-of-performance must be conducted on the radial on which the monitor point is located.
2) Ratio and analyze the measurements as provided for in the previous section (6.03)
3) Select a new monitoring point on the radial (Use the criteria in section 5.10)
4) Write a description of the routing to the new point
5) Draw a map showing the location and routing to the new point
6) Take a photograph of of the new point
7) Submit an informal application to the FCC containing the information specified in steps 2, 3, 4, and 5 above

A modification of the existing station license will be issued. It must be posted with the original station license.

If the description to an existing monitor point specified in the station license is no longer correct (due to construction, a closed road, etc.) an informal application to the FCC for a corrected station license must be prepared and submitted. It must contain the information contained in 4 and 5 above.

6.05 Hanging Other Antennas on One of the Directional Antenna System Radiators

Figure 6-3

the proper method of introducing an FM or auxiliary communications transmission line onto a grounded AM tower

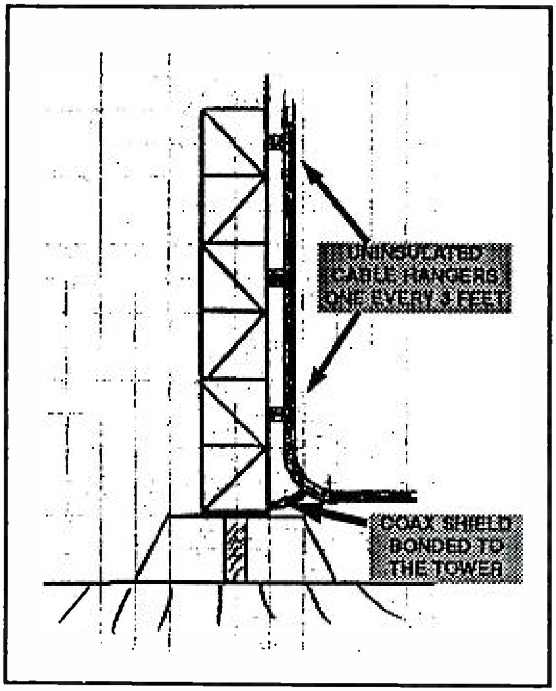
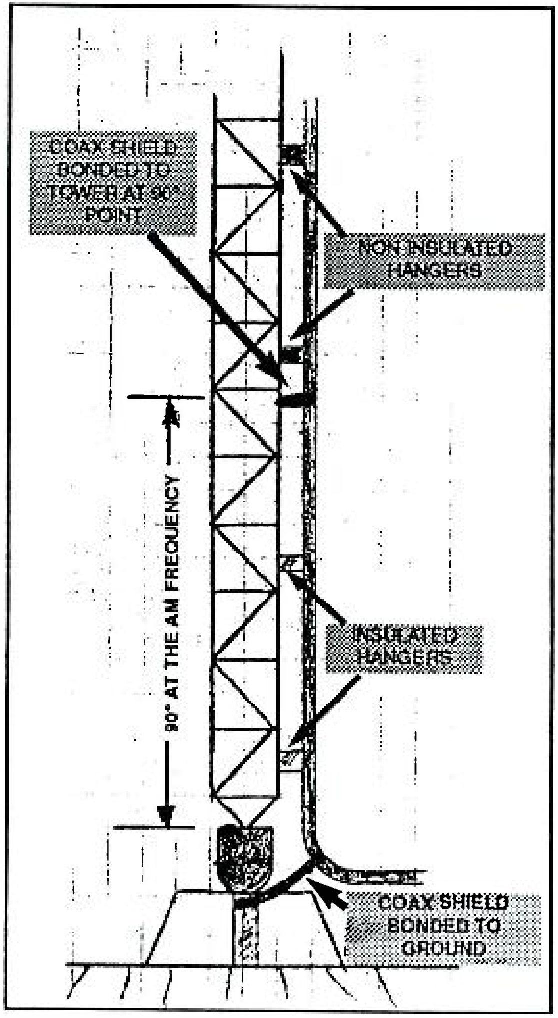


Figure 6-4

FM or auxiliary transmission line isolated at AM frequency by a quarter wave stub



The towers that make up a directional antenna system are ideal supports for FM broadcast antennas, the receive antenna of a microwave studio transmitter link, remote pick up receive antennas and other communication antennas. More than one antenna may be hung on a tower. More than one of the towers may be used for this purpose.

Where a unipole or other type of grounded radiator is used, the only requirement is that the shield of each coaxial cable running up the tower be securely bonded to the tower at its base. Where base insulated series fed radiators are used in the DA system, special provisions must be made to bring the coaxial transmission line for the other antenna(s) across the insulator. Obviously, if these provisions are not made the purpose of the insulator is negated and an RF short circuit at the AM frequency will exist.

Before beginning any of these modifications to a tower that is part of a directional antenna system, it is advisable to make a partial proof-of-performance on the system. Immediately before beginning any modifications take a good set of operating parameters. Base currents and their ratios, loop currents and their ratios and phases should be recorded without modulation. After the installation has been completed you will want to readjust - if necessary - the operating parameters back to these exact values.

There are three ways to accomplish this: A 90 degree insulated transmission line; an isocoupler; or an isolation coil.

Where the antenna is located more than a quarter wavelength up the tower (90 degrees at the AM frequency) the transmission line is mounted on insulated hangers from the base to the quarter wave point. There the shield of the coaxial cable is bonded to the tower. This is a little short of 90 degrees in free space. The velocity factor of the transmission line is not taken into account as it serves only as a transmission medium for the FM or STL signal.

A practical way of locating the point where the shield should be shorted to the tower is to first measure the self impedance of the tower - before the antenna or line is installed. The line should be hung on insulated hangers to a point 20 or 30 feet above the calculated position of the shorting point. The shield of the line should be securely bonded to the ground system at the point it leaves the tower. Use a grounding kit supplied by the manufacturer of the coax for the proper size of cable. Then, with the climber on the tower, the impedance bridge should be set up. A temporary strap from the shield of the transmission line to the tower should be made at the calculated 90 degree point. This will require removing a small piece of the vinyl jacket from the coax and scraping some paint from the tower. The self impedance of the tower s again observed and noted. The temporary shorting strap should be moved down a few feet. If the impedance moves toward the originally measured self impedance you are on the right track. If not go up above the calculated 90 degree point with the shorting strap. Continue the process until you find the point where the self impedance is closest to the originally measured value. Install the permanent shorting strap - shield to tower leg - at this point. A manufacturer supplied grounding kit for the proper size coax and tower leg should be used for the permanent strap. Don't forget to tell the tower climber to weather proof the test points where he removed insulation on the coax and to touch up the paint where he scraped it off the tower to make the test shorts.

If you were able to bring the self impedance back to the same value it was before the installation of the line and antenna, the array will require little if any touch up adjustment. If you are not so lucky, some turning of knobs will be required to bring it back to the same current ratios and phases that existed before the installation.

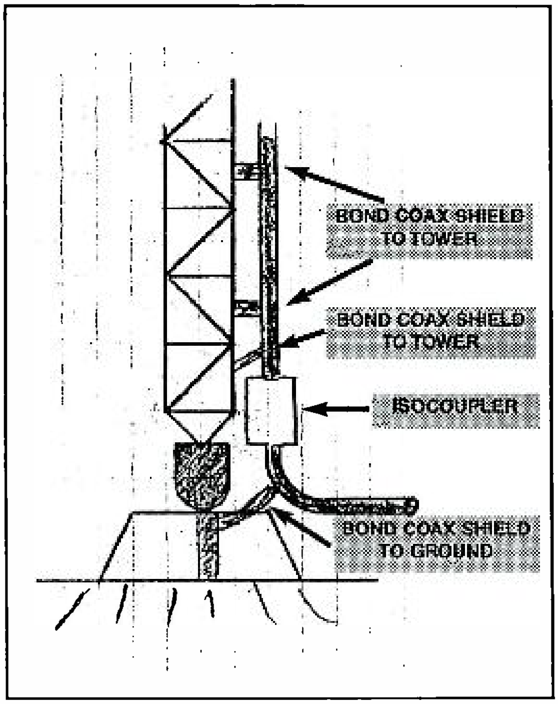


Figure 6-6

isocoupler used across AM base insulator

An isocoupler is a device consisting of two small inductors in close proximity to one another. RF energy at the FM or STL frequency is inductively coupled across the base insulator. It is installed at ground level just as the transmission line leaves the tower. The loss at the STL, FM or RPU frequency through the typical isocoupler is 0.5 db.

A Moseley isocoupler suitable for STL or RPU use can be mounted on the tower just above the base insulator. Install a non-insulated cable hanger about 2 feet above the insulator. Ground the cable to the tower with a grounding kit. Hang the cylindrically shaped isocoupler on the coax. Below the coupler mount an insulated hanger. The isocoupler is now supported on the coax between the two sets of hangers. Tie the low side of the coax shield to the ground system using a manufacturer supplied grounding kit.

A Kintronic isocoupler suitable for STL or RPU use is best mounted on a 4X4 treated post. Run a 2 inch strap from the ground system up the post grounding the isocoupler housing. Bring the coax off the tower into the top fitting of the isocoupler. The other I/O port on the this isocoupler is on the bottom. On the RF hot side of the coupler, securely bond the coax shield to the tower. On the cold side bond the shield to the ground system.

An isocoupler suitable for high power FM use is a larger device capable of handling many kilowatts of RF energy. It's not unusual to mount such a device - especially one intended for high power use - on a concrete pad adjacent to the tower base. Again, make sure the housing of the isocoupler is bonded to the ground system and the FM transmission line securely bonded to the tower at the point where it leaves the structure.

There are two considerations to keep in mind when choosing an isocoupler: the amount of RF energy to be transferred across the base insulator (i.e. the STL, RPU or FM transmitter power), and the amount of AM RF voltage that exists across the base insulator. The latter is dependent on the amount of AM RF power delivered to the tower and the driving point impedance of the tower. If you supply this information to the manufacturer they can recommend a suitable device.

The typical STL or RPU isocoupler introduces a small amount of capacity across the base insulator - about 9 to 30 pf depending on the manufacturer. The reactance at AM broadcast frequencies produced by this capacity is very high. It will have a minimal effect on the self impedance, thus the driving point impedance of the radiator. Minimal adjustment of the array should be required. A larger device, intended for FM broadcast use, will have a higher internal capacity. This will possibly necessitate considerable readjustment.

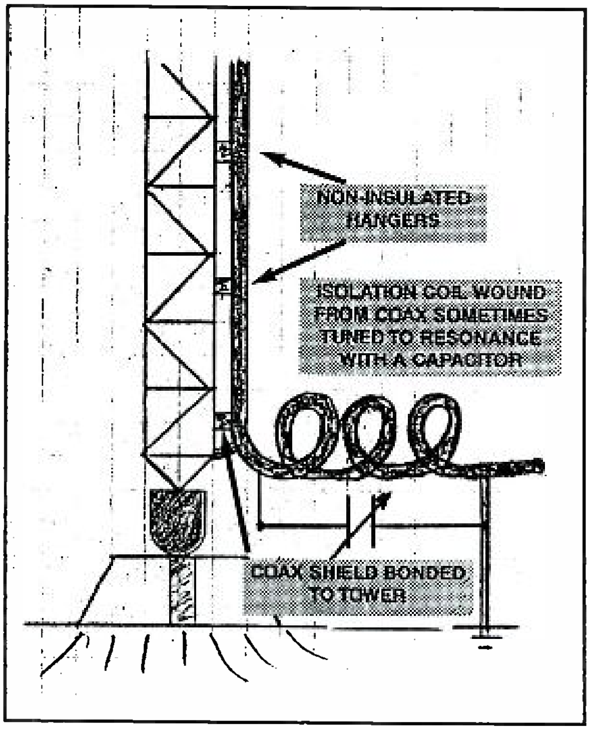


Figure 6-7

an isolation coil wound from coaxial cable is either used alone or sometimes in combination with a capacitor to form a parallel resonant circuit across the AM radiator's base insulator

A third method of bring a coaxial transmission line across the base insulator of an AM radiator is an isolation coil. The coil is wound out of coaxial cable of the appropriate size. For STL or RPU installation it is typically 1/2 inch or 7/8 inch cable. For higher power/lower loss isolation, coils wound form 1 1/4 inch and 1 5/8 inch cable are available. The loss introduced into the transmission line path is dependent on the loss through the length of coax from which the isolation coil is made. This, in turn, is dependent on the size and type of cable used to make the inductor.

The shield of the transmission line is bonded to the tower at the point it leaves the structure. The isolation coil is wound on a form and has coaxial connectors at each end. Electrically the inductor is across the base insulator. Physically it is usually mounted inside the LTU cabinet or a separate weatherproof housing. The bottom side of the coil is bonded to the ground system.

A 100 uH inductor will present about 1000 ohms of reactance across the base insulator at the top end of the AM band and about 350 ohms at 540 Khz. It is not uncommon to put a vacuum variable capacitor across the isolation coil and tune it to parallel resonance. This has the effect of raising the reactance to the point where it is hardly noticeable when placed across the base insulator of the AM radiator.

As previously mentioned, it's not a bad idea to make a "before" partial proof-of-performance on a DA system, even though it might not be required, before starting any of the installations described in this section. It will eliminate the possibility of throwing more variables into an already existing problem. You are far better off knowing that the array is working properly before beginning any modifications.

More than likely, some adjustment of the array will have to be made after the installation is complete. Parameters should be adjusted back to where they were previous to the installation of the antenna, transmission line and isolation device. Monitor points should then be measured. If they are not within tolerance some adjustment of the array as described in Section 5 will have to be made. When they are in tolerance, a partial proof is made. Measurements of the common point impedance is also required.

As part of the application for a license for the STL, RPU or FM facility, a showing must be made that the directional antenna system is adjusted to produce a radiation pattern that is contained within the envelope of the standard pattern on file with the FCC.

6.06 Detuning Parasitic Radiators

When a structure 45 degrees or more in height at the operating frequency, is located in a high RF field of an AM broadcast station, it will become a parasitic radiator. The AM broadcast station provides the energy to the parasitic radiator and it re-radiates some of it. This re-radiated energy can arrive at a specific location in-phase or out of phase with the energy from the DA system. The end result is distortion of the directional pattern.

Where the parasitic radiator is located close by and lays in the major lobe of the directional antenna system, a large re-radiated field will result. It might not be possible to adjust the array to produce minimas with low values of inverse field strength.

Obviously, it is not advisable to build a DA system near such a potential source of trouble. If there is no parasitic radiator there will be no problems. However, in this era of personal communications systems, sooner or later a cellular or two-way tower is apt to spring up. When they are last in it is their responsibility to bear the expense of detuning the structure and making a partial proof on your DA system. Make sure you go on record with the Commission as soon as you are aware of the possibility of such construction. Insist on input as to who does the detuning and the "before" and "after" partial proofs on your DA system - be it their consultant or your consultant.

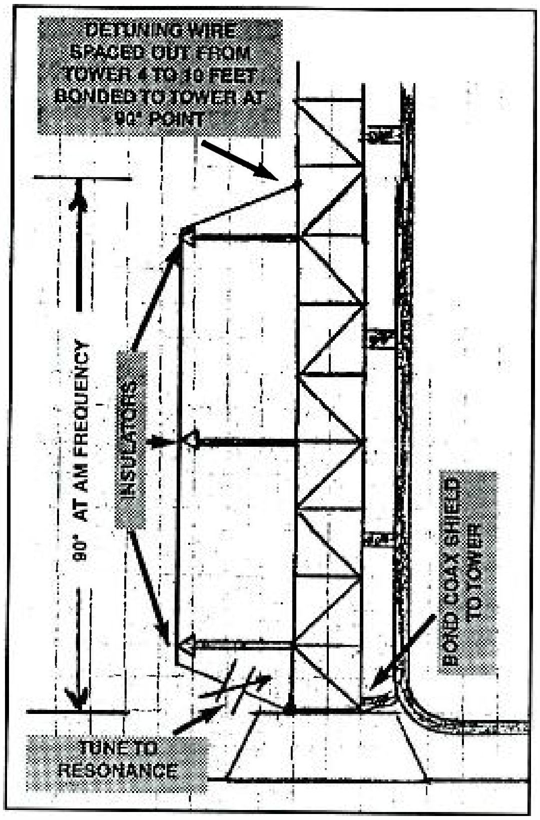
Take a field intensity meter and locate yourself about 200 to 300 feet away from the suspected parasitic radiator. The direction of the DA system, at the point where you are standing, should be at a 90 degree angle to the suspected parasite. Turn the meter slowly from its peak when pointed toward the directional antenna system until it is pointed at the suspect structure. If this is a source of trouble, the indicated field strength will not fall much or it might even indicate a higher field when pointed toward the parasitic radiator.

In Chapter 4 unused radiators were detuned. That was rather simple. There was a tower with a base insulator and a good ground system under it. A parallel resonant circuit from the radiator to ground was the device that made the unused towers ineffective parasitic radiators.

Parasitic radiators present a different problem. Water tanks, cellular or two-way towers, and steel light poles do not have base insulators nor do they have ground systems under them! The technique employed in Chapter 4 to detune unused towers in the array will not work.

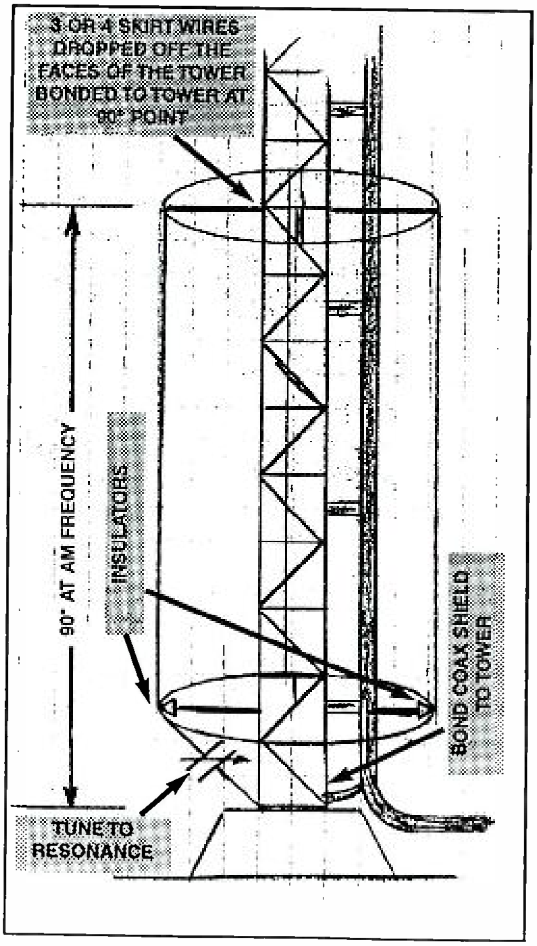
Back in Chapter 1 we discussed the grounded tower as an AM radiator. It is energized by a wire running up one side of it or a skirt of 3 or more wires dropped down the face of it. This same technique can also be used to render a "foreign" structure an ineffective parasitic radiator.

Figure 6-8



drop wire method of detuning a grounded communications tower

Figure 6-9



skirt method of detuning a grounded communications tower

Where the culprit is a communications tower or a tall metallic light pole, it can be detuned with a single wire dropped down the face of it. The wire should be suspended 5 to 10 feet off the face of the tower. It must be securely bonded to the tower at the top and supported on brackets with insulators at intervals of about 50 feet down the tower. Inch and a half steel angle make good support brackets. Don't depend on the angle for an electrical connection at the top. Take the wire back to the tower. Make a good electrical connection and weather proof it. Near the base, a variable capacitor is installed in a weather proof box mounted a few feet up the tower. The capacitor is connected between the wire and the tower. A good electrical bond to the tower is necessary. A vacuum is the capacitor of choice. There isn't much RF voltage to contend with but stability of this high-Q circuit is of importance if the structure is to stay detuned. Figure 6-8 is a functional drawing.

Self supporting towers and large diameter water tanks can be most effectively detuned by installing a skirt. Three wires, spaced at 120 degree intervals around the tank, are installed. They must be electrically bonded to the tank either at the top or if it especially tall, at the 90 degree point above ground. A variable capacitor is connected between the lower end of the skirt and the base of the structure. Figure 6-9 is a functional drawing of the detuning skirt. Where the tower is less than 90 degrees in height, the skirt will be dropped from the top. Where it is more than 90 degrees tall the skirt should be installed at the quarter wave point.

The field intensity meter set up on a tripod is used as an indication of resonance. This is procedure is discussed in section 4.04.

To further assure electrical stability of the detuning stub or skirt, the shield of all coaxial transmission lines running down the face of the structure must be electrically bonded at the point they leave it. Use manufacturer's grounding kits for this purpose. AC wiring for obstruction and hazard lights should be bypassed to the tower with .001 or larger capacitors at the point they leave the structure.

6.07 Troubleshooting the Antenna Sampling System

Is it an antenna problem or is it a sampling system problem? This is a question that must be answered before you even think of making any adjustments. Isolate the problem to either the directional antenna system or the antenna sampling system. Here are some procedures to help you make that determination.

Measure the field strength at the monitoring points. If they haven't changed you have a sampling system problem. If a loop current ratio changes you should also see a change in base current ratio. This is especially true of you are using torroidal current transformers for pickup devices. A change in phase of more than a degree or two will also be accompanied by a change in loop current and base current ratio. If this is not the case a sampling system error is to be suspected. A defective torroidal current transformer can cause a change in loop current without affecting phase. Move the pickup transformer to another tower. If the discrepancy follows the transformer you have identified the problem.

If you are using thermocouple type ammeters in the base of the towers, make sure that meter switch is in the position that takes the meter out of the circuit. In addition to inviting an open tower feed in the event of a lightning strike, when the meter is in the circuit it is likely to introduce a few degrees of phase lag even when a compensation loop is part of the meter switch.. Operators have been known to try to adjust phase controls to compensate for this change in operating parameters. When you do this the current ratio is likely to change. And then you try to compensate for that shift; and then . . . . . ! Before you know it you will have created a problem where there was none!

If you measured the resonant frequency of the sample lines when the system was working, remeasure them again. Compare the *then* and *now*.

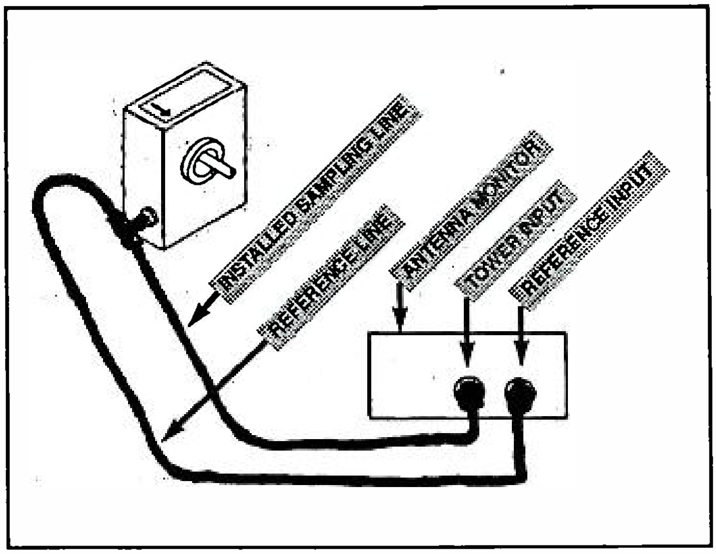


Figure 6-10

use the antenna monitor and a reference line to check the integrity and phase delay of the sample lines

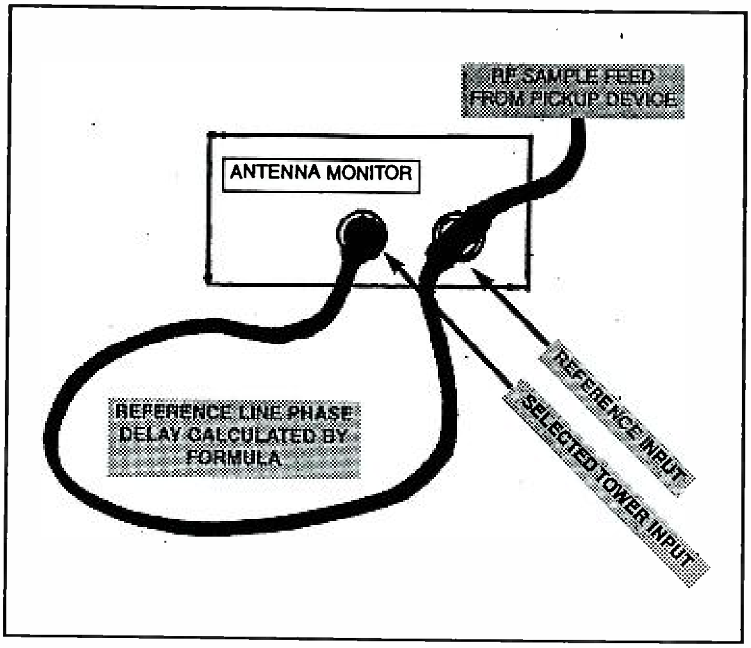
If you have no *before* measurements you can check the integrity of equal length sample lines by acquiring a length of coax that will reach from the antenna monitor to the farthest tower. It need not be special coax or low loss coax. A piece of Radio Shack RG58 or RG59 will do. We are only going to use it as a reference against which we will measure phase delay in the other lines. Obtain a tee connector and connectors for both ends of your test cable.

Install the tee on the output of the toroidal current transformer. If your system uses tower mounted loops and isolation inductors, install the tee on the ground side of the coil. Feed both the test cable and the phase sampling line from the tee. Disconnect the reference tower sampling line from the antenna monitor. Connect the test cable to the reference input. Note the phase as indicated on the monitor. Repeat the procedure for all towers in the system. When you come to the reference tower, connect its sample line to one of the other inputs. Figure 6-10 illustrates the hookup for this test.

What you have measured is the phase delay in each sample line referenced to your test cable. For equal length sample lines the phase reading you get on the antenna monitor should be identical for each line. Where you have loops on the towers, the line between the hot end of the isolation coil and the loop - or the coil itself - could be bad. Use a bridge to measure the resonant frequency of the coil, cable and loop by looking into the grounded end of the inductor. Obviously this must be done with the system de-energized.

Figure 6-11

use the reference line to check the calibration of the antenna monitor



The antenna monitor phase indication can be checked using the same piece of coaxial cable. Using a 100 foot or longer tape, accurately measure the length of the test coax. Using formula #5 in Chapter #1, page 4, calculate the physical length of the coax in electrical degrees. Divide the physical length by the velocity factor of the coax that makes up your test cable. This will give you the amount of delay in degrees through the test cable .

For example:

If our test cable is 350 feet, at 1480 kHz it is -

physical length = .366 X 1.48 X 350 = 189.6°

If the test cable is RG58 with a polyethylene dielectric its velocity factor is .66

electrical length = 189.6 / .66 = 287.3°

Note : Foam dielectric cable has a velocity factor of approximately .80
Air dielectric cable of small diameter has a velocity factor of approximately .85

Put the coaxial tee on the antenna monitor input for the reference tower sample line. Connect the reference tower sample line to one side of the tee and the test coax to the other side. Connect the other end of the test cable to one of the other inputs on the antenna monitor. Switch the antenna monitor to measure the phase on the input to which you have connected the test cable. It should read the delay through the test cable. In this case -287.3°. (This same value can be read as 360 - 287.3) +72.7°. Figure 6-11 illustrates the hookup for this test.

For another quick test of the antenna monitor, remove the reference test cable and replace it with a short coaxial jumper (6 or 8 inches long). The phase indication on the monitor should read very close to zero.

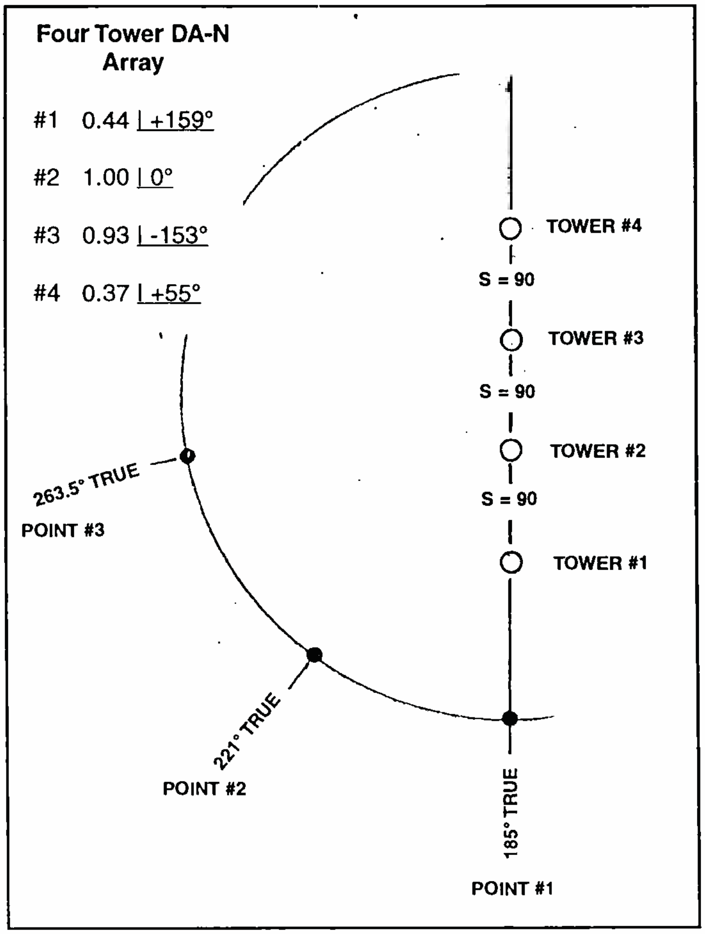
6.08 Vector Analysis

Vector analysis is a graphical method of determining what effect the adjustment of current ratio or phase of any element in a directional antenna system will have on radiated field strength in a particular direction. The vector quantity of each radiator in the DA system, as it appears at a particular azimuth, is drawn to scale on graph paper. These vectors are added pictorially. The sum is the relative amount of inverse field strength radiated in the direction of interest. The effect of the manipulation of the phase or magnitude of the individual current in each radiator is easily seen.

Let's position ourselves at a point about 1 mile from the center of a 4-tower array on the 185° radial. Actually, our position can be anywhere beyond about 5000 feet from the center of the array - 10 times the radiator spacing - on this azimuth. At points closer, the vectors have not yet added up. We run the danger of measuring radiation from each element in the system rather than the sum of all. At an azimuth of 185° true we are right in line with the towers in our imaginary array. Figure 6-12 identifies our position as observation point #1. The tower closest to us is tower #1. Tower #2 is 90 degrees farther away than #1. Tower #3 is 180 degrees farther away than tower #1. Tower #4 is 270 degrees farther away than tower #1.

Figure 6-12

illustration depicting the relative distance to each tower from observation points on various azimuths



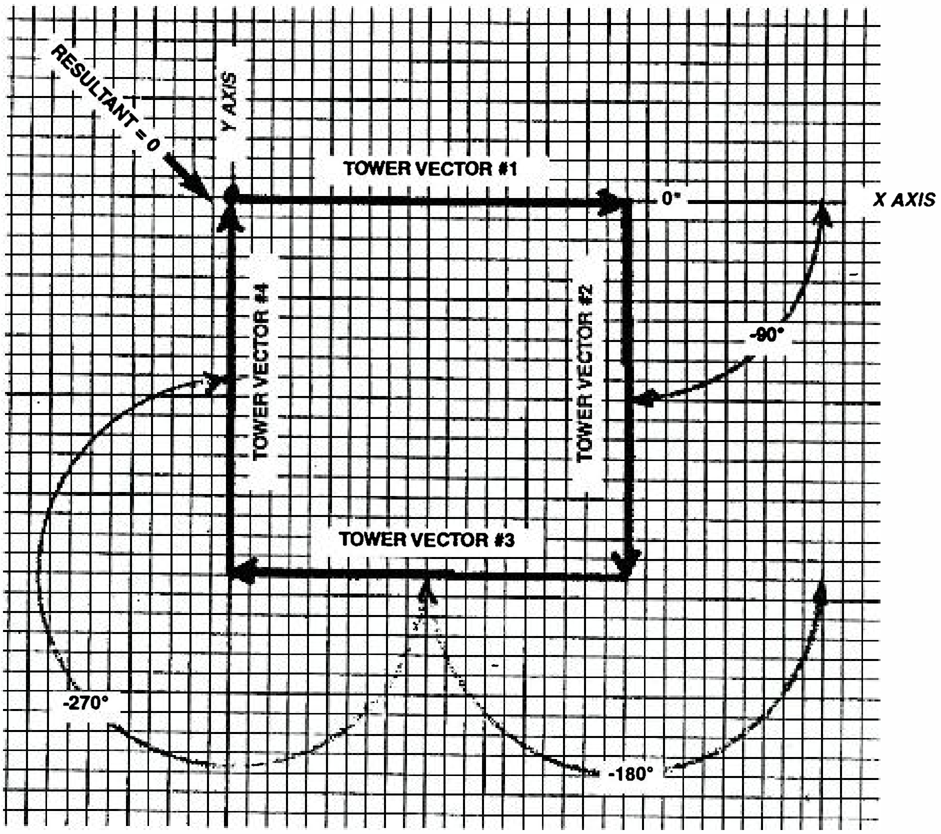
For a moment, let's consider the situation if each tower was energized with equal amounts of RF current that is in-phase with each of the others. The phase relationship of the four signals (one from each tower) reaching this observation point would be: #1 = 0°; #2 = -90°; #3 = -180°; #4 = -270°. The phase lag of the signal from towers #2, #3 and #4 would be due to the extra distance the signal would have to travel, referenced to tower #1, to reach the observation point. This phenomenon is called space phasing.

Next we draw each vector to scale on linear graph paper. When drawing a vector 0° is to the right on the X axis (horizontal axis) and positive phase angles are always measured in a counter clockwise direction. The addition of the vectors (magnitude and phase) from each tower as they appear at 185° true, off the end of the line of towers, is as shown in Figure 6-13. The magnitude of each vector is its length. The phase its direction.

Figure 6-13

vector addition of four towers fed with equal amounts of current each at the same phase angle

observation point is at 185° in line with the towers



The resultant of this addition is the distance between the origin of vector #1 and the tip of vector #4. In this direction, 185° true, under these conditions of phase and current ratio, all radiators fed in phase with equal amounts of RF current, the resultant is zero; the tip of #4 touches the origin of #1.

In the night time XYZ array, the four towers are not fed in phase nor are they fed with equal amounts of RF current. They are energized with phases and currents as shown in left top corner of Figure 6-12. These vectors can also be pictorially added. The direction of the line on our graph (phase) is the space phasing plus the electrical phase of the RF current with which the radiator is energized. The magnitude is the relative length of the line. In Figure 6-14 a magnitude of 1.0 is represented by a line 10.0 cm in length. Thus, at 185°, the phase and magnitude of the four vectors is:

#1 space phasing 0° + electrical phase +159° = # 1 phase at 185° true = +159°
magnitude = 4.4 cm

#2 space phasing -90° + electrical phase 0° = #2 phase at 185° true = -90°
magnitude = 10.0 cm

#3 space phasing -180° + electrical phase -153° = #3 phase at 185°true = -333° (or +27°)
magnitude = 9.3 cm

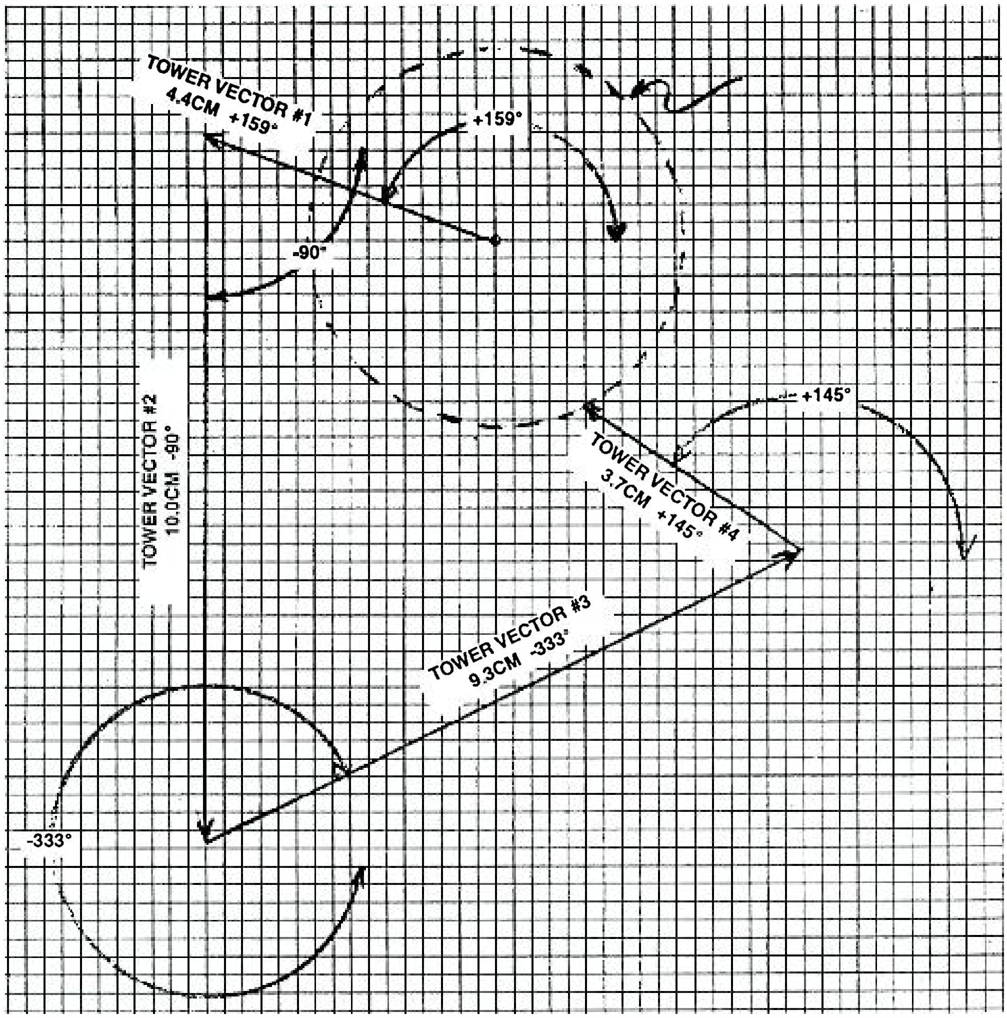
#4 space phasing -270° + electrical phase +55° = #4 phase at 185°true = -215° (or +145°)
magnitude = 3.7 cm

The resultant signal on this azimuth is represented by the dotted straight line. Any adjustment to any operating parameter (phase or current ratio) that will bring the tip of the #4 vector closer to the origin of the #1 vector will lower the inverse field at 185° true. Any point inside the dotted circle is closer to the origin of the #1 vector. Two very obvious adjustments that will decrease the inverse field are to make the phase in tower #3 less negative or to increase the current in tower #4.

Figure 6-14

vector addition on the 4 tower DA-N array at 185° true

operating parameters are shown at the top left of Figure 6-12



This same concept and vector analysis is valid for any azimuth. However, once we move off the line of towers the space phasing is no longer easily visualized. Let's move to observation point #2 as shown in Figure 6-12. It is at 221° true - 36° off the line of towers. It is evident that tower #1 is still the closest radiator. It is also evident that towers #2, #3 and #4 are no longer 90, 180 and 270 degrees more distant than #1. This determination of space phasing for each tower to the observation point can be calculated by the formula:

(#19) **space phasing = S cos (Ø - ϑ)**

where: Ø is the true bearing of the tower in degrees from the reference point

ϑ is the true bearing in degrees of the azimuth we wish to analyze

S is the distance in degrees of the tower to the reference point

The reference point can be anywhere you wish! It is usually chosen to be the location of one of the towers or the center of the array. For our purposes the location of tower #1 has been chosen.

Thus, the relative space phasing from each of the towers to any point on the 221° radial is:

#1	SP = 0 cos (0 - 221) = 0 (cos -221) = 0 (0.755) = 0
#2	SP = 90 cos (5 - 221) = 90 (cos -216) = 90 (-0.809) = -73°
#3	SP = 180 cos (5 - 221) = 180 (cos -216) = 180 (-0.809) = -146°
#4	SP = 270 cos (5 - 221) = 270 (cos -216) = 270 (-0.809) = -218°

What this tells us is: On the 221° radial, reference the #1 tower, #2 tower is 73 degrees more distant, #3 tower is 146 degrees more distant and the #4 tower is 218 degrees more distant. With this information in hand, when we add the electrical phase of the current with which each tower is energized, we have all of the information needed to draw our vectors.

#1	0° + 159° = +159°
#2	-73° + 0° = -73°
#3	-146° + (-153°) = -299°
#4	-218° +55° = -163°

Figure 6-15

vector addition on the 4 tower DA-N array at 221° true

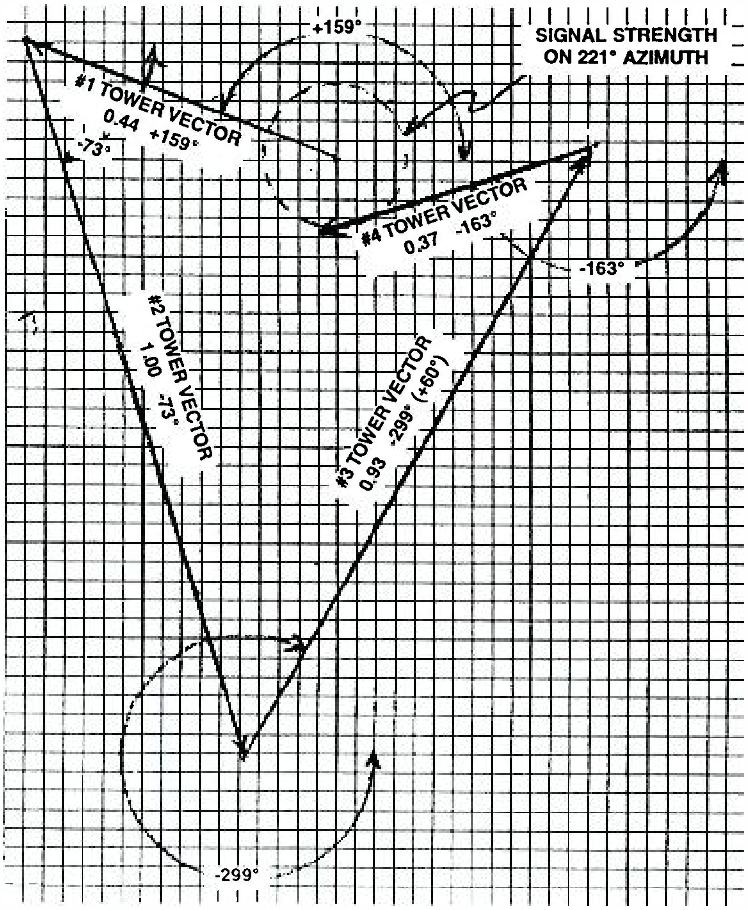


Figure 6-15 is the diagram of the addition of the individual tower vectors as they appear at 221° true. It is evident that making the #4 phase more negative or increasing the current in the #3 radiator will decrease radiation in this direction. The vectors can be added in any order with the same result. Its easier to see the effect of adjustment to the last tower added. By adding these vectors in four different orders, making each tower in turn the last to be added, makes it far easier to see the effect of current ratio and phase adjustment to each.

Figure 6-17 is a vector analysis on the 263.5° radial. This is a minima where the individual vectors from the towers add up to near zero. As you can see the tip of vector #4 just about touches the origin of vector #1. The adjustment of current ratio or phase in any element of the system will have a great effect on the inverse field in this direction. A change in phase of one degree on some radiators is apt to cause a 100% change in the measured field at 263.5°.

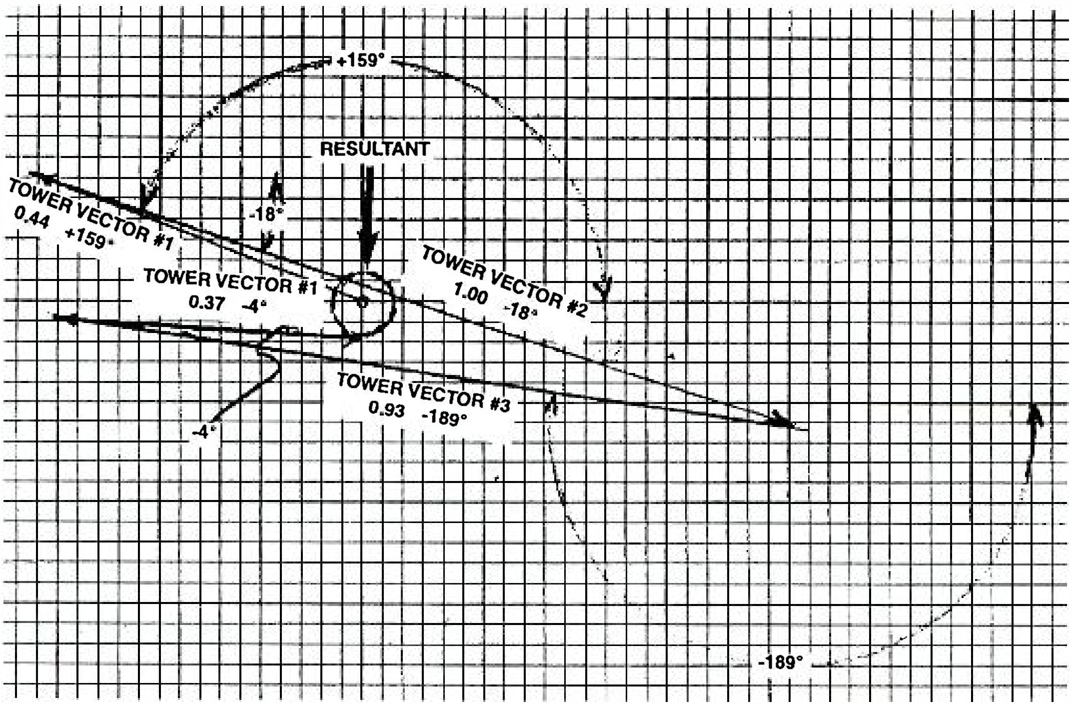


Figure 6-16

vector analysis on the 263.5° radial

A vector analysis can be utilized with any type of array - in-line, dog leg, parallelogram, etc. All you need know are the operating parameters of the system, the spacing between towers and the azimuth(s) on which the towers are laid out.

Vector analysis is a useful tool when you are called upon to make some minor adjustments to an array where a monitor point has drifted a bit above its maximum authorized value. By doing an analysis on all of the azimuths where there is a monitor point you can readily see what effect an adjustment is likely to have on each of the points. This is especially helpful when it is you alone who handles field intensity meter and reads the antenna monitor! It can save a lot of miles and time on trips out to the monitor points.

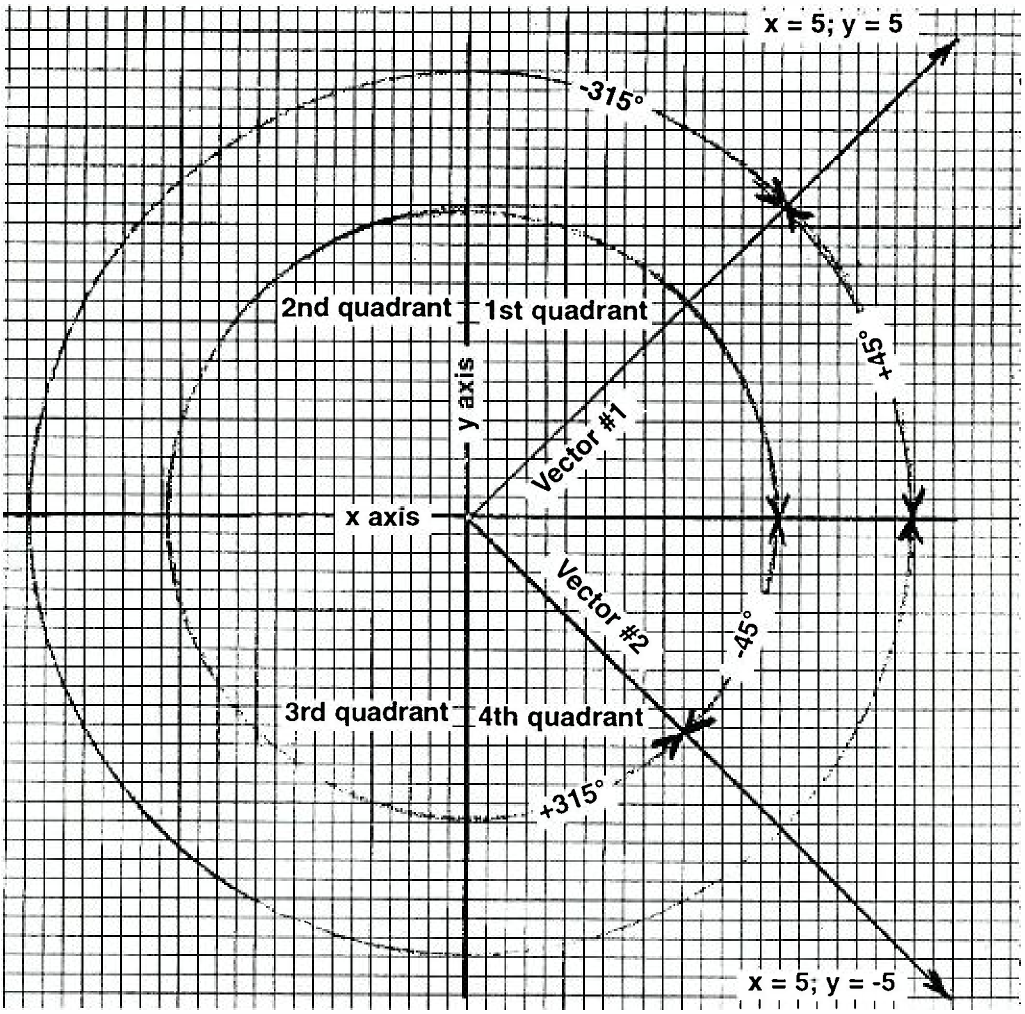
● ● ● ●

Appendix A

Vectors

Vectors have a magnitude and a direction. Depending on the discipline in which one is working the magnitude might express speed, force, influence, voltage or current. The direction might express a compass direction, an elevation angle or a phase angle. Vectors can be expressed in polar or rectangular notation.

The circle shown in Figure A1-1 is divided into four quadrants by two lines; one vertical and one horizontal. The vertical line is called the y axis. The horizontal line is called the x axis.



When a vector is expressed in polar notation, it will have a magnitude and an angle expressed as Z |Ø . Z is the magnitude and Ø is the angle. The magnitude is the length of the line and is measured from the junction of the x and the y axes. The magnitude of both vectors #1 and #2 is 7.07 based on 5 blocks on the graph paper being equal to one unit. A positive angle is measured in a counter clockwise direction from the right side of the x axis. A negative angle is measured in a clockwise direction from the right of the x axis. Vector #1 has an angle of +45 degrees. When the angle is positive the plus sign can be omitted as it is understood. This same vector can be expressed with a negative angle of -315 degrees if measured in a clockwise direction from zero. Just add or subtract 360 degrees from the angle. In polar form vector #1 is noted as (five divisions = 1.0) 7.07 |+45° or 7.07 |-315° .

Vector #2 has an angle of -45 degrees. It can also be expressed as +315 degrees. In polar form vector #21 is noted as (five divisions = 1.0) $7.07\,\underline{|-45^\circ}$ or $7.07\,\underline{|+315^\circ}$.

When a vector is expressed in rectangular form (also called cartesian form) x and y values will be given. All values of x to the right of the y axis are positive; all values of x to the left of the y axis are negative. All values of y above the x axis are positive; all values of y below the x axis are negative. In rectangular form, vector #1, in Figure A1-1, is expressed as x = 5; y = 5; Vector #2 is expressed as x = 5; y = -5.

When the rectangular form of a vector is used to express an impedance consisting of resistance (R) and reactance (X) it is expressed as R ±jX. Vector #1 would be 5 +j5; vector #2 would be 5 -j5..

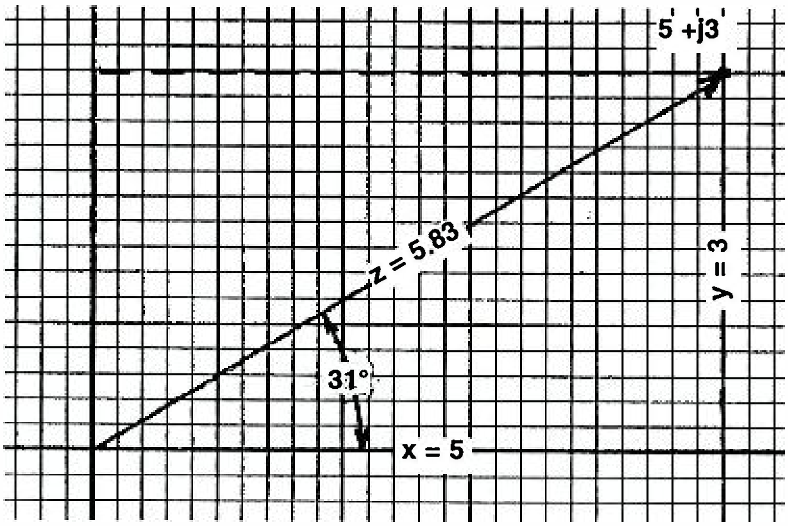


Figure A1-2

the relationship between polar and rectangular expression of vectors

The vector shown in Figure A1-2 expressed in rectangular form is 5 +j3. It's easy to see that the dotted vertical line and the X axis along with the vector forms a right triangle. From basic trigonometry the length of the hypotenuse - the magnitude of the vector - can be determined by the formula:

$Z = \sqrt{x^2 + y^2}$

where:

Z = magnitude

x = x value of the rectangular coordinates

y = y value of the rectangular coordinates

therefore the magnitude is:

$Z = \sqrt{52 + 32} = \sqrt{25 + 9} = \sqrt{34} = 5.83$

The angle formed by the x axis and the vector can be also be determined by using basic trigonometry:

$\varnothing = \tan^{-1} y/x$

where:

Ø = angle of the vector

x = x value of the rectangular coordinates

y = y value of the rectangular coordinates

therefore the angle is:

$\varnothing = \tan^{-1} 3/5 = \tan^{-1} 0.60 = 31^\circ$

Expressed in rectangular form, the vector 5 +j3, shown in Figure A1-2, is $5.83\,\underline{|31^\circ}$.

therefore the angle is:
$\text{Ø} = \tan^{-1} 3/5 = \tan^{-1} 0.60 = 31^\circ$

Expressed in rectangular form, the vector 5 +j3, shown in Figure A1-2, is $5.83\ \underline{|31^\circ}$.

If the vector had originally been expressed in polar notation and one wished to change it to rectangular notation, the following formulae would be used:

$x = Z \cos\text{Ø}$
$y = Z \sin\text{Ø}$
where:
Z = the magnitude of the vector
Ø = the angle of the vector
sin and cos are the trigonometric sine and cosine functions of the angle Ø
therefore $5.83\ \underline{|31}^\circ$ in rectangular form is:
$x = Z \cos \text{Ø} = 5.83 \cos 31^\circ = 5.83\ (0.857) = 5.0 = x$
$y = Z \sin \text{Ø} = 5.83 \sin 31^\circ = 5.83\ (0.515) = 3.0 = y$

The trigonometric functions of sine, cosine and tangent, as well as arc tan or tan-1, are most conveniently determined by using a calculator. The conversion of vectors from rectangular to polar notation is necessary when one performs arithmetic operations (addition, subtraction, multiplication and division) on them.

The addition and subtraction of vectors is easily performed when they are in rectangular notation. One simply adds or subtracts the x and the y values:

$(5.0 + j3.0) + (4.2 - j6.5) = 9.2 - j3.5$
$(5.0 + j3.0) - (4.2 - 6.5) = 0.8 + j9.5$

The multiplication of vectors is most conveniently performed when they are in polar notation. The magnitudes are multiplied and the angles added:

$(5.0 \mid 50^\circ)(6.0 \mid 20^\circ) = 30.0\ \underline{|70^\circ}$

The division of vectors is most conveniently performed when they are in polar notation. The magnitudes are divided and the angles subtracted:

$$\frac{5.0\ \underline{|50^\circ}}{6.0\ \underline{|20^\circ}} = 0.833\ \underline{|\ 30^\circ}$$

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Appendix B

Tables of Mutual Impedance Between Radiators

The coupling between between radiators in a directional antenna system, known as mutual impedance, must be known in order to calculate the input point impedance - the driving point impedance - of the radiators when the array is in operation. The mutual impedance between two radiators can be measured, calculated or taken from published tables. The usual procedure for design purposes is to use published values of self impedance, mutual impedance and the theoretical operating parameters of phase and current ratio to arrive at the driving point impedance of each radiator.

The opposite page gives representative values of mutual impedance between radiators with heights between 70 and 120 degrees, for spacings out to 600 degrees. The values given for 120 degree radiators can be used for the calculation of driving point values for the initial set up of systems that employ taller radiators. NAB publications contain charts and graphs of values of mutual impedance for radiators of different heights. As outlined in Chapter 5, it is always advisable to measure the actual driving point impedance of each radiator once the array has been brought into tune with proper current ratios and phase values.

Column #1 is the spacing between radiators - S. Column #2 is the phase of the mutual impedance. Phase remains relatively constant as the height of the radiators increase and is determined mainly by the spacing between radiators. The next six columns indicate the magnitude of the mutual impedance for various radiator heights - G. Note that magnitude diminishes as the spacing is increased. Note too that the magnitude of the mutual impedance is much larger for taller towers with the same spacing.

To use the table first locate the column for the correct tower height, then find the spacing between the radiator under study and each of the others in the system.

For example:

> In a four tower in-line array, using 110 degree tall towers, with spacing between elements of 140 degrees, the mutual impedance between tower #1 (an end tower) and tower #2 is $37.0\,\underline{|{-75^\circ}}$; between tower #1 and tower #3 it is $22.5\,\underline{|{+155^\circ}}$ (the spacing between #1 and #3 is 280°); and between tower #1 and tower #4 is 16.0 $\underline{|{+20^\circ}}$ (the spacing between #1 and #4 is 420°). These values are to be used with the formulae for calculating driving point impedance shown in Chapter 2.

* * * *

S	Phase	Magnitude					
		G=70	G=80	G=90	G=100	G=110	G=120
40	±0°	17.00	23.75	33.50	47.00	65.00	90.00
60	-15°	14.75	21.25	30.00	43.00	56.00	80.00
80	-30°	14.00	19.25	26.25	38.00	50.00	70.00
100	-45°	12.50	17.25	23.00	34.00	45.00	63.00
120	-60°	11.25	15.50	20.75	30.50	40.00	57.00
140	-75°	10.00	14.00	19.00	28.00	37.00	52.00
160	-95°	9.25	12.75	17.50	25.75	34.00	48.00
180	-112°	8.25	11.75	16.25	23.75	31.00	45.00
200	-130°	7.50	10.75	15.00	22.00	29.00	41.00
220	-148°	7.00	10.00	13.75	20.50	27.00	39.00
240	-166°	6.500	9.25	12.50	18.75	25.00	36.00
260	+175°	6.00	8.75	11.75	18.00	24.00	34.00
280	+155°	5.75	8.50	11.00	16.75	22.50	32.00
300	+135°	5.25	7.75	10.50	16.00	21.50	30.50
320	+116°	5.00	7.25	10.00	15.00	20.00	29.00
340	+96°	4.75	6.75	9.50	14.25	19.00	28.00
360	+78°	4.50	6.50	9.00	13.50	18.00	26.00
380	+58°	4.25	6.25	8.50	12.75	17.00	25.00
400	+40°	4.25	5.75	8.00	12.25	16.50	24.00
420	+20°	4.00	5.50	7.75	11.75	16.00	23.00
440	±0°	3.75	5.25	7.50	11.25	15.00	22.00
460	-20°	3.50	5.25	7.25	11.00	14.50	21.00
480	-40°	3.50	5.00	7.25	10.75	14.00	20.50
500	-59°	3.25	4.75	7.00	10.25	13.50	20.00
520	-79°	3.25	4.50	7.00	10.00	13.00	19.50
540	-98°	3.00	4.50	6.75	9.75	12.50	19.00
560	-118°	3.00	4.25	6.75	9.50	12.00	18.50
580	-138°	2.75	4.00	6.50	9.00	11.75	18.00
600	-158°	2.75	4.00	6.50	9.00	11.50	17.25