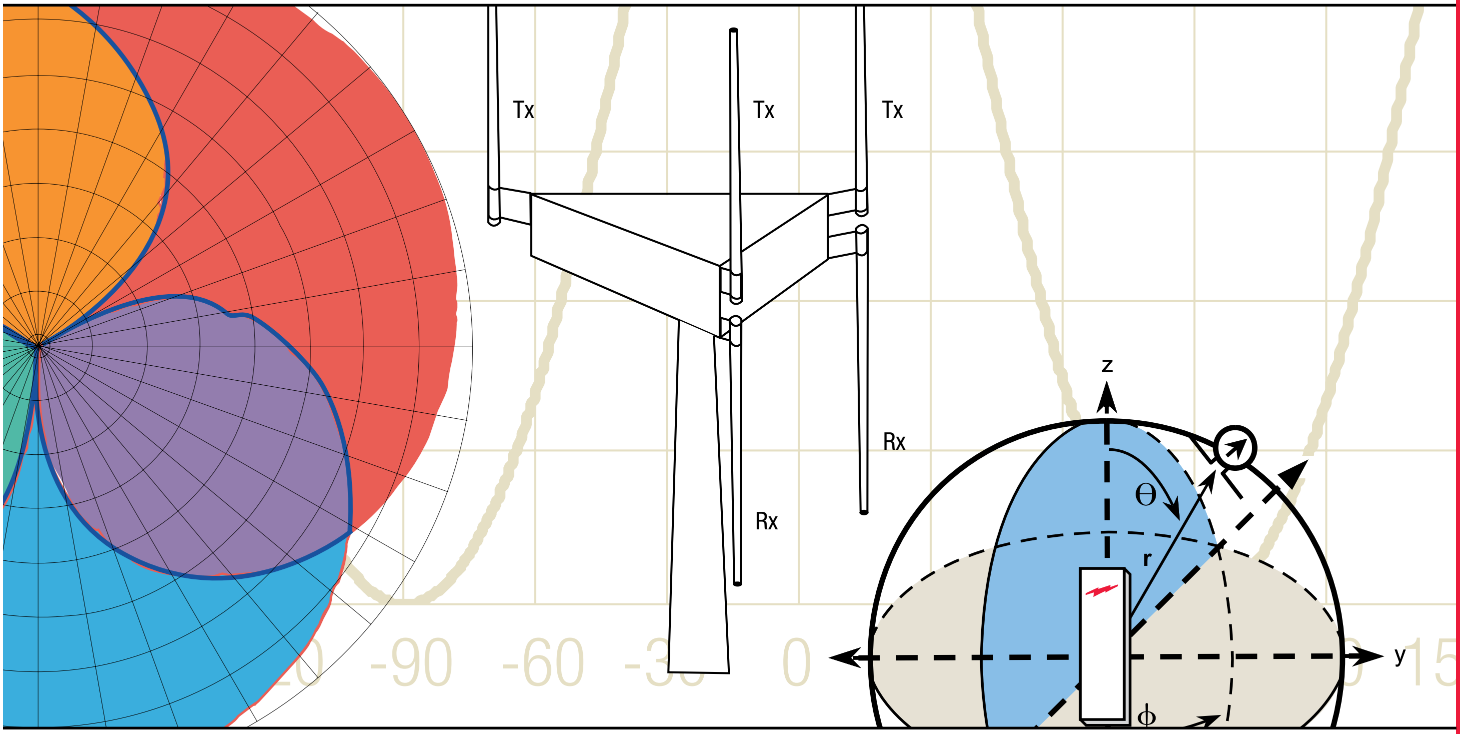
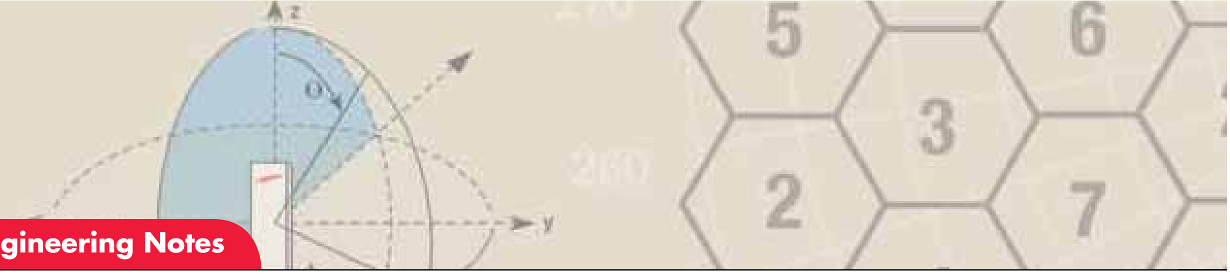
ANDREW®

APPLICATIONS/ENGINEERING NOTES



- Basic Antenna Types Used in Cellular Style Systems
- Antenna Fundamentals
- Base Station Antenna Materials and Mechanical Characteristics



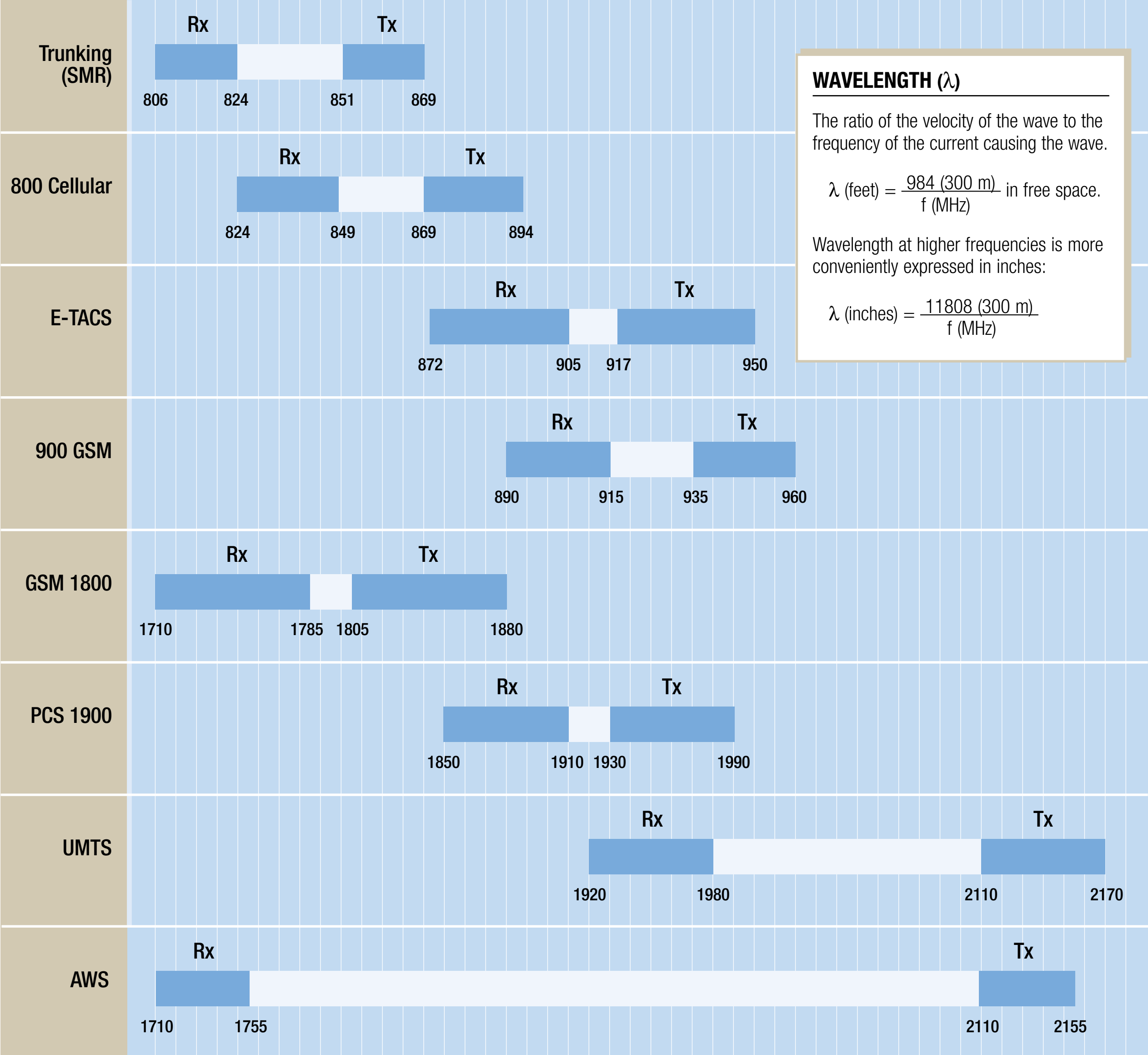
Overview

Andrew Corporation designs, manufactures, and delivers innovative and essential communications equipment and solutions for the global telecommunications infrastructure market. Our products cover virtually the entire radio frequency (RF) footprint for applications that connect the world.

Andrew offers base station antenna system solutions for professional communications systems. Recognized around the world as the most technically advanced professional base station antenna systems, Andrew incorporates multiple value-added features that have made them the preferred products of system managers, designers, and engineers.

The Applications/Engineering Notes are a comprehensive information guide to base station antennas. For all other Andrew product information please visit www.andrew.com.

Frequency Band Reference Chart



WAVELENGTH (λ)

The ratio of the velocity of the wave to the frequency of the current causing the wave.

$$\lambda \text{ (feet)} = \frac{984 \text{ (300 m)}}{f \text{ (MHz)}} \text{ in free space.}$$

Wavelength at higher frequencies is more conveniently expressed in inches:

$$\lambda \text{ (inches)} = \frac{11808 \text{ (300 m)}}{f \text{ (MHz)}}$$

Basic Antenna Types Used in Cellular Style Systems

There are two basic types of base station antennas used in cellular style systems: omni-directional (omni) antennas and directional or sector antennas.

Omni antennas are generally used for low capacity sites where sectorization is not required. Typical examples are more rurally located sites.

Most sites in urban and suburban areas use sectorized antennas to achieve higher capacity. To date, the most popular option is a 3-sector (120°) solution, but 6-sector solutions are used where capacity issues are severe.

Diversity/Air Combining

For many rural and suburban sites, diversity is accomplished using spatial diversity. To achieve spatial diversity, two uplink antennas per sector are placed far enough apart so that the signals they receive are uncorrelated.

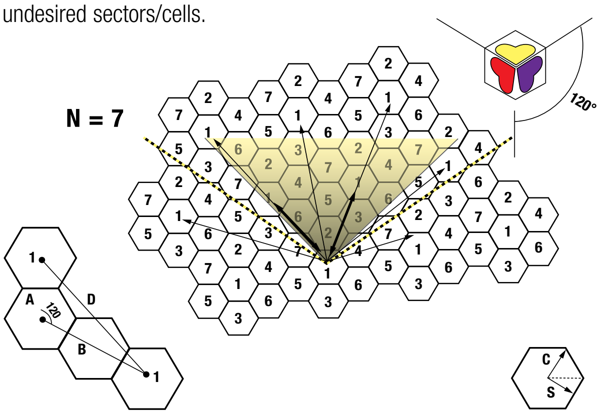
High Density Cell Configuration Using Diversity Polarization for Diversity Gain

The use of a single antenna containing two arrays at orthogonal polarizations (horizontal/vertical or ±45°) is useful in dense urban areas with high multipath. Some studies note that in urban areas with high multipath, polarization diversity gain results can outperform spatial diversity. The use of a quad or four port ±45° antenna can provide for air combining, which is useful in avoiding additional transmit combiner losses when overlaying additional frequency.

Cell Reuse

The principles behind the cellular concept employ the reuse of frequencies over and over again throughout the network to gain capacity. Typically cells are represented as hexagons (Figure 1), which shows a reuse pattern of N=7.

Depending on the capacity requirement, these cells can have diameters measured either in miles or in hundreds of feet. Since given frequencies are reused throughout the system, the channel sensitivity becomes interference limited rather than noise limited like older non-cellular systems. Therefore it can be seen that specialized pattern shaping, both azimuth and elevation, can go a long way toward optimizing coverage inside the desired sector and minimizing interference from and into undesired sectors/cells.



$D^2 = A^2+B^2-2AB\times COS(d)$

$D = 5.3S$

$C^2 = S^2+(C/2)^2$

$S^2 = C^2-(C/2)^2$

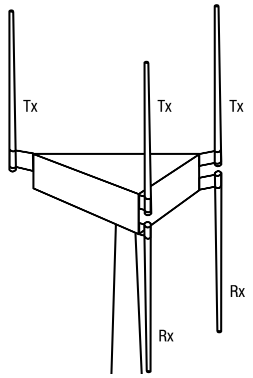
$S^2 = 0.75C^2$

$S = 0.866C$

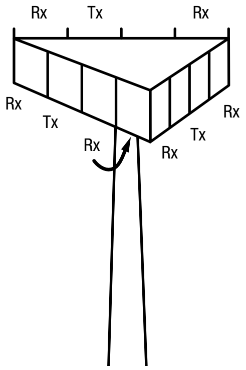
● **Figure 1**

Basic Antenna Types Used in Cellular Style Systems

Typical Antenna Installations

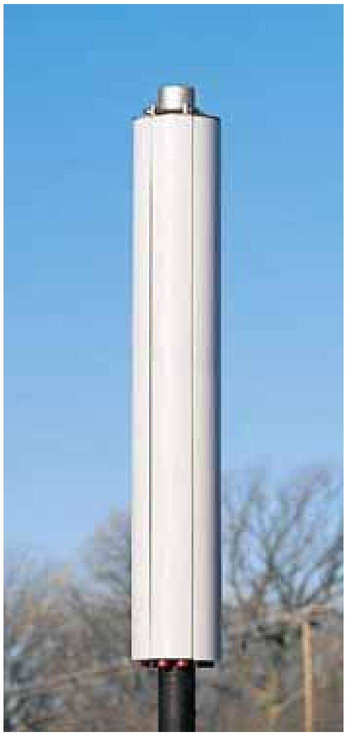


Omni



Sector/Platform

Tower



Disguised/Microsite

Building

Shown above are typical 3-sector sites. 6-sector sites are used for additional capacity.

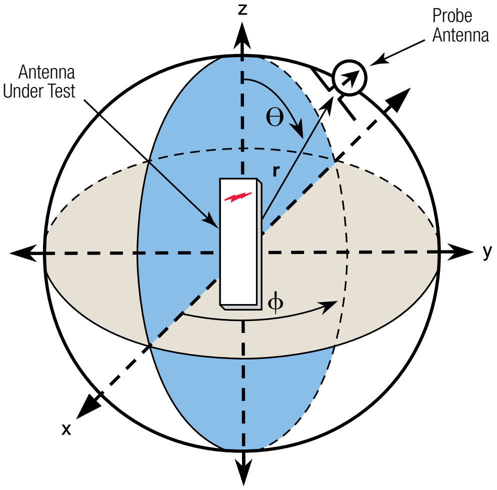
One of the most critical elements of a wireless communications system is the antenna. A base station antenna represents only a small part of the overall cost of a communications site, but its performance impact is enormous. Its function is to transform conduction currents (found on wires, coaxial cable, and waveguides) into displacement currents—it's this invisible phenomenon that makes radio communications possible. The antenna's impact on the radio system is determined by choosing the antenna with the appropriate characteristics defined by its specifications.

The following information describes and defines the most common parameters used to specify base station antennas.

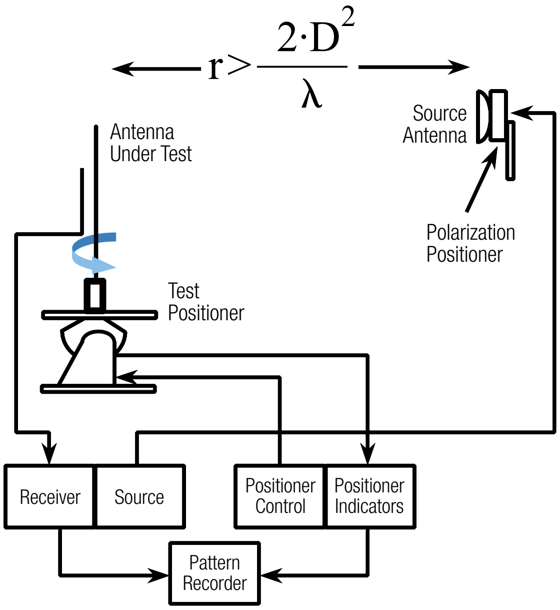
Radiation Pattern

The most important requirement is describing where an antenna radiates energy into the space around it. A radiation pattern is a graphical representation of where and how much energy is radiated. Every antenna should come with such a representation.

The radiation characteristics of an antenna are determined by moving a simple probe antenna, which is connected to a radio receiver, around the antenna at a constant distance, noting the received signal level as a function of angular coordinates. For a complete 3-dimensional characterization, the probe antenna would be moved over a spherical surface. See Figure 2. A typical far-field range setup is shown in Figure 3 where D is the maximum dimension of the Antenna Under Test.



◉ **Figure 2** Measuring Radiation Patterns



◉ **Figure 3** Typical Far-Field Range Setup

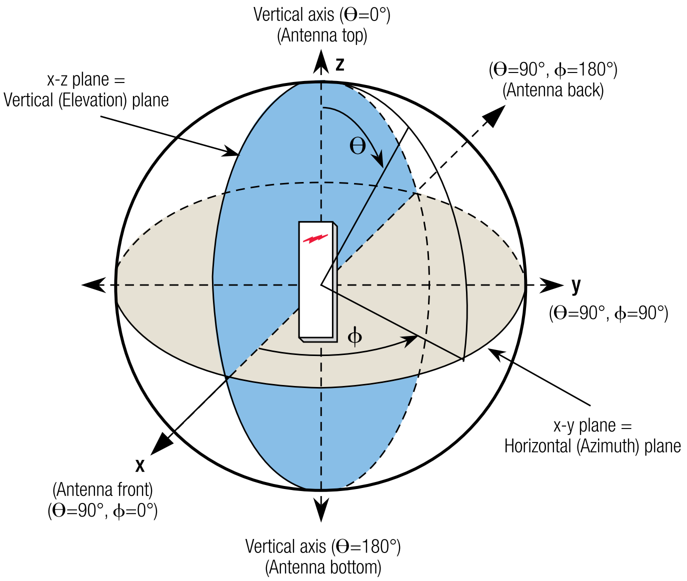


Figure 4 Spherical Coordinate System

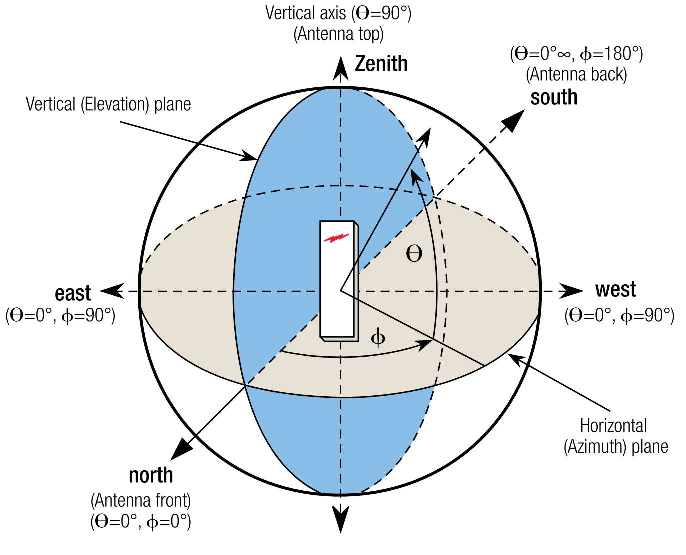


Figure 5 Altazimuth Coordinate System

The coordinate system used for defining antenna radiation patterns is the spherical coordinate system shown in Figure 4, while that used by surveyors and RF engineers is the altazimuth coordinate system shown in Figure 5. Pattern data supplied by Andrew Corporation is in the form that is defined by the altazimuth coordinate system.

Most antennas are physically symmetrical about the x-y and x-z planes, which means the antenna's radiation characteristics are aptly described by only two radiation patterns. These principle plane patterns are the horizontal (azimuth) radiation pattern and the vertical (elevation) radiation pattern. To measure the horizontal pattern, the probe moves in the x-y plane ($\Theta = 90^\circ$ and ϕ varies). To measure the vertical pattern, the probe moves in the x-z plane ($\phi = 0^\circ$ and Θ varies).

The radiation pattern can be graphically represented in two ways. One is by a rectangular plot, where angular position is defined by the x-axis and signal level by the y-axis. The second is a polar plot, where angular position is equivalent to the angular position on a circle—relative to a reference radial—and signal level is plotted relative to the center of the circle at a distance proportional to the signal level.

The signal level can be plotted as a function of linear voltage or linear power. In this case, the center of the polar plot is zero. If the levels are absolute values, the outside value of the polar plot is greater than one; for relative plots, the outside value is one. The pattern can also be plotted as a function of absolute logarithmic power level. In this case, the outside value of the polar plot is zero, and the center is not zero.

Examples of rectangular and polar plots using the altazimuth coordinate system are shown for an isotropic radiator and a half-wave dipole in Figures 6–9 (see following page). Figure 6 shows the absolute voltage elevation patterns where the peak value for the isotropic radiator is 1.00 and the dipole is 1.28. Figure 7 shows the absolute power elevation patterns where the peak value for the isotropic radiator is 1.00 and the dipole is 1.64 = 1.28². Figure 8 shows the absolute power elevation patterns in dBi where the peak value for the isotropic radiator is 0.00 dBi = 10 $\log_{10}$ (1.00) and the dipole is 2.15 dBi = 10 $\log_{10}$ (1.64). Figure 9 shows the relative power elevation patterns in dB where the peak value for both is 0.00 dB. Andrew uses the polar plot format, shown in Figure 9, for all Andrew base station antennas.

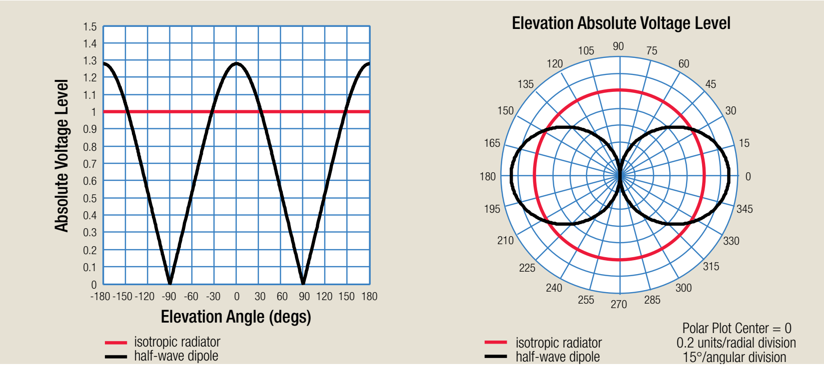


Figure 6
Rectangular and Polar Plots of Absolute Linear Voltage Levels for an Isotropic Radiator and a Half-Wave Dipole

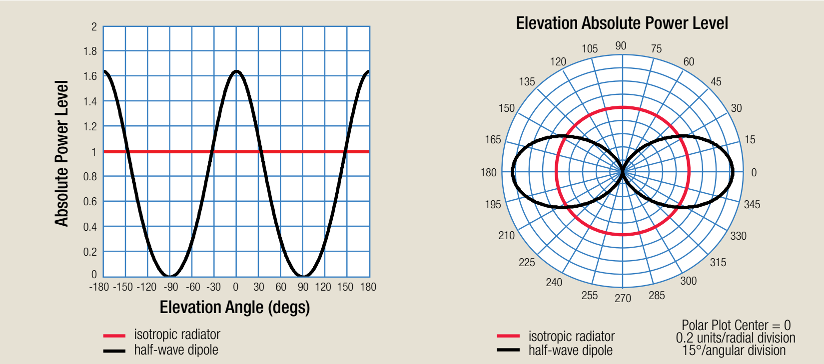


Figure 7
Rectangular and Polar Plots of Absolute Linear Power Levels for an Isotropic Radiator and a Half-Wave Dipole

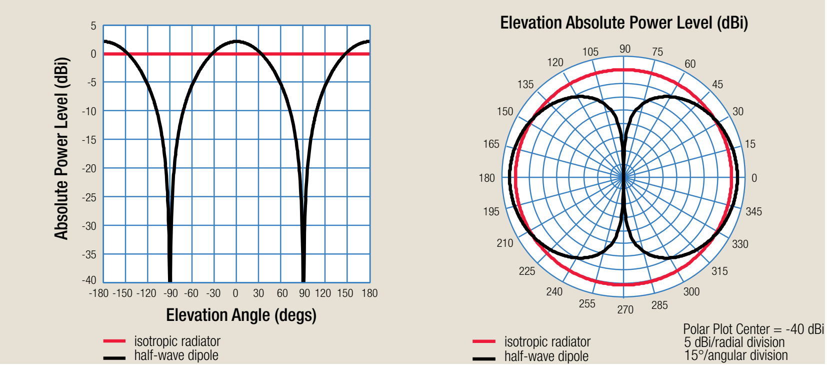


Figure 8
Rectangular and Polar Plots of Absolute Power Levels in dBi for an Isotropic Radiator and a Half-Wave Dipole

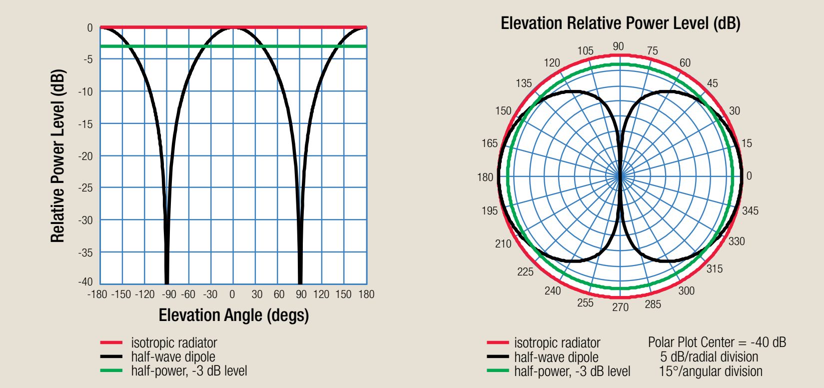


Figure 9
Rectangular and Polar Plots of Relative Power Levels in dB for an Isotropic Radiator and a Half-Wave Dipole

Antenna Gain

Perhaps the second most important parameter in selecting a base station antenna is gain. Gain is proportional to the product of directivity and the antenna's efficiency. Directivity is a measure of how an antenna focuses energy, while the antenna's efficiency accounts for losses associated with the antenna.

$$G = e\,D$$
$$G\ (\text{dBi}) = 10 \log_{10} (e\,D)$$

where G = antenna gain relative to an isotropic radiator
e = antenna efficiency
D = antenna directivity relative to an isotropic radiator

$$G\ (\text{dBi}) = D\ (\text{dBi}) - L\ (\text{dB})$$

where L = losses due to resistance of conductors, dielectrics, impedance mismatch, polarization

Gain is always referenced to an isotropic radiator (a device that radiates energy in all directions equally). The unit of measure is the dBi. Gain also may be referenced to a half-wave dipole, where the unit of measure is dBd. The gain of a dipole is 2.15 dBi or 0.00 dBd.

Figure 10 compares the gain of a given antenna rated in dBi (dB with respect to an isotropic radiator) to the same antenna rated in dBd (dB WRT a 1/2 wave dipole).

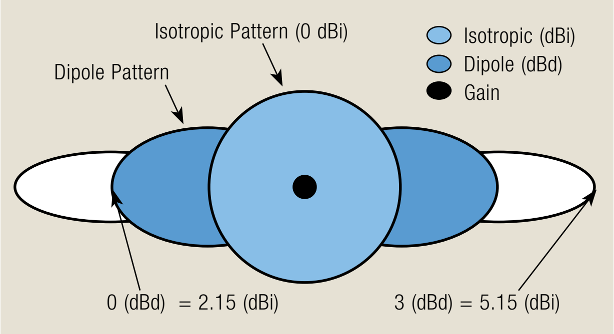


Figure 10

Gain is a function of the frequency, as shown:

$$G = \frac{4\pi}{\lambda^2} A_e$$

where λ = wavelength, m
A_e = effective aperture area, m^2

$$\lambda = \frac{c}{f}$$

where c = speed of light, m/sec
f = frequency, Hz

As aperture size increases, gain increases. For wireless sector and omni antennas, aperture size is mainly determined by the antenna's length. In general, gain doubles (3 dB increase) when the antenna length doubles. Practically, as length increases so do the losses, and a length will be reached where any increase in size will not give any substantial increase in gain, due to a matching increase in loss.

Half Power Beamwidth

Half power beamwidth (HPBW) is a parameter that measures the shape of the radiation pattern. It is the angular width of the radiation pattern's main lobe. It is measured between the points where the power pattern is one-half (3 dB down) the main lobe's peak value. HPBW is usually specified for the horizontal and vertical radiation patterns. The exception to this is the horizontal pattern of an omnidirectional antenna that is circular.

Directivity can be estimated from the two principal plane HPBWs by using:

For sector antennas (1):

$$\mathbf{D\ (dBi) = 10{*}\log_{10}\left[\frac{41250}{(0.53{*}HBW_{3dB}+0.25{*}HBW_{10dB}+18){*}VBW_{3dB}}\right]}$$

For omnidirectional antennas (2):

$$\mathbf{D \approx 191.0\ \sqrt{0.818 + 1/\Theta_V} - 172.4}$$

where Θ_H = horizontal pattern half power beamwidth, degrees
Θ_V = vertical pattern half power beamwidth, degrees

These formulas show that directivity increases as HPBW decreases.

An assumption needs to be made concerning the efficiency or the losses associated with an antenna to determine the gain. These formulas can then be used to ensure the appropriate gain has been chosen for specified horizontal and vertical HPBWs.

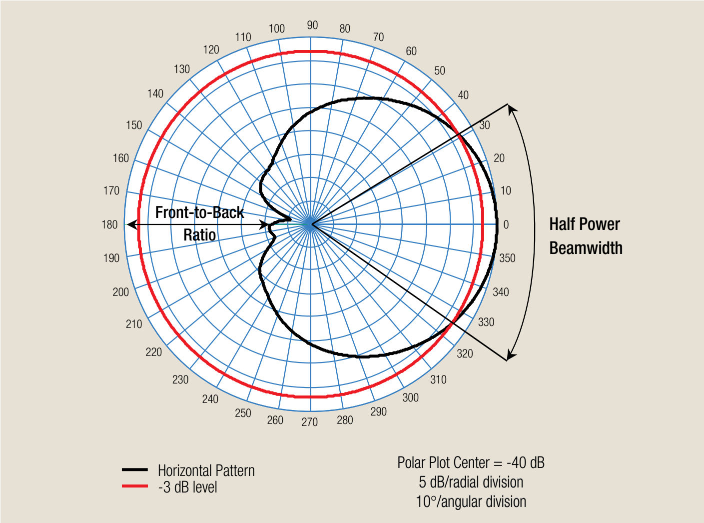


Figure 11 Horizontal Pattern Polar Plot showing HPBW and Front-to-Back Ratio

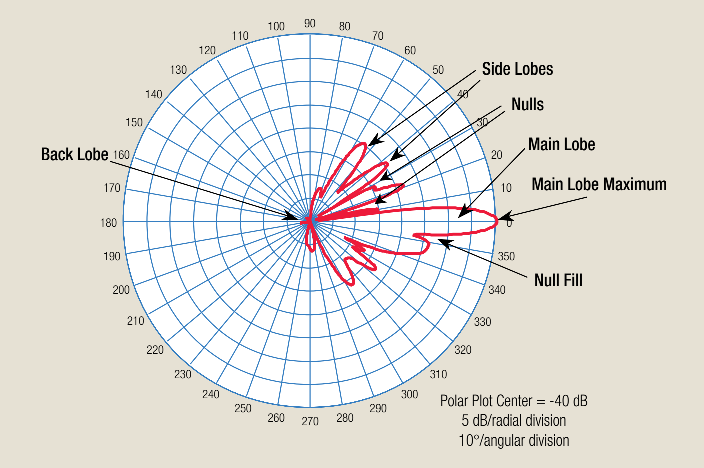
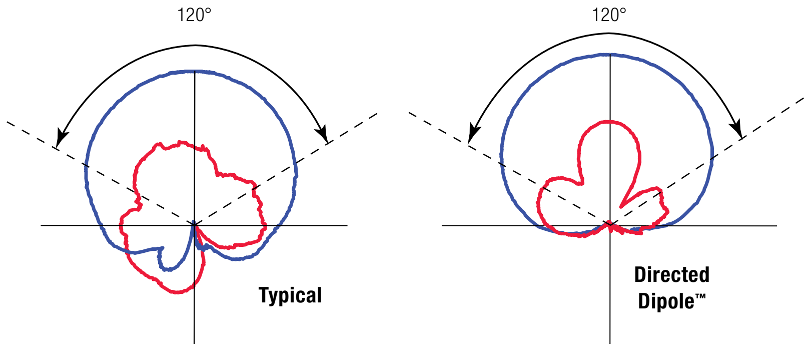


Figure 12 Elevation Pattern Polar Plot showing Pattern Parameters



Cross-Pol Ratio (CPR)

Front-to-Back Ratio

The front-to-back ratio is the ratio of the maximum directivity of an antenna (usually at $\Theta = 0°$, $\Phi = 0°$ in the altazimuth coordinate system) to its directivity in a rearward direction antenna (usually at $\Theta = 0°$, $\Phi = 180°$ in the altazimuth coordinate system). Figure 11 shows the HPBW and front-to-back ratio for a typical horizontal pattern.

Side Lobes and Nulls

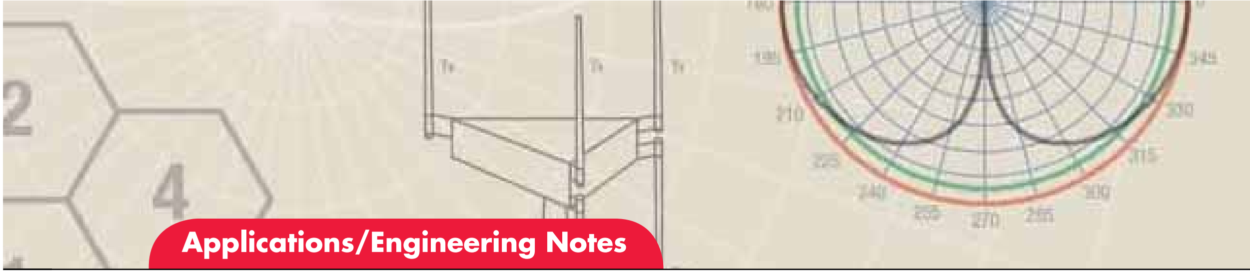
A typical vertical pattern is shown in Figure 12. The main lobe (or main beam or major lobe) is the lobe in which the direction of maximum radiation occurs. A number of minor lobes are found above and below the main lobe. These are termed side lobes. Between these side lobes are directions in which little or no radiation occurs. These are termed nulls. Nulls may represent a 30 or more dB reduction (less than one-thousandth the energy of the main beam) in received signal level in that direction.

Techniques exist to lower upper side lobes and redirect some of the radiating energy and fill in nulls. This is termed null fill. Often, the consequence of doing this is to widen the main lobe and thus lower the directivity and reduce the antenna's gain.

Cross-Polarization Ratio (CPR)

CPR is a comparison of the co-polarized vs. cross-polarized pattern performance of a dual-polarized antenna generally over the sector of interest (alternatively over the 3 dB beamwidth).

It is a measure of the ability of a cross-polarized array to distinguish between orthogonal waves. The better the CPR, the better the performance of polarization diversity.



Beam Squint

The amount of pointing error of a given beam referenced to mechanical boresite.

The beam squint can affect the sector coverage if it is not at mechanical boresite. It can also affect the performance of the polarization diversity style antennas if the two arrays do not have similar patterns.

Horizontal Beam Tracking

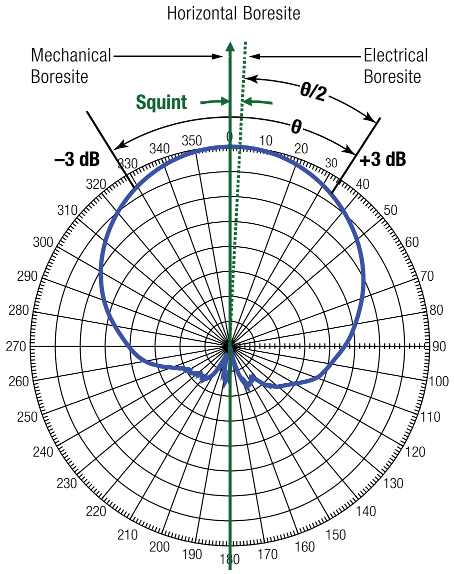
Refers to the beam tracking between the two beams of a ±45° polarization diversity antenna over a specified angular range.

For optimum diversity performance, the beams should track as closely as possible.

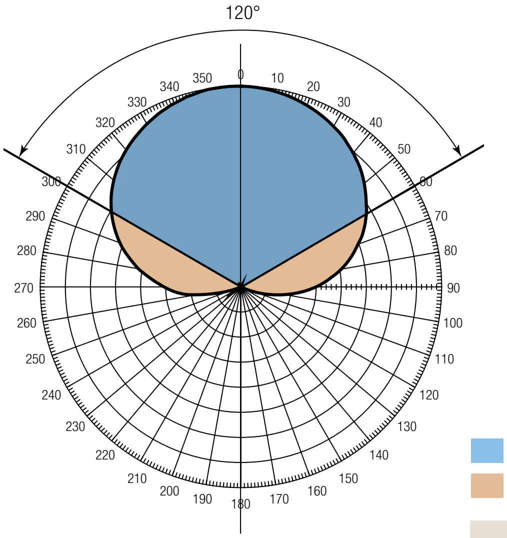
Sector Power Ratio (SPR)

SPR is a ratio expressed in percentage of the power outside the desired sector to the power inside the desired sector created by an antenna's pattern.

It is a percentage that allows comparison of various antennas. The better the SPR, the better the interference performance of the system.



Beam Squint

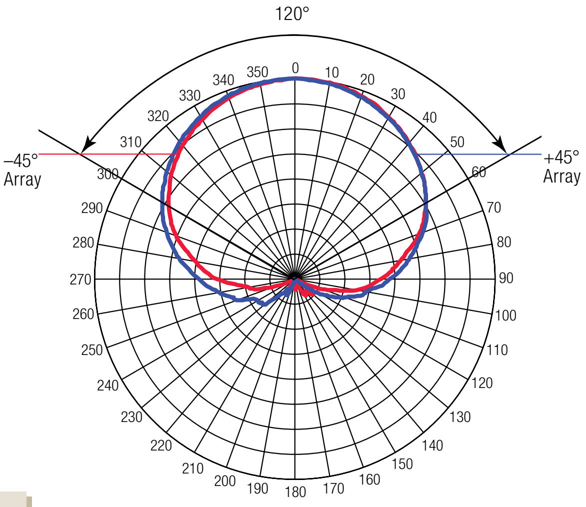


🟦 Desired

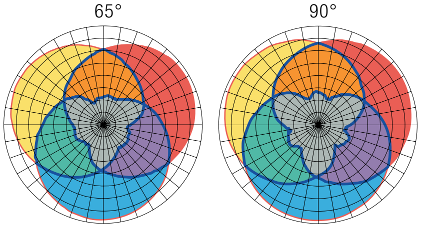
🟧 Undesired

Sector Power Ratio

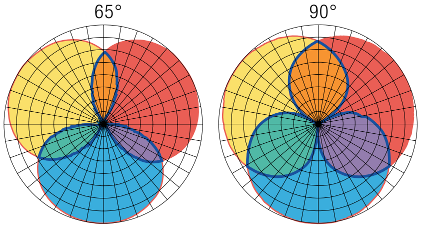
$$\text{SPR }(\%) = \frac{\sum_{60}^{300} P_{\text{Undesired}}}{\sum_{300}^{60} P_{\text{Desired}}} \text{ X } 100$$



Horizontal Beam Tracking



Traditional Flat Panels



Directed Dipole™

The Impact

Lower Co-Channel Interference/Better Capacity and Quality

In a three sector site, traditional antennas produce a high degree of imperfect power control or sector overlap.

Imperfect sectorization presents opportunities for:

- Increased softer hand-offs
- Interfering signals
- Dropped calls
- Reduced capacity

The rapid roll-off of the lower lobes of the Directed Dipole™ antennas create larger, better defined "cones of silence" behind the array.

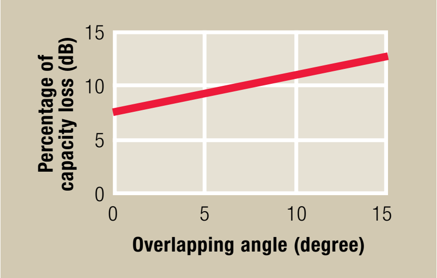
- Much smaller softer hand-off area
- Dramatic call quality improvement
- 5%–10% capacity enhancement

120° Sector Overlay Issues

For network optimization, much emphasis has been placed on improved elevation (vertical) pattern shaping, such as downtilt, null fill and upper sidelobe suppression. References from two technical papers are shown below that support the fact that azimuth pattern shaping can also play a large role in network optimization.

". . . From the numerical results, the user capacities are dramatically decreased as the imperfect power control increases and the overlap between the sectors (imperfect sectorization) increases . . ."

The quote noted above was used in the following technical paper:
"On the Capacity and Outage Probability of a CDMA Hierarchial Mobile System with Perfect/Imperfect Power Control and Sectorization"
By: Jie ZHOU et al., *IEICE TRANS FUNDAMENTALS*, VOL.E82-A, NO.7 JULY 1999



The graph shown above was used in the following technical paper:
"Effect of Soft and Softer Handoffs on CDMA System Capacity"
By: Chin-Chun Lee et al., *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY*, VOL. 47, NO. 3, AUGUST 1998

Parameters like improved azimuth pattern rolloff beyond the 3 dB points and improved front-to-back ratio—both co-polarization and cross-polarization—are key features. The goal is to have enough sector-to-sector overlap to accommodate desired handoffs, while minimizing the excess overlap which can result in interference. In CDMA type systems this shows up as pilot pollution, while in GSM systems it can show up as unwanted coverage. The excerpt graph shown above presents a quantitative measure of how this overlapping angle can affect capacity loss in a CDMA network. Qualitatively, excessive overlay also reduces capacity of TDMA and GSM systems.

Polarization

The polarization of an antenna is a property of the radio wave that is produced by the antenna. Polarization describes how the radio wave (displacement current, electric field vector) varies in space with time. This is an important concept because for a radio wave transmitted with a given polarization to be received by another antenna, the receive antenna must be able to receive this polarization and be oriented to do so. At a given point in space, the general shape traced by the electric field vector is an ellipse, shown in Figure 13.

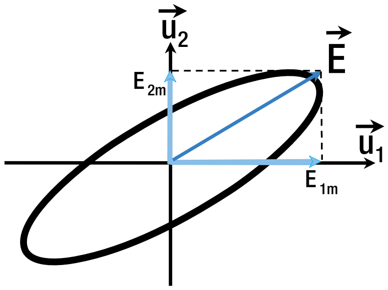


Figure 13 General Polarization Ellipse

The instantaneous value of the wave (blue arrows) can be written as:

$$\vec{E}(t) = E_{1m}\cos(\omega t)\,\vec{u}_1 + E_{2m}\cos(\omega t + \delta)\,\vec{u}_2$$

Where δ is the phase by which the u_2-component leads the u_1-component.

A summary of basic polarization types and necessary component values is shown in the table below.

Polarization	E_{1M}	E_{2M}	δ
Vertical	0	1	0°
Horizontal	1	0	0°
Slant right 45°	$1/\sqrt{2}$	$1/\sqrt{2}$	0°
Slant left 45°	$1/\sqrt{2}$	$1/\sqrt{2}$	180°
Right-hand circular	$1/\sqrt{2}$	$1/\sqrt{2}$	–90°
Left-hand circular	$1/\sqrt{2}$	$1/\sqrt{2}$	90°

Figure 14 illustrates these basic polarization types. Polarizations are said to be orthogonal if any arbitrary polarization can be expressed as a combination of the two orthogonal polarizations. The most common two orthogonal polarizations are vertical and horizontal. All practical antennas are composed of two orthogonal components. The cross-polarized response is the power received by the polarization orthogonal to the desired polarization (co-polarization) in a specified plane.

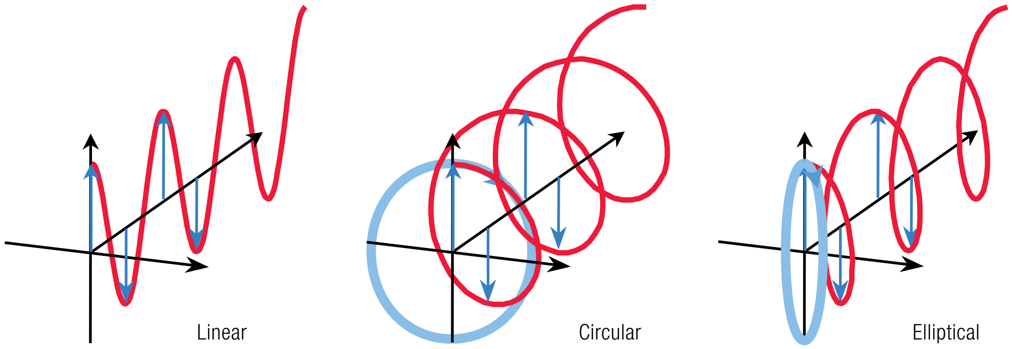

Linear
Circular
Elliptical

Figure 14 Polarization Types

Figure 15
Mechanical Downtilt

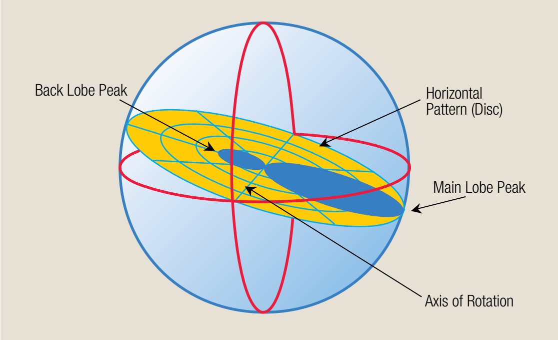


Figure 16
Patterns using Mechanical Downtilt

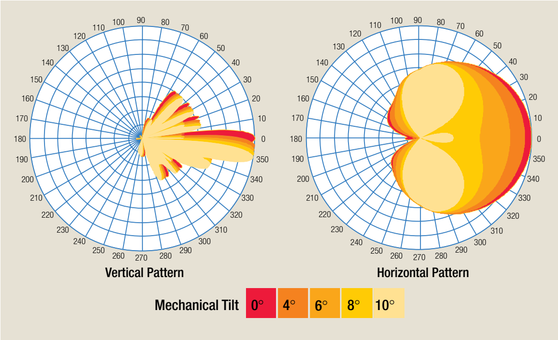


Figure 17
Electrical Downtilt

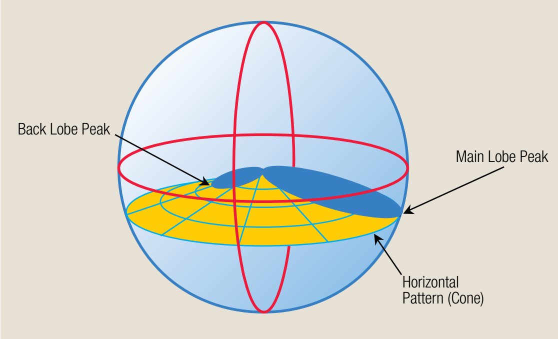
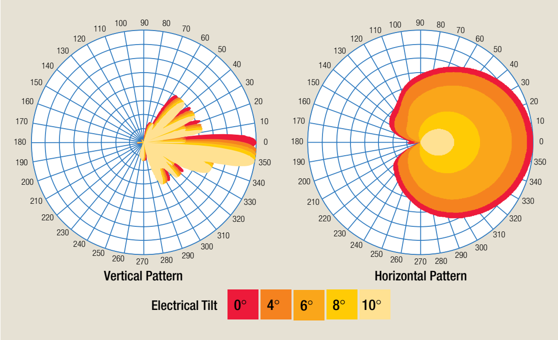


Figure 18
Patterns using Electrical Downtilt



Beamtilt

To reduce the coverage of a specific antenna, not only can the input power be reduced but the main lobe can be tilted below the horizon (maximum radiation does not occur in the direction of the horizon). The simplest way to achieve this is to mechanically tilt the antenna. The antenna can also be designed so that the main lobe does not point toward the horizon. This is achieved by electrical techniques associated with the antenna's feed network and is termed electrical downtilt.

When an antenna is mechanically tilted, its radiation characteristics do not change. However, the coverage on the ground is affected. This can best be explained by using Figure 15. Imagine that the horizontal pattern is a disc that is rotated about an axis that lies perpendicular to the direction of main radiation (main lobe). When the disc is rotated so that the main beam tilts down, at ±90 degrees from the peak (axis of rotation), nothing happens, while at ±180 degrees (back lobe), the pattern points upwards, Thus, a mechanically tilted sector antenna gives a reduced coverage footprint at the peak of the beam, but as the angle increases from this point, the effect of the beamtilt decreases.

Figure 16 shows how the horizontal radiation pattern becomes distorted as mechanical tilt increases. This is because at a constant distance, as the pattern tilts, the received signal level is not a function of the main beam peak but is a function of the slope of the main lobe or even an upper side lobe. While at ±90 degrees, no change in the horizontal pattern occurs.

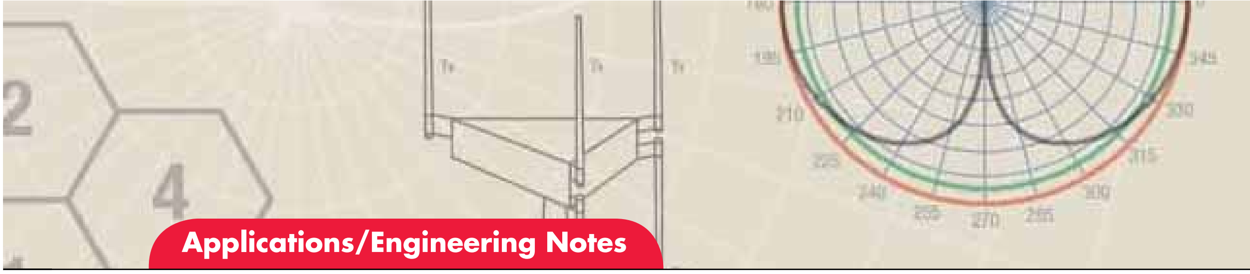
With electrical downtilt, the radiation characteristics of the antenna do change. This can be visualized by taking the horizontal pattern disc, mentioned above, and cutting into its center so that a cone can be formed. Now, the whole pattern is tilted, as shown in Figure 17.

Figure 18 shows how the horizontal radiation pattern remains the same shape as electrical tilt increases.

Andrew Corporation offers two categories of antennas with beam-tilting capabilities:

- Manual electrical tilt (MET)
- Remote electrical tilt (RET)

To adjust a Manual Electrical Tilt antenna, a person must physically adjust the antenna's tilt mechanism. The tilt mechanism allows re-configuration of the antenna while it is installed in its mounted location. This often involves the climbing of a tower while the RF equipment at the site is turned off.



As an alternative, a remote electrical tilt antenna has an actuator or motor drive attached to the antenna to allow the tilt to be adjusted remotely from the base of the tower using a local controller. Multiple antennas/sites can be controlled independently or in groups using this concept.

See the Teletilt® section of this catalog for more information.

VSWR and Return Loss

VSWR and return loss (RL) are measures of how much energy is reflected from an antenna's input. The amount of energy reflected by the antenna depends on the antenna's input impedance. The input impedance of an antenna consists of two parts, the self-impedance and the mutual impedance. The self-impedance is that impedance determined by the antenna on its own. The mutual impedance is determined by the antenna's surroundings (energy radiated by the antenna that is reflected back into the antenna from surrounding objects). The relationships between an antenna's input impedance, Z, and its VSWR and RL, Γ, are:

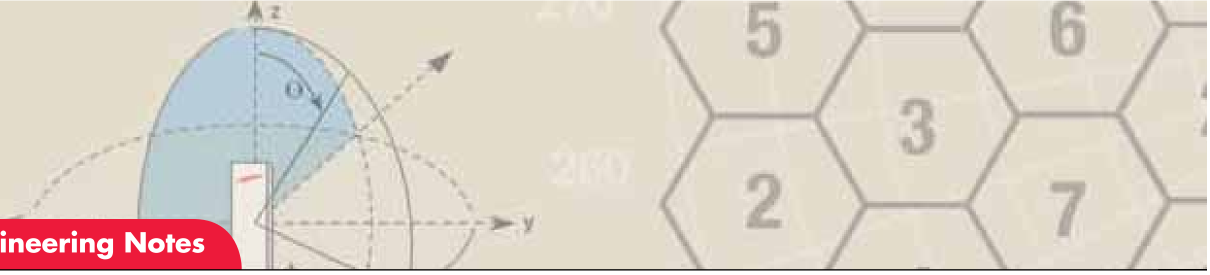
$$\Gamma = \frac{Z - Z_0}{Z + Z_0} \qquad \mathrm{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$\mathrm{R.L.} = 20 \log_{10} (\Gamma) = 20 \log_{10} \left(\frac{\mathrm{VSWR} - 1}{\mathrm{VSWR} + 1} \right)$$

where Γ = reflection coefficient
Z = antenna's input impedance
Z_0 = characteristic impedance of system

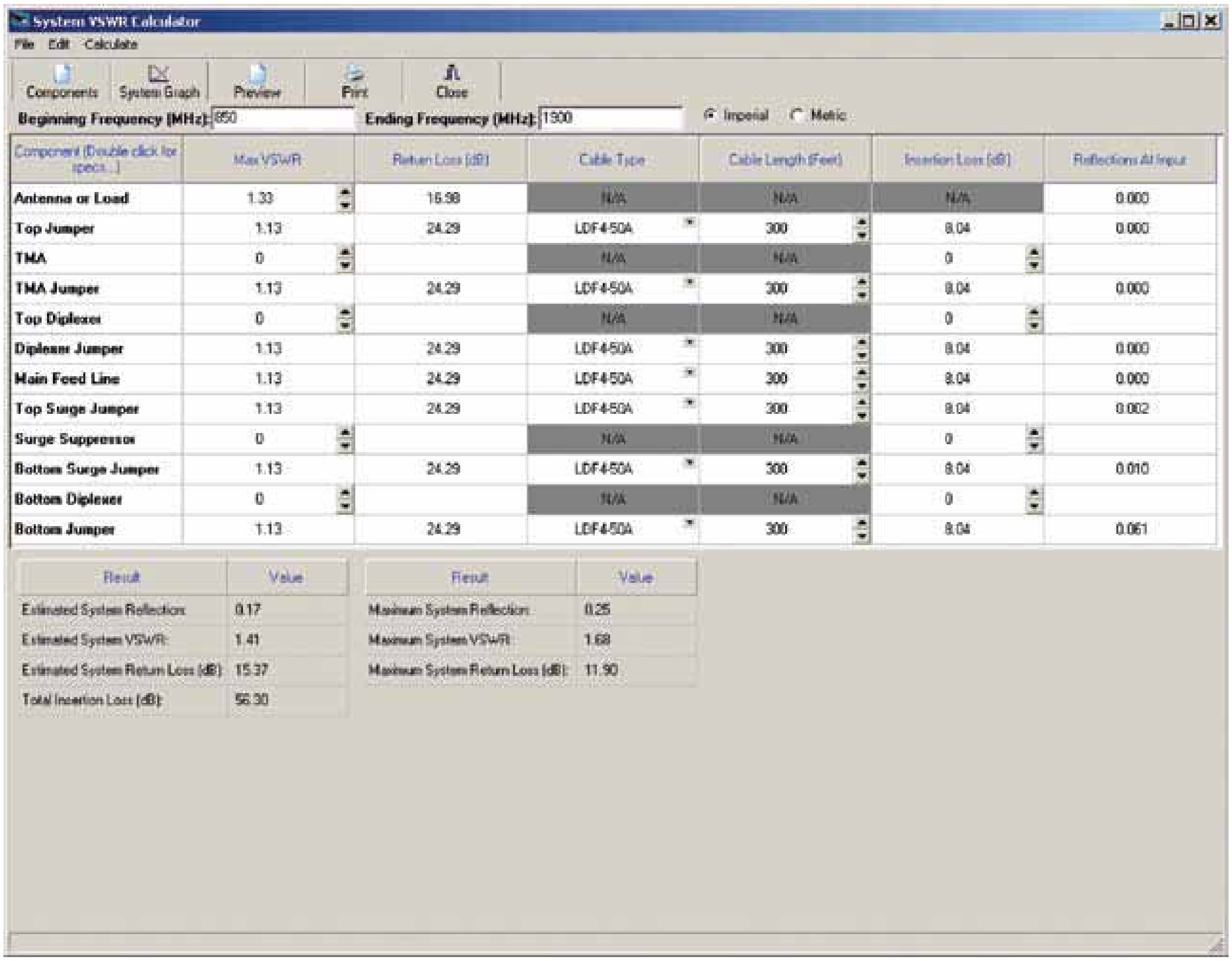
VSWR or return loss is only one component of an antenna. The table below shows how VSWR can increase (RL will decrease) without significantly increasing the antenna's overall loss (decreasing the antenna's gain).

VSWR	Return Loss, dB	Transmission Loss, dB	Power Reflected, %	Power Transmitted, %
1.0	∞	0.00	0.0	100.0
1.10	26.4	0.01	0.2	99.8
1.20	20.8	0.04	0.8	99.2
1.30	17.7	0.08	1.7	98.3
1.40	15.6	0.12	2.8	97.2
1.50	14.0	0.18	4.0	96.0
2.00	9.5	0.51	11.1	88.9



System VSWR Calculator

Often system VSWR (or return loss) readings are measured near the base station equipment at the base of the tower. These readings will be influenced by all the various components in the RF path. The estimated system VSWR calculator shown in Figure 19 mathematically calculates the theoretical RMS value expected for the combination of the components specified. Please visit www.andrew.com and click on Software, CableMaster™ to download the latest VSWR calculator tool and experience its capabilities.



Beginning Frequency (MHz): 850 Ending Frequency (MHz): 1900 ● Imperial ○ Metric

Component (Double click for specs...)	Max VSWR	Return Loss (dB)	Cable Type	Cable Length (Feet)	Insertion Loss (dB)	Reflections At Input
Antenna or Load	1.33	16.98	N/A	N/A	N/A	0.000
Top Jumper	1.13	24.29	LDF4-50A	300	8.04	0.000
TMA	0		N/A	N/A	0	
TMA Jumper	1.13	24.29	LDF4-50A	300	8.04	0.000
Top Diplexer	0		N/A	N/A	0	
Diplexer Jumper	1.13	24.29	LDF4-50A	300	8.04	0.000
Main Feed Line	1.13	24.29	LDF4-50A	300	8.04	0.000
Top Surge Jumper	1.13	24.29	LDF4-50A	300	8.04	0.002
Surge Suppressor	0		N/A	N/A	0	
Bottom Surge Jumper	1.13	24.29	LDF4-50A	300	8.04	0.010
Bottom Diplexer	0		N/A	N/A	0	
Bottom Jumper	1.13	24.29	LDF4-50A	300	8.04	0.061

Result	Value
Estimated System Reflection:	0.17
Estimated System VSWR:	1.41
Estimated System Return Loss (dB):	15.37
Total Insertion Loss (dB):	56.30

Result	Value
Maximum System Reflection:	0.25
Maximum System VSWR:	1.68
Maximum System Return Loss (dB):	11.90

◉ **Figure 19** System VSWR Calculator Shown at 850 MHz Frequency

Intermodulation

A characteristic of passive devices used in radio systems that is becoming increasingly important is intermodulation distortion (IMD). Nonlinearities within these passive devices cause the appearance of unwanted frequencies equal to the integral multiples and sums and differences of integral multiples of the unwanted frequencies. The simplest scenario is when two carriers at frequency f_1 and f_2 are fed into an antenna. If a nonlinearity is present, then the following frequencies are generated:

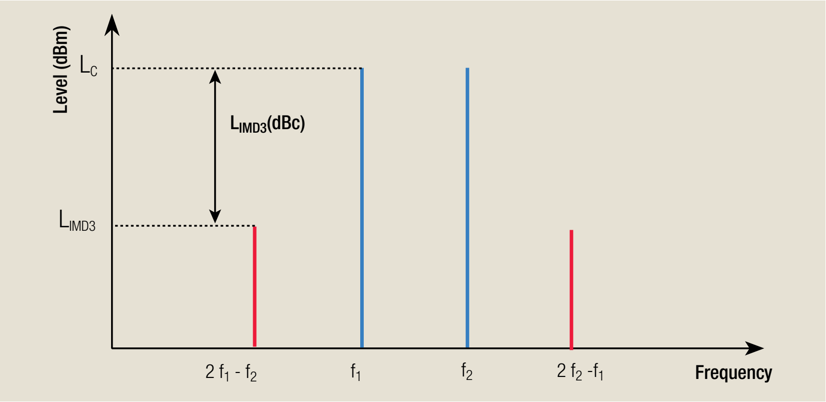
$$f_{IMD} = n\, f_1 \pm m\, f_2$$

where f_{IMD} = frequency generated by nonlinearity
$n = 0, 1, 2 \ldots.$
$m = 0, 1, 2 \ldots.$

when n or $m = 0$, then f_{IMD} is a harmonic
n and $m \neq 0$, $n + m$ is the order of the f_{IMD}

For passive devices, the f_{IMD} that contain the most amount of energy are the third order products, $2\,f_1 - f_2$ and $2\,f_2 + f_1$. Although these products do not often cause problems, they are the easiest to measure and usually specified. Figure 20 is a graphical representation of the 2-carrier IMD situation.

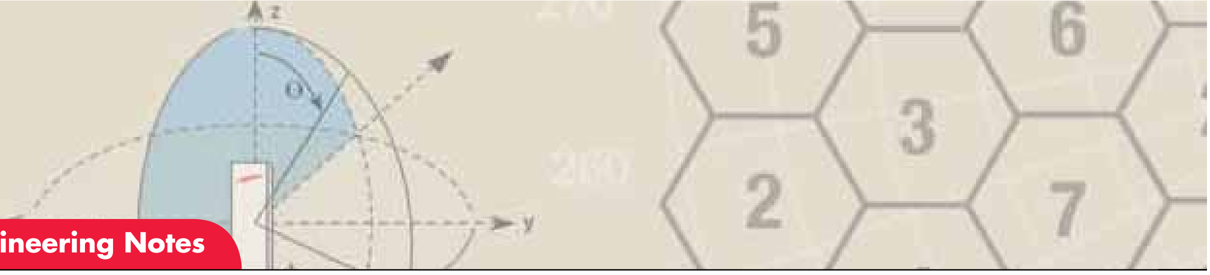
In passive devices, significant intermodulation is usually caused by ferromagnetic components in the RF path and poor connections between metal parts. The presence of significant intermodulation can be mitigated by a combination of good design and good construction practices.



● **Figure 20** Third Order Intermodulation Distortion Representation

Power Rating

The input power to the antenna terminals verifies that the antenna can safely handle and deliver its rated performance. Generally, it is limited to the power handling capacity of the feed line. Many digital systems will include both average power and peak power requirements.



Base Station Antenna Materials and Mechanical Characteristics

Materials

The selection of materials that will be used in an antenna or array breaks down to materials for the component parts:

- The radiating elements and support members
- Radomes
- Feed harness and connectors
- Hardware and mounting

Radiating Elements and Support Members

In base station antennas, where size and weight must be considered, aluminum alloys that combine high strength, low weight, good resistance to corrosion, and good conductivity are a natural choice in metals.

Pressure cast aluminum is very well suited to certain parts such as bases, sockets, mounts and clamps. It has higher resistance to corrosion than the high strength aluminum alloys while its hardness prevents metal “creep,” undesirable in clamps.

Copper and brass also are frequently used where size and weight are not factors. Principal advantages are ease of plating and similar metal contacts with the feed cable.

Radomes

Radomes are typically fabricated from high strength, low RF loss materials such as fiberglass or ABS. Materials must be ultraviolet (UV) resistant to avoid deterioration after long exposure to sunlight.

Mechanical Failure

This generally occurs when wind and ice loads exceed the yield strength of the material or where metal fatigue occurs after long-term cycling back and forth of a member due to wind vibrational forces. The material shape and size should be selected so that the maximum forces imposed on it—including fatigue—will be less than the yield point of the material. Experience is the best guide for proper safety factor.

Corrosion

This is an important consideration in metallic members and where dissimilar metals are brought into physical contact; care must be given to the materials used in order to avoid severe galvanic corrosion. Galvanic corrosion occurs as a speed-up of corrosion where moisture is present between dissimilar metals causing electrical current flow between them similar to a battery or electroplating action.

Galvanic corrosion can be eliminated by the use of similar materials or by passivating the materials in contact by plating or chemical conversion treatment (aladine or iridite). Where dissimilar metals must be brought into contact under stress conditions where the surface of chemical conversion would be scratched or impaired, the metals should be close to each other in the galvanic series (see Table of Galvanic Series) so that galvanic action is very slow.

For example, copper or brass lugs should be zinc plated (not silver) for connection to aluminum, and steel clamps or mounts to aluminum should be hot dip galvanized (molten zinc). Copper or brass should never be placed in contact with aluminum without passivating or plating the metal surfaces in contact.

Table of Galvanic Series

Relative Position of Metals and Platings Commonly Used

(1) Magnesium
(2) Zinc
(3) Aluminum
(4) Aluminum Alloys
(5) Cadmium
(6) Steel or Iron
(7) Stainless Steel (active)
(8) Lead-Tin Solders
(9) Lead
(10) Tin
(11) Nickel (active)
(12) Brass
(13) Copper
(14) Monel
(15) Silver
(16) Gold
(17) Platinum

Note: Low number is anode and high number cathode. Metal flows from low number to high number in galvanic action. Water accumulation in hollow members can be avoided with drainage holes near the low point. Not only does this reduce corrosion but it protects against freeze bursting in cold weather.

Insulators

These include radiator support insulators, insulated element spacers or insulated stiffeners. In general, insulators should be avoided wherever possible since they are subject to breakage or damage and can deteriorate performance. At the higher frequencies, they can introduce dielectric capacitance that produces higher antenna VSWR. Desirable qualities in such insulators are: low dielectric constant, low power factor (low loss) at the operating frequencies, low water absorption, ability to operate well within the temperature range without

undue change, resistance to ultraviolet radiation from sunlight and to certain gases, mechanical strength, mechanical impact resistance, and workability in machining or molding. Depending on the application, certain of the newer urethanes, epoxies, and synthetic resins meet most of the basic requirements at reasonable cost.

Coaxial and Printed Circuit Feed Networks

Element feed networks are generally coaxial harnesses, printed circuits, air dielectric stripline or a hybrid combination of all three.

A feed harness or "feed" includes the transmission line (generally coaxial) from the antenna input terminal to the actual connection on the radiator(s). This includes all matching transformers and interconnections between radiators such as tees or multi-junction connections.

Mechanical strain must be avoided on the cables and connectors. The inner conductors of small cable such as RG-141 should be given relief from direct strain. Sharp bends should be avoided in all cables.

Printed circuit feed networks are more often employed above 800 MHz where they can facilitate elevation beam shaping with upper sidelobe suppression and null fill. Often the feed network and the radiating elements can occupy the same printed circuit board. Whenever printed circuit boards are employed the use of conformal coating is mandatory to protect the circuits from environmental contamination (moisture, corrosion, etc.).

Air Dielectric Striplines

Air dielectric stripline-feed networks provide the lowest loss technology available. The feed networks are formed from a single piece of material, thus minimizing RF connection points. The use of high quality fabrication techniques yields very repeatable patterns and performance. By careful design, this technology can also facilitate the same type of beam shaping provided by printed circuit board technology.

Mechanical Characteristics

While electrical characteristics determine antenna performance, mechanical characteristics are equally important in overall considerations of the antenna system since they largely determine the life and serviceability.

Station antennas often are mounted on tall towers where the expense of installation may equal or exceed the price of the antenna itself. It is important, therefore, that the antenna be capable of withstanding the environmental conditions of wind and ice without failure, and also be able to resist the weathering effect of atmospheres it is normally subjected to.

Wind and Ice

Since antennas are installed in all areas under various conditions of wind and ice, it is difficult to set a value of wind and ice loading that will satisfy the maximum or severe conditions without overdesigning with unduly high cost for those areas where severe conditions of wind and ice as encountered on some mountaintops must be handled by specially rugged designs.

The force (F) or load that wind of a given velocity exerts on an antenna surface is

$$\mathbf{F = A\frac{\rho V^2}{2} C_d}\text{, where}$$

A—Antenna area projected on a surface perpendicular to the vector of wind velocity
ρ—Air density
V—Wind velocity
C_d—Drag coefficient, for antennas depends on cross section shape, ratio of Length/Width (Depth) and Reynolds number

Wind load can also be calculated using equivalent flat plate area (A_{fp}, see product data sheets available on the Andrew web site at www.andrew.com) per formula shown below:

$$\mathbf{F = A_{fp}\frac{\rho V^2}{2} C_{d_{fp}}}\text{, where}$$

drag coefficient of flat plate

$$\mathbf{C_{d_{fp}} = constant = 2.2}$$

The minimum design criteria for wind load should be to handle true wind velocities of 100 mph (161 km/hr) without ice and when feasible the design should be capable of handling stronger winds because many hurricane areas are subjected to winds in excess of 100 mph (161 km/hr). Where icing conditions are prevalent a separate loading should be calculated for 0.5 in (12.7 mm) radial ice with maximum wind velocity reduced because with such icing it is not usual to have hurricane force winds. The area should be the maximum area that the antenna could present to the wind, figuring that the wind could come from any direction.

Connectors and Termination

Type N and 7–16 DIN connectors are suitable for use in mobile radio communications; however, UHF connectors should not be used above 300 MHz. For the demanding intermodulation (IM) specifications required by high-capacity systems, the 7–16 DIN Family of connectors is strongly recommended.

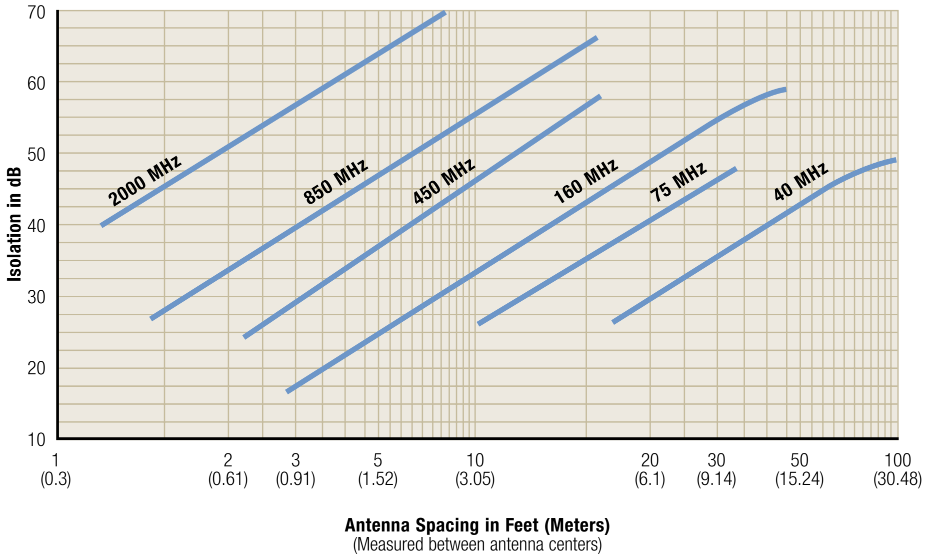
As in the case of fittings, there are preferences for antenna termination. Some users like the connector rigidly attached to the antenna support, while others prefer a flexible cable with fittings attached to its end. In either case, some flexible lead is desirable between the antenna and most transmission lines to facilitate installation and test. Andrew offers a selection of factory fabricated jumper cables—both standard and superflexible—to interface between tower mounted components.

Hardware and Mounting

Small hardware such as bolts, nuts, and rivets used for attachment of radiating elements or support members should be of sufficient strength and resistant to corrosion. Stainless steel meets these requirements and is desirable for many applications. High strength aluminum alloys also are suitable and offer some advantage for aluminum-to-aluminum connection where galvanic corrosion is a problem.

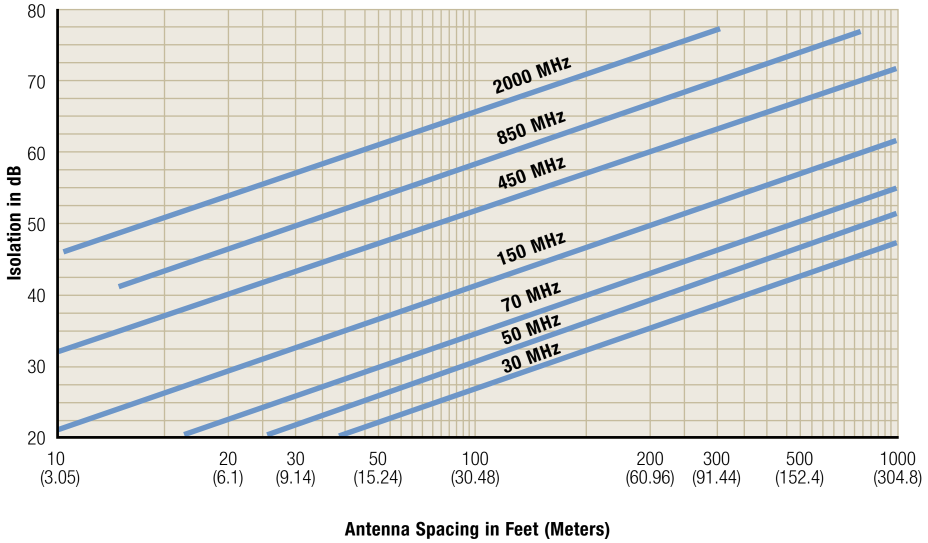
Isolation Provided by Antenna Separation

ATTENUATION PROVIDED BY VERTICAL SEPARATION OF DIPOLE ANTENNAS



The values indicated by these curves are approximate because of coupling that exists between the antenna and transmission line. Curves are based on the use of half-wave dipole antennas. The curves will also provide acceptable results for gain type antennas if (1) the spacing is measured between the physical center of the tower antennas and (2) one antenna is mounted directly above the other, with no horizontal offset (exactly collinear). No correction factor is required for the antenna gains.

ATTENUATION PROVIDED BY HORIZONTAL SEPARATION OF DIPOLE ANTENNAS



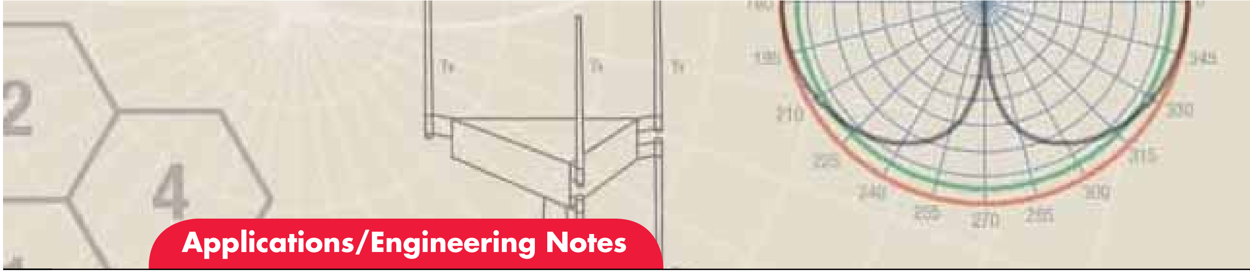
Curves are based on the use of half-wave dipole antennas. The curves will also provide acceptable results for gain type antennas if (1) the indicated isolation is reduced by the sum of the antenna gains and (2) the spacing between the gain antennas is at least 50 ft. (15.24 m) (approximately the far field).

Heavy hardware such as clamps, orientation mounts and offset brackets, should be steel, protected with hot dip galvanize finish, or cast aluminum—depending on the application. Heavy directive arrays should incorporate into the mount a convenient means of orientation with positive position locking. Clamps and mounts should be heavy duty in order to transfer the full antenna load to the support tower or mast.

Stainless steel locking bands of the radiator hose type are very suitable for many attachments provided that they are properly applied. The draw-up screws should always be positioned so as to draw down against a firm member (preferably round) in order to force locking and holding of the screw to the band slots. Properly applied, these clamping bands are extremely strong and will maintain clamping force indefinitely. They offer a convenient means of fastening to various sizes and shapes of towers and masts.

Painting Base Station Antennas

To help antennas blend into the background and make zoning easier, many customers desire to paint the entire antenna. This can be easily accomplished if a non-metallic based paint is used and smooth surfaces are slightly roughed for better adhesion. For more information please visit our website at www.andrew.com/products/antennas/bsa and select BSA Technical Literature.



Performance of Commonly Used Coaxial Cables/Transmission Lines

Attenuation losses in dB/100 ft. (30.48 m) of line and maximum average power ratings in watts[1] coaxial transmission lines commonly used with 2-way radio antenna systems.

Frequency in MHz	30	50	88	150	450	894	960	1700	2000
RG-8/U	1 dB 1100 W	1.4 dB 900 W	1.7 dB 500 W	2.8 dB 300 W	5.2 dB	8.6 dB			
RG-58/U	2.2 dB 450 W	3.5 dB 300 W	4.4 dB 250 W	6.8 dB 170 W	12 dB 80 W	17.5 dB			
1/2" Super flexible FSJ4-50B	0.557 dB 5750 W	0.724 dB 4420 W	0.971 dB 3300 W	1.28 dB 2490 W	2.31 dB 1380 W	3.38 dB 947 W	3.52 dB 909 W	4.88 dB 656 W	5.37 dB 597 W
1/2" LDF[2] LDF4-50A	0.357 dB 6460 W	0.463 dB 4980 W	0.619 dB 3730 W	0.815 dB 2830 W	1.45 dB 1590 W	2.09 dB 1100 W	2.17 dB 1060 W	2.97 dB 777 W	3.25 dB 710 W
7/8" AL AL5-50	—	—	—	0.464 dB 5100 W	0.824 dB 2900 W	1.19 dB 2000 W	1.24 dB 1900 W	1.69 dB 1400 W	1.85 dB 1300 W
7/8" LDF[2] LDF5-50A	0.195 dB 14100 W	0.254 dB 10800 W	0.34 dB 8080 W	0.449 dB 6120 W	0.808 dB 3410 W	1.18 dB 2340 W	1.23 dB 2240 W	1.7 dB 1620 W	1.86 dB 1480 W
7/8" AVA[3] AVA5-50	0.183 dB 14000 W	—	—	0.417 dB 6140 W	0.744 dB 3440 W	1.08 dB 2380 W	1.12 dB dB 2290 W	1.54 dB 1670 W	1.68 dB 1520 W
1 1/4" LDF[2] LDF6-50	0.135 dB 22000 W	0.176 dB 16900 W	0.237 dB 12600 W	0.314 dB 9470 W	0.571 dB 5220 W	0.841 dB 3540 W	0.876 dB 3400 W	1.22 dB 2430 W	1.35 dB 2.21 W
1 5/8" AL AL7-50	—	—	—	0.271 dB 8090 W	0.487 dB 4500 W	0.711 dB 3090 W	0.740 dB 2970 W	1.02 dB 2140 W	1.13 dB 1950 W
1 5/8" LDF[2] LDF7-50A	0.109 dB 30900 W	0.142 dB 23600 W	0.191 dB 17500 W	0.254 dB 13200 W	0.467 dB 7180 W	0.694 dB 4830 W	0.724 dB 4630 W	1.02 dB 3280 W	1.13 dB 2960 W
1 5/8" AVA[3] AVA7-50	0.105 dB 28000 W	—	—	0.243 dB 12100 W	0.439 dB 6720 W	0.643 dB 4590 W	0.67 dB 4410 W	0.93 dB 3170 W	1.02 dB 2880 W
2 1/4" LDF[2] LDF12-50	0.091 dB 39800 W	0.119 dB 30400 W	0.161 dB 22500 W	0.215 dB 16800 W	0.4 dB 9060 W	0.601 dB 6030 W	0.628 dB 5780 W	0.896 dB 4050 W	0.994 dB 3650 W

[1] Power ratings are based on EIA standard Rs-100 for a maximum inner conductor temperature of 100°C at 40°C ambient. Ratings should be divided by VSWR as measured at the input to the transmission line to account for hot spots.

[2] Low density foam dielectric, copper conductors.

[3] Virtual air.

Side-Mounted Omnidirectional Antennas at 450 MHz and 800 MHz

At these frequencies standard towers have dimensions of several wavelengths and therefore become complicated reflectors. It is preferable at these frequencies when side-mounting an omnidirectional antenna, to mount off the leg of the tower, rather than the face, and at a distance as far as practical. However, if the desired coverage area does not have to be circular, mounting the antenna at one quarter to five quarter wavelengths is often acceptable. Pattern nulls of 10 to 15 dB can usually be tolerated in areas where communication is not needed.

References

Balanis, C.A. *Antenna Theory: Analysis and Design*, New York, NY: Wiley, 1982

Schrank, H. 1993. *IEEE Antennas and Propagation Magazine*, 35:5, 50-1

Notes