# Matching FM Antenna Patterns and Coverage

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## Abstract

Broadcast coverage is determined in great part by the pattern of the transmitting antenna, but antenna patterns are often somewhat confusing to engineers not accustomed to them. This paper provides a basic explanation of what antenna patterns are, what they show, and how they are related to the coverage achieved by the broadcast station.

## Introduction

The coverage achieved by a broadcast station is in great part determined by the pattern of the transmitting antenna. This fact makes a careful consideration of antenna requirements imperative when contemplating a new station or antenna upgrade; however, many engineers not accustomed to dealing with antennas a day to day basis find antenna patterns and terminology somewhat confusing. This paper is intended to provide these people with an introduction to antennas and antenna pattern basics and to show the relationships between antenna patterns and the resulting station coverage.

## Antennas and radiation: some basic theory

The primary functions of an antenna are to efficiently radiate power from a transmitter into the space around its antenna and to concentrate the radiated power in desired directions so that it is not wasted in directions where there is no audience. The second function, that of concentrating the radiated power in desired directions, is the one with which we are concerned.

In order to visualize how an antenna concentrates power in certain directions, let's start at a rather illogical place: let's start with a theoretical antenna that radiates equally in all directions, called the isotrope or isotropic radiator. Imagine an isotrope sitting in the middle of the air somewhere and radiating P watts of power. Since the isotrope radiates equally in all directions, the P watts of power are spread evenly in all directions, a lot like light leaving the sun. Now, let's stretch the imagination even further by surrounding the antenna with a huge ball or sphere made of some radio opaque absorbing material and having a radius of R meters; put the isotropic antenna right in the middle so that the antenna is R meters from the sphere's inner surface in all directions. The radiated power cannot penetrate the surface and, therefore, is stopped and dissipated on that surface by creating currents (I) over the surface which then dissipate the power as $I^2R$ losses in the surface resistance of the sphere. Since all P watts were radiated and nothing between the antenna and the sphere absorbed power, P watts are dissipated over the sphere's surface. The surface area of the sphere is $4\pi R^2$ square meters, and there is P watts spread out (and dissipated) over the $4\pi R^2$ square meters, so we can define a power density, S, as watts per square meter

(1) $$S = \frac{P}{4\pi R^2} \frac{\text{watts}}{\text{meter}^2}$$

If we were to take away the absorbing ball, what would change? There would no longer be anything to dissipate or stop the radiating power, but the power would still be there. If we went out to a point R meters away from the isotropic antenna and measured the power density, we would still find $P/4\pi R^2$ watts per square meter. If we went to a distance of twice R and took a measurement, we would find that the power density would be one fourth as large as it was at R.

What we have just demonstrated is one of the fundamental laws of radiation: power density (often just stated as power) falls off as the square of distance from the source. This is true for any radiation whenever the point at which we are observing the radiation is far from the source of the radiation. There are some other interesting relationships that are true for radiation far from its source, but first, we have to define just what "far from the source" means.

As most of us know, associated with any frequency is a wavelength λ, found by

(2) $$\lambda = \frac{C}{f}$$

where C is the speed of light in whatever units wavelengths are desired, and f is frequency in Hertz (cycles per second). Associated with any antenna we can find the maximum physical dimension, D, (length, width, height) in the same units as λ. Finally, we define the distance from the antenna to the point at which we wish to observe the field as the radius of observation, r. Whenever r is greater than a particular distance (to be shown below) a number of approximations and simplifications can be made in the otherwise complex fields of an antenna. The distance beyond which these simplifications are true is referred to as the far field region of an antenna and includes all distances, r, for which

(3) $$r \geq \frac{2D^2}{\lambda}$$

where D and λ were explained above. As an example of calculating this for an FM antenna, let's see where the far field region begins for a five bay antenna operating at 98 MHz. The bay spacing is approximately one wavelength which, at 98 MHz, is 10 feet. This makes a five bay antenna about 40 feet high and gives us the largest linear dimension, D = 40 feet. With D and the wavelength known, we can find the beginning of the far field region

(4) $$r = \frac{2D^2}{\lambda} = \frac{2(40)^2}{10} = 320 \text{ feet}$$

Beyond 320 feet, we can use any far field relationships with confidence that they will be reasonably accurate.

We previously derived one far field re¬lationship, the inverse square law relating power density (S), total radiated power (P), and distance (r)

$$S = \frac{P}{4\pi R^2} \tag{5}$$

Let's look at a couple of others. most of us remember Ohm's law for circuits as if it were permanently etched on the inside of our eyelids, but here it is again, just to refresh everyone's memory:

$$V = IR, \text{ or } I = V/R, \text{ or } R = V/I \tag{6}$$

where V is voltage across some resistance, R, and I is the current through the resistance. Some of you may be asking yourselves what this has to do with antennas. Simple: in the far field region of an antenna, the electric field (E), magnetic field (H) , and free space impedance ($Z_0$ = 377 ohms) follow the same relationship as the circuit parameters so that, at every point in an antenna's far field,

$$|E| = \frac{|H|}{Z_0} \quad \text{or} \quad |H| = \frac{|E|}{Z_0} \quad \text{or} \quad Z_0 = |E|\,|H| \tag{7}$$

where the double bars, | |, indicate magnitude of the enclosed quantity. Also analogous to circuit theory is the relationship between power density (S), electric field (E), and magnetic field (H). In circuit theory, voltage, current, resistance and power are related by

$$P = VI = V^2/R = I^2R \tag{8}$$

and, in electromagnetics, S E , H and Z0 are related by

$$|S| = |E|\,|H| = |E|^2/Z_0 = |H|^2 Z_0 \tag{9}$$

From this last equation and the first one we derived (using S, P and r), we can find

$$|S| = \frac{P}{4\pi r^2} = \frac{|E|^2}{Z_0} = |H|^2\,Z_0 \tag{10}$$

$$|E| = \frac{Z_0\,P}{4\pi r^2} = \frac{1}{r} \cdot \frac{P\,Z_0}{4\pi} \tag{11}$$

$$|H| = \sqrt{\frac{P}{4\pi r^2\,Z_0}} = \frac{1}{r} \cdot \sqrt{\frac{P}{4\pi r\,Z_0}} \tag{12}$$

These equations show two things: first that the power density at any point is proportional to the square of the E or H fields, and that the E and H fields are proportional to the square root of power radiated; and second, that the E and H fields decrease as a function of 1/r.

Now that we have covered some of the basics of radiation, we can move on to see how these relate to antenna patterns and coverage.

## Antenna patterns

We previously used a theoretical antenna, the isotropic radiator, in some of our explanations. This antenna radiated equally well in all directions so that a pattern would really show very little information. No buildable antenna, however, has an isotropic pattern, nor is one desired as a rule. So, for real antennas, we need to be able to describe graphically the radiation pattern in order to determine how the antenna concentrates the radiated power.

We have a problem to solve when trying to show an antenna's radiation on paper: a piece of paper is suited for displaying two dimensional information, but since an antenna radiates in three dimensions, we need some way of showing three dimensions using only two. The answer, of course, is to use two paper plots to represent each antenna pattern. Although other plots are possible, the two most common are the elevation and azimuth patterns. If we could see RF energy as we can see light, the elevation pattern would be a "picture" of the shape of radiation intensity from an antenna taken from beside the antenna and looking at it horizontally; the azimuth pattern would be a "picture" of the shape of radiation intensity as seen from far above the antenna looking down. Let's take a few minutes to look a bit into how antenna patterns are measured.

## Antenna pattern measurements

We have established that an antenna radiates power into the air, or free space, in the form of electromagnetic waves consisting of electric and magnetic fields. Most of us depend for our livelihoods upon the fact that a second antenna will feel some effect from these fields allowing some of the radiated power to be received. In fact, we can receive this radiated power and actually calculate the power density (in watts per square meter) or field strength. So, we can just walk around an antenna with our antenna and field strength meter, writing down the readings, and later, in the comfort of our offices somewhere, plot the antenna pattern. Right?

Almost right. We are reading volts per meter, or amps per meter, or watts per square meter from our instrument. From this, we can make up an azimuth pattern that shows the variation of field strength (or power density) with angle around the antenna . . . at some distance, r, from the antenna . . . and with some power, P, being radiated from the antenna. What happens if we would like to compare two different antennas? We either must make some rather complicated corrections to compensate for measurements taken at different distances and powers, or we must ensure that all conditions (other than the antennas themselves) are identical when measurements are made on the two antennas; or, we normalize both patterns.

Recall that the power density, S, had the form

$$S = \frac{P}{4\pi R^2} \tag{5}$$

for the isotropic radiator. This was true because the isotropic radiator radiated equally in all directions. Now, we are talking about a non-isotropic antenna that radiates more in some directions than in others. This means that S depends not only on P and r, but on azimuth and elevation angles, Φ and Θ, respectively. We can indicate this by writing S at $\Phi_0$ degrees from true north and $\Theta_0$ degrees above horizontal as $S(\Phi_0, \Theta_0)$, and from this, find a definition of angular power gain, G, for a 100% efficient antenna

$$G = \frac{S(\Phi, \Theta)}{S_i} \tag{13}$$

where $S_i$ is the power density of radiation from an isotropic antenna fed with the same power as the antenna being measured and measured at the same distance, r. in other words,

$$S_i = \frac{P}{4\pi R^2} \tag{14}$$

and

$$G(\Phi, \Theta) = \frac{S(\Phi, \Theta)}{P/4\pi R^2} = \frac{S(\Phi, \Theta)\, 4\pi R^2}{P} \tag{15}$$

Notice that, for distance r and input power P constant, the gain is simply a constant $4\pi r^2 / P$ times the power density $S(\Phi, \Theta)$. Therefore, if we can measure $S(\Phi, \Theta)$, we can find the gain. This is what an antenna pattern range does.

A receiving antenna can be classified according to its "effective aperture," which is related to its gain. If a particular antenna has an effective aperture of D square meters and is held in a field having a power density of S watts per square meter, the antenna will produce an available power at its terminals of

$$P = SD \text{ watts} \tag{16}$$

which can be fed to a receiver. If we have a receiver from which we get an output signal proportional to the input power, we can write

$$X_{out} = C_1 P_{in} = C_1 DS = C_2 S \tag{17}$$

i.e., the output signal is simply some constant times the power density. If the receiver output is proportional to the input voltage or current (as is the more usual case), we can write

$$X_{out} = C_3 \sqrt{P_{in}} = C_3 \sqrt{DS} = C_4 \sqrt{S} = C_5 E \tag{18}$$

where E is the electric field in the area of the antenna corresponding to a power density of

$$E = \sqrt{S Z_0} \tag{19}$$

in volts per meter and $C_5$ is a constant that contains all conversion factors between E and $X_{out}$. In either case of receiver output, we have a value for S (either $X_{out} = C^2 S$ or $X_{out}{}^2 = C_5{}^2 Z_0 S$). If we take an antenna and spin it horizontally (i.e., varying the angle Θ), the variation of the receiver output indicates the antenna azimuth pattern; if we spin the antenna vertically, the receiver output indicates the elevation pattern. All we need do is plot the receiver output versus angle, which brings us to our main point, normalization.

If we were to simply plot the receiver output, $X_{out}$, we would have a plot of output (in volts, amps, watts or whatever) versus angle. But remember, $X_{out}$ is proportional to either S(Φ, Θ) or S(Φ, Θ), and since S(Φ, Θ) is proportional to input power and inversely proportional to the square of the distance, so is Xout, and we have not succeeded in our original goal of producing patterns (of different antennas taken on different ranges) that are easily compared. However at some point or points, the power density: S(Φ, Θ), will be maximum. Call this power density $S_{max}$. If we divide the power density at all points in the pattern by the maximum power density, $S_{max}$, the result will always be between 0 and 1. So, define A(Φ, Θ) as the normalized antenna pattern defined by

$$A(\Phi, \Theta) = \frac{S(\Phi, \Theta)}{S_{max}} = \frac{G(\Phi, \Theta)\ P/4\pi r^2}{G_{max}\ P/4\pi r^2} = \frac{G(\Phi, \Theta)}{G_{max}} \tag{20}$$

and

$$0 \leq A(\Phi, \Theta) \leq 1 \tag{21}$$

Notice that, not only is A(Φ, Θ) normalized such that it is always between zero and one, but it does not depend at all on the range at which the pattern was measured or on the power used to take the pattern. This normalization can be performed using either power density or the electric or magnetic field. This can be shown by using the relationship

$$S(\Phi, \Theta) = \frac{|E(\Phi, \Theta)|^2}{Z_0} \tag{22}$$

in our expression for normalized pattern, A(Φ, Θ).

$$A(\Phi, \Theta) = \frac{S(\Phi, \Theta)}{S_{max}} = \frac{|E(\Phi, \Theta)|^2 / Z_0}{|E_{max}|^2 / Z_0} = \frac{|E(\Phi, \Theta)|^2}{|E_{max}|^2} = \frac{G(\Phi, \Theta)}{G_{max}} \tag{23}$$

Define a(Φ, Θ) as the normalized electric field pattern,

$$a(\Phi, \Theta) = \frac{E(\Phi, \Theta)}{E_{max}} \tag{24}$$

and we find that

$$A(\Phi, \Theta) = \frac{S(\Phi, \Theta)}{S_{max}} = \frac{|E(\Phi, \Theta)|^2}{|E_{max}|^2} = [a(\Phi, \Theta)]^2 = \frac{G(\Phi, \Theta)}{G_{max}} \tag{25}$$

or

$$a(\Phi, \Theta) = \sqrt{A(\Phi, \Theta)} = \sqrt{\frac{G(\Phi, \Theta)}{G_{max}}} \tag{26}$$

This provides us with the relationship between power patterns and field patterns.

Normalized patterns of any number of antennas from any number of ranges can now be easily compared as long as they are plotted identically! There are three common scales used to plot antenna patterns: linear field, linear power, and logarithmic or dB. Linear plots are typically plots of a(Φ, Θ) or A(Φ, Θ) on circular (for azimuth) or semicircular (elevation) paper marked off in angle (either Φ or Θ) and radial distances from 0 at the center to 1 at the outer edge. The levels are often read as percent field or percent power (i.e., a level of 0.5 is equivalent to 50%). The relationship between linear field, a(Φ, Θ) and linear power, A(Φ, Θ) is given by the equations

$$a(\Phi, \Theta) = \sqrt{A(\Phi, \Theta)} \tag{27}$$

and

$$A(\Phi, \Theta) = [a(\Phi, \Theta)]^2 \tag{28}$$

What this means is that, if a field plot shows a value of a(Φ, Θ) = 0.4 at some angles Φ and Θ, then the relative power at this point is

$$A(\Phi, \Theta) = [a(\Phi, \Theta)]^2 = [0.4]^2 = 0.16 \tag{29}$$

Going in another direction, if A(Φ, Θ) = 0.5, then the relative field value can be found by

$$a(\Phi, \Theta) = \sqrt{A(\Phi, \Theta)} = \sqrt{0.5} = .707 \tag{30}$$

The third type of plot is the logarithmic or dB plot; call the dB plot B(Φ, Θ). At each angle of Φ and Θ, B(Φ, Θ) is simply ten times the log of the normalized power pattern, A(Φ, Θ). Because of the square re¬lationship between power, A(Φ, Θ) and field, a(Φ, Θ), plots of the dB value, B(Φ, Θ) can be found from a(Φ, Θ) by finding ten times the log of a(Φ, Θ) squared or twenty times the log of a(Φ, Θ),

$$B(\Phi, \Theta) = 10 \log [A(\Phi, \Theta)] = 10 \log [[a(\Phi, \Theta)]^2] = 20 \log [a(\Phi, \Theta)] \tag{31}$$

Figures 1, 2, and 3 show examples of the same pattern plotted in field, power and dB just to show how dramatic the changes in appearance can be between the three types of plots.

The three types of patterns are used in much the same way. Let's say that we have a rating of 100 kW ERP. The ERP is actually an abbreviation for Effective (isotropically) Radiated Power. The 100 kW ERP indicates that, at the angle of maximum gain, at any radial distance from the antenna, there should be a power density equal to the power density that would exist at that point if 100 kW were radiated from a theoretical isotropic radiator in free space. In other words, with 100 kW ERP, we should be able to go anywhere in the main beam (where the normalized pattern is 1) at any distance, r, and measure a power density, S, of

$$S_{max} = \frac{100 \text{ kW}}{4\pi r^2} \tag{32}$$

Using our relationships between S, E, H and $Z_0$, we can find equivalent electric and magnetic field strengths:

$$E_{max} = \sqrt{SZ_0} = \frac{(377)(100 \text{ kW})}{4\pi r^2} \tag{33}$$

$$H_{max} = \sqrt{\frac{S}{Z_0}} = \frac{100 \text{ kW}}{(377)\, 4\pi r^2} \tag{34}$$

Once we have found S and E, we can then use the linear A(Φ, Θ) or a(Φ, Θ) plots to find S(Φ, Θ) or E(Φ, Θ) at any other angles but at the same distance simply by using

$$S(\Phi, \Theta) = A(\Phi, \Theta)\, S_{max} \tag{35}$$

and

$$E(\Phi, \Theta) = a(\Phi, \Theta)\, E_{max} \tag{36}$$

The dB plot is used in much the same way. As an example, let's say that our antenna pattern, A(Φ, Θ), is one at some point (some Φ, Θ) corresponding to a direction towards our city of license, which is 30 kilometers away. At this point (30 km or 30,000 meters) from the antenna, we find $S_{max}$ to be

$$S_{max} = \frac{100{,}000}{4\,(30{,}000)} = 8.8 \times 10^{-6}\, \frac{\text{W}}{\text{m}^2} = 8.8\, \frac{\mu\text{W}}{\text{m}^2} \tag{37}$$

So, in our city of license, at this point, de should have about 8.8 microwatts per square meter. Using

$$E_{max} = \sqrt{S_{max}\, Z_0} \tag{38}$$

we find that this corresponds to about 58 millivolts per meter of electric field. we can then use this to find our signal strength at the same point in dBu's, which are defined as twenty times the log of the electric field strength divided by one microvolt per meter

$$E_{max} \text{ in dBu} = 20 \log \frac{E}{1 \times 10^{-6}} = 20 \log \frac{58 \times 10^{-3}}{1 \times 10^{-6}} = 95 \text{ dBu} \tag{39}$$

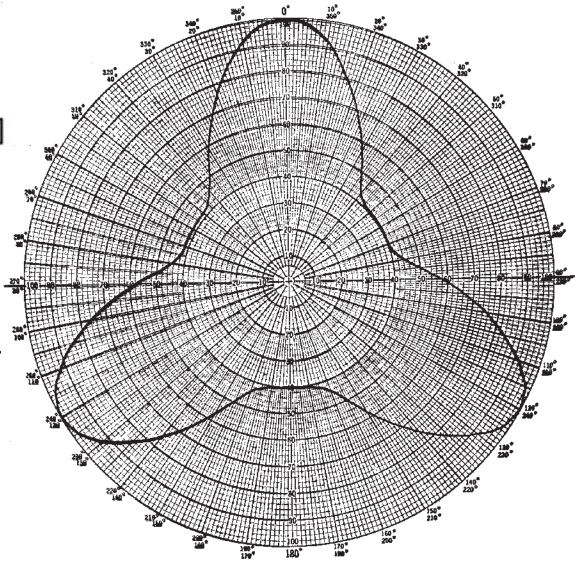
Figure 1

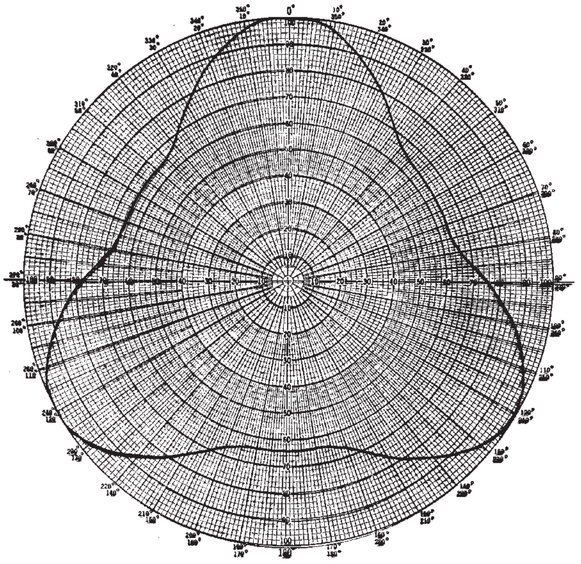
Figure 2

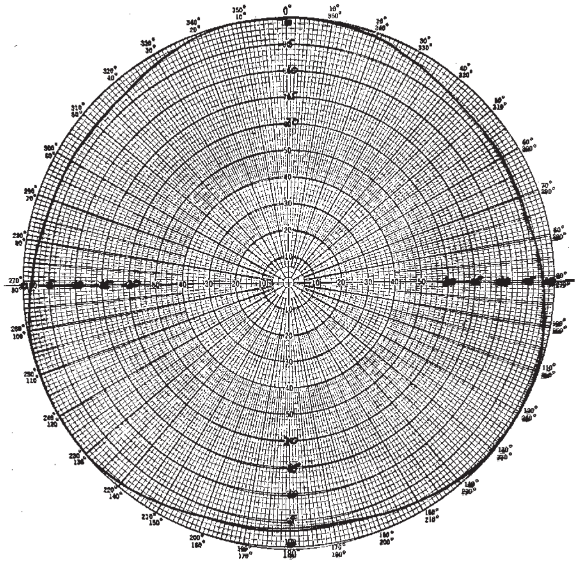
Figure 3

Now, suppose that there is a second city located 30 km away from the antenna, but 65° away from the first city in azimuth. We look at our antenna pattern and find $A(\Phi, \Theta)$ for this direction to be $A(\Phi, \Theta) = 0.43$. This corresponds to

$$a(\Phi, \Theta) = \sqrt{A(\Phi, \Theta)} = \sqrt{0.43} = 0.66 \tag{40}$$

$$B(\Phi, \Theta) = 10 \log [A(\Phi, \Theta)] = 10 \log (0.43) = -3.67 \text{ dB} \tag{41}$$

Our ERP in this direction is simply

$$ERP(\Phi, \Theta) = A(\Phi, \Theta)[\text{rated ERP}] = 0.43(100 \text{ kW}) = 43 \text{ kW} \tag{42}$$

Our power density is found from

$$S(\Phi, \Theta) = S_{max}\, A(\Phi, \Theta) = 8.8\, \frac{\mu W}{m^2}(0.43) = 3.78\, \frac{\mu W}{m^2} \tag{43}$$

Our electric field strength is

$$E(\Phi_0, \Theta_0) = E_{max}\, a(\Phi_0, \Theta_0) = 58\, \frac{mV}{m}(0.66) = 38.28\, \frac{mV}{m} \tag{44}$$

and our field, in dBu, is

$$E_{dBu} = E_{max,\, dBu} + B(\Phi, \Theta) = 95 - 3.67 = 91.33 \text{ dBu} \tag{45}$$

We have now seen how to take and use the antenna pattern to estimate what the approximate coverage will be. Remember, however, that raw antenna patterns, such as are normally received from the manufacturer, do not take into account attenuation or scattering due to the ground or surrounding terrain. The pattern measurement performed by an antenna manufacturer is a reasonable picture of an antenna's radiation if the antenna and tower were suspended in free space, far from the earth or any other obstacles. However, anything in the path of an antenna's radiation may perturb or change the pattern somewhat. Let's take a quick lock at the general methods of interaction, and then go a bit deeper into a few specific radiation obstacle situations.

## Scattering and reflection

Just about everyone has, at one time or another, thrown a small pebble into a quiet pond or puddle and watched the concentric rings of ripples move away from the initial point of impact, slowly decreasing in amplitude as they move. This is a reasonably good two dimensional picture of radiation from the ideal isotropic radiator in free space. The radiation travels outward in all directions, diminishing in strength as it gets further from the source.

Now, think of the same pebble dropped into the water only a few inches from a wall. Initially, the ripples leave the point of impact just as they did when the wall was not nearby. But soon, the first ripples hit the wall. Depending on many factors (such as the wall shape, size and material), the ripples will partially or wholly reflect from the wall and begin moving back towards the source of the ripples, the place where the pebble landed. The backwards traveling ripples meet the forward traveling ripples and create interference patterns. Where two ripples, one forward, one backward traveling, meet with both ripples high (the ripple or wave level above the flat water or average water level), the resulting level is the sum of the two and is higher than either. Where two ripples meet with low (below average) water levels, the resulting level is lower than either of them.

Electromagnetic fields exhibit the same type of phenomena. As might be imagined, predicting the resultant pattern for a com¬plex arrangement of antenna, tower and surrounding landscape is nearly impossible to any great accuracy. However, the antenna manufacturer can usually do a very good job of measuring the effects of the tower and its contents, as described below, and a consultant can utilize statistical curves, maps, computers and other tools to predict the effects of surrounding terrain. Now that everyone has a basic knowledge of what patterns are and how nearby objects can affect them, the rest of this paper will delve a bit deeper into some specific problems that commonly are seen.

## Antenna pattern distortion

Thus far, we have talked mainly about antennas in free space - in other words, antennas suspended in air without towers or other supporting structures of any kind. This discussion is of immense value when trying to understand and visualize how the antenna system produces the pattern required by broadcasters for use by their listening audiences. However, in order for these antennas to radiate signals to as large an area as possible, they must be physically positioned with respect to their intended listeners so that interfering structures such as hills and buildings will not absorb, reflect or otherwise block these signals from reaching the audience. Also, there must be a way of channeling the signal from the station's transmitter system to the antenna.

In order to overcome the adverse effects of buildings and mountains, antenna systems can be placed high above the area for which the broadcast is intended. This allows most of the transmitted signal to travel over these obstructions, unencumbered, to its destination. That is why antennas are usually mounted high on tall buildings or atop tall towers. The need for transmission of the signals from the station's transmitting plant to the antenna is filled by use of what is known as an antenna feedline. Signals exit the transmitter and radiating elements that are physically attached to the feedline. We should now be able to visualize the entire configuration; the antenna elements mounted to the feedline, and that entire assembly bolted to a tower or other supporting structure. This is how most side mounted FM antennas are constructed.

If we think for a moment about the radiation pattern from this type of system, we may begin to suspect that the feedline and tower, positioned so close to the antenna elements, will have a profound effect. Electromagnetic radiation, which is exactly what a radio signal is composed of, is created or excited by time varying or oscillating electric currents flowing in and around any physical structure that will conduct electricity. The station's transmitter produces a signal that causes oscillating currents to flow in and around the conducting elements of the antenna. These currents, in turn, produce electric and magnetic fields around the antenna that give rise to the radiated signal that travels out to the listeners. However, these fields around the antenna do other things too. Besides producing the intended radiated signals, the fields induce currents in other structures that conduct electricity near the antenna, such as the outside surface of the antenna feedline, so-called ground straps along the antenna feedline that electrically bond the line to the tower, legs and support members in the tower, and mounts that secure the antenna to the tower or other support structure. These induced secondary or parasitic currents will then produce electric and magnetic fields of their own. These secondary fields will interact with the primary fields from the antenna itself, producing a resultant field distribution that is altered significantly from the field distribution that would otherwise be present from the antenna alone. And, since it is this resultant field distribution that will determine the final antenna pattern, the need for a thorough evaluation of these effects should be apparent to ensure that the resultant antenna pattern is suited to the needs of the broadcaster.

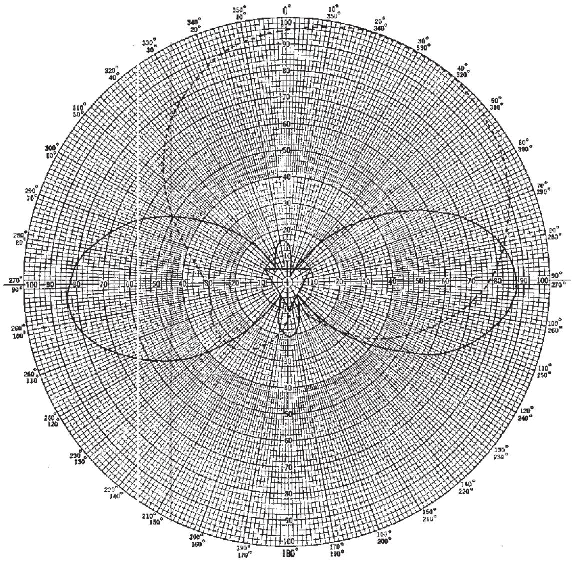

Figure 4

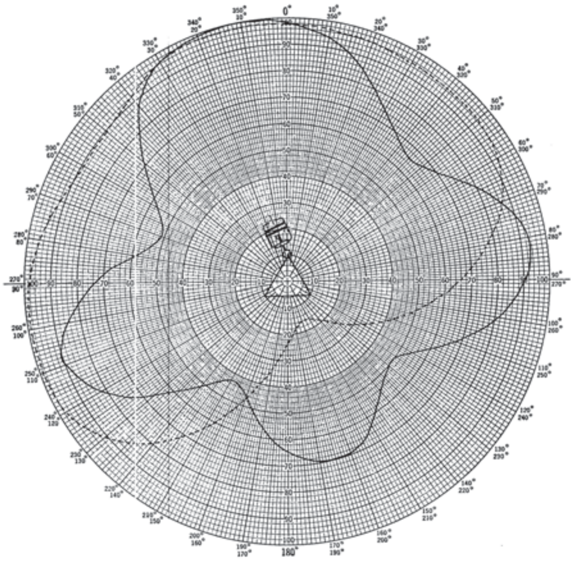

Figure 5

Figures 4, 5 and 6 are patterns measured on our range for three different sidemount antennas. These patterns make evi¬dent the amount of interaction between the antenna and its immediate surroundings, and the necessity for evaluation.

## Directional antennas

In certain cases, this parasitic effect can be extremely useful. Antenna patterns can be manipulated greatly by the conducting elements near the antenna. These aptly named parasitic elements have no direct electrical connection to the antenna feed¬line. Their field producing currents are induced by the fields from the feedline-driven elements in the antenna in exactly the same manner as the other conducting members do, as discussed earlier.

The type and degree of antenna pattern alteration by parasitic activity depends on several factors. Prediction of the pattern by analytical means from a given configuration may be done; however, it is quite complex and carries with it a certain degree of uncertainty. It requires the superposition of the complex fields from all current carrying members in and around the antenna. These fields describe what are called radiation moments. Each radiation moment has an associated relative strength or magnitude, as well as an associated relative direction or phase. Because of the fact that these quantities have both a magnitude and a phase associated with them, they are said to be complex or vector quan¬tities. Computer pattern calculation is done by summing all these radiation moments at each point in space around the antenna.

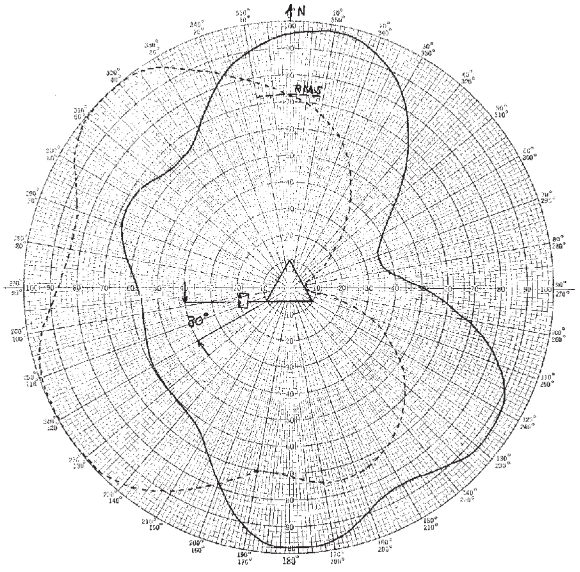

Figure 6

Directional antennas are implemented by introducing radiation moments from other antenna elements, usually parasitic, and allowing them to interact with the moments from the antenna elements driven by direct connection to the antenna feedline. The system is adjusted so that this interaction will take place in such a manner that the resultant antenna field distribution will produce a net reduction of the radiated signal in directions where too much signal is undesirable, such as government receiving installations, and an augmentation of the radiated signal in desired directions such as large cities where there are many listeners.

Figure 7 shows a representative pattern for an intentionally directionalized antenna.

One specific type of antenna that affords a high degree of control over the pattern is the so called panel antenna. Panel antennas have incorporated within them a shielding panel or screen positioned between the antenna radiating elements and the tower, that greatly reduces the magnitude of parasitic currents in tower and support members. Panel antennas produce relatively distortion free predictable azimuth patterns which are ideal in high quality installations or in situations where a specific directional pattern is mandated that cannot be achieved with a side mounted antenna.

Figure 8 shows the high level of omnidirectionality in azimuth which can be achieved with a panel antenna.

Directional antennas must be specifically applied for on the application for a construction permit with the Federal Communications Commission.

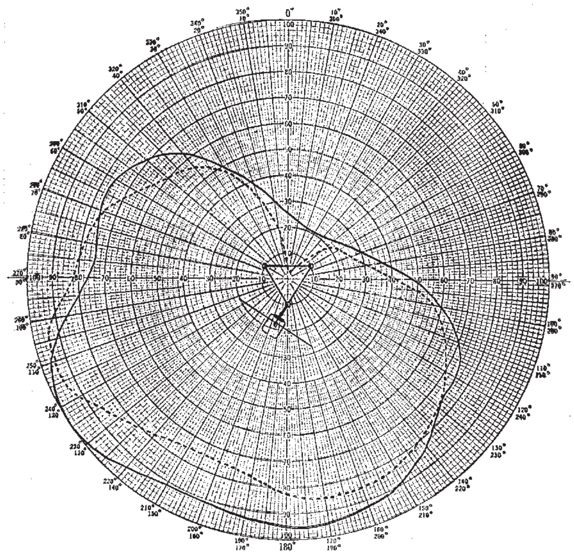

Figure 7

## Range- and field-measured patterns

Antenna patterns, though they may be numerically calculated as described above, are usually measured on an antenna pattern range. A single element of the antenna is mounted on a tower containing all conducting members and structures that may carry currents producing fields that can distort the pattern. The physical configuration of the entire antenna system, including feedline, feedline grounding straps, distance between the tower and antenna and parasitics, if any, is adjusted so that all radiation moments, when added together, produce the desired or required pattern. The pattern range itself must be constructed extremely carefully. As the signal is radiated and travels from the transmitting to the receiving antenna, the range must not introduce any parasitic effects of its own that will not be incorporated in the final antenna system in the field. Range parasitic effects may be suppressed by the careful placement of special radio absorbing material around the test site so that an accurate pattern picture of the entire antenna system is assured.

Once the antenna is placed in the field, the pattern may finally be measured by actually flying around the antenna site at a constant distance with the proper recording instruments, and plotting the relative field strength as a function of azimuth angle. There should be little discrepancy between the pattern measured on the test range and that measured in the field if cautious measuring practices are carried out on a properly constructed pattern test range.

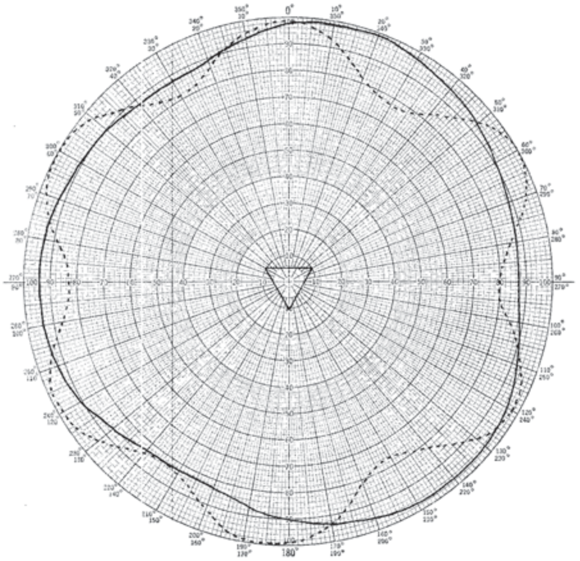

Figure 8

## Terrain and multipath

The overall performance of a broadcast station is influenced by other factors aside from the antenna system itself. The antenna may be producing a pattern that should provide a high level of signal over a given area, but when that signal is measured, the results show otherwise.

As mentioned earlier in this paper, large structures such as buildings and mountains will reflect and/or absorb signals from an antenna on their way to a listener's radio receiver. This was seen when we described waves on the surface of a pond and how they interacted when they encountered a piece of wood. If these obstructions are large enough, or if they are located in such a position with respect to the intended listening area, they absorb and/or reflect the signal, resulting in a reduction of this signal to unacceptable levels. In this situation, unless the antenna site is relocated, there is little that can be done about these obstructions outside of using a D9 bulldozer or a freight train load of high explosives!

Another phenomenon that is a causal factor for ulcers is known as multipath. In some areas, mountains and buildings may set up a path for a signal to follow as it travels from the station's antenna to the listener's receiver. The signal leaves the transmit antenna, propagates until it hits a mountain or building, reflects and then moves on to the receiving antenna. At the same time, a signal that leaves the transmit antenna at a slightly different angle may have a clear line of sight path from the transmitter to the same receiver. It should be apparent that these two signals have taken two different paths on their way from the transmitter to the receiver. These signals each produce currents in the receiving antenna that is passed on to the receiver circuits. These currents are parasitic currents, and as such, are vector quantities, as discussed earlier. The magnitude and phase of these currents induced in the receiver antenna are determined, among other things, by the length of the path from the transmitter to the receiver. If the two paths taken by each signal are of lengths such that the receive antenna currents resulting from the each signal are nearly equal in magnitude but opposite in phase, the signal will cancel in the receive antenna and never reach the receiver circuits. The result is an apparent loss of signal.

In some cases, the antenna pattern may be adjusted to reduce the effects of multipath, however, in the majority of severe cases, multipath must be dealt with using other options.

## Conclusion

Whenever an antenna is built and mounted to a supporting structure, it is virtually impossible to exactly predict the resulting pattern characteristics without complex involved computer calculated or range measured patterns. In this paper, we have seen how an antenna works, and have investigated some "real world" effects on patterns, and how the radiated field or power density at any specific point around an antenna is influenced. We are able to measure the effects of these factors and, to a large degree, control the resulting interaction of all the radiation moments in a system producing a pattern that is both legal and desirable. Because the Federal Communications Commission requires all patterns to be as omnidirectional as possible, with the exception of permitted directional antennas, pattern measurement becomes almost required. In any case, antenna patterns are extremely important, and the proper installation of an antenna system should include a thorough evaluation of these effects to insure many years of optimum, trouble free performance.

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