Discussion of Propagation, Multipath, and Antennas as Related to Radio Direction Finding

CONTENTS

Introduction

The Importance of Understanding the Environment.

I was once told by an engineer that he knew everything there was to be known about Radio Direction Finding. After a little bit of questioning, it was apparent that he knew next to nothing. *(Note: This writer has an MSEE degree, with emphasis on Radio Communications, so he is not speaking from a bias against engineers.)*

But it’s not too hard to see how an inexperienced person with some knowledge about radio might come to the conclusion that RDF is "easy." "After all, you just take a bearing with a beam antenna and plot that on a map. You then go to another location, and do it again. Where the 2 bearings cross, that is where the transmitter is located. Simple!"

If you have been doing any RDF work at VHF or UHF, you KNOW it isn't simple. I sure do. I have been on many a hunt where (at least at first) what I was seeing was very confusing. Not only do the laws of physics conspire against the hunter (which this paper discusses), but also the hider is doing his best to scramble your brains (that's a subject of another paper, "Dirty Tricks"). Its a real Sherlock Holmes adventure. You are presented with a large amount of data, much of which may seem to be contradictory or not make any sense at all, and you must sort it all out. In Real Time. In unfamiliar territory. At night. At freeway speeds. Lots of luck!

Successful RDF boils down to:

- Equipment 33%
- Experience 33%

- Knowledge 33%
- Luck 33%

TOTAL 132% (Well, at least it seems that way!)

So, if you have been bitten by the T-Hunt bug, you are in for quite an adventure! And part of that adventure is in learning.

This paper is an attempt to answer some of these questions.

"How does the signal REALLY get from point A to point B? What effects it along the way, and how is it effected?" "What are the characteristics of T-Hunt antennas? The strengths and weaknesses of each? The situations where I would best use each? How does each type interact with its environment?"

Ground Wave Absorption

If you have operated on the HF bands, you have probably heard of the "ground wave." You probably know that the ground wave gets weak to the point of disappearing over a rather short distance. And you know that the sky wave travels up and bounces off the ionosphere, and returns to earth very far away.

But did you know that there is a ground wave at VHF?

Just what is a ground wave, and why does it have so very much attenuation over short distances? Envision a radio wave traveling parallel to the ground. The part of the wave that is actually in contact with the ground interacts with the ground (and the objects sitting on the ground). This energy see a dielectric constant which is much greater than that of the air. A radio wave traveling through a high dielectric constant travels slower than through a low dielectric constant. As a result, the energy near the ground travel slower than that which is far away from the ground (up high). The wave front which is radiating out from the transmitting antenna is in effect dragging its feet along the ground. This causes a bending of the wave front, where that part which is near the ground is "leaning" forward in the direction of travel.

Now it turns out (if you take graduate level university courses in electromagnetic theory!) that the energy in a radio wave front ALWAYS flows in a direction perpendicular to the wave front. Thus the energy at the foot of the wave front dragging along the ground is traveling at a slant, down towards the ground. This means that much of the energy near the ground will be absorbed by the ground. So the wave front near the ground is depleted of its energy. Hence the loss for the ground wave is very much more than that for a wave traveling in free space. The HF signal drops into the noise after traveling only a short distance. (A distance much too short to be accounted for by the curvature of the earth.)

So of what importance is this at VHF? At VHF the effect is very pronounced. The strength of a signal only 20 feet above the local ground level can be very much stronger than that 6 feet above ground level. This effect was hammered home to the writer by observing his Doppler while driving on the freeway, with the signal coming from straight ahead. On open parts of the road, the bearing was consistently dead ahead. But every time we went under a large overhead sign (across the freeway), the bearing flipped to dead to the rear! You see, the energy bouncing down upon us from the overhead sign was substantially stronger that the energy coming from in front of us at a height of 6 feet off the ground. In order for a bounce like that to be stronger, the energy level of the signal hitting the sign must have been rather significantly stronger than the "ground" signal.

There is another example of this known to a lot of Southern California hunters. There is a stretch of freeway which passes by a single very tall building about a block off the freeway. The freeway is often used by T-hunters while hunting. On two meters, as you come near this building, all bearings will be towards the building. More than one T-hunter has been "pulled off the freeway" at this point. Of course, what was happening was that the upper part of the building was seeing very much stronger RF wave front that the hunter in his car. The building scatters the energy in all directions. When you are close enough, the energy coming down from the building overpowers the "direct" ground wave.

If you know about this effect you are not as likely to be fooled by it!

Reflections

At radio frequencies you will seldom encounter true reflections. By true reflections I refer to situations where the signal bounces off of an object like a beam of light bounces off of a mirror. It can happen when the object is rather large compared to the wavelength, and has a surface that has only holes or changes of contour that are small compared to the wavelength. The side of a large metal sided building, like a hanger or industrial building with few or no windows or doors would produce reflections.

Scattering

The more usual situation is scattering of radio energy. This is analogous to a broad beam of light hitting a stucco wall. The light scatters in all directions, so the area illuminated on the wall can be seen from any location with a clear view of the spot. The radio signal hits a mountain, hill, or building with a complex surface, and signal scatters from it in many directions.

Knife Edge Diffraction

This is a term borrowed from optics. It refers to an effect as a light beam passes across the edge of a sharp object like a knife blade. On the side of the blade away from the light source, light bends downward into the "shadow" area. The sharper that bend angle, the less the light intensity. The percentage of energy bent in this fashion is very small. An important parameter is the width of the edge of the knife blade in relation to the wavelength of the light.

The same thing can happen at VHF radio frequency. (Remember, radio and light are exactly the same physical phenomenon; the only difference is the frequency.) Because the wavelength is so much longer than light, the sharp ridge of a hill can act as the "knife" blade.

We actually made use of this effect on one hunt where we were hiding. (See the article, "Dirty Tricks," the section on Knife Edge.

Generally, this effect has very little importance because the amount of energy bent is so very tiny. It is included here primarily for completeness.

Gradient Bending

Gradient bending refers to any situation where an electromagnetic beam passes from an area of one dielectric constant into another area of slightly different dielectric constant. If you have studied optics you should know this is how glass lenses work. If you have ever stuck a straight stick part way into a body of water, and the stick appeared bent at the point at the surface of the water, then you have seen this effect.

Seashore Bending

A vertical interface: A horizontal gradient

The same thing occurs at radio frequencies. Here is a classic example. Consider a long straight beach at the ocean shore. The air over the water is cooler and wetter than the air over the land, therefore it has a higher dielectric constant. A radio signal coming ashore will pass from an area of more dense air into an area of less dense air. Assume the signal comes ashore at an angle other than perpendicular to the shore The signal path will bend (to one side) at the shoreline, making the angle even farther from the perpendicular to the shore. Thus if you are taking a bearing from the land to the sea, there may be a slight error. This is exactly the same as light emerging from a glass lens.

Density layer bending

A horizontal interface: A vertical gradient

One real-world example: This writer was training the owner of a new SuperDF to use it to take bearings on ships in distress at sea (from his home on a bluff above the shore). After DFing several ships, we tuned in one who was transmitting a long "shopping list" for the ship's supplies. We took the bearing, and then stopped to talk. A few minutes later we noticed that the ship was no longer "On Bearing." It had moved 5 degrees! The DFer said that was impossible, as he knew that it was a research vessel which was permanently anchored on station, and not moving. "So what happened?" he asked. I asked him to spot the ship on his map, and he did so. I then asked for the the elevation of his DF antenna above sea level. I then calculated the visual horizon at sea for his antenna. This showed that even accounting for the probable height of the ship's antenna, that the two antennas where not line of sight. I then explained.

The air above the ocean is most dense near the surface, where it is cooled by the water and carries a lot of water vapor. Radio wave travel more slowly through this dense air than through the "thinner" air higher up. This causes a bending of the radio signal slightly downward. Thus a signal transmitted from over the horizon will bend enough to be heard loud and clear. But why did the bearing shift? The answer is that these condition of air density are not constant, and vary from time to time and from place to place. Wind shifts can make a big difference. The bending can even have a side ward component, causing the apparent bearing to shift (a small amount).

Another example is sometimes referred to as tropospheric bending or temperature layer bending. Here the radio signal encounters a near horizontal layer in the atmosphere where the air density changes rapidly with altitude. If the change is from dense to less dense at increasing altitude, then the radio signal can be bent, and come back down, hitting the ground a long distance away. The writer has seen this. A signal was heard loud and clear in the San Gabriel Valley from a station in Baja California, Mexico. At the same time, a repeater on top of Mt. Palomar (6000 feet) could not hear the signal (on its input frequency). Mt. Palomar is quite a bit closer to the station than the author. What was happening was the signal was going up, hitting one of these layers, and bending down so that I could hear it. Because the layer was below the repeater, the signal never reached the repeater. Later, the layer either lifted or dissipated, and the signal was heard through the repeater, and I no longer heard it directly.

There are specific things to look for to tell if you are seeing this kind of propagation. These layers are not stable for long periods of time, nor are they perfectly flat. They move up and down, produce wiggles and bubbles in their surface, and they tilt at different angles. As a result, there can actually be several paths from the station bouncing off this layer and down to your antenna. As a result, there is a multipath condition at your antenna, and as the various individual paths change, the signal will change signal strength (from reinforcement or cancellation). This is usually a very rhythmic fluctuation of the S meter, with the time for a cycle ranging from several minutes down to a fast flutter. I saw it go from full quieting to gone in a few minutes.

Thus, if you have an interfering signal, and it behaves in this way, then you know you will be in for a long drive, should you choose to find the source! Do you really want to burn 120 miles in each direction, with the prospect that the signal will go off the air before you get there? Instead, telephone other hunters in areas where it might be coming from (on that bearing). I know of one incident where this was the case, and the hunter who was called made the find (which later resulted in an FCC bust!)

Local Dielectric Bending

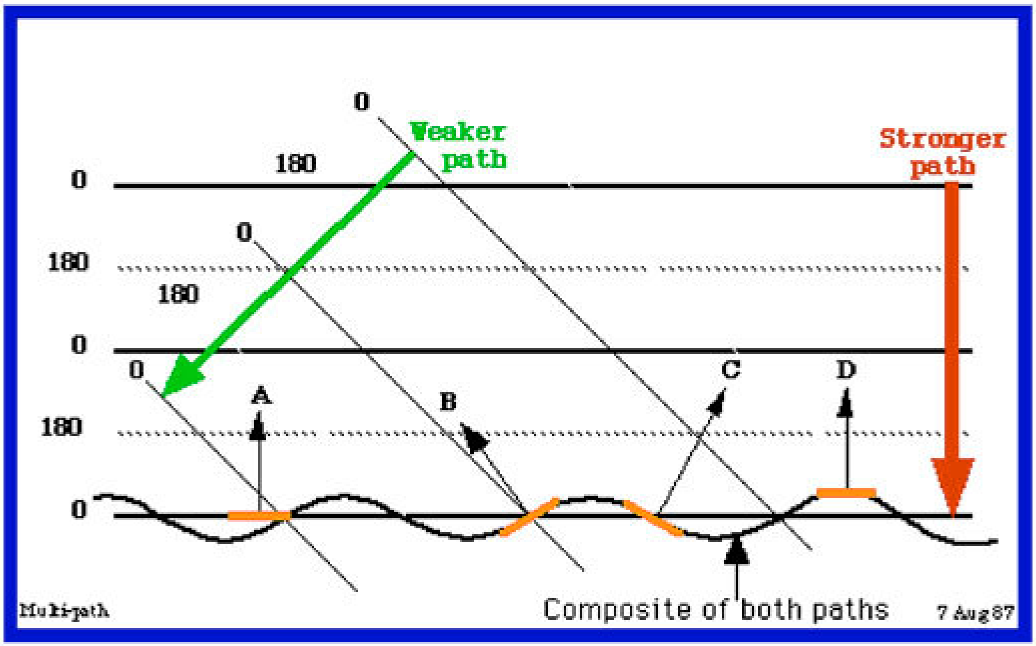
We have already discussed the dielectric bending which produces high ground wave loss. This same bending can be produced locally by dense bushes or trees. A radio signal can pass through areas devoid of bushes while nearby passing though dense vegetation, resulting in differing velocity of the radio signal. This bends the wave front. If you are DFing from an area where this bend is present it can result in a bearing error. The bending is from the path without vegetation toward the path with the vegetation. This tells us that we should seek out location to take bearing from that are uniform in environment. The best place is at the edge of a bald hill, facing the direction the signal is coming from.

Multipath Environment

In a multipath situation RF energy is traveling from the source to your RDF antenna by more than one path. One path may be a direct path, straight from the radiating antenna to your RDF antenna. It is also possible that there is no direct path at all; all energy is reaching the RDF antenna by two or more scattered (or reflected) paths. At each particular exact location of the receiving antenna, these multiple paths will combine, obeying laws of superposition of sine waves. The net combined wave can be a strong signal where all paths combine in phase, or a very weak signal when the net combination results in cancellation. Moving the antenna only a few inches or feet can result in a very large change in signal strength. This is the mechanism that causes a signal to flutter in strength or momentarily disappear while you are mobile in motion.

The objects producing the multipath can be at any distance from you. They can be a few feet away, many tens of miles away, or anywhere in between.

In addition to the amplitude variation that multipath can cause, there is another effect which is important to phase sensitive systems like SuperDF. If you were to measure the relative RF phase over many nearby (fixed) points in space, you would find that the apparent phase front of the arriving signal takes on a wavy shape, rather than a straight line (for a distant transmitter). See the figure below for a two dimensional representation of this phase front distortion. The view point is from directly overhead, looking down at the ground. The numbers 0 and 180 refer to the phase angle. This is a "freeze-frame" view. The wave fronts are really traveling at the speed of light in the directions of the colored arrows.



Two wave fronts coming from different directions combine to show a sine wave like composite wave front.

Multipath wave-front.

"A" in the figure shows a bearing that would be produced by a SuperDF moving at a reasonable road speed. It doesn't matter in what direction it is moving. Note that it is the bearing of the stronger path. Bearings B, C, and D indicate three different bearings that would be obtained at their respective locations taken by a stationary SuperDF.

Antenna Aperture Defined

Antenna aperture is a concept that may need some explanation. It is a way to describe how effective an antenna is at absorbing RF energy from the signal passing by. It is expressed such as . . "An aperture of 1 square meter." This means that the antenna will absorb an amount of RF energy equivalent to all the energy coming through a "window" of 1 square meter area. Note that it does not refer to the physical size of the antenna (as viewed by eye from the "front.").

Large Antenna Response in Multipath Conditions

A good example of this is the long Yagi beam antenna. Viewing it from the front, it looks to the human eye to be no bigger than a single dipole. Yet, its aperture is very much bigger than a dipole. The long Yagi is what is called a Slow Wave Structure. The director elements interact with the moving wave front to slow down the speed of radio signals whose frequency is close to the design frequency for the antenna. This slowing effect causes the wave front close to the directors to lag behind the energy farther off-axis with the antenna. This causes the wave front to become curved, like the surface of a bowl, with the open face of the bowl facing towards the driven element. This bending of the RF wave front acts to bring energy that initially was not directly in line with the antenna to a focus at the driven element. It does so because energy flow is always perpendicular to the wave front. The curvature of the wave front has been bent (by the directors) such that the perpendicular to the wave front points towards the driven element. Thus energy flows to the driven element from positions considerably off-axis. Hence, a large aperture.

From the above discussion we see that a long Yagi is able to sample energy from a large surface area of the incoming wave front.

Now consider a multipath situation. There are signals coming from several directions. When the beam is swung around the compass, as it comes to the bearing of one of the multipath signals, the energy from that path is focused on the director. The aperture of the antenna as it faces the signal, is very much larger than the antenna aperture for signals coming in off-axis. This on-axis energy can likely be stronger than the off-axis energy, even though the signal it is "looking" at is weaker, therefore we get a peak in signal strength as seen by the receiver.

But, except in special cases, a long Yagi is not practical for mobile radio direction finding.

Small Antenna Response in Multipath Conditions

Short Yagis can provide useful gain for T-hunting, and produce a bearing. However, they cannot sort out weaker multipath signals and give clean bearings on the several paths that may be present. They cannot bring a weak path up enough in response to overcome the energy of stronger paths which are hitting the driven element from off-axis (without benefit of the bending effect of the Yagi). Its (forward-looking) aperture is not big enough to absorb enough energy coming from the front to be able to overpower the energy picked up from the stronger off-axis signal (coming from the side).

Synthetic Aperture Defined

So what's a T-hunter to do? There is another way to obtain a large aperture for T-hunting while using a small aperture antenna (such as SuperDF or Doppler). Its called a synthetic aperture. It is "created" by moving the antenna through space while averaging the data collected at each point along the path of travel. This creates a synthetic aperture equal in size to the distance traveled while collecting the data. This method is not able to sort out the various paths to give a bearing of each, but it does produce a much improved bearing of the strongest path.

The Doppler Antenna at Rest

These antennas have a rather small aperture at rest. Thus they are very sensitive to local variations in the phase front condition present where they
are located. (Yes, the Doppler is a phase measuring device: it is not a true Doppler shift device.) As you move very slowly through space, they
will indicate a rather wide shift in bearing. When stopped, they are very likely to give an incorrect bearing.

The Doppler RDF Antenna Mobile in Motion

A Synthetic Aperture Realized

The Doppler RDF antenna creates a synthetic aperture antenna in two ways.

First, there is some filtering the electronics does. Most Dopplers I have seen do not have a long time constant to do averaging over a long distance, because that would greatly slow down the response time (that is, how long it takes for a new signal to produce a stable display.) I have seen this in my own Doppler. Too much time constant make the unit take "forever" to come to rest, so it becomes difficult to get a bearing on a short transmission.

With a short time constant for integrating (adding up the readings taken while moving) the synthetic aperture is not very long, but it is significantly better than when standing still. Therefore, the Doppler gives much better bearings when moving at a good road speed.

The second effect is really the work of the human mind. My Doppler has 32 LEDs in a ring. As I travel through a multipath environment, I will typically see a "swath" of light from a group of adjacent LEDs. This might be anything from 2 to 8 LEDs (22.5 to 90 degrees), depending on how bad the multipath is. The human brain is able to answer the question, "Where is the center of the swath of light," and use that as the bearing. Thus the brain "creates" the synthetic aperture.

Strengths and Weakness of a Doppler, Summarized

Doppler is an automatic system. It does not require rotation of the antenna hardware. Does not require an attenuator nor an S meter. Receiver does not overload. Hunts best while in motion. Very wide frequency coverage. Ignores even the wildest signal strength fluctuations.

Typical Dopplers are hard of hearing. They fail the hunter at weak signal levels while beams or SuperDF are still able to hunt easily. Can't be easily taken on foot.

Can't hunt horizontal signals well. It becomes susceptible to scattered of reradiated signals, often seeing them better than the direct horizontal signal. This is because the secondary signals are likely to have vertical components, which the Doppler sees well, while it pretty much ignores the direct horizontal signal.

The SuperDF Antenna at Rest

These antennas have a rather small aperture at rest. Thus they are very sensitive to local variations in the multipath phase front condition present where they are located.

The SuperDF samples RF phase at two (nearby) points in space. When multipath is present using the SuperDF will result in detecting the distorted phase front. The bearing will likely be incorrect, as shown by arrows B & C of the Figure 9. If you are lucky, the phase front measured will matched the strongest path, as shown by arrow D.

Often Bearings taken with SuperDF and Dopplers can be quite good from tops of hills looking down into the valley where the transmitter is located. In these cases the direct path is very strong compared to what other paths that might be present.

In multipath situations you will not be able to obtain a complete nulling out of the RDF tone as you take your bearing. If you can hear the RDF tone at its weakest point, there is some multipath present. If the multipath is severe enough as you swing the SuperDF around the compass headings to take a bearing, you will find headings where the tone suddenly takes on a rather harsh or raspy sound. Thus by listening to the quality of the tone and the depth of the tone null, you can make a judgment of the amount of multipath present.

When on foot, multipath situations can be compensated for by taking many bearings from locations that are rather close together (every foot or so) and noting the two most extremely divergent headings. Snoop around looking for the most extreme bearings. The best bearing is at the middle of the two extremes.

The SuperDF RDF Antenna Mobile in Motion

A Synthetic Aperture Realized

Multipath becomes virtually a non-problem when DFing is mobile-in-motion. Referring to Figure 9 again, note that the average phase front is exactly the phase front of the strongest path only, as indicated by arrow A. Thus if you are moving fast enough the SuperDF will take a long enough average of the various phase fronts seen so that it indicates the direction of the strongest path. The SuperDF is sampling the phase front about 800 times per second. At 30 miles per hour (44 feet / sec) this is a sample about every 0.66 inches! The slow response mode of SuperDF has a time constant of about 1 second. So in this example, we are taking about 800 samples over a distance of about 44 feet. This distance is likely to be many cycles of the sinuous (distorted) phase front. Thus the bearing taken while moving will be much better than when standing still. In general, the higher the operating frequency and the faster the road speed, the better the average, and the better the bearing.

SuperDF provides a very stable bearing corresponding to the strongest path. But remember, the bearing obtained while moving is that of the strongest path, which is not necessarily the map heading to the transmitter. This would happen if the direct path is shadowed by a hill or other large obstruction, while there is a relatively strong signal scattered to your location from another large hill.

Strengths and Weakness of SuperDF, Summarized

SuperDF must be rotated by hand, which is a complication in relation to a Doppler.

It is extremely sensitive. See the article which explains SuperDF Sensitivity. Does not require an attenuator nor an S meter. Can be used quite easily on foot. Receiver does not overload. Hunts best while in motion. Can hunt either vertical or horizontal signals (by changing the mounting). Can measure the angle of elevation of the signal when used hand held. Very wide frequency coverage. While mobile in motion it supplies a very stable and very accurate bearing on the strongest path present. Excellent accuracy, better than the other antennas listed in this article.

Very fast response time compared to a beam. Ignores even the wildest signal strength fluctuations.

Stationary Beam

A long Yagi antenna is the very best T-Hunt antenna for stationary use. This is because it has a large aperture without having to be moving. Thus it can provide a very good indication of the direction of the strongest path, and probably several weaker paths (provided they are not too close together in direction).

What is the best large beam antenna for fixed use? I believe it is two medium sized (minimum of 6 elements each) Yagis stacked horizontally. There is a formula for staking horizontally to obtain the minimum side lobes (look in the ARRL Handbook). It is a function of the gain of the two (identical) Yagis to be stacked. Minimum side lobes is important, because it means that a response from a weaker path is easier to separate from the antenna's side lobe responses. (Note: maximum gain does not occur with minimum side lobes.)

Mobile Beam

Very long Yagis present mechanical problems for mounting on a car. They have a lot of mass that can put stress on the mounting. They must be stowed in a fixed position while moving. It is doable. One hunter here had 11 elements on a mast up through the center of the roof on his van.

Another problem with hunting with the beam is that you must pull off the road and stop to take a bearing. While moving, there can be too much multipath fluctuation of signal strength to be able to peak a reading accurately. Having to stop to take readings can be a real problems in hunts where the signal is intermittent. It "never" comes on the air when there is a place to pull off the road, and it "always" does when there is no place to stop! (At least it seems that way!)

Small beams make good mobile T-Hunt antennas. Mounting is not too difficult. They provide some gain for when the signal is weak. They rotate quickly with just a flip of the wrist.

There are some designs that are better than others. The 3 or 4 element quad is a favorite here. The really important thing is minimum side lobes. In the dynamic excitement of a T-Hunt, this is more important than gain. While a small beam will have difficulty sorting out weak paths, the minimum side lobes means that with one quick spin of the antenna, it is easy to spot when the front lobe passes over the signal; there will be one big jump in the S meter. I have such a beam, made by my good friend Ray Frost, WA6TEY (now a silent key). It has only one lobe. I hope to publish the design on this page.

Strengths and Weakness of the Beam, Summarized

The best T-Hunt antenna for stationary use.

Can measure the angle of elevation of the signal when used hand held. Can hunt either vertical or horizontal signals (by changing the mounting). Fairly good sensitivity.

Its major weaknesses are that it requires an S meter and an attenuator in order to hunt. Even then, many setups cannot hunt in close to a reasonably powered signal, such as another mobile. The problem is that there is enough signal leaking into the radio by paths other than the antenna to drive the S meter to full scale. The system is then completely useless. Not accurate if used in motion. Frequency coverage of only a few MHz.

George R. Andrews (Russ, K6BMG)
BMG Engineering, Inc.
9935 Garibaldi Avenue
Temple City, CA
91780, USA
(7 Feb 1996)