Newcomers and Elmers Net: Antenna Gain and Efficiency 03-26-17
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The topic of antenna gain is one which comes up often amongst hams, and it is a constant source of confusion for many, not just the newbies!
-- I think the confusion stems from the word itself—gain.
-- With almost every other usage of the word we are typically referring to an increase in power, even when it comes to radios and certain antenna accessories.
-- Maybe it is time we started referring to an antenna's "directivity" since the term more accurately describes what is going on.
-- Yes, I know, it is almost three times as long in length, and it sounds like we are using a $10 word when a 10¢ word will do, but sometimes we have to go the more expensive route for clarity.

Perhaps viewing this from another angle will bolster my argument.
-- When we talk about "gain" with an antenna, we are also, by implication, talking about loss which is easily as significant, and sometimes more so.
-- As local noise becomes more and more of a problem for amateur radio operators, how much noise we attenuate is just as important, if not more so, as the signal we boost.
-- Whoops! There is another word like "gain"—"boost" sounds good, but it's a bit misleading as it tends to ignore the attenuated part.

We properly talk about the gain of an amplifier because it does take the 100w signal and raise it to a 1000w signal, but the antenna is not adding power in any way—it is only adding *directivity*. The antenna apportions the signal based on its design, sometimes working with (and sometimes against) local conditions.

I will not fight against all of our conventions, and so an amplifier can stay a radio amplifier, and a tuner can remain an antenna tuner (although I do like "transmatch"!). But when talking about antennas, I really do vote for changing "gain" to "directivity," or perhaps at least a compromise: "directional gain."

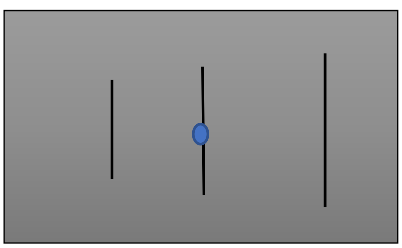
Isotropic Antennas

Isotropic antennas are perfectly radiating imaginary antennas used to act as a reference point or comparison to determine, among other things, directivity.
--"Iso" comes from the Greek *isos* meaning "equal," and "tropic" comes from the Greek *tropos*, meaning directional growth. Isotropic means equal growth in all directions.
-- We say an isotropic antenna has zero gain because it radiates equally in

all directions, thus no directional gain.
-- This can only exist as a point in space; as soon as we start shaping the antenna in any way, or placing it in any “real world” setting, the antenna starts to have directivity.
-- This means certain directions will have more signal while other directions have less.
-- Even antennas we often call omni-directional antennas are not truly omni-directional. A vertical antenna may radiate 380 degrees around the radiating element, but it still has nulls on the ends.
-- We do not mind this because rarely do we want our signals going straight up, but there are nulls nevertheless.

Directivity, or directional gain, is what we deal with in real terms with any antenna.
--We can usually ignore it, for example, when dealing with 2-meter repeaters because simply having our polarization match the repeater antenna is usually sufficient.

What if we wanted to increase our signal strength toward a particular repeater?

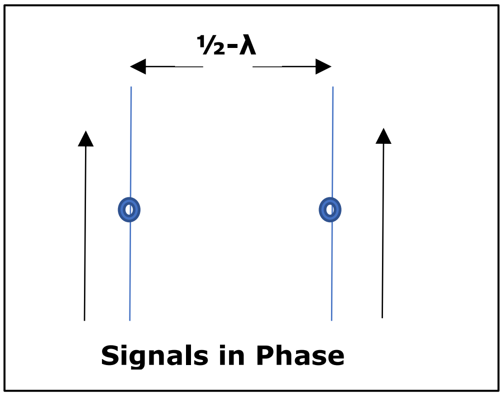


Then we could add a slightly smaller directional element such as a parasitic director element in front of the driven element, in the direction we wanted to extend our reach. We could also add a slightly longer parasitic reflector behind our driven element and create an even stronger directional signal, all *passively.*

Back to our original thought. All real antennas have at their core some level of directivity which influences how power is distributed from the antenna.
-- When we talk about signals coming off of an antenna we are sending a single frequency from our radio to the antenna, and a single frequency to the receiving antenna.
-- The signal, which consists of multiple waves, must have those waves travelling in phase, meaning they must be cycling together.
If the waves are out of phase for any reason, there will be some cancelation of the signal depending on the degree to which the waves are out of phase.
-- If they are 180 degrees out of phase, they cancel each other out completely.

Adding Directional Gain with Multiple Driven Elements
A common way to add directivity to an antenna is to duplicate a dipole with another driven dipole spaced ½-wavelength apart so the two signals are in

phase. When we do this with two vertical antennas we create a radiation pattern similar to the figure-8 pattern of a standard dipole, i.e. a directional broadside pattern.



In this design the signal is perpendicular to the dipoles, just as we would expect.
-- However, if we were to reverse polarity on only one dipole, the resulting pattern would switch because the broadside signals would be perfectly out of phase and thus cancel one another.
-- The antenna would then radiate like an end-fire array. The radiation pattern would then be shifted 90°, a useful way of changing directivity.
-- This can also be accomplished by adding a half-wavelength to one dipole, electrically or mechanically.

On the horizontal side of things, similar directivity may be achieved by placing two horizontal dipoles with one coplanar above the other.
-- At minimum elevations of ½-λ the broadside pattern directs more of the signal toward the horizon rather than a typical dipole.
-- The advantage is more signal at lower take-off angles while still using horizontal polarization.

There are numerous variations of two- and three-element dipole configurations along with phase shifting options which will allow for directional gain in the desired locations.

Keep in mind, while we talk often about directional gain in terms of the benefit we get in a certain direction, there are benefits to designing a directional antenna to block or reduce input from unwanted directions during receive.
--A variation on the two horizontal dipoles fed in phase mentioned above, by spacing two dipoles ¼-λ apart, one in front of the other, when fed 90° out of phase the radiation pattern becomes directional with a strong null ratio front-to-back.

Reflections
For now I will use VHF/UHF signals as the example, but the same issues are present at HF levels, just not as prevalent.
-- If we are in an area filled with buildings such as a downtown square, we are likely to receive signals slightly out of phase with each other from multiple directions.

-- This happens because some signals might reach the antenna of our HT directly (called incident waves), which other signals arrive at the antenna at slightly later times because they are actually reflections from builds, the street, or other possible sources of reflections (reflected waves).

The mixing of incident and reflected waves means the same information is arriving by multiple waves with some level of time shifting, which can in turn cause muddied reception, or in extreme cases, signal cancellation.
--However, not all reflections are bad. Reflections can also increase signal strength when re-directed to the intended target.

The reflector mentioned in our 2-meter dipole example above is designed to do just that: take a portion of the signal which would have continued travelling in the opposite intended direction in its absence, and instead, capture waves through inductance and reflect them back in phase with the forward moving portion of the signal.
--This increases signal strength in the desired direction.

Parasitic Arrays
The parasitic arrays mentioned above are popular for several reasons.
-- First, they tend to show greater directivity and thus enjoy larger front-to-back and front-to-side ratios than multi-driven elements.
-- A second reason they are preferred is rather simple—they are easier to construct.
-- With only one driven element, the only real challenge is sizing and spacing the elements, and there are many Yagi calculators available to take most of the guesswork out of the process.

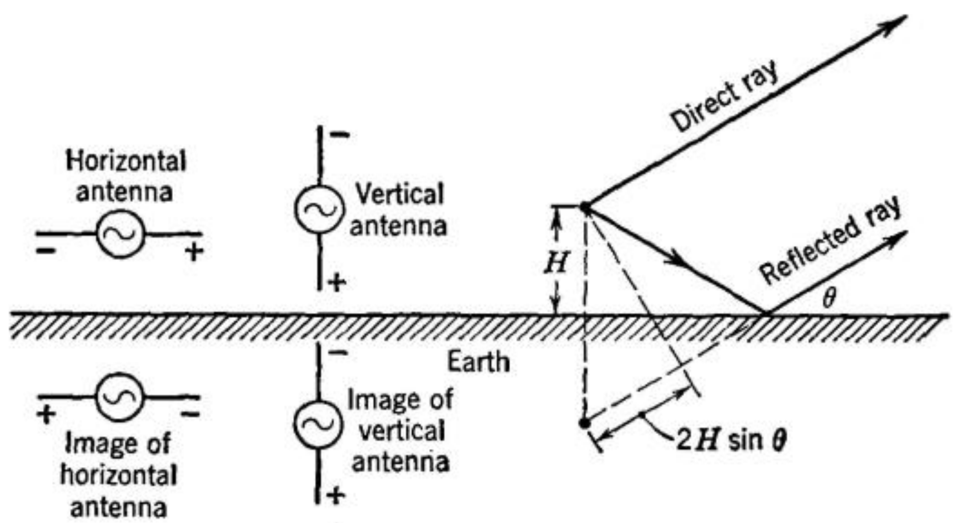
Yagis for HF tend to be used only for 20 meters or higher, but occasionally someone will make a 40-meter Yagi, and I envy them the space and height!
-- At HF the length of the elements and the weight of the supporting structure typically limit the antenna designs to 3- or 5-band designs.
--At VHF and UHF frequencies the Yagis tend to be designed with many elements since size, weight, and especially cost are greatly reduced.

Like the dipole arrays above, similar principles apply for stacking Yagis in a coplanar fashion for greater directivity and for concentrating more of the signal toward the horizon.
--This is particularly important for line-of-sight communications typical of VHF/UHF work. Yagis can be stacked either vertically or horizontally, and shifting phase will produce interesting radiation patterns.

Ground Reflections
With ground signals reflected waves become in phase with incident waves when the reflected wave is ½-wavlength longer than the incident wave.
--This does not happen (at least for our purposes here) with vertical antennas as their incident waves are reaching out to the horizon, but this can happen with horizontally polarized antennas, giving greater directional gain with the in-phase signals.

When talking about horizontal dipoles and producing directional gain, the antenna has to be of sufficient height above ground to allow for the reflected waves to achieve the proper take-off angle and length to become in-phase with the incident wave.
--This usually requires a height above ground of at least ½-wavelength.

Determining reflections from ground is an inexact science to be sure, particularly given the variable nature of ground materials.
-- To simplify things a bit assumptions are usually made as to the general condition for ground, and often for calculation and angle formation purposes, a zero-loss ground is assumed.
-- Another related assumption is the presence of an “image antenna” for help in visualization of the reflected portion of the wave.



The action of the reflected wave for horizontal and vertical antennas can be represented as if an image of the antenna, or an ''image antenna," were an equal distance below the surface of the earth. The polarity of an image antenna is the same as would be induced in a wire at that point. To reach a distant point, the reflected ray, assumed to come from the image antenna, must travel a distance 2H sin θ farther than the direct ray
(Image – *Electrical Communication*, 1964)

By their very nature ground reflections are difficult to achieve such that they overcome the losses inherent in most ground conductivity.
--Lower angles of incidence will give the best reflections and provide the least amount of absorption, and this is why vertical antennas can often out-perform horizontal antennas for larger wavelengths.

Remember for directional gain to occur the reflected wave must overcome the 90° out-of-phase condition by becoming ½-wavelenth longer than the incident wave.
--This only happens with horizontally polarized antennas, so they are starting out at a slight disadvantage already, as more of their signal will be absorbed.
-- This is where highly reflective surfaces can give a real boost to signals, such as a saltwater surface. This has the highest reflectivity coefficient, and this is also why someday I want to live on my very own island in the middle of the ocean!

Conclusion
Gain is a commonly misunderstood and misapplied term which might be better thought of as directivity or directional gain to emphasize the passive nature of antenna gain.
--No antenna design boosts power, and anything after the transmitter which does boost power should be thought of as a pre-amplifier.
-- The shape and design of an antenna can only redistribute power—it can never increase it.

There are numerous ways to both increase directivity of a signal or decrease it and thereby create sharper nulls.
--Both conditions can have advantages depending on one's needs. Noise reduction and decluttering of a busy band can help during contests or when seeking to work weak-signal stations, and the ability to send more of one's signal in a particular direction has obvious benefits.
-- The upside to understanding directional gain for antennas is that directivity is a two-way street. Whereas an amplifier only sends power increases outward, a good directional antenna boosts receive as well as transmissions, and this is by far the "best bang for the buck."