Brass Tacks

An in-depth look at a radio-related topic

Utah Valley
Amateur Radio Club
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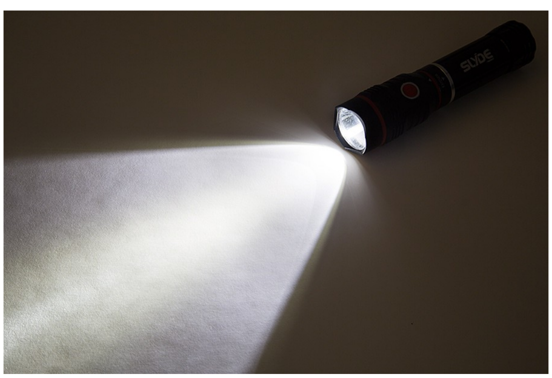
Antenna gain

When I was much younger, my grandpa showed me the basics of electricity. I wondered in wide-eyed fascination as he connected a wire from a simple D-cell battery to a small light bulb lying on the counter, bringing the bulb to life when he touched the tip of the bulb contact to the battery.

I thought that was pretty neat, but childishly pointed out that the light didn't seem as bright as the one in my one-cell flashlight. He then asked for my flashlight, removed the bulb from it, and told me to connect my flashlight bulb the same as he did the first bulb. I was again amazed to see that the brightness of the removed bulb was the same as that of the small bulb on the counter, and asked what changed.

Was there something about the flashlight body or internal mechanism that made the difference? He then placed the bulb back into the flashlight head, reassembled the flashlight, and turned it on. Sure enough, its light now seemed a lot brighter. My grandpa pointed out that the amount of electrical energy going into the bulb was the same in both cases, and so the amount of light emanating from the bulbs were the same too. But he also said that the light in the flashlight was *focused*, or concentrated more in one direction than in others, and so it seemed to shine brighter in that direction.



A radio antenna works in a very similar principle, often focusing more radio energy in one direction than in others. The focus of signal energy by an antenna in this manner is called *gain*, a very misunderstood concept, possibly because it's not very visible to human eyes.

Many hams purchase antennas based on this gain value, not realizing what one value means, over another. When you examine an antenna sale that advertises a specific gain value for a particular frequency band, the two questions you need to ask are, ***Compared with what?*** and ***In what direction(s)?*** Once you understand these two parameters, you're better-equipped to arrive at a more intelligent conclusion.

Except for the shadow cast by the battery and my hands, when I connected that little light bulb, it seemed as though the light was shining with equal brightness in all directions. And using that *isotropic* (equal strength in all directions) tool gave me a reference, by which I could compare the brightness and direction of all other flashlights. Only problem is, that's an impractical and unfair comparison, since nobody pulls out a battery and flashlight bulb to compare with a flashlight when they go looking to buy one. Instead, people tend to compare a prospective purchase with a known flashlight reference that uses the same type of power source.

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Two reference antennas

For the purposes of amateur radio, people today have developed two references by which we compare the gain value of antennas. One reference is known as an *isotropic radiator*, again meaning an ideal antenna that radiates ("shines with equal brightness") in all directions. The other is none other than the *dipole antenna*. Just like my battery-and-bulb example, it's both impractical (indeed, nearly impossible) and unfair to compare an actual antenna with an isotropic radiator, so we tend to compare an antenna with a dipole, which we can easily construct, and whose gain (strength and direction) characteristics are fairly well-known.

Antenna gain comparisons made in reference with an isotropic radiator use the unitless designation *dBi*, meaning *gain compared with that of an isotropic antenna*, and is calculated

$$\text{value dBi} = 10\log_{10}(P_A/P_I)$$

in which P_I is the power output of an isotropic antenna in the direction of maximum strength, and P_A is that from the antenna we want to measure. This way, if we're trying to examine the gain of an isotropic antenna, we compare it with itself, such that $P_A/P_I = P_I/P_I = 1$, and $\log_{10}(1) = 0$. What this means to us is that, any antenna with a dBi gain value greater than zero has greater gain than this imaginary antenna.

Because a physical isotropic antenna is nearly impossible to construct for a proper comparison, amateurs and engineers have selected the simple dipole antenna as the proposed basis for an antenna gain reference. A dipole antenna has three advantages that make it a nearly ideal choice for a reference antenna: it's easy to build, it's inexpensive, and it's nearly lossless. A fourth advantage might be that many amateur antennas are adaptations of dipoles themselves, making the comparison a little closer to realistic.

So, just how much gain does a typical dipole exhibit? The gain of a lossless half-wave dipole is calculated as follows (don't try this at home — only meant to show the origin of the value).

radiation intensity : $$U(\theta) = \frac{1}{2}r^2\frac{|E_\theta|^2}{\eta} = \frac{1}{2}\frac{\eta I_m^2}{(2\pi)^2}\frac{\cos^2(\pi/2\cos\theta)}{\sin^2\theta}$$

radiated power : $$W_{rad} = \int_0^{2\pi}\int_0^{\pi} U(\theta)\sin\theta d\theta d\phi$$

directivity : $$D_m = \frac{4\pi U_m}{W_{rad}} = \frac{4\pi}{8\pi^2}\eta I_m^2 \cdot \frac{1}{36.5640 I_m^2} = 1.64$$

So, from these we conclude that a lossless half-wave dipole has 1.64 times the gain of an isotropic antenna, allowing us to use that constant in measuring other antennas with respect to an known, actual antenna. Putting this in terms of decibels, we have a new unitless designation called *dBd*, meaning *gain compared with that of a dipole antenna*, and is calculated

$$\text{value dBd} = 10\log_{10}(P_D/P_I) = 10\log_{10}(1.64) \approx \mathbf{2.15\ dBi}$$

Now we need to answer our two questions. *Compared with what?* Answer: an isotropic antenna. *In what direction(s)?* Answer: symmetrically radially outward in all directions, broadside

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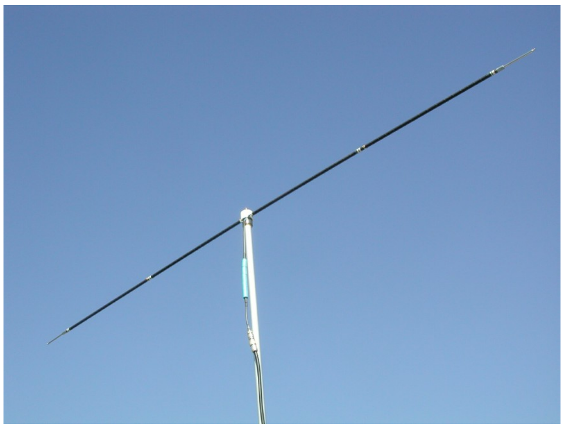
(perpendicular) to the length of the dipole, from the center of the dipole.



With all of this, you're now armed with the ammo you need, to make a more informed decision regarding antenna gain, but you're still going to have to use your head. When you see an antenna specification of "3 dBd gain" you now know that it's 3 dB compared with a dipole, but it's not always obvious in which direction(s) that gain is measured, so examining the physical style and layout of the antenna might be necessary to determine that.

You'll eventually run into an antenna listing that advertises "6 dB of gain!!" Ok, compared with what? Well, the ad doesn't say, and if there's no indication what the gain is relative to, *you must assume it's dBi*. Advertisers list it the way they do because either they don't know better, or they want to inflate the gain number to attract more attention. I mean, which sounds better to you, 3 dB or 0.85 dB? Well, if the first is actually dBi and the second is dBd, the values are the same, but the first might sell better. That's why you need to know, and that's why you must assume dBi.

Some antennas exhibit gain in more than one direction, and that's why we ask the question *In what direction(s)?* with the "s" in parentheses. A "magnetic" loop antenna, for example, exhibits gain in two directions, both directions perpendicular to the plane of the loop, in opposite directions. A whip antenna on your HT or vehicle is considered "omnidirectional" but means its gain is pointed in all directions radially outward from the antenna, perpendicular to the orientation of the whip.

magnetic loop antenna

Breaking the laws of physics

I once built a 20-meter Yagi beam whose design bragged "18 dBd" gain. That means it was allegedly able to send a radio signal out that's 3 dB + 3 dB + 3 dB + 3 dB + 3 dB + 3 dB (do the math: 2 x 2 x 2 x 2 x 2 x 2 = 64 times!) stronger than an ordinary dipole was capable of sending. And my signal reports from Italy, Japan, Indonesia, and Curacao seemed to verify that was likely the case. But how was that possible? And where did all that extra energy come from? Was I in possession of a magical device that somehow turned my 100-watt radio into a 6,400-watt radio station, violating the 1500-watt power limit rule of amateur radio?

Going back to my flashlight example, reality sets in as I realize all that happened was that the flashlight reflector focused as much of the light that it could in a single direction, making the light appear much brighter in that direction than it might otherwise have. No extra batteries were added, no magical device was installed, and no new energy was generated. My delusion comes to an end, and I'm

whip antenna

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once again forced to conclude that the laws of physics are safe from my meddling after all.

PEP vs. ERP

But wait, what about that 6,400 watts my beam was cooking the airwaves with? Isn't that against the rules? Well, it turns out that my radio transmitter was putting out 100 watts, which we call *peak envelope power* (PEP), but the antenna was sending out 6,400 watts of focused signal, called *effective radiated power* (ERP). In the simplest terms, ERP is calculated

ERP = PEP + gains — losses

and if you examine the ARRL band allocation chart, at the top under the title, it reads, "(b) No station may transmit with a transmitter power exceeding 1.5 kW PEP." So, my rig transmitting at 100 watts was well within the legal limit, regardless what the antenna might have done with the energy it was handed.

By the way, is it possible for an antenna to exhibit negative gain? That is, can it actually radiate with less strength than an isotropic antenna? Returning to the flashlight example, turn on your flashlight, only this time cover the front with black construction paper. Not a whole lot of light exits the paper, yet the same amount of electrical power is being expended. Many rubber duck (electrically shortened, stock) antennas and dummy loads exhibit negative gain by design.

Summary

Antenna gain is the measure of an antenna's ability to focus radio energy in a particular direction or directions, compared with that of a reference antenna. The reference antenna by theory is the isotropic radiator, which exhibits equal radiation strength in all directions, but is an impractical measuring tool. A more useful reference is the lossless dipole antenna, which is fairly easy and inexpensive to construct, and so provides a more realistic reference. This is why it's important to understand what the reference is, when examining an antenna specification. So, an antenna that has higher gain than another doesn't mean that it requires more electrical power, but that it's able to focus more of the same power in one direction than another antenna can.

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