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COLUMNS

The Darker Side

Antenna Performance Measurement Made Easy

Covering the Basics

If you're doing any kind of wireless communications application, that probably means including an antenna in your design. The science of antennas is complex. But here Robert shows how the task of measuring an antenna's performance is less costly and exotic than you'd think.

By
Robert Lacoste

Now that wireless communications is ubiquitous, chances are you'll be using Bluetooth, Wi-Fi, cellular, LoRa, MiWi or other flavor of wireless interface in your next design. And that means including an antenna. Unfortunately, antenna design is not an easy topic. Even very experienced designers sometimes have had to wrestle with unexpected bad performances by their antennas. Case in point: Google "iPhone 4 antenna problem" and you will get more than 3 million web pages! In a nutshell, Apple tried to integrate a clever antenna in that model that was threaded around the phone. They didn't anticipate that some users would put their fingers exactly where the antenna was the most sensitive to detuning. Was it a design flaw? Or a mistake by the users? It was hotly debated, but this so-called "Antennagate" probably had significant impact on Apple's sales for a while.

I already devoted an article to antenna design and impedance matching ("The Darker Side: Antenna Basics", *Circuit Cellar* 211, February 2008). Whether you include a standard antenna or design your own, you will never be sure it is working properly until you measure its actual performance. Of course, you could simply evaluate how far the system is working. But how do you go farther if the range is not enough? How do you figure out if the problem is coming from the receiver, the transmitter, propagation conditions or the antenna itself? My personal experience has been that the antenna is very often the culprit. With that in mind, it really is mandatory to measure whether or not an antenna is behaving correctly. Take a seat. This month, I will explain how to easily measure the actual performance of an antenna. You will see that the process is quite easy and that it won't even need costly or exotic equipment.

SOME ANTENNA BASICS

Let's start with some basics on antennas. First, all passive antennas have the same performance whether transmitting or receiving. For this article, I'll consider the antenna as transmitting because that's easier to measure. Let's consider an antenna that we inject with a given radio frequency power $P_{conducted}$ into its connector. Where will this power go? First off, impedance matching should be checked. If the impedance of the antenna is not well matched to the impedance of the power generator, then a part of the power will be reflected back to the generator. This will happen in particular when the transmit frequency is not equal to the resonant frequency of the antenna. In such a case, a part of $P_{conducted}$ will be lost. That is known as mismatch losses: $P_{available} = P_{conducted} - MismatchLosses$. While that itself is a very interesting subject, I have already discussed impedance matching in detail in my February 2008 article. I also devoted another article to a closely linked topic: standing waves. Standing waves appear when there is a mismatch. The article is "The Darker Side: Let's play with standing waves" (*Circuit Cellar* 271, February 2013).

For the purpose of discussion here, I will for now assume that there isn't any mismatching—and therefore no mismatch loss. The full $P_{conducted}$ power is available for the antenna. A significant part of this power will hopefully of course be radiated into space. Let's call that part $P_{radiated}$. Because the antenna is not perfect, $P_{radiated}$ will for sure be lower than $P_{available}$. Remember that power is never actually lost or created from nothing. That means the difference $P_{available} - P_{radiated}$ is dissipated somewhere—meaning either the antenna or its surroundings will warm up a little. This allows to define the first—and an important— performance characteristic of an antenna: power efficiency. By definition, the power efficiency of an antenna is the ratio between $P_{radiated}$ and $P_{available}$. If all the available power is radiated by the antenna then its efficiency would be 100%. But in reality, small antennas made with small conductors have low efficiency. Meanwhile, large antennas built using thick and gold-plated conductors will usually have high efficiency.

Now let's talk about the gain of the antenna. The concept is illustrated in **Figure 1**. Any antenna has a given radiation pattern, which means it transmits more power in certain directions of space. An

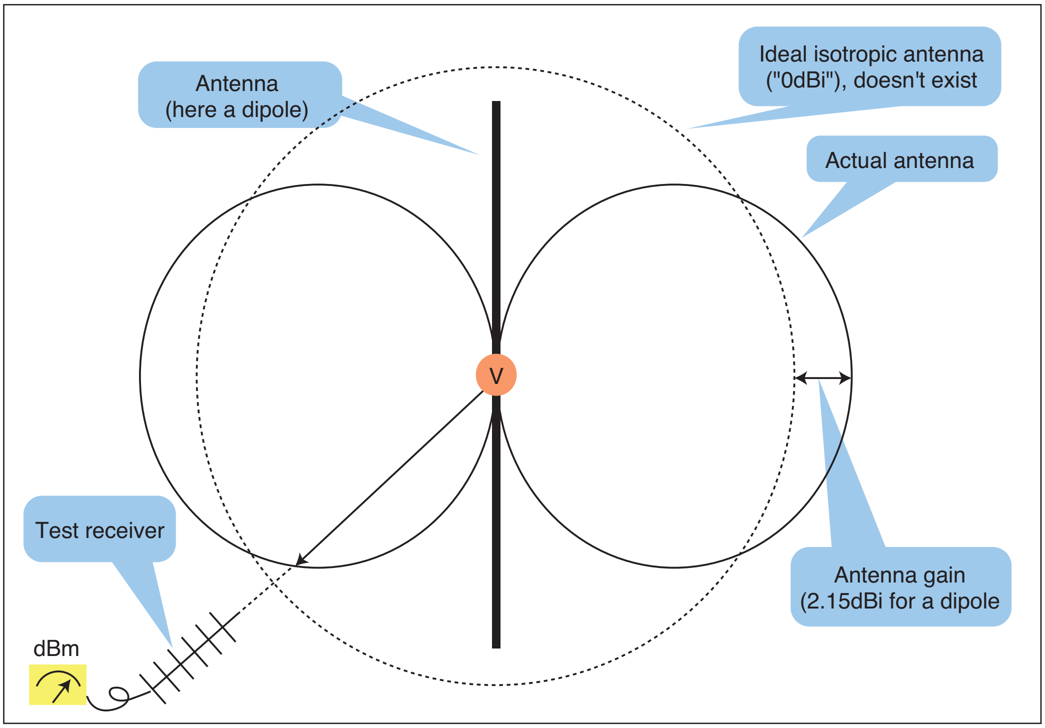

FIGURE 1
By definition, the gain of an antenna is the difference between its radiated power and the power radiated by an isotropic antenna, measured in the direction where its radiation is maximal.

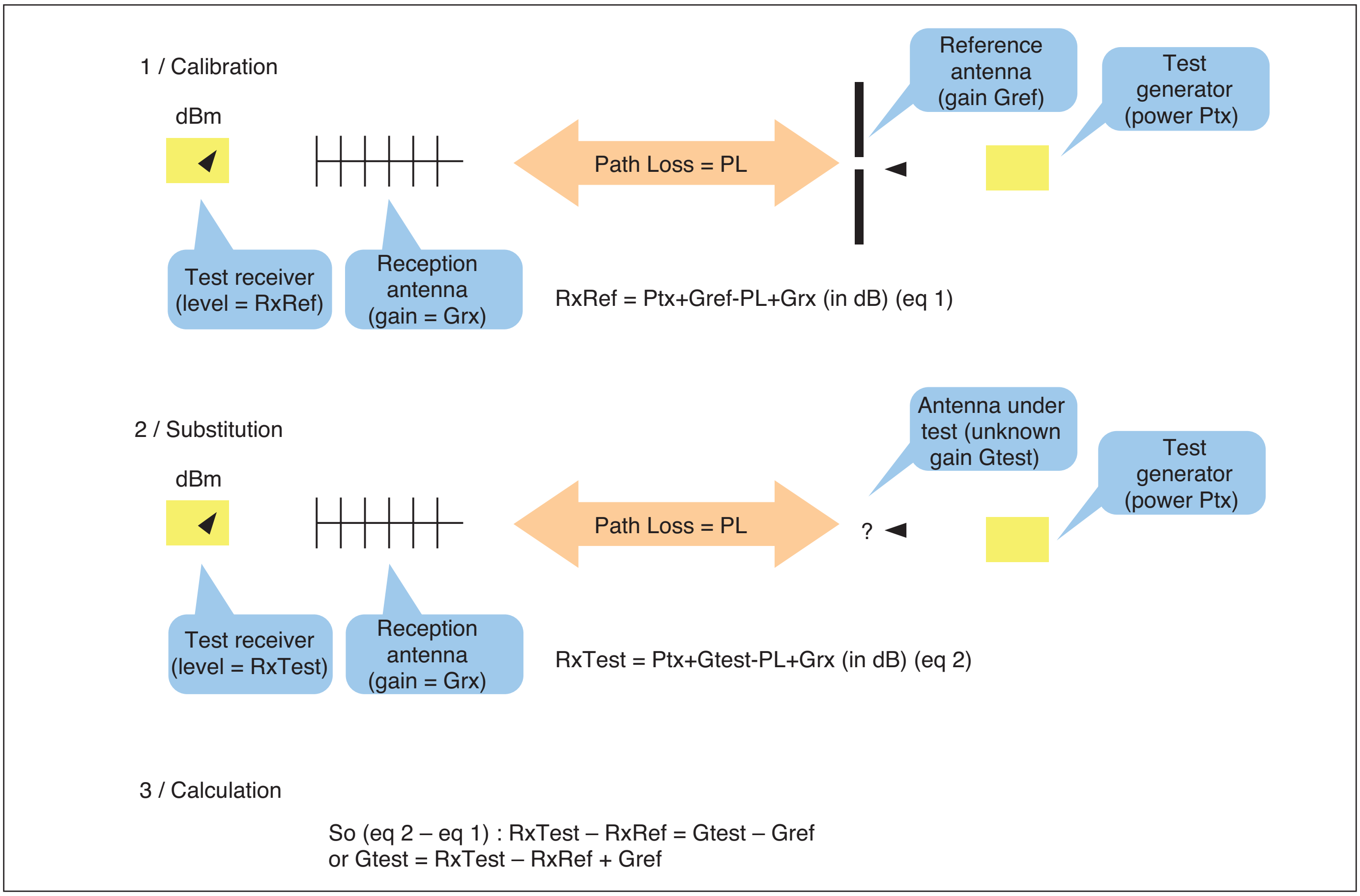

FIGURE 2
The substitution method allows you to measure the gain of a given antenna by comparison with a reference antenna. The accuracy of the test generator and test receivers as well as the gain of the reception antenna doesn't matter because they cancel out.

PHOTO 1
A professional grade set of reference dipole antennas. Each one in the set covers a specific frequency band.

antenna which would radiate the same power in any direction is called an isotropic antenna—but those don't exist except as a concept. Such an isotropic antenna is taken as a reference, and a real antenna is compared to it. Imagine that you take a test receiver and move it around the antenna under test at a constant distance from it. You can find out the direction where the transmitted power is the highest. Then you compare that to the transmitted power of a theoretical isotropic antenna with the same input power. The difference between the two is called the gain of the antenna and is expressed in dBi. dBi is the decibel compared to an isotropic antenna—"i" for isotropic. Remember that a decibel is just the ratio of two powers—expressed using a logarithmic scale: decibel = 10 log (P_{out}/P_{in})

You may be wondering: How is this gain linked to the efficiency I talked about earlier? The relationship is far from obvious. In fact, the gain of an antenna concerns its directivity. When an antenna radiates a strong signal in a given direction, its gain is high—even if this radiation occurs in a very narrow angle. In contrast, the efficiency is linked to the total radiated power of an antenna. To measure it you would need to evaluate the transmitted power in all directions and sum them all—

an operation that mathematicians call an integration. More exactly the total radiated power is the integral of the radiated power over a sphere. Of course, a lower efficiency also implies a lower gain as the total available power is reduced. But a low efficiency antenna can still have high gain. Aren't you convinced? Consider a huge parabolic antenna—it could have gain of +30 dBi. This means that the radiated power is focused in a very narrow direction. And in that direction a receiver will see a signal 30 dB higher than if using an isotropic antenna. Of course, the antenna is not creating any power. It's just focusing it, like a lens focuses light. Now add a 20 dB attenuator between the transmitter and the parabolic antenna—dividing the power by $10^{20/10}$ = 100). The overall gain will still be a reasonable 30-20=10dBi—even if 99% of the power will be dissipated in the attenuator.

SUBSTITUTION METHOD

Whether a high gain or a high efficiency antenna is the best choice really depends on the application. Usually you would need both. Now let's look at how to measure the gain of an actual antenna. The method is very simple, even if applying it correctly needs some care. The idea is to compare the antenna under test with a known antenna (**Figure 2**). What do you need? The only critical item is a reference antenna with a known gain. More on that later. You will also need a kind of RF generator, a reception antenna and a test receiver. Aside from the reference antenna, the other items don't need to be calibrated or even accurate. They just need to be stable over time. For the RF generator, you could of course use your transmitter itself. Similarly, your actual receiver can make a reasonably good test receiver as long as you have a way to read a received signal strength indicator (RSSI).

How to proceed? Set the generator to any transmit level and tune it to the desired working frequency. Connect it to the reference antenna and switch it on. Then connect the reception antenna to the receiver. Fix it in front of the reference antenna—say 5m away, in the direction of its maximal gain. Read the reception level as indicated by the receiver. Let's call this level RxRef.

Now substitute the reference antenna with the antenna you want to test. Don't change anything—neither on the generator nor on the receiver. Turn the antenna under test until you get a maximum value on the receiver (RxTest). If you look at the math illustrated on Figure 2, you will see that the gain of the antenna under test is very easily calculated. It's calculated as the gain of the reference antenna (Gref), plus the difference of the receive levels RxTest - RxRef. All the other

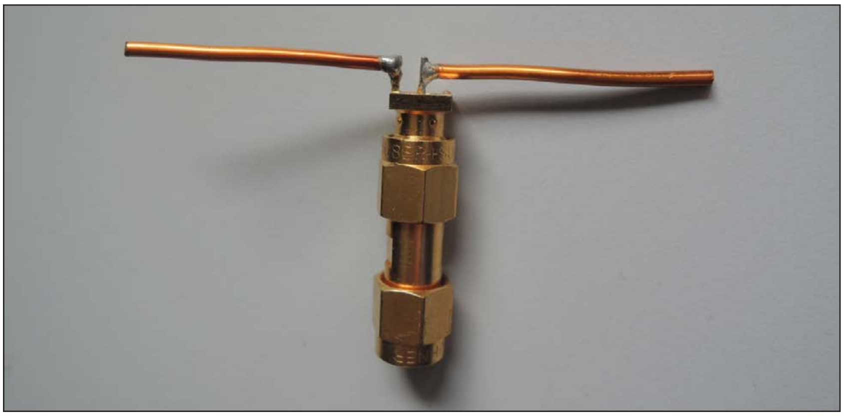

PHOTO 2
A homemade ¼ wave dipole antenna in the 2.4 GHz band. Its gain will be very close to the theoretical 2.15 dBi even if such an antenna is lacking a balun.

PHOTO 3
Here is another ¼ wave dipole—also tuned for 2.4 GHz—but including a so-called folded balun structure. The vertical segment is made with the same coaxial cable as the main connection and is also a ¼ wave long.

PHOTO 4
An example of an actual open field measurement. This picture was taken 15 km away from Paris.

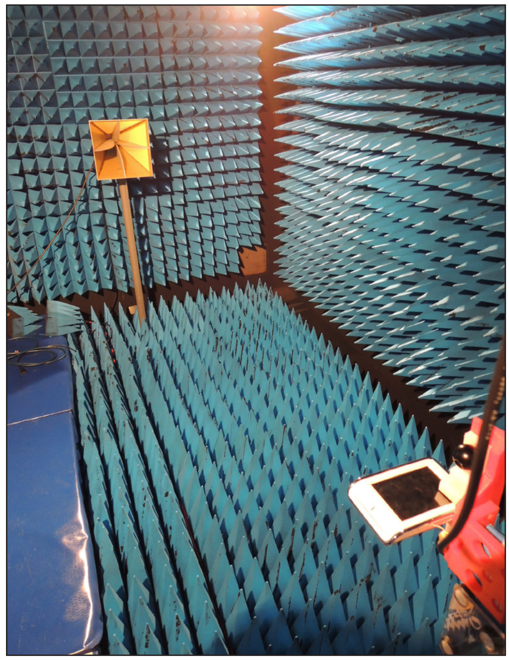

PHOTO 5
An anechoic chamber provides a nice alternative to an open-field measurement. Here the reception antenna on the back is a dual polarized horn antenna. It's able to measure both polarizations at the same time. The device under test, in the front, is fixed in a 3D motorized positioner, driven by an external PC using optical fibers to avoid any interference.

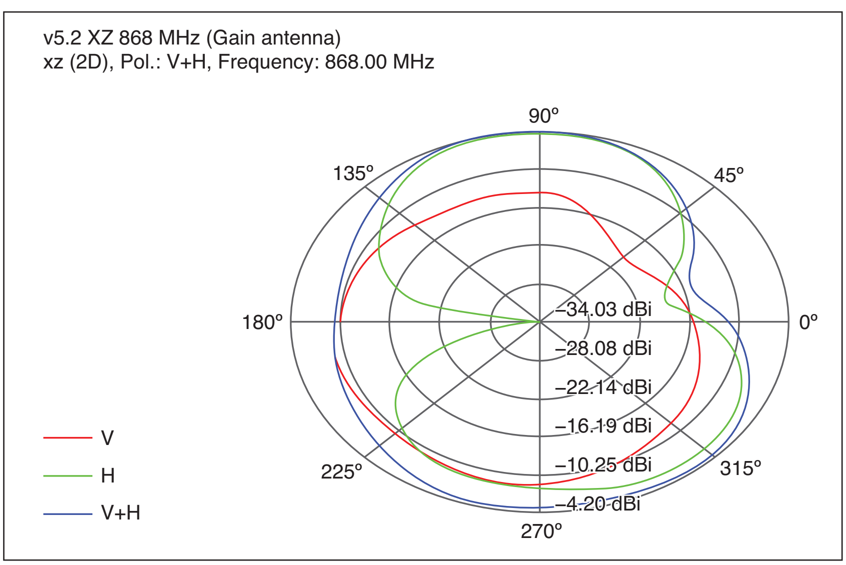

FIGURE 3
An example of a 2D antenna pattern measurement. Here the object was rotated only on a plane. The red and green plots show the gain respectively in vertical and horizontal polarizations, with their sum in blue.

factors cancel out! If you have time, the same method enables you to measure the overall radiation pattern of the antenna. You just measure the receive level for all orientations of the antenna under test and plot the result.

For simplicity's sake, I have skipped an important topic in this discussion: polarization. RF waves are usually polarized, and a reception antenna will "see" only one polarization. You will need to do the measurement in the two polarizations—just turn the reception antenna by 90°. At least check that you are using the good polarization—meaning the one giving the highest value. A last note of caution: Of course, do not stand between the antennas when doing the measurements as your body may interfere.

REFERENCE ANTENNAS

As explained earlier, the only exotic item required in all this is a reference antenna. Any antenna can be used, but its gain must be as precisely known as possible. That's a chicken and egg kind of problem. You need an antenna with a well-known gain to measure the gain of an antenna. So how then to get such reference antenna? If you have deep pockets, the easiest choice of course is to buy one. On eBay, you can find calibrated antenna sets (**Photo 1**) that include several adjustable dipole antennas to cover a wide frequency range. These come with precisely defined calibration tables. But if you are more budget constrained, there are option options. You can very easily build your own dipole reference antenna. As **Photo 2** shows, it couldn't be simpler! You just cut two segments of copper wire to exactly a quarter of the wavelength and solder them to an RF connector—a SMA connector in this case. For example, if you are working at f = 2.4 GHz then one wavelength in space is calculated as c/f—with c the speed of light. The result is:

$$\frac{3\times10^{8}\,\mathrm{m/s}}{2.4\times10^{9}\,\mathrm{Hz}} = 0.125\mathrm{m}$$

A quarter of the wavelength is 12.5 / 4 = 3.13 cm. Such a dipole antenna has a theoretical gain of 2.15dBi. All that said, this home-built dipole antenna has a flaw: it is lacking a transformer called a balun. The balun converts the balanced structure of the dipole in a unipolar coaxial line. The name balun is derived from "BALanced to UNbalanced"—hence balun. Without such a balun, its gain will be a little lower, and you will not know exactly how much. But don't worry. Assuming it is somewhere between 1 and 2 dBi that will usually be precise enough for your needs. If you prefer to build a more accurate dipole with a built-in folded balun then look at **Photo 3**.

ABOUT THE AUTHOR

Robert Lacoste lives in France, between Paris and Versailles. He has 30 years of experience in RF systems, analog designs, and high speed electronics. Robert has won prizes in more than 15 international design contests. In 2003 he started a consulting company, ALCIOM, to share his passion for innovative mixed-signal designs. Robert's bimonthly Darker Side column has been published in Circuit cellar since 2007. You can reach him at rlacoste@alciom.com.

OPEN FIELD

Now you have everything required to measure your antenna. You just need to find a proper place for the measurement. If you live in the center of New York, then this a good chance to get in your car and travel some tens of miles away. There are two reasons for this. First, you of course need to reduce the amount of ambient RF noise that could jeopardize your measurements. The second reason is more insidious. In order to measure the radiation pattern of an antenna, you need to reduce as much as possible the reflections on surrounding objects. If you don't, then you will measure something, but never know if you're detecting the RF field directly sent by the antenna, or one radiated in another direction and scattered around. With all that in mind, put all your stuff in your car and don't forget to bring something to power everything with. An Uninterruptable Power Supply (UPS) is perfect for that—or a small generator. Find a really open field like the one illustrated on **Photo 4**. Then you have just to follow the substitution method as explained earlier. Don't forget to move your car away before doing any measurements. A car is an excellent reflector.

Of course, if you have an anechoic chamber in your basement everything gets far simpler. Such a chamber simply emulates nearly perfect open field conditions: no perturbations thanks to shielded walls and no reflections thanks to RF absorbers on the walls. My company is lucky enough to have one in house (**Photo 5**). It enables us to do antenna measurements as often as we want and even in bad weather! And here's a caution if you plan to buy one: we bought ours on the second-hand market, so it wasn't expensive. But that meant moving it by ourselves to our location—and that was really an adventure!

WRAPPING UP

Measuring an antenna is the only way to know if it is actually working as expected. As I've discussed in this article, such measurement is not a complex task, even though it must be done methodically. Anybody can do an open-field antenna measurement with home-made reference antennas and by using the actual transmitter and receiver as test gear. All that said, I admit that professional grade test equipment does make life easier, but don't hesitate to try by yourself on your next wireless project. With some experience, you will soon be able to generate nice antenna pattern measurements like the ones illustrated in **Figure 3** and **Figure 4**!

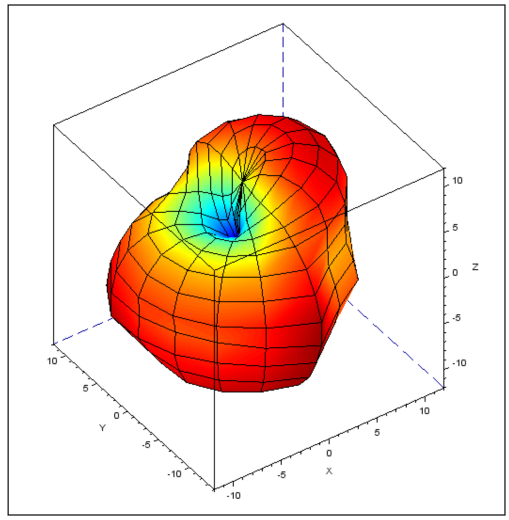

FIGURE 4
A 3D antenna pattern plot is very sexy, but is far more difficult to read than 2D plots. Here you can clearly see that this antenna had a specific directivity with nearly no radiated field.

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