Chapter 1

Receiving Antennas are Different!

One of the best-known cardinal doctrines of antenna theory is the concept of *reciprocity*. The gain, directivity, radiation pattern, and electrical impedance of an antenna are the same, whether it's used as a transmitting antenna or receiving antenna. While on the most fundamental level, reciprocity is certainly true; in many cases it is over-applied. It can be easy to overlook the fact that transmitting and receiving antennas perform very different roles in the real world, and are subject to very different requirements and priorities. We will often find that factors well outside the control of the antenna are absolutely *not* reciprocal.

We dedicate considerable space in this book to the non-reciprocal and *bi-refringent* behaviors of the ionosphere, and ways to not only mitigate the effects of these, but also to actually take advantage of them! Since the reciprocal properties of antennas have been covered thoroughly in many other excellent works, we will concentrate in this book on the theory and methods that make receiving antennas *different* from transmitting antennas. We will also present evidence to confirm that nearly every Amateur Radio station can benefit from separate transmitting and receiving antennas in many cases.

It is probably helpful, therefore to modify our definition of *reciprocity* for the remainder of this book. When referring to the immutable reciprocal character of an antenna (even down to the atomic level), we will call

The Limitations of Reciprocity

Transmitting and receiving antennas perform different functions! The well-known Theorem of Reciprocity for antennas is often misunderstood by radio amateurs. While it is true that the fundamental characteristics of antennas apply to both transmission and reception, the requirements and priorities of receiving antennas can be vastly different from those of transmitting antennas. The function of transmitting antennas is to radiate power from the transmitter efficiently, while the function of receiving antennas is to present the best signal-to-noise ratio to the receiver. The focus of this book will be entirely on *receiving* antennas, both active and passive, and their associated circuits. There are relatively few cases where a radio amateur cannot benefit from a separate, well-designed receiving antenna or antenna system.

it reciprocity. When we refer to a complete path between a transmitter and receiver, we will refer to the path as being either *unilateral* or *bilateral.*

Something Old, Something New

The concept that transmitting and receiving antennas are different is not exactly new. In the very early days of Amateur Radio, transmitting and receiving functions were entirely separate entities in the typical ham shack. The nearly universal use of the same antenna for transmitting and receiving roughly coincided with the advent of the *transceiver* in the late 1950s and early 1960s. The convenience and generally good performance of the mechanically steerable beam, primarily in the form of the Yagi-Uda array or cubical quad, rapidly accelerated the adoption of the "transceiving" antenna as the norm during this general time frame. As with many other current standard practices in ham radio, it's easy to forget that they weren't always standard practice. Another prominent example of this is the use of coaxial cable, which only became readily available after World War II. Before then, the use of open wire feed line was the "obvious" way to get power from a transmitter to an antenna.

The Insufficiency of Efficiency

The glaring difference in priorities between transmitting and receiving antennas becomes more…well…*glaring*…when we start looking into the concept of *efficiency.*

When designing an antenna for transmitting, efficiency is generally of paramount importance. Our priority is explicitly to convert as much of our precious RF power into electromagnetic radiation as possible, while dedicating as little of that energy as possible to heating up copper wire (or earthworms). Technically, heat generated in an antenna wire or nearby dirt *is* electromagnetic radiation. It's just not at a frequency that does us much good!

As we will discover, some of the most effective receiving antennas are abysmally poor performers when efficiency alone is considered. In fact, some of the best performing receiving antennas are *utterly unsuitable* for transmitting. (The converse is not generally true; most decent transmitting antennas *will* serve as reasonable, though not necessarily outstanding, receiving antennas.)

What a Receiving Antenna Must Do

Most radio amateurs, even seasoned ones, are surprised to learn just *how feeble* the signals are that they deal with on a regular basis. It really is amazing that radio works at all when we start looking at what the actual numbers are, on a *power* basis. For the sake of this discussion, we'll look only at HF receiving systems, as VHF and UHF receiving is even *more* implausible!

A typical S-meter on a general coverage receiver or HF transceiver is calibrated so that a 50 μV (microvolt) signal at the antenna input terminals results in a reading of S-9. This is an old, old standard which is still very useful, as we shall see. A typical modern receiver has a nominal input impedance of 50 Ω. Let's look at the *power* level of an S-9 signal. Now, note that an S-9 signal is a *strong* signal…not something we have to dig out of the noise. How do we figure out the power? Well, since we know the input impedance and the input voltage, we can use E squared over R (E^2/R). Some simple algebra yields the answer: 50 μV is 0.00005 V. We square that, and we come up with 0.0000000025. We now divide that by 50, our load impedance, and come up with the staggering figure of 0.00000000005 W. That's 50 *picowatts.* Or fifty trillionths of a watt. This is for a *strong* signal!

How about an S-1 signal, one that's right near the noise floor? Well, the S-meter scale is designed so that each S-unit represents a 2-to-1 change in voltage, or a 4-to-1 change in power. There are 8 S-units difference between an S-1 and an S-9 signal. If each S-unit is 4-to-1 power ratio, the total power ratio between S-1 and S-9 is 4 to the 8th power (4^8) or 65,536. So to figure out our *power* at S-1, we divide our 50 picowatts by 65,536, which comes out to 0.00000000000000076 W … or 0.76 *femtowatts*! Or 0.76 quadrillionths of a watt. That's not a lot of watts! (By the way, these numbers don't sound anywhere near as impressive…or daunting…when expressed in decibels, the topic of our entire second chapter).

Despite the incredibly minuscule amount of power represented here, we routinely deal with these signals with extremely pedestrian equipment. There isn't a receiver built today that can't create a usable audio output with an S-1 signal! In fact, the lowly regenerative receiver of nearly 100 years ago could do this. You don't need to be impressed with our technology; you just need to be impressed with the physics that allows this all to happen.

Capture This

When it comes to receiving antennas, one very telling measuring stick is what is known as "capture area." While there are no universally accepted units for capture area (you won't find the figure listed on any commercially manufactured ham antennas), the concept is quite useful.

At any appreciable distance from a transmitting source, a receiving antenna can only intercept a minuscule fraction of the total radiated power. As the signal retreats from the transmitting antenna, it spreads out over a large volume of space. Regardless of how much antenna gain exists at the transmitter, the total energy is distributed pretty much spherically. For all practical purposes, we can consider the wavefront from any distant transmitter as being spherical. This means that the signal intensity will diminish as the inverse square of distance.

A receiving antenna can only intercept that portion of a signal that would ordinarily pass through its "personal space." There is nothing in a receiving antenna that can "pull" a radio wave toward itself, contrary to some advertising literature to the contrary. Sales terms such as "Wave Magnet" or "Signal Grabber" were fairly commonly employed in the past by manufacturers touting the capabilities of their receivers and their associated antennas. Fortunately, we don't hear too much of this language any more. A radio wave goes where it goes, and if a receiving antenna happens to be in the wave's predetermined path, it can extract energy from the wave. If not, it can't. If you could actually invent a wave magnet, you could become very rich. In reality, the only way you can grab more signal is with a bigger mitt…or antenna. The more "sky" your receiving antenna occupies the more radio wave it can intercept.

Now, there is a bit of a subtlety we need to add to this concept. Because of the complex interaction of the electric *and* magnetic field of an electromagnetic wave (including the inevitable *re*-radiation from any receiving antenna), a wire antenna actually has a bit more capture area than the actual cross sectional area of the wire exposed to the passing wave. To fully explain this would require delving into Maxwell's equations a bit more deeply than most of us would care to, or need to…at least for the purposes of this book. From another vantage point, capture area for an antenna is approximately equivalent to "aperture" as applied to a lens, at optical wavelengths.

The salient point here is that the more capture area you have, the stronger your received signal will be. All other things being equal, it's fair to say that the longer the antenna, the better it receives. This is consistent with the concept of Total Copper (or aluminum) Content (TCC) as a yardstick of overall Amateur Radio station performance. The more copper (or aluminum) you have in the air the better you'll talk and the better you'll hear!

Diminishing Returns

Taking the previous discussion at face value, it would appear that the gain of a receiving antenna will increase indefinitely as a function of the aperture, to the point where the aperture is so large that it intercepts *all* the transmitted energy. Of course, the only time this would happen would be if you entirely surrounded the transmitter antenna with your receiving antenna — not a very practical solution. (It is also illuminating to go the other way. Shrink the length of a dipole to where is a very tiny fraction of a wavelength, and notice that the aperture area limits to $l^2/4\pi$, and directive gain never gets below 1.5 or 1.76 dB compared with 1.64 or 2.15 dB for a half wave dipole.)

For a simple single-wire antenna, the gain advantage versus length reaches the point of diminishing returns on the order of a half wavelength or so. The 5/8 wave vertical or the "extended double Zepp," at twice this length, generally represent the maximum gain scenario for single-element antennas. One notable exception to this constraint is the *wave antenna,* such as the Beverage, where, indeed, the gain continues indefinitely as the length is increased. We will discuss wave antennas in detail in later chapters.

Signal-to-Noise, the Bottom Line

There is a strong temptation to evaluate the performance of a receiving antenna by looking at the S-meter alone. Although the gain of a receiving antenna is indeed reflected in the S-meter reading, the connection between readability and S-meter reading can be quite indirect at best, and utterly meaningless at worst. The ultimate goal of a receiving system isn't to exercise the springs on your S-meter's D'Arsonval movement (or at least it shouldn't be), but to optimize intelligibility, which is a function of signal-to-noise ratio than actual gain. As we will discover, it is often to great advantage to sacrifice a little bit of raw gain in order to achieve a much greater reduction in noise — and thus significantly increase the signal-to-noise ratio at the receiver's input. That's our ultimate goal. In fact, the bulk of this book is actually centered on devices and methods specifically designed to do just that.

What is Noise?

In order to achieve our supposed goal of optimizing signal-to-noise ratio, it's obviously useful to know what noise is. In simplest terms, noise is what we don't want to hear, and signal is what we do want to hear. Signal is useful, meaningful information. It is what we generate on the transmitter side of the equation. Noise is all the accumulated non-signal stuff that arrives at your antenna. Interference is generally *not* included in the definition of noise, although it can be. Effective receiving antennas can reduce or eliminate certain types of interference, as well as reduce noise.

The noise we will primarily deal with is either natural ionospheric and atmospheric noise ("static"), or manmade electrical noise, generally more localized in nature. While receiver or "electronic" noise is also commonly included in the definition, it is generally not a factor in modern well designed receivers at HF and lower frequencies. We'll learn why this is so in short order.