Signal Attenuation

1 Signal Attenuation Defined

Attenuation is the loss of signal strength as a signal travels from one place to another. There are 3 general types of attenuation:

- Distance attenuation,
- Obstacle attenuation, and
- Multipath attenuation

2 Distance Attenuation

The strength of a signal arriving at a receiver decreases rapidly as the receiver moves away from the transmitter. Another way of saying this is: the further a signal travels the weaker it gets.

In the simplest case, the signal from a transmitting antenna radiates out in all directions. The radiation is kind of like the surface of a balloon with a tiny transmitter located inside the balloon at the balloon's center (Figures 1 and 2). The receiver is located on the surface of the balloon. The balloon in Figure 2 has many different receivers located on its surface, each represented by a small circle. A receiver is close to the transmitter when the balloon is small and the intensity of the transmitted signal at the receiver is relative strong. This is important. Since the transmitting antenna radiates in all directions, the transmitted signal spreads out evenly over the entire balloon surface. If the intensity of the signal at the transmitting antenna is P then the intensity I at any receiving location on the balloon's surface is

$$I = \frac{P}{4\pi r^2}$$

where r is the radial distance from the balloon's center to its surface, and $4\pi r^2$ is the balloon's surface area. This is a famous equation that is encountered many times in science and engineering. It is known as the inverse square law. The intensity I at a location r on the surface of a sphere is proportional to the inverse of r squared, that is proportional to $1/r^2$.

As the balloon is inflated, the receivers (still located on the surface of the balloon) recede further and further away from the transmitter as r increases. The intensity of the signal at a receiver is now less because the transmitted signal must be spread over a larger surface area.

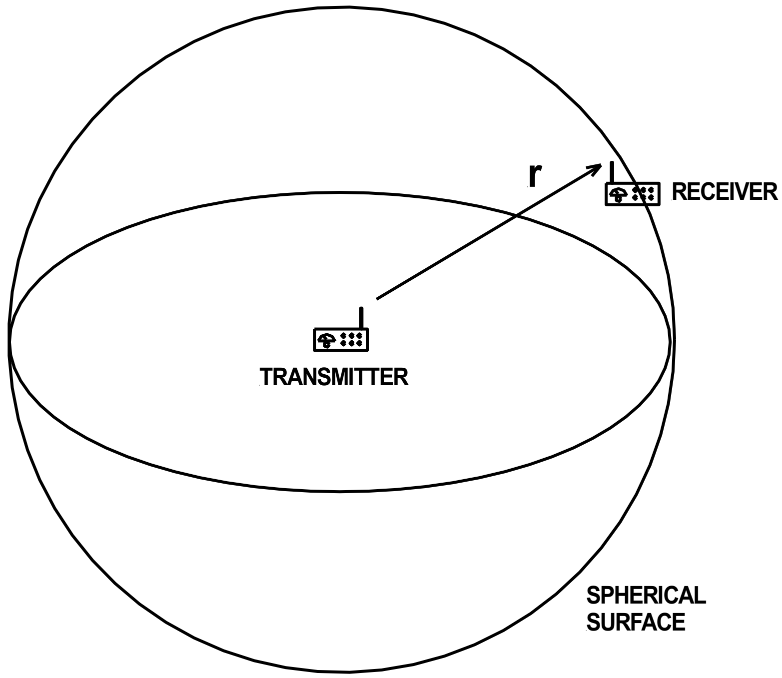

Figure 1 Transmitter – Receiver Balloon Analogy (source: author)

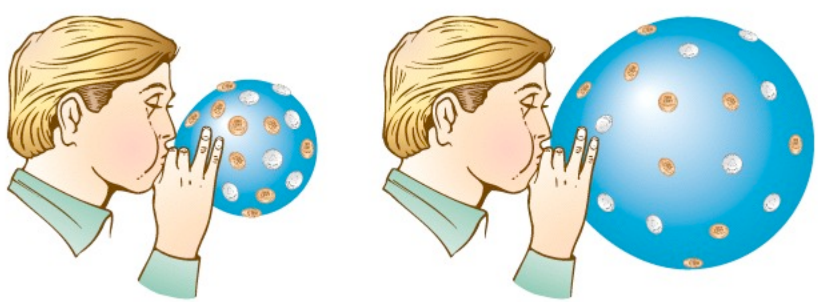

Figure 2 Inflating a balloon (source: astronomy stack exchange)

Think of a balloon that is deep blue in color. As the balloon is inflated it becomes a lighter shade of blue because its blue color is spread over the inflated balloon's larger surface area. The color of the balloon becomes a very light shade of blue as the balloon is inflated to an even larger size (unfortunately Figure 2 does not show this as well as one would like). The same is true for the intensity of the signal at a receiver. The signal intensity drops quickly (by the inverse square law) as the receiver moves further and further from the transmitter.

This is distance attenuation.

A signal is attenuated as it travels from the transmitter to the receiver. The further a receiver is from the transmitter, the greater the attenuation (the weaker the signal at the receiver becomes).

This is illustrated in Figure 3.

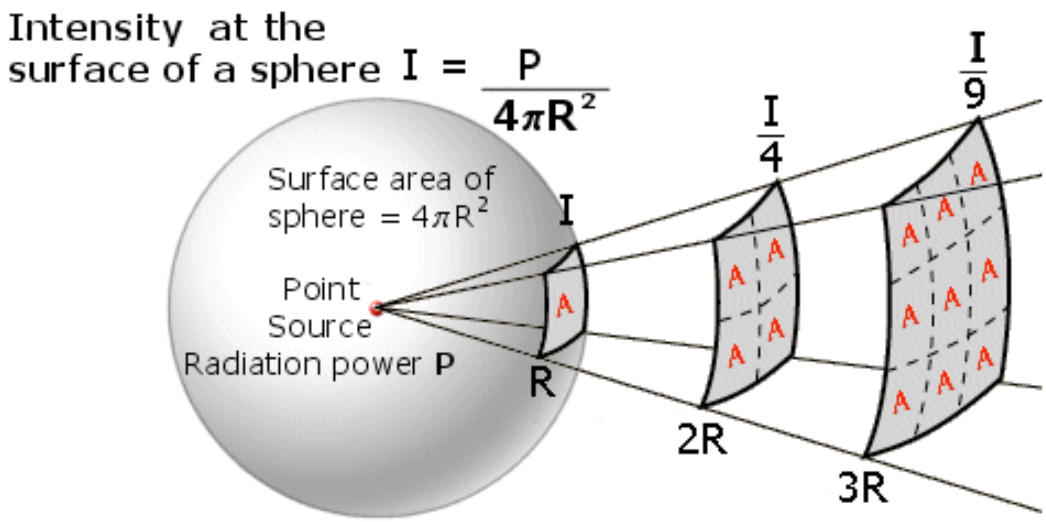

Figure 3 Inverse square law (source: Blaze Labs Research)

The signal intensity at a receiver located a distance r from the transmitter is I. The intensity of the signal at a receiver located a distance 2r from the transmitter is $\frac{1}{4}I$. For a receiver at a distance of 3r the signal strength is a very weak $\frac{1}{9}I$.

Distance attenuation is always present. You can't do anything about it. It is always present.

The type of antenna being discussed above is called an isotropic antenna, an antenna that radiates equally in all directions. It is a theoretical antenna. Most practical (real) antennas do not radiate equally in all directions. For example, the radiation pattern from a vertical dipole antenna is shown in Figure 4. In this figure the length of the dipole antenna is along the z-axis. Notice that there is a null or hole at the top and bottom of the pattern because signals do not radiate off the ends of a dipole antenna. But as you can see there is excellent radiation off the sides of the antenna. While the shape of this antenna pattern is more donut shaped than spherical, it is close enough to a spherical shape so that the inverse square law still applies, except for the ends of the antenna that do not radiate.

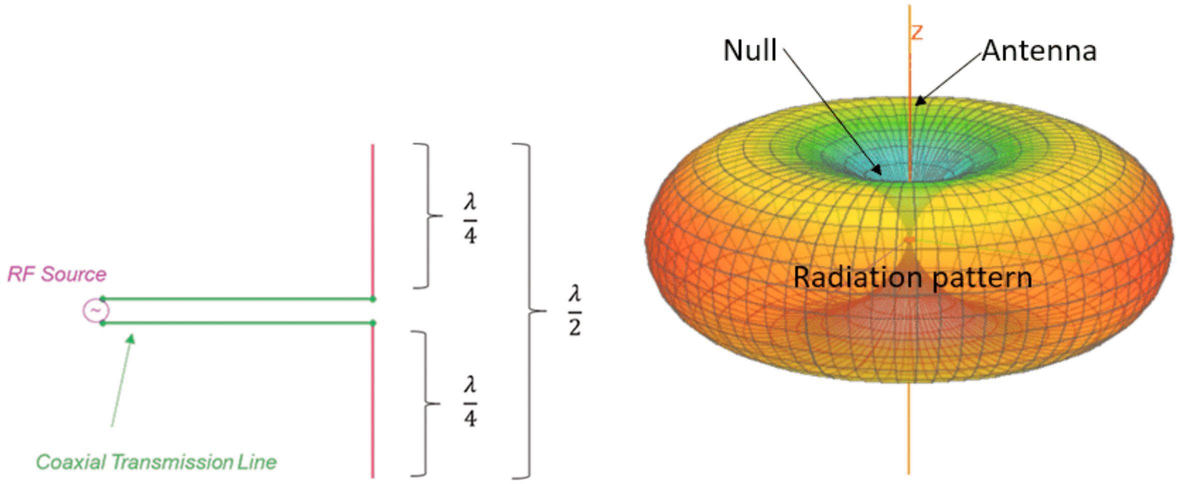

Figure 4 Vertical (red) dipole antenna and its radiation pattern (source: pt enos tour medan)

3 Obstacle Attenuation

A radio signal will pass through most houses. They pass through trees and other obstacles as well. You know that radio signals pass through houses because you can use your cell phone inside your house. While radio signals pass through these kinds of obstacles, they lose power in doing so. The signal is weaker after passing through an obstacle.

This is obstacle attenuation

4 Multipath Attenuation

Multipath attenuation is a little more difficult to explain. The shortest most direct path for a radio signal is a straight line from the transmitter to the receiver as shown in Figure 5. But a transmitter radiates its signal in many different directions. Some of its radiated signal invariably reflects off other objects, such as tall buildings, with the reflected signals eventually ending up at the receiver as illustrated in Figure 5. The reflected path is longer than the direct path which means that it takes a reflected signal longer to arrive at the receiver than the direct path signal. This results in interference between the direct path signal and the various reflected path signals.

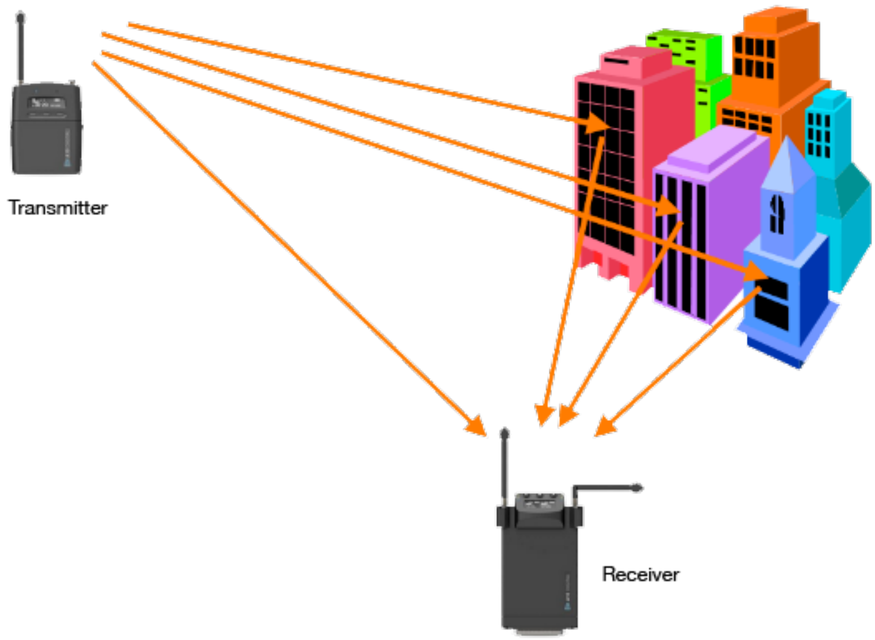

Figure 5 Multipath signal propagation (source: Sound Devices)

Think of the transmitter sending the message:

A B C D E F G H

This is the message that would arrive at the receiver if there were no multipath interference. That is, the only path from the transmitter to the receiver is the direct path.

When we introduce multipath propagation, the same message is sent in all directions. It travels from the transmitter directly to the receiver. It also travels a longer distance reflecting off of buildings before arriving at the receiver. The reflected signal is delayed relative to the direct path signal since the reflected signal must travel a longer distance to get to the receiver.

What the receiver hears is both signals. What it receives is

A B C D/A E/B F/C G/D H/E

where the blue letters represent the reflected signal arriving later than the green letters which were received directly from the transmitter. The receiver can not differentiate between the two signal paths. It hears whatever ends up at its receiving antenna. What it gets is a garbled message: **A**, **B**, and **C** are received ok, they are in the clear. But when the delayed signal arrives, **D** is mixed with and inseparable from **A**, **E** is mixed with and inseparable from **B**, etc. The message is garbled from **D** on.

This is a conceptual example of multipath interference.

What really happens is at the signal level illustrated in Figure 6.

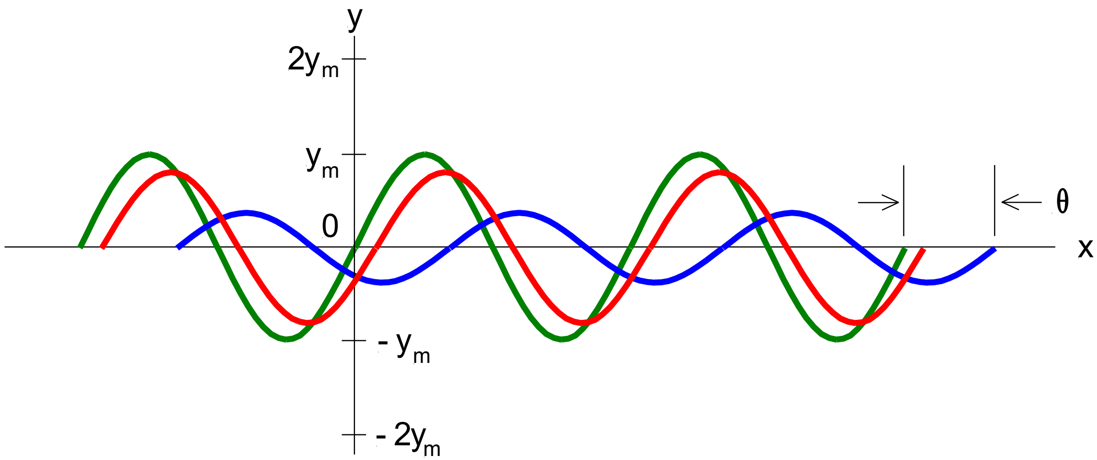

Figure 6 Two signal waves green directed path blue reflected path (source: author)

In this figure the green sine wave is the radio signal sent directly from the transmitter to the receiver. The blue sine wave is the signal that reflected from one or more buildings before eventually arriving at the receiver. Notice that the blue signal is delayed (arrives behind) the green signal. Notice also that the blue signal is smaller than the green signal indicating that the blue signal incurred at least partial obstruction attenuation when it reflected from the buildings. What the receiver actually hears is the red signal which is the green and blue signals added together.

Notice that the red signal, what the receiver actually hears, is weaker (smaller) than the green signal which it would have received if multipath interference had not occurred.

This is multipath attenuation.

In the worse case scenario, the reflected signal is not attenuated during reflection. Instead, it arrives at the receiver at the same signal level as the direct signal. The reflected signal is simply delayed. If it is delayed enough the direct and the reflected signals will cancel each other out meaning that the receiver does not hear anything. This is the situation shown in Figure 7b. Because of its longer path the reflected signal (in this example green) arrives at the receiver completely out of phase with the direct signal (orange). When the orange signal goes up, the green signal goes down. When these two signals are added together at the input of the receiver, the result is that they cancel each other out and the receivers hears nothing.

Another situation, constructive interference, occurs in Figure 7a. In this case the reflected signal (green) is delayed exactly enough so that when it arrives at the receiver it is completely in phase with the direct signal. The green reflected signal goes up at exactly the same time as the orange direct signal does up. When the receiver adds these two signals together the result (what the receiver hears) is a signal twice as strong as the direct signal by itself. In this case the interference of the reflected signal with the direct signal actually helps. So when you transmit what are you going to get, constructive or destructive interference? You do not really know until it happens. Unfortunately, destructive interference happens most of the time, or at least it is more noticeable, more annoying, than constructive interference

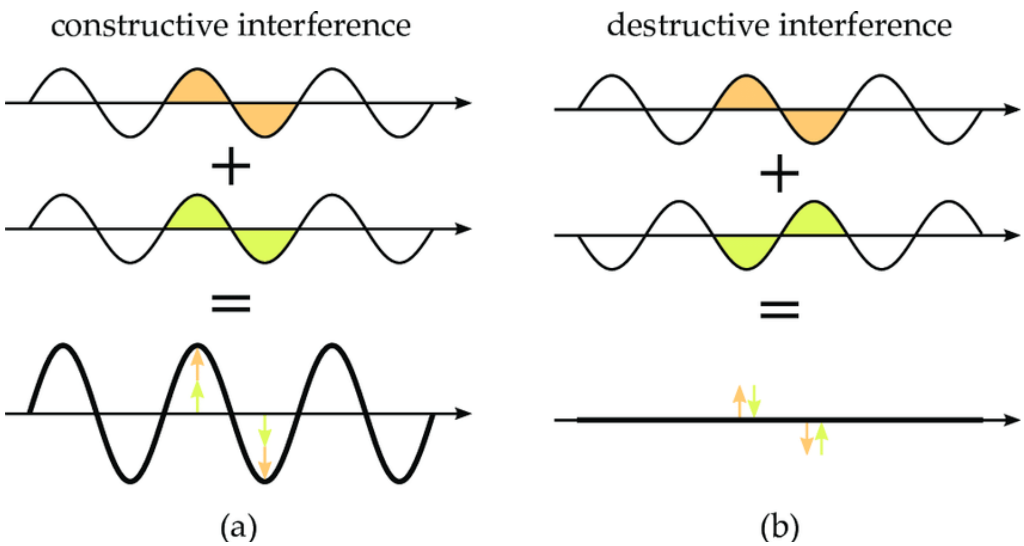

Figure 7 Constructive and destructive interference (source: ResearchGate)