Radio/Antenna Basics for R/C Modellers

Most R/C Modellers take their transmitter and receiver antennas for granted and do not realize that a few simple tips can help increase their range and radio reliability. For most people, even most electronic engineers, antenna theory is way over our heads and involves advanced mathematics and electromagnetic wave theory.

Fortunately, with only a modicum of elementary knowledge, the basics of radio and antennas can be easily understood by non-electronic people. David Harrison, of the Rideau Nautical Modellers, Ottawa, Canada, explains basic radio and antenna principles, and how we can optimize our antennas to get the most out of our radios.

What is an Antenna?

This, perhaps rather obvious, question has some simple definitions.

1) A Transmitter antenna is a (usually) straight electrically conducting wire whose purpose is to convert a radio frequency (RF) electrical signal to a radiated electromagnetic field with minimal energy losses. A radio frequency alternating electrical current is applied to one end or to some point along the wire and the other end must be open and not connected to anything.

2) A Receiver antenna is a (usually) straight electrically conducting wire whose purpose is to convert a radio frequency (RF) radiated electromagnetic field to an electrical signal as high as possible in "strength". Again, one end is open and the other is connected to a radio receiver.

3) Antennas have many designs and shapes ranging from a simple length of wire to complex Yagi beam antennas and microwave antennas incorporating reflective dishes. (Note: the dish itself is not the antenna. It is an electrically reflective "mirror" to help gather and focus weak radio waves onto the actual antenna which is often a simple dipole (explained later).

What is Frequency?

Frequency is simply the number of times some event occurs in a defined time period. In the radio world, frequency is measured in Hertz (abbreviated Hz), after the famous scientist and inventor Heinrich Rudolph Hertz. Until the 1960's, radio frequencies were measured in cycles per second (c/s) or megacycles-per-second. One Hertz is the same as one cycle per second. RF frequencies are usually measured in Megahertz (abbreviated MHz), one million Hertz.

What is a Radio Band?

A Radio Band is simply a range of frequencies allocated for a particular purpose by the Federal Communications Commission (FCC) in the U.S., the Canadian Radio-television and Telecommunications Commission (CRTC) in Canada and the International Telecommunication Union (ITU).

It is important that only the designated usage for a radio band is used, otherwise unexpected interference causing unreliable reception occurs.

In North America, the designated bands for radio controlled models are the 72MHz band for Model Aircraft and 75MHz for surface (Model cars, trucks, boats etc.). There are also an infrequently used 27MHz Band and also higher frequency bands. Other countries use other frequency bands e.g. 35MHz and 41MHz in the UK and UHF bands at 435MHz.

Worldwide the unlicensed 2.4GHz ISM band (Industrial, Scientific, Medical) is used extensively for R/C and many other applications and has advantages due to its much shorter antennas, all digital transmission and frequency hopping or other spread spectrum schemes.

Each non-2.4Ghz band is divided into many “Channels” that are separated by a few Kilohertz. Because the frequency separation between adjacent channels is small, all R/C transmitters are crystal controlled to maintain their transmitted frequency within very narrow tolerances.

An online resource for a list of North American R/C Channel numbers is at :

http://rcsource.hobbypeople.net/faqs/freqlist.htm

So What is an Electromagnetic (EM) field?

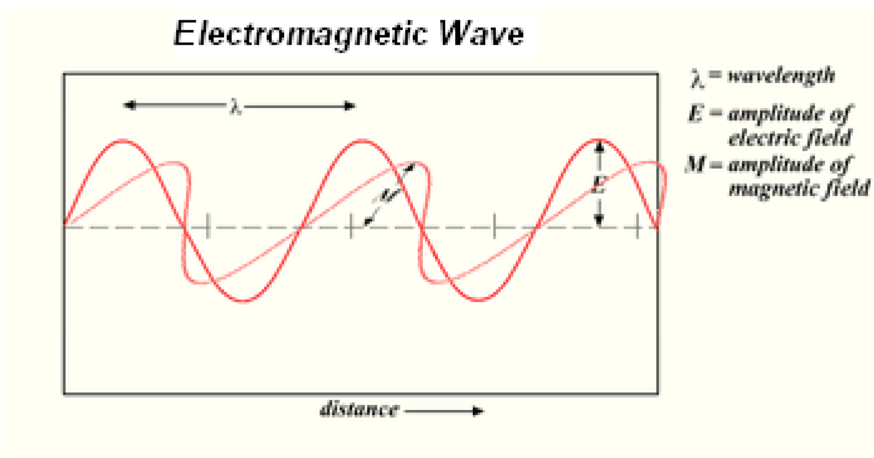
When an electric current passes through any electrical conductor, a magnetic field is created at right angles to the wire. If the current is an unchanging D.C. (Direct Current), then the magnetic field is steady and can be used to create electromagnets for lifting, relays, door bells etc.

By virtue of the fact that the wire is a conductor, there is also an electric field created at right angles to the wire, but perpendicular to the magnetic field. Most people can easily relate to a magnetic field but an electric field is somewhat more difficult to grasp. We all know how we get sparks from static electricity and our hair stands on end when we get an electric charge. It is the electric field around our hair that is pulling it away from our head. If the strength of the electric field becomes too great, the air around the wire breaks down and a spark ensues. The breakdown of air occurs at about 3000Volts/mm. So if a spark jumps across a 1cm gap e.g. from your finger to the doorknob, you were charged by static electricity to a voltage of 30000Volts above ground!

When the current in the wire is alternating (A.C. i.e. changes direction) at radio frequencies, the magnetic and electric fields also change and propagate through space at the speed of light. The radiated EM field contains energy converted from the electrical energy in the signal applied to the end of the wire.

Taken to extremes, a laser beam is radiated electromagnetic energy concentrated into a very narrow beam at a visible or infra-red light frequency. Beyond visible light we have X-Rays, Gamma rays and other energy beams. Below visible light we have infra-red, or heat radiation, but all these are no different in principle to radio waves.

Following the AC cycle, these electric and magnetic fields expand from zero to maximum intensity, then fall to zero, then expand in the opposite direction and again fall back to zero. Each time the cycle is at its maximum, the magnetic and electric fields expand to their greatest distance from the wire and each time the cycle is zero, the fields collapse back into the wire. As the electrons (negatively charged sub-atomic particles) constituting the flow of current move along the wire, a rising and falling of electric and magnetic intensity (i.e. a wave) moves along the wire in the direction of the electron flow.



Standing Waves along a Wire

As electrons move along a wire the magnetic field associated with them accompanies them along the wire. If an electrical pulse is applied to one end of the wire, the electrons move toward the other (open) end of the wire. When they reach the open end there is no place for them to go and so the current dies. As the current drops to zero, so does the magnetic field associated with it. Since a changing magnetic field about a wire induces current in it (the generator effect), the collapsing magnetic field induces a current in the wire which flows in the opposite direction to the original pulse. Thus energy is reflected back from the open end. Now extend this concept to a continuously changing current at radio frequency and you can see that there is a forward (incident) wave and a reverse (reflected) wave.

The incident and reflected waves interfere with each other and either reinforce, reduce or cancel each other out. Thus the net energy also follows a wave like pattern as you move along the wire. This varying energy distribution stays in a stationary pattern as long as the signal is applied. These waves are therefore called standing waves.

If one was to place an RF voltmeter along the wire at different points, it would indicate varying levels of electric field strength varying from zero to a maximum value at the end of the wire.

Similarly, if a magnetometer measuring magnetic field strength were moved along the wire, it would also vary in strength from a maximum to zero at the end of the wire (it has to be zero at the end, because there is nowhere for the current to go to). These instruments are measuring the standing wave along the wire.

Air Waves?

When radio was first invented, it was thought, at least by the public, that the radio waves were carried by the air, hence the terms “airwaves” and “on-the-air”. It was quickly discovered that radio waves travel through a vacuum and free space.

Antenna or Transmission Line?

In non-antenna use, an electrical wire is usually used to conduct electrical energy from one place to another. When its sole purpose is to carry electric current to another place with minimal losses, it is called a transmission line. There are all kinds of transmission lines from the very low frequency power grid running at 60Hz in North America to very high frequency transmission lines used to carry power from a radio transmitter to the actual antenna at the top of a mast.

When electrical current is flowing in a wire, it does not flow without losses. Various physical properties of the wire create what is called an “impedance” to the current i.e. it tries to impede the flow of current. It is beyond the scope of this article to discuss exactly what impedance is – so for now just accept that it exists and that it is measured in Ohms (**Ω**). Any wire or cable has an inherent impedance. Depending on construction and materials, a wire’s natural impedance varies between about 30 Ω and 600 Ω at radio frequencies.

At one extreme, a short circuit is a zero impedance, at the other, an open circuit is an infinite impedance (approximately).

So if a wire is short circuited at the other end, again there is nowhere for the energy to go, so it is all reflected back and in fact is dissipated in the losses of the wire and the signal source itself. We have already seen that an open ended wire also reflects energy back, but is not dissipated in the wire – it is radiated out as an EM field. Somewhere in between these two extremes, if an electrical load with an impedance equal to the inherent impedance of the wire is connected, then there is no reflected energy and all the incident energy is dissipated in the load. In this case, we have an ideal transmission line since there is no standing wave, and no radiated energy.

So you can also consider an antenna as a special case of a transmission line ending in an infinite impedance and thus converting all the incident energy into a radiated EM wave at radio frequency.

Frequency, Speed and Wavelength

All electromagnetic waves travel through space at the speed of light which is 300,000km/second.

Wavelength is the distance of one cycle of the radio wave.

If you are walking at a certain pace, your stride is equivalent to one wavelength (λ), and the number of steps you take per second/minute is your frequency (f).

Therefore your speed (c) is the number of paces per second multiplied by your stride ($c = f\lambda$)

This basic formula, $c = f\lambda$ or $\lambda = c / f$ governs how wavelengths are related to frequency, given that the speed is constant.

The speed of light in air or any other material is slightly slower than in free space, depending on its density and a property known as “dielectric constant”. The speed of radio waves in water in considerably lower than in air and thus water has a “detuning” effect on any antenna used in a model submarine, thus reducing its effectiveness, not to mention that impure water is a slight electrical conductor and therefore acts as an electrical screen to radio waves.

At the surface model frequency band of 75MHz, the wavelength is thus :

$300000 \times 10^3 / 75 \times 10^6$ = **4 metres.**

Remember these numbers – they are important to understand R/C antenna lengths!

R/C Antenna Lengths

Now that we understand standing waves and wavelength, we can see why R/C antennas have to be as long as they are. The base fed, open ended single rod antenna used in R/C equipment is called a ¼ wave Marconi antenna and works in association with a nearby ground plane at right angles to it,

With this type of antenna, the current is maximum at its base and, as we have already seen, has to be zero at its open end. Thus the longest (and most efficient) standing wave along the antenna is exactly ¼ of a full cycle, or ¼ wavelength or **1 metre** at 75MHz. This is why most R/C transmitter antennas are very close to 1 meter or 39” long.

Similarly, on the receiver, there is also zero current at the open end and maximum at the receiver end. Therefore the optimum receiver antenna length is also 1 metre.

As the frequency goes up, for example to the ISM (Industrial Scientific and Medical) band in the 2.4GHz region, the wavelength goes down and the antenna length can come down.

At 2.4GHz, the wavelength is only **0.125 meters, 12.5cm or 4.92 inches**

Therefore a ¼ wave antenna is 1/32 meter or 3.1cm! This is why cell phones are so compact – their antennas are so short yet still remain effective.

¼ Wave and ½ Wave Antennas – the dipole

This basic ¼ wave antenna depends on having a good ground plane at its base. The ground plane acts as a kind of "mirror" and reflects into the ground a second phantom ¼ wave antenna that is base to base with the actual antenna. These two ¼ wave antennas then make up a ½ wave dipole antenna where one half is the phantom in-ground part. The ½ wave dipole (called a Hertz antenna) is the basis for nearly all other antenna designs, and even by itself, is more efficient than the ¼ wave antenna. It also does not require a nearby ground plane, and can therefore be used high up on a mast.

A real ½ wave dipole is centre fed, not base fed, with each ¼ half being fed in anti-phase from the transmitter. "However for 75/72MHz and lower R/C use, a half wave dipole is impractical, given that it would be 2 metres long or more!"

Antenna Grounding

The ¼ wave Marconi antenna requires that the ground terminal of the transmitter or receiver be connected to a very good ground connection. There is little we can do to improve the ground connection at the R/C transmitter end. In fact the R/C operator him/herself is the nearest ground terminal!

However we can ensure a good ground connection for the R/C receiver ground (the negative battery terminal) especially in the model boat world. You connect the receiver negative battery line to your brass stuffing tube and make sure there is some paint scraped off at the propeller end to make contact with the water. This will help your receiver have a more efficient antenna, and help ground any radio interference signals that may be generated in your negative battery lines.

See my previous article on RFI for other grounding and RFI suppression tips.

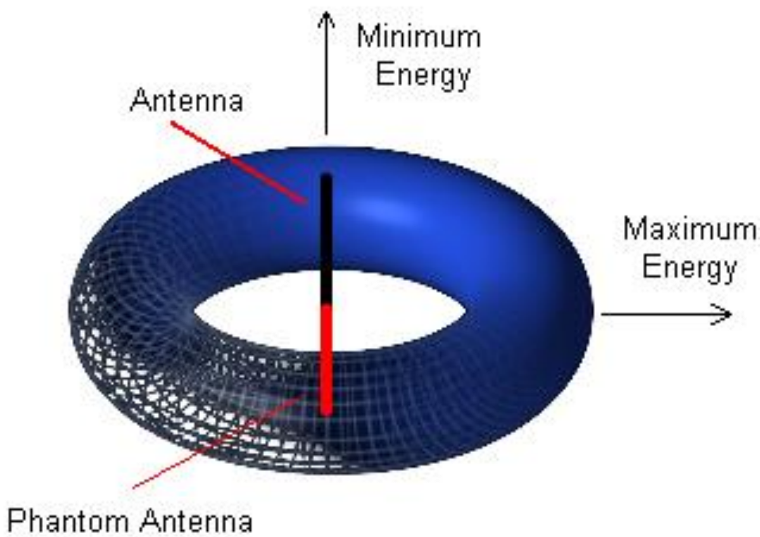
http://www.modelsoundsinc.com/articles/DavidsOriginalArticles/RFIArticleMarch2006.pdf

Radiation Patterns

The ¼ wave Marconi antenna depends on having a good ground plane at its base, and being at right angles to the ground plane i.e. vertical.

Some R/C modelers point their transmitter antenna at their model in the mistaken belief that the radio waves somehow come out from the end of the antenna. This is clearly not the case!

If we were able to measure the total energy strength at all points around the antenna in three dimensions we would find that it would resemble a doughnut, or toroidal shape, with a very small hole around the wire on its axis. This is intuitive, given that the energy strength is maximum at right angles to the wire and zero on its axis. The doughnut shape is actually two ½ doughnuts, the top half coming from the real antenna, the bottom half coming from the phantom antenna.



Can I shorten my Antenna Wire?

Yes and no! As you have seen, the optimum length for maximum efficiency is ¼ wavelength or 39" at 75MHz. If you shorten your transmitter antenna, the impedance of the antenna is no longer matched to the output impedance of the transmitter circuitry and so some energy is reflected back into the transmitter.

Not only does this reduce the amount of radiated energy, it also makes the transmitter work a lot harder, increasing its battery consumption and heating up the output transistor.

It is therefore recommended that you operate your transmitter for test purposes with the antenna down for only short periods at a time. Operate the transmitter with the antenna fully extended when controlling your R/C model.

The receiver antenna always operates at best efficiency when at full length, as provided by the receiver manufacturer. However, in scale models it is not always possible to have a 39" antenna sticking out from your model.

Model boats and other surface models are fortunate in that they do not have to maintain the long ranges necessary for model aircraft. Therefore some decrease in receiver antenna efficiency is permissible.

There is also the possibility of making what is called a "base loaded antenna". There is a component of the antenna impedance called inductance (due to the magnetic field around the wire). When the antenna is shortened, its inductive impedance (properly called reactance) is reduced and is therefore no longer matched to the receiver. It is possible to insert an inductor (a coil of wire) near the base of the receiver antenna to make up this difference and restore the electrical length of the antenna. However, this impedance matching still does not make up completely for the lost efficiency due to the shortened antenna.

It turns out that very approximately, the amount of wire that has to coiled into an inductor is the length of wire by which the antenna is shortened. However, the wire cannot be just haphazardly coiled in a random bunch. It should be wound onto an insulating former e.g. a piece of polystyrene rod. Without any RF measuring equipment, this can only be done by trial and error. There are no hard and fast rules about how a base loading coil for an R/C antenna should be made. It is also affected by the presence of nearby conducting objects such as your motors and battery!

On-line Resources about EM Radiation and Antennas

Wikipedia –Invention of Radio

Wikipedia - History of Radio

Wikipedia – Electromagnetic Radiation

Wikipedia - Heinrich Rudolf Hertz

Wikipedia - Guglielmo Marchese Marconi

Antenna Basics

Happy modelling and R/C operation!

David L Harrison