The Radio Hotel – The Impedance of Space

by Rick W5RH

At first, more questions than answers.

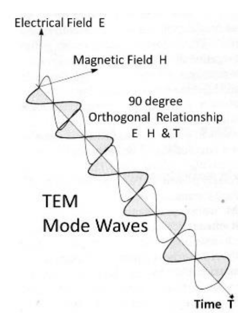
Bet you a dollar that you have never even thought about it. Me too. But recently I have been looking into the subject of the impedance of space with wide eyes and wild anticipation of finding out how to improve my antenna system. Possibly matching the antenna's output impedance to the impedance of space—(forcing Jacobi's Law -- the Maximum Power Transfer Theorem). During this short period of due diligence, what I ran into was a quagmire of factual discovery and analysis on my part that led me to, not a breakthrough, but a realization that there *ain't nuttin* I could do about it. The pathway to this knowledge was arduous, but fun. What follows is a cursory guide through the gory details.

My hypothesis: The electro-magnetic radiation from our antennas has some impedance (z) that matches, to some degree, the characteristic impedance of space. I was also asking these questions: 1) does space actually have an impedance? If so, why? 2) does the impedance of space affect our antennas performance? 3) can we design an antenna to be more effective for matching to the impedance of space? But, to be truthful, what I really wanted to know was: "What is the output impedance (z) of an antenna?".

In my 30 or so years of mostly empirical HF antenna interest, I have never read about the output Z of an antenna. Input Z, feed point Z, Radiation Resistance – Yes; but nothing on the business side of the antenna transducer. So, with my typical, "I don't know squat about this" outlook, I ventured off into a land of new books, new terms, theories, and maybe, just maybe, a discovery that I could use to improve my antenna systems at the house.

The adventure starts here.

You do know that an antenna is a transducer, right? *A Transducer – a device that transforms one type of energy into another.* Like a toaster, which uses electrical voltage and resistance to generate a current flow in a heating element. This produces heat, which radiates thru the air and toasts our 'near field' breakfast treats. Kind of a strange analogy for a transducer, but one that is quite relevant to an antenna -- electrical on the input and radiation on the output.



An antenna, as a transducer, does two things for us. 1), it converts a varying AC voltage at RF frequencies to **Transverse Electomagnetic** mode waves -- **TEM**. And 2), it is an impedance matching device transposing the Antenna's Radiation Resistance to the impedance of space. **TEM** waves are orthogonal waves (90 degrees out from each other) of E and H (charge and flux) electromagnetic radiation traveling in the direction of propagation down a transmission line or through the medium of air or space.

Another fact that must be considered is that of the "void of space". *Ain't no "void" out there, Batman*. Out in space, in the antenna's Far Field (Fraunhofer Zone), the TEM waves spread out so much that they become a plane wave; literally, thousands of thin sheets within each wavelength cycle of homogenous E and H charges traveling away from the antenna at the speed of light. But, what causes these waves to travel?

Space may not have any air, a vacuum, but it exhibits many other characteristics that can be advantageous. Like permittivity (capacitance) and permeability (inductance) – the ability to store electrical charge and magnetic flux, respectively. These are two very good, and necessary, characteristics to have when you want your RF energy to 1) travel down your coax to your antenna or 2) radiate from your antenna to the other side of the globe. Just like the toaster's heat needs air to get to the toast, our TEM waves need space's permittivity and permeability to travel within the medium of space.

If you remember your transmission line theory, all transmission lines have the properties of permittivity C and permeability L. These 2 values are used to calculate the characteristic impedance of the coax you are using. So, if a coax transmission line's surge impedance can be calculated with these two values, and space also has these 2 characteristics, then the impedance of space can be calculated. The Square Root of Permeability--u0 in space divided by the Permittivity--e0 in space calculates to 120π or 377 ohms -- the Impedance of Space. (factoid -- the Greek letter 'eta' or '**n**' is used for the impedance of space, to avoid confusion with electrical impedance letter Z) So, now we know, the impedance of space '**n**' is 377 ohms.

But, I still want to know, what is the output Z or **n** of an antenna? Here is the simple answer -- As the E and H TEM waves from our antenna are radiated from the wire into the antenna's Near Field (Fresnel Zone) and then into the Far Field (Fraunhofer Zone), they literally conform to the impedance caused by the permittivity and permeability of space. Another analogy here: Sort of like water flowing from a large pipe to a smaller pipe. The large pipe's water will conform to the smaller pipes diameter, but while doing so will change the volume of flow and the pressure, based on the small pipe's dimensions. For the antenna, the E and H wave impedance takes on the value of 377 ohms, as the waves conform to the Far Field medium of space. This conforming action causes an exact match of the antennas radiated output impedance to the impedance of space (**n**). Exactly what I wanted to know. Sweet! *[Note that a significant amount of wave mechanics and E/H interaction happens in the Near Field. More on this in a later column*]

Now we know, the impedance of space; plus, how it affects our antenna's output characteristics. Know too that **all** antennas generate TEM wave output that conforms to this 377 ohm impedance. But, what about terrestrial RF traveling through air, you ask? Rest easy, my friends, as the Permittivity and Permeability of the atmosphere we breathe is very close in value to that of space. No disruptive impedance bump will be encountered when your RF is traveling from your backyard antenna to the hinterlands of the galaxy.

So, what about our antenna designs? Can they be improved? Output impedance wise…..the answer is no. Of course, realize that the output impedance of an antenna "transducer" has an inherent influence on the antenna's Radiation Resistance and therefore also, on the Feed Point impedance. But **n** – 377 ohms is what it is, a constant….always has been, always will be. Our best efforts should instead be put towards designing antennas with improved gain, beam width, front to back ratio, capture area and efficiency. No need to even think about trying to control the output impedance, it's a useless exercise.

Summary

Looking back at this whole space/antenna output impedance discovery process, although interesting and informative, the most I can say is that it gives us one less antenna system characteristic to worry about during the design or concept phases. There is no data to use and improve a Ham Radio station's antenna performance. No pushing the envelope, state of the art, break thru, wiz bang, antenna output Z design implementations to utilize. Sorry. So, the only other advantage is in the realm of trivia. Your knowledge of some esoteric radio theory fact. Keep it safely tucked away in the back of your mind, so that the next time we play Ham Radio Trivia at a club meeting and we ask "What is the Impedance of Free Space?". You can be Johnny-on-the-spot with the answer -- 377 ohms.

Enjoy your hobby. 73…Rick – W5RH

Next time…. The Illusive "Wet Noodle" and 200 Degrees

*The purpose of **The Radio Hotel** is to give you a practical kickstart into exploring the workings of antenna systems Google the buzz words and find out what they mean. Read up on antenna system theory to see how it all works together. You will be glad you did.*