**AARC Program**

*What you Always Wanted to Know ABOUT HAM RADIO BUT were afraid to ask!*

#2

**VELOCITY FACTOR**

**PLEASE NOTE THAT VELOCITY FACTOR IS RELATED TO TRANSMISSION LINES AND NOT TO ANTENNAS**

In free space, electrical waves travel at the speed of light, or 299,792,458 **meters per second**. Converting to **feet per second** yields 983,569,082. The length of a wave ***in free space*** is related to frequency given by wavelength (λ) = wave velocity/frequency. Thus, the **full** wavelength of a 1 Hz signal in free space is 983,569,082 ft. Changing to a more useful expression gives:

**λ=983.6 / f** (1)

where λ = wavelength is in feet, f = frequency in MHz

The formula (1) above **IS NOT** an antenna formula but rather a fundamental relationship of wavelength and frequency derived from the speed of light which is a universal constant. The formula is used to develop a Velocity Factor (VF) formula for transmission lines. You will see later how this same formula (1) is used to derive the ARRL antenna formula λ=468/f.

It is important to note that wavelength (λ) may also be expressed in electrical degrees. A full wavelength is 1 λ is 360°, 1 ⁄2 λ is 180°, 1 ⁄4 λ is 90°, and so forth. This is important when we design antennas later.

Waves travel slower than the speed of light in any medium denser than a vacuum of free space. A transmission line may have an insulator (dielectric) which slows the wave travel down. The actual velocity of the wave is a function of the insulator dielectric characteristic. We can express the variation of velocity as the ***velocity factor*** for that particular type of dielectric — thus VF is ratio of the wave’s propagation velocity in the transmission line compared to that in free space. Why do we care? Often for short transmission lines we don’t. But for long transmission lines and high frequencies, a transmission line’s VF can affect the signal’s wavelength at the radiating antenna elements. If the VF is 1 (which is free space) then there is no effect on either the wavelength or frequency. But if a piece of coax is long and has a low VF, say 0.66, then the frequency and wavelength can look different as it is launched onto the radiating elements. Fortunately, ham don’t have extremely long coax runs and coax today, RG 213 or RG 8, have very good VF characteristics.

So, what affects the VF in a coax cable?

Now, the velocity factor is related to the dielectric constant of the material used in the transmission line.

VF = 1/

$$ε$$

$$\sqrt{ε}$$

where VF = velocity factor = dielectric constant. Modifying the formula above, the wavelength in ***a real transmission line*** (not free space) becomes:

 **λ =983.6 \* VF/f** (2)

As an example, many coax cables use polyethylene dielectric over the center conductor as the insulation. The dielectric constant for foam polyethylene is 1.5, so the VF is 0.82 per formula (2). The VF and other characteristics of many types of lines, both coax and twin lead. There are differences in VF from batch to batch of transmission line because there are some variations in dielectric constant during the manufacturing processes. When high accuracy is required, it is best to actually measure VF by using an ***antenna analyzer*** to measure the resonant frequency of a length of cable.

$$ε$$

**Antenna Design**

Let’s start with formula (1):

**λ=983.6 / f**

This is a full wave and as you can see from the example at the beginning of this paper that a low frequency (i.e., 14 MHz or 20 m band) would be quite long 70’ for example. From a radiation efficiency point of view engineer’s have found that a half wavelength (1 ⁄2 λ) provides almost the same signal radiation efficiency as a full wavelength at half the distances. So, taking formula (1) and modifying it for 1 ⁄2 λ our 14MHz antenna design would go from 70’ down to 35’ which is much easier to handle and install.

Thus formula (1) would become:

 λ = 491.8 / f

where f is in MHz and λ is in feet.

But our formula that we often use out of the AARL Handbook for a dipole is λ=468/f. How do you get that?

Actually, the formula is λ=491.8 \* K/f (3)

The constant K is measured and is a function of wire diameter and wavelength.

* You can refer to the ARRL Handbook ¶ 21.1.7 for a graph that defines K for different wire sizes & wavelengths.

Typically, K is 0.951 for antenna wire sizes and frequencies used by ham radio operators.

Thus formula (3) is reduced to λ = 491.8 \* 0.951 /f or with rounding **λ = 468/f**. The old familiar half wavelength dipole formula.

Here is a helpful hint when using an antenna analyzer to “tune” your new dipole antenna.

* If the antenna resonant frequency is too low – antenna is too long and needs to be shorted.
* If the antenna resonant frequency is too high – the antenna is too short and needs to be lengthened.