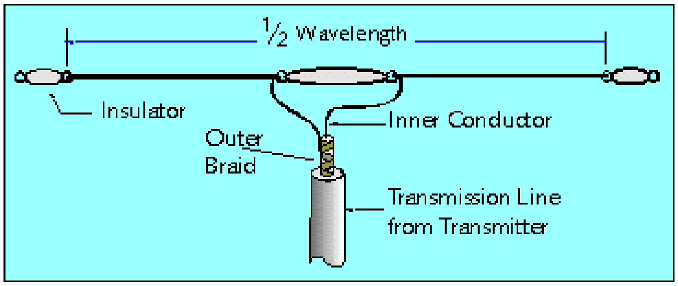
Basic Dipole Antenna Build

Presented to the Chelsea Amateur Radio Club

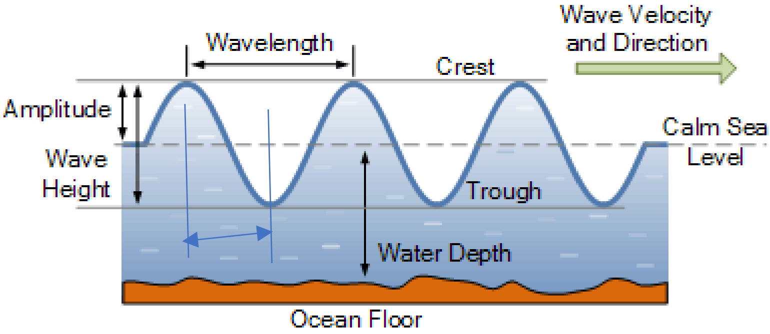
Wesley Cardone, July 2021



In this presentation we will build a very simple dipole antenna and consider many practical aspects of what it takes to get a high performing antenna.

The dipole antenna concept is really quite simple. The antenna itself consists of two equal lengths of wire, separated by an insulator. The end-to-end length of the two wires including the connecting insulator is a half-wavelength. But what is a wavelength?

The nature of a wavelength is buried in its name. A wavelength is as the name implies—the length of a wave. Have your ever been to an ocean beach and watched the…"waves" coming in? While ocean waves are of course 3 dimensional, let's just for now look at a cross-section of an ocean wave in 2 dimensions—height and… length.



In the middle of the ocean where the depth is for practical purposes infinite, a given wave will travel at some velocity. If you had a tape measure you could measure the distance between crests which represents one complete wave. The distance crest-to-crest for this one wave is a wavelength.

Now for the big question of the day: what length would a half-wavelength be?

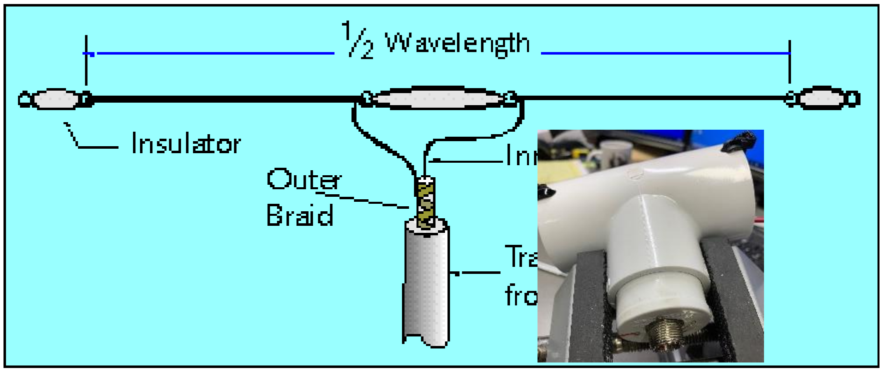
There is another way to talk about wavelengths. One wavelength may also be called one cycle or Hertz.

On a given day out on the beach, there may be X number of waves coming in per hour telling us how frequent the waves are or what "frequency" they have. If a set of waves are coming in at 1 wave every second, we can speak of 1 cycle per second for a frequency.

Now, let us suppose that we have measured the length of each wave to be 1 foot crest-to-crest. The speed of the waves (velocity) is therefore 1 foot per second.

As the wave approaches land, the ocean floor is no longer infinite and slows the velocity of the wave. As the wave slows, the time it takes from crest to crest also slows. If in the free ocean the wave velocity were 1 foot per second, in closer to shore the velocity might slow to 1 foot every two seconds. For convenience we can say that waves in close to land have a "velocity factor" of 0.5 in this case. With a free ocean velocity of 1 wave per second, and a known velocity factor of 0.5, we can say that the wave velocity in close to shore is half that of in the free ocean. That is, their speed is decreased by 50% because of the resistance of the land underneath the water.

These same principles apply to the propagation of electro-magnetic energy. In free space where there is nothing to slow the flow of energy, electro-magnetic energy travels at the speed of light. However, if that same energy were made to travel in a copper wire, the velocity would decrease by a velocity factor. The actual velocity factor depends on properties of the wire including its insulation. But in any case, the velocity would be significantly less than the speed of light in free space.



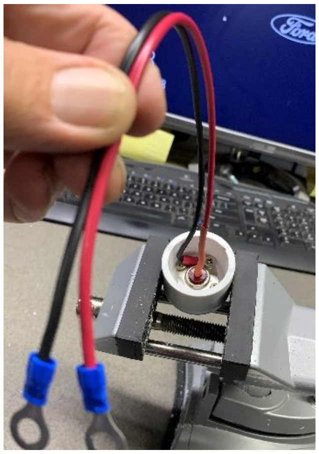
We are now in a position to return to the dipole antenna and wavelengths.

First consider the feed point and hub for the antenna which is the joining point for the two wires. For this build we will be using PVC pipe. The centerpiece will be a tee connector. In the tee will go the feed point using an SO-239 connector as shown in the illustration.

On the other side of the SO-239 two wires are connected which will be used to connect to each of the quarter wave wires.

In the fabrication of the gap wire assembly, try to keep the two wires of equal length. Also, carefully measure the length of the two gap wires and make a notation as to the length. We will be using this measurement when we determine what length to use for the two antenna elements.

Structural integrity might seem beneficial but improved results are obtained by keeping the wires distant.



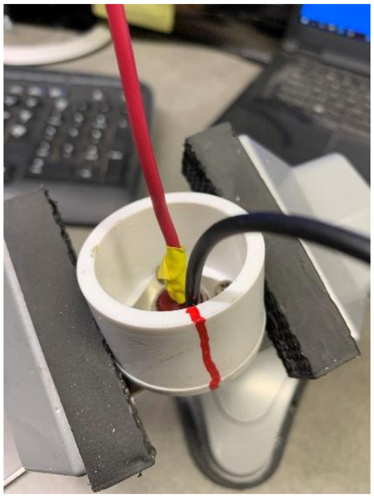
This brings up a question often asked but rarely answered: What is the maximum width a dipole gap can be? Probably the reason it is little discussed is because there is not much to answer. There is no theoretical maximum gap width but there are considerations that contribute to optimal operation.

To address the question of a maximum gap width it is important to recognize that the electrical wave that we place on the dipole is trans-conductional. While the wave certainly travels through the gap wires, the wave also travels trans-conductionally through the air of the gap in parallel with the wires. Therefore, the gap wires should be as short as possible without going to extraordinary means to make them short. It's okay to leave some slop but try to minimize gap wire lengths.

Make a mark of some type to index the location of one of the gap wires. In the illustration you can see a big, fat red mark. This will be very important when it is time to insert and cement the feed point into the tee. In this way you will be able to positively align the hub such that each wire will be at a position closest to one of the tee connector outlets. In this way the wires maintain a maximum distance from each other. Without attention to this detail, it would be easy to cross the wires inside the tee connector where they are unseen or difficult to see. Such a condition would degrade the performance of the antenna.

Insert and cement the feed point into the tee hole of the antenna hub. When doing so, align the score mark you made earlier with either one of the outlet holes. In the illustration you can see the red score on the left side. This tells us that the black wire will be routed through the left hole and the red wire will be routed through the right hole. In the illustration the red wire can be seen exiting the right hole.

Try to keep the gap wires of the same length. While there is no electrical advantage, it will help avoid confusion in your calculations later.



Mark in some way either side of the hub corresponding with one of the wires.

Next, consider the right and left exit holes through which each of the gap wires has been routed. We drilled 7/32” holes in each outlet so that cable tie straps could be looped through them. Later, these will be used to attach each antenna ¼ wavelength element to. To add a mechanical advantage, several mini cable straps were looped around each strap.

Each of the two gap wires were routed through these cable straps in such a way that there would be a minimum of looseness inside the hub and such that another mini cable tie could be used to lash each gap wire to the edge of the pipe. In this way the gap wires are unlikely to shift position.

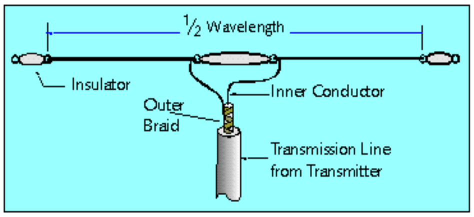
We’ve now completed building a hub that is fundamentally universal as far as what frequency antenna it is going to be used for. With some limitations, this hub can be used for any frequency that the antenna will be designed for. The main limitation is that there is a maximum frequency it can be used for. This is because of the gap wires which contribute directly to what the resonant frequency will be.

But before we can even begin a dipole antenna build, we must first define what amateur radio band the antenna will be expected to work. The hub we have discussed so far is somewhat independent of the frequency the antenna will serve. Its major limitation is that it will only be practical to use for frequencies up to maybe possibly 2 meters as noted earlier.

We will symbolize the operating frequency as f_o.

STEP 1: Pick a frequency that the antenna will be expected to operate at, f_o:

f_o=14.1875 MHz.



STEP 2: Find the half-wavelength for 14.1875 MHz:

$$\lambda/_2 = \frac{299.792}{14.1875} 0.5 = 10.56536\, meters = 34'\, 8\frac{1}{4}"$$

STEP 3: Determine the applicable velocity factor.

Assume a velocity factor: vf = 0.86

If we were using copper hookup wire of some type the velocity factor would likely be closer to 0.95 but in this build project we will be using ***agriculture electric fence wire***. This has been measured to have a velocity factor of 0.86.

STEP 4: Make and accounting for the gap wires. Each gap wire has been measured at:

11 inches = 27.94 cm = 0.2794 meters

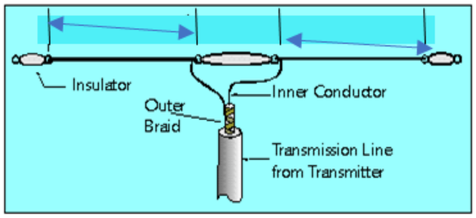
It will be important to remember that this gap wiring contributes DIRECTLY to the overall half-wavelength of the antenna. Remember that the end-to-end length of the antenna must be a half wavelength. Therefore, each of the two antenna wires' lengths are supplemented by the gap wire length.

Our final antenna length will therefore be

- the first element length
- plus 27.94 centimeters
- plus the second 27.94 centimeters
- plus the other element length.

All of those together add up to a half-wavelength as we shall see later.

STEP 5: Solve for the length each of the two antenna elements must be. Because we are using agriculture's electric fence wire, this is a case where the 468 rule found on the FCC amateur exam question pool goes out the window. It doesn't work.



Each of the two elements of the dipole must be a quarter wavelength less an allowance for the gap connection wires.

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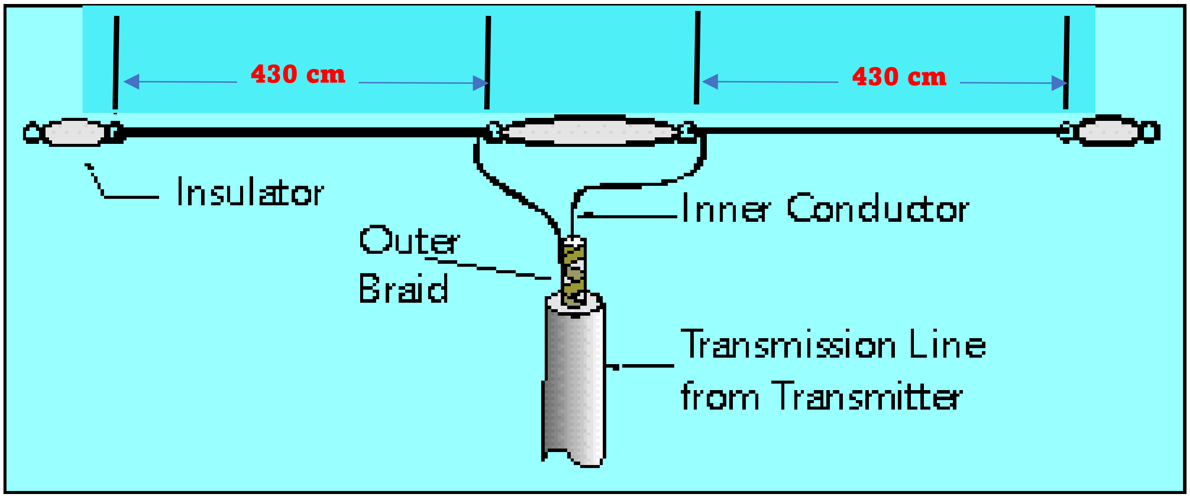
$$element\ length = \left\{ {}^{\lambda}/_{2} - len_{gapw} 2/vf_{gapw} \right\} \frac{vf_{braid}}{2} = \frac{\left\{10.565 - 0.28 * \frac{2}{0.95}\right\} 0.86}{2} = 4.302m$$



A fully configured dipole antenna for 14.1865 MHZ, using agriculture electric fence wire and a gap connection wire length of 28 cm, will have each element of length 430 cm.

The two wires were constructed using agriculture electric fence wire. The photo below on the right shows that each wire measured 431 cm. Note that the missing couple centimeters was on account of the other end of the element where the tape measure was placed at its tail.

Let us mention at this point that a balun or choke was not used in this project. In theory, an optimized dipole would have an impedance of 73 Ohms while a coax transmission line has only 50 Ohms characteristic impedance. This is not much of a difference but a balun could correct for it further optimizing the antenna. The other purpose of a balun or choke is to block RF energy from returning down the transmission line. This would only happen if the antenna were NOT resonant or had a serious impedance mismatch. However, a balun or chock would be advised nevertheless if the antenna were intended to work harmonics. When working harmonics we start getting slight mismatches and would see some, though small, RF energy coming back down the transmission line.

So, the next step was to assemble the dipole and make it operational.

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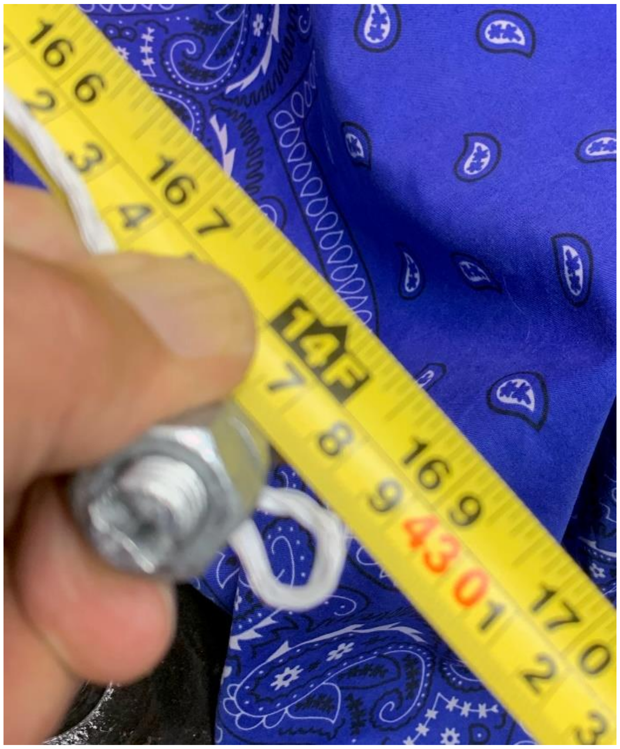
Shown above are the two dipole elements fully assembled and precisely cut to length. SPECIAL NOTE: Do not overtighten these lugs. Tighten them down finger tight and then an additional half-turn with a wrench. These things are mere cast iron and will easily rupture with too much torque.



Each dipole element wire was carefully measured to see that its length matched what was earlier solved for. Note that while we were looking for 430 cm the pictures shows only 329 cm. The other end of the element also had a lug as this end which was not included in this measurement. This accounted for an additional 2 cm so the total actual length here was 431 cm.

Measuring the vector impedance at 14.187 MHz we see as shown in the picture on the right that we are right on the money, dead center for having the antenna have a neutral reactance. The vector impedance was measured as:

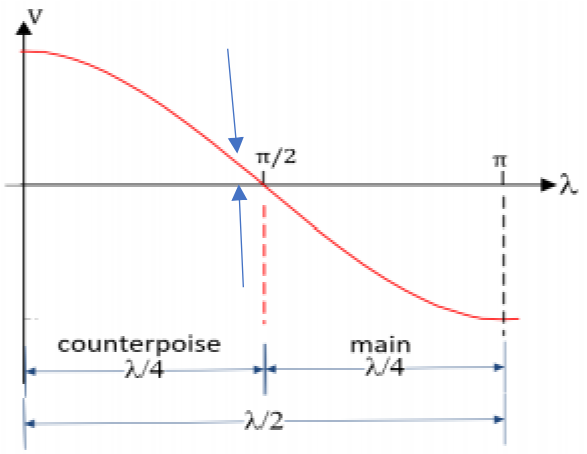
16.7 -j0.5 Ohms

While the reactance has been properly nullified (anything less than 1 Ohm reactance is called zero), the real impedance vector is severely low which will result in a high SWR and a reflected wave. It will be necessary to transform the real portion to 50 Ohms by means of a 3:1 balun. The likely cause for this is the proximity of the gap wires to the PVC housing.

To circumvent the limitations we can include a balun (balanced-to-unbalanced) transformer inserting it between the antenna feed point and coax feed cable. But this antenna feed-point has already been constructed so that adding a balun is not practical for this point in the project. But baluns are a subject for another discussion. We will now try a clever trick to circumvent the problem of a low resistance.

Why is it that a classic dipole is center-fed? It is center-fed because that is where the voltage is a minimum and we are most likely to find 50 Ohms. How then would we increase the real portion of the vector impedance? We can change the dimensions of the dipole elements so as to change the feed point so that it is no longer centered. That means the the voltage will be increased and the real impedance will in turn increase. However, it is critical to maintain the same overall antenna length. Therefore, we will shorten one element and lengthen another.

In the illustration on the right we can see that at the center, the voltage passes through zero. According to Ohms Law, what is the resistance whenever the voltage is zero? Ordinarily the answer is zero but in this case it is more correct to say that the resistance is relatively low. Therefore, when we move the feed-point off center in either direction, the voltage increases and therefore the resistance increases.



The question now is, how much or what percentage should we move the feed-point off center? We don't have any hard numbers to solve this question with but we can estimate. Let us assume that the real resistance at the antenna ends is 5,000 Ohms where the voltage is by definition a maximum. For the center, let us say zero Ohms just as a gross approximation but the actual answer is that it is low relative to the impedance at the ends. But the weak point here is our assumption of 5,000 Ohms. It could be as low as 2,000 Ohms or as high as 10,000 Ohms. Therefore, this is our educated guess.

Let's take an analytic approach to define what limits there are that we have to operate in for this center-point shift procedure.

Our measured vector impedance is 17 – j 0.5 Ohms. The objective is to pick off 50 Ohms instead of 17 Ohms. What percentage of feed-point shift is a good estimate? To keep things simple, let's figuratively split it up into one hundred segments in a linear fashion. One may be inclined to formulate a non-linear approach considering the nature of a sine wave. However, while the voltage increases as we move the feed-point away from the center, the current is decreasing in a corresponding non-linear fashion. The result is a linear slope.

Five thousand Ohms divided by 100 nets 50 portions or portions. If this relationship is reasonably valid, it means that for every 1% of center-point shift that we will see a 50 Ohms increase while the reactance will be unchanged.

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On the practical side of this center-point shift procedure, there is only so much accuracy that we can shift it by repeatably. Assume that plus and minus 1 centimeter is the smallest increment that the center-point can be shifted with any accuracy and repeatability.

What percentage does 1 centimeter of feed-point shift correspond to? In other words, what is the smallest percentage increment that we have to work with? We have each of the two antenna elements at 430 cm (0.430 m). 1 cm represents 1/430 or 0.23% which is an incremental factor of 0.0023.

How does 0.23% relate to each element length? If moving the center point by a minimum of 0.23%, that is the same thing as moving the center-point by 1 cm. 430 times 1.0023 is 431 and likewise, 430 minus 0.23% leaves 429 cm. But, what is the sum of 429 and 431? It is the same as the sum of 430 plus 430. The elelectrical length has not changed meaning that the antenna resonant frequency has not been moved but the real impedance will increase.

Our objective is to increase the resistance by 33 Ohms. Therefore, less than 1% of center-point shift is required. A 1% shift, according to our assumptions would produce an increase of 50 Ohms (0.01*100*50) for an increased resistance of 67 Ohms which would be perfectly fine.

Here are the new element lengths facilitating moving the feed-point:

426 cm and 434 cm

We are removing 4 cm from one element and adding that 4 cm to the other element so as to create an off-center fed dipole. In reality, however, this is still considered center-fed and will likely work fine on the harmonics.

If we were to shift the feed point off-center by 1.25 we would expect to see the real impedance jump to 60 Ohms. But the important part is that while we have adjusted the real portion of the vector impedance, the reactive portion will not have shifted. It will remain neutral.