Waves & Coffee –
The electron drift velocity
How do electrons move in our antennas?
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Possibly the most critical component of our ham radio station is our antenna. This device acts as a coupling interface which attaches our station to the atmosphere or whatever medium we are transmitting our signals through.

A valid question that hams ask is, what causes the radiation of electro-magnetic waves in our antenna. Well, the stock answer is that it is due to moving electrons in the metal of our antenna. But is there more to the story?

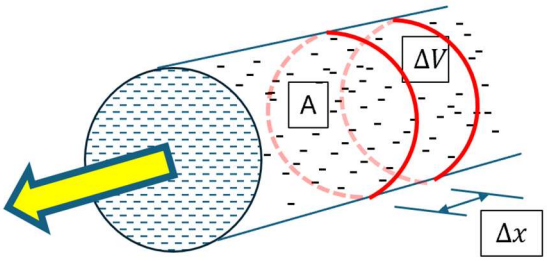
As usual, we resort to our physical intuition to begin our answer to the question.

First, we observe that there seem to be a couple of things going on in our antennas: 1). electrons move, or drift, in response to an applied voltage and 2). Our HF radio signal propagates out from our antenna at close to the speed of light c.

OK, so electrons are sloshing from one end to the other in the metal of our antenna element and that gives rise to the electromagnetic wave coming from the antenna. That wave then propagates out at the close to the speed of light. But, if the electrons *themselves* are moving at close to the speed of light, won't Einstein's special relativity affect them?

Let's look at the physics of what's going on. First, we'll model a potential difference, or voltage, in our antenna while we transmit our ham radio signal. Say we're using a dipole antenna; we'll have a high voltage at the end which drops to zero at the antenna feedpoint. If we freeze that quarter wave of voltage in time, we can model the electrons getting pushed to one extreme of the antenna element by the potential difference.

Looking closely at our metal segment, we see that we'll have free electrons filling up our wire. We can then consider a crossectional volume in the middle of our wire. The volume will cut the wire into the shape of a cylinder. In that volume, we'll have many electrons that are free to move throughout the cylindrical volume since it's metallic. We'll choose to make the volume element small; therefore, the electric charge contained in it will also be small. Let's sketch a picture of that small segment of our antenna wire so it makes more sense.



A = Wire cross-section
ΔV = volume element
Δx= length element
= current density

The electric charge Δq in the small volume ΔV will be equal to the number of electrons N multiplied by the charge of each electron e. We write this as follows:

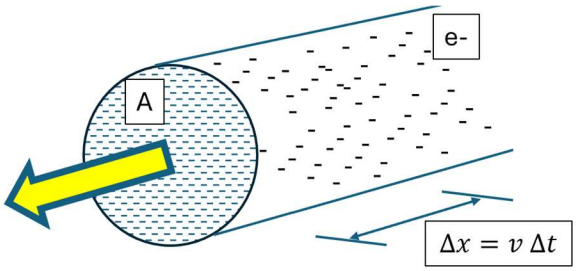
$$\frac{\Delta q}{\Delta V} = Ne \quad (1)$$

But the volume element that contains that amount of electric charge can be expressed as the crossectional area A times the length of the wire element, in this case Δx,

$$\Delta V = A\,\Delta x \quad (2)$$

With this new expression in hand, we insert equation (2) into equation (1) and simplify a bit,

$$\Delta q = Ne\,A\,\Delta x \quad (3)$$



A = Wire cross-section
e- = electrons
Δx= distance of travel
= current density

The length of the wire element, Δx, can be expressed in terms of the velocity v and the time interval Δt,

$$v = \frac{\Delta x}{\Delta t}$$

Which rearranged gives,

$$\Delta x = v\Delta t \quad (4)$$

Again, with this new expression in hand, we insert equation (4) into equation (3), and get,

$$\Delta q = Ne\,A\,v\Delta t$$

Here v refers to the velocity of the electrons in the wire which is called the 'drift velocity' of the electrons and is referred to as v_d.

Next, we divide both sides by Δt,

$$\frac{\Delta q}{\Delta t} = \frac{Ne\,A\,v_d \cancel{\Delta t}}{\cancel{\Delta t}}$$

We cancel the Δt on the right-hand side and notice that the left-hand side is charge divided by time, which is the definition of current,

$$I \equiv \frac{\Delta q}{\Delta t} = Ne\ A\ v_d$$

Solving for v_d,

$$v_d = \frac{I}{NeA}$$

We plug into this expression typical numbers for a copper wire (atomic weight & density of copper, radius of an 18 AWG wire, Avogadro's number, and the charge of the electron),

$$N = \frac{6.02\ x\ 10^{23}}{\left(\frac{63.5\ x\ 10^{-3}\ \frac{kg}{mole}}{8960\ \frac{kg}{m^3}}\right)} = 8.5\ x\ 10^{28}\ \frac{electrons}{m^3}$$

$$e = 1.602\ x\ 10^{-19}\ \frac{C}{electron}$$

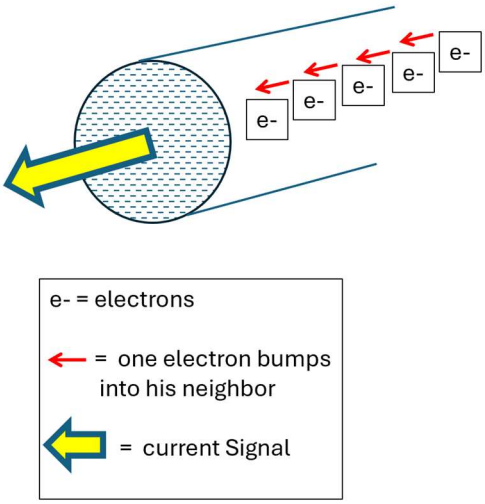
$$A = \pi(0.5\ x\ 10^{-3})^2 = 7.9\ x\ 10^{-7} m^2$$

$$I = 2.0\ Amp$$

This gives the drift velocity of the electrons as,

$$v_d = 0.0001859\ m/sec$$

This is $0.19\ mm/sec$ which is ***very, very*** slow!



So, we've seen that the drifting electrons in our antenna are not moving at close to the speed of light.

However, the electrons in a conductor don't have to move that fast, or that far. They only need to *electrically bump* into their next-door neighbor to pass along the charge. That *moving charge* is what radiates our HF at close to the speed of light! Thank those moving charges for our QSOs!

Lastly, we observe that since the drifting electrons *themselves* are not moving at close to the speed of light, Einstein's special relativity won't affect them noticeably.

Bibliography

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Physics with Professor Matt Anderson YouTube channel
https://youtu.be/i_GYP77vgCQ?si=Hs_k9U86qWBCTqaj