Antenna Magic

How do Antennas Work?

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How Much do We Really Understand?

- I recently concluded that much of what I accepted about antennas, I did not really understand.
- I decided to investigate and see if I could improve my understanding.
- I was not able to find satisfactory explanations in the books I have nor on the internet—just bits and pieces that needed to be assembled to improve my overall understanding.
- I want to share the results with the group with the intent to help further our understanding of the magic that happens in the antenna.

Examples of "Magic" in Antennas

- Current flows in an open circuit
- Resistance appears where there is nearly none
- Radio signals jump from one antenna to another through free space

- I will try to explain these phenomena, and more, without getting too technical or using too much math. Yes, I know that *any* math is too much math.

Two Fundamental Concepts

- Field: a region or space where a given effect exists.
- We will talk about both electric and magnetic fields.
  - Electric field is caused by a difference in potential charge (voltage).
  - Magnetic field is caused by current flow. Permanent magnets are not of much interest in this discussion.
- Wave: a disturbance or variation that transfers energy progressively in a medium.
  - Magnetic waves caused by changes in the magnetic field.
  - Electric waves caused by changes in the electric field.

Current Flow

- From basic circuits, we know that when there is no complete circuit current does not flow.
  - Open a light switch and the light goes off because you interrupted the circuit.
  - A straight piece of wire connected to only one terminal of a battery will not conduct any current.
  - You need a complete circuit for current to flow.
- What about a dipole antenna?
  - We know that current flows in the transmission line and into the antenna.
  - So where is the complete circuit that must exist?

Voltage

- Voltage is the potential that causes current to flow in a complete circuit.
- Voltage is essentially the same measured any place along a piece of wire.
  - This is true for direct current (DC) and large (low resistance) wire.
  - It is not as true for alternating current (AC) due to the effects of capacitance and inductance.
  - Radio is AC; really high-frequency AC.
  - The higher the frequency, the less true the statement is about constant voltage.

Voltage Applied to Dipole

- If we connect a battery to a dipole antenna, not much appears to happen.
  - What does happen is that one element takes on an electric potential charge opposite of the other element and equilibrium is achieved.
  - Each element is surrounded by an electrostatic field.
  - In other words, one element goes positive and the other element goes negative.
- Now reverse the battery so the opposite polarity is applied to each element.
  - The electrons (negative charge) will rush to the opposite side to achieve the new electric potential equilibrium.
  - The movement in electrons is caused by the changing electrostatic field surrounding the element.

Example of electrostatic attraction.

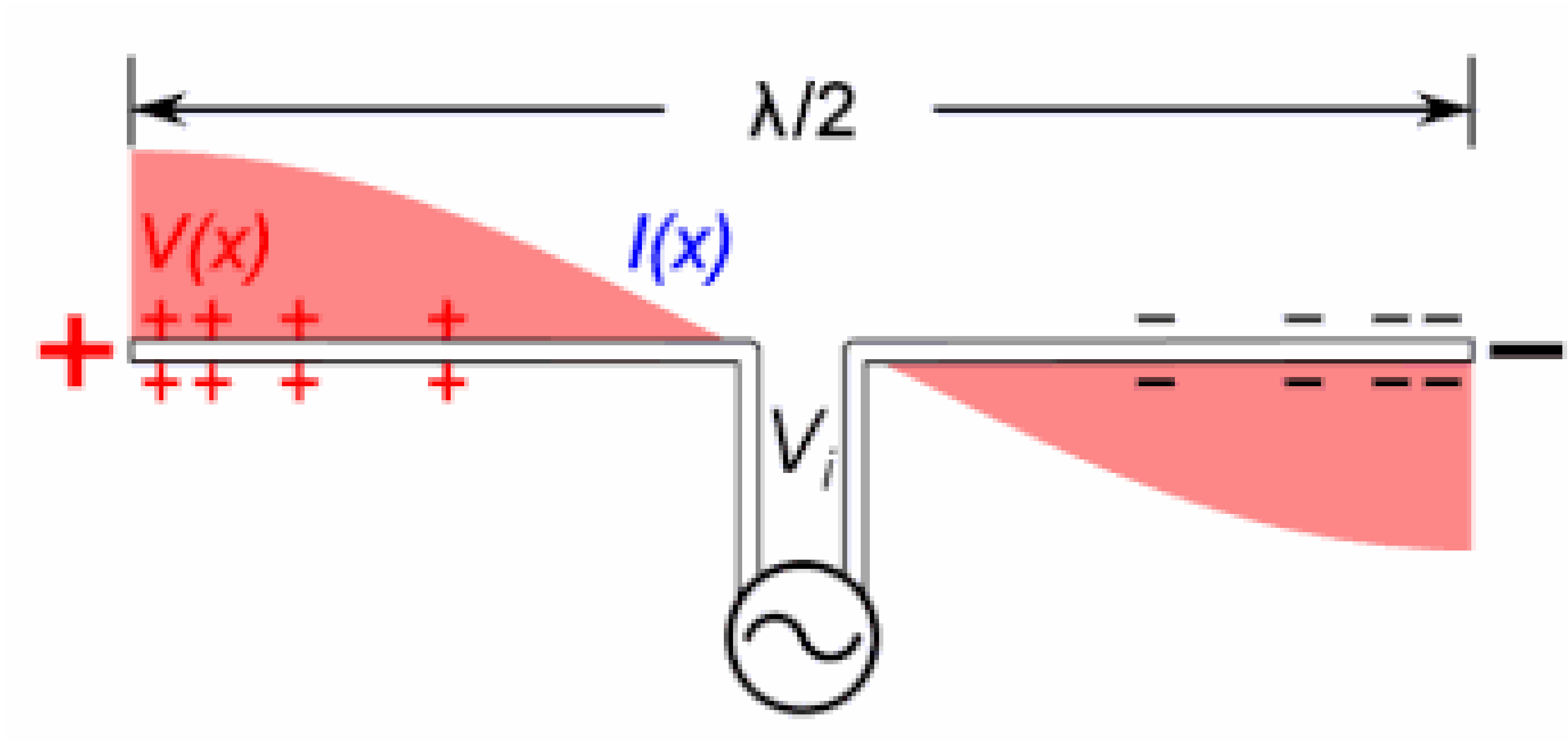
Current Flow

- If we change the applied potential back and forth (oscillator), the electric charge (electrons) will rush back and forth along the elements.
- This movement of charge is current flow.
- 1 ampere = flow of 6.24×10^{18} electrons/second.
- 6.24×10^{18} = 6,240,000,000,000,000,000. That is a lot of electrons!
- While the movement of electrons is a useful concept, it is not quite accurate. The electrons do move, but at a substantially lower velocity than the effect of the force causing them to move.
- The effect of force is what moves at the speed of light, or roughly 300×10^6 meters/second.

Current and Voltage in a Dipole

- Now that we have discussed the voltage applied to a dipole antenna and the current flow that follows the voltage, we can take a look at the relative distribution of current and voltage over a *resonant* dipole.
- Notice the wave-like motion in the following illustration where the voltage is represented in red and the voltage in blue.

Current and Voltage in Dipole



Waves make it all work

- We have all heard of radio waves.
- The interesting thing about wave theory is that all waves whether light, electric, or mechanical behave similarly.
- In 1959 Dr. John Shive invented the Shive wave machine.
  - This machine demonstrates the behavior of mechanical wave motion.
  - Since all waves behave in a similar manner, this can give us insight into electrical (and other) wave behavior.
  - Absolutely the best visual demonstration of wave phenomena because you can see it!

Voltage In the Dipole

- In the previous illustration, we saw that the voltage was at a peak at the end of the dipole.
- The end of a wire represents a free boundary to reflect the voltage wave.
- When the element is $\lambda/4$ long, the voltage wave will reflect constructively over its entire length.
- The Shive wave machine demonstrates this concept.

Free Reflection

- Video has been removed

Current in the Dipole

- In the illustration we saw that current is at a minimum (node) at the end of the dipole.
- For a resonant dipole there is no reflected current since the end is at a node.
- What if the dipole is not resonant?
  - There would be reflected current.
  - The reflected current would be a mirror image and would subtract from the forward current because the end of a wire represents a closed boundary to current.

Closed Reflection

- Video has been removed

Resonant Antenna

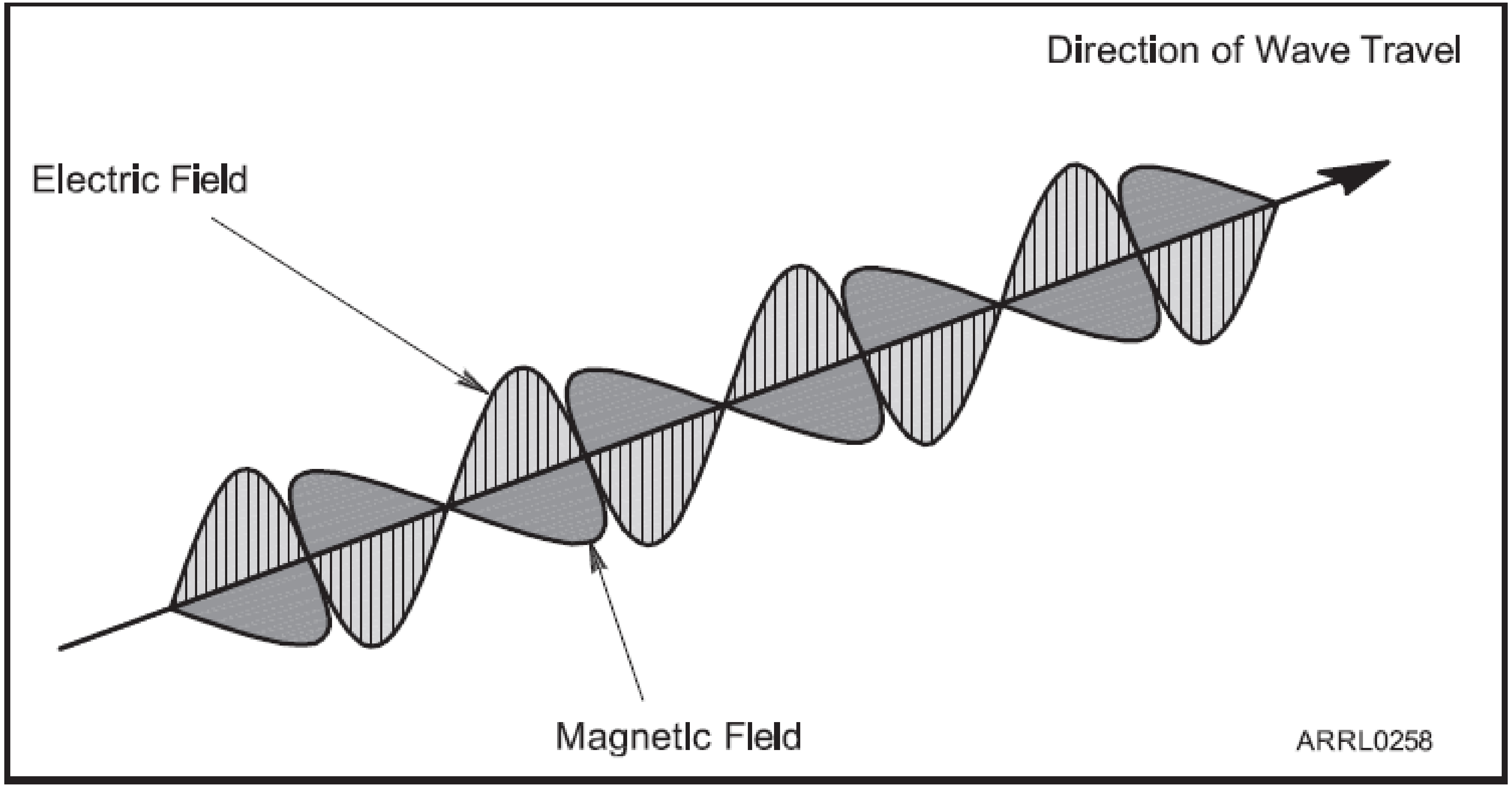
- We can see the importance of resonance and why a dipole antenna does not work well when we are far from the resonant frequency (or an odd multiple thereof).
- When the antenna is operated off resonant frequency:
  - The current wave is reflected in a destructive manner.
  - The voltage wave is still a positive reflection, but it does not add over the full length of the element.

Radiation

- Now that we have looked at the voltage and current relationship in the dipole, we can explore how it radiates.
- Any time we have current flow in a conductor, a magnetic field is caused around that conductor.
- The alternating current in the dipole causes an alternating magnetic field around the wires along with its associated electric field.
- We may recall that radio waves are electromagnetic waves consisting of alternating E-fields (electric) and alternating H-fields (magnetic), with a right angle displacement between them.

Electromagnetic Wave

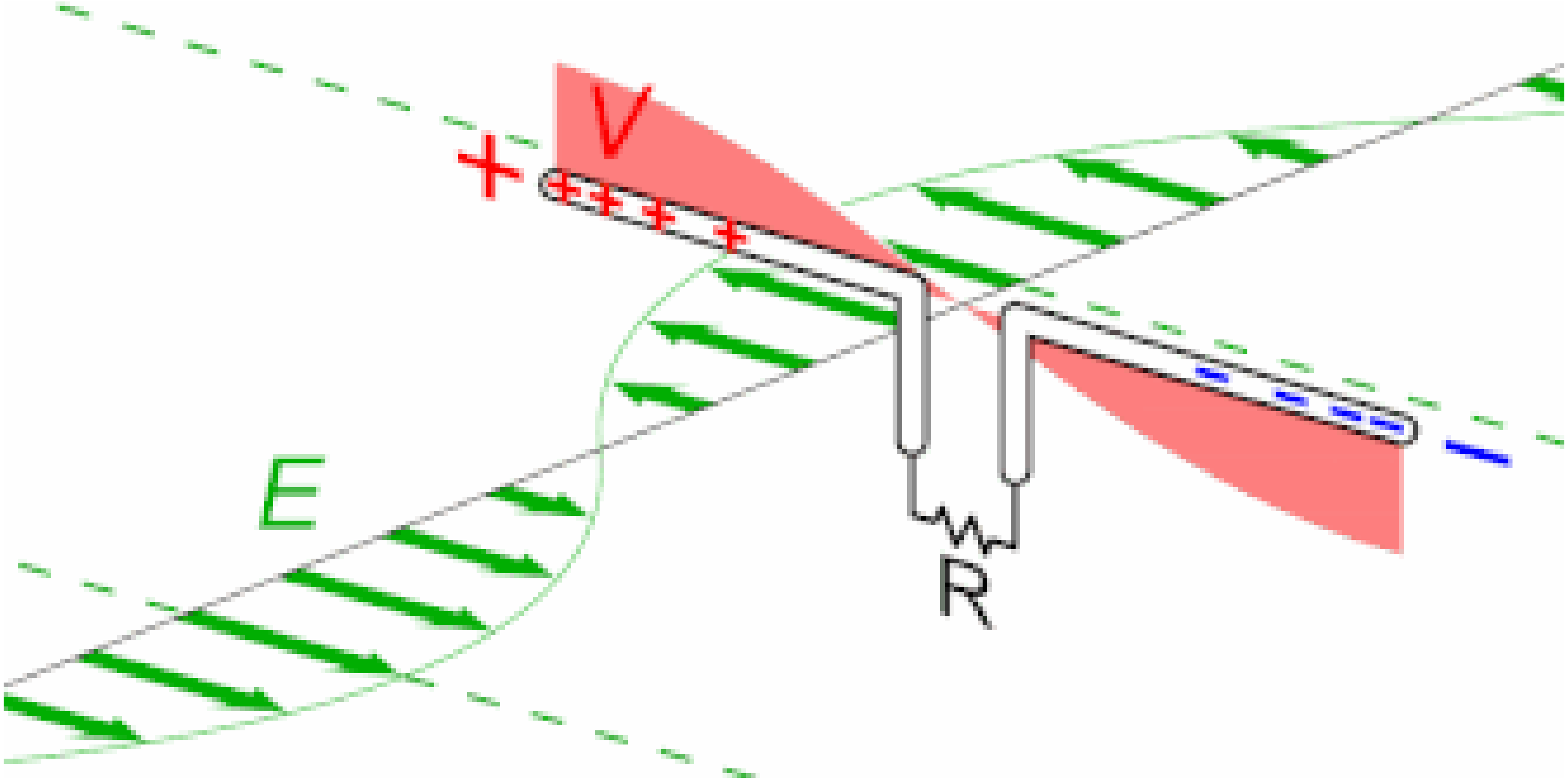
From ARRL Antenna Book 23rd Ed.



Reciprocity

- So far we have been talking about antennas used to transmit radio waves.
- In general an antenna that transmits well will also work well to receive.
- The process is just the reverse—the alternating magnetic field induces (causes) an alternating current to flow in the antenna element.

Reception



Radiation Resistance

- This one is a little more difficult to explain. An internet search will turn up equations involving calculus and I promised very little math.
- The “hand waving” explanation is that in electricity, for any real work to happen there must be resistance in the (equivalent) circuit.
  - The real power transfer from your transmitter to the antenna has to be resistive.
  - Similarly, the real power transfer to free space must be resistive.
- The ability to transfer power is radiation resistance and the antenna is purely resistive when the antenna is operated at resonance.

Additional Reading

- Zavrel, Robert J. Jr. *Antenna Physics: An Introduction.* ARRL, 2016.
- Caron, Wilfred N. *Antenna Impedance Matching.* ARRL, 1989.
- *ARRL Antenna Book, 23rd Edition.* ARRL, 2015.
- *AT&T Archives Similarities of Wave Behavior (Bonus Edition).* https://youtu.be/DovunOxlY1k