
Displacement Current *The Final Puzzle Piece*

By
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Miller's Proposition

“When AC is applied to a capacitor, the near-surface electrons contained in the plates alternately move toward or away from the surface. Since electron movement ALWAYS is associated with a magnetic field, it is this mechanism -- not Displacement Current -- that permits Maxwell's equations to function.”

Introduction: At least three years ago, I became interested in what was represented as a new class of antennas. Included in this new class were antennas such as the CFA, Lal and EH. All shared a common trait. They all claimed to use the magnetic field associated with Displacement Current (as found in one of Maxwell's equations) to help generate antenna structures that were highly efficient and volumetrically compact.

My own measurements yielded different results. The same was true of virtually all independent tests. Clearly, something was wrong! And that “something” led me on several years of investigation.

Two-plus years ago, I published the two-part *antenneX* article, “Displacement Current Does Not Exist.” (Please see the appendix for links to the articles in *antenneX*.) In this article, using transmission line theory, I showed that the major characteristics of a capacitor -- including the exponential charging rate -- could be replicated using the characteristics of a parallel plate transmission line. Displacement Current was not required.

But the article left the following issues unanswered:

1. *How to explain the presence of a magnetic field associated with the inter-plate E field.*
2. *Maxwell's adaptation of Ampere's law can be stated as: $\nabla \times H = J + \frac{\partial D}{\partial t}$ But, if there is no Displacement Current, how can time-varying fields be supported?*

About a year ago, I was able to resolve issue #1 in my article, “How A Capacitor Really Works.” (Please see the appendix for links to this article in *antenneX*.) *Please note that there is one serious error in the article. I assumed perfect (imaginary) conductors, whereas Miller's Proposition is only applicable for real conductors such as Copper, Aluminum, etc.*

Here is a (very) brief synopsis. When voltage is applied to a capacitor, near-surface electrons migrate toward (or away from) the inside surfaces of the capacitor plates. The migration direction depends on the polarity of the applied voltage. Since electron movement is ALWAYS associated with a magnetic field, it is apparent that this near-surface electron movement is the probable source of magnetic fields in a capacitor. Displacement Current has nothing to do with it!

However, this solution added an additional unanswered issue:

3. According to my analysis, the magnetic fields inside a capacitor should cancel except at the rim. Instead empirical evidence shows that magnetic fields produce concentric “rings” of magnetic flux whose shape is identical to that of the perimeter and are centered on the geometric center of the plates. Why?

In my article, “Some Thoughts On Maxwell’s Equations and Radiation,” I attacked issue #2. (Please see the appendix for links to the article in antennex.) By looking at conduction currents at the charge level – a luxury not afforded Maxwell – I show that there are TWO types of current: Longitudinal (the traditional current) and Orthogonal. (Please note that I called these “Transverse currents. I now believe that Orthogonal is more descriptive.) Each of these currents has a magnetic field associated with it. Orthogonal currents are extremely small except at the plates of a capacitor. At that point, they are the ONLY source of current flow, and their motion generates the magnetic field that has been previously attributed to Displacement Current.

Magnetic Fields In A Capacitor

In order to provide a convincing argument that Miller’s Proposition is correct, the remaining puzzle is how to explain issue 3. To do this, we must understand HOW electricity flows into a capacitor. And to help us, let us draw on our knowledge of transmission line principles.

Shown below (**Figure 1**) is a rather unusual configuration of a voltage source, a pair of source resistors, and a coaxial transmission line.

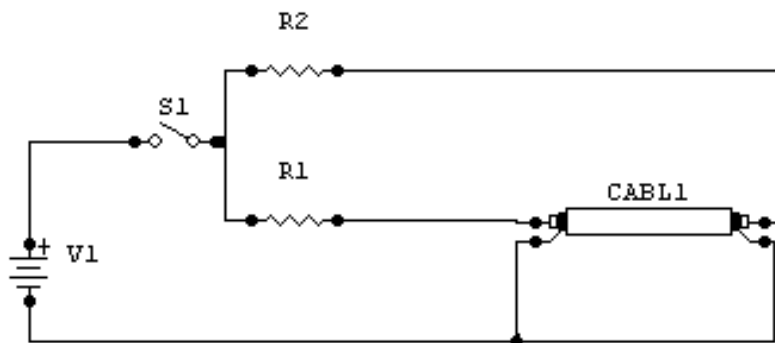


Figure 1. Dual Driven Coaxial Cable

In the example above, $R_1 = R_2 = R$. CABL 1 is coaxial cable with a characteristic impedance of Z_0 and a length, L . We assume that the coax is much longer than the equal length hookup wires. The time it takes for a signal to travel from one end of the coax is T , where $T = \frac{L}{c}$ and c is the speed of light in the medium.

When the switch, S_1 is closed, a continuous voltage pulse V_1 appears at the input side of each resistor. On the cable side of those resistors, a voltage division occurs between the source resistance R and the cable's characteristic impedance Z_0 . The result is a cable

$$\text{voltage, } V_c = V_1 \frac{Z_0}{R + Z_0}.$$

At time $T/2$ the leading edge of each of the two voltage flows will meet at the exact center of the cable.

At that point, a discontinuity occurs. The leading edges have the same amplitude, but the sense of the current is opposite. The currents cancel, and the result is an expanding rectangular pulse centered at the middle of the line and with amplitude of $2V_c$.

When this pulse arrives at the source resistor R , the resistor absorbs a portion, and a portion will add to the original V_c . (Please see Part 2 of "Displacement Current Does Not Exist" for a detailed explanation of how this works.) These two augmented voltages will flow into the cable until they meet at the center. At that point, the previous process repeats indefinitely.

The effect is an exponential charging of the coax to its final voltage, V_1 .

Now that we understand what happens when we feed a transmission line at both ends, let's replace the coax with a parallel plate line. That way, we can "look" at the fields inside the line.

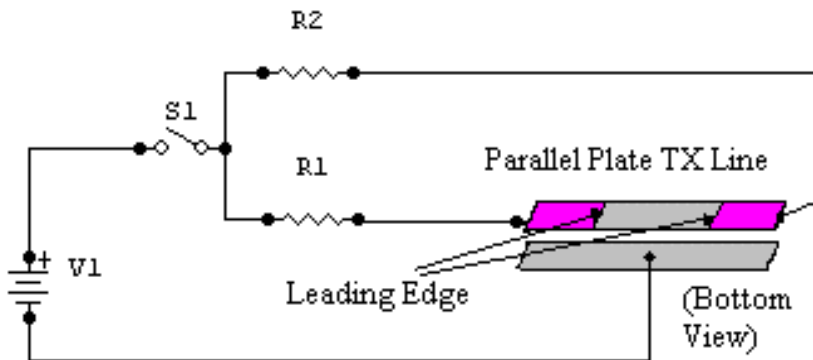


Figure 2. Dual Driven Parallel Plate Transmission Line

In **Figure 2**, if the width is W , we assume that $W \ll L$. Also, if the gap between the plates is G , then $G \ll W$.

As in the case of the coaxial cable, when $S1$ closes, a voltage pulse begins flowing from both ends of the transmission line towards the center. The leading edge of this “chunk” of voltage is parallel with the narrow side, W of the parallel plate and perpendicular with the long edge of the plate, L .

As the leading edge of the pulse passes over the plate, near-surface electrons will be “pushed” toward the metal’s interior, thus making the surface more positive. A similar effect will be found on the opposite plate. However, electrons on the opposite plate will be “pulled” toward the surface, making it more negative.

As before, when the pulses meet at the center, a rectangular pulse will be formed and will flow back to the source. The same interactions as before will occur.

Now that we can “see” what is going on in the plates, let us consider the consequences of this voltage pulse. Please recall that electron motion is ALWAYS associated with a magnetic field. Thus, at the leading edge of all the pulses, magnetic “lines” will form on each plate, and will follow their respective pulses toward the center of the transmission line – AND BACK!

For simplicity, the next 3 diagrams will show just one side of the line. But we must not lose sight of the fact that both sides of any parallel plate device are active.

Let us now construct a slightly different transmission line, as shown below.

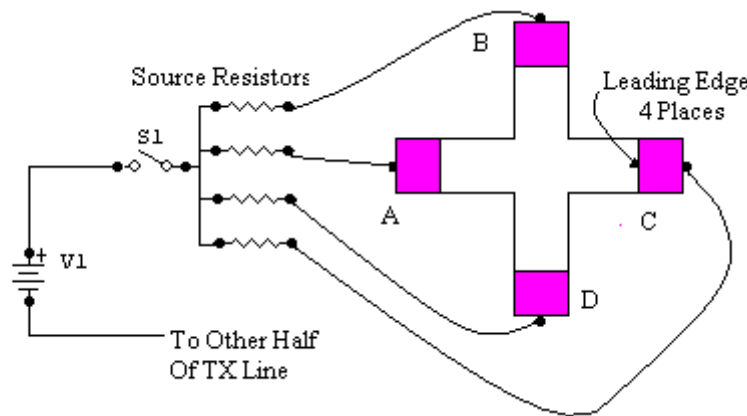


Figure 3.. Cruciform Transmission Lines

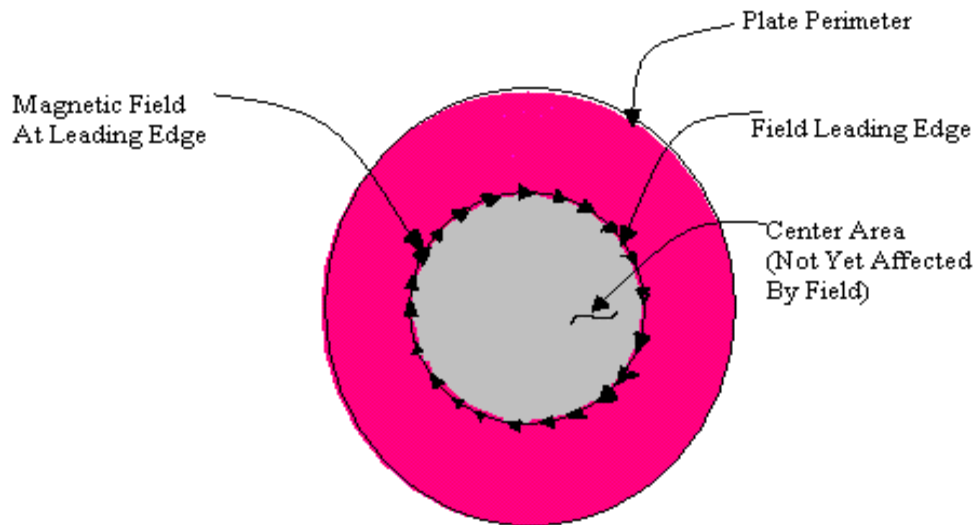
In **Figure 3** above, we have added an additional set of parallel plate transmission lines at 90 degrees to the first set. In this configuration, we have FOUR feed points and FOUR identical pulses that travel toward the center.

When the pulses arrive, Voltage Pulse A will interact with Pulse C, and Pulse B will interact with Pulse D. Associated with those four pulses will – as before -- be four sets of magnetic lines. These interacting pulses will also generate two different sets of rectangular reflections as in the previous examples.

It does not take too much imagination to move to an asterisk-shaped transmission line constructed with another four lines. The results will be the same: Pulses enter, meet their counterparts at the center, and form rectangular pulses that move back to the source. But why stop there? Why not continue to add elements until we have a circular shape?

Such a circular transmission line shape is well known. However, in all the analyses that I have seen, it is the center that is driven (via a small hole) and the edges are either terminated or left open. In this embodiment, the center hole is shorted and the EDGES are driven.

What does one of the plates on such a device “look” like when viewed from the opposite plate? It looks like this:



View Of Circular Transmission Line Plate

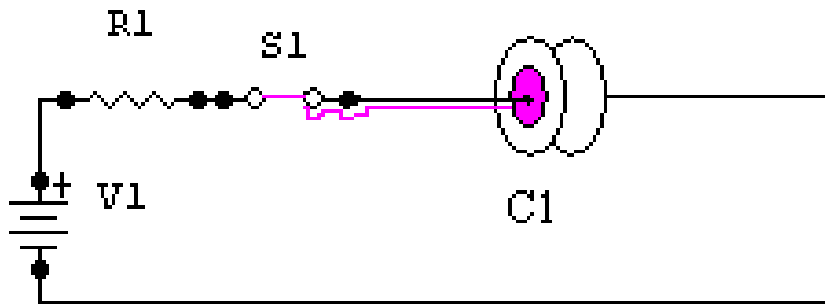
Figure 4. Circular Transmission Line Fed At Perimeter

In **Figure 4**, the individual fields have merged into a uniform field, and this field is headed toward the center of the plate. Note also that the leading edge of the energy field has the same shape as the perimeter. Of particular interest, note that the magnetic field associated with orthogonal electron movement at the leading edge of the field ALSO has the shape of the plate’s perimeter.

It should not be much of a challenge to recognize the similarity between a circular transmission line and a capacitor with circular plates.

BUT in the classical representation of a capacitor, the conductors are connected to the OUTSIDE CENTER of the capacitor. Doesn't this connection mean that a circular capacitor is more akin to a Circular Transmission Line driven at the center?

To answer this question, let us look at a diagram showing such an interconnection.



Circular Plate Capacitor With Circuitry

Figure 5. Circular Plate Capacitor

Figure 5 illustrates the situation just after switch S1 has closed. The colored items illustrate the progress of the energy field as it moves to the right at lightspeed. Please recall that the conductors guide this field such that the field always follows the conduction path, no matter where it leads.

In the illustration, it has already reached the junction between the conductor and the capacitor. It has “turned the corner,” so to speak, and will soon flow to the outside perimeter of the capacitor, turn that corner, and will soon be in the same state as that shown in **Figure 4**.

What about the longitudinal current that might, logically, flow THROUGH the center of the capacitor and emerge on the other side? Please recall that the speed of electron flow in an excellent conductor is about 1 cm per second whereas the speed of energy flow is lightspeed! Unless the connection point and the capacitor's thickness are both infinitely short, the EXTERNAL energy pulse will make its way along the conductor, up the outside area of the plate, descend to the plate's center and be reflected back to the source long before the INTERNAL longitudinal flow even GETS TO the capacitor!

Obviously, energy flows ONLY from the perimeter of a capacitor to the center and back. This fact explains WHY the magnetic field associated with a circular capacitor is circular, and gives us additional insight – should we need it – into the shape of ALL magnetic fields associated with capacitors of arbitrary perimetrical shape.

Conclusion

In my articles, I have shown that a capacitor is nothing more than an open circuit transmission line. I have shown that TWO types of current flow always accompany energy flow, and that these types are: Longitudinal and Orthogonal. I have shown that each of these currents has a magnetic field associated with it. I have demonstrated that Amperes Law no longer needs a fictitious Displacement Current factor in order to explain AC current flow through a capacitor. In this article, I have shown that, in a circular plate capacitor, the magnetic field's shape is derived from the circular shape of the energy flow.

In short, I believe that I have satisfied all the criticisms (except one) that have been (correctly) aimed at my individual works in process.

The remaining criticism is: *Since Maxwell's Equations have been in existence for over a century, they are sacred and not subject to examination or change.*

I'm not sure I ever CAN answer that!

Mea Culpa: In the process of developing my proposition, I went down a number of paths that I should not have followed, in retrospect. Here are a few: In earlier works, I was sloppy in my choice of initial assumptions. In my initial article discussing Orthogonal Currents, I got the "sense" of the magnetic fields around the moving electrons exactly backwards! (Yes, I fixed it.) In one case, I completely mis-stated the characteristics of E (and H) fields in the non-capacitive structures. I also devoted more space in some of my articles to speculation about where my proposition might lead us.

For these errors and mis-statements, I apologize. I also offer my thanks to those who (sometimes gleefully) pointed them out.

Historical Note I am not the first to question the notion that Displacement Current was not the REAL explanation of how current moved through the "open circuit" of a capacitor. Oliver Heaviside was the man that "decoded" the immensely complex equation used by Maxwell, re-gauged them to simplify their scope, and restated them in the forms that we know today. In his book, *Electromagnetic Theory* (1893) Page 28, Section 30, he noted with regard to Displacement Current that Maxwell "cut the Gordian knot."

The significance of this statement is largely lost on today's engineers and physicists. But in Victorian times, a Classical History knowledge was expected of *any* well educated person.

When Alexander (The Great) entered the kingdom of Gordia, he encountered a huge rope knot in the town center. Whosoever could untie the knot, he was told, would be king. He was invited to try his hand. Instead, he drew his sword, and slashed the knot until it unraveled.

Classically educated people in Heaviside's time understood that "cutting the Gordian knot" meant, "to obtain the desired result without solving the problem." –30-

References

1. Miller, William C., KT4YE, "How a Capacitor Really Works," antennex Archive VII, article #14, <http://www.antennex.com/> .
 2. Miller, William C., KT4YE, "Some Thoughts on Maxwell's Equations and Radiation," antennex Archive VII, article #34, <http://www.antennex.com/> .
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Author's Biography [Email](#)

William C. (Bill) Miller holds a BSEE from the University of California, Berkeley. He has held Engineering, Product Management and Marketing positions with a variety of well-known companies, including Eitel-McCullough, Ampex, Schlage and Yale.



In the late 1980's he tired of corporate life. Bill and his Fijian-born wife, Sardha, now own a chain of floral shops in Charlotte, NC. In his worldwide travels, he became familiar with a wide variety of cultures. He speaks Spanish, French and Portuguese as

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Bill has been a licensed radio amateur since 1957 and holds an Advanced Class license with the call sign KT4YE. He is an active member of the GARDS, an International Group of compact antenna researchers.

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