Comments On Dr. McDonalds's Critique

By William C. Miller, KT4YE

Introduction In the January 2005 edition of *antenneX*, Professor Kirk McDonald (Professor of Physics, Joseph Henry Laboratories, Princeton University) took time to provide some comments regarding my article, "SOME THOUGHTS ON MAXWELL'S EQUATIONS AND RADIATION." I appreciate the time that he took, and some of his comments were very illuminating. In particular, I found his thoughts regarding initial assumptions to be very useful. So was his clarification of the charge distributions on capacitor plates.

However, some other aspects of the critique disappointed me. First, he made statements about some of my technical positions that were false or misleading. He then – naturally – demolished those claims. Second, he appeared to have misread the article, since some of his points appeared to have nothing to do with the issue at hand. I will touch on these later in this correspondence.

These could all be accepted as part of the normal give-and take of discourse if he had addressed the **key point** of my concept. For convenience, I will condense it into what I will call **Miller's Proposition** (Unfortunately, The Miller Effect is already taken!)**:**

> "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 equation to function."

But aside from a brief reference to an experiment involving transmission lines, my concept seems to not have been addressed in his critique.

What is all this about? For those that have not read my articles, nor participated in the (often lively) antenna-discussion list, here is a brief overview:

An experimenter, using readily available equipment such as a pith ball and thread, a magnetic compass, a coil of wire, ammeter, bar magnet, battery, etc. can readily verify the truthfulness of all of Maxwell's equations except one.

The equation that defies verification is Maxwell's re-statement of Amperes law. Even with state-of-the-art measurement apparatus and superconducting coils, verification of the mere *presence* of magnetic fields seems nearly impossible. Yet this equation is the basis of modern electromagnetic theory, especially as it relates to radiation.

This equation – in words – states that a magnetic field can come about as the result of conduction current (AC or DC) and ALSO as the result of a (non-physical) current commonly called "displacement current."

Professor McDonald – and others – have pointed out with academic precision that by re-arranging the equation one could, for example, re-state it as requiring that magnetic fields and/or electric fields "cause" displacement current.

But this begs the question. Technicians, engineers and – I assume – sub-doctoral physicists are being taught that Displacement Current **causes** magnetic fields. For example, here is an excerpt from an otherwise-excellent undergraduate textbook, *Electromagnetic Field Theory Fundamentals* by Guru and Hiziroglu:

> b) Because $\frac{\partial D}{\partial t}$ acts as a *source* for the magnetic field, a time-varying electric field creates a time-varying magnetic field."[1]

I urge those with similar undergraduate textbooks to look closely at your book's contents. It is likely that yours contains similar wording.

If my concept is correct, I maintain that the people who design, build and apply modern electronic equipment are being mis-taught.

Evolution of the concept

I have long been skeptical that Displacement Current is the source of magnetic fields – whether in a capacitor or elsewhere. This skepticism led to two articles and several – usually animated – "threads" on the antenna-discussion list.

On June 17, 2004, that list was considering a question that I had posed: Has anyone ever tested the concept of Displacement Current using reciprocity? That is, has anyone ever injected a magnetic field *into* a capacitor and gotten either a voltage or current *out* of it?

In the course of the discussion, Prof. McDonald made the following (excerpted) comments, that I will henceforth call "**Kirk's Teaching**":

> "There is a vast body of electrical engineering that depends on detailed understanding of the time dependence of charges on the surfaces of "capacitors" and other conductors… Part of this lore is reconciling the fact that charges in metals move very slowly (~ 1 cm/sec!) with the fact that charge and current DISTRIBUTIONS can change at the speed of light."
>
> He then went on to explain that, "When 1 Volt is applied, the charge on a plate is Q = VC = 1e-11 Coulombs = 10 million electrons. Now, the number of free electrons on 1 cm^2 surface of copper is about 1e15. So, to establish our 1 Volt on the capacitor, we need to have moved the electrons from 1e-8 cm^2 of the

> plate onto the wire. The maximum distance these electrons need to travel is sqrt(1e-8) = 1e-4 cm = 1 micron = 1/100 the width of a human hair. If the frequency of the AC voltage is 100 Hz, the required velocity of the electrons is only 0.01 cm/sec."

Please note that I concur completely with this concept. I have also seen it expressed in a number of other locations and by other professionals, but never quite so concisely. In my view, this idea — that the motion of near-surface electrons leads to energy transfer along conductors — is the only sensible idea to explain how SLOW electrons can transfer electricity at LIGHTSPEED. It is also consistent with the observation by many antenna discussion list participants that an antenna merely *guides* RF energy. The antenna itself does not radiate!

On June 20, I awakened at 3:00 AM with the realization that Kirk's Teaching held the answer to my frustrated search for an alternative to Displacement Current. As the surface electrons move toward or away from the surface, this motion must be associated with a magnetic field. This magnetic field is not accounted for in Maxwellian analysis of circuits.

But it *must* be accounted for if Kirk's Teaching is correct. And if Kirk's Teaching is NOT correct, then we would need to develop an entirely new – and equally sensible – explanation for how slow electrons can allow light speed energy transfer.

Starting with this rudimentary concept, I developed a series of articles culminating in the "Thoughts" article that Prof. Mc Donald has critiqued.

Comments on the critique

To follow along, the rigorously inclined may want to print out a copy of my article and Prof. Mc Donald's comments. Otherwise, following along may be much like attempting to follow a tennis match with your eyes closed!

Prof. McDonald gets off to a rough start before he even starts the critique, when he says, "The article… by Bill Miller… purports to give new insights into magnetic fields in low-frequency circuits that include a capacitor." Anyone that has read my articles should be aware that my interest is in Radio Frequency devices; NOT low-frequency circuits. If Prof. McDonald feels that my article differs in content from my obvious intention, I believe he has a clear obligation to state this deviation in a clear, cogent manner. Anything else is misrepresentation.

The numbers refer to the numerical points in Prof. Mc Donald's critique.

1. Prof. McDonald seems to be excessively concerned with my motives. This would be an excellent subject for a psychotherapist, but seems to have little place in the critique of a technical article. I am trained as an engineer, and – yes - we engineers tend to be *very* interested in the "why" of things. If we are not, we end

up with a Tacoma Bridge, Tower 4 or Soyuz 11 – to name just a few situations where "why" was inadequately asked or answered.

I was delighted to see, in the footnotes, that Prof. Mc Donald developed an alternative viewpoint that expresses B only in terms of J, x and t. It was disappointing, however that he did not expand or clarify this to show the 3-dimensional nature of the B term that is missed by the classical interpretation of Maxwell's equation.

2. I'm not quite sure that I understand Prof. Mc Donald's concerns. He seems to be returning to his worry about WHY things happen rather than discussing the merits of the same. In the case of the derivation he is discussing, it was adapted slightly from the previously mentioned text by Guru and Hiziroglu. [2] Perhaps these authors share my supposed "unease with intrinsic ambiguities?"

3. I thank Prof. Mc Donald for reminding me that in a truly perfect conductor, all currents are parallel to the surface.

If Prof. Mc Donald will look closer at Fig. 5, he will see that it has nothing to do with dielectrics, nor with polarization. Instead, it is a close-up view illustrating my understanding of Kirk's Teaching. I would welcome an alternate illustration if mine were inadequate.

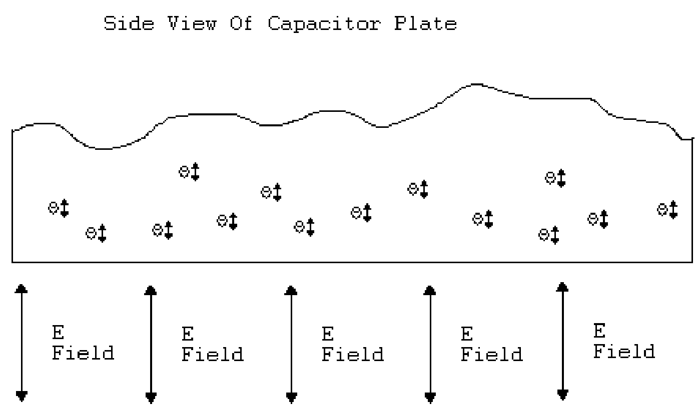

Figure 5 from my earlier article "Thoughts"

Finally, the phenomenon of sub-surface transverse current flow has nothing at all to do with eddy currents. Also, it is not surprising that his reference (Stratton) dismisses transverse current effects. In a transmission line, the primary means of energy transfer is longitudinal. Transverse currents, in comparison, are – as he notes – SMALL in comparison. However, in a capacitor, longitudinal currents vanish, leaving transverse (or as I prefer, orthogonal) currents as the ONLY mechanism for current flow.

4. Prof. McDonald's analysis of what happens on the inner and outer surfaces of a capacitor's plates addresses what is, indeed, a fascinating subject. Unfortunately, while he was correcting my assumptions regarding current distribution – for which I am grateful – he again left untouched the key issue: What is the shape and character of the magnetic fields that must be associated with this current flow?

   By the way, I deliberately broke the symmetry of the capacitor by feeding it at the edge rather than the center. I did this to call attention to the difference between longitudinal currents that flow along a wire and orthogonal currents on the plates. Prof. Mc Donald correctly noted that this makes a simple analysis of current flow quite difficult. That was also deliberate, since I have a problem with Prof. Kirk's invoking symmetry during SOME integration processes. Please see my comments under section 5.

5. Prof. Mc Donald has mis-interpreted my statement, "In other words, in a solid structure, there is no magnetic field!" He has taken this to mean that fields INSIDE the metal, when I made it clear in the previous sentences that I was referring to fields at the SURFACES!"

   However, the above is moot, since Prof. Mc Donald has already clarified in (4) above that the currents in different surfaces are different. That, in turn, implies that the magnetic fields at the surfaces of different parts of a capacitive structure will be different. And *this* insight may prove very useful to antenna designers.

   I do not believe this is the forum to re-engage the email exchange regarding fields inside wires. Suffice it to say that my view is consistent with techniques used to analyze magnetic fields in solenoids.[3] Interested readers may follow these links and think about what would happen if the solenoid wires — and spacings — were infinitesimal as they would be in an integration process.

   But I believe that all of the above is moot to this discussion, since in a real RF conductor, the conduction occurs near the surface (skin effect) and no magnetic fields will exist in the wire's center.

   Prof. Mc Donald makes some excellent points regarding the choice of assumptions to be used. I disagree with Prof. Mc Donald's assertion that my paper contains, "examples like that (sic) of Miller which are related to almost DC behavior of circuits." However, grammatical issues aside, in the future, I will attempt to be more rigorous/consistent in my assumptions than I was in this paper.

6. Please see my comments contained in 1.

7. Prof. Mc Donald is correct that the sentence contains the redundant word, "continuous."

   I am fascinated to learn that, according to Prof. Mc Donald, radio waves flow from South Africa to Princeton via, "the 'displacement' current that fills up the space between me and the broadcast antenna in South Africa."

8. I would like to suggest that, in Prof. Mc Donald's analysis, he might have slightly mis-characterized the "negligible" nature of the transverse magnetic field. "Negligible" isn't very specific, but I wonder if we would agree that a figure of 0.26% is considered "negligible?"

   If so, then I agree completely with Prof. Mc Donald's assessment.

   By the way, the reciprocal of 0.26% is 377.

   But the above is only part of the story. Let's look at how my suggested equation performs when the inverse condition applies. That is, when $\mathbf{H}_{TR} = \mathbf{0}$. This occurs in a capacitor. When we take the cross product of $\mathbf{H}_{TR}$ and $\mathbf{H}_{TA}$ we learn that the Poynting vector**,** **S** is also zero.

   Amazingly enough, this statement proves a capacitor does not radiate. I think I learned that fact in 1956 when I mis-connected the output of my 6L6 transmitter to chassis ground through a 0.1 μF disc ceramic capacitor!

Vindication? In closing, I would like to share some just-gleaned information. The source bears this somewhat unwieldy title: "CLASSICAL ELECTROMAGNETISM VIA RELATIVITY An Alternative Approach To Maxwell's Equations," by W.G.V. Rosser, M.Sc, Ph.D and Senior Lecturer in Physics, University of Exeter. I give my thanks to fellow GARDS' member, Dave Cuthbert, WX7G for its loan.

In this text, Dr. Rosser demonstrates how, using the theory of special relativity, it is possible to derive Maxwell's equations.

Dr. Rosser's process consisted of analyzing what happens as a POINT CHARGE travels in a straight line in the vicinity of a measurement point *P*. The manipulations are beyond the scope of this text, but the end result was – sure enough – Maxwell's Equation.

BUT, here is what Dr. Rosser said about the result: " The Maxwell term $\varepsilon_0 \partial E / \partial t$ **(my note, this expression equals** $\partial D / \partial t$ **)** does not produce the magnetic field at P… Both the electric and magnetic fields at P arise from the moving charge. The electric and magnetic fields at P have a common cause, namely the moving charge."[4]

In other words, according to Rosser, Displacement Current, when derived from the special theory of relativity, does not *cause* magnetic fields. Since this is the *same* Displacement Current that we have been discussing, I would like to suggest that this independent derivation validates my conclusion that Displacement Current does not *cause* magnetic fields.

Summary

I was sloppy in my choice of assumptions regarding conductivity. I did not correctly analyze the currents and charges associated with the plates of a capacitor. I am grateful to Prof. Mc Donald for his tutorial.

But the core concept of the paper remains sound. The motion of electrons causes magnetic fields. No "magic" Displacement Current is needed. **–30-**

Bibliography

[1] Electromagnetic Field Theory Fundamentals, Guru and Hiziroglu, China Machine Press, copyright 1998 PWS Publishing Co., page 269.

[2] Electromagnetic Field Theory Fundamentals, Guru and Hiziroglu, China Machine Press, copyright 1998 PWS Publishing Co., pp 267-269

[3] Web pages showing solenoid field analysis:
http://www.rsphysse.anu.edu.au/~rwb112/SP3/Helen/edu/sol_page/solenoid.html Hhttp://www.physics.northwestern.edu/classes/2001Fall/Phyx135-2/15/physics.htmlH
Hhttp://staff.aes.rmit.edu.au/frank/Magnetic%20Fields%20and%20Electromagnetism.docH
http://farside.ph.utexas.edu/~rfitzp/teaching/302l/lectures/node61.html

[4] CLASSICAL ELECTROMAGNETISM VIA RELATIVITY An Alternative Approach to Maxwell's Equations., W.G.V. Rosser, copyright 1968, Butterworth & Co., page 81

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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 well as having a working knowledge of German, Italian, Japanese and Hindi.

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