An Answer to the Catt Question

And Related Issues in EM Theory

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INTRODUCTION

<u>Physical Viability—the Key to the Catt Question</u>

In a paper by Stephen Crothers to be published next month [1], in which a previously proposed answer to the "Catt question" is criticized and discredited, the question posed by Mr. Ivor Catt [2] is expressed as follows:

"*The Catt Question [3 [ref [2] in this post]] pertains to the propagation of a Transverse Electromagnetic (TEM) wave along a transmission line. Upon closure of a switch, the TEM wave (step) travels at the speed of light between the conducting wires of the transmission line, from battery to load, as depicted in Fig. 1 [excluded from this post]. An electric field E appears between the conductors, directed from the top wire to the bottom wire. This electric field is orthogonal to the two parallel wires and moves towards the load; thus there are positive charges on the top conductor and negative charges on the bottom conductor in the region of the transverse electric field. The Catt Question is: Where does this new charge come from? [3]*"

The answer to this question given herein does not appear to be in any way mysterious. That is, it does not appear to challenge classical electromagnetic theory or the physical existence of electrical current consisting of drifting electrons, a challenge that has been suggested by others who have addressed this question, most notably here F. Bishop in various [private communications over the last few months of 2015 (cf. his two emails dated 5 December 2015 and other earlier and later emails with various subject titles).]

I consider the answer proposed herein to be valid and unassailable on scientific grounds, assuming the validity of the long standing theory of EM, mostly summarized in Maxwell's equations. The approach taken to develop this answer is also used briefly, prior to its use to answer Catt, to challenge some mathematical models of EM phenomena and discredit several challenges, from others, to classical EM theory, including the Bessel-functions force-free model of plasma current, the magnetic reconnection model of explosive release of magnetic energy, and a recent challenge to the notion of electric current in hard-wired circuits including transmission lines.

However, there does remain one unanswered question that seems to trump all others: *What is the nature of force and the mechanism(s) by which it travels?* It apparently travels in some instances, such as gravity, faster than the speed of light. The nature of force and energy propagation is an issue that has been considered by EU enthusiasts and has been the focus of Wal Thornhill's work for some years. Some possibly new thoughts on this issue, presently being discussed with Wal, may be included in the forthcoming TB post [3].

It should be clear that the Catt question about the fundamentals of electromagnetism in connection with transmission lines should not be addressed using non-physical models such as a lossless transmission line or a vacuous propagation medium, as has been so commonly done in the past. The answer to the Catt question proposed herein (and soon to be posted together with an appendix on the basics of transmission-line modeling and further discussion of some of the following subsections) in [3] is therefore based on the most physically viable class of models (those which are the most widely applicable in practice without any added conditions) among those known and used or, more recently, justifiably proposed as dictated by principles of sound *Electric Universe Theory*. The result is that it is shown herein that the Catt question does not challenge the standard well-known (classical) theory of electromagnetism, including the existence and nature of electrical current in conductors. (Ivor Catt has challenged the conventional theory of electromagnetism, and has put forth carefully prepared arguments in his two-volume book [4] and elsewhere, but it should be understood that the scope of the argument in this post is far more limited. No inferences are intended here that this argument addresses anything else about Catt's work, although it might.)

Is the Flow of Charged Particles a Viable Model for Electric Current?

On the basis of the above statements, which are validated in the next section, the so-called "forbidden equation" i = qc introduced by a follower of Catt, Mr. Forrest Bishop, should actually be forbidden from use in any scientific studies of the fundamentals of electromagnetism because it is valid only for models of transmission lines that are non-physical (lossless) or, more generally, lines in which the drift speed of free electrons in the conductors equals or exceeds the propagation speed of the EM wave in the dielectric. The fundamental concept of electron drift in a conductor cannot even exist for a lossless line, because the conductivity 1/R is unlimited ("infinite") or, stated another way, the resistivity R is zero. This should ring a bell for Electric Universe enthusiasts, who scoff at astrophysicists who have in the past or do still use the model of the interstellar medium as lossless and therefore incapable of supporting an electric field, which led (in the 1940s) to the concept of "frozen-in" magnetic fields in which a magnetic field and the plasma it is in are frozen together. This concept is contradicted by observations of physics in action under certain circumstances of considerable practical interest; although, this can be a useful approximation over limited periods of time and under other circumstances that might well exist throughout extensive regions of space—but not everywhere. In contrast, i = qc is unlikely to ever be a useful approximation because there is unlikely to be any physically viable conditions under which the drift speed S in a physical conductor is almost as fast as the propagation speed c in a physical dielectric surrounding that conductor, for which $c = 1/\sqrt{\mu\varepsilon}$ where μ is the permeability and ε is the permittivity of the dielectric. The mobility of free electrons in conductors is just too small given the physically viable range of values of the reciprocal square root of the product of permittivity and permeability, which is generally many (as much as 10 or more) orders of magnitude larger than any drift speed corresponding to physically viable levels of mobility.

Is the Bessel Functions Model for Birkeland Current Physically Viable?

Similarly, the recently revived (from the 1950s) Bessel-functions field-solution for force-free magnetic fields in plasma, most recently promoted by Prof. Donald Scott and referred to in posts in this list, is derived from a model taken from MHD (magnetohydrodynamic) theory in which the plasma has zero resistivity and therefore contains no electric field. This is a non-physical model for frozen-in fields from which we cannot expect to derive a new understanding of physics without very careful evaluation of the physical viability of the mathematical solution obtained from the non-physical model. The starting point for deriving the Bessel-functions solution is an equation defining a frozen-in magnetic field, which is used to equate to zero the magnetic Lorentz force. This equation requires the current density field to be proportional to the magnetic field and it disallows any longitudinal or transverse electric fields. (It might be interesting to investigate the possibility of a useful analogy between (1) this fields solution or, better yet, a physically viable solution which can be interpreted in terms of spatially distributed inductance, capacitance, and conductance in plasma containing a cylindrically symmetric TEM (transverse EM) field configuration and a uniform longitudinal EM component, with plasma particles experiencing centrifugal and frictional mechanical forces—to the extent they are not negligible—and (2) the longitudinal EM wave and the transverse EM wave, created by EM forces, propagating down a coaxial transmission line, with a peculiar radial profile of conductivity, permeability, and permittivity.)

Although the Bessel functions solution is believed to be a useful approximation under certain circumstances, those circumstances exclude the possibility of explosive release of magnetic energy (ERME), a topic of great practical and theoretical interest in astrophysics and electrical power generation by the process of controlled fusion. If, as has been hypothesized, ERME can result from a progressive sufficiently strong pinch in a current stream and if that current stream, away from the pinch, is well modeled by the Bessel-functions solution, then whatever causes the pinch must violate the frozen-in condition that is assumed in order to obtain the Bessel-functions solution. Another point of interest: In the field solution obtained, the magnetic field surrounding the current decays radially beyond the cylindrical plasma conduit containing current in accordance with conventional theory—inversely proportional to square of the radial distance from the conduit of current. However, the field in the solution decays less rapidly-inversely proportional to the square root of the radial distance from the central axis of the cylindrical conduit to its surface—*inside* the conduit where the current exists. If this latter result contradicts conventional theory, the first thing to ask is: would this same result hold for a more generally physically viable model of cosmic current that excludes exactly frozen-in fields?

So, there is it seems an analogy between the physical limitations of lossless transmission lines incapable of supporting longitudinal electric fields and lossless interstellar media incapable of supporting electric fields. Without a scientific approach that is based on generally applicable physically viable models and sufficiently critical thinking, EU enthusiasts proposing new electromagnetic fundamentals will be at risk of retarding progress. The key to such critical thinking that is illustrated by this brief investigation of the Catt question is the necessity of understanding how to bring physics and mathematical models of physics (and their analysis) together in a meaningful way that does not allow mathematics to dictate non-physical "physics". Mathematics is an essential tool in science, but one that can easily be and is commonly misused—presumably unconsciously.

More detailed discussion of the modeling of Birkeland current may be included in the forthcoming TB post [3].

<u>Are Black Holes Physically or Even Mathematically Viable?</u>

Other examples include the theory of black holes that has been most convincingly discredited by Mr. Stephen Crothers by careful study of the mathematical models adopted and the invalid mathematical analysis of those models. It doesn't matter whether one is an EU enthusiast or not, we all are subject to misleading ourselves and others by insufficiently-critical thinking in the process of formulating models and analyzing them, while being sure to always use physical viability as the ultimate test. In the case of black holes, there is overwhelming evidence of the lack of both physical viability and the absence of a mathematically valid derivation.

<u>Is Magnetic Reconnection Physically or Even Mathematically Viable?</u>

EU enthusiasts should also recognize the analogy between the lesson illustrated here for the Catt question and that illustrated by the posted argument [5], the most relevant excerpts of which are included in [3]; this argument establishes that the physics of explosive release of magnetic energy widely used by astrophysicists for decades cannot be deduced using the non-physical model called "magnetic reconnection". This is established by proving that the "magnetic reconnection" model is not only non-physical, but also non-mathematical: the mathematics itself is invalid. Fortunately, in this case, there is a potential alternative mechanism for explaining ERME that admits an apparently physically viable model described in the recent Thunderbolts Project Space News [6] by Prof. Jeremy Dunning-Davies and attributed to Prof. Hans Alfven (around 1970). For some hard-to-fathom reason, astrophysicists seem to have ignored this apparently physically viable model in favor of the completely absurd "magnetic reconnection" model originally proposed about ten years earlier and actually stated at that time by its originator, J. W. Dungey, to be non-physical. Despite this, it was agreed at a 2009 discussion meeting hosted by the Royal Astronomical Society that "magnetic reconnection had evolved over the past 50 years from an important but controversial proposal, to a general paradigm". This paradigm remains in force today outside of EU theory, despite its unscientific basis.

ANSWER TO THE CATT QUESTION

The Roles of Static Charge and Reflection

Consider what are commonly called "free electrons" distributed along two conductors in parallel that form a transmission line at some static voltage relative to ground, which requires some static charge; that is, there is a fixed voltage present throughout the transmission line and the line is not net neutral. In this static state, there is no current present (i = 0 everywhere). These conductors contain positive charge on atoms held in a lattice structure due to those atoms having contributed to the pervasive sea of free electrons. These positive ions and free electrons together produce a net neutral conductor except for any static charge present, corresponding to some static voltage.

In preparation for considering what happens to these electrons when an approximately rectangular voltage pulse of spatial length L = cT and positive voltage V > 0 volts lasting T units of time appears across the two conductors at the left end of the transmission line, denoted by +conductor and –conductor, we must consider static charge. It is assumed here, for specificity, that the voltage pulse arises from switching a battery of V volts nominally connected across the ends of the two conductors into the transmission-line circuit and then, T units of time later, switching it out of the circuit. It doesn't matter, when the battery is switched out of the circuit, whether the battery is replaced with an open circuit or a short circuit or some resistance or even reactance, unless and until the voltage pulses propagating down the line get reflected at the right end and propagate back toward the left end, where the nature of any reflection at the left end will depend on what the battery was replaced with. In answering the Catt question, there is no need to consider reflections, since the same propagation phenomenon that applies to the initial left to right movement of voltage also applies to any and all voltage pulse movements due to reflections. Assuming the transmission line is operating in its regime of electrical linearity, the temporally and spatially overlapping voltage pulses propagating in opposite directions at either end of a conductor, as the reflection is taking place, simply add together to produce the net voltage pulse throughout the period of reflection, which is greater than T in length because of dispersion that has occurred during travel.

Just before the battery is switched into the circuit, it may have some static charge giving it a reference voltage relative to ground. The static charges on the battery and the line, if not equal, produce a temporary voltage difference that equalizes the charge, resulting in a new value of reference voltage shared by the battery and the line. The discussion that follows ignores the transient currents that flow during this initial equalization phenomenon. Thus, it is assumed that the reference voltage shared by the battery and line is constant. Assuming that the transmission line is operating within its regime of electrical linearity, the superposition principle validates this approach of determining the response of the line to the applied voltage pulse independently of any determination of the static-charge equalization transient. Because of this, the reader can think of a uniform transmission line in which case there won't be any reflections occurring along the line, just at the ends of the line in some cases. This uniformity is not used in any part of the argument presented here.

The reason for even discussing this transient is to justify the assumption that, because the battery and line share a common reference voltage, say V_r , the voltage at the positive terminal of the battery must be $+V/2 + V_r$ and that at the negative terminal must be $–V/2 + V_r$. Consequently, the voltage difference between the leading edge of the voltage pulse, as it leaves the battery, and the line voltage on the +conductor, just to the right of this leading edge, must be $(+V/2 + V_r) – (V_r) = +V/2$. Similarly, the voltage difference on the –conductor must be $(–V/2 + V_r) – (V_r) = –V/2$; so the voltage pulses appear anti-symmetrically on the pair of lines: a positive pulse will propagate down the

+conductor and the negative of that pulse will propagate down the –conductor, at least initially (the pulse shapes may begin to differ from each other as they travel down the line).

To prove that the battery voltages at the pair of terminals must be as stated above, we assume otherwise and show that this leads to a contradiction. Assume the pair of voltages at the battery terminals are $+V/2 + V_r + U$ and $-V/2 + V_r + U$. By selecting a non-zero value of U, we can make the pair of voltages as asymmetric as we like, while maintaining the difference voltage at V. For example, the choice $U = +V/2 - V_r$ produces the pair of voltages V and 0. However, this addition of U corresponds to addition of static charge to the battery, thereby violating the condition of charge equalization. In summary, the sole effect of assuming the terminal voltages are not anti-symmetric is to violate the assumption that the charge equalization transient can be ignored while we investigate the propagation of the voltage difference down the line. However, it must be recognized that the complete transient behavior of current and voltage on the line is the sum of the transients due to (1) application of an anti-symmetric voltage pulse to the line and (2) equalization of static charge between battery and line. In conclusion, for the purpose of answering the Catt question, we can just assume there is no initial static charge on either the battery or the line, in which case we must use +V/2 and –V/2 as the pair of voltages applied to the pair of conductors. We cannot use V and 0 or any other pair of values. This may have been a source of error in past attempts to answer the Catt question.

<u>The Physical Mechanisms of EM Wave Propagation and Electron Drift</u>

This longitudinal voltage difference along z inside each conductor, as well as the voltage difference between conductors at each value of z, generally changes shape as it travels down any physically viable transmission line together with an associated EM wave, both traveling at the speed of EM propagation, c, for the medium surrounding the two conductors. Because both conductors are everywhere net neutral before application of the initial voltage pulse, which source is itself net neutral, the system containing the source and line is net neutral before connection and remains so after connection. The exact shape of the propagating current and voltage waves down a physically viable line, $i_+(z,t)$, $i_-(z,t)$, $v_+(z,t)$, and $v_-(z,t)$, on the +conductor and –conductor must be determined from Maxwell's equations but, even if the applied voltage is a rectangular pulse, neither the propagating voltage pulse nor current pulse waves are rectangular because of the losses present, in the conductors and the medium, in addition to the capacitance and inductance. Moreover, the pulse energy decreases with distance traveled, z, and becomes negligibly small for sufficiently long lines. But the Catt question can be answered without quantifying all these details.

However, under certain restrictive conditions, the effects of conductor losses and/or the dielectric losses on electrical behavior of interest can be negligible. In some such cases, the propagating waves are purely transverse (TEM waves). This is true for every case except that in which the losses in the conductors are not negligible (or, more precisely not zero). Since such models are, strictly speaking, non-physical, they are not considered in the answer to the Catt question provided here.

Because a physically meaningful answer to the Catt question cannot be obtained from a transmission line model that is not physically viable, both purely resistive lines (with no inductance and no capacitance) and purely reactive lines (lossless lines) with no resistance are ruled out. Also ruled out is a dielectric consisting of a vacuum, or "free space", which is not physically viable, despite its pervasive use in physics. With regard to the speed c of wave propagation considered here, there is no need in the argument presented to adopt the idea that a medium carrying energy can be a vacuum. Given the present lack of any physical explanation of how an EM wave can carry energy through a vacuum, it is suggested that—consistent with the principle of sticking to physically viable models—the reader assume the value of c used herein is the speed of propagation in a physical medium, such as

Wal Thornhill's *plenum of neutrinos* plus, possibly, any dielectric matter (solid, liquid, or gas, including "air"), or nothing.

More discussion of drift speed and propagation media & speed may be included in the forthcoming TB post [3].

Retaining a bit more generality (non-zero V_r) than needed, for purposes of illustration, we consider the absolute voltage initially placed on the +conductor to be $+V/2 + V_r$ and that on the –conductor to be $–V/2 + V_r$. As the traveling voltage pulse on the –conductor first reaches any point z along the –conductor at some time t > 0 (z is the number of units of distance from the voltage source), there is a longitudinal voltage difference of $v_–(z,t) – V_r$ between z and every other point to the right of z at time t. At time t = 0, this voltage difference is –V/2 < 0 and it grows smaller in magnitude (due to resistance) as it travels. According to classical EM theory, at the time t = z/c when the leading edge of the voltage pulse $v_–(z,t)$ first reaches the location z, the electrons at z begin to drift to the right. They will continue this drift at z until the trailing edge of voltage pulse is past the point z, and then the drift at z will cease (exact initial and final transients, such as rise times and fall times, depend on line resistance, capacitance, and inductance). The spatial length of the traveling pulse of voltage is initially L = cT but, for z > 0 and t > 0, L and T increase with increasing z and t.

If the drift speed is denoted by S, then electrons at the left end of the pulse moving to the right will have drifted a distance ST in T units of time and those at the right end will not have drifted at all (yet). This results in a *pulse of drift* with drift speed S that travels down the conductor at the speed of the voltage pulse, which equals the speed c of EM propagation in the medium. None of the electrons are traveling at c, only the electrical pressure wave associated with the longitudinal voltage difference is moving at c.

(The concept of a "pulse of drift" moving at some speed greater than the speed of drift within the pulse may have been a stumbling block for some in past considerations of the Catt Question. If there is a flaw in the explanation given here, it would most likely be the invalidity of this as a physically viable concept. But, what I question most in this discussion is not this but rather the concept that a conductor drift speed can exceed the propagation speed in the medium, the non-physical implications of which are addressed in the introductory section and also at the end of the present section, in connection with Bishop's claim.)

Continuing, in the –conductor, the pulse of electron drift toward the right locally bunches up free electrons and thereby increases the lineal density of free electrons inside the pulse, which produces a pulse of net negative charge traveling to the right at the speed c in the otherwise neutral conductor. The added electrons in the pulse are initially supplied by the voltage source during the period of length T that it is active, because it is pushing electrons into the conductor faster than they can travel down the conductor. As this pressure wave travels down the conductor at speed c, the bunching of electrons due to their speed limitation of S also travels down the line at c.
In the other conductor, the +conductor, the same phenomenon occurs except the polarity of the voltage is reversed and therefore the direction of electron drift is reversed from toward the right to toward the left, but the direction of propagation of the pulse of drift is still from left to right. This pulse of electron drift with drift direction from right to left caused by the EM wave traveling in the medium produces a traveling region of free-electron depletion with travel speed of c toward the right. The net charge in this pulse is positive because the depletion leaves less electrons than +ions held in the conductor lattice. During the initial period of length T that the voltage source is active, this pulse of electrons is delivered to the source, balancing those delivered *by* the source to the –conductor.

The magnitudes of $v_+(z,t)$ and $v_-(z,t)$ will continuously decrease as the pulse travels down the line and the values of z and t at which the voltage is non-zero increase, because of the finite conductance. As these opposite polarity pulses of net charge density propagate from left to right, they produce an electric field extending from the net positive pulse in the +conductor to the net negative pulse in the –conductor. This transverse electric field between the conductors propagates longitudinally at speed c. It is not uniform throughout the segment of transmission line where it resides at any one time because the shape of the net charge density pulses are not uniform (rectangular) and, as stated above, the width L of this band of E-field grows as it moves to the right (even for a uniform line). If and when the pair of pulses and their associated longitudinal E-field component and transverse EM-field

component reach the end of the transmission line before fully dissipating, they may partially or fully reflect back toward the source, depending on the load and the characteristic impedance of the line, and/or the current pulses may pass through the load in which case energy will be dissipated if the load is lossy (exhibits electrical resistance to the drifting electrons). Thus, energy is dissipated in resistance, causing heat, all along both conductors and in the load. This is true, regardless of where it is argued that the energy travels from source to location of dissipation: inside the conductors or inside the medium. With a physical medium, such as a plenum of neutrinos, there is nothing non-physical about the concept of energy flowing through the medium—something that would be non-physical if the medium was a vacuum.

Since the transmission line has been assumed to be physically viable, the losses result in finite series and parallel resistance and this will partly determine some finite drift speed that is (as assumed here) less than the speed of propagation of the EM wave. On the other hand, if the conductors are assumed to be perfect—that is, to have infinite conductance in series and infinite resistance in parallel, producing a lossless line which is not physically viable—then the drift speed would apparently be infinite which also is not physically viable. So the Catt question should be of interest to physicists only in the case of real conductors (finite conductance) and real dielectrics (having energy carrying capability). (If one allowed for infinite drift speed, then drifting electrons whose drift motion cannot precede the arrival of the wave producing the drift, would move at the speed of propagation, which Mr. Bishop agrees is impossible, but this is what his equation $i = qc$ indicates, though he argues otherwise.)

Reference Voltage and Grounding

Because the current from one point to another in the conductor depends on voltage only through the difference in voltages along the line, not on the actual values of voltage at one particular position on the line, the above explanation of a traveling pulse of drift current with travel speed higher than the speed of drift is valid regardless of the value of the reference voltage. So, it is stated once again that the value of the reference voltage in this discussion is arbitrary; we can, for example, make the initial voltage at the left end of either of the two conductors zero, by choosing V_r to be either $+V/2$ or $– V/2$. In this case the voltage on the conductors prior to arrival of the initial voltage pulse is either $V_r = +V/2$ or $V_r = – V/2$, so that its difference from the reference voltage at the left end of one of the conductors is zero.

Although it is not necessary, one can interpret the assumption $V_r = 0$ as a result of grounding one of the conductors in the line, say the –conductor. This raises the question of whether or not an actual connection to ground changes the physics described above, which is argued to be valid regardless of the value of the reference voltage, as long as we separate the static-charge equalization transient from our consideration of the propagating wave due to the applied voltage. Considering the fact that the exact nature of the grounding connection (for example, it could be a long conductor with one end buried in the earth or the –conductor could actually be touching a copper rod driven into the earth) must be described before we can proceed (recall the importance of adopting a physically viable model). This takes us beyond the scope of the answer to the Catt question provided here, and is not discussed further. But it does have bearing on whether or not the Catt question is relevant and answerable when one of the conductors in a transmission line is the earth itself. This cannot be tackled by modeling the earth as a large conducting plate above which a wire runs parallel to the plate, because it does not address the grounding issue.

Expressions for Current

The preceding discussion answers the Catt question. There is nothing inexplicable about the origin of pulses of positive and negative net charge that propagate down the conductors of a net neutral transmission line. The remainder of the discussion here derives a standard characterization of the traveling current wave in the conductors of the transmission line. The subscripts + and – are eliminated, but do in fact apply to every quantity i, Q, q, v, and S to designate which conductor is being considered. The standard direct definition of current in a conductor is i(z,t) = Q(z,t)/ΔT, where Q(z,t) is the total net charge passing through a cross-section of the conductor at longitudinal position z in a small interval of time of length ΔT << T (for this application), starting at t. This can be re-expressed in another form as follows. The charge Q(z,t) can be expressed as Q(z,t) = q(z,t)ΔL(z,t), where q(z,t) is the average lineal density of total charge throughout the cross section of the conductor over a distance of length ΔL(z,t), starting at point z in the conductor at time t, and ΔL(z,t) = S(z,t) ΔT is the average distance traveled over the time interval of length ΔT by electrons having an average axial component of velocity (drift speed) S(z,t) in the ΔL-length section of conductor. Substituting ΔL(z,t) = S(z,t) ΔT into Q(z,t) = q(z,t) ΔL(z,t), and substituting the result into the definition i(z,t) = Q(z,t)/ ΔT yields the equation i(z,t) = q(z,t)S(z,t).

This result i(z,t) = q(z,t)S(z,t) is a standard characterization for the current in a conductor in terms of drift speed (not the speed c of propagation in the current-expression for a non-physical lossless line). Both the above standard expressions for current in a lossy line accommodate dependence of current on time t and location z. Dependence of the drift speed S(z,t) and the lineal charge density q(z,t) result from any dependence of the voltage v(z,t) on z and t, which can result from propagation, as in the case under consideration: a voltage pulse v(z,t) applied to a transmission line. (The notation ΔT and ΔL is used here instead of the more common Δt and Δx to emphasize that in order for the calculated current i(x,t) to follow the variation of the causative voltage pulse v(x,t), of length T in time and L in space, we must have ΔT<<T and ΔL<<L .)

Power Flow

In association with EU questions about current flow in a transmission line, there have been questions about energy flow in time and space and power flow in space. Standard EM theory provides us with Poynting's theorem to address these topics in a concise manner. It is mentioned above in passing (and addressed in [3]) that we have two alternatives for describing the propagation of electromagnetic energy down a transmission line operating in its electrical linearity mode: (a) electromagnetic field waves and current density fields in the dielectric(s) and conductors that comprise the transmission line and (b) voltages and currents in continuously distributed RLC circuits that model the conductors and dielectrics of a physical transmission line. For alternative (b), we have the following Poynting's formula:

$$
\begin{aligned}
\frac{\partial}{\partial z}\frac{\partial}{\partial t}\mathcal{E}_A(z,t) &= \frac{\partial}{\partial z}\mathrm{P}_A(z,t) = \frac{\partial}{\partial z}\big(v(z,t)i(z,t)\big) \\
&= -\frac{\partial}{\partial t}\left(\frac{1}{2}C_A(z)v^2(z,t) + \frac{1}{2}L_A(z)i^2(z,t)\right) - i^2(z,t)R_{A\cap C}(z) - v^2(z,t)G_{A\cap D}(z)
\end{aligned}
\tag{1}
$$

In (1), $\mathrm{P}_A(z,t)$ is the power passing through a cross-sectional region A that captures all non-zero fields at longitudinal location z and at time t. To obtain the power contained in a longitudinal-segment (a z-interval) W of space with cross-sectional region A, one integrates the z-density of power $\partial \mathrm{P}_A(z,t)/\partial z$ over W. $\mathrm{P}_A(z,t)$ is, of course, the time derivative of stored energy contained in A. To obtain the total energy contained in A propagating past the longitudinal point z over a time interval T, one integrates the t-density of energy $\partial \mathcal{E}_A(z,t)/\partial t$ over T. Similarly, by redefining A to be any sub area of the entire area containing fields, the power and energy in that subarea can be calculated using (1).

In (1), $C_A(z),\ L_A(z),\ R_{A\cap C}(z),\ \text{and}\ G_{A\cap D}$ are the z-densities of capacitance between the conductors for a dielectric with permittivity ε, inductance of the conductors for a surrounding region with permeability μ , resistance of the conductors occupying cross section C, and conductance of the dielectric between conductors occupying cross section D.

For alternative (a), we just substitute the following field equations for stored energy due to the build-up of electric and magnetic fields (the time derivative of which is reactive power)

$$\begin{aligned}\frac{1}{2}C_A(z)v^2(z,t) &= \frac{\varepsilon}{2}\int_A \left\|\mathbf{E}(x,y,z,t)\right\|^2 dxdy \\ \frac{1}{2}L_A(z)i^2(z,t) &= \frac{1}{2\mu}\int_A \left\|\mathbf{B}(x,y,z,t)\right\|^2 dxdy\end{aligned} \tag{2}$$

and the following field equation for z-density of power flow (dissipation) due to the Lorentz electric force acting on free electrons

$$i^2(z,t)R_{A\cap C}(z) + v^2(z,t)G_{A\cap D}(z) = \int_A \mathbf{J}(z,t)\cdot\mathbf{E}(z,t)dxdy \tag{3}$$

where $\mathbf{J}(z,t)$ is the current-density field-vector and A is the cross-sectional area of the transmission line including conductors and all parts of the dielectric exhibiting non-zero conductance in which electric fields not orthogonal to $\mathbf{J}(z,t)$ are non-zero. (A can be reduced to the portion that intersects with $C \cup D$.)

Physically, the energy is spatially distributed in 3 dimensions and is carried by the EM fields that propagate in the z direction. The power dissipated in R is dissipated inside the conductors and that dissipated in G is dissipated inside the dielectric between the conductors and is determined by that part of the E-fields that are aligned with the J-fields in those regions. The power at z that is not dissipated at z continues to flow in the z direction, getting ever smaller as the dissipated power accumulates. There is nothing in this description of energy and power flow that is inconsistent with standard EM theory. However, that theory is still silent on the fundamental question of HOW energy is carried by the EM fields in the dielectric(s) (brief discussion in [3]).

RELEVANCE OF THE CATT QUESTION

Any explicit solution for propagating current and voltage and net charge in a physically viable transmission line, corresponding to some specified initial voltage, is not a simple calculation [3]. Continuously distributed (or, for computational purposes, discretely distributed) RLC models, or Maxwell's equations, must be used for determining current flow due to applied voltage if the frequencies in the initial voltages' frequency content are high, relative to spatial dimensions, such that the wavelength is comparable to or less than the physical dimensions of the circuit, making lumped RLC models inaccurate. On the other hand, at sufficiently low frequencies, relative to spatial dimensions, wave propagation through a circuit can be ignored, the Catt question is irrelevant, and lumped RLC models, with their relatively simple ordinary differential equations relating current to voltage, can be used.

To quantify the conditions under which traveling wave models are called for, we consider here (for convenience only) a Gaussian pulse of voltage, which has a Gaussian Fourier transform (specifying its frequency content) with frequency bandwidth B equal to $1/\pi$ times the reciprocal of the time width or duration T (this is true regardless of the definition of width; e.g., it can be the "standard deviation" or any fraction or multiple thereof). Thus, for a circuit of total length d, the shortest wavelength is much longer than the circuit when $c/B = cT >> d$. For c = 3e8 meters/sec, this requires T >> (d/3)e-8. For a circuit length of d = 1/10 meter, we require T>> 3.3e-10 sec = 0.33nanosec or, say T > 3.3 ns. Thus wave propagation in circuits of this size is negligible for voltage pulses no shorter than 3.3 ns. If we're interested in a transmission line of length 1, or 100, or 10,000 meters long, then we require T > 33ns, or T > 3.3 microsec, or T > 330 microsec, respectively. Consequently, there are many applications involving manmade circuits that do not require consideration of propagating waves, but there also are many that do, and this becomes more so as the movement toward miniaturization of electrical devices continues [7]. In a purely resistive circuit with lumped resistance, the formula for current is given simply by Ohm's law, $i(t) = v(t)/R$, which can be thought of as equivalent to $i(t) = q(t)S$, where q(t) is the lineal net charge density from an increase above or a decrease below the nominal density of free electrons, which is taken to be uniform throughout the resistor whose length is assumed to be negligible.

THE USE OF MATHEMATICS IN SCIENCE

Reflecting on the issue, raised in some of my earlier posts, of bringing mathematics and physics together in a meaningful way, it should be mentioned here that, partly in response to those posts, Mr. Bishop's posts have taunted a few participants in the conversation to derive on their own the equation $i(z,t) = q(z,t)c$, without his having defined the physical situation of interest. In fact, he claimed to have shown this equation to be very-generally valid for current in a conductor. When he finally revealed his derivation (a few lines of algebra), it became clear that it is valid for only the non-physical uniform lossless transmission line with speed of propagation c. This mathematical result based on a non-physical model, is actually of no physical significance (and has no bearing on the Catt question) and, more importantly, the absence of drift speed in this equation does not justify questioning the standard formula $i(z,t) = q(z,t)S(z,t)$, and does not justify the claims made to the effect that electrical current in a transmission line has nothing to do with electron drift, and does not by itself justify or discredit the concept of "energy current" (although the physical process described herein does call into question the concept that the energy delivered to the load on a transmission line is conveyed by the current flowing in the conductors of the line; rather, the energy is apparently conveyed by the EM fields that propagate down the line) or claims that Maxwell's equations, when applied to physically viable models of EM phenomena, are not self consistent. In fact, $i = qc$ is valid when and only when the drift speed S of the conductor exceeds the propagation speed c of the medium [3]. For a lossless conductor, the drift speed is unlimited (some would say "infinite") and, therefore, definitely greater than any finite c. Because, in this case, any drifting electrons would not lag behind the leading edge of a TEM wave propagating alongside a conductor at speed c, such electrons *would* move at speed c in the non-physical lossless transmission line. If c is the speed of light, and the mass of an electron is non-zero, one might say this is a contradiction of the Einstein proposition that nothing with finite mass can travel at this speed; however, Einstein's proposition was, one would hope, intended for physical phenomena, which excludes lossless transmission lines and massless electrons (but may not have excluded vacuous media). These observations about the pitfalls of using non-physical models to invent physics explain why Mr. Bishop's label "the forbidden equation" is actually quite appropriate. But, it is not just because he has found no one else who mentions or uses it; rather, it is because it should be forbidden from physics, not admired as a new discovery about physics.

The unjustified pronouncements about EM theory and current briefly reviewed in the above paragraph provide an excellent example, in addition to those cited earlier in this discussion, of what can (and often does) happen when physically unviable mathematical models are adopted and mathematically manipulated to draw new conclusions about physics that contradict established physics, without going back and making sure the contradictions are not simply a result of faulty assumptions, like non-physical models.

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[1] Crothers, S. J., "On an Apparent Resolution of the Catt Question" *Progress in Physics*, http://ptep-online.com/index_files/2016/PP-44-13.PDF, January 2016
[2] Catt, I., "The Catt Question", http://www.ivorcatt.co.uk/x54c1.htm, 12 April 2015
[3] Gardner, W. A., "An Answer to the Catt Question and a Falsification of Magnetic Reconnection", to be posted at www.thunderbolts.info
[4] Catt, I. *Electromagnetic Theory, Vols. 1 & 2*, http://www.forrestbishop.4t.com/EMTV1/EMTVolumeI.htm; http://www.forrestbishop.4t.com/EMTV2/EMTVolumeII.htm, 1980, C.A.M Publishing, St. Albans, England
[5] Gardner, W. A., [private communication], 4 Oct 2015
[6] Dunning-Davies, J., "Magnetic Reconnection Alternative", Thunderbolts Project Space News, https://www.youtube.com/watch?v=VaTGsPr1r54, 29 Dec 2015
[7] Catt. I., Walton, D., Davidson, M., *Digital Electronic Design, Vols 1 & 2,* http://www.forrestbishop.4t.com/DEDV1/DEDVolumeI.htm; http://www.forrestbishop.4t.com/DEDV2/DEDVolumeII.htm, 1978, C.A.M Publishing, St. Albans, England