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An Answer to the Catt Question

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INTRODUCTION

In a paper by Stephen Crothers published this 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 Intersect posts over the last few months of 2015.

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. The answer to the Catt question proposed herein (and soon to be posted together with an appendix on the basics of transmission-line modeling [3] at www.Thunderbolts.info) is therefore based on the most physically viable model (that which is the most widely applicable without any added conditions) among those known and used. 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.)

On the basis of the above statement, the so-called "forbidden equation" i = qc that has been focused on 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 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 ("infinity") 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 to the concept of "frozen-in" magnetic fields (in which plasma and the magnetic field it is in are frozen together) that contradicts observations of physics in action.

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, 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 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 setting the magnetic Lorentz force equal to zero. This equation (with the usual assumption of constant α) requires the current density field to be proportional to the magnetic field. This is precisely what a frozen-in field is. 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, 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 physically viable model of cosmic current that excludes frozen-in fields? Perhaps not.

So, there is a direct and obvious analogy between lossless transmission lines incapable of supporting longitudinal electric fields and lossless interstellar media incapable of supporting any electric fields. Without a more scientific approach that is based on physically viable models and more critical thinking, EU enthusiasts proposing new electromagnetic fundamentals cannot be expected to make much 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 unconsciously misused.

Other examples include the theory of black holes that has been most convincingly discredited 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, always using physical viability as the ultimate test.

EU enthusiasts should also recognize the analogy between the lesson illustrated here 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: it is mathematically inconsistent. Fortunately, in this case, there is a potential alternative mechanism for explaining explosive release of magnetic energy 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 many years back. For some hard-to-fathom reason, mainstream astrophysics has for many decades ignored this apparently physically viable known model in favor of the completely absurd model "magnetic reconnection".

ANSWER TO CATT QUESTION

Consider what are commonly called "free electrons" uniformly distributed along two neutral conductors in parallel that form a uniform transmission line with no voltage (relative to some specified reference level V_r; that is, the line voltage is V_r everywhere) and no current ($i = 0$ everywhere) present, and consider what happens to these electrons when a rectangular voltage pulse of spatial length $L = c/T$ 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. This voltage difference between conductors 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 between and possibly surrounding the two conductors. Because both conductors are everywhere net neutral before application of the voltage source that creates 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. Because the transmission line is uniform, the conductivity per unit length is independent of longitudinal position. So too are the line capacitance and line inductance per unit length. 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.

A physically meaningful answer to the Catt question cannot be obtained from a transmission line model that is not physically viable. This rules out purely resistive lines (with no inductance and no capacitance) and lossless lines with no resistance.

Without loss of generality, we can consider the absolute voltage initially placed on the +conductor to be $+V/2 + V_r$ and that on the other conductor, 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 reached the location z, the electrons at x to begin to drift to the right. They will continue this drift at x 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 propagation speed c. 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 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 I see no reason why an EM wave and the pressure or force it represents cannot propagate faster than the drift speed of electrons affected by that force. What I *do* question is a drift speed that exceeds the propagation speed, which is addressed below.)

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.

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, 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.

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 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.

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 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.

As these opposite polarity pulses of net charge density propagate from left to right, they produce an electric field extending from the positive pulse in +conductor to the 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 toward the load.

If and when the pair of pulses and their associated longitudinal E-field component and transverse E-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 or outside the conductors.

Because the current along a conductor depends on voltage only through voltage differences along that conductor (not on the actual values of voltage at any particular point), the above explanation of a traveling pulse of drift current in each of the two conductors, with pulse-travel speed c higher than the speed of drift, applies equally well to a transmission line with either one of the conductors being grounded (having zero voltage relative to the voltage of Earth in the vicinity of the conductor).

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 (has always been assumed to be) 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 finite conductance. (If one allowed for infinite drift speed then drifting electrons, whose 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.)

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 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. The standard direct definition of current in a conductor is $i(z,t) = Q(z,t)/\Delta T$, 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 $\Delta T << T$, starting at t. This can be re-expressed in another form as follows. The charge $Q(z,t)$ can be expressed as $Q(z,t) = q(z,t)\Delta L(z,t)$, where $q(z,t)$ is the average lineal density of charge over a distance of length $\Delta L(z,t)$, starting at point z in the conductor at time t, and $\Delta L(z,t) = S(z,t)\ \Delta T$ 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 $\Delta L(z,t) = S(z,t)\ \Delta T$ into $Q(z,t) = q(z,t)\ \Delta L(z,t)$, and substituting the result into the definition $i(z,t) = Q(z,t)/\ \Delta T$ 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 $q(z,t)$ results from any dependence of the voltage $v(z,t)$ on z and t, which can result from propagation, as in the above case of 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 a voltage pulse $v(x,t)$, of length T in time and L in space, we must have $\Delta T<<T$ and $\Delta L<<L$.)

RELEVANCE OF THE CATT QUESTION

But 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], except when wave propagation can be ignored due to additional conditions being satisfied. Discretely or continuously 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 so high that the wavelength is comparable to or less than the physical dimensions of the circuit, making lumped RLC models inaccurate. In fact, the drift speed in the +conductor of a line need not be the same as the drift speed in the –conductor. On the other hand, at low frequencies, 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 charge density, 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 it has been shown (e.g., Mr. Bishop's posts) by others studying the Catt question that $i(z,t) = q(z,t)c$ for the non-physical uniform lossless transmission line with speed of propagation c. This mathematical result for a non-physical transmission line is 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 $i(z,t) = q(z,t)S(z,t)$ or, for a uniform (but not lossless line) $i(z,t) = q(z,t)S$, 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 the 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 exceeds the propagation speed, c [3]. For a lossless conductor, the drift speed is unlimited (some would say "infinite") and, therefore, definitely greater than any finite c. In this case, there are no drifting electrons lagging behind the leading edge of the TEM propagating at c and, therefore, electrons *do* 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 also massless electrons.

The above unjustified pronouncements about EM theory and current 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., Intersect posting "Intersect's Purpose and Practice", 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