Reforming Electromagnetic Units, Equations, and Concepts: An Extension of Ivor Catt's Theory

Forrest Bishop
PO Box 30121, Seattle, WA 98113
e-mail: info@bishopcubes.com

Some of the problems, paradoxes, and clutter within the mathematical physics of the past few centuries are briefly reviewed. Catt's concept of illusory static fields created by TEM (transverse electromagnetic) waves replaces the electrostatic and magnetostatic field concepts, removing any number of these paradoxes at once. Z_0 , the vacuum wave impedance, is a physical constant as fundamental as the speed of light; together they replace permittivity and permeability. A units system -"MNSZ"- is proposed in which either the ohm or Z_0 replaces the ampere, allowing physical constants and equations to be rewritten without reference to coulomb, generally in a more compact form. By replacing the dielectric constant in some cases with the index of refraction, the common electrical equations may be reduced to more compact forms that highlight the wave nature of the purported electric charge. Several example applications are shown, including a compact new expression for the voltage of the photon. Recent experimental results are presented which refute the exponential-decay model of a discharging capacitor.

1. Introduction

There's something added in that shouldn't be there. A vast theory was built on top of it and yet it does not exist. No one has ever seen it nor measured it, despite their protestations to the contrary. A fundamental unit of measure has even been named in honor of this enshrined ghost—the ampere. All of our electric high technology is said to descend from this comfortable dream. Its heretics are denounced as viciously as ever while its believers remain devoted. It's not like we haven't been here before.

The idea of electric current is very old and familiar: it descends from the ancient Greek and later Medieval theories of visible and invisible fluids like the humors, moving from one body to another, influencing them like a spirit might. They didn't have the instrumentation back then to test the ideas of invisible electric humors, but we do, and have for well over a century. Caloric and phlogiston have already fallen by the wayside, though new ones like Dark Matter way out in the cosmos have risen in their stead, outside the range of our instruments.

Due to the numerous problems with conventional electromagnetic theory, a few mentioned below, a more advanced theory is required. No attempt is made herein to construct a general theory of the Aether or a Theory of Everything: we simply do not know enough about the properties of electricity, magnetism, and electromagnetic radiation yet. Instead, some old ideas and some new ideas are presented, a few in the form of questions that apparently have never been asked or answered before.

2. Some Problems with Conventional Electricity Theory

> *"It was once told as a good joke upon a mathematician that the poor man went mad and mistook his symbols for realities; as M for the moon and S for the sun."* —Oliver Heaviside [1], p. 133.

There are far too many problems with contemporary electromagnetic theory to make an exhaustive study here. Where is the energy in an electric circuit located? If a lamp has a switch on it, and a battery is located a great distance away, how does the battery know when to stop sending electric current to the lamp when its switch is opened? How does electric energy travel from a battery to a lamp—within the wires or in the space around the wires? When lightning strikes near a power line, where does the induced charge on the line come from? If the wires of an electric circuit are neutral, why is there a voltage between them? Since electric energy is known to move at the speed of light for the dielectric surrounding the wires, how do the electrons inside the wires know how fast to move? And so on.

The Catt Question [2, 3] has generated many conflicting responses over the past thirty years. Some come up with novel theories of electricity in the process—"these electrons would have flowed in along with the pulse" and "the charge causes the electrons to flow" [4], or "the signal conductor… is the only conductor that is being energized…. Current in the lower conductor is created by an electromagnetic field emanating from the upper conductor…" [5]. (Darney concludes his exposition with "There was certainly no need to invent a completely new theory.").

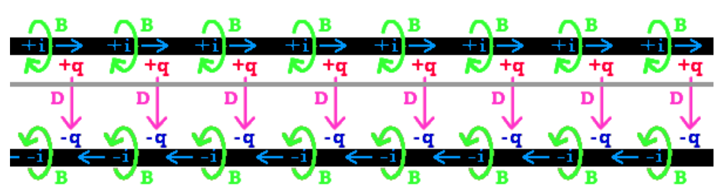

Fig. 1. "The Catt Question." Traditionally, when a TEM step (i.e., logic transition from low to high) (Figs. 3, 4, 5 in [7]) travels through a vacuum from left to right, guided by two conductors (the signal line and the 0V line), there are four factors which make up the wave: electric current in the conductors *i*, magnetic field, or flux, surrounding the conductors **B**, electric charge on the surface of the conductors (+*q*, -*q*), electric field, or flux, in the vacuum terminating on the charge. The key to grasping the question is to concentrate on the electric charge -*q* on the bottom conductor. The step advances one foot per nanosecond. Extra negative charge appears on the surface of the bottom conductor to termi-

nate the new lines (tubes) of electric flux **D** which appear between the top (signal) conductor and the bottom conductor. Since 1982 the question has been: Where does this new charge come from? [2] Image credit: Eugen Hockenjos, 2000.

Others such as Lago claim that "The charges come to the surface to help the wave go by" [3], or Secker that "The favoured explanation…attributed to Professor Pepper [6], namely that as a TEM wave advances, so charge separation occurs close to the conductor surface effectively giving a transitory current flow at right angles to the direction of wave propagation" [3], violating Gauss's Law. McDonald [9] claims that "the fields of the step create a surface charge density on the wires, which in turn creates an axial electric field that 'pulls' forward the free electrons that are already inside the wire"—another example of a novel theory which, besides violating Gauss, proposes a longitudinal effect from a radial, transverse, orthogonal cause.

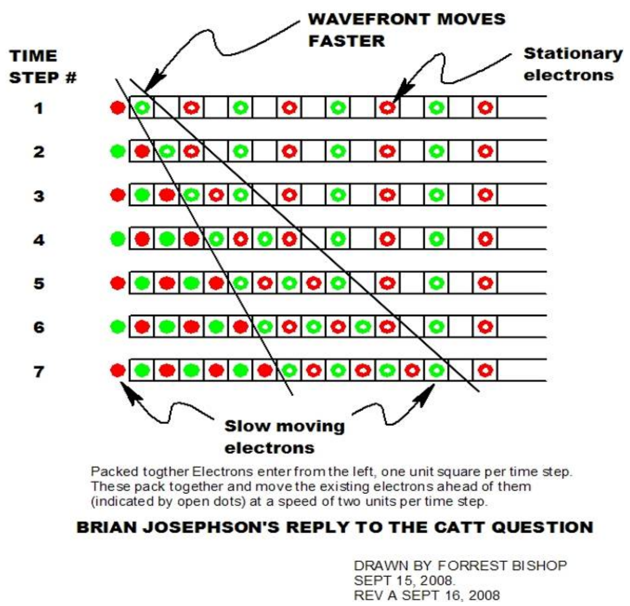

Fig. 2. A Westerner-style reply to "The Catt Question" [8]. Image credit: Forrest Bishop, 2008.

The 'Westerner' view that electrons are supplied from the battery does not solve the problem of electrons that have to move at *c*. Each electron in the 'compression' wave (Fig. 2) still has to move at *c* to participate in the new, transverse electric field. They have to continue moving at *c* to account for the net line charge moving at *c*. Once they pass through the load resistor, they have to thin out somehow for the return journey to the 'West' on the upper wire while moving backwards: still moving at *c*. How these electrons are supposed to disconnect and reconnect to the transverse electric field lines moving the other direction is an entirely new question for the electric-current hypothesis.

Is the wire neutral or charged? The confusion on this point may be why there are two principle schools of thought (along with several others) on The Catt Question—the "Westerners", who would have electrons coming from the battery to the left; and the "Southerners", who imply the electrons rise up from within. The Southerners may think the wire is neutral. But the voltage between the two wires has to be the result of an electric field, and so there has to be a net charge to terminate the field lines. This is not generally taught; in fact the opposite is claimed:

Griffiths teaches [10] p. 196: (when a current is present) "I could hold up a test charge near these wires and there would be no force on it, indicating that the wires are in fact electrically neutral". [10] p. 202: "A neutral wire, of course, contains as many stationary positive charges as mobile negative ones. The former do not contribute to the current." [10] p. 226: "But if we arrange to keep the wire *neutral*, by embedding in it an equal amount of opposite charge at rest…but of course this is precisely what happens in an ordinary current-carrying wire." (*emphasis* in original)

So there is another layer to The Catt Question. Other writers, e.g., [11, 12], claim the wires of an electric circuit do indeed have a net charge—positive or negative—usually as a surface charge. Jefmimko [13] demonstrates this with a simple experiment; a different example is presently on YouTube [14]. Fromhold [15] comes close to stating the problem, then typically veers off. In a perfect, symmetric version of this problem, there is a "neutral point" at the center of the electric-current load resistor where the transverse electric field drops to zero. The current, *i*, on either side of this point is the same, but one side has positive carriers and the other side has negative carriers—otherwise there isn't any transverse electric field.

These authors generally go on to derive Maxwell's Equations—Ampere's circuital law in particular—with no regard for this additional, transverse electric field. On this count alone those equations cannot be correct.

Two different answers come from the electromagnetic force relations give for a single step or pulse on a transmission line. Ampere's force law [16], p. 767, says the force is proportional to the product of the currents in the two parallel, non-coaxial conductors, yet a summation of the transverse electric and magnetic forces yields zero net force [17], pp. 258-260. The ampere of SI units is defined in terms of these forces [18]. By setting up special conditions on a high-impedance transmission line terminating in a low-impedance load, the electric force is made arbitrarily small so that Ampere's magnetic force law can appear to work.

When two pulses of the same polarity, launched from opposite ends of a transmission line, meet in the middle, is the transverse electric field spanning the two wires now static between them (Fig. 3)? How did it decelerate from *c* to zero? Or were moving electrons setting up static fields? How can two different electric currents exist in the same circuit without violating Faraday's Law [19]?

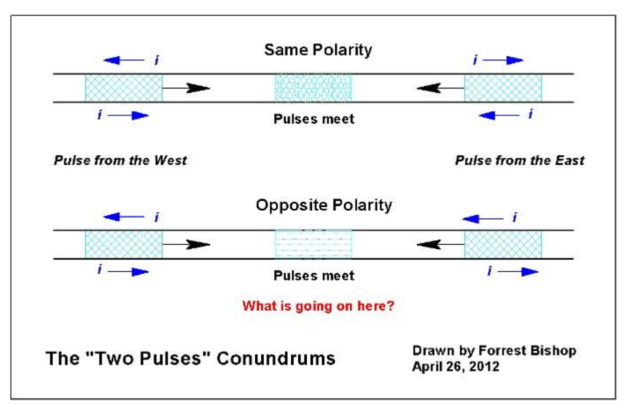

Fig. 3. When two pulses overlap, do their fields come to a standstill while two electric currents obliviously pass though each other? Image credit: Forrest Bishop, 2012.

Each of the two (or more) electron currents presents a Coulomb barrier to the other. How does Current #2 overcome the net Coulomb barrier of Current #1 (e.g., a Drude or Fermi gas [15])? Even if it were possible for two electric currents to travel through each other, we would expect some effect of one on the other.

For similar reasons, electric current cannot be spread over the cross-section area of a wire as is commonly claimed. Net charge has to migrate to the surface in order to satisfy Gauss's law for conductors. Now the problem is even worse, for both currents are on the surface trying to pass through each other's Coulomb barrier at a much higher current density.

When the switch to the West is disconnected, why should the "compressed electrons" at the back of the "compressed electron wave" care to continue moving to the East? Shouldn't they, being in effect spring-loaded, want to reverse course and head back to the West? What compels them to continue to the East?

McDonald [20] claims "At the moment when the magnetic energy goes to zero, all of the pulse energy is in the electric field…. At this special moment, all the field energy is 'electric'". This theory requires some new physics to account for how the fields of one TEM wave can remove the energy from the magnetic field of another such "just so" and then restore it later on.

Haus et al. [21] discuss this problem without resolving the questions above. In the course of this, they bring up an example of charge appearing out of nowhere on an infinite transmission line (Fig. 4).

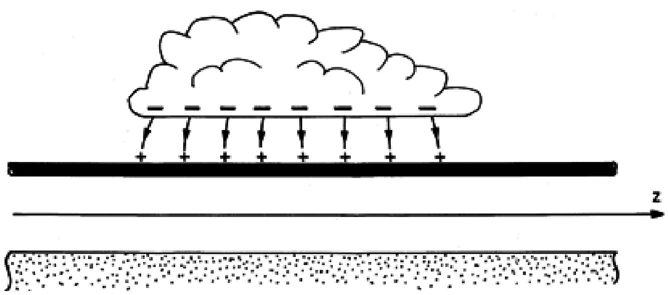

Fig. 4. Where does "an accumulation of charge on the line imaging the charge in the cloud" come from? Image credit: MIT, 1998.

This problem is The Catt Question again, only worse, as there is no obvious battery or other electron/hole source available.

As Gauthier notes in his discussion of the use of superposition in the unresolved Two Pulses problem [22], "many Ph.D. physicists…either are unable to answer it or are able to answer it only after considerable thought''.

Superposition is a mathematical technique used to arrive at what Feynman calls a vector "good field" [23], one in which every point has a single vector value. This math procedure cannot cause the physical fields themselves to be erased by "cancellation", a word that needs careful examination. $-1+1=0$ does not necessarily mean that the entities pointed to on the lhs cease to exist. The word "cancel" doesn't mean "annihilate". This is a source of the confusion. For the Two Pulses, the confusion also stems from "a mathematical accident": $2+2=2^2$ [7], p. 4.

In the "Two Pulses" problems, the "Catt Capacitor" below, the "TEM Waveguide" below, electrostatics, and many other places, the math can be rigged using superposition to come up with somewhat useable results at the expense of creating new physics, new paradoxes, and losing information.

The Dancing, Swishing TEM Wave arrives on [16] p. 877 as "You can see that the variations in **E** and **B** are intimately connected with one another: a varying **E** field gives rise to a varying **B** field, which in turn gives rise to a varying **E** field, and so on. In this way the electric and magnetic fields of the wave sustain one another through empty space, and no medium is required for the wave to propagate."

Feynman, [23], p. 18-8, Vol. II, agrees that "So, by a perpetual interplay—by the swishing back and forth from one field to the other—they must go on forever…. They maintain themselves in a kind of dance—one making the other, the second making the first—propagating onward through space".

Since the flat-topped pulse doesn't have time-varying fields within the wave, this commonly used 'explanation' for propagation cannot work here. That explanation also has several more problems, not the least of which is a need for instantaneous, two-dimensional transverse action.

Feynman does admit later, [23] p. 20-10, Vol. II, "I'll tell you what I see. I see some kind of vague, shadowy, wiggling lines—here and there is an **E** and **B** written on them somehow, and perhaps some of the lines have arrows on them—an arrow that disappears when I look too closely at it. When I talk about the fields swishing through space, *I have a terrible confusion* between the symbols I use to describe the objects and the objects themselves…," echoing Heaviside (emphasis added, substituting **E**, **B** for M, S).

Some basic information is missing from the theory of electricity: what happens when it meets an impedance change or goes around a corner (Fig. 5)?

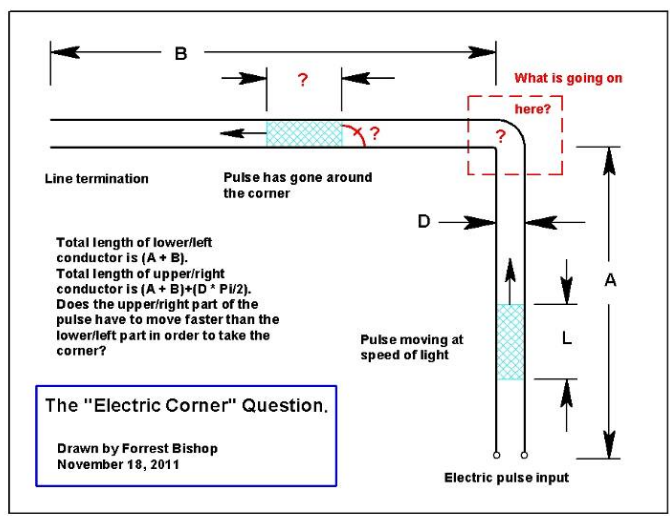

Fig. 5. Mysteries of Electricity. Image credit: Forrest Bishop, 2011.

Infinite reaches of fields and potentials are commonly applied, in Coulomb's Law, Faraday's Law, solutions to Maxwell Equations, Gauss's Law, and so on. So either 'real' fields and potentials can go to infinity or they have to stop before reaching infinity. The infinity claims cannot be tested without going to infinity with an infinitesimally accurate meter. If the fields stop before reaching infinity, then the math is inaccurate, so either the math is inaccurate, it is un-testable, or, as argued here, both.

In particular, if the electric and magnetic fields stop in a finite distance, they violate Gauss's Law, $\nabla \cdot \mathbf{E} = \rho$ and $\nabla \cdot \mathbf{B} = 0$ respectively. Consider a short, flat-topped TEM pulse (½ of one cycle of a square wave *sans* the rest of the square wave) moving at c on a line. It has a beginning and an end. If it doesn't reach to infinity transversely, then it has sides there as well. Either Maxwell's Infinite Equations are correct or nature is correct.

Common plane-wave solutions to Maxwell's equations cannot describe this phenomenon as they require infinity on all six sides. The sides of a laser beam have this same problem, for **B** as well as for **E**. Calling it a Gaussian profile doesn't make the problem go away. The photon itself also has this problem. How long and how wide is a photon? How many times does it wiggle? Chopping things off with artful mathematical declarations like eikonal end-caps cannot solve these scientific problems.

This brief tour only touches on some of the incongruities within conventional electromagnetic theory, upon which a great deal of modern physics is built. Those are some of the reasons that theorists have had to resort to multi-dimensional spaces, mystical explanations, and 10^{500} possible Universes.

3. Some Essential Concepts

The theory of electricity and the rest is in need of major revision, some of which is shown below. It may have seemed above that two different things were being discussed: electric circuits and transmission lines. After all, there are at least two (actually many more) different conventional theories for these two terminologies. An electric circuit is the same thing as a transmission line (Fig. 6): whatever applies to one applies to the other.

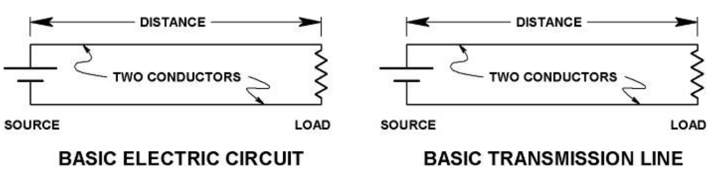

Fig. 6. Identity of Concepts. Image credit: Forrest Bishop, 2011.

Several terminologies are used to distinguish between different types of "current":

1. **Electric Current**, *i*, is a fluid-like "humor" composed of a line charge Q_L that moves through solid metal objects. Example equations: $V = iR$, $i = Q_L c$.
2. **Electron (or Ion) Current** is a flow of charged electrons or ions in, e.g., a CRT, a photomultiplier, or a battery. These "corpuscles" can be counted and measured. In these particular cases, it flows at right angles to Energy Current.
3. **Energy Current, or the TEM wave,** is the flow measured by the so-called "ammeter" and "voltmeter". It moves at the speed of light for the dielectric and exists outside of the solid metal objects: well-known facts used every day. Example equation: $S = EH/c$.

Of the three types, only two have ever been measured. The third, Electric Current, is an hypothesized invisible fluid from the late Middle Ages when various similar "humors" were thought to account for things like heat, fire, and medical conditions. It is described in math by taking the square root of Energy Current, then conflating that with Electron Current.

A "wave" does not necessarily mean a sine wave. A moving wave of constant amplitude can appear to be a static object. This may be the most important and difficult concept.

A TEM wave, or transverse electromagnetic wave, has electric and magnetic fields orthogonal to each other, in phase, and transverse to the propagation direction. It moves at the speed of light. It may be a quasi-sine, a square, a pulse, etc. One difference between the TEM wave called "electricity" and the TEM wave called "light" is the geometry of the respective transverse fields.

Electric field can exist without charge but charge cannot exist without an electric field. If something depends on the existence of something else, then only one of the two can be closer to fundamental.

The side of a laser beam is a place in free space where the transverse fields of a TEM wave stop. The surface of a conductor is another place, or the surface of an electron. The side of a TEM wave creates the electric-charge and current illusion, a proposition used below in several places. The electric field of a Gaussian profile is $\mathbf{E} = \mathbf{E}_0 e^{-r^2/\omega_0^2 c^2}$, so $d\mathbf{E}/dr = -2\left(\mathbf{E}_0/\omega_0{}^2 c^2\right) r e^{-r^2/\omega_0{}^2 c^2}$.

But **E** of the TEM_{oo} mode presumably doesn't have an 'azimuthal' or tangential component, or any longitudinal variance, so $\nabla \bullet \mathbf{E} = d\mathbf{E}/dr \neq 0$, in contradiction of the initial assumption that led to the wave equation. If **E** does have any closed-loop component, then **B** necessarily diverges, again contradicting initial assumptions.

Two different sets of mutually exclusive TEM wave constants exist [24]. They are either the set composed of the electric permittivity and the magnetic permeability $\{\varepsilon_0, \mu_0\}$:

$$\varepsilon_0 = \frac{1}{Z_0 c} \tag{1}$$

$$\mu_0 = \frac{Z_0}{c} \tag{2}$$

or they are the set composed of the wave impedance and the speed of light $\{c, Z_0\}$

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \tag{3}$$

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \tag{4}$$

One part of removing the clutter in contemporary electromagnetic theory is to use either one or the other of these two sets of wave constants. Mixing them together introduces spurious relationships. In the development below, $\{c, Z_0\}$ is selected as the exclusive set of vacuum electromagnetic constants.

4. Catt Contrapuntal Capacitor

A transmission line, composed of two conductors at differing voltages and extending through space, is a capacitor. Therefore, a capacitor, composed of two conductors at differing voltages and extending through space, is a transmission line. Calling it a "lumped element" of capacitance obscures the fact that it takes a finite amount of time for energy to propagate through it. A capacitor is a transmission line: whatever applies to one applies to the other.

Catt, Davidson, Walton [25], and others have shown, by experiment [26, 27, 28] and theory [21], that a capacitor charges and discharges in a stepwise fashion with the well-known 'RC exponential' as its envelope.

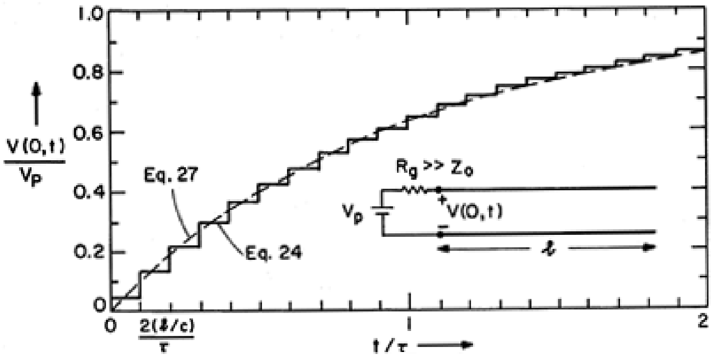

Fig. 7. MIT construction of the Catt Capacitor as a transmission line, from [21]. Image credit: MIT, 1998.

In the simplest case, as a TEM step-wave of, say, $5V$ moves into the gap of the capacitor, a voltmeter ahead of it will read zero until the TEM wavefront reaches it. The TEM wave continues on to the far side and reflects without inversion at the open. When the reflected wave gets back to the voltmeter, its reading jumps to $10V$. At all times the observer might think he is looking at a static field. Computer simulations of this process are at [29].

An important experiment was recently performed by Anthony Wakefield using a brilliant substitute (Fig. 8) for an electronic gate or pulse generator. In this experiment we observe the 'discharge' or 'voltage' profile of a long, thin capacitor arranged as two coaxial conductors. This arrangement isolates the phenomenon of interest by including all fields within the capacitor gap, by excluding external influences, and most importantly by restricting the path of the 'discharge' to a single axis. The 960pf coaxial capacitor was probed at a number of stations along its principle length. A variety of resistors were tried in various configurations; one of these is described in pictures below (Figs. 8, 9).

Tony Wakefield describes his setup [48]:

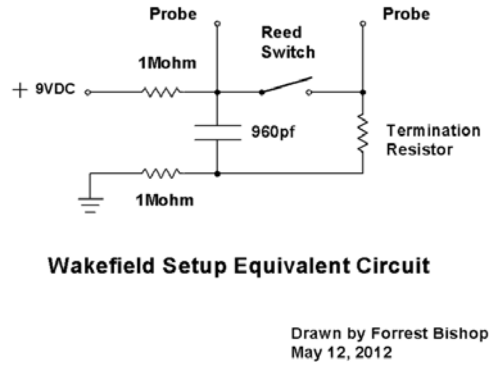

Fig. 8. The 2012 Wakefield Experiments, typical setup in electric circuit terms. Image credit: Forrest Bishop, 2012.

"75 ohm coax Length = 18 meters, Velocity Factor 0.81 measured, Air-spaced Polyethylene dielectric. The Left Hand Side [LHS-FB] is open circuit.

"The Right Hand end of coax is connected to a small 1cm long normally open Reed Switch. On the far side of the reed switch is a 40 Ohm Termination resistor. A hand held magnet is used to operate the switch.

"The Coax is charged up from a 9v battery via 2 x 1 meg ohm resistors close coupled at the switch to center and ground. Two resistors are used to isolate the relatively long battery wires from the coax. High value resistors are used so as to minimize any supply charge when the switch is closed relative to when the switch is open.

"A 2 channel HP 54510B digital sampling scope set to 2v/div Vertical and 50 ns/div Horizontal is used to capture 6 images:

1. *Right hand side of coax connected to the reed switch.*
2. *25% to the left of the reed switch [4.5 meters].*
3. *50% to the left of the [reed] switch [9 meters].*
4. *75% to the left of the [reed] switch [13.5 meters].*
5. *At extreme left the unterminated end of the coax [18 meters].*

By conventional circuit theory, the discharge profile would be an exponential decay with an RC time constant of $40\,\Omega \cdot 960$pf, or

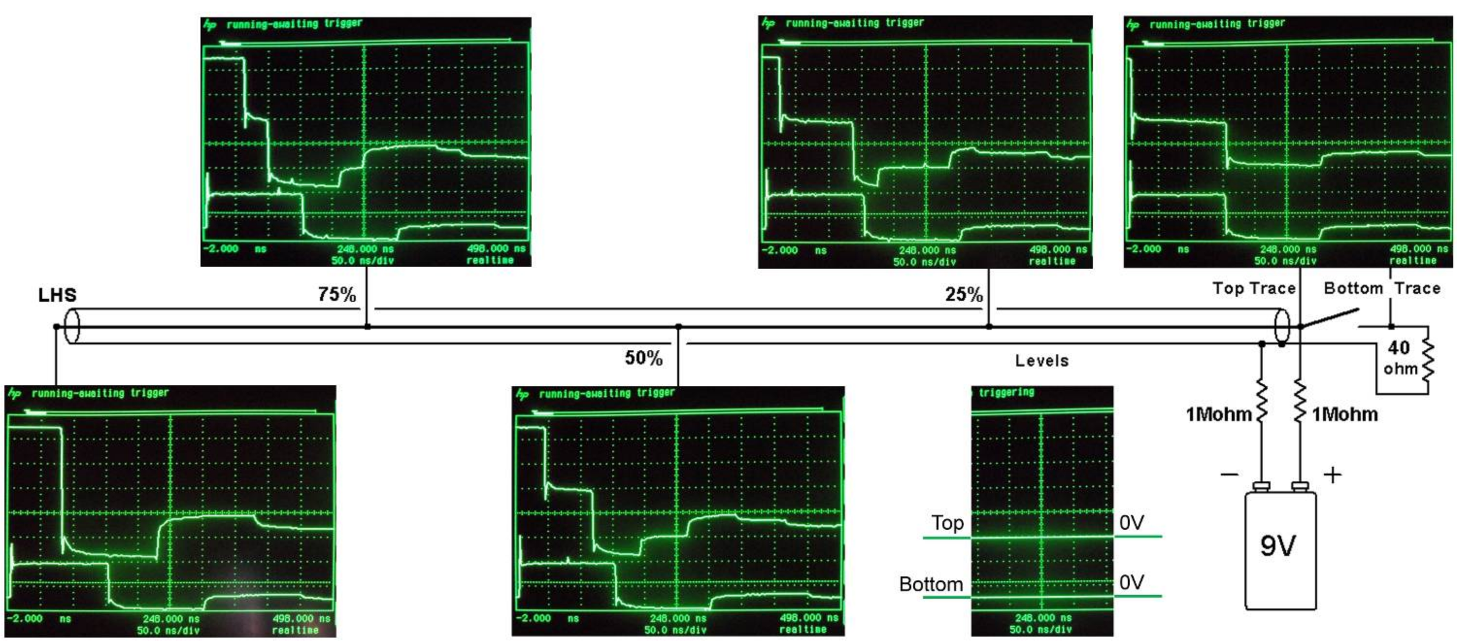

Fig. 9. 'Discharge' profiles along a long, thin coaxial capacitor. Each oscilloscope picture is referred to the place where the sample was taken, in the manner of a tourist map. Image credit: Tony Wakefield, Forrest Bishop, 2012.

38.4ns (Fig. 10), but from transmission line theory it would be similar to the waveforms depicted in the scope pictures. In this picture, all parts are TEM waves moving at c/n (c times the velocity factor). One half of the energy is traveling to the left, where the open is, and one half to the right, where the resistor is. With a $40\,\Omega$ termination resistor on a $75\,\Omega$ line, the incident TEM reflects with inversion, eventually driving the voltage negative, in "catastrophic" contradiction of circuit theory. Wakefield tells us he deduced the identity of capacitors and transmission lines himself after looking at the results before he was aware of Catt's model.

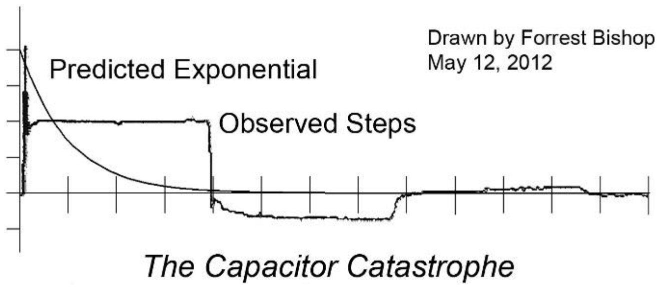

Fig. 10. Horizontal axis denominated in 38.4ns RC time constants for R = 40Ω, C =960pf. Vertical axis in ~2V increments. Image credit: Forrest Bishop, 2012.

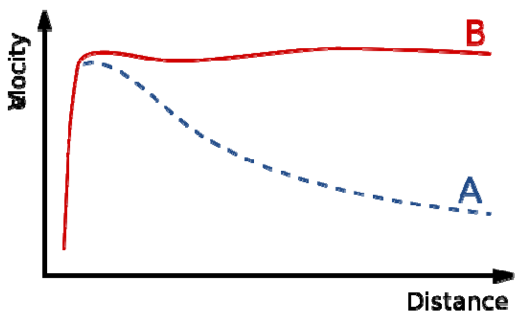

Fig. 11. Predicted (A) and observed (B) orbital speeds of stars in galaxies. 'Distance' is radial from galaxy center. Image credit: Phil Hibbs, 2005.

There are many precedents to the "capacitor catastrophe" in the history of science. The stars in the galaxies refuse to "obey" Newtonian gravity, instead orbiting at a preferred speed regardless of distance from the center (Fig. 11), and so the exquisitely named Dark Matter was invented to save that theory—an invisible humor imbued with magical powers as with electric current.

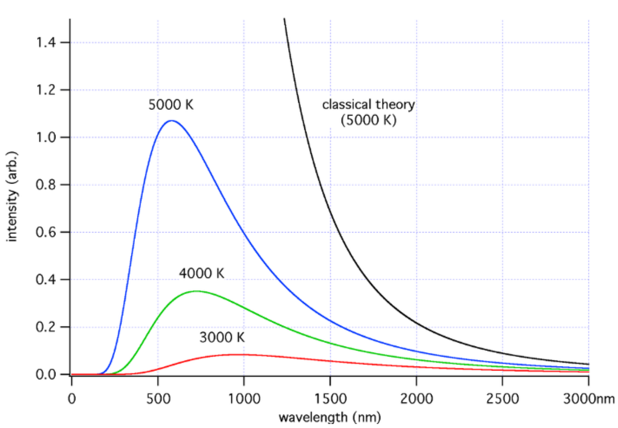

Fig. 12. The 'Ultraviolet Catastrophe' for blackbody radiation that led to quantum mechanics. Image credit: Drphysics, 2007.

Another famous example, called the "Ultraviolet Catastrophe" (Fig. 12), stems from the misapplication of classical electrodynamics to a radiant body, a topic also in need of review. Either electric circuit theory is closer to the truth or transmission line theory is closer to the truth, but not both. These latter two theories are shown by experiment to be mutually exclusive.

For a 'two-dimensional' plate capacitor, the problem is much more difficult and a topic of current research. In particular, the Huygen's model is in need of revision for various reasons (Fig. 13). It is not too hard to design experiments that gradually change the geometry from a long coax to a short one, or to parallel plates, and so provide observations of how TEM waves—or whatever replaces that concept—actually propagate.

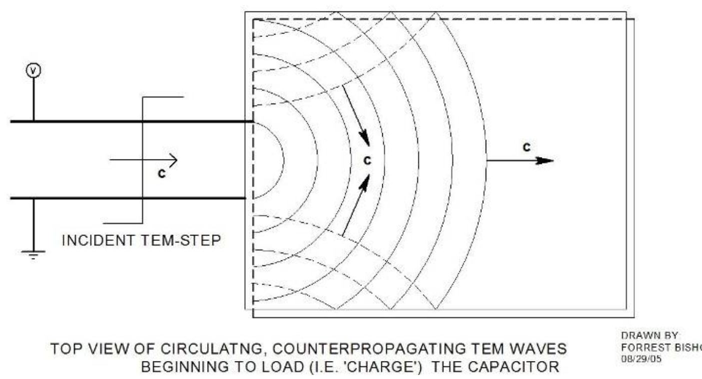

Fig. 13. Huygen's construction of Catt Capacitor. Image credit: Forrest Bishop, 2005.

5. Index of Refraction for Dielectric Constant

In some cases the dielectric constant can be replaced with the index of refraction. From [30], the index of refraction, n, is the ratio of the speed of light in vacuum, c, to the speed of light in an isotropic, bulk dielectric material, c_{M} , or

$$n \equiv \frac{c}{c_{\mathrm{M}}} \ . \tag{5}$$

The dielectric constant κ, also called the relative permittivity ε_{r} ,is defined as

$$\kappa \equiv \varepsilon_{\mathrm{r}} \equiv \frac{\varepsilon}{\varepsilon_0} \ . \tag{6}$$

From Eqs. (5) and (6), and with the caveats of non-magnetic media (letting $\mu = \mu_{\mathrm{o}}$) and elastic, non-resonant scattering,

$$n \equiv \frac{c}{c_{\mathrm{M}}} = \frac{\sqrt{\mu\varepsilon}}{\sqrt{\mu_0\varepsilon_0}} = \frac{\sqrt{\varepsilon}}{\sqrt{\varepsilon_0}} = \sqrt{\kappa} \ . \tag{7}$$

This can be extended to the anisotropic and magnetic cases in a straightforward manner.

Consider two long, flat-plate conductors of width b separated by a distance a, with a dielectric material of resistivity ρ between the plates. Neglecting fringing-field effects, the dielectric resistance per unit length is

$$R_{\mathrm{L}} = \rho\frac{a}{b} = \rho f \ . \tag{8}$$

As an aspect ratio relates two different dimensions of a single object, so the generalized geometric factor f is a dimensionless ratio relating the size of the two conductors to the distance between them [7], p. 18. Both of these lengths lie in the plane transverse to the direction of motion of the transverse electromagnetic (TEM) wave. For capacitance per unit length the expression is

$$C_L = \varepsilon \frac{b}{a} = \frac{\varepsilon}{f} \ . \tag{9}$$

For inductance per unit length the expression is

$$L_L = \mu \frac{a}{b} = \mu f \ . \tag{10}$$

For the characteristic impedance

$$Z = \sqrt{\frac{L_L}{C_L}} = \sqrt{\mu f \left(\frac{f}{\varepsilon}\right)} = f\sqrt{\frac{\mu}{\varepsilon}} \ . \tag{11}$$

With the above background in place, I can now state the general electromagnetic formulae in terms of the set of TEM wave constants $\{c, Z_0\}$, together with the index of refraction and the three-dimensional geometry of the device in question. The bulk dielectric wave impedance is

$$Z_M = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_0}{\varepsilon_0 \kappa}} = \sqrt{\frac{\mu_0}{\varepsilon_0 n^2}} = \frac{Z_0}{n} \ . \tag{12}$$

In the presence of the two conductors, their geometry modifies the bulk dielectric wave impedance Z by an amount calculated using f :

$$Z = f\sqrt{\frac{\mu}{\varepsilon}} = f Z_M = \frac{f Z_0}{n} \ . \tag{13}$$

The capacitance per unit length, C_L , is then

$$C_L = \frac{\varepsilon}{f} = \frac{\varepsilon_0 \kappa}{f} = \left(\frac{n^2}{Z_0 c}\right)\frac{1}{f} = \left(\frac{n^2}{Z_0 c}\right)\frac{Z_0}{Zn} = \frac{n}{cZ} = \frac{1}{Z c_M} \ . \tag{14}$$

Similarly for the inductance per unit length L_L

$$L_L = \mu_0 f = \mu_0 \frac{Zn}{Z_0} = \frac{Z_0}{c}\frac{Zn}{Z_0} = \frac{Zn}{c} = \frac{Z}{c_M} \ . \tag{15}$$

This shows that capacitance and inductance per length are strictly a function of $\{c, Z_0\}$, the geometry of the conductors, and the index of the dielectric when Eq. (7) is true. At no point was it necessary to invoke things like electric charge and voltage.

Multiplying Eq. (9) by the length of the capacitor plates, x, called "Distance" in Fig. 6, yields a prototype lumped-element model for capacitance

$$C = x C_L = \frac{x}{c_M Z} \ . \tag{16}$$

But since

$$C = \frac{Q}{V} \tag{17}$$

is the master equation that defines capacitance in terms of electric charge and voltage, then

$$\frac{Q}{V} = \frac{x}{c_M Z} = \frac{\kappa \varepsilon_0 A}{a} = \frac{n^2 b x}{Z_0 c a} \ . \tag{18}$$

Setting a travel time of the TEM wave as $t = xn / c$, noting that this is for one-way propagation,

$$\frac{Q}{V} = \frac{t}{Z} = \frac{nt}{Z_0 c f} \ . \tag{19}$$

This eliminates the ratio of charge/voltage in favor of the measured values. By doing so, electric charge and voltage are again shown to be auxiliary variables of a mathematical nature.

Similarly for lumped-element inductance,

$$L = \frac{xZ}{c_M} \ . \tag{20}$$

So then

$$\frac{\phi}{i} = L = \frac{xZ}{c_M} = Zt \ . \tag{21}$$

This method only works as given when Eq. (7) holds, which is not the case for materials such as water. Some further development may be able to cover all cases.

6. MNSZ Units: Impedance replaces Current

What does an electrometer, an ammeter, or a voltmeter measure? Does the voltmeter measure voltage or does it actually measure something associated with V^2 or Q^2 , which is then converted to V or Q by the mathematician taking a root? Two charges, Q_1 and Q_2 , are always presumed involved to arrive at the voltage or the current, never a single charge, Q. But V and Q aren't what is being measured by an electrometer: F is, the force that drives the two leaves apart. V is a mathematical manipulation of F and r. For a voltmeter or ammeter, two objects are present, two coils for example [18]. One of them moves in response to an increase of magnetic energy around it while the other is held steady. Current is not what is measured by an ammeter: a magnetic field around the wires is measured. In all cases, what is measured is an interaction between two objects, what O'Rahilly [31] calls "measure ratios".

An examination of the primitive units of capacitance, resistance, inductance, current, and voltage suggests that Q^2 is more realistic than the singular Q. The measure of charge Q is always done in tandem with other such Q's, either of the same or opposite sign. Q never actually shows up all by itself in any real setting but as a product, as in "Coulomb's" force relation— $F = kQ_1 Q_2 / r^2$, which is effectively the definition of charge.

The unit of resistance, R, or more generally impedance, Z, in a set of {force, length, time, charge} such as $\{\mathrm{N, m, sec, C}\}$, or generally, [32] p. 612, $\{F, L, T, Q\}$ has dimensions of

$$Z \to \frac{FLT}{Q^2} \ . \tag{22}$$

In a set of {energy, length, time, charge} units, $\{U, L, T, Q\}$,

$$Z \to \frac{UT}{Q^2} \ . \tag{23}$$

The squared charge of 'Coulomb's Law' can be restated in a units systems of $\{F, L, T, Z\}$, $\{\mathrm{N, m, sec, \Omega}\}$ as

$$Q^2 \to \frac{FLT}{Z}, \qquad (24)$$

or in the set $\{U, L, T, Z\}$, $\{\mathrm{J, m, sec}, \Omega\}$ as

$$Q^2 \to \frac{UT}{Z}, \qquad (25)$$

which may be action/impedance. Then "bare charge" Q is

$$Q \to \sqrt{\frac{FLT}{Z}}. \qquad (26)$$

Q, like voltage, current, etc., is a mathematical artifact, found by taking the square root of measurable quantities. The rhs of Eq. (24) or (26) can be substituted in for Q^2 or Q in the various electromagnetic equations by considering the impedance, Z, to be the more fundamental property, instead of Q. The units of Q^2 might be interpreted as (energy*time)/impedance, which might be interpreted as (action)/(impedance), so perhaps the concept of wave impedance means impedance of the action of the TEM wave.

The dimensions of ε_0 (Farads/m) and μ_0 (Henry/m) are as in Eq. (1) and (2). Any relation that contains them can be expressed in terms of $\{c, Z_0\}$ in lieu of the two prior quantities. For capacitance in Farads, the dimensional units $\{F, L, T, Q\}$ carry over to $\{F, L, T, Z\}$ as

$$C \to \frac{Q^2}{FL} \to \frac{T}{Z} \qquad (27)$$

in Farads, or sec/Ω;

$$Z \to \frac{FLT}{Q^2}, \qquad (28)$$

while permittivity, with the same units as capacitance/length, is

$$\varepsilon_0 \to C_\mathrm{L} \to \frac{C}{L} \to \frac{T}{LZ}. \qquad (29)$$

For inductance L_i (not to be confused with length, L)

$$L_\mathrm{i} \to \frac{FLT^2}{Q^2} \to ZT \qquad (30)$$

$$\mu_\mathrm{o} \to L_L \to \frac{FT^2}{Q^2} \to \frac{ZT}{L} \qquad (31)$$

Henry, or Ω-sec. For electric current

$$I \to \mathrm{amp} \to \sqrt{\frac{\mathrm{N\text{-}m}}{\Omega\text{-}\mathrm{sec}}},$$

$$I \to \frac{Q}{T} \to \sqrt{\frac{FL}{ZT}}, \qquad (32)$$

a quantity involving the inverse of the square root of time among other curiosities. Its square is closer to reality:

$$I^2 \to \frac{FL}{ZT} \to \frac{U}{TZ} \to \frac{P}{Z}, \qquad (33)$$

and so on for any other expression in MKSA or SI. Force was used in the above because mass is a concept derived from it.

7. Recasting the Physical Constants

> *"…that alpha has just its value 1/137 is certainly no chance but itself a law of nature… the explanation of this number must be the central problem of natural philosophy."* – Max Born

One place to start such an explanation is by removing the redundancies in the algebraic expressions.

The fine-structure constant, α, as given in e.g. [33] is written typically as

$$\alpha = \frac{e^2}{4\pi\varepsilon_0\hbar c}. \qquad (34)$$

I recast this in my 2007 paper [24] using Eq. (1) to receive

$$\alpha = \frac{Z_0 e^2}{2h}. \qquad (35)$$

The fundamental quantum of Hall resistance called the von Klitzing constant [35] is $R_\mathrm{K} = h/e^2 = 25{,}812.807\ \Omega$. With

$$\alpha = \frac{Z_0 e^2}{2h}, \qquad (36)$$

then

$$\alpha = \frac{Z_0}{2R_\mathrm{K}}, \qquad (37)$$

so

$$R_\mathrm{K} = \frac{Z_0}{2\alpha}. \qquad (38)$$

To put that into perspective, the quantized Hall Effect is used by NIST to calibrate the value of the SI volt, yet there are no volts or charge in it. They are measuring something else.

The Larmor formula for the power alleged to be radiated by a non-relativistic point charge is commonly expressed as

$$P = \frac{e^2 a^2}{6\pi\varepsilon_0 c^3}, \qquad (39)$$

which can be expressed in a form that does not refer to charge as

$$P = \frac{\alpha h a^2}{3\pi c^2}. \qquad (40)$$

In general, when the quantity h/e^2 shows up in a composite physical constant, it can be replaced with $Z_0/2\alpha$. The above three sections are a work in progress. This development has not fully eliminated charge, voltage, electric field, and the other "square root of reality" [36] quantities, aside from direct substitution. The next steps, unpublished, involve some advanced new concepts both physical and mathematical.

8. The TEM Waveguide

> *"It is not enough for a theory not to affirm false relations; it must not conceal true relations."* —Henry Poincaré, **Science and Hypothesis**

Between waves on an electric-circuit/transmission-line and waves in free space lies an intermediate case of partly confined waves in the waveguide. There are at least two distinct schools of thought on how electromagnetic energy propagates in a metal tube, and in that distinction we find a very clear case of how mathematics can trick and obscure just as easily as enlighten.

One school, exemplified by the treatments in [10, 23, 37], separates solutions to Maxwell's "governing" equations into longitudinal and transverse parts, with resultant mode examples shown in Fig. 14.

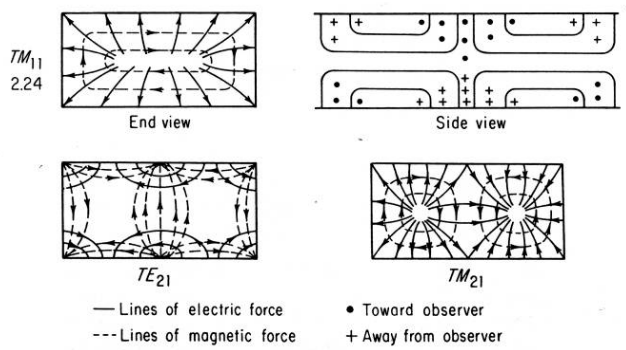

Fig. 7-8 Field configurations of higher order modes in the rectangular waveguide.

Fig. 14. Waveguide modes in the superposed Maxwellian picture. Image credit: McGraw-Hill, 1964.

Taking Jackson [37] p. 334-350 as representative, he claims among other things that 1) Maxwell's Equations contain all the relevant information [37] p. 218, 2) the outside **E** field can only be normal and the **H** field tangential to the conductor [37] p. 335, 3) the waves are sinusoidal both lengthwise and transversely [37] p. 336, and 4) the solutions have a longitudinal dependence [37] p. 340.

These authors go on to imply that a) t*he presence of a metal tube nearby can slow an electromagnetic wave down to considerably less than c*, b) *the amount of slowing depends on the size and shape of the metal tube*, c) *parts of the electric and magnetic fields can extend in the propagation direction*, d) *these new kinds of TE, TM electromagnetic waves can somehow turn into regular TEM waves when they reach the open end of the tube,* and e) *the solutions to the wave equation(s) cover all possible modes of propagation.*

Jackson, [37] p 341, mentions that "we take note of a degenerate or special type of solution, called the *transverse electromagnetic* (TEM) wave… the TEM mode cannot exist inside [a perfect wave guide]". Griffiths, [10] p. 390, states that "I shall now prove that TEM waves cannot occur in a hollow wave guide"—a claim easily disproven by shining a flashlight into a metal pipe. The math has led to conclusions diametrically opposed to known physics.

The other school treats the waves as ordinary TEM waves, bouncing back and forth at an angle to the walls of the waveguide exactly as any other TEM-wave reflection. Each 'piece' of TEM wave therefore follows a zig-zag path through the waveguide (Fig. 15). Curiously, each of several authors [38, 39, 40] who describe this picture then go on to disavow it by implication without stating any reason why. One reason may be that it shows that the propagation velocity of the alleged charge on the surface of the conductor would have to be superluminal, moving at the phase velocity: a situation even worse than the one highlighted by The Catt Question. Another reason might be that it implies that the electric and magnetic fields can terminate on the waveguide walls without this superluminal charge or current present, violating several of the claims around Maxwell's Equations. This is akin to the "Side of the Laser Beam" issue called out above.

In this picture, as improved on herein, one or more TEM waves - planar or not, quasi-sinusoidal or not - create the illusion of the TE and TM modes by superposition without "cancelling" each other's physical properties, just as free-space waves act.

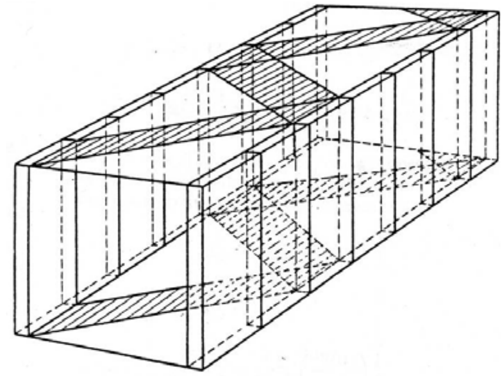

Fig. 3.—Hollow rectangular metal tube. Top and bottom walls (for clearness shown as having no thickness) imagined to be cut into zigzag transmission lines (one line shown shaded). The side walls of the tube imagined as "slabs" forming semi-infinite transmission lines in the direction of their thickness.

Fig. 15. Path of a TEM wave in the waveguide. From [39]. Image credit: John Kemp, 1941.

These mode-artifacts of observation are very much like how the perceived static electric fields of a Catt Capacitor are artifacts of reciprocating energy currents, or *like moving Moiré patterns*.

Feynman [23] Vol. II, 24-12 concludes his exposition of waveguides, similar to Jackson's, by including a method of constructing the modes from sources external to the waveguide (Fig. 16). He does not mention the "bouncing" TEM wave solution, which falls out of that construction by simply realizing that the internal and external waves cannot penetrate the sides of the waveguide.

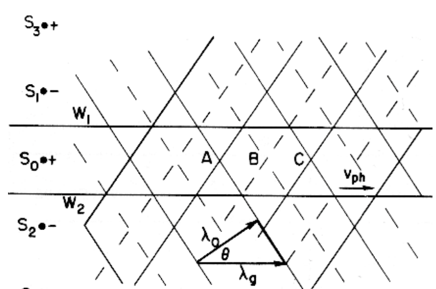

Fig. 24–17. The waveguide field can be viewed as the superposition of two trains of plane waves.

Fig. 16. Image credit: Addison-Wesley, 1964.

It can be seen from Fig. 16 that a wave slanting up, combined with a wave slanting down, can 'superpose' to produce the illusion of transverse and longitudinal components.

Griffiths [10] p. 392 calls the "bouncing" TEM wave "…an ordinary plane wave, traveling at an angle θ …which serves to illuminate many of these results…."

Using the conventions in Fig. 17 from [40] (noting that (d) is turned sideways to the rest), the group and phase velocities, with $v = c_{\mathrm{M}} = c\,/\,n$, are illuminated as

$$v_{\mathrm{p}} = \frac{c}{n \sin\theta} \ , \tag{41}$$

$$v_{\mathrm{g}} = \frac{c}{n} \sin\theta \ . \tag{42}$$

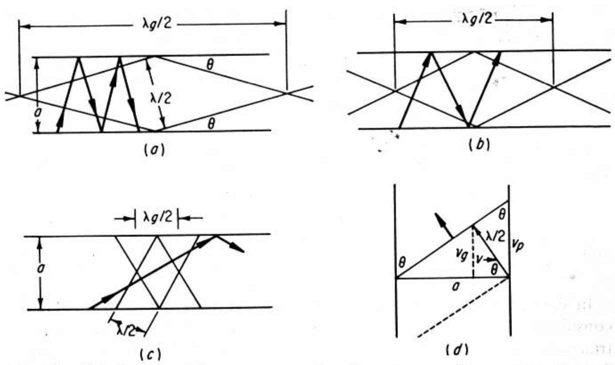

Fig. 7-4 Relationship of free-space wavelength and waveguide wavelength. Low frequency and the corresponding long wavelength is represented at (*a*). At (*b*), the frequency is higher than at (*a*) and lower than at (*c*). (*d*) Velocity and wavelength relationships.

Fig. 17. Relationships between incident, group, and phase velocities and wavelengths. Image credit: McGraw-Hill, 1964.

From Fig. 17 the mode wavelength is simply

$$\sin\theta = \frac{v}{v_{\mathrm{p}}} = \frac{\lambda}{\lambda_{\mathrm{g}}} , \tag{43}$$

where λ is the free space wavelength. The cut off wavelength is found from a casual inspection of Fig. 17 to be

$$\lambda_{\mathrm{cutoff}} = 2a , \tag{44}$$

because the wave is bouncing back and forth perpendicular to the long axis without moving forward into the tube. Whether it therefore decays exponentially in the longitudinal direction cannot be established without experiment—another example of the edge of the TEM wave where Maxwell is mute.

The higher sinusoidal harmonics, 'eigenvalues', etc. are easily found by subdividing the cross section into integral-number sub-waveguides, as treated in [39]. The Maxwellian treatment does not cover all possible modes of propagation in the waveguide: nor can any analogous expansion for other physics. Consider a short pulse launched from feed geometry X.

Consider a waveguide that flares out into an antenna horn. If the waves in the waveguide, which are fed by TEM waves from a two-conductor line, are different from the ones in free space, then some sort of new-physics process has to take place at the mouth of the horn and another one earlier at the feed, first to convert the incoming TEM waves to TE, TM waves, then to convert those into free-space TEM waves. I don't believe that there is any new physics here, just the same TEM waves changing their geometry in response to their environment.

To push the idea a little further, this zig-zag motion may be the mechanism behind refraction in a dielectric. The TEM wave never moves at anything but *c*, it merely appears to move slower as it is diffracted at an angle from one atom to the next: the larger the angle, the greater the index, the slower the net velocity. The diffraction angle, using the angle convention in Fig. 17, is simply

$$\theta = \sin^{-1}\left(\frac{1}{n}\right) , \tag{45}$$

and so refraction would be a collective form of diffraction, an idea that may be old.

The TEM Waveguide is a kind of crossover case from the Contrapuntal Catt Capacitor to free-space wave propagation. It has features of both. The TE, TM modes appearing to move at much less than *c*—depending on the shape of the metal tube—are quite like the illusory static fields of the Catt Capacitor, allegedly moving at zero speed. As with that case, better things come from better theory. This is an easily tested hypothesis—by launching sub-cutoff-wavelength pulses down a waveguide and measuring the radiation pattern at the horn.

9. The Voltage of the Photon

An electric field has a voltage along it, so many volts/meter by definition, and since the photon is supposed to have a transverse electric field there has to be a voltage of a photon. If it doesn't have a voltage then it doesn't have an electric field. The same can be said of the classical free-space TEM wave. It has an electric field: the "**E**" in TEM. If it were an infinite plane wave, the voltage would have to be infinite or the electric field strength would be zero. So how much voltage does a plane TEM wave have? How long and how wide is a photon? As it has a frequency, how many times does it wiggle?

The photon itself, a quantized TEM wave, may be an example of the TEM pulse, the penultimate basic primitive of "TEM Wave Electrodynamics". The least amount of undulation that a wave can make and still be assigned a frequency and polarization is ½ of one cycle. Emission and absorption by way of the famous "quantum jump", or transition, is an example of a very short process taking place without any obvious cycling between initial and final states (though there are speculations that posit this kind of cycling). These types of transitions might not "wiggle" around between initial and final states. Anything more than ½ of a cycle reverses the fields and so adds a complication to the transition process. A half-wave "pulse photon" has no entities multiplied beyond necessity while still being divisible [41] and polarized, with the usual twist in the case of circular polarization. A ½-cycle pulse-wave of finite transverse extent looks a lot like a particle.

For a free-space wave in vacuum, I speculate that

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \sqrt{\frac{L}{C}} = \sqrt{\frac{L_{\mathrm{L}}}{C_{\mathrm{L}}}} = \frac{V}{i} = \frac{V}{Q_{\mathrm{L}}c} = \frac{\phi_{\mathrm{L}}c}{i} = 377\Omega , \tag{46}$$

since electric current has been shown to be massless and moving at c. Let $i^2 = P/Z_0$, $i = \sqrt{P/Z_0}$, and $V = iZ_0$ for the photon and for the classical TEM wave. For a photon of wavelength λ the defining energy equation is

$$E_{\mathrm{p}} = hf = \frac{hc}{\lambda} . \tag{47}$$

The total length of a half-cycle pulse photon is $x = \lambda/2$; its time of passage is $t_{\mathrm{p}} = 1/(2f)$. Power of this photon is therefore

$$P_{\mathrm{p}} = \frac{E_{\mathrm{p}}}{t_{\mathrm{p}}} = \frac{hc}{\lambda}\frac{2c}{\lambda} = 2hf^2 , \tag{48}$$

proportional to frequency squared as expected. The 'electric current' of this photon is then

$$i_{\mathrm{p}} = \sqrt{\frac{P_{\mathrm{p}}}{Z_0}} = f\sqrt{\frac{2h}{Z_0}} , \tag{49}$$

bearing in mind that this 'current' refers to the edge of the TEM wave moving at *c* as before. Now

$$V_p = i_p Z_0 = f\sqrt{2hZ_0} \tag{50}$$

is the RMS voltage of the ½ wavelength photon. The factor of 2 comes from the assumption of a ½-cycle square wave without rise or fall time. Without those assumptions, the time factor could be different—perhaps 1 as for a single, full-cycle wave. For that case the current and the average voltage of the photon become

$$i_p = \sqrt{\frac{P_p}{Z_0}} = f\sqrt{\frac{h}{Z_o}} \tag{51}$$

$$V_p = i_p Z_0 = f\sqrt{hZ_0}\ , \tag{52}$$

a result as elegant as any. Putting in numbers, the root term is 4.9962398*10-16 J-sec/C. At 1 gHz, the voltage is then 5×10^{-7} V. The voltage of the 121.6nm H first ground transition (Lyman 1->2) works out to be 1.23V. The voltage of some electronic-transition radiation appears to be in the range of electrochemical voltages, an interesting result, though not directly congruent with the 10.2eV energy of the transition. This speculative linear association of specific voltages with specific photon frequencies is possibly novel, and is not intended to validate the photon concept beyond an artifact of emission from a quantized object.

10. The TEM-Ring Electron

Catt introduces a spherical electron [7] p. 10 composed entirely of Energy Current, or TEM waves, moving in circles about a sphere of tiny radius, with one side of the wave always pointing inwards. This model has the same stability problems as a spherical charge distribution—it would probably explode. Nonetheless, the central idea of a purely electromagnetic mass is there, but only if the side of a TEM wave is a gradient that has no charge.

According to Arthur Compton [42, 43], who studied their behavior in great detail, low-energy electrons scatter as if they are loops. This appears to be in direct contradiction to how they scatter at high energy.

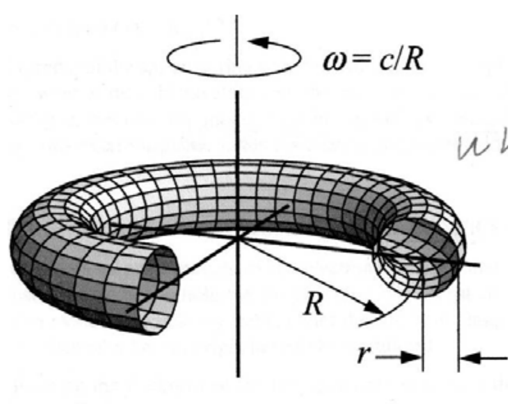

Figure 1: The Spinning Ring Model of the Electron

Fig. 18. From [44]. Image credit: David Bergman, 1990.

Bergman and Wesley [44] propose a spinning loop, or ring, of charge, and shows how this structure may be made stable by its electric and magnetic forces balanced in opposition (Fig.18). The total charge, *e*, is a kind of insubstantial substance that moves at *c*—an electric current, *i*. In this idea, the magnetic moment of the electron is found by direct, straightforward calculation.

Bergman [45] and Lucas [46] then show, among other things, how this loop structure absorbs radiation and reduces to 'point-like' scattering at higher energies by contraction under acceleration.

With these models as the starting place, the TEM-wave ring electron, speculative for now, only changes a few features of each while presuming to retain the results and character of the spinning-ring electron (Fig. 18).

The static electric and magnetic fields of the electron are replaced with the electromagnetic fields of the TEM wave, always moving at c, going in a circle, confining itself.

The TEM wave is a Heaviside slab-wave; it does not undulate unless perturbed. The electric and magnetic fields do not cause each other; they are co-existing aspects of the TEM wave. There is an irreversible, but non-dissipating process at work here.

The circling TEM wave maintains a constant energy density at every radius unless perturbed, maintaining the illusion of static fields just like the Catt Capacitor and the Catt Inductor.

The spinning ring of charge, moving at *c* in a toroidal fiber of small minor radius, is simply the gradient at the side of this TEM wave, just like the side of the laser beam. The TEM wave is massless, moving at *c*.

The circling TEM wave is automatically a (Galilean) relativistic light clock.

The positron is the same structure turned inside out; the positive side of the TEM wave changes places with the negative side. The circling, self-confined TEM wave simply 'predicts' the positron.

This structure is entirely electrodynamic—it is composed entirely of "flat-top", i.e., "slab", TEM waves. Inertial mass is proposed to be an effect of a self-confined, circulating, Heaviside TEM slab-wave. When it travels in lines, we call it electricity and light; when it travels in circles we call it matter.

If we presume that the two charges are in reality the gradient on opposite sides of two sets of reciprocating or circling TEM wave fields, then the force which appears between the 'charges' is caused by the one TEM wave moving through the other, *just as with the net force that develops between two wires when two pulses are present*. Q^2 is expresses the TEM waves of that interaction.

I did this work on the electron, waveguide, and some of the other things in 2005-6 but have not published on it until now. One difficulty with this electron model is the idea that TEM waves can bend, go around corners, and go in circles, with all parts moving at the speed of light. This is as the "Electric Corner" problem described in Fig. 5. Since we know that electricity is composed of TEM waves and we know that it can go around a corner without much complaint, we then know there are gaps in our knowledge. Such "self-bending" light rays have been proposed [47] and perhaps observed: "In 2007, physicists… manipulating laser light... found that the resultant beam curved slightly as it crossed a detector."

11. Conclusion

The development above is neither complete nor definitive, just a work in progress, albeit one already giving spectacular results.

> *We now have experimental proof that...[h]alf the energy in a charged capacitor is travelling from right to left at the speed of light,*

and the other half from left to right…there is no such thing as a stationary field, electric or magnetic. Not only in the case of a charged capacitor, but always….” —Ivor Catt [49]

Catt has opened the door to a previously unknown world of great promise. Who will walk through that door?

References

[1] O. Heaviside, **Electromagnetic Theory,** 3rd Ed., Vol. 1-3 (Chelsea Publishing Co., ISBN 0821835637, 1971).

[2] I. Catt, “The Catt Question”, www.electromagnetism.demon.co.uk/cattq.htm.

[3] I. Catt, **The Catt Anomaly,** 2nd Ed., (Westfields Press, ISBN 09063 40152, 2001), www.ivorcatt.com/28anom.htm.

[4] J. Ellis, “‘Alien’ Sinewaves Concept?”, *Electronics World*, p. 42 (June 2009), www.electronicsworld.co.uk.

[5] I. Darney, “Transmission Line Transients”, *Electronics World*, p. 42 (June 2009), www.electronicsworld.co.uk.

[6] M. Pepper, Response Letter to Master of Trinity and Catt (1993), http://www.ivorcatt.com/2812.htm.

[7] I. Catt, **Electromagnetics I,** 2nd Ed., (Westfields Press, ISBN 09063 40101, 2001), www.ivorcatt.com/em.htm.

[8] B. Josephson, in email circulation (2006-2012).

[9] K. T. McDonald, Antenna Discussion List, (17 Mar 2012), http://antennex.com/listarch/archives.html.

[10] D. J. Griffiths, **Introduction to Electrodynamics**, 2nd Ed. (Prentice Hall, ISBN 0134813677, 1989).

[11] H. Härtel, “Voltage—a Basic Term in Electricity”, http://www.astrophysik.uni-kiel.de/~hhaertel/PUB/voltage_girep.pdf.

[12] B. Sherwood, “Charges in Circuit” (1999), http://www.matterandinteractions.org/Content/Articles/circuit.pdf.

[13] O. Jefimenko, “Demonstration of Electric Fields of Current-Carrying Conductors”, *AJP* **30**: 19-21 (1962), http://electret-scientific.com/author/ajp/1962ajpv30n1pp19-21.pdf.

[14] www.matterandinteractions.org/Content/Materials/Videos/SurfaceCharge.mov.

[15] A. T. Fromhold Jr., **Quantum Mechanics for Applied Physics and Engineering** (Dover, ISBN 0486667413, 1981).

[16] D. Halliday, et al., **Physics,** 4th Ed., Vol. 2, Extended (Wiley, 1992).

[17] I. Catt, **Electromagnetic Theory**, Vol. 2 (C.A.M. Publishing, St. Albans, England, ISBN: 0906340039, 1980, 1986), http://www.forrest bishop.4t.com/EMTV2/EMTVolumeII.htm.

[18] Williams, et al., NIST, “Absolute Determination of the Ampere”, http://nvlpubs.nist.gov/nistpubs/sp958-lide/056-058.pdf.

[19] I. Catt, “Does Faraday Allow Superposition?”, *Proceedings of the NPA* **8**: 111-116 (2011), www.worldsci.org/pdf/abstracts/abstracts_6168.pdf.

[20] K. T. McDonald, Antenna Discussion List (16 Mar 2012), http://antennex.com/listarch/archives.html.

[21] H.A. Haus, J. R. Melcher, **Electromagnetic Fields and Energy**, MIT, HTF, (1998) http://web.mit.edu/6.013_book/www, http://web.mit.edu/6.013_book/www/book.html.

[22] N. Gauthier, “What Happens to Energy and Momentum When Two Oppositely-Moving Wave Pulses Overlap?”, *Am. J. Phys.* **71**:797-790 (2003).

[23] R. Feynman, **The Feynman Lectures on Physics**, Vol I-III, (Commemorative Issue, Addison-Wesley, 1989, 1964).

[24] F. Bishop, “The Fine-structure Constant and Some Relationships Between the Electromagnetic Wave Constants”, *Apeiron* **14** (4): 379-384, (Oct 2007), http://redshift.vif.com/JournalFiles/V14NO4PDF/V14N4BIS.pdf.

[25] I. Catt, G. Walton, M. Davidson, "Displacement Current...", *Wireless World* 51-52 (Dec 1978), www.ivorcatt.org/icrwiworld78dec1.htm.

[26] L. F. Woodruff, **Principles of Electric Power Transmission,** 2nd Ed., p. 165, Fig. 87 (Wiley, 1938).

[27] MIT Radar School Staff, **Principles of Radar,** 2nd Ed., pp. 6-4ff (McGraw Hill, 1946).

[28] K. Nalty, “Propagation, Termination and Discharge Labwork for Coaxial Transmission Lines” (2008), http://www.kurtnalty.com/TransmissionLines.

[29] I. Catt, F. Bishop, “…Computer Simulations”, http://www.forrestbishop.4t.com/THEORY_C_ANIMATIONS/THEORY_C_ANIMATIONS.htm.

[30] F. Bishop, “A Coherent Reframing of the Master Equations of Electromagnetic Theory”, *General Science Journal* (2011), http://wbabin.net/Science-Journals/Essays/View/3846.

[31] A. O’Rahilly, **Electromagnetics: A Discussion of Fundamentals** (Longmans, Green and Co. Ltd., 1938).

[32] W.B. Boast, **Vector Fields** (Harper & Row, 1964).

[33] P.A. Tipler, **Modern Physics** (Worth, 1978).

[34] P. Cameron, “Photon Impedance Match to a Single Free Electron”, *Apeiron* **17** (3): 193-200 (Jan 2010).

[35] K. von Kiltzing, “25 Years of Quantum Hall Effect (QHE): A Personal View on the Discovery…”, *Sèminaire Poincaré* **2**: 1-16 (2004), www.bourbaphy.fr/klitzing.pdf.

[36] F. Bishop, “The Death of Voltage”, *General Science Journal* (2011), http://wbabin.net/Science-Journals/Essays/View/3815.

[37] J.D. Jackson, **Classical Electrodynamics,** 2nd Ed. (Wiley, ISBN 0471 43132X, 1975).

[38] L. Page, N. I. Adams, “Electromagnetic Waves in Conducting Tubes”, *Physical Review* **52**: 647 (1937).

[39] J. Kemp, “Electromagnetic Waves in Metal Tubes of Rectangular Cross-section”, *Electrical Communication* **XX** (2): 73-79 (1941).

[40] A. L. Lance, **Introduction to Microwave Theory and Measurement**, (McGraw-Hill, LoC 63-23468, 1964).

[41] E. Reiter, **The Unquantum Effect**, www.unquantum.net.

[42] A. H. Compton, “The Size and Shape of the Electron”, *Phys. Rev.* **14:** 20 (1919).

[43] A. H. Compton, “The Size and Shape of the Electron”, *Phys. Rev.* **14:** 247-259 (1919).

[44] D. L. Bergman and J.P. Wesley, “Spinning Charged Ring Model of Electron Yielding Anomalous Magnetic Moment”, *Galilean Electrodynamics* **1**: 63-67 (1990).

[45] D. L. Bergman, “Forces on Moving Objects”, *Proceedings of Physics as a Science,* Cologne (1997), http://www.commonsensescience.org/pdf/articles/forces on moving objects.pdf.

[46] D. L. Bergman, C.W. Lucas, “Physical Models of Matter”, *Proceedings of Physics as a Science* (1997), Cologne, http://commonsensescience.org/pdf/articles/physical_models_of_matter_correct.pdf.

[47] N. Owano, “Physicists Turn to Maxwell’s Equations for Self-Bending Light” (12 Apr 2012), http://phys.org/news/2012-04-physicists-maxwells-equations-self-bending.html.

[48] A. Wakefield, private communication (May 2012).

[49] I. Catt, “The End of the Road”, *Electronics World* (2012) in press.