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Cable Telegraphy and Poynting's Theorem

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Abstract. Wireless EM radiation relates to magnetization while the magnetic fields that travel alongside the conducting wires in transmission lines are commonly associated with capacitance and linear polarization. This article will examine how these two phenomena may or may not be treated using the same basic electromagnetic wave equations.

The Electromagnetic Wave Equations

I. The original electromagnetic wave equation for wireless radiation,

$$\nabla^2\mathbf{H} = \mu_o\varepsilon_o\partial^2\mathbf{H}/\partial t^2 \qquad \textbf{(1)}$$

was derived in 1864 for the magnetic intensity vector **H** by Scottish physicist James Clerk Maxwell. It appeared in his 1865 paper ***"A Dynamical Theory of the Electromagnetic Field"***, and it was derived in connection with the electromagnetic momentum vector **A**, where $\nabla\times\mathbf{A} = \mu_o\mathbf{H}$ **[1]**. Since **H** is a vorticity in the momentum field, equation **(1)** must be describing the propagation of angular acceleration through a sea of tiny aethereal vortices that pervade all of space **[2]**.

This is further confirmed by the fact that another EM wave equation can be derived for the electric field vector **E**, where $\mathbf{E} = -\partial\mathbf{A}/\partial t$, providing that $\nabla\cdot\mathbf{E} = 0$. This could be the case for a radial **E** providing that it obeys an inverse square law in distance, but then this would mean that $\nabla\times\mathbf{E} = 0$, whereas the derivation requires that $\nabla\times\mathbf{E} = -\mu_o\partial\mathbf{H}/\partial t$ (Faraday's Law). The only alternative is that **E** represents a force that accelerates **A** transversely to the polar origin, as would be the case in the context of a vortex that is undergoing angular acceleration. We'll call the force $\mathbf{E}_K$ in order to distinguish it from the radial electrostatic $\mathbf{E}_S$. In a steady state magnetic field, the momentum density, **A**, will represent the aether circulation within the individual vortices and no transfer will be taking place between neighbouring vortices, but in the dynamic state where angular acceleration takes place, there will be an overflow of aether from the vortices to their immediate neighbours. This is known as time varying electromagnetic induction and it is the basis of electromagnetic waves.

The speed of these waves is c, where $c^2 = 1/\mu_o\varepsilon_o$, with μ_o representing magnetic permeability and ε_o representing electric permittivity, and where c is the speed of light. The magnetic permeability is related to the magnetic flux density while the electric permittivity is inversely related to the elasticity and the dielectric constant. The equation $c^2 = 1/\mu_o\varepsilon_o$ is then essentially Newton's equation for the speed of a wave in an elastic solid, equivalent to $\mathbf{E} = mc^2$ in the context **[3]**.

The Telegrapher's Equations

II. A telegrapher's equation linking electric signals in a conducting wire to the speed of light was first derived by German physicist Gustav Kirchhoff in 1857 **[4]**. This was four years before Maxwell linked the speed of light to electric and magnetic phenomena in space, and seven years before Maxwell derived the electromagnetic wave equation. The commonality between Kirchhoff's telegrapher's equation and Maxwell's EM wave equation is the fact that both used the result of the 1855 Weber-Kohlrausch experiment in order to import the speed of light into the proceedings. The 1855 experiment was the first historical linkage between optics and electromagnetism **[5]**. It involved establishing the ratio between electrodynamic and electrostatic units of electric charge by discharging a Leyden jar (a capacitor).

Some years later in 1883, English physicist John Henry Poynting made a proposal regarding the transfer of energy in electric circuits. While it was traditionally accepted that electric energy is transferred through the conducting wires in a circuit, Poynting proposed that at least some of the energy is actually transferred through the space outside the conducting wires **[6]**. This idea was also taken up by English electrical engineer Oliver Heaviside **[7]**. From then on, it has been assumed that the telegrapher's equations apply to the electric and magnetic fields that propagate alongside the electric current in a wire in the dynamic state, and that this is what Kirchhoff had been originally driving at.

The telegrapher's equations are in all essential details the same as the electromagnetic wave equations only they traditionally derive from the capacitance and the self-inductance within a laboratory electric circuit, with $Q = CV$ replacing the electric elasticity equation $\mathbf{D} = \varepsilon\mathbf{E}$ (Maxwell's

Fifth Equation) in the wireless equivalent. But since capacitance involves the electrostatic force, $\mathbf{E_S}$, while inductance involves the electromagnetic force, $\mathbf{E_K}$, then we should not ideally be able to combine the capacitative and the inductive parts in the same analysis. Besides, $\mathbf{E_S}$ acts perpendicularly to the conducting surfaces while $\mathbf{E_K}$ acts along the conducting wires. Furthermore, the propagation of the electric current in the wire is being driven by the external power source and not by the induced back EMF. It would therefore seem that Kirchhoff has actually derived the electromagnetic wave equation for wireless waves, while wrongly applying the electric permittivity to capacitance rather than to the inductive displacement current, $\mu_o\varepsilon_o\partial\mathbf{E_K}/\partial t$, which he knew nothing about at the time **[8]**. It looks like Kirchhoff assumed that he had derived a wave equation in connection with an electric signal in a wire where in fact he had really just derived the electromagnetic wave equation for waves travelling through space, similar to what Maxwell would later derive.

The question still remains though as to how the speed of signals in a wire is so closely related to the speed of light. It has previously been suggested in ***"The Telegrapher's Equations"*** **[9]**, that the reason why a signal propagates along a wire at the speed of light is because electric current is in fact more fundamentally an aethereal electric fluid which flows from positively charged particles (sources) to negatively charged particles (sinks) at an average speed in this same order of magnitude The first tendency then when the power is connected to any electric circuit will be for the current to move into the outgoing conducting wire and immediately cut across the dielectric gap to the return wire. This will linearly polarize the dielectric space between them and set up a back EMF which will impede further current flow across the gap. The current will therefore carry on along the outgoing wire while continually splitting and branching off at right angles into the surrounding dielectric and then back along the return wire.

Polarization and Magnetization

III. Poynting's and Heaviside's attentions were focused on the moving magnetic field that accompanies a pulse of electric current in a wire. If we consider a single pulse in an AC current, then due to the charge density in the wire, there will be an electrostatic field radiating outwards from the wire at right angles to the magnetic field. It's upon this basis that many people think that we are dealing with electromagnetic radiation and that we can apply the Poynting vector, $\mathbf{S} = \mathbf{E_S}\times\mathbf{H}$, where $\mathbf{E_S}$ is the electrostatic field. This travelling magnetic field however does not constitute electromagnetic radiation. Electromagnetic waves radiate into space perpendicularly from the conducting wire and they are based around the time varying electromagnetic induction relationships, $\mathbf{E_K} = -\partial\mathbf{A}/\partial t$, where $\nabla\times\mathbf{A} = \mu_o\mathbf{H}$. The magnetic field that travels alongside a pulse of electric current in a wire is a convective effect involving an electrostatic field superimposed upon a magnetic field. It is not a wave and its motion is sourced in the electric current in the wire.

Electric current is fundamentally a flow of the primordial electric fluid known as the aether. It's the stuff that everything is made of. It is denoted by **A** and it is known variously as the *electrotonic state*, the *electromagnetic momentum*, the *displacement current*, or the *magnetic vector potential*. As it flows through conducting wires, it has a tangential effect on the surrounding dielectric space, and this induces a leakage which results in the creation of a magnetic field. The electrostatic pressure in the current, known as the electric charge, also results in a leakage, but this time moving radially outwards from the wires. If space is dielectric and the individual constituent dipoles are rotating, then we have a basis upon which to distinguish between magnetization on the one hand and linear polarization on the other hand. See ***"The Double Helix Theory of the Magnetic Field"*** **[10], [11].**

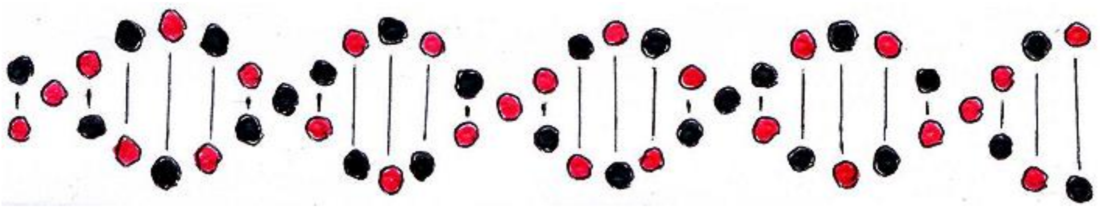

Fig. 1. A single magnetic tube of force. The electrons are shown in red and the positrons are shown in black. The double helix is rotating about its axis with a circumferential speed equal to the speed of light, and the rotation axis represents the magnetic field vector **H**.

Magnetization is the alignment of the rotating dipoles along their mutual rotation axes as this occurs naturally in conjunction with Ampère's Circuital Law, which is closely related to the fundamental Coriolis force. The rotation axes determine the direction of the magnetic field lines **H**. Polarization on the other hand is the separation of charges due to the application of an external electric field. When an electrostatic field is applied parallel to a magnetic field, it causes a torque which induces a precession in the tiny rotating dipoles. This has a destructive effect on a magnetic field. However, when we apply an electrostatic field at right angles to a magnetic field, as is the case in the immediate vicinity of a current carrying wire in the dynamic state, then the convective electromagnetic force, $\mathbf{F} = q\mu_o\mathbf{v}\times\mathbf{H}$, is induced in the **A** field that is associated with the electrostatic $\mathbf{E_S}$ field **[12]**. This deflecting force will cause **A** to swirl and get embroiled in the already existing sea of dipolar aether vortices, and as such it will enhance the already existing magnetic field. In the all-pervading electron-positron sea, an electrostatic field at right angles to a magnetic field is where polarization and magnetization converge.

The Speed of an Electric Signal in a Conducting Wire

IV. The convergence of magnetization and polarization when an electrostatic field is superimposed at right-angles to a magnetic field is of importance in the first moments after the power is connected to an electric circuit. The non-zero charge density, which arises in the conducting wire in the dynamic state, constitutes an aether pressure that expands into the surrounding dielectric, which due to the current flow, is in a magnetized state. This is different from the case of electric current that flows into a parallel plate storage capacitor. In the latter, the geometry is not conducive to the induction of a magnetic field around the plates so there will then be no magnetic field perpendicular to the current which flows across the plates. Hence the current crossing between the plates encounters a capacitative impedance which grinds the current to a halt. But in the case of a circuit which has just been switched on, the leakage current moving sideways out of the wires encounters an inductive impedance from the magnetic field.

In the first moments after the power is connected, the electric current will expand as a closed circulation surrounded by a magnetic field, and the part of the current that enters the dielectric space will encounter an inductive impedance exactly as in the case of the part that moves in the conducting wire. This means that the problems raised section **II** above regarding the derivation of the telegrapher's equation have been partly solved. The aethereal current flows around the circuit at a speed in the order of the speed of light, although this speed is pressure (voltage) dependent as per Bernoulli's Principle, and any changes that occur to either the current or the voltage in the dynamic state will therefore be propagated with the flow at its instantaneous speed. The parameters that determine the impedance in the conducting wire due to the changing magnetic field, as in electric permittivity and magnetic permeability, are the same as those used in the electromagnetic wave equation for waves in space, and so we might then be willing to accept that Kirchhoff's telegrapher's equation correctly applies to the speed of an electric signal along a wire. There are however more variables to consider. The pressure (electric charge) in the conducting wire is caused by the external power source and this differs from the standard pressure of the all-pervading electron-positron sea at large. As the current in the conducting wire expands into the surrounding space, it transforms from a simple flow into a fine-grained vortex flow at a reduced pressure and an increased speed, as per Bernoulli's Principle. The fine-grained vortex flow constitutes wireless electromagnetic radiation and it is this which both the electromagnetic wave equations and the telegrapher's equations apply to. They do not apply to the speed of an electric signal along a wire. In low voltage situations however, where the pressure will be closer to that in the background electron-positron sea, the speed of electric signals along a wire will surely be close to the speed of light.

Poynting's Theorem

V. Poynting's theorem follows from the equation of continuity as used in the context of energy density,

$$\nabla\cdot\mathbf{S} - \partial w/\partial t = 0 \qquad \textbf{(2)}$$

where **S** is the rate of flow of energy per unit area across a surface and *w* is the energy density. It is applied to regions of space where the energy density is the sum of the electric energy density $½\varepsilon_o\mathbf{E}^2$ and the magnetic energy density $½\mu_o\mathbf{H}^2$ as per,

$$w = ½[\varepsilon_o\mathbf{E}^2 + \mu_o\mathbf{H}^2] \qquad \textbf{(3)}$$

So long as we can link **E** and **H** through Faraday's Law, $\nabla\times\mathbf{E_K} = -\mu_o\partial\mathbf{H}/\partial t$, and Ampère's Circuital Law, $\nabla\times\mathbf{H} = \varepsilon_o\partial\mathbf{E_K}/\partial t$, then we can use the vector identity $\nabla\cdot(\mathbf{E_K}\times\mathbf{H}) = (\nabla\times\mathbf{E_K})\cdot\mathbf{H} - \mathbf{E_K}\cdot(\nabla\times\mathbf{H})$ to show that $\mathbf{S} = \mathbf{E_K}\times\mathbf{H}$. The vector $\mathbf{E_K}\times\mathbf{H}$ is known as the Poynting vector. The electrostatic $\mathbf{E_S}$ does not contribute towards the Poynting vector which therefore applies exclusively to wireless electromagnetic radiation and electromagnetic induction. The best applications of the Poynting vector will be in the case of AC transformers.

Poynting and Heaviside got confused between wireless radiation on the one hand and travelling magnetic fields in an electric circuit on the other hand. The Poynting vector applies to the radiation that radiates outwards from an electric circuit in the dynamic state, or inwards when the power is switched off. It does not apply to the simple current in the wire or to the magnetic field which moves along with a discrete pulse of simple current.

As regards trying to apply Poynting's theorem to wireless EM radiation beyond the near field of an electric circuit, there is the problem of isolating distinct values for **E** and **H**. This would be difficult in the case of starlight in deep space because the disturbance is passing through the already existing background magnetic field rather than carrying its own magnetic field with it. Nevertheless, wireless waves in space still operate under the principle of electromagnetic induction which means that energy is being continually transferred between electric circuits. This implies that space needs to be densely filled with tiny electric circuits. That's where Maxwell's sea of molecular vortices plays a role **[2]**, **[3]**, **[13]**, **[14]**. The sea of vortices is of course the sea of dipolar electron-positron vortices.

Light is often treated using the packaging theory know as *quantum mechanics* where relationships are dealt with in terms of the energies associated with emissions and absorptions from different sources. This in no way detracts from the underlying fundamental electromagnetic wave nature of light.

The DC Transmission Line Pulse

VI. There is an interesting case involving a DC pulse in a parallel wire transmission line. In such a pulse, the external power is disconnected before it reaches the end of the line, but it continues on its own momentum under Newton's first law of motion, while bringing its magnetic field with it. There will be no electrostatic field because the sources and sinks have been disconnected and the aethereal electric current flow is solenoidal. The electric current circulating around the edge of the pulse is akin to a free-wheeling caterpillar track riding on the return wire. No time varying electromagnetic induction is involved, and neither is there an electric field, and so the Poynting vector does not apply.

Before the power is actually disconnected, the leading edge of the pulse will be pushed along under the pressure (voltage) from the power source. When the power is disconnected, the pressure in the pulse will equalize and the pulse and its magnetic field will spread out to a maximum equilibrium length at a pressure in harmony with the background electron-positron sea. It is at this truncated stage where the speed will be closest to the speed of light.

On the other hand, in the case of a storage capacitor, the current on the large scale will grind to a complete halt although it will continue at the speed of light on the fine-grained scale within the individual precessing electron-positron dipoles.

Conclusion

VII. A wave is a propagated disturbance in a particulate medium and its associated elasticity is related to the inter-particle bonding forces. These bonding forces in turn are determined by the speed of flow of the fundamental aethereal medium that exists in the interstitial spaces between the particles and which mediates the bonding forces. This fundamental medium is the primordial electric fluid from which everything is made. It's the aether. It flows between positive particles (sources) and negative particles (sinks) at an average speed in the order of the speed of light. In a conducting circuit, the electric fluid enters under pressure from the positive terminal and it pushes positive charges along with it. Meanwhile negative particles eat their way in the opposite direction towards the positive source at the terminal. Due to resistance in a conducting wire, these particles are never accelerated to anything like the speed of the aether itself. Electromagnetic radiation is a complex flow of electric fluid through a sea of tiny vortices that pervades all of space. This flow radiates outwards from the side of a conducting wire when the conduction current is in the dynamic state. Inside the conducting wire when the power is connected, the current will be in a compressed state, but when it expands into the surrounding space it will equalize with the background sea of tiny dipolar aether vortices. With the pressure reduced at the boundary, then as per Bernoulli's Principle, the speed will increase, and it will increase to the speed of light. The telegrapher's equations do not therefore accurately apply to the speed of electric signals along a conducting wire, and neither to the magnetic fields that travel alongside discrete pulses of electric current. At low voltages however, the speed of an electric signal along a conducting wire will be close to the speed of light.

References

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http://gsjournal.net/Science-Journals/Historical%20PapersMechanics%20/%20Electrodynamics/Download/4105
In relation to the speed of light, *"The most probable surmise or guess at present is that* ***the ether is a perfectly incompressible continuous fluid, in a state of fine-grained vortex motion,*** *circulating with that same enormous speed. For it has been partly, though as yet*

incompletely, shown that such a vortex fluid would transmit waves of the same general nature as light waves— i.e., periodic disturbances across the line of propagation—and would transmit them at a rate of the same order of magnitude as the vortex or circulation speed"

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https://www.researchgate.net/publication/338898407_The_Significance_of_the_Poynting_Vector

[13] Whittaker, E.T., ***"A History of the Theories of Aether and Electricity"***, Chapter 4, pages 100-102, (1910)
"All space, according to the younger Bernoulli, is permeated by a fluid aether, containing an immense number of excessively small whirlpools. The elasticity which the aether appears to possess, and in virtue of which it is able to transmit vibrations, is really due to the presence of these whirlpools; for, owing to centrifugal force, each whirlpool is continually striving to dilate, and so presses against the neighbouring whirlpools."

[14] O'Neill, John J., ***"PRODIGAL GENIUS, Biography of Nikola Tesla"***, Long Island, New York, 15th July 1944, quoting Tesla from his 1907 paper ***"Man's Greatest Achievement"*** which was published in 1930 in the Milwaukee Sentinel,
"Long ago he (mankind) recognized that all perceptible matter comes from a primary substance, of a tenuity beyond conception and filling all space - the Akasha or luminiferous ether - which is acted upon by the life-giving Prana or creative force, calling into existence, in never ending cycles, all things and phenomena. The primary substance, thrown into infinitesimal whirls of prodigious velocity, becomes gross matter; the force subsiding, the motion ceases and matter disappears, reverting to the primary substance".
http://www.rastko.rs/istorija/tesla/oniell-tesla.html
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Appendix I
(Cause and Effect in Faraday's Law and Ampère's Circuital Law)

It's well known that a changing magnetic field causes an electric field. This is expressed in Faraday's law of electromagnetic induction,

$$\nabla\times\mathbf{E}_{\mathbf{K}} = -\mu_o\partial\mathbf{H}/\partial t \qquad \textbf{(1A)}$$

It's also a well-established myth that Ampère's Circuital Law with Maxwell's displacement current added, as in,

$$\nabla\times\mathbf{H} = \varepsilon_o\partial\mathbf{E}_{\mathbf{K}}/\partial t \qquad \textbf{(2A)}$$

means that a changing electric field causes a magnetic field. But it means no such thing. That was never the basis upon which Maxwell derived the displacement current concept. Maxwell derived the concept on the basis of elasticity in a dielectric medium. See the preamble to Part III of Maxwell's 1861 paper ***"On Physical Lines of Force"*** **[3]**. An electric current causes a magnetic field, and the electric field which drives that electric current doesn't have to be changing.

When electromagnetic induction is occurring, both of these two equations describe a changing magnetic field causing an electric field. The electric field in question will necessarily be changing too, but that is incidental and nothing to do with any cause. The correct general rule, ***applying equally to both equations***, is that,

(1) A ***changing magnetic*** field causes an ***electric*** field.
(2) An ***electric*** field causes a ***changing magnetic*** field.