the general science journal

Cable Telegraphy and Poynting's Theorem

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24th July 2019

Abstract. Wireless EM radiation relates to magnetization while the waves that travel alongside the conducting wires in transmission lines relate to 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,

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

was derived for the magnetic intensity vector **H** by Scottish physicist James Clerk Maxwell in his 1865 paper ***"A Dynamical Theory of the Electromagnetic Field"***, and it was derived in connection with the electromagnetic momentum vector **A**, where $\nabla\times\mathbf{A} = \mu\mathbf{H}$ **[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 $\nabla.\mathbf{E} = 0$. 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 $\nabla\times\mathbf{E} = -\mu\partial\mathbf{H}/\partial t$ (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 when the aether flow is occurring between two neighbouring vortices. 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 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 will be c, where $c^2 = 1/\mu\varepsilon$, with μ representing magnetic permeability and ε 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 dielectric constant. The equation $c^2 = 1/\mu\varepsilon$ 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. The electromagnetic wave equations apply to wireless EM radiation in space and the derivation involves both Faraday's law for time varying EM induction and a reverse form of Ampère's Circuital Law where the current is being induced by a changing magnetic field. In a similar manner we can derive a variant of equation **(1)** using either voltage, *V*, or current, *I*, in connection with self-inductance within a laboratory electric circuit involving conducting wires. These latter two equations are known as the *"Telegrapher's Equations"*. A telegrapher's equation linking electric signals to the speed of light was first derived by German physicist Gustav Kirchhoff in 1857 **[4]**.

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 **[5]**. This idea was also taken up by English electrical engineer Oliver Heaviside **[6]**.

It was already known that electrical energy is transferred through the space between two electric circuits in the case of electromagnetic induction, but Poynting was now suggesting that directly applied electrical energy might also travel through space in the vicinity of conducting wires. In the steady state we would expect electric current and all electrical energy transfer to totally occupy the conducting wires, otherwise what would be their purpose? Who would ever observe a complex maze of electric wires and not think that they are the actual conducting channels for the flow of electrical energy? Poynting's theorem however, which is explained below in section **IV**, makes it clear by virtue of the time varying dependence of the **E** and **H** fields, that the electric space-waves which troll the conducting wires only occur in the transient state. The question then arises as to how these trolley-waves, bound to electric circuits, compare in physical nature to the wireless electromagnetic waves that travel through space, unbounded and far from electric circuits.

Linear Polarization

III. The transverse electric and magnetic waves that propagate alongside a conducting wire in a transmission line are a capacitive effect involving linear polarization in the surrounding dielectric. Faraday's law is not significant in a transmission line since we are concerned with the changing magnetic field that has been caused by the externally applied electric field. The externally applied **E** field may itself have been caused by the changing magnetic field of a primary winding at the power source, but that is of no interest with respect to the circuit under investigation. Since the electromagnetic wave equation at equation **(1)** was derived from Faraday's law, we can no longer assume that this equation will apply to the electromagnetic energy that is delivered as trolley-waves alongside the conducting wires. The wireless waves are an inductive effect whereas the trolley-waves are a capacitative effect.

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. Because electric permittivity, implicit and explicit in these two equations, can be linked to the speed of light through the 1855 Weber-Kohlrausch experiment, [7], it is believed that the telegrapher's equations relate to the speed of an electric signal in a conducting wire. But since capacitance acts perpendicularly to the conducting surfaces and since the current is not being powered by the self-induced back EMF, it's hard to see how these equations can relate to the signal speed in the wire. On the other hand, since experiments tend to confirm that the speed of an electric signal along a wire is indeed in the order of the speed of light, it would seem like a coincidence if the telegrapher's equations weren't in fact applicable in the context.

This problem can be solved firstly by changing the sign in Faraday's law and reversing its meaning so that we now have $\nabla\times\mathbf{E} = \mu\partial\mathbf{H}/\partial t$ referring to the changing magnetic field that is caused by the electric field supplied from the external power source. Secondly, in wireless EM radiation the displacement current, $\varepsilon\partial\mathbf{E}/\partial t$, is a fine-grained angular displacement (magnetization) current in the all-pervading sea of tiny aethereal vortices **[8]**, but in cable telegraphy it needs to be a linear polarization in a dielectric medium, at the point where this medium falls along the path of the electric current. Thirdly, since displacement current is now a reaction to the applied **E** field, we change the sign in Ampère's Circuital Law so that it becomes $\nabla\times\mathbf{H} = -\varepsilon\partial\mathbf{E}/\partial t$. As such we can then derive an equation identical to equation **(1)** but with the meaning changed so as to refer to the propagation of a signal through the dielectric space alongside an electric current in a conducting wire.

It had previously been suggested in ***"The Telegrapher's Equations"*** **[9]**, that the reason why a signal propagates along a wire at a speed in the order of 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 this same speed. 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 space 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 continue along the outgoing wire while continually splitting and branching off at right angles into the surrounding dielectric and back along the return wire.

The electric permittivity, ε, in the trolley-wave equation is the elasticity factor in the linear polarization, but it is also the direct linkage to the speed of light, hence implying that the elasticity itself is directly connected with the speed of the aether flow. See ***"The Double Helix Theory of the Magnetic Field"*** **[10]**. The cable telegraphy trolley-wave wave is therefore a wave of linear polarization caused by the lateral expansion of an electric current, from the conducting wire into the surrounding dielectric. The aethereal electric fluid current will be moving along the wire at a speed in the order of the speed of light. Positively charged particles will be accelerated by the electric fluid, but their terminal speed will never remotely reach the speed of light. Negative particles, being sinks, will eat their way in the opposite direction.

Since linear polarization of a rotating dipole leads to a precession, and since wireless EM waves also involve the precession of rotating dipoles, **[10]**, and since both the trolley-waves and the wireless waves involve a flow of aethereal electric fluid, and since both propagate at much the same speed, it would seem that the two kinds of waves are very closely related. Indeed, in the case of an antenna, there is a continuum transition between the two kinds of wave. One might object that a trolley-wave is powered by an external power supply, but as in the case of wireless waves, a trolley-wave is nevertheless self-propagating when the power supply is disconnected.

When Maxwell applied the electric elasticity equation $\mathbf{D} = \varepsilon\mathbf{E}$ to his magnetic wave equation **(1)**, he was taking somewhat of a liberty owing to the fact that the elasticity equation was based on space being dielectric, as opposed to being based on space being filled with aethereal vortices. It was the latter which Maxwell used to derive the equations of electromagnetic induction, but it was the former with which he linked the elasticity to the speed of light. Since however both the wireless (magnetic) waves and the cable (linear polarization) waves involve torque in rotating electron-positron dipoles, **[10]**, it would seem that Maxwell was justified in extending the dielectric elasticity into the magnetic realm.

Poynting's Theorem

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

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

where **S** is the rate of flow of energy per unit area across a surface and σ is the energy density. It is applied to regions of space where the energy density is the sum of the electric energy density $\frac{1}{2}\varepsilon\mathbf{E}^2$ and the magnetic energy density $\frac{1}{2}\mu\mathbf{H}^2$ as per,

$$\sigma = \tfrac{1}{2}[\varepsilon\mathbf{E}^2 + \mu\mathbf{H}^2] \qquad \textbf{(3)}$$

So long as we can link **E** and **H** through the equations $\nabla\times\mathbf{E} = \mu\partial\mathbf{H}/\partial t$ and $\nabla\times\mathbf{H} = -\varepsilon\partial\mathbf{E}/\partial t$ mentioned in section **III** above, then we can use the vector identity $\nabla.(\mathbf{E}\times\mathbf{H}) = (\nabla\times\mathbf{E}).\mathbf{H} - \mathbf{E}.(\nabla\times\mathbf{H})$ to show that $\mathbf{S} = -\mathbf{E}\times\mathbf{H}$. The vector $\mathbf{E}\times\mathbf{H}$ is known as the Poynting vector.

It's only in the vicinity of an electric circuit where we are likely to find a distinctly isolated and interconnected **E** and **H** where we can apply Poynting's theorem and the Poynting vector. We can then conclude in line with J.H. Poynting, that in the dynamic state, such as in the case of alternating current, that some of the energy in a circuit is transferred as a wave through the space outside the wires. In the case of the energy delivered between the two windings in an AC transformer, since we will now be dealing with electromagnetic induction, we will have to reverse the signs in the two curl equations again and this will lead to $\mathbf{S} = \mathbf{E}\times\mathbf{H}$ with a positive sign this time. By this analysis, the Poynting vector only applies in the dynamic state, meaning that in the steady state all the energy is channelled along the conducting wires.

In the case of an electrostatic field that surrounds a charged sphere, when this field is superimposed upon the steady state magnetic field of a bar magnet, no energy will be flowing, and so in this context the Poynting vector $\mathbf{E}\times\mathbf{H}$ will be even less meaningful than considering the axial vector $\mathbf{g}\times\rho\mathbf{v}$ for the case of a horizontal river flowing in a vertical gravitational field. The vital ingredient in Poynting's theorem which makes $\mathbf{E}\times\mathbf{H}$ a real live energy flow is the fact that the two Maxwell curl equations combine to predict a travelling wave. It can be assumed that **E** and **H** will be in phase with each other for the very reason that we are dealing with a wave. The **E** is in effect the potential energy term while the **H** is in effect the kinetic energy term. In simple harmonic motion, these two are out of phase by ninety degrees providing that there is no energy leakage from the system. However, when an oscillation is propagating through a medium accompanied by energy transfer, each individual case of a simple harmonic system at the molecular level is constantly losing its energy to its immediate neighbour, and so the phase difference between **E** and **H** will close to zero.

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], [11], [12].**

The DC Transmission Line Pulse

V. 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, bringing its electrostatic and magnetic fields with it. The electrostatic field exists in the form of a state of linear polarization in the space between the two wires. This state of polarization is continually discharging/unwinding at the rear of the pulse while continually charging at the leading edge of the pulse. Since we will have a flow of energy density through the space in and around the wires, with distinctly defined values for **E** and **H**, we therefore have a basis upon which to consider applying the Poynting vector. While Poynting's theorem will apply at the leading and trailing edges of the pulse, as these are in the dynamic state, the situation within the main body of the pulse itself as regards the use of the product **E**×**H** is more complex. In some respects, using **E**×**H** within the main body of the pulse is akin to using the familiar formula $V \times I$ that is associated with electric power delivery, where V is voltage and I is current. In the DC transmission line pulse, the potential energy is represented by the state of linear polarization between the wires. Although the net value of **E** is zero due to the cancelling back EMF, **E** nevertheless represents the magnitude of the state of stress. As regards **H**, this is the magnetic field caused by the aethereal electric current which circulates around the perimeter of the pulse like a caterpillar track. Typically, the energy stored in a magnetic field is expressed in terms of the current which causes it. We use the expression $\frac{1}{2}LI^2$ for magnetic energy where L is inductance, and values for **H** itself are established from the value of the current I in the Biot-Savart Law. We could therefore perhaps use **H** in the Poynting vector in connection with a DC transmission line pulse to represent the kinetic energy associated with both the magnetic field and the causative electric current flow. Although this usage lies outside of Poynting's theorem, we are dealing with a transient state context that is physically tied up with, and bordered front and rear, by a dynamic state that does fall within the jurisdiction of Poynting's theorem.

References

[1] Clerk-Maxwell, J., ***"A Dynamical Theory of the Electromagnetic Field"***, Philos. Trans. Roy. Soc. London 155, pp. 459-512 (1865). Abstract: Proceedings of the Royal Society of London 13, pp. 531--536 (1864). Maxwell's derivation of the electromagnetic wave equation is found in the link below in Part VI entitled 'Electromagnetic Theory of Light' which begins on page 497,
http://www.zpenergy.com/downloads/Maxwell_1864_4.pdf

[2] Lodge, Sir Oliver, ***"Ether (in physics)"***, Encyclopaedia Britannica, Fourteenth Edition, Volume 8, Pages 751-755, (1937)
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"*

[3] Clerk-Maxwell, J., ***"On Physical Lines of Force"***, Part III, equation (132), Philosophical Magazine, Volume XXI, Fourth Series, London, (1861)
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https://www.scribd.com/document/294114501/The-1855-Weber-Kohlrausch-Experiment-The-Speed-of-Light

[8] Tombe, F.D., ***"Displacement Current and the Electrotonic State"*** (2008)
https://www.gsjournal.net/Science-Journals/Research%20Papers-Mechanics%20/%20Electrodynamics/Download/228

[9] Tombe, F.D., ***"The Telegrapher's Equations"*** (2008)
https://www.researchgate.net/publication/333353577_The_Telegrapher's_Equations

[10] Tombe, F.D., ***"The Double Helix Theory of the Magnetic Field"*** section IV, *"The Speed of Light"* (2006)
https://www.researchgate.net/publication/295010637_The_Double_Helix_Theory_of_the_Magnetic_Field

[11] 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."

[12] 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
http://www.ascension-research.org/tesla.html

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,

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

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

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

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. This induced electric field will then produce its own changing magnetic field and we will have to change the signs on equations **(1A)** and **(2A)** in order to describe this aspect. 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.