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The Deeper Physical Nature of Displacement Current

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Abstract. Displacement current is associated with wireless radiation, capacitors, and transmission lines. This article will seek to establish the commonality between these three distinct physical manifestations.

Ampère's Circuital Law

I. The textbooks present *Ampère's Circuital Law* in the dynamic state, in the form,

$$\nabla\times\mathbf{B} = \mu(\mathbf{J} + \varepsilon\partial\mathbf{E}_S/\partial t) \qquad \mathbf{(1)}$$

where $\varepsilon\partial\mathbf{E}_S/\partial t$ is said to be Maxwell's displacement current, with the term $\mathbf{E}_S$, satisfying *Gauss's Law of Electrostatics*,

$$\nabla\cdot\mathbf{E}_S = \rho/\varepsilon \qquad \mathbf{(2)}$$

The idea, however, that $\varepsilon\partial\mathbf{E}_S/\partial t$ represents displacement current will now be challenged, and it will be proposed instead, that *actual* displacement current, whether in the case of a capacitor, or a transmission line, or wireless radiation, is represented in equation **(1)** above by the conduction current term, **J**, and for reasons which will become clear, we will use the magnetic vector potential, **A**, to represent **J** in the special case of displacement current. Meanwhile, it needs to be explained, that the electrostatic term, $\varepsilon\partial\mathbf{E}_S/\partial t$, is merely a reactive term without any causative effect. It arises due, either to a change in electric charge density, or due to the separation of charges in a dielectric, but $\varepsilon\partial\mathbf{E}_S/\partial t$ itself is not an actual electric current. We know from its absence in the Biot-Savart Law that $\varepsilon\partial\mathbf{E}_S/\partial t$ is not involved in inducing a magnetic field, however, in the case of a charging or a discharging capacitor, the surrounding magnetic field does indeed continue unbroken between the plates, and so we can only conclude that there must exist a real conduction current of some kind flowing across the gap, but that this cannot be $\varepsilon\partial\mathbf{E}_S/\partial t$. This conduction current will of course have to be something more fundamental than the flow of charged particles, and it is now proposed that this more fundamental electric current is a flow of the fluid-like aether, this aether

being the electric fluid within which all charged particles constitute sinks and sources.

Capacitors and Transmission Lines

II. In the case of a charging or a discharging capacitor, the electric fluid leaks out of the conducting circuit and crosses the gap between the plates, until it is blocked from doing so by a back EMF, caused either by dielectric polarization, or by the accumulating charge on the plates, or by both. In the case of accumulating charge, the electrostatic term, $\varepsilon\partial\mathbf{E}_S/\partial t$, in equation **(1)** is necessary in order to maintain a zero divergence across both sides of the equation. Equation **(1)** is in what is known as the *Lorenz gauge*.

Meanwhile, the 1855 Weber-Kohlrausch experiment, [1], if correctly interpreted, tells us that electric current flows at a speed in the order of the speed of light, [2]. In the case of a transmission line pulse, the main action is the motion of the electric fluid in the live conducting wire, but this fluid also leaks out to form a magnetic field in the space outside the wire. In a two-wire line, the aether leaks across the gap to form a closed electric circuit. This circuit is in motion at around the speed of light and the picture looks somewhat like a caterpillar track, with the momentum being on only one side of the two-wire line. Since a transmission line pulse is therefore a closed circulation, the electrostatic term, $\varepsilon\partial\mathbf{E}_S/\partial t$, in equation **(1)** vanishes, except when it is undergoing a reflection at the end of the line, [3].

The leaking electric current in both capacitors and transmission lines constitutes displacement current of a kind that leaks perpendicularly out of the conductor, and in both cases, it is covered by **J** in equation **(1)**. But in neither case do we have a mathematical formula for it, and so we cannot derive a wave equation in connection with these manifestations of displacement current.

Wireless Radiation

III. Wireless radiation arises when the electric fluid leaks tangentially from the conducting wire, [4]. We are then in the *transverse gauge* (*Coulomb gauge* or *radiation gauge*), where $\nabla\cdot\mathbf{A} = 0$ and $\nabla\times\mathbf{A} = \mathbf{B}$. Hence the electrostatic term, $\varepsilon\partial\mathbf{E}_S/\partial t$, in equation **(1)** vanishes, and meanwhile the conduction current term, **J**, takes the form $\mathbf{A} = \varepsilon\partial\mathbf{E}_K/\partial t$, where $\mathbf{E}_K = -\partial\mathbf{A}/\partial t$, and hence $\mathbf{A} = -\varepsilon\partial^2\mathbf{A}/\partial t^2$, where ε is the elastic constant, [5]. The term $\mathbf{E}_K$ is the electric field that arises in connection with time-varying electromagnetic induction, with $\varepsilon\partial\mathbf{E}_K/\partial t$ being the associated displacement current. See, ***"The Derivation of Maxwell's Displacement Current"***, [5], [6]. Wireless radiation therefore has a physical nature characterized by the swirling of electric fluid through a dense sea of tiny aethereal vortices, [7]. The average speed from vortex to vortex will be the speed

of electric current, which the 1855 Weber-Kohlrausch experiment matched with the speed of light, [1], [2].

Conclusion

IV. Displacement current manifests itself differently in capacitor circuits, transmission lines, and wireless radiation. The underlying commonality, however, is that in all cases, it constitutes the leakage of electric fluid from conducting wires into the surrounding space.

References

[1] Weber, W. E. and Kohlrausch, R.H.A., ***"Elektrodynamische Maassbestimmungen insbesondere Zurueckfuehrung der Stroemintensitaetsmessungen auf mechanisches Maass"***, Treatises of the Royal Saxon Scientific Society, vol. V, Leipzig, S. Hirzel, (1856)
For an English translation by Professor A.K.T. Assis, see chapters 6 and 7 in this link, and especially page 179 regarding mentions about the speed of light.
https://www.ifi.unicamp.br/~assis/Weber-in-English-Vol-3.pdf
Prof. A.K.T Assis has also written an excellent summary of this work in an article entitled ***"On the First Electromagnetic Measurement of the Velocity of Light by Wilhelm Weber and Rudolf Kohlrausch"***,
https://www.ifi.unicamp.br/~assis/Weber-Kohlrausch(2003).pdf
Weber and Kohlrausch further wrote a short precis of their paper, and this can be found in Poggendorf's Annalen, vol. XCIX, pp. 10-25. An English translation of this precis is presented in the appendix at the end of Prof. Assis's paper.
See also, Tombe, F.D., ***"The Commonality between Light and Electric Current"***, (2022)
https://www.researchgate.net/publication/364337354_The_Commonality_between_Light_and_Electric_Current

[2] Kirchhoff, G.R., ***"On the Motion of Electricity in Wires"***, Philosophical Magazine, vol. XIII, Fourth Series, pp. 393-412, (1857)
English translation by Professor A.K.T. Assis, vol. 3, chapter 8
https://www.ifi.unicamp.br/~assis/Weber-in-English-Vol-3.pdf
See page 212 for Kirchhoff's periodic equations in linear charge density and electric current. Page 213 is where he suggests an analogy between the electric charge equation and the equation for the propagation of longitudinal waves and see page 214 regarding the connection between Weber's constant and the speed of light.
Meanwhile, a summary by Professor A.K.T. Assis can be found on pp. 280-282 in this link,
https://www.ifi.unicamp.br/~assis/Weber-Kohlrausch(2003).pdf

[3] Tombe, F.D***., "The Deeper Physical Nature of Electric Current"***, (2022)
https://www.researchgate.net/publication/363887411_The_Deeper_Physical_Nature_of_Electric_Current

[4] Tombe, F.D., ***"Wireless Radiation Beyond the Near Magnetic Field"***, (2019)
https://www.researchgate.net/publication/335169091_Wireless_Radiation_Beyond_the_Near_Magnetic_Field

[5] Tombe, F.D., ***"The Derivation of Maxwell's Displacement Current"***, (2025)
https://www.researchgate.net/publication/392083357_The_Derivation_of_Maxwell's_Displacement_Current

[6] Tombe, F.D., ***"Displacement Current and the Electrotonic State"***, (2008)
https://www.researchgate.net/publication/303112543_Displacement_Current_and_the_Electrotonic_State

[7] Lodge, Sir Oliver, ***"Ether (in physics)"***, Encyclopaedia Britannica, Fourteenth Edition, vol. 8, pp. 751-755, (1937)
See pp. 6-7 in the pdf file in the link below, beginning at the paragraph that starts with, ***Possible Structure.*** −, and note that while the quote suggests that the ether is incompressible, this is almost certainly not the case. The quote in question, in relation to the speed of light, reads, ***"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"***
http://gsjournal.net/Science-Journals/Historical%20PapersMechanics%20/%20Electrodynamics/Download/4105