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Radio Transmission and AC Transformers

Frederick David Tombe,
Northern Ireland, United Kingdom,
sirius184@hotmail.com
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***Abstract*. Radio transmission and AC transformers share the fact that both involve the propagation of electromagnetic energy through space, from one electric circuit to another. This article will take a closer look at the application of Faraday's law as it applies in both of these two contexts.**

The Near Magnetic Field

I. Even though radio transmission and AC transformers involve Faraday's law in connection with energy being transferred through space from one electric circuit to another, there are several important differences between the two phenomena. Apart from the obvious differences in range, frequency, and power, the energy transfer mechanism in the AC transformer is always associated with flux linkage between the secondary winding and the near magnetic field of the primary circuit, whereas in the case of radio waves, these propagate well beyond the near magnetic field.

Before continuing with the comparison, it is important to first define the term, ***"near magnetic field"***. It will be defined here as the magnetic field that would form around an electric circuit when a DC power source is applied.

Radio Transmission

II. In any electric circuit, when the power is connected, prior to reaching the steady state, or in the case of an AC power source, wireless EM radiation is emitted sideways from the conducting wires to a greater or lesser extent, **[1]**. In the case of an AC circuit, the higher the frequency, the less is the impedance to radiation leakage, and this impedance can be further reduced by altering the capacitance in order to tune the circuit to a resonant state. When applying Faraday's law to the emitted radiation, this is done so in connection with Maxwell's displacement current, **[2]**.

The AC Transformer

III. The AC transformer, unlike the radio transmitter, usually only transfers energy to a single receiver nearby, known as the secondary winding. And unlike the receivers at a distance in radio transmission, the very presence of the

secondary winding in an AC transformer reduces the impedance of the primary circuit, enabling a powerful flow of electromagnetic energy to cross through the space between the two windings.

Meanwhile, it's important to note that the secondary winding doesn't actually have to be immersed in, or even touching the near magnetic field for a transformer to function efficiently. The secondary winding in a toroidal transformer, while wrapped around the iron core, could be further out from the primary winding, while the near magnetic field resides entirely inside the iron core, and this is where the commonality with radio transmission arises. There is a region of space between two electric circuits, where electromagnetic energy crosses the gap without passing through the near magnetic field.

Wireless Radiation

IV. It's well known that Faraday's law is involved when deriving the EM wave equations in space, and that this is even though there is no obvious source for the electric and magnetic fields at the points in space where the EM waves are passing through. It's the involvement of Maxwell's displacement current that makes this possible, but only if we apply the equations of electromagnetism in a fractal way. By that, it is meant that the electric and magnetic fields in space, that are being disturbed as EM radiation passes through, are understood in connection with the individual tiny aethereal vortices that Maxwell considered to fill all of space, **[3]**, **[4]**, **[5]**. The magnetic vector potential, **A**, applies to the circumferential momentum of these vortices, and to Maxwell's displacement current when in the dynamic state. Meanwhile, the electric field of time-varying EM induction is expressed in the form, $\mathbf{E}_K = -\partial\mathbf{A}/\partial t$, where $\nabla\times\mathbf{A} = \mu\mathbf{H}$, while **H** represents the vorticity. This electric field is the force that acts on the circumference of the vortices, causing them to precess in connection with the EM wave propagation mechanism. In the steady state, these tiny vortices align solenoidally in a fractal manner into the familiar pattern of a magnetic field. When EM radiation passes through the prevailing magnetic field, it doesn't matter what the relative orientation is. The vortices will precess while striving to align their rotation axes momentarily with the rotation axes of their immediate neighbour along the line of propagation, **[6]**, **[7]**, **[8]**, **[9]**. This temporary alignment maximizes the flux linkage on that tiny scale, in like manner to the flux linkage on the large scale in a toroidal transformer, where the magnetic axis threads its way through the middle of the two electric circulations. The tiny vortices filling all of space amount to miniature electric circuits, probably on the picometre scale.

Conclusion

V. Maxwell applied Faraday's law to outer space, beyond the near magnetic field of any laboratory apparatus, and he did so in conjunction with displacement current, hence predicting the existence of electromagnetic radiation, with light being just one example. Heinrich Hertz, in 1888, is said to have proven Maxwell's theory by virtue of having used electromagnetic apparatus to transmit a signal well beyond the near magnetic field.

By that time in history, the concept of time-varying EM induction, whereby electromagnetic energy could travel through space between two electric circuits, was already well known, but this energy transfer process had not so far been identified with EM waves, and in all matters to do with AC transformers, to this day, the energy transfer process is analysed in terms of flux linkage in connection with the near magnetic field of the primary winding, even though the energy transfer between the windings doesn't actually have to pass through the near magnetic field. In the case of a toroidal transformer in which the secondary winding is farther out from the iron core than the primary, although flux linked with the near magnetic field, it doesn't actually touch it. This discrepancy has caused some to question the validity of Faraday's law in this particular context, but it need not have done so. It should be clear that the form of energy transfer in an AC transformer is identical in principle to that of any other wireless radiation, distinct only by virtue of the low frequency, short range, and high power.

The commonality between radio transmission and the AC transformer lies in the fact that wireless electromagnetic radiation travels through space between a primary circuit (transmitter) and a secondary circuit (receiver), and that in both cases, in relation to this transfer of energy, we apply Faraday's law. Since it is not essential that the secondary winding in an AC transformer need actually be in contact with the near magnetic field of the primary circuit, we can conclude that Faraday's law applies in both radio transmission and in AC transformers, ***in connection with Maxwell's displacement current***, and that it applies on the scale of the tiny aethereal vortices that Maxwell believed filled all of space. These vortices are miniature electric circuits, and the application of Faraday's law in connection with these tiny circuits, has a fractal relationship to the near magnetic field of the emission source on the large scale. These miniature electric circuits constitute electric and magnetic dipoles at the most fundamental level, **[10]**, **[11]**, and it is within the context of these tiny dipoles that we apply the Poynting vector, $\mathbf{S} = \mathbf{E}_K \times \mathbf{H}$, **[12]**. If we apply Faraday's law to the near magnetic field in a toroidal transformer, while this will account for the EMF induced in the secondary winding, it will not account for the actual transfer of electromagnetic energy in the space between the two windings in the cases where the near magnetic field is absent in this zone. Without acknowledging the existence of Maxwell's all-pervading sea of tiny molecular

vortices, the energy transfer process between the primary and secondary windings of a toroidal transformer will remain a mystery, since the secondary winding is not touching the near magnetic field. For the significance of the iron core, see the appendix after the reference section.

References

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

[2] Tombe, F.D., ***"Maxwell's Displacement Current in the Two Gauges"***, (2021)
https://www.researchgate.net/publication/355361120_Maxwell%27s_Displacement_Current_in_the_Two_Gauges

[3] Clerk-Maxwell, J., ***"On Physical Lines of Force"***, Philosophical Magazine, vol. XXI, Fourth Series, London, (1861)
http://vacuum-physics.com/Maxwell/maxwell_oplf.pdf

[4] Whittaker, E.T., ***"A History of the Theories of Aether and Electricity"***, chapter 4, pp. 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."

[5] O'Neill, John J., ***"PRODIGAL GENIUS, Biography of Nikola Tesla"***, Long Island, New York, 15th July 1944, Fourth Part, paragraph 23, 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, filling all space, the Ākāśa 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

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http://gsjournal.net/Science-Journals/Historical%20PapersMechanics%20/%20Electrodynamics/Download/4105
See pp. 6-7 in the pdf file in the link above, 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"

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https://www.researchgate.net/publication/319914395_The_Double_Helix_and_the_Electron-Positron_Aether

[12] Tombe, F.D., ***"The Significance of the Poynting Vector"***, (2020)
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Appendix
(The Purpose of the Iron Core)

In the case of a toroidal transformer where the primary winding and the secondary winding are both wrapped all the way around the iron core in its entirety, the purpose of the core is to provide a high impedance on the inner side of the primary. Meanwhile, the presence of the secondary winding reduces the impedance on the outer side, and so energy flows from the primary outwards to the secondary.

In the case of transformers where the primary and secondary windings are on opposite sides of the toroidal iron core, the core additionally serves as a low reluctance magnetic circuit which channels the energy from the primary round to the secondary, from where it then radiates out to the secondary.