Review of: "Circuits, Currents, Kirchhoff, and Maxwell"

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Review of “Circuits, Currents, Kirchhoff, and Maxwell” (Qeios - L9QQSH.3)

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Despite the poor aesthetics of the manuscript and the apparent lack of novelty, the present work is truly interesting. It revisits in a simple and didactic manner Kirchhoff’s law for charge current conservation, starting directly from Maxwell’s equations, and therefore emphasizing the importance of Maxwell’s displacement current in the formulation of this law, which is usually neglected for large enough time scales. The historical point of view and the accurate citations of this manuscript makes it worthwhile on its own, and applications to complex systems presenting fluctuations, or biological systems. These include the propagation of self-excited currents in nerve cells, frequently appearing in the modeling of physiological problems, which are superficially discussed. The reading is recommended to teachers and researchers on electromagnetism, especially those interested in electronic circuits and the application of circuit theory to biological systems, such as in the study of cellular neural networks, as pioneered by Leon Chua. In this respect, the reviewer congratulates the author for his insight and wide experience.

However, the referee believes that the manuscript presents several defficiencies:

1) Firstly, the presentation is truly poor, discouraging the reader from the beginning. In some parts of the paper, as in the "Introduction", the text is not even aligned. I think that such interesting content deserves a better container, perhaps with a LaTeX editor. Some equations are informally written, where we can find formulas like the div (ANYTHING) in Eq.(3), unnumbered equations, and things of the style. If it is not too much to ask, an equation editor is deserved with the nabla operator. Conservation laws could be made more general by using covariant notation, or at least using both space and time coordinates. Sections should be properly numbered and some of them should rather be considered subsections, such as those concerning Kirchhoff coupling. Even the title could be more specific. Something like: “The role of displacement currents in Kirchhoff’s law”. Or, perhaps: “Kirchhoff’s general law for current conservation”.

2) The purpose of the work could be more clearly and concisely stated in the Abstract and the Introduction. The introduction would benefit from stating the structure of the paper very briefly, as well.

3) The section entitled *Electrodynamics is universal*, would be correct only as long as we consider the Einstein-Maxwell equations since no theory is universal as long as the general principle of relativity is disregarded. A universal theory is valid in any reference frame and for any observer, which simply does not occur in Maxwell’s classical electrodynamics,

which is reserved for inertial observers. In this same section, the author says that charges do not exist in a vacuum, neglecting the possibility that particles are themselves the field's energy stabilized (solitons) and electric charge is a topological property of knotted solutions in the vacuum of the electromagnetic fields [1]. This idea, which we owe to J. A. Wheeler [2] among others, is introduced in his works utilizing the concept of geon, which would be some sort of electromagnetic vortex or electromagnetic knot [3], as originally proposed by Lord Kelvin [4].

4) The section "Steady-states are misleading" would benefit from a clear specific example, as a filamentary conductor with surface charge density. The stray capacitance to represent displacement currents also cries for an explanation, and so forth. Even though references to works with examples are provided, the manuscript would be much better if it was more self-contained. Otherwise, the author feels uncomfortable, since it seems that a great number of papers must be read to appreciate the details of the reasoning and the importance of the general character of Kirchhoff's law. Another example is the section "Series Circuits are a simple example". Here we find cited figures that are absent but referenced. These figures would illustrate better the present manuscript if the author wants to provide insight into his main law. Or perhaps the present manuscript only has the purpose of advertising the core idea, without properly entering into the details. That would be a pity, for the main tenet is philosophically important and deserves to be adequately ornamented.

5) In this same section "Series Circuits are a simple example", the author claims "Everything is coupled to everything else because of Kirchhoff's law". This is incorrect, it is the fields that couple everything in the universe, and Kirchhoff's law is just a corollary coming from the conservation of charge and gauge invariance, according to the Lagrangian of Maxwell's electrodynamics and Noether's theorem. Or, if preferred, simply and directly because of Maxwell's equations. Useful as it is from the viewpoint of circuit theory, Kirchhoff's law is not a fundamental law, but a conservation law. It is misleading to interpret that a system behaves physically in a way to conserve something. Conservation is a consequence, not a cause. Only the electromagnetic fields are real causes and have real existence.

Further ahead, the author insists on the wrong view that arises from the usage of mechanical reasoning in electrodynamic problems. This last paragraph on page 8 is very interesting since the author emphasizes here the preponderance of electrodynamics over mechanics. The referee is really glad to read this and the following paragraphs and encourages the author to read two papers [5,6], where Newton's laws are derived from Maxwell's electrodynamics. These ideas were claimed by great physicists of the late nineteenth century when the many disciples and contemporaries of Maxwell (Abraham, Lorentz, Wien, Kelvin, Heavyside) defended the electromagnetic origin of mass, which supports an electromagnetic view of the universe and an electromagnetic origin of inertia.

6) In the section "Coupling implied by Kirchhoff's law", the number of interactions is overstated since fields decay with distance, and even if all the pairs of an Avogradro number were interacting, combinatorial numbers are a quotient of factorials, and not simply a factorial.

7) In the following section concepts such as "knock on" and "know off" deserve clarification for the inexperienced reader. Also the more modern concepts of mean-field and also mean-field theories should be discussed about Gibb's concept of coarse-graining.

8) The biological examples should be more deeply discussed, providing instructive and pedagogic figures and biophysical processes. The concept of voltage clamp is not clearly explained, but it is rather assumed that the reader is familiar with it. The Hodking-Huxley model could be briefly introduced and explained, to enlighten the discussion. Also, the respiratory chain, which is of the greatest importance for eukaryotic cells, deserves some succinct explanation. Again, figures from other references are cited, which would be very welcomed by the reader to enlighten the main ideas of these examples.

In summary, the importance of this viewpoint on Kirchhoff's general law, including displacement currents, is beyond dispute and makes the present essay worth of read. The reviewer himself, despite his profuse knowledge of electrodynamics, confesses having missed this crucial point, and thanks the author for transmitting this idea in the present paper. However, more careful writing and organization of the manuscript, with nice equations and more beautiful figures illustrating the central examples would encourage the reader to support this point of view of Kirchhoff's law, which is more respectful of the spirit of field theory and the existence of fields as the fundamental substance of the universe, from which even matter should be derived. Sincerely,

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