# What Happened to Electromagnetic Theory

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For 40 years I thought that the problem at the centre of classical electromagnetism arose in around 1890, when Heaviside showed that he was unsure about how to choose between two contradictory models for the Transverse Electromagnetic Wave. Although I quote him as backing "The Heaviside Signal" [4], the truth is that he vacillated between the two. However, recently I realized that the problem of misinterpretation of experimental results arose much earlier, with Faraday in 1831.

## 1. Introduction

On 21 April 1820, during a lecture, Ørsted noticed a compass needle deflected from magnetic north when an electric current was nearby.

Faraday's breakthrough came when he wrapped two insulated coils of wire around an iron ring, and found that, upon passing a current through one coil, a momentary current was induced in the other coil. This phenomenon is now known as mutual induction. Published in 1831. Or did he really pass a current passed one coil, and what exactly was induced in the other coil. Was it electric current? This question was not asked for the next 200 years.

This second discovery closed the loop in an elegant way. Electricity caused magnetism, which caused electricity. But did it?

Regarding Faraday, consider a single turn transformer.

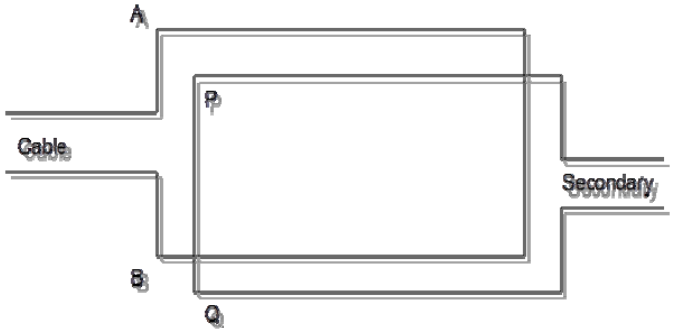


**Fig. 1**. Single turn transformer.

When the switch to the battery off to the left is closed, a voltage/current step advances towards the transformer at the speed of light, as shown in Figs. 2 and 3.

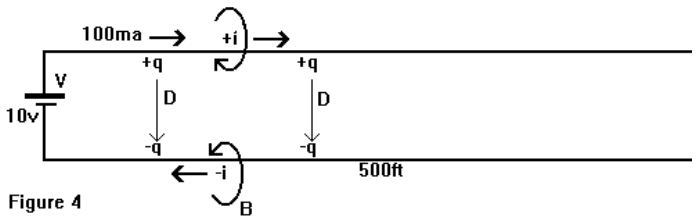


**Fig. 2**. Advancing TEM step wave


**Fig. 3**. TEM wave fields

There are four factors which make up the wave [1];

1. electric current in the conductors *i*
2. magnetic field, or flux, surrounding the conductors **B**
3. electric charge on the surface of the conductors $+q$ , $-q$
4. electric field, or flux, in the vacuum terminating on the charge, **D**

Reaching the transformer, some of it continues on its journey at the reduced speed $1/\sqrt{\mu\varepsilon}$ for the magnetic material. Some of this transverse electromagnetic wave leaks out into the secondary, continuing to travel at the $1/\sqrt{\mu\varepsilon}$ , as discussed in my article in Electronics World in January 2011 [2]. When the energy reaches the right hand end of the transformer, some of the TEM wave in the secondary proceeds further to the right and some reflects. The TEM Wave proceeding further to the right reached Faraday's galvanometer, which could only measure electric current and failed to detect the accompanying magnetic field. At every stage, only TEM Waves, made up of electric and magnetic field, or electromagnetic field, was involved. At no stage was there isolated electricity or isolated magnetism. Electricity did not cause magnetism which did not cause electricity. At every stage, a TEM Wave was involved, causing further TEM waves.

In 1861 Maxwell enshrined the alleged causal link between electricity and magnetism in Maxwell's Equations. These are taken to imply causality, but as my co-author Dr. David Walton points out, the mathematics does not do so. It merely describes the relationship between **E** and **H** in a TEM wave, which is one of fixed proportion. However, Maxwell obviously thought causality was implied, because he proposed a crabwise process for electromagnetic waves and light travelling though space, with **E** causing **H** causing **E** further away.

Maxwell's Equations for a TEM Wave can be written;

$$\frac{\delta \mathbf{E}}{\delta x} = -\frac{\delta \mathbf{B}}{\delta t} \qquad \nabla \times \mathbf{E} = -\frac{\delta \mathbf{B}}{\delta t}$$

$$\frac{\delta \mathbf{H}}{\delta x} = -\frac{\delta \mathbf{D}}{\delta t} \qquad \nabla \times \mathbf{H} = \frac{\delta \mathbf{D}}{\delta t}$$

They are taken to indicate causality. Not surprisingly, the equally valid equation

$$\frac{\delta \mathbf{E}}{\delta x} = -Z_0 \varepsilon_0 \frac{\delta \mathbf{E}}{\delta t} \qquad \nabla \times \mathbf{E} = -Z_0 \varepsilon_0 \frac{\delta \mathbf{E}}{\delta t} ,$$

which I published in *Electronics World* in November 1985 [3], is overlooked. This last equation tells us that **E** causes **E**! If **E** causes itself, does it really cause **H** in the same way?

When addressing a sinusoidal TEM wave travelling at the speed of light guided by two conductors, a lecturer will tell you that a changing **E** causes **H**, and a changing **H** causes **E** further along. No text book or lecturer will tell you that **E** and **H** are in phase, and perhaps they do not know it. Properly read, the first two formulae above tell you that changing **E** correlates with changing **H**. If one caused the other, we would expect to see something like

$$\frac{\delta \mathbf{D}}{\delta t} = \pm \mathbf{B} \ldots\ldots \frac{\delta \mathbf{D}}{\delta t} = \pm \mathbf{J}$$

(displacement current causes magnetism), but that is not what we see.

All lecturers and text book writers, versed in the history of the subject, knowing of the discoveries of Oersted and Faraday, "know" that **E** causes **H**, which causes **E**. This was fine for analogue radio and even radar, when sine waves were the only signals, and there was always a changing **E** and a changing **H**, so long as their relative phase was unknown or ignored, as it was. However, along came digital electronics, where the signal from one logic gate to the next was not a sine wave, but a steady voltage of 0v suddenly changing to a steady voltage of 5v. While at 5v for some time, a steady, constant flow of energy in the TEM wave involving fixed **E** and fixed **H** travelled along the transmission line at the speed of light – and perhaps could be classed as light. According to Aristotle and today's lecturers and text book writers, something must still be helping the signal along. Since **E** and **H** were not changing, the change in **E** could not be causing **H** and the change in **H** could not be causing **E**. However, Fourier Series came to the rescue. Lecturers and text book writers told each other that any (periodic) waveform could be represented by a combination of sine waves, or possibly was a combination of sine waves. (The word "periodic" was overlooked, since a step is not periodic, and cannot be represented by sine waves.) Professor Archibald Howie, while head of the Cavendish, went so far as to tell me that physical reality was composed of sine waves! So in the middle of a steady signal, changing **E** and **H** causing each other in one frequency component of the steady 5v signal, helping each other along, while changing **E** could be causing **H** and **H** causing **E** in another superposed sine wave! After all, it was known that in white light, different colours (frequencies) could be superposed. The different colours must be helping themselves along with their own varying **E** and **H**, ignoring the other colours with their varying **E** and **H**, sometimes varying in the opposite direction. So at the same point, a rising **E** caused **H** while a falling **E** caused an **H** in the opposite direction.

The early discoveries of Oersted and Faraday, combined with the impression that Maxwell's Equations (above) imply causality, make the lecturer and text book writer unable to envisage Heaviside's correct version of the TEM Wave, which I called "The Heaviside Signal" in this *Wireless World* in July 1979 [4]. This was admirably described by Dr. David Walton in the same journal in November 1979 and November 1980;

> "I understand that Aristotelians believed that a force was necessary to keep bodies in motion and that, in the absence of this force, the motion would cease. This theory led them into certain difficulties. For instance a spear, once thrown, appeared to continue to move without a force being present. The philosophers rose to this challenge magnificently with the theory that air, displaced from ahead of the spear, rushed to the rear and generated the requisite force - the theory was saved. Unfortunately they missed the simple point first noted by Newton, that it is in the nature of a moving body to continue to move.
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> "In the same way I fear that Maxwell invented a complex explanation for a very simple phenomenon, i.e. that electromagnetic radiation, or energy current $[\mathbf{E}\times\mathbf{H}]$, moves at the speed of light - and that's all, because that is what energy current does. No mechanism invoking **E** producing **H** and **H**, in return, producing **E** is required.
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> "… a faulty set of primitives can lead to problems in a theory which necessitate the introduction of ad hoc causality relations. In a similar way I believe that the causality relations alleged to reside in Maxwell's equations (i.e. changing magnetic field producing electric field and changing electric field producing magnetic field) are spurious. A moving body continues to move because that is what moving bodies do; an electromagnetic disturbance or energy current, of whatever distribution, continues to move because that is what energy currents do. In other words the statement "energy current travels at the velocity of light" is a primitive assumption in my theoretical framework which requires no further explanation. In my framework the moving energy current is the simple situation and 'static' electric and magnetic fields are composite.
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> "These ideas are unknown to any lecturer or text book writer, and you will not find them published by any such. They are at the core of a valid electromagnetic theory, which at present is stalled."

## References


[1] http://www.ivorcatt.co.uk/x21.htm.

[2] Ivor Catt, "The End of Electric Charge and Electric Current as We Know Them, Part 1", *Electronics World*, pp. 20-24 (Jan 2011).

[3] Ivor Catt, *Electronics World* (Nov 1985).

[4] Ivor Catt, "The Heaviside Signal", *Wireless World* (July 1979).