Fundamentals of electromagnetic energy transfer

Discussion of some weaknesses in the traditional approach to e.m. theory, and the establishment of a sounder foundation

by Ivor Catt.

The rise of digital electronics has highlighted weaknesses in our approach to the fundamentals of electromagnetic theory. This paper discusses some of the weaknesses and begins the building of a more sound approach at the fundamental level.

In the 1870s Oliver Heaviside, the father of digital electronics, worked with his brother Arthur to improve pulse signalling down a transmission line, using theory and experiment to improve the performance of the undersea telegraph line between Newcastle and Denmark. This practical experience gave him a mastery of electromagnetic theory which remained unequalled for a century. It led to his greatest achievement, the discovery of the concept of 'energy current'[1,2,3], which he himself undervalued, and never mentioned again after Hertz demonstrated the more glamourous wireless waves ten years later.

Ever since its advent in around 1900, wireless signalling has been regarded as a major advance. In fact, it stunted theoretical development. Wireless is a resonant, neo-steady state activity. It is far less central to the successful development of electromagnetic theory than its apparent primitive precursor, the TEM step or transient, travelling undistorted at the speed of light, guided by two conductors. The glamour, the magical nature of signalling without wires caused the suppression and then the loss of understanding of the mechanism by which a pulse travels at the speed of light from one logic gate to the next. In 1949, this suppression even made it possible for Albert Einstein to dismiss the

SEPTEMBER 1984

This paper was given at the IERE International Conference on Electromagnetic Compatibility at the University of Surrey in September 1984, and published in their Proceedings. The same was published in "Wireless World" in September and October.

very idea of a logic pulse as absurd!

> "...If I pursue a beam of light with the velocity c (velocity of light in a vacuum), I should observe such a beam of light as a spatially oscillatory electromagnetic field at rest. However, there seems to be no such thing, either on the basis of experience or according to Maxwell's equations." (ref.4)

A deep chasm developed between the post Einstein Community, who call themselves 'modern physics', and digital electronic engineering, the latter being based on the logic pulse which the former dismissed as absurd. (Within the 'modern physics' community, the only viable electromagnetic wave is the sine wave, whereas digital electronics is based on the pulse[3,5].

Einstein never read Heaviside, and Heaviside, although very interested in Einstein, lacked the information needed to grasp the nature of the gaffe Einstein had committed. Today, the chasm could be bridged if only professors of modern physics would look at high-speed logic pulse using a sampling oscilloscope[5]. They would then be forced to admit that, far from being absurd, Heaviside's slab of energy current exists.

> "Thus the whole slab moves bodily to the right at speed v, so that a moves to A and b moves to B in the time given by vt = aA or bB.
>
> "The disturbance transferred in this way constitutes a pure wave. It carries all its properties unchanged... in the same way, all moving along independently and unchanged.
>
> "... Since every slab is independent of the rest, there need be no connection between the directions [= polarity, sign,] of E in one slab and the next. The direction may vary anyhow along the wave."[3]

Since Einstein went on to say that the false statement of his is the very basis of relativity, we can see why 'modern physics' contributes no help, but only confusion, to the work of computer designers.

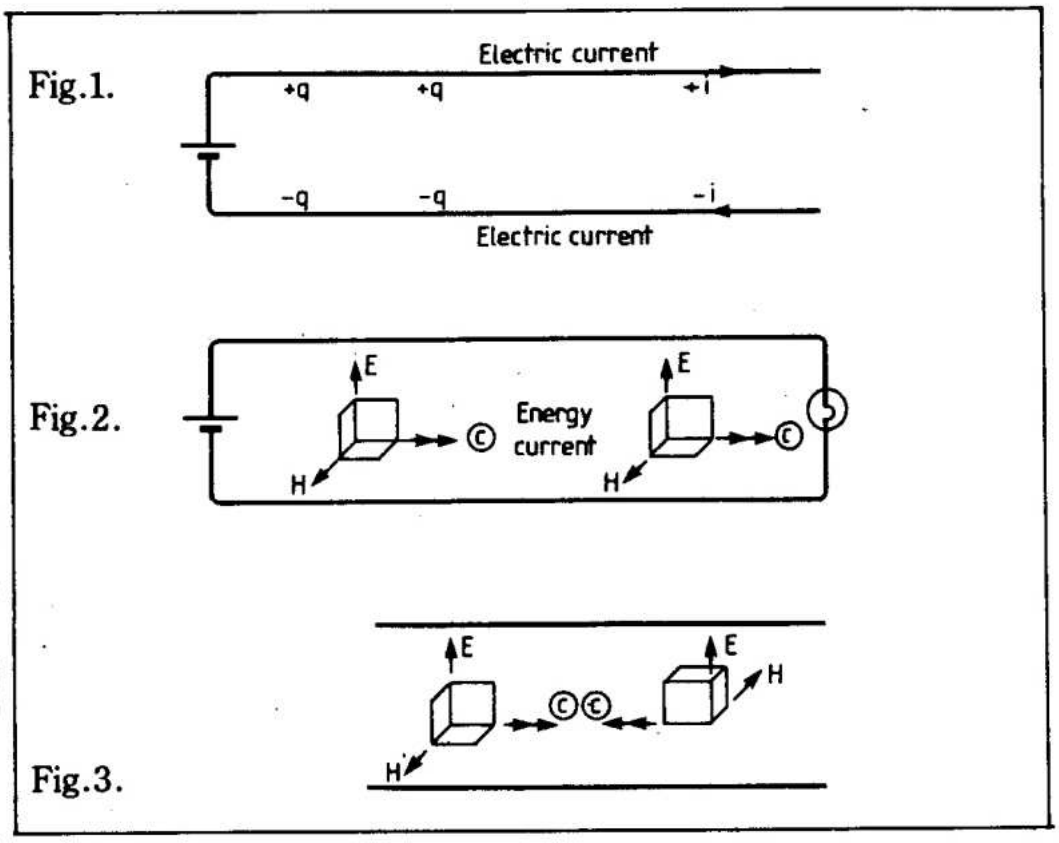
Energy current

Whereas the conventional approach to electromagnetic theory is to concentrate on the electric current in wires, with some additional consideration of voltages between the wires, Heaviside concentrates primarily on what he calls 'energy current, this being the electromagnetic field which travels in the dielectric between the wires. It has an amplitude equal to the Poynting Vector, E × H. Heaviside's phrase, "We reverse this"; points to the great watershed between the 'etherials' who with Heaviside believe that the signal is an 'energy current' which travels in the dielectric between the wires, and the 'practical electricians', who like Sprague believe that the signal is an electric current which travels down copper wires, and that if there is a 'field' in the space between the wires, this is only a result of what is happening in the conductors[1].

Fig.1. **Theory N. Electric current is the cause.**

Fig.2. **Theory H. Energy current is the cause.**

Fig.3. **Trapped energy current.**



Oliver Heaviside announced Theory H a century ago[2].

> "Now in Maxwell's theory there is the potential energy of the displacement produced in the dielectric parts by the electric force, and there is a kinetic or magnetic energy of the magnetic induction due to the magnetic force in all parts of the field, including the conducting parts. They are supposed to be set up by the current in the wire. We reverse this; the current in the wire is set up by the energy transmitted through the medium around it..."

The importance of Heaviside's phrase, "We reverse this", cannot be overstated. (See Fig. 1, Fig. 2.) It points to the great watershed between the 'practical electricians'[7,8], who have held sway for the last half century, promulgating their theory — which we shall call 'Theory N', the Normal theory: that the cause is electric currents in wires and electromagnetic fields are merely an effect — and the 'etherials', who believe what we shall call 'Theory H': that the travelling field is the cause, and electric currents are merely an effect of this field.

The 'energy current' approach, Theory H, is much the

more helpful approach for the digital designer. The car battery delivers energy which is guided between the OV and +12V lines, to the car headlight. The electromagnetic energy travels down through the dielectric at the speed of light.* When the energy reaches the lamp, it penetrates into the filament, is absorbed and converted.

If the car lamp is removed, the energy current reflects at the resulting open circuit and returns back towards and into the battery, always travelling at the speed of light. This results in an endless dance of energy. The energy current continually flows from the battery at the speed of light; reflects at the open circuit to the right; and flows back into the battery, there to reflect back out again from the (left hand) far end of the battery plates and down between the wires for a second time.

In the resulting, apparently stationary, quiescent state, there is no mechanism for the energy current, which has been delivered into the dielectric between the wires at the speed of light, ever to slow down as it oscillates from end to end.

If the two wires are now suddenly cut at the middle, then energy current (conventionally thought to be electic charge) is trapped between the wires to the right. The energy is apparently stationary, but in fact is all moving at the speed of light. If these wires were very wide and close, we would have a conventional charged capacitor. At any moment, half of the energy trapped in a charged capacitor is moving to the right, and the other half if moving to the left. Using either theory N or H[8], the total current in each plate (or wire) is zero, so there are no i^2R losses, only dielectric leakage G losses, which would be zero in the case of a vacuum dielectric. Attempts to detect the magnetic field component of the energy current would be frustrated by the fact that the leftwards travelling energy current has a magnetic field component in the opposite direction to that of the rightwards travelling energy current[9,10] (Fig.3).

*The density of this energy at any point is equal to the product of the electric field D and the magnetic field B, which are always at right angles to each other and to the direction of energy flow. The flow rate of energy across unit area is E × H, which is called the Poynting Vector.

Nature of space and ether

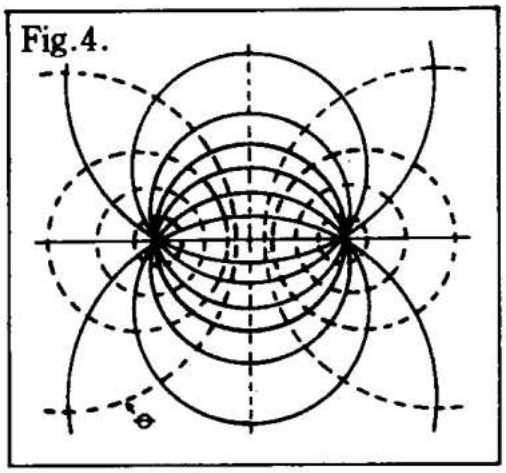
A logic pulse is a TEM wave (Transverse Electromagnetic Wave), which means that both the electric field and the magnetic field are at right angles to the direction of propagation. Also, at every point, the electric field and the magnetic field are at right angles to each other. If the wires in Fig.2 are circular, the field pattern is as in Fig. 4.

The vertical E lines and the circular H lines divide the surface into what are called 'curvilinear squares' of equal width and

height. Down one side of a square the electric potential drop is E and along the other side the magnetic potential drop is H. If the dielectric medium has permittivity ϵ and permeability μ then the ratio of E to H is $E/H = \sqrt{\mu/\epsilon}$, which in the case of a vacuum dielectric turns out to be 377 ohms. Further, the velocity of propagation of this energy current into the paper is equal to $1/\sqrt{\mu\epsilon}$ which in the case of a vacuum turns out to be 300,000 km per second.

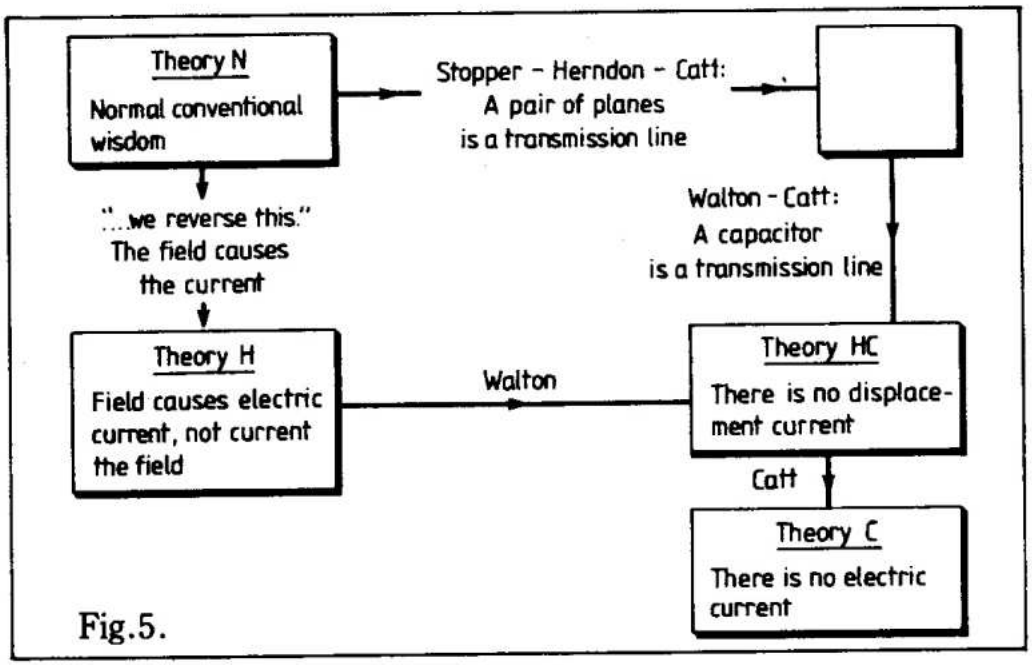
(It is noteworthy that Einstein himself and also the whole post-Einstein community who call themselves 'modern physics', never mention the impedance of free space $\sqrt{\mu/\epsilon}$, although it is one of the key primitives on which digital electronic engineering is based. The reader is encouraged to look for reference to it in the literature of modern physics.)

Fig.4. **Curvilinear squares.**



As energy current flows through one of the squares in the (vacuum) dielectric in Fig. 4, it is resisted in its attempt to proceed. This is necessary, because if energy is flowing through the square, work must be done. The E × H energy works against the impedance of the square surface, 377 ohms, as it passes through that surface. The resistance (impedance) of a square of vacuum is innate. Thus, empty space has

Fig.5. **The theories.**



the physical characteristic, impedance (resistance), a fact which has to be ignored in modern physics which conforms to the belief that empty space has no features. (It is remarkable that, while ignoring $\sqrt{\mu/\epsilon}$, modern physics can still make such play with velocity, $1/\sqrt{\mu\epsilon}$.)

In the world view of the digital electronic engineer, it is convenient to say that free space and the ether are synonymous. This includes the assertion that the ether exists; it is the something which resists the passage of energy and so, paradoxically, makes the passage of electromagnetic energy $E \times H$ possible. (It is impossible to give kinetic energy to a brick with zero mass. Similarly, it is impossible to deliver potential energy to a spring whose Young's Modulus is either zero or infinity. Energy may only enter a region when its entry is reasonably resisted — hence the need for free space to have an impedance (resistance),. if energy is to be able to enter it.)

Via a devious route, we have come to think that the fundamental primitives in a region of space are permittivity and permeability, ϵ and μ. However, when it comes to actually measuring anything, which mean measuring the impedance (of space) or the velocity (of space), we find that we always use ϵ and μ in combination in order to form velocity © or impedance Z_0. It seems clear that the latter two are more primitive, being more fundamental and also measureable, and ϵ and μ are merely subsidiary parameters lacking fundamental physical reality. To sum up; whereas it is usual to start with ϵ and μ and derive the impedance $Z = \sqrt{\mu/\epsilon}$ and velocity © $= 1/\sqrt{\mu\epsilon}$, it is more correct to start with Z and ©, the directly measurable parameters of a region of space.

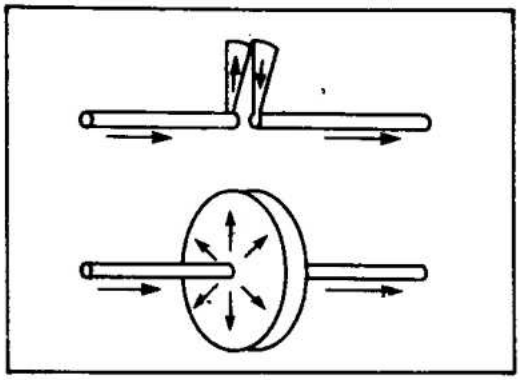
Should we be so disposed, we could then derive ϵ and μ using the formulae $\epsilon = 1/Z©$ and $\mu = Z/©$. However, although being far divorced from physical reality, ϵ and μ remain useful instruments for use in calculation.

(A further advance which the reader might wisely ignore initially is made when we realise that length of a region of (single velocity) space and velocity of propagation through that region cannot be independently measured. All that we can measure is the time delay through that region. We should move to the idea of a segment of space being of length t, e.g. 1 n, rather than of length 1 foot[11].) ↘ 1 nsec

Theories

A number of different dualisms obtain within or in the vicinity of electromagnetic theory as it is developing. The student needs to be warned against thinking that only one dualism is involved, and that he is merely seeing different expressions of the same dualism.

Fig.6. **Two voltage planes act as transmission line.**



The mutually distinct dualisms include:

wave-particle dualism
Theory N — Theory H[8]
The Rolling Wave — The Heaviside signal [19]

It will be seen later that one of these is in fact a three-way split between Theory N, Theory H and Theory C.

Historical development. The transition from classical, wireless-based electromagnetic theory, loosely equivalent to Theory N[8], to one of the preferred theoretical positions for the digital electronic designer, Theory H or Theory C[8], is via a complex development shown in Fig. 5.

The capacitor

In the early 1960's I pioneered the inter-connection of high speed (1 ns) logic gates at Motorola, Phoenix, Arizona[12]. One of the problems to be solved was the nature of the voltage decoupling at a point given by two parallel voltage planes. I asked Bill Herndon about this problem, and he gave me the answer: "It's a transmission line"[13]. Bill learnt this from Stopper, whom I never met, who now works for Borroughs in Detroit.

The fact that parallel voltage planes, when entered at a point, present a resistive, not a reactive, impedance, was for me an important breakthrough. (It meant that as logic signal speeds increased, there would be no limitation presented by the problem of supplying +5V.). The reader should be able to grasp the reason why voltage plane decoupling is resistive by studying Fig. 6, which shows the effect of a segment only of two planes as they are seen from a point[14].

During the next ten years, with the help of Dr D.S. Walton, I gradually came to appreciate that, since a conventional capacitor was made up of two parallel voltage planes it also had a resistive, not a reactive (i.e. capacitive or inductive) source impedance when used to decouple the +5V supply to logic. Since the source impedance (= transmission line characteristic resistance) is well below one ohm, the transient current demand of logic gates approaching infinite speed can still be successfully satisfied with +5V from a standard capacitor of any type[15]. (The reason why the myth has developed that the worst (low capacitance, 'r.f.') capacitors are the best in this role is discussed elsewhere[16]).

The capacitor is an energy store, and when energy is injected, it enters the capacitor sideways at the point where the two leads are joined to the capacitor. Nothing ever traverses a capacitor from one plate to the other. This is clearly understood in the case of a transmission line. By definition, when a TEM wave travels down a transmission line, nothing travels sideways across the transmission line, or we would not have a transverse electromagetic wave.

Spring cleaning

"Then there were the remarkable researches of Faraday, the prince of experimentalists, on electrostatics and electrodynamics and the induction of currents ...The crowning achievement was reserved for the heaven-sent Maxwell, a man whose fame, great as it is now, has, comparatively speaking, yet to come"[17]

"Now, there are spots on the sun, and I see no good reason why the faults in Maxwell's treatise should be ignored. It is most objectionable to stereotype the work of a great man, apparently merely because of the great respect thereby induced..."[18]

"Heaviside, seventy years ago, missed the key point by a whisker. He failed, but he failed gloriously. He never discovered the flaw in the structure, displacement current."[19]

"Heaviside put together the main features of the new concept, but it took another century to put flesh on to the bare bones."[20]

"Closely related is Heaviside's concept of an electromagnetic wave, which in principle does not undulate, but only propagates itself. This concept leads to interesting insights which have not yet been fully realised. ...Many questions concerning this concept exist which, as Heaviside said, 'Have still to be worried about."[21]

The Catt anomaly

Until recently, the only flaws in classical electromagnetism were shown up by the new theoretical discoveries indicated in Fig.5. However, more recently, thanks to Dawe[22], I have been led to a flaw at a more simplistic level. We shall deal with this flaw, called the 'Catt Anomaly', first.

Traditionally, when a TEM step (i.e. a logic transition from low to high) travels through a vacuum from left to right, (Fig.7.), guided by two conductors (the signal line and the 0V lines), there are four factors which make up the wave:

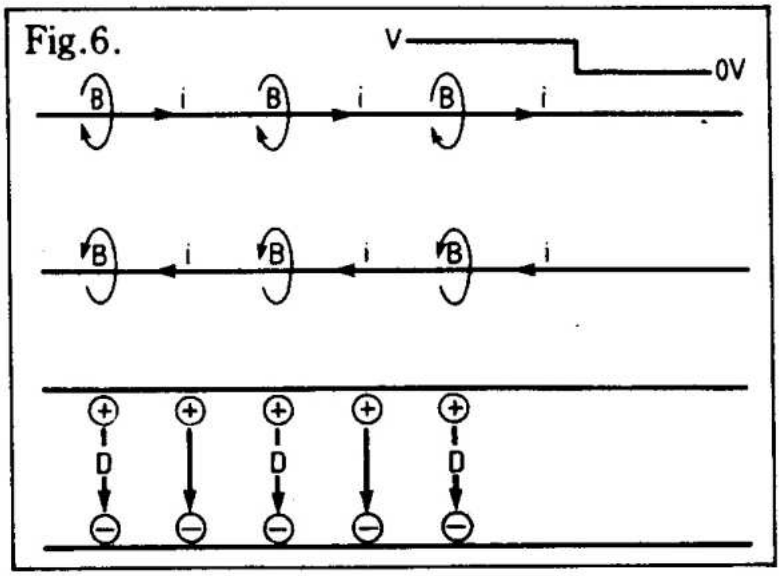
electric current in the conductors;

magnetic field, or flux, surrounding the conductors;

electric charge on the surface of the conductors;

electric field, or flux, in the vacuum terminating on the charge.

Fig.7. **Four factors in a TEM wave.**



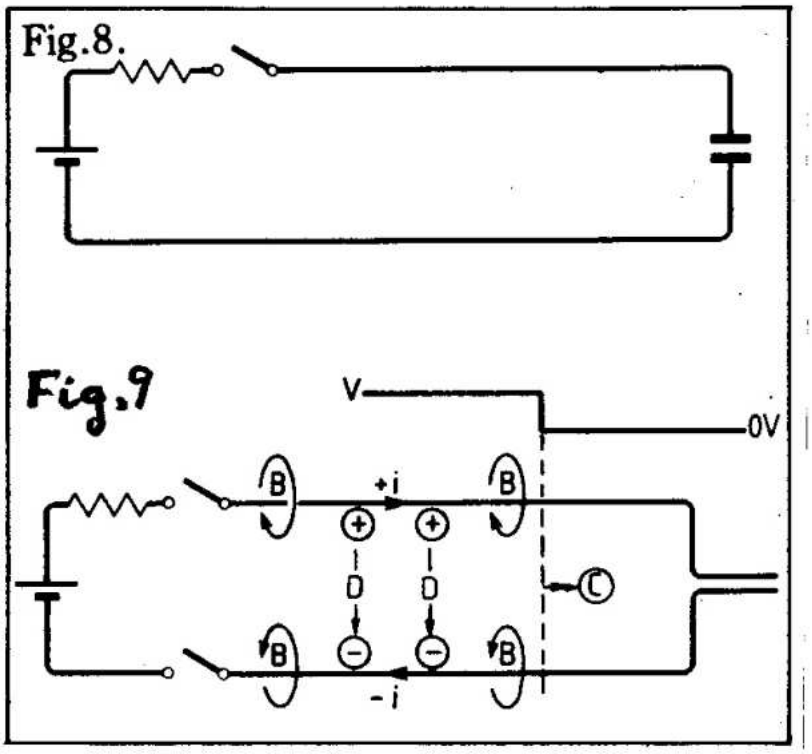
The key to grasping the anomaly is to concentrate on the electric charge on the bottom conductor.

During the next 1 nanasecond, the step advances one foot to the right. During this time, extra negative change appears on the surface of the bottom conductor in the next one foot length, to terminate the lines (tubes) of electric flux which now exist between the top (signal) conductor and the bottom (0V) conductor.

Where does this new charge come from? Not from the upper conductor, because by definition, displacement current is not the flow of real charge. Not from somewhere to the left, because such charge would have to travel at the speed of light in a vacuum. (This last sentence is what those "disciplined in the art" cannot grasp, although, paradoxically, it is obvious to the untutored mind.) A central feature of conventional theory is that the drift velocity of electric current is slower than the speed of light.

Displacement current and the TEM wave. The concept of the transmission line and the TEM wave came after Maxwell's time, so he could not use it to resolve the anomaly which dogged electromagnetic theory in the mid-nineteenth century. This anomaly arose from consideration of the performance of the capacitor in a closed electric circuit, which upset the techniques which have been developed to relate electric current to nearby magnetic field. These were the Biot-Savart Law, $H = \frac{i\,dl\,\sin\theta}{4\pi r^2}$ and Ampere's Rule, $\oint Hdl = i$. To resolve the anomaly, Maxwell proposed that the build-up of electric flux $\epsilon\,dE/dt$ (i.e. dD/dt) across the plates of a capacitor

Fig.8. **The problem Maxwell faced.**



behaved just like real electric current in that it generated magnetic flux nearby as per the Biot-Savart Law. However, the assumption underlying the anomaly which he purported to solve was as follows. In a closed circuit (Fig.8) comprising battery, resistor and capacitor, at the moment the switch is closed, electric current instantaneously flows in all parts of the circuit, including the capacitor.

Since Maxwell's time, we have learnt that there is no instantaneous action at a distance, and part of that body of knowledge is the TEM wave which travels at the speed of light. We, who follow in the wake of the telegraph equations and the development of the TEM wave in a transmission line, known that when we close the switch(es), (Fig.9.) the current and field move across from left to right at the speed of light. We also know that the capacitor is merely a change in the characteristic impedance of the transmission line, and that the wave front enters it sideways.

Maxwell's difficulty with the anomaly disappears, and his fudge factor, displacement current, traversing the capacitor from top to bottom and creating magnetic field in the horizontal, forward, direction, becomes an embarrassment because by generating forward magnetic flux (which is why Maxwell invented it,) it contravenes the requirements of a TEM wave, that all magnetic field should be transverse. Once it is realised that a capacitor is a transmission line[23], we have to conclude that the traditional treatment of the capacitor (i.e. displacement current, generating forward magnetic flux) is incompatible with the traditional treatment of the transmission line (i.e. the TEM wave). We are forced to remove the concept of displacement current from our theory to prevent it from undermining the important concept of the TEM wave.

Repeated LC model for transmission line.

It is traditional to offer the LC model (Fig.10) as a good way of understanding the operation of a transmission line, with inductors either in the top line or in both lines. This is a disastrous model for a number of reasons: the series L induces the student to think that a lossless transmission line has a high frequency cut-off, which is untrue; it outlaws the possibility of signalling in both directions at the same time, and is largely to blame for the general tendency to only half-use the capacity of long, expensive lengths of coax. or twisted pair cables; my erstwhile co-author Malcolm Dividson has pointed out that since a capacitor *is* a transmission line, the model is absurd — modelling something in terms of itself.

My erstwhile co-author Dr D.S. Walton has proposed a new model (Fig10), for the lossy transmission line, where losses R and G remain as discrete resistors periodically along the length, but each section is a delay unit with a certain characteristic impedance (i.e. resistance). According to this model, a signal passes alternately through resistive loss segments R—G, and delay segments. There are no reactive components. Dispersion will arise from repeated partial two-way reflections at each R—G element, and will of course be more apparent for 'high frequencies'.

Displacement current

I have argued that free space had at least one innate characteristic — inpedance. In this section, written by F. David Tombe of Belfast College of Technology, another argument is presented for space having at least one innate characteristic, which he suggests is 'polarization', or paired poles.

Maxwell's displacement cur-

144 I should not have let F. David Tombe include this section. He had been suppressed for a long time. I Catt, 2011

rent is introduced in modern textbooks using the following argument.

Ampere's circuital law can be written:

$$\text{curl } \underline{B} = \frac{4\pi}{c} \underline{J} \qquad (1)$$

$$\text{div curl } \underline{B} = \frac{4\pi}{c} \text{div } \underline{J} \qquad (2)$$

Since the div of a curl is always zero, we arrive at

$$\text{div } \underline{J} = 0 \qquad (3)$$

But the equation of continuity states that

$$\text{div } \underline{J} = -\frac{\delta\rho}{\delta t} \qquad (4)$$

This dilemma results in the conclusion that equation (1) only holds for static situations and that a modification is required for time varying B fields. The additional modification term must be such that

$$\text{div (the additional term)} = + \frac{\delta\rho}{\delta t} \qquad (5)$$

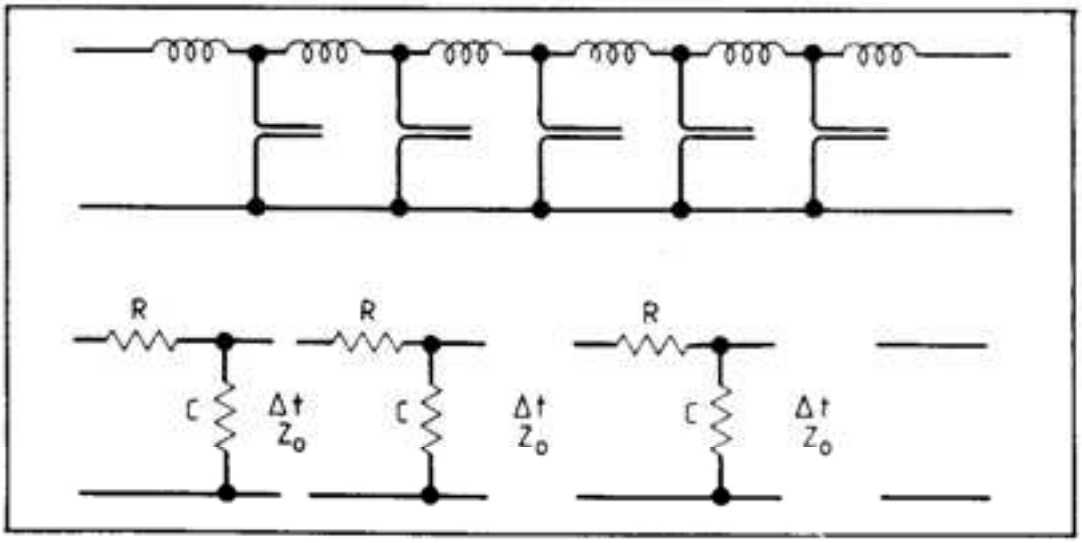
so as to always cancel out with div $\underline{J}$. The result is that the 'displacement current' is added on and the equation now looks like this;

$$\text{curl } \underline{B} = \frac{4\pi}{c} \underline{J} + \frac{1\delta \underline{E}}{c\,\delta t} \qquad (6)$$

But this extra term must surely contradict the original derivation of equation (1), since taking the curl (spatial differentiation) has no relevance to the time dependent aspect of B.

The 'displacement current' can in fact be justified another way simply by viewing it is a

Fig.10. **Old (1) and new (b) models for lossless line.**



polarisation current component implicit in the original $\underline{I}$ term. If we define the vector $\underline{D}$, having direction of current, such that

$$\underline{I} = \frac{\delta \underline{D}}{\delta t} \qquad (7)$$

Then

$$\text{div } \underline{I} = \frac{\delta}{\delta t} (\text{div } \underline{D}) \qquad (8)$$

From the equation of continuity

$$-\frac{\delta \rho}{\delta t} = \frac{\delta}{\delta t} (\text{div } \underline{D}) \qquad (9)$$

therefore, integrating, we get

$$-e + \text{constant} = \text{div } \underline{D} \qquad (10)$$

Now

$$\text{div } \underline{E} = 4\pi\rho \text{(Gauss's Law)} \qquad (11)$$

Combining (10) and (11) we see that

$$\underline{D} = -\frac{\underline{E}}{4\pi} + \underline{D}_2 \qquad (12)$$

Hence using (1) and (7),

$$\underline{I} = \frac{\delta \underline{D}_2}{\delta t} - \frac{1}{4\pi} \frac{\delta \underline{E}}{\delta t} \qquad (13)$$

$$\text{curl } \underline{B} = \frac{4\pi}{C} \underline{I}_2 - \frac{1}{C} \frac{\delta \underline{E}}{\delta t} \qquad (14)$$

Such a derivation implies that electromagnetic waves cannot possibly exist in the absence of a medium in which polarisation is linked to displacement current. The minus sign means that the displacement current is in the opposite direction to the opposing electric field caused by the linear ether stress of polarisation. This is identical in principle to Lenz's Law for torsional aether stress which occurs in Faraday's Law.

TEM wave

The conventional wisdom on electromagnetism contains two mutually contradictory versions of the Transverse Electromagnetic Wave. The first, the Rolling Wave, is the view of 90% of academics. Opposed to this view, the second, correct version, called the Heaviside Signal, attracts the remaining 10% of academics. It is remarkable that the contradiction has never been noticed[24].

Rolling Wave. Kip[25] describes the Rolling Wave;

> "...Our demonstration involves the use of the first two Maxwell equations to show that such a postulated time and space variation of E gives rise to a similar time and space variation of H (but at right angles to E) and that this H variation cuts back to cause the postulated variation in E. Thus, once such a wave is initiated, it is self-propagating."

The two relevant Maxwell Equations are

$$\frac{\delta E}{\delta x} = -\frac{\delta B}{\delta t} \text{ and } \frac{\delta H}{\delta x} = -\frac{\delta D}{\delta t}$$

Heaviside Signal. Opposed to the Rolling Wave is what we shall call the Heaviside Signal. The most highly developed form of this view is that at any point in space, an electromagnetic signal always contains one kind of energy only. The energy density is equal to the product of D and B at that point. The rate of flow of energy, which travels at the speed of light ©, through unit area is

equal to the product of E and H at that point. E, H and © are always mutually perpendicular. $E/H = \sqrt{\mu/\epsilon}$ and $© = 1/\sqrt{\mu\epsilon}$ There is no interaction between E and H, which are co-existent, co-substantial, co-eternal[3].

Beyond Theory H

For the last century, the lost debate in electromagnetic theory as between Theory N (Fig.1), that current and charge in/on wires cause fields, and Theory H (Fig.2) that the electromagnetic field travelling down between two conductors is the cause and electric current and charge in the wires are effect of that cause. I call the debate 'lost' because some 70 years ago the wrong theory, Theory N, won the debate and suppressed all evidence of the existence of the (energy current) alternative, Theory H. (The recent assertion of Prof. Ziman FRS, that 'The aim of science is to achive consensus' gives the seal of approval to this suppression.)

Fundamental to all three theories, N, H and C, is the principle of conservation of energy. The measure of energy flow is the electromagnetic field $E \times H$ (i.e. the Poynting Vector). In the case of Theory N, the current and charge in the wires *cause* the field, which field transports the energy. A theory which is energy based must retain the energy carrier, $E \times H$. It must also retain the *cause* of the energy carrier, i and ρ. In the case of Theory H, the energy carrier $E \times H$ is the *cause*, and i and ρ, being secondary effects of that cause, are not essential to the transport of energy. Heaviside failed to notice that in Theory H, i and ρ were outside the path of the theory from (a) prime mover $E \times H$ to (b) effect, the flow of energy. He never questioned the need for i and in his revoluntionary Theory H.

Although the Catt Anomaly was discovered after Theory C, it shows us that major problems arise when electric charge tries to play its part properly in the passage of TEM wave guided between two conductors. The way out of the dilemma is to excise i and ρ from Theory H, leaving us with a non-dualistic theory, Theory C.

Theory C

In 1873 Maxwell wrote[26]

> "Since ...the theory of direct action at a distance is mathematically identical with that of action by means of a medium, the actual phenomena may be explained by the one theory as well as by the other, provided suitable hypotheses be introduced when any difficulty occurs."

This statement led Hertz to say, "Maxwell's Theory is Maxwell's set of equations."

If we allow ourselves Maxwell's extraordinary licence, we find that Theory C is also Maxwell's Theory. Even though in Theory C, charge and current have been excised from the theory of a TEM wave propagating down between two conductors,

Maxwell's Equations still serve us by making us able to manufacture instruments, i and ϱ, since they have been found to be useful constructs in the past, although now they lack physical reality (in the say way as acceleration lacks physical reality, being merely a mathematical manipulation of physically real distance and physically real time).

Numerous well known (but very confusing) theoretical bodies of knowledge are transformed by the change of view caused by Theory C. In the case of a transistor or thermionic valve, the problem is no longer one of how the charge (electrons) travels from emitter (cathode) to collector (anode). Now, all movement is in a different direction. Energy current, guided by the two conductors, (Fig.11), enters sideways into the critical interface between emitter (cathode) and base (grid), gradually accumulating as it vacillates to and fro along the junction. After a time, the density of the energy reaches a critical value (0.7V) and this causes other energy current, travelling towards the transistor (valve) guided between the emitter wire and the collector wire, to see a shot circuit (instead of the earlier open circuit) by when it reaches the far side of the component. Whereas before, the incident energy current arriving between emitter and collector wires reflected without inversion, it is now inverted before it reflects back towards the +5V supply. Electric charge is not involved — it would collide with the Catt Anomaly.

REFERENCES

1. Catt, I. et al., 'Digital Hardware Design', Macmillan, p65, 1979
2. Heaviside, O., 'Electrical Papers Vol 1', Macmillan, p438, 1892
3. Heaviside, O., 'Electromagnetic Theory Vol 3' chapter 9, art. 451 seqq., 1912
4. ed Schilpp, P.A., 'Albert Einstein, Philosopher-Scientist', Library of Living Philosophers, p53, 1949
5. Catt, I., 'Crosstalk (Noise) in Digital Systems', *IEEE Trans. Electron.* Computers, Vol. EC-16, No. 6, p757, Fig. 39, first trace, Dec. 1967
6. ref. (1), p57
7. Sprague, J.T., 'Electricity: Its Theory, Sources and Applications', p239, 1892
8. Catt, I., 'The Death of Electric Current', *Wireless World*, p79, Dec. 1980
9. Catt, I., 'The L—C Oscillator Circuit', *Proc. IEEE*, Vol. 71, No. 6, p773, June 1983
10. Catt, I., 'Waves in Space', *Wireless World*, p43, March 1983
11. Catt, I., 'Electromagnetic Theory Vol.2', C.A.M. Publishing, p241, 1980
12. Catt, I., et al., 'A High Speed Integrated Circuit Scratchpad Memory', Fall Joint Computer Conference, Nov. 1966.
13. ref. (5), p40
14. ref. (1) p40
15. Ref. (1), p29
16. Catt, I., 'Digital Electronic Design Vol. 2' C.A.M. Publishing, p216, 1979
17. Heaviside, O., 'Electromagnetic Theory Vol. 1', p8, 1893
18. ref. (17), p68
19. Catt, I., et al., 'The History of Displacement Current', *Wireless World*, p68, March 1979
20. Catt, I., 'The Heaviside Signal', *Wireless World*, p73, July 1979
21. van der Pol, B., 'Oliver Heaviside', *Electronics & Power*, p222, March 1978, reprinted from 1938
22. Dawe, P.G.M., *Wireless World*, p39, August 1981 and Catt, I., *Wireless World*, p59, August 1982
23. Catt, I., et al., 'Displacement Current', *Wireless World*, p51, December 1978
24. Catt, I., 'Electromagnetic Theory Vol.1', C.A.M. Publishing, p18, 1979
25. Kip, A.F., 'Fundamentals of Electricity and Magnetism', McGraw-Hill, p320, 1962
26. Maxwell, J.C., 'Treatise on Electricity and Magnetism Vol. 1', p70, 1873
27. ref.(1), p29

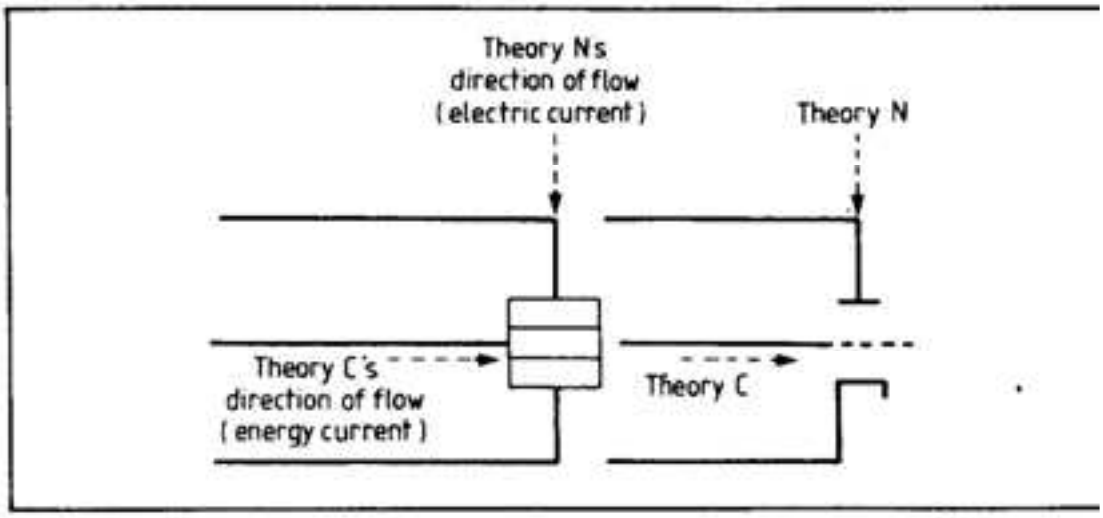


Fig.11. **Theory C turns e.m. through 90°.**