ELECTROMAGNETIC THEORY

VOLUME I

IVOR CATT

C.A.M. PUBLISHING

" We reverse this; the current in the wire is set up by the energy transmitted through the medium around it." ("Electrical Papers" Vol. 1, page 438, by Oliver Heaviside.)

"It was once told as a good joke upon a mathematician that the poor man went mad and mistook his symbols for realities; as M for the moon and S for the sun." ("Electromagnetic Theory" Vol. 1, page 133, by Oliver Heaviside.)

"... the universe appears to have been designed by a pure mathematician." ("The Mysterious Universe", page 115, by Sir James Jeans, Cambridge U.P., 1931.)

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Volume 1

By

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PREFACE

Digital semiconductor electronics has great potential, but is held back by two problems,

1) The practical day to day design procedures are virtually untaught and unknown.

2) The basic electromagnetic theory underlying the work is inadequate and in any case virtually unknown today.

The first problem is the subject of a previous series entitled Digital Electronic Design, currently extending to two volumes. (Except for North America, vol. 1 has been re-issued by Macmillan under the title Digital Hardware Design.) The second problem is addressed in this series. However, the division is not rigidly maintained.

There is far less knowledge and understanding of electromagnetic theory today, and this includes those in the highest places, than an outsider could possibly suppose. Text book writers and lecturers generally repeat what they do

not grasp. Tragically, they do not even realize that there is a large subject which they do not understand, fondly believing that their sometimes skilful manipulation of meaningless mathematical symbols is the subject. This creates a growing problem which is compounded by the inadequacy of the classical theory, so that we have to try to move the allegiance of the "experts" from their present theory, which they do not grasp, to another, called "Theory H". These theories are so far divorced, and the students have been so badly misled, that the process will only be accomplished by stages, with multiple approaches to the problem, rather than by a single, logical, ordered argument. We have to make an escape which is more difficult than that made from Plato's cave. At least the cave-men knew and understood their shadow world. Our student does not even know where he is coming from, and we have to try to show him where he is going to.

The C.A.M. Consultants team, I. Catt, M.F. Davidson and D.S. Walton, have worked together for a number of years. Individual credit for work done is difficult to apportion. The previous two books were attributed to all three, and this volume is attributed to one only, but this is only a rough guide to the contributions by individuals.

CONTENTS

ELECTROMAGNETIC THEORY

Minor flaws in the conventional approach to research in industry coupled with fundamental flaws in the educational system have led us through crisis to super-crisis in the theoretical region linking digital design with electromagnetic theory. Whereas one would hope that digital electronic ideas would at least gradually infiltrate into academia, the situation is in fact one of polarization and a last-ditch, doomed-to-failure stand by academia against the fundamental implications for electromagnetic theory of the digital experience.

Since they are given no other option, experts in the new electromagnetic theory are being forced to discredit and destroy the ivory towers that they are unable to enter.

In Galileo's time, I believe that some academics refused to look through the powerful new telescopes. In the same way as a more powerful telescope, which made it possible to see other moons than our own for the first time, had a major

effect on astronomical theory, so it was possible that high speed (1 nsec) logic and high speed (100 picosecond) sampling oscilloscopes which came into use in the early 1960's might have repercussions for electromagnetic theory.

I was the first man to study 1 nanosecond logic gates thoroughly, starting in 1964 at Motorola in Phoenix, Arizona. I was one of the first users of the remarkable (now defunct) E-H 125 pulse generator, with its clean ten volt, approximately 100 picosecond rose time output. (Actually, for the record, it was a negative, fall time.) This made it possible for me to experimentally refute the reigning theory on crosstalk in digital systems. The high quality pictures of high speed signals in my paper "Crosstalk (noise) in digital systems", IEEE Trans. EC-16, Dec. 1967, pp. 743-763, made it easy to convince any reader that the old (single velocity) theory must be discarded in favour of the new (two velocity) theory.

The implications of what I saw in 1964 with those expensive, sophisticated instruments have gradually been borne home to me during the succeeding fifteen years. However, still, today, probably

no professor, lecturer or text book writer on electromagnetic theory has seen what I saw in 1964. Probably none of them have ever used a sampling oscilloscope.

This creates an unequal competition which I am bound to win on the technical level. Certain notions are obvious and others ridiculous if you have been regularly looking at real cases with the best instruments. The analogy is the sight of other moons through Galileo's telescope.

Established astronomers clung to epicycles long after it was suggested that the earth moved. (Incidentally, today an adherence to the Theory of Relativity with no absolute velocities makes one agree that the pre-Copernican view with Ptolemy's epicycles is no less valid than Galileo's view, which only has meaning and can be distinguished from Ptolemy if absolute space and position are assumed.)

When one looks at a high speed (e.g. 200 picosecond wide) pulse travelling down a printed circuit transmission line using a passive probe into a sampling oscilloscope, one gains a

radical new insight into Einstein's seminal problem of an observer sitting on a beam of light as on a magic carpet. In a Kuhnian revolutionary sense, one cannot then talk meaningfully to the gedanken experiment Relativity gurus gedanken-ing their way along with their eyes shut.

In the same way as we feel free to laugh at the scientists who insisted on clinging onto Ptolemy's epicycles, the current dogged adherence to "total Fourier" and other hangups will be looked on with astonishment by future scientists. Some of the current hangups are as follows:

1) Any (periodic) waveform is the superposition of pure sine waves. (In the case of a series of square pulses, the set of sine waves from which it is constructed is infinite in time, space and frequency range. Whether the word "periodic" above is mandatory is a question which is persistently evaded.)
2) Physical reality is composed of sine waves.
3) A T.E.M. step of zero rise time is philosophically inconceivable.
4) If you do a Laplace or other

transform; that is, if you stand on your head, squint your eyes and bite your tongue hard, you are still looking at physical reality; still handling real concepts.

5) The " = " sign has only one meaning.

6) If you don't understand something, it becomes understandable, controllable and real if you bury it in large quantities of inter-related, obscure mathematical symbols, formulae and equations.

(1), (2) and (3) are remarkable in that they are anti-relativistic. At the core of Relativity is the outlawing of instantaneous action at a distance. A sine wave is anti-relativistic as a primitive because it necessarily exists at more than one point in space at the same instant in time. (3) is a statement diametrically opposed to Relativity. The only conceivable primitive waveform in a relativistic universe is a step (or spike) of zero rise time, because it exists at one point only in space.

(6) points to the excessive faith in symbolism; a failure to realize how ambiguous many symbols are, in particular the " = " sign, means that almost

all the apparently impressive hieroglyphical work in science is meaningless.

" = " is used for the following distinct and mutually contradictory meanings:

a) Identity (i.e. congruence)

Circle $\equiv$ Circle

b) Causality

Force $\longrightarrow$ mass acceleration

c) Implication

Sun $:\!\!>$ light

d) Correlation

e : mc^2

If you study the set of equations representing Newton's Laws, or Maxwell's Equations, as normally stated, concentrating on the = signs, you can easily see what an ambiguous mess they are. The algebraic manipulations to which, for instance, Maxwell's equations are then subjected are a travesty of physics, science, logic and truth, and no meaning can be attached to the "results" of such manipulations. (See for example "Classical Electrodynamics" by J D Jackson, Wiley, 1962, page 178; "Electricity and Magnetism" by B I Bleaney and B Bleaney, Clarendon, 1957, page 236.)

However, if in conversation you insisted that your elder daughter was identical to your younger daughter, whereas in fact their "equality" only related to their parentage, every conclusion that followed this absurd assertion would not necessarily be absurd. For instance, if you knew the address of one daughter you might therefore know the address of the other. In the same way, it is possible for "valid" results to come from absurd postulates based on misuse of the = sign.

To say that div D = ρ (or $e = mc^2$) without making it clear whether identity, causality, implication, correlation or something else is meant by the = sign, invalidates anything that follows even though what follows, or some of what follows, might by chance be true; as the two non-identical daughters might have the same address. It is these "echoes of truth" which masquerade as scientific truth today.

Electromagnetic theory is riddled through with confused nonsense, much of it emanating from the highest places, so that the clean-up task, so necessary if our digital systems are to function properly, will be long and arduous.

THE HEAVISIDE SIGNAL

Maxwell faced up to the paradox that whereas electric circuits, in order to function properly by allowing the passage of electric current, were thought to require a complete closed circuit of conductors; electric current still seemed to flow for a time when a capacitor (which of course is an open circuit) was placed in series with the closed loop of conductors. He "cut the Gordian knot" (according to Heaviside) by postulating that a new kind of current, which he called "displacement current", leapt across the plates within the capacitor. This electric current, which was uniformly distributed in the space between the capacitor plates, could even flow through a vacuum.

Maxwell followed up this daring idea by suggesting that electromagnetic waves might exist in space. Scepticism about his postulated "displacement current" was silenced in 1887 when Hertz discovered the predicted waves in space. The classic pre-Popperian requirement of a

good scientific theory seemed to have been met - the prediction of further results which are later confirmed by experiment.

There are two versions of the Transverse Electromagnetic Wave,

a) The Rolling Wave.

b) The Heaviside Signal.

We shall discuss only the wide variety of views among those who believe (with the Relativists) that there is no instantaneous action at a distance.

THE ROLLING WAVE

The lack of action at a distance creates creates a fundamental difficulty for the wave in space if it is to be launched by a force in the direction of propagation. The key to the ability of a force to project a wave is that there is a pressure difference between two points along the line of propagation. However, knowledge of a difference in pressure between two points A and B which are separated by distance implies instantaneous knowledge at B of the pressure at A; that is, instantaneous action at a distance, which has been outlawed.

This dilemma seems to be overcome if

it is postulated that the force which projects the wave is a lateral, shear, force. It seems as though a shear force can act at a point, and so not contradict Relativity, whereas a longitudinal force cannot.

The above kind of reasoning, combined with the postulation of displacement current, which seemed to flow at right angles to the direction of propagation, joined forces to create the notion of the Rolling Wave. The Rolling Wave contains alternating concentrations of magnetic energy $\frac{1}{2}\mu H^2$ and electric energy $\frac{1}{2}\epsilon E^2$ in the direction of propagation. It is useful to think of a road with alternate red trucks and white motor cars. The magnetic energy, or flux, (by Faraday's Law of Induction) generates electric energy and displacement current ahead of itself, which in turn (by the Biot-Savart Law) generates magnetic flux, or energy, ahead of itself. Each type of energy, or flux, topples over and forward, changing as it topples into the other kind of energy. It is as though in the road containing the alternate red trucks and white cars, first the red trucks reappear as white cars a little further ahead while at

the same time the white cars turn into red trucks a little further ahead; then the rucks and cars change back again, moving forward a little with each metamorphosis. The analogy with the pendulum has been proposed. One can think of a long line of pendulums, alternate ones having potential energy and kinetic energy, and communicating their energy forward step by step with a change of type of energy with each advance.

THE 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, which is equal to the product of E and H at that point, where $\frac{E}{H} = \sqrt{\frac{\mu}{\epsilon}}$. Further, the Heaviside Signal always travels forward unchanged at the speed of light, $\textcircled{c} = 1/\sqrt{\mu\epsilon}$ and never any slower. E, H and $\textcircled{c}$ are always mutually perpendicular.

The two men most likely to understand the "Heaviside Signal" point of view and to oppose the "Rolling Wave" were Oliver

Heaviside himself, in honour of whom it takes its name, and Poynting, the man whose name is attached to the vector E x H. However, their writings show that neither man arrived at a full understanding of the Heaviside Signal described in the previous paragraph.

Heaviside vacillated between the two views, the Rolling Wave and the Heaviside Signal. He always applauded the idea of Displacement Current, which appears to put him on the side of the Rolling Wave. Further, on page 6, art. 453 of volume 3 of his "Electromagnetic Theory", when he says that the curl of E, not E itself, is the real source of the waves, he is again arguing for the Rolling Wave. Curliness is obviously a bid for shear, vorticular forces, a concept intrinsic to the Rolling Wave. However, elsewhere he seems to stand firmly for the Heaviside Signal. For instance (ibid, art. 451, page 4), he says, "It carries all its properties with it unchanged," which is a clear statement of the Heaviside Signal. In art. 452, the mention of a "slab" of signal is strongly on the side of the Heaviside Signal. Heaviside mentions the slab elsewhere in his writings. One

does not conceive of slabs rolling, or generating shear forces or stresses. Almost by definition, a slab, like a slab of heavy granite, moves forward unchanged at constant velocity.

Professor Poynting, who first suggested that energy was distributed in space with a density E x H, also had a partial vision of the Heaviside Signal. He definitely did not know that E is always perpendicular to H, and that the x in E x H means simply multiplication. (He had a term $\sin\theta$ for the angle between them.) Poynting was writing before the general agreement that light is electromagnetic, and so did not know that this Poynting Energy E x H always moved forward (in the third dimension) at a constant speed, $1/\sqrt{\mu\epsilon}$, the velocity of light in the medium.

Poynting had a very good grasp of the direction of energy flow and its magnitude, but did not seem to grasp the importance of reflections at a change of medium, which leads one to think of one energy current E x H flowing backwards along its previous path, passing through the next portion of forward travelling energy current. This superposition of forward and backward energy currents

(implicit in the phrases "phase velocity" and "group velocity") has prevented a clear understanding of the electromagnetic wave.

For fifty years, technology did not give us the power to drive the medium with an electromagnetic signal. With the low power at our disposal, all we could do was resonate the medium with periodic (simusoidal) excitation in the same way as we move a child on a swing. In a resonant medium, energy is necessarily flowing in both directions; most of the forward energy returns to aid the source on the next cycle.

Our inability to drive a medium except periodically insinuated itself into our group psyche, until we came to assert that nature was periodic (and even that it was sinusoidal). Implicit in this view was the wrong belief that

1) electromagnetic energy is necessarily contrapuntal, that
2) $\frac{E}{H} = \sqrt{\frac{\mu}{\epsilon}}$ is not always true, (e.g. when two waves are passing through each other so that H cancels but E does not, so that $E/H = \infty$), and that
3) signals can travel slower than

the speed of light $1/\sqrt{\mu\xi}$

The absurdity of this third idea is easy to demonstrate if we consider a two directional highway. If all cars move at 60 mph but some (A per hour) move eastwards and some (B per hour) move westwards, no one would argue that the total passage of cars eastwards per hour past a reference point, that is, (A - B), would help us to determine the velocity of cars by the formula

Flow of cars = (A-B) per hour
Distance between cars = L
Therefore velocity of cars
= (A-B)L mph.

However, this seems to be done, at least subconsciously, with phase velocity and group velocity. The very terms imply some such calculation.

Some ten years ago, the successful manufacture of high speed (1 nsec.) logic elements capable of driving a 100 ohm load made it possible, for the first time for fifty years, to drive a medium rather than gently resonate it, as a matter of normal routine. Those driving a high speed logic step could clearly see it travelling at the speed of light for the dielectric (never any slower) and remaining unchanged on its journey.

For the first time for seventy years, high speed digital engineers were privileged to see the Heaviside Signal, an unchanging slab of E x H energy current guided between two conductors from one logic gate to the next. Reflections were prevented by proper termination at the destination, so that notions of phase velocity and group velocity evaporated. We saw a slab of energy launched from one point, travelling naltered, to be absorbed by the terminating resistor at the destination.

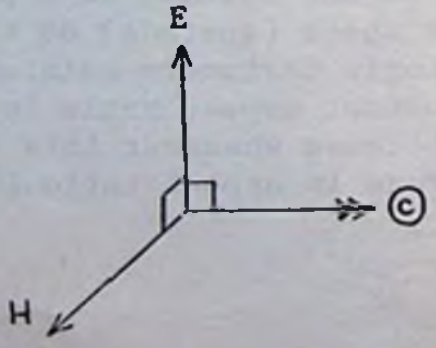
At this point we just had to unburden ourselves at the theoretical level of implicit contrapuntal notions.
A beautiful vision resulted, now called the Heaviside Signal, of a lateral strain E x H (where $E/H = \sqrt{\mu/\epsilon}$) which by definition travelled forward at velocity $1/\sqrt{\mu\epsilon}$. As it travelled forward it filled (or probed) the space ahead of it in the same way as the ripples on the surface of a pond will fill the space (surface) as they come to it. Logic designers maintained a near constant aspect ratio in the space ahead, because whenever this slab came to a change in aspect ratio (= change

of characteristic impedance, better termed characteristic resistance,) some of the energy current would double back on its tracks according to the well known laws of reflection. However, this did not lead back to the old "phase velocity" and "group velocity" notions; rather, the slab of energy current split into two slabs, one to continue forward and the other to return, both slabs continuing to probe, or fill, the space presented to them on their journeys.

The Heaviside Signal offers us a dramatic simplification of our view of the fundamentals of electromagnetic theory.

DEFINITIONS

First define Energy Current (= T.E.M. Wave = Poynting Vector) as our Primitive, where Energy Current is as follows:



Now $\sqrt{\mu/\epsilon}$ and $1/\sqrt{\mu\epsilon}$ can be independently defined. Let us define

a) $\sqrt{\frac{\mu}{\epsilon}} = \frac{E}{H}$ which defines a constant proportionality for the medium.

b) $\frac{1}{\sqrt{\mu\epsilon}}$ = velocity of propagation = ©,
again a constant for the medium.

c) Define $D = \epsilon E$, $B = \mu H$

DERIVATIONS

$$\frac{E}{H} = \sqrt{\frac{\mu}{\epsilon}}, \quad B = \mu H$$

$$\therefore \frac{E\mu}{B} = \sqrt{\frac{\mu}{\epsilon}} \tag{1}$$

$$\therefore \frac{E}{B} = \frac{1}{\sqrt{\mu\epsilon}} = © \tag{2}$$

$$\therefore E = B© \tag{3}$$

By definition *,

$$©\frac{\partial E}{\partial x} = -\frac{\partial E}{\partial t} = -©\frac{\partial B}{\partial t} \tag{4}$$

$$\therefore \frac{\partial E}{\partial x} = -\frac{\partial B}{\partial t} \tag{5}$$

This is equation (12.5.1) in Carter, (G.W. Carter, The Electromagnetic Field in its Engineering Aspects, Longmans, 1954, page 268), (when he believes he is deriving the T.E.M. wave,) which is supposed to result from a causality relationship between E and B (Faraday's Law of Electromagnetic Induction). Carter is clearly developing the Rolling Wave.

We see on the last page that the equation $\frac{\partial E}{\partial x} = -\frac{\partial B}{\partial t}$ is a simple derivation from the definition of the Heaviside Signal and is not based on $\partial B/\partial t$ causing E, as Faraday thought he had discovered.

We have shown that the passage of a T.E.M. wave and all the mathematics that has mushroomed around it does not rely on a causality relationship (or interchange) between the electric and magnetic field. Rather, they are co-existent, co-substantial, co-eternal. The medium can only be strained in the two lateral dimensions ($\overline{E}$ and $\overline{H}$) in fixed proportion. (In a similar way, pressure in a liquid in direction x does not cause pressure in the y (and z) direction; they co-exist.)

Faraday's great discovery in the 1830's was not electromagnetic induction; not a causality relationship. His great achievement was to discover that change was important. This started us on the road to discovering the now postulated primitive, the Heaviside Signal, which can only move; it cannot stand still. Heaviside put together the main features of the new concept, but it took another seventy years to put flesh onto the bare bones.

* By convertion, if a voltage step is travelling from left to right (i.e. in a positive direction) it has a positive velocity; dx/dt is +ve.

$\frac{\partial E}{\partial t}$ is +ve but $\frac{\partial E}{\partial x}$ is -ve.

This (reversal) problem is well known by anyone who has drawn out an oscilloscope trace onto paper with voltage and distance axes. This explains the -ve sign in equation (4) three pages back.

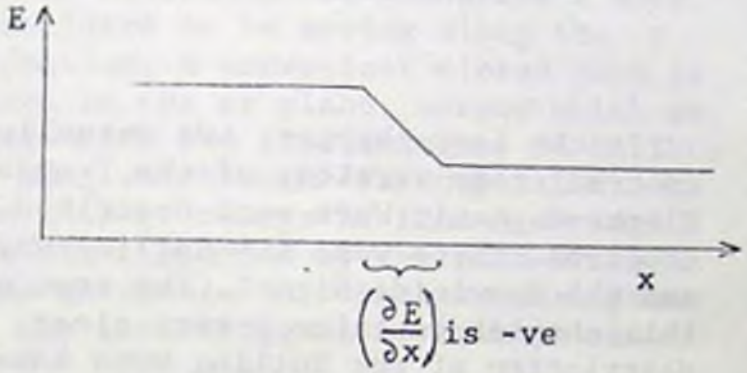
When we travel, we gain distance while we lose time. However, we regard our velocity dx/dt as positive.

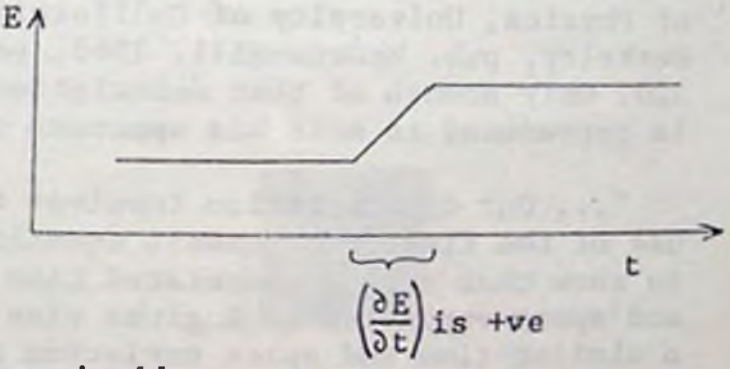
It is strange that this ambiguity in sign convention had led to a negative sign in electromagnetic theory. This in turn introduced the idea of a "Lenz's Law" reluctance, or back e.m.f., in which lies nexted the idea of causality,

$i \longrightarrow \int H dl$ and $\frac{dB}{dt} \longrightarrow v$

In fact, electric and magnetic fields have a positive relationship, and co-exist rather than cause each other.

$$\frac{dx}{dt} = ©$$





Numerically,

$$© \left|\frac{\partial E}{\partial x}\right| = \left|\frac{\partial E}{\partial t}\right|$$

Since by convention $\partial E/\partial t$ is +ve, $\partial E/\partial x$ -ve and © +ve, we must conclude that © $\partial E/\partial x = - \partial E/\partial t$

THE ROLLING WAVE

In the last chapter, two mutually contradictory versions of the Transverse Electromagnetic Wave were described and compared. These were the Rolling Wave and the Heaviside Signal. The rest of this chapter contains a very clear description of the Rolling Wave taken from "Fundamentals of Electricity and Magnetism" by Arthur F. Kip, Professor of Physics, University of California, Berkeley, pub. McGraw-Hill, 1962, page 320. Only enough of that description is reproduced to make his approach clear.

"... 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 acts back to cause the postulated variation in E. Thus, once such a wave is initiated, it is self-propagating.

"The figure on the next page is used

to show the application of Faraday's Law of Induction to the plane E wave, postulated to be moving along the x direction. A convenient closed path is drawn in the xy plane, around which we shall take the line integral of E. This is equated through Faraday's Law to the rate of change of flux H through the plane bounded by the path of the line integral. Only the vertical parts of the line integral contribute since

E is in the y direction, so that E.dx=0. If we go around in a counter-clockwise direction, the line integral around the path chosen becomes

$$\oint E.dl = (E_y)_{x+dx}dy - (E_y)_x dy$$
$$= \left[(E_y)_{x+dx} - (E_y)_x\right] dy$$

where we are to take the values of E_y at x+dx and x, respectively. The difference between these two values of E_y at the two positions is $(\partial E_y/\partial x)dx$, so we can write the line integral of Faraday's Law of induction as

$$\frac{\partial E_y}{\partial x} dxdy = -\mu_o \frac{\partial H_z}{\partial t} dxdy$$

Since this relationship is true for any area dxdy, we may write

$$\frac{\partial E_y}{\partial x} = -\mu_o \frac{\partial H_z}{\partial t}$$

(This ends the extract from Kip. To get to the Carter equation we have to replace μH by B, of course.)

UNFORTUNATE PASSAGES IN THE TEXT BOOKS

Oliver Heaviside had something to say about writers on electromagnetic theory. ("Electrical Papers", Macmillan, 1892, page 28.)

"The very first step to the understanding of a writer is to find out what he means. Before that is done there cannot possibly be a clear comprehension of his utterances. One may, by taking his language in its ordinary significance, hastily conclude that he has either revolutionised the science of induction, or that he is talking nonsense. But to do this would not be fair. We must not judge by what a man says if we have good reason to know that what he means is quite different. To be quite fair, we must conscientiously endeavour to translate his language and ideas into those we are ourselves accustomed to use. Then, and then only, shall we see what is to be seen."

So wrote Heaviside a century ago. The situation has deteriorated markedly

since then, so that today, try as we might, we would never succeed in attaching much menning to the utterances of most text book writers when they "discuss" such fundamentals as Faraday's Law of Induction, Displacement Current, the Transmission Line etc. The reason for this is that the writer himself did not understand these very difficult ideas, but merely copied his material from earlier text books, perhaps adding a further twist to the mathematical barrel organ.

Since most text books are nonsensical when it comes to the most important subjects, so that it is impossible to start to discuss their content, we are forced to pick on those writers who were brave enough, or perhaps foolhardy enough, to try to write clearly, and not bury their writings in a fog of curls, divs, transforms etc. etc.

B.I. Bleaney and B. Bleaney, "Electricity and Magnetism", Clarendon, 1957, page 238, clearly show that they think that displacement current is uniformly distributed across the capacitor plates. It follows that they do not know that a capacitor is a transmission line.

"If for simplicity we take a parallel plate condenser with plates of area A, surrounded by a guard ring, the field in between the plates is uniform, and the displacement D has the value $D = q/A$, where q is the total charge on the positive plate." The authors are discussing the flow of current through a capacitor, and the above sentence is completely wrong.

S. Ramo and J.R. Whinnery, "Fields and Waves in Modern Radio", Wiley, 1944, page 153;

"Total displacement current flowing between the plates is the area of the plate multiplied by the density of displacement current." This wrongly implies a uniform E field across the plates.

G.W. Carter, "The Electromagnetic Field in its Engineering Aspects", Longmans, 1954, page 277;

"We have seen that, with increasing frequency, the displacement current becomes increasingly important. If that current were non-existent, electromagnetic effects would be transmitted with infinite velocity; but, with displacement current taken into account, the velocity is found to be high, yet finite." Here we see the Displacement

Current mythology developing, enveloping and confusing the whole subject.

S. Ramo and J.R. Whinnery, "Fields and Waves in Modern Radio", Wiley, 1944, page 152, reach the extreme in unscientific fudging and foolery;

"Now that the displacement current term has been acquired, we should be much happier about the problem of varying fields, for it is now possible to explain certain other things that should have proved worrisome had only conduction current been included in the law of Biot and Savart.

"... If conduction current alone were included, the computation would have indicated no current passing through this surface and the result would be zero. The path around which the integral is evaluated is the same in each case, and it would be quite annoying to posess two different results. It is displacement current which appears at this point to preserve the continuity of current between the plates of the condenser, giving the same answer in either case."

When did this sloppy attitude creep into the treatment of electromagnetic theory? The answer is, very early indeed, and a great deal of the blame could be

said to rest with Maxwell himself. We can see the precursor to the rot that was to set into the subject later on on page 70 of his Treatise on Electricity and Magnetism, 1873, Vol. 1;

"Since, as we have seen, 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."

The answer to this shocking statement is surely that if one set of mathematics describes both systems including direct action at a distance and systems excluding action at a distance, then the equations are so bland as to describe nothing at all. It led Hertz to say, "Maxwell's Theory is Maxwell's set of equations." And on down the slippery slope we inevitably went, to the present state of confused nonsense. One suspects that if Maxwell had not been so ambitious to gain a professorial chair, the subject would be in far better shape today.

In his book "Electromagnetic Theory", Vol. 1, page68, 1893, Oliver Heaviside

had this to say on the subject;

"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 ster otype the work of a great man, apparently merely because it was so great an advance, and because of the great respect thereby induced....

".... It is, I believe, a fact which has been recognised that not even Maxwell himself quite understood how .... his "general equations of propagation" [operated]. We need not wonder, then, that Maxwell's followers have not found it a very easy task to understand what his theory really meant, and how to work it out. I had occasion to remark, some years since, that it was very much Maxwell's own fault that his views obtained such slow acceptance; and, in now repeating the remark, do not abate one jot of my appreciation of his work, which increases daily. For he devoted the greater part of his treatise to the working out and presentation of results which could be equally well done in terms of other theories, and gave only a very cursory and incomplete exposition of what were peculiarly his

own views and their consequences, which are of the utmost importance. At the same time, it is easily to be recognised that he was himself fully aware of their importance, by the tone of quiet confidence in which he wrote concerning them."

Let us now analyse some of the muddled material in a book by the Professor of Physics at Berkeley, University of California. The book is "Classical Electrodynamics" by J. D. Jackson, Wiley, 1975.

On page 217 he says,

$$\nabla.D = 4\pi\rho \qquad (6.21.1)$$

First we should cross out the term 4π which appears merely because Jackson uses an archaic pre-rationalised system.

$$\nabla.D = \rho$$

D is an expression of ρ. It is not the same thing as ρ, any more than candlelight is the same thing as candles. Although in a very limited sense it is permissible to say

Candle power outputted = no. of candles lit,

the key point is that candlelight is <u>not</u> the same thing as candles. Obviously an arrow $\longleftarrow$ would be safer than the =

sign and less open to the generation of confusion, thus:

$$\nabla . D \leftarrow \rho$$

On page 218 Jackson says,

$$\nabla . J + \frac{\partial \rho}{\partial t} \equiv 0 \quad (6.24)$$

This is a statement of conservation of charge, and I have strengthened Jackson's $\equiv$ to $\equiv$. This is a very tight identity; totally different from the sloppy $\equiv$ on the previous page which I have replaced by a $\leftarrow$.

(6.24) says that:

(the number of candles entering a surface) + (the number of candles leaving the surface) + (the rate of change of candles within the surface) $\equiv 0$

Each term must of course have the correct sign. (6.24) makes no mention of candlelight.

Summary

$$\nabla \cdot J_{\text{candles}} + \frac{\partial \rho}{\partial t}_{\text{candles}} \equiv 0 \qquad (6.24)$$

$$\downarrow$$

$$\frac{\partial^2}{\partial t^2}(\Delta \cdot D)$$

candlelight

(6.21.1)

Obviously it is nonsense to substitute the term from (6.21.1) which refers to candlelight into an equation about candles (6.24), yet that is what Jackson does. You could produce a new valid equation about the candlelight coming from J added to the candlelight coming from ρ :

$$\nabla \cdot J + \frac{\partial \rho}{\partial t} = 0 \qquad (6.24)$$

new term; candle-light from J

$$+ \frac{\partial (\nabla \cdot D)}{\partial t} = 0 \qquad (I.C.)$$

But you cannot carry $\nabla \cdot J$ into equation (I.C.). That is a travesty of physical reality, of common sense, and of mathematical logic. The fact that other text book writers write such rubbish does not justify Jackson in doing so.

On page 210, when discussing Faraday's Law of Induction, Jackson says,

"The changing flux induces an electric field around the circuit, the line integral of which is called the electromotive force, $\mathcal{E}$. ...."

This is a false statement of what Faraday discovered and what he believed. Faraday did not discover an electric field and integrate it. He discovered a voltage around the loop in the single small gap in a conductor lying around the loop.

The following mathematical derivations from the postulate of "Displacement Current" are taken from B.I. Bleaney and B. Bleaney, "Electricity and Magnetism", Clarendon, 1957, p 236. They are followed by some commentary from G.W. Carter, "The Electromagnetic Field in its Engineering Aspects", Longmans, 1954, p 262.

Define $\text{div } D = \rho$

$$\text{div } j = -\frac{\partial \rho}{\partial t}$$

$$\therefore \text{div } j = -\frac{\partial}{\partial t}(\text{div } D)$$

$$\text{div } \left(j + \frac{\partial D}{\partial t} \right) = 0$$

Hence we define j' as

$$j' = j + \frac{\partial D}{\partial t}$$

Then $\text{div } j' = 0$

Ampère's Law becomes

$$\text{curl } H = j + \frac{\partial D}{\partial t} = \sigma E + \frac{\partial D}{\partial t}$$

"It was a leap of genius on the part of Clerk Maxwell to [postulate displacement current $\partial D/\partial t$]..... Maxwell proceeded to show that his surmise led to the discovery of electromagnetic waves which are transmitted through space with a certain velocity; we shall presently follow him along this path.

"The super-current $I + \frac{\partial D}{\partial t}$ is now generally known as the <u>total current</u>... ..... It may require some effort of imagination from the reader to begin to think about a "current" which is not a flow of electrons...."

It is instructive to compare Maxwell's postulate of Displacement Current in electromagnetic theory with Catt's seminal new concept, "Circularity", in the geometry of the circle. Both postulates illuminate and clarify their subject.

$$A = \pi r^2$$

$$C = 2\pi r \qquad r = \frac{C}{2\pi}$$

$$A = \frac{C^2}{4\pi}$$

Define α by $\alpha = \frac{C^2}{4\pi^{\frac{1}{2}}}$

Then $A = \frac{\alpha}{\sqrt{\pi}}$

It was a leap of genius on the part of Catt to postulate the new concept of <u>Circularity</u>, α, in the geometry of the circle. Catt proceeded to show that this new concept led to the prediction that a circular wheel can <u>roll</u>. This was brilliantly confirmed experimentally

twenty years after Catt's first daring proposal. It may require some effort of imagination from the reader to begin to think about "circularity" when he first comes across it. However, this concept will lead him to a much deeper understanding of Euclidian geometry in general and the nature of circles in particular, as we shall see below.

Since the rate of increase of A as r is increased, usually called the "Divergency" of a circle, is

$$\frac{\partial A}{\partial t} = 2\pi r \frac{\partial r}{\partial t}$$

it follows that since

$$A = \frac{\alpha}{\sqrt{\pi}} \quad ,$$

$$\frac{\partial \alpha}{\partial t} = 2\pi^{\frac{1}{2}} r \frac{\partial r}{\partial t}$$

Here we see how mysterious, how mathematically beautiful, is the universe that God has placed us in. We see why Sir James Jeans said, "The Great Architect of the Universe now begins to appear as a pure mathematician." (Sir J. Jeans, "The Mysterious Universe", Cambridge U.P. 1930, p 134.)

THE BREAKDOWN OF MEANING IN ELECTRONICS

My pioneering work on high speed (1 nsec) logic interconnection in the early 1960's divorced me from classical theory and practice in electromagnetics, and for many years I merely continued to assemble fast logic successfully while others failed. (See Fall Joint Computer Conference, Nov. 1966, page 315, "A High-Speed Integrated Circuit Scratchpad Memory.") I formulated my own philosophical, theoretical and practical position only to the extent that I needed to in order to succeed as a practical engineer designing and assembling reliable digital systems. (See my paper in IEEE Trans. E.C., Dec. 1967, page 743-763.)

It was many years later, when I had stopped trying to earn my living as an engineer and turned to writing, that I came to look more deeply into the reasons why other engineers were unable to assemble fast logic (and even normal 5 nsec logic) successfully. I was writing a text book on digital design, and among other things, wanted to help

other engineers with their basic electromagnetic theory. The book was never published because of my failure to resolve this problem.

I read all the text books, and was horrified by the rubbish I found in even the most highly regarded books. Faraday's Law of Magnetic Induction, Displacement Current and the rest were treated in an offhand, incompetent way. I did not know that the authors were ignorant; I assumed that they were merely slovenly. Discovery that celebrated text book writers on E-M Theory were ignorant was to come much later, when I began to correspond with them.

To try to understand the welter of confused nonsense, I decided to go back in time and read Faraday and Maxwell, to understand the origins of such notions as Displacement Current. I thought this would give me a clue to the ramblings of writers a century later.

On my first visit to the IEE library, the then librarian Mrs. Goodship strongly urged me to investigate the library of Heaviside's books, which had been gathering dust (and suffering

damage and loss) there for decades, unnoticed and unread.

Although I had by then been studying digital design and electromagnetic theory for some twelve years since graduating, I had no idea that Oliver Heaviside had made any contribution to the subject; indeed, he was virtually unmentioned in any text book on the subject published during this century. I was staggered to find the wealth of ideas in his writings, some of them closely allied to the ideas that I had been painfully developing as a result of my practical experience with high speed logic. When I read his phrase, "We reverse this...", it was like hearing a thunderclap. Heaviside had been there before me! I had an ally!

Later, of course, I was to find that this long dead ally plus my two research colleagues, Walton and Davidson, were to have a long, uphill struggle against the forces of ignorance and suppression entrenched in the faculties, journals and institutions; a struggle of such proportion that it took us three years before we succeeded in recording, let alone communicating, anything of our very successful researches. We have won

the battle now against the very same kind of people who a century before suppressed (and almost destroyed from the record) Oliver Heaviside's brilliant insights into Electromagnetic Theory.

We still cannot publish in any "reputable" journal or teach in any college or faculty. But the battle is over; it is known that we have a contribution to make on the subject, and parts of that contribution are readily available to the diligent student and researcher.

The discussion which completes this chapter is included for historical reasons. It was eight years ago rejected by all "reputable" journals in Britain and the U.S.A. It represents a milestone in my theoretical development which I have now advanced far beyond, so that today I am only somewhat in agreement with its content. It begins with the next paragraph.

I see both an insistence on being formal and at the same time a refusal to be formal (rigorous). Putting it another way, one must say things in a mathematical language, but one refuses to be definite about the meaning of the

mathematical statements.

The example I am very familiar with (because it prevents engineers from fully comprehending Faraday's Law and so they cannot make reliable digital systems) is as follows;

Faraday's Law says that if there is a change of magnetic flux through a surface, then an e.m.f. proportional to the rate of change of flux is developed around the perimeter of the surface. This can correctly and usefully be stated mathematically as follows:

$$V = - \frac{d\phi}{dt}$$

where V is an e.m.f. which tends to make a current flow around the perimeter of the surface in such a way as to generate magnetic flux which cancels the original impressed flux ϕ. If a conductor is laid around the full perimeter of the surface, no V will be seen, because current will flow in the conductor so that the total rate of change of flux through the surface is zero. However, if a small break is made in this wire, the voltage V will be seen across the break - we have gone back to Faraday's original experiment.

So far so good (except that it looks trivial because we have only managed to muster one equation with three terms in it). The next step, which occurs in every test book on electromagnetic theory, is illegal. They all say that the above equation can be rewritten

$$\oint \text{Eds} = - \frac{d\phi}{dt}$$

where E is the potential gradient along the perimeter s of the surface. (s is distance, not area.)

There are two reasons why this new formulation of the equation is brought in.

1. It looks more mathematical, and so more reputable.

2. To quote E.A. Burtt, "The Metaphysical Foundations of Modern Science," page 17, ".... the whole magnificent movement of modern science ..... especially the all-important postulate that valid explanations must always be in terms of small, elementary units [lots of little E's] in regularly changing relations." And again, page 16, ".... the notion that true explanations, of man and his mind as well as of other things, must be in terms of their simplest parts."

The danger is that one might break down a valid whole (V) into lots of little illegal or even non-existent elements (E). M. Polanyi ("Personal Knowledge", RKP 1958 page 63,) fears that "to transpose a significant whole into the terms of its constituent elements is to transpose it into terms deprived of any purpose and meaning." We seem to want to fragment something which is real into lots of little things whether they be real and helpful or not.

To quote M.A. Biot's article in "Mechanical Engineering" for February 1963;

"This trend towards a formalism devoid of humanistic content, this emphasis on form at the expense of substance is found not just in engineering. It also prevails in our contemporary art and literature and obviously results from deeper, and perhaps self-destructive, under-currents in our culture.

"It constitutes a retrogression toward the abuses of medieval scholasticism and away from that intimite union of craftsmanship and science so characteristic of the Renaissance period.

"..... Generally speaking, the

professional mathematician of today is a specialist in logical systems and rigour. His lack of flexibility makes him unable to exercise one of the very essential functions of mathematics in the natural sciences and engineering, which is to separate the relevant from the irrelevant, to simplify the formulation of complex phenomena, to synthesize and to unify the substance rather than the form."

The real tragedy in my complaint about the second formulation of the equation, that is, $\oint E ds = - d\phi/dt$ does not evaporate if my assertion that this statement is illegal is proved to be unfounded. The real tragedy is that no one really cares whether this formulation is valid or not. (See M. Polanyi, "Personal Knowledge", RKP, 1958, pages 15 and 182; also K. Popper, "Conjectures and Refutations", RKP, 1963, page 100.) My complaint about this equation will be regarded as obscurantist, whereas in fact the original introduction of the equation was obscurantist.

I conclude this chapter with the argument against the equation.

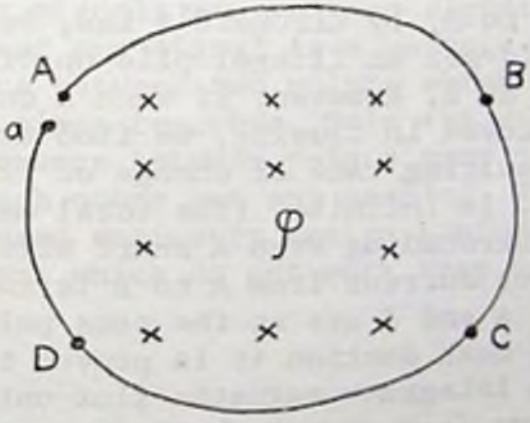
One might think of the contemporary scientist as a traveller without a map. But it's worse than that, because he also feels that cartography is a waste of time, that it's obscurantist. It's extraordinary that the scientist, supposedly the ultimate in clear, logical thinking, doesn't seem to care whether what he says has any meaning.

The sociological implications of all this are important. If the equation I complain of is invalid, it will take one or two years for me to make the point in my own text book. [Actually it took eight years!] Then if other text books follow suit, in about eight more years most books will contain the new doctrine. Then we have to wait another eight years or so for those trained in the new doctrine to gain the ascendancy. So to get over the problem which I claim is holding up the development of computers (one of many) will take nearly twenty years. This means that the rate of technological and social change will not accelerate, because we do not have the means to generate rapid change. So we can look forward to Future Calm instead of Future Shock, with change either continuing at the present rate

or slackening off as we drown in complexity.

REFUTATION OF THE EQUATION $\oint E ds = - \frac{d\phi}{dt}$

We can measure the voltage drop between A and a, and it equals V, where $V = - d\phi/dt$, and this is not in dispute. We cannot however measure the voltage drop from A to C. If we could connect a voltmeter between A and C and it could measure a meaningful voltage drop, it would not know whether to measure the voltage drop along ABC or along ADC.



They are not equal, because if they were, the voltage all the way round, along ABCDA, would be zero, because it would equal $V_{ABC} - V_{ADC}$. But we know that the voltage all the way round equals V, and not zero. So we see that only the full voltage drop around the loop, V, can be measured. A voltage drop along a segment of the loop cannot be measured, and for that reason has doubtful scientific credentials. Let us now see whether such a voltage drop, V_{AB} for instance, has meaning.

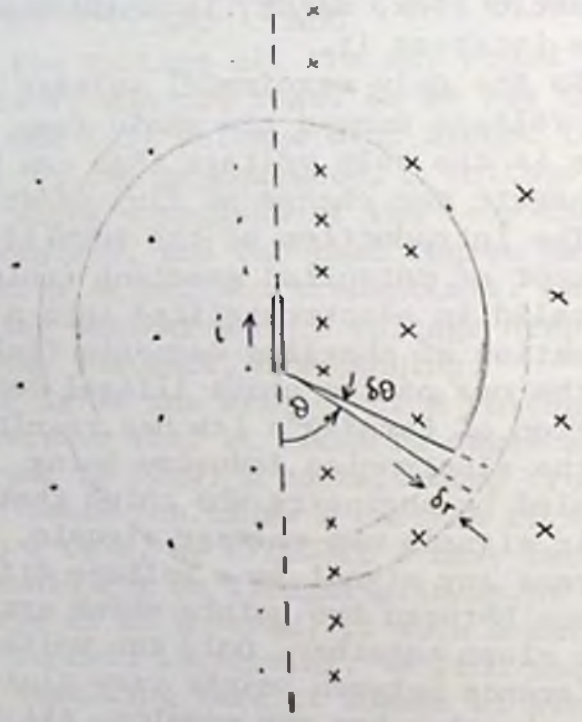
It is of the essence of a voltage difference that it tends to cause a current to flow. A voltage drop from A to B could not cause a current to flow from A to B, by Kirchoff's Law, because we would get an illegal pile up of charge at B. However, if such a current did succeed in flowing, we find that the resulting rate of change of flux, $d\phi_2/dt$, is infinite. (The total magnetic flux surrounding even a short wire carrying current from A to B is infinite unless A and B are at the same point. In the next section it is proved that if you integrate magnetic flux out sideways from even a short current

carrying wire it adds up to infinity.) Far from such a voltage and current tending to reduce the total change of magnetic flux, $d\phi/dt$, it would therefore increase it.

So the only meaningful voltage is V, the voltage around the whole loop, and this is the only voltage that can help to negate the change of flux $d\phi/dt$.

The introduction of the invalid concept of potential gradient (which is valid in electrostatics) into a situation of changing magnetic fields by the use of the above illegal formulation of Faraday's Law has resulted in the electronics industry being peopled by engineers who think that their signals are voltage signals, whereas any signal is a voltage difference between two points which are very close together. Only the voltage difference between points very close to each other has any meaning. All these confused engineers design confused systems which do not work very well.

PROOF THAT THE TOTAL FLUX GENERATED BY EVEN A SHORT LENGTH OF STRAIGHT WIRE CARRYING A CURRENT IS INFINITE



Consider a short length of wire Δs radius a carrying a current i. Let us integrate the total magnetic flux entering the paper by first finding the flux in a small area $\delta r \times r\delta\theta$, integra-

ting from $0 = 0$ to $\theta = \infty$ so as to get the total flux, φ_{ring}, through the half-ring, and then integrating outwards to get the total flux through the whole surface, starting at a distance r, from the wire and ending at infinity.

$\delta\varphi$ = area of element x flux density

$$= \delta r \cdot r\delta\theta \times \mu\,\delta H$$

$$= \delta r \cdot r\delta\theta \times \frac{\mu i \Delta s \sin\theta}{4\pi r^2}$$

by the Biot-Savart Law.

$$\varphi_{ring} = \frac{\delta r}{4\pi r} \mu i \Delta s \int_0^{\pi} \sin\theta d\theta$$

$$= \frac{2\,\delta r \mu i \Delta s}{4\pi r}$$

Now let us integrate the flux in the half-rings, from r to ∞.

$$\int_r^{\infty} d\varphi = \varphi = \frac{2\mu i \Delta s}{4\pi} \int_{r_1}^{\infty} \frac{dr}{r} = \infty$$

So if a current flows down a short length of straight wire, the resulting total magnetic flux is infinite.

ATTITUDES TO DISPLACEMENT CURRENT

Two articles published in WIRELESS WORLD resulted in a large response in letters to the editor which covered the spectrum of attitudes to the subject of Displacement Current. They are reproduced here because they seem to provide valuable insight into the subject.

The original articles were:
DISPLACEMENT CURRENT by Catt, Walton and Davidson, Wireless World, Dec. 78, pp51-52. Reprinted in part in the book DIGITAL ELECTRONIC DESIGN VOL 2 by the same authors, pub. C.A.M. Publishing, page 212.
HISTORY OF DISPLACEMENT CURRENT by Catt, Walton and Davidson, Wireless World, March 79, pp67-68. Reprinted on page 253 of the same book.

"The explanation given by Messrs Catt, Davidson and Walton (Dec 78 p51) of the flow of current 'through' a capacitor without resorting to Maxwell's concept of displacement current is attractive to me, because notwithstanding my immense respect for Maxwell I

have always felt that displacement current was a kind of subterfuge to get over a logical difficulty. (But I never had, or heard of, a difficulty created by imagining current having to flow across the capacitor plates faster than light. Where did the authors get that idea? And why wouldn't it apply also to the current in the leads?) But before wholeheartedly accepting this alternative I would like to be given certain reassurances.

"At the foot of column 1 the authors point out that the parallel elements of the disk capacitor depicted can be regarded as transmission lines whose characteristic impedance Z_o is continuously decreasing towards the far end. So there would be gradual reflection all the way. But in the mathematical proof [reprinted in DIGITAL HARDWARE DESIGN by the same authors, pub. Macmillan, London, 1979, p32] Z_o is treated as constant and there is reflection only at the far end. This made me feel I was being conned.

"According to Ampère's Law, the connecting leads carrying the charging current must be everywhere encircled by a magnetomotive force numerically

equal to the current. In the authors' Fig. 1 the leads are horizontal and the plates are in vertical planes, parallel to one another and also to the m.m.f. around the leads. But what about the m.m.f. in the space between the plates, due to what we have become accustomed to calling displacement current? This current, being a continuation across the capacitor gap of the external current, one naturally sees its m.m.f. also as in a vertical plane. Can the authors show clearly how this follows from the geometry of their transmission line currents, which flow everywhere at right angles to the current in the leads? This aspect is of some importance, since the propagation of radio waves depends on it. Can the authors convincingly get rid of dosplacement currents in space?" - M.G. Scroggie, Bexhill, Sussex.

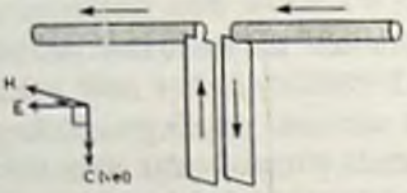
The authors reply: The article discusses a circular capacitor. The appendix discusses a rectangular capacitor in order to minimize mathematical complexity. The appendix proves that if a voltage source is switched across a resistor and a rectangular capacitor in series, a waveform results

which approximates to an exponential. As Mr. Scroggie points out, it does not prove the same for a non-rectangular capacitor.

If you ask us to resolve paradoxes in classical theory, you are asking us to say that we are saying nothing that is fundamentally new; you are asking us not to publish anything. Do you believe that "new" information is only acceptable if it indicates no flaws in the conventional wisdom, i.e. if it is not really new?

As to the m.m.f. in the space between the plates, this has never been measured. If it had been measured it would have been found to be non-uniform, and the revered B.I. Bleaney and B. Bleaney ("ELECTRICITY AND MAGNETISM", Clarendon 1957, p238) and others would not have written "....the field between the plates is uniform....", which of course it is not; a TEM waveform advancing between the plates of a capacitor (= transmission line) creates a field behind itself but not ahead of itself.

The last paragraph of Mr Scroggie's letter is crucial. If the capacitor were rectangular and oriented much as shown in our Fig. 1(c) then no m.m.f.



in the vertical plane would result from current in the capacitor plates. Vertical m.m.f. would mean that the waveform was not TEM, but we know that it <u>is</u> TEM and travelling vertically downwards between the capacitor plates. That is, E and H fields are at right angles to the (downwards) direction of propagation, and therefore are horizontal. This is no more paradoxical than trying to apply Ampère's Law to a TEM step travelling along any transmission line.

Ampère did not know that a TEM wave (E x H) travels forward between two wires at the speed of light. He did not know that a capacitor is a transmission line; he did not know about transmission lines.

These matters will be discussed further in a forthcoming article in WIRELESS WORLD. A paper "The Heaviside Signal" will further clarify the situation (see "Electromagnetic Theory" pub. C.A.M. Publishing).

Now for the second letter.

"I am slightly alarmed by some of the statements in the article "Displacement current - and how to get rid of it" (December 1978). I suggest that there would justifiably be an outcry if the authors were to have written paragraph 5 as follows...

> Since the inductance has now become a transmission line, it is no more necessary to postulate 'magnetic flux' in an inductor than it is necessary to do so for a transmission line. The excision of 'magnetic flux' from electromagnetic theory has been based on arguments independent of the classic dispute ....(an apparent negation of Faraday's law of Induction).

"Displacement current (without the inverted commas) is as real and justifiable a concept as conduction, or convection, current in charge transport-

it is directly analogous to the time differential of magnetic flux in magnetic theory ($\partial\bar{D}/\partial t$ instead of $\partial\bar{B}/\partial t$ if you want to be precise). Displacement current is neither a mathematical convenience nor an artefact of a faulty model for a capacitor, it is a fundamental part of Maxwell's equations.

"To those who have designed high frequence networks, interchanging between a capacitor or inductor and a transmission line is common practice: the inductors and capacitors used actually look like short transmission lines. Such circuits can be analysed using either of two methods; the discrete approach in which case each line has an equivalent inductance and capacitance or the distributed approach in which case characteristic and terminating impedances are important. Paragraph 4 could be misleading because it confuses lumped and distributed techniques: a transmission line used as a capacitor, or a capacitor appearing as a transmission line, must have some inductance which is inherent in the component construction. This will become clear in the next paragraph.

"Consider an ideal transmission line.

For analysis this has a few useful parameters; L - the series inductance per unit length, C - the shunt capacitance per unit length, Z_o - the characteristic impedance ($= \sqrt{L/C}$), and v - the characteristic velocity ($1/\sqrt{LC}$). (And where do we get these parameters from? Why, of course, from electromagnetic theory using $\bar{B}, \bar{H}, \bar{E}, \bar{J}$, and naturally enough D the electric flux or displacement vector.) The impedance measured at the end of an open circuited transmission line of length d is simply $Z_{in} = Z_o/j \tan(\omega d/v)$. But if $(\omega d/v)$ is small, a condition of lumped circuit analysis, we can expand the tan term to obtain
$Z_{in} = Z_o/(j\omega d/v) + \frac{1}{3}Z_o(j\omega d/v)$.
Using the transmission line parameters this gives $Z_{in} = 1/j\omega(dC) + j\omega(dL/3)$ which can be interpreted quite easily as a capacitor and inductor in series. To me that would seem a very plausible mechanism for an internal series inductor in a capacitor.

"At 'low frequencies' a capacitor may well be a good equivalent circuit for a particular form of transmission line, but at increased frequencies the series inductance must be considered:

eventually we must switch to a distributed analysis, otherwise we are going to be barking up the wrong tree in the wrong ball park. For digital systems whrre harmonics extend into the GHz re region very careful consideration must be given to distributed effects in what are nominally lumped components."
- P.I. Day, Maidstone, Kent.

The authors reply: We would like to make three points which we hope will clear up any misunderstanding that Mr Day has over the statements we made.
1. He wrongly assumes that we say inductance does not exist. Series induc tance does not exist as a separate entity, but distributed inductance does, linked to distributed capacitance as a measured property of a transmission line defined as characteristic impedance.
2. We are considering an ideal step response of a component and the inclusion of frequency in the discussion is making an unnecessary complication. (See WIRELESS WORLD June 1978.)
3. If Mr Day believes that you can swap "magnetic flux" with the displacement vector (current) then where does this exist when a step is propagating down a transmission line?

Third letter.

"I would be grateful, sir, if you would kindly give me space to point out, and endeavour to correct, certain errors and misconceptions that occur in the article "Displacement Current" by Catt, Davidson and Walton in the December 1978 issue.

"To say, as they do, that inductance does not exist in a capacitor is just not true: it may be small, but nevertheless it is there. A bifilar resistor has inductance but it is made small by doubling the wire back on itself in the form of a hair pin so as to give a loop enclosing a small area. The same is true when the wire is replaced by a thin conducting sheet doubled back on itself. Snipping the sheet along the folded edge gives, when rolled up, a rolled-foil capacitor - but it still has inductance. In field terms, this inductance represents the magnetic field in the very narrow space occupied by the dielectric. It is quite valid, as the authors do, to consider the capacitor as a transmission line; indeed it is necessary to do so if the length of the foild (or the radius of the circular plates in the authors' Fig. 1)

is comparable with a wavelength. In undertaking such an analysis, it is necessary to consider the inductance and capacitance (respectively L_1 and C_1 per unit length) of the equivalent transmission line. The characteristic impedance $Z_o = /(L_1/C_1) = /(u/\ )$ in the loss-free case, needs a non-zero inductance to give it a non-zero value. Likewise the velocity of propagation $v = /(1/L_1C_1) = /(1/u\ )$ needs a non-zero inductance to give a finite propagation velocity, a requirement the authors state in their second paragraph. In trying to dispense with this inductance, the authors' analysis in the Appendix becomes confused.....

"In spite of appearances, such as introducing ideas of reflections on a transmission line, the authors' analy is is a quasistatic one and the equation they are deriving is quasistatic also. This being so, it is of little consequence whether one assumes an infinite propagation velocity, which the authors object to, or a zero propagation time which the authors are actually doing. ....."

(The remaining three quarters of this letter are now omitted)

- K.O. Sharples, Department of Electrical and Electronic Engineering, The City University, London E.C.1

The authors reply: We do not say that (distributed) inductance does not exist in a capacitor. We said that series inductance does not exist. The conventional model of a capacitor with stray series inductance is wrong. Thence, the idea of a capacitor's self-resonant frequency is wring. Distributed inductance, such as exists in a transmission line, does exist, and we use the formula $Z_0 = \sqrt{(L/C)}$. We feel that the whole of Mr Sharples's letter founders because he confuses series inductance with distributed inductance.

Another letter

"The pattern of magnetic field made when a very sharp edge of voltage propagates along any TEM wave structure is the same as that obtained if the wave front is replaced by a thin sheet of uniform conductor and the current of the wave is applied as a balanced d.c. on one side only of this sheet.

"If this experiment is performed it will be found that there is no magnetic field whatever beyond the sheet and no

longitudinal magnetic field at any point, despite the fact that lateral current is clearly flowing in the sheet. On page 67 of the March issue this result is described as being absurd, but it is nevertheless true.

"Since the field pattern is just the same for the propagating edge as for the d.c. case it seems only reasonable to talk of a "displacement current" when a magnetic field is caused by change of vector D rather than by real current. There is no question whatever of "displacement current" not causing magnetic field in some particular cases, and neither Maxwell nor Heaviside have overlooked a discrepancy in this matter."
- K.C. Johnson, Cheadle, Cheshire.

The authors reply: In Mr Johnson's first paragraph, when he writes "uniform conductor" he must of course mean "uniform resistor."

When a TEM signal advances at the speed of light, there is a close mathematical correlation between the E field and the H field at every point.

When a TEM signal glides through a dielectric edged by a perfect conductor, there is a close mathematical correlation between the H field and the

electrical current in the surface of the conductor.

D being a mathematical function of E and i also being a mathematical function of E, it is not surprising that the two mathematical derications from the same source, E, correlate, even to the extent that there is a consistent relationship between $d(\epsilon E)/dt$ and i. One could say that these two derivations from E correlate by definition. Since $d(\epsilon E)/dt$ and i are obviously functions of E, it is mathematically impossible for the reserse mathematical process (cf. logs and anti-logs) to produce anything other than the original E field from which i and displacement current are derived.

The key question is, "Does any function which is correctly derived from a real physical entity also have physical reality?" For instance, to carry the point to absurdity, what physical reality can be attached to the "circularity", $\propto$, of a circle, defined in terms of the circumference as follows: $\propto = \frac{C^2}{4\pi^{\frac{1}{2}}}$

from which it can be deduced that the circle's area A is $A = \frac{\propto}{\sqrt{\pi}}$

We could have just as much futile fun with "circularity" as we do with "displacement current". They are both the results of valid mathematical manipulation. But do they exist physically, and are they useful?

Displacement current has shed no light and produced much fog. Is it anything more than a mathematical derivation from the Poynting Vector, which we call the Heaviside signal?

To put it another way; if we describe an E x H wave which has an edge, does it have an edge? Displacement current "shows" that we have the thing we defined.

Now for a letter from Australia.

"In the December Wireless World, Catt Davidson and Walton purport to show that Maxwell's concept of displacement current is incorrect and their "true" model, which replaces a capacitor by a collection of pie-shaped transmission-lines is correct. They argue that this dispenses with the need for displacement current, and go on to say: "Since any capacitor has now become a transmission line, it is no more necessary to postulate

displacement current in a capacitor than it is necessary to do so for a transmission line". Unfortunately, it is necessary to do so for a transmission line, or have they forgotten Kelvin's (1873) original equation:

$$-\frac{dI}{dx} = GV + \frac{CdV}{dt}$$

G being leakance and C the capacitance per unit length. The second term on the r.h.s. of this equation is the displacement current. What they have done in their subsequent algebra is to show that the transmission line approach and the lumped capacitance approach agree very closely. In no sense have they dealt with the topic indicated in their title: "Displacement current - and how to get rid of it". It looks as if Maxwell's equations may be right after all!" - Professor E.P. George, School of Physics, The University of New South Wales.

The authors reply: I agree with Professor E.P. George that it is good policy to give Kelvin's equation an airing on every opportunity. I did so on page 760 of my 1967 IEEE paper, referenced at the end of our article. [IEEE Trans. Computers, Dec. 1967]

I even went so far as to derive the Kelvin equation as equation (4) of my article in "Design Electronics", July 1969, page 60. However, if one always displays all ones equational credentials the reader might become bored. For instance, repetition of v=ir probably doesn't gain one many points, although by missing it out one might give the impression that one has forgotten it.

Another letter.

"Your contributors (I. Catt et al., December and March issues) are not alone in their dissatisfaction with the usual textbook assertions about the magnetic fields "caused" by "displacement currents". A more satisfying viewpoint supporting theirs is presented in the book "Classical Electromagnetism via Relativity", by W.G.V. Rosser, Butterworths (1968), (see particularly Chapter 4, Appendix 2 (p.243) and Appendix 6). However, Maxwell's equations remain unchallenged, only our interpretation of certain terms is in question. Both electric and magnetic fields are associated with the moving charges set in motion when a condenser

is discharged and the changing electric field in the airgap does not "cause" a contribution to the magnetic field by the Biot-Savart relation. There is no paradox to be explained when a finite-sized condenser is regarded as a short transmission line.

"Incidentally the controversy about Relativity and Time Signals, (L. Essen, October issue) is touched upon by Professor Cullwick in another philosophical book on electromagnetism ("Electromagnetism & Relativity" E.G. Cullwick, Longmans (1959) see Chap. 5, p.72)."

The authors reply: With the best will in the world, R.W. Watford's letter is based on the premise that, in the main, the body of knowledge in E-M Theory and Relativity is sound and coherent. He feels that all that is needed is to brew up the right mix of existing knowledge and all will be well. His contribution is to bring Relativity to the rescue; a nice touch in the centenary year.

Previously, with less good will, P.I. Day brought ω to the rescue.

I would prefer that we leave both

out. After all, ω is incompatible with Relativity. (A sine wave exists at more than one point in space at the same time, which makes it unacceptable as a Primitive in a relativistic universe which excludes instantaneous action at a distance.) These men have brought up two incompatible fire engines to put out the fire.

It is of the utmost practical importance that digital designers have a theoretical framework which makes them able to design and build working, reliable systems. We must not continue to abandon high speed digital systems very late in the development cycle, as we have continually done in the past. (cf. COMPUTING, 16 March 78, page 2 and 30 March, letter.) ω has nothing to do with their problems, theoretical and practical. Also, computers do not rush past other computers at the speed of light.

Maxwell's theory is pre-Relativity. If someone has cobbled up a post-Relativity Maxwell, please tell us where the ex cathedra statement of this theory is. Einstein did not do this, because he was not expert in electromagnetic

theory. (Physics Bulletin, July 1978, page 297.) Einstein never read Oliver Heaviside, and did not have a grasp of his concept of a transverse electromagnetic wave which travelled forward unchanged at the speed of light. Also, he never mentioned the impedance of space - a major oversight if E-M is being considered. Einstein did not know Heaviside's concept of Energy Current. Neither do contemporary Relativity theorists, including Cullwick. Cullwick does not know about Heaviside's contribution to electromagnetic theory. Einstein's famous gedanken experiment, performed when he was aged sixteen and restated by him fifty years later (See "Albert Einstein: Philosopher-Scientist", ed. P. Schilpp, 1949) as the cornerstone of Relativity, is incompatible with the concept of Energy Current.

We must not let the ignorance and oversights of the last half century prevent us from building a sound electromagnetic theory from the ground up, and building thereon a viable digital electronics industry.

Another letter.

"Apparently many people find the concept of displacement current useful and some find it distasteful. Not being a member of either group I would normally be prepared to continue as a passive spectator of the fascinating correspondence which has been stimulated by the recent articles on the subject; after all, no-one is suggesting that $\partial D/\partial t$ should be struck out from Maxwell's equations, and presumably no-one is insisting that everyone must believe that there is any physical reality in a current which is said to flow in empty space where there is nothing to carry it (and nothing to be displaced). I would even leave it to others to point out in Figure 4 of "The History of Displacement Current" that the current $\underline{i}$ will vary continuously between B and B', as is the way with transmission lines, so if you want a continuous "current" you do need a displacement current, not localised at B, but distributed along the length of the transmission line.

"However, the excellent iconoclasts Catt, Davidson and Walton have spurred

me to action by their uncharacteristically unquestioning use of a concept/mathematical construct which is far less harmless than displacement current, namely the Poynting vector or "energy current" E x H. A single example will show what I mean. Suppose I take a battery and connect it to a lamp by a pair of good thick metal wires. Since the electric field is negligible inside the wires the Poynting vector is too. In fact the Poynting vector is mainly localised in the space surrounding and particularly between the wires. By examining the Poynting vector one can validly draw the conclusion that energy flows from the battery to the lamp. One could even, in principle, integrate the Poynting vector over a surface containing the battery or the lamp, but not both, and calculate correctly the rate at which energy flows from the battery to the lamp, but one would be allowing oneself to be blinded by ones own mathematics to deduce from the fact that the Poynting vector is practically zero in the wires and is at a maximum between the wires that the energy flows mainly between the wires and not to any appreciable

extent through them.

"In case anyone does believe that even in this case the Poynting vector represents a physical energy flow I propose the following experiment. First, interpose a metal screen between the battery and the lamp, insulated from the wires themselves, but fitting as closely as possible, so as not to leave more than the tiniest space for the Poynting vector to squeeze through. Note the effect (if any) on the amount of energy which gets to the lamp. Now take away the screen and make a break (just a little one, mind) in one of the wires. Again, note the effect on the amount of energy (if any) which gets through. A similar experiment could be carried out on telegraph lines, at some inconveninence to the public. If the Poynting vector really represents a flow of energy, the screen should have more effect than the break. After all, what do we mean when we say (if we do) that the energy flows between the wires rather than through them, other than that if we wish to obstruct the flow of energy we would do better, to a first approximation at least, to insert a barrier where the energy flows

than where it does not flow.

"Perhaps it is time someone did a hatchet job on the Poynting vector along similar lines to that of Catt, Davidson and Walton n displacement current, with the hoped-for result being that it is cut back to its proper size, not that it is necessarily cut out completely. It may be less entertaining (surely not if the same team could be persuaded to take on the job) but the usefulness in actual practice would arguably be greater." - C.M.K. Watts, Western Electric Patent Department, Woodford Green, Essex.

The authors reply: The last sentence of Watts' first para. shows that he does not understand the mechanism for a T.E.M. signal travelling undistorted between two perfect uniform conductors.

We should however applaud, not condemn, those who come out in the open and discuss electromagnetic theory even though their grasp of the fundamentals is weak. C.A.M. Consultants have found that those professors and text book writers who are hiding from the present dialogue, although their professional

duty would direct them otherwise, are more ignor nt than Watts and the other brave men who are rushing in to the vacuum. C.A.M. Consultants challenge professors of physics and electronics to come out of the undergrowth and start earning their salaries by discussing the fundamentals of electromagnetic theo theory.

Returning to para. 2. If Watts bares his chest to the sun, does he believe that the electromagnetic energy (light) burning his skin is travelling from the sun to mim down conducting wires, or through a dielectric?

Watts' paragraph 3 is very instructive. (Why must he leave the "tiniest space"? Why leave a space at all if the conductor is what it is all about?) Our book ELECTROMAGNETIC THEORY VOL 2 discusses such situations thoroughly, on pages 245 and 319 and elsewhere. Referring again to his second sentence, conventional transmission line theory lets us calculate the mechanism by which energy current rapidly builds up to a high flow rate through a small gap as a result of repeated reflections. The argument somewhat resembles that in the appendix to our article in Wireless

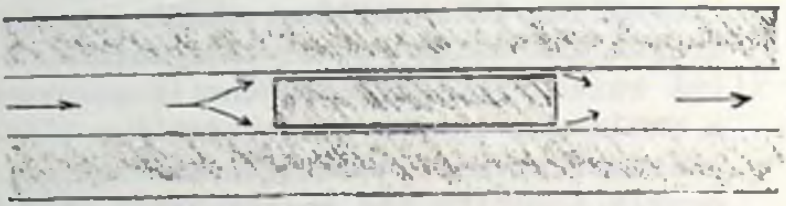
World Dec. 1978 [Also in DIGITAL HARDWARE DESIGN by the same authors, pub. Macmillan 1979, page 32]. If in his second sentence, the screen hugs the conductors for a long length (say one mile), creating a long section with very low characteristic impedance, transmission line reflection theory correctly tells us that energy flow from battery to lamp is delayed. More conventionally, this delay would be thought of as an R - C time constant, the C being the narrow gap between conductor and screen for the very long distance. Referring to his sentence 4; once the tiny break in the conductor (which Heaviside called an obstructor) is made, energy current flows through the break and out into the vast space beyond. This space presents a rapidly increasing (characteristic) impedance, causing all the outgoing energy current to be reflected back through the break into the narrow channel through which energy was previously gliding calmly (at the speed of light) from the battery to the lamp. After the initial disturbance of the steady state caused by the breaking of the conductor (obstructor), the lines of energy current gradually, through the

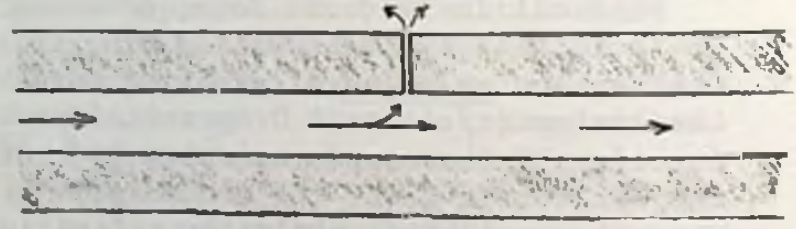
mechanism of reflections, settle down to a new pattern where energy (of the same amplitude as before the conductor was broken) flows out of the battery to the gap in the wire, there to be fully fully reflected back into the battery, in a "continual dance of energy" which Carter dismissed as absurd but C.A.M. Consultants do not. (The Electromagnetic Field in its Engineering Aspects by G W Carter, pub Longmans 1954, page 321.) If however the break made in the conductor is extremely narrow (and long), it will take time for its existence to become apparent. Very traditionally, this very narrow, long gap in the conductor would be regarded as a capacitor. We should regard it as a transmission line of very low characteristic impedance.

Dealing with his third para. in a lighter vein, one is urged to suggest that it is the "phlogiston" in a balloon material which keeps it doing its job. The absurd theory that it is the air pressure in the space inside which maintains a balloon's femininity can easily be disproved by making a tiny hole in the balloon; too small to let the air out but large enough to collapse

any imagined air pressure inside. Alternatively, we can show that goods travelling in a railway system travel inside the rails rather than between the rails. See what happens if we put a small gap in the rails, or an obstruction across between the rails, nearly touching the rails; close enough to leave too little space for the train wheels to get through. This will prove that goods are really piped along inside the railway lines and it is absurd to think that the lines merely guide the flow of merchandise

When all is said and done, however, the acid test is the question of whether the velocity of propagation of the energy (/electric) current is a function of the characteristics μ, ϵ of the dielectric or of the conductor. When a seagull (or merely the reflection of a seagull) glides along above (/below) the surface of the water, does its speed depend on the nature of the air or of the water?





Many more letters were received by Wireless World, and more will be reproduced in Volume 2 of this book. They are valuable because they show how confused present knowledge is of the crucial subject of displacement current.

To date, Wireless World has published the following letters: Feb.79, M.G. Scroggie; Mar.79, P.I.Day; May 79, K.O. Sharples; June79, K.C. Johnson; July79, B. Lago; Aug.79, R.W. Watford; Sep.79, J.L. Haine; Oct.79, E.P. George (with a reply by Walton, not the reply by Catt here published on page 81).

In August 1979, page 43, Wireless World published a refutation of the two papers on Displacement Current by Professor D.A. Bell, Head of the Department of Electrical Engineering at Hull University and previously Reader in Electromagnetism at Birmingham University. A reply to Bell's article (which he called "No Radio without Displacement Current") by D.S. Walton was published in Nov. 79, page 79, along with Bell's rejoinder.

The editor of Wireless World, Tom Ivall, is to be congratulated for giving so much space to this very important but almost totally neglected subject. His action is the one hopeful sign, and contrasts starkly with the pervasive attitude to electromagnetic theory of indifference, fear and ignorance shown by other journal editors, lecturers and officials of professional institutions.

MAXWELL'S EQUATIONS REVISITED

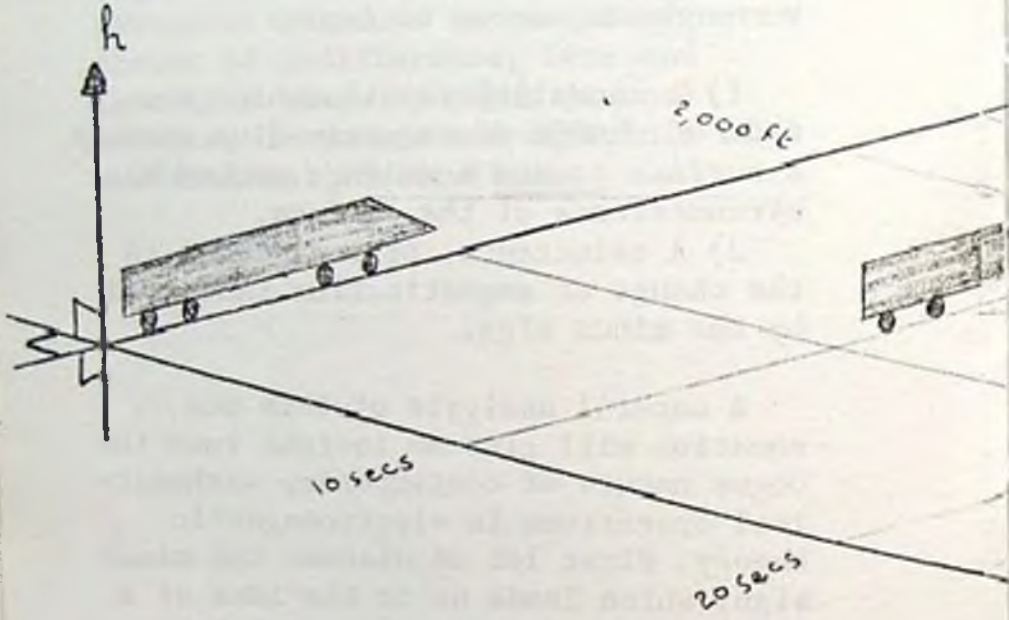
Faraday's Law of Induction, $v = - d\varphi/dt$, seems to imply:

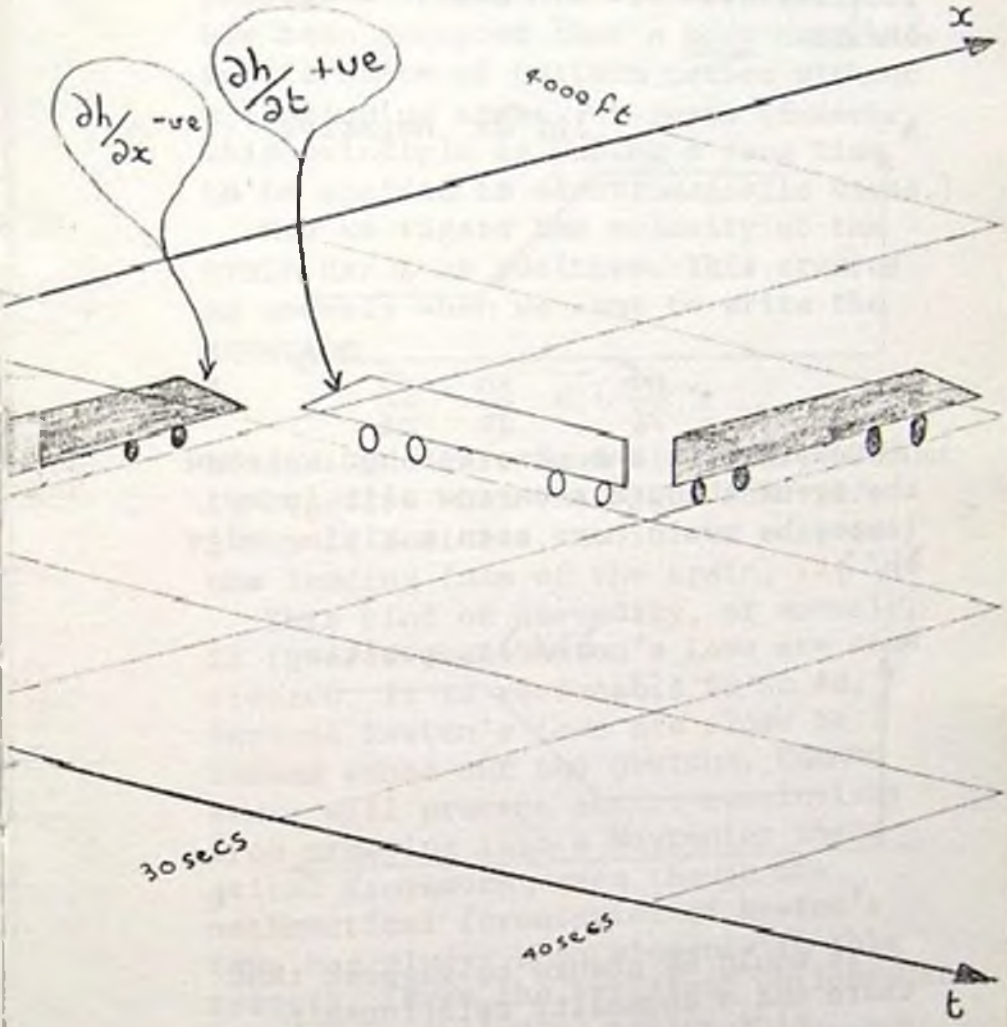
1) A causality relationship; the rate of change of magnetic flux through a surface causes a voltage around the circumference of the surface,

2) A reluctance, or resistance to the change of magnetic flux indicated by the minus sign.

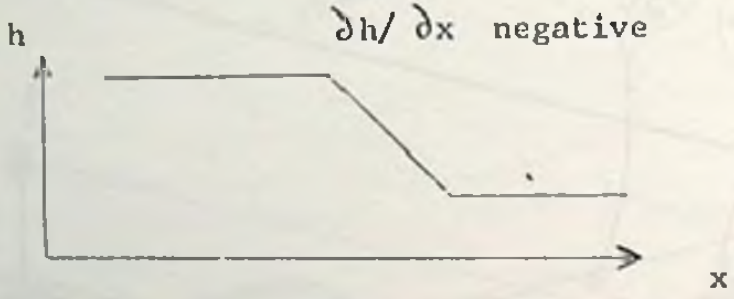
A careful analysis of this one equation will give an insight into the bogus nature of contemporary mathematical operations in electromagnetic theory. First let us discuss the minus sign, which leads us to the idea of a Lenz's Law reluctance, or resistance, to the change $d\varphi/dt$. We shall see that a minus sign can occur in an equation when no causality can be involved.

Consider a high speed (125) railway train with sloping front passing an observer.

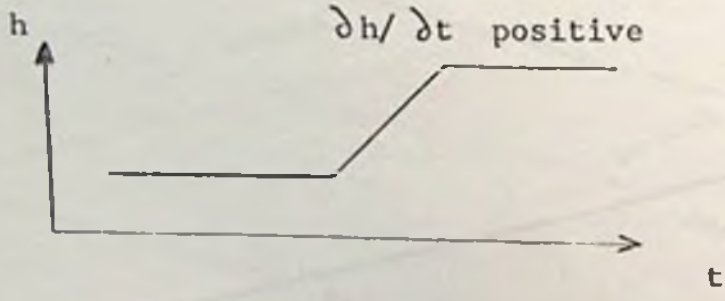

h
2,000 ft
10 secs
20 secs


x
$\frac{\partial h}{\partial x}$ -ve
$\frac{\partial h}{\partial t}$ +ve
4000 ft
30 secs
40 secs
t

As the front face passes, the observer will see a negative slope $\partial h/\partial x$.



However, if the observer had watched the event through a narrow slit in a fence, he would have seen a rising edge $\partial h/\partial t$.



It would be absurd to suggest that there was a causality relationship between $\partial h/\partial x$ and $\partial h/\partial t$. They are

both descriptions associated with the passage of the train. Since Newton, it has been accepted that a body continues in its state of uniform motion without a continuing cause, or push. (However, this principle is taking a long time to be applied to electromagnetic waves.)

Now we regard the velocity of the train dx/dt as positive. This creates an anomaly when we want to write the equation

$$\frac{\partial h}{\partial x} \cdot \frac{dx}{dt} = \frac{\partial h}{\partial t}$$

because the left hand side (LHS) product is negative when the right hand side (RHS) is positive, as in the case of the leading face of the train.

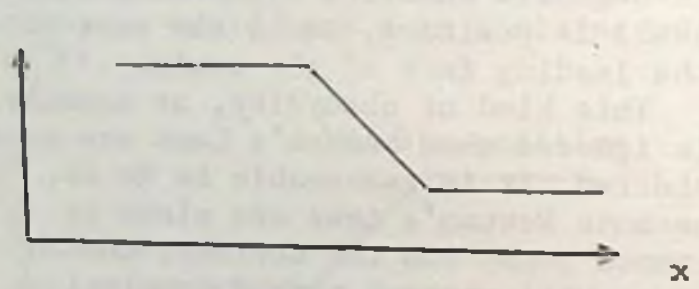
This kind of absurdity, or anomaly, is ignored when Newton's Laws are considered. It is reasonable to do so, because Newton's Laws are close to common sense and the obvious. Common sense will prevent absurd conclusions from creeping into a Newtonian theoretical framework, even though the mathematical formulation of Newton's Laws has always been slovenly in this respect. (Even the brilliant philosopher Ernst Mach failed to notice this

anomaly.)

(Another perhaps permissible slovenly aspect is the use of the = sign for numerous different, mutually contradictory meanings.)

Maxwell's Equations are not in the same class. Common sense will not save us from absurdity and nonsense if our initial formulations are ambiguous or wrong.

Let us consider an electromagnetic wave front advancing at the speed of light. When the step (or more accurately ramp) passes, $\partial H/\partial x$ is negative.



However, $\partial H/\partial t$ for the step is positive. To get the algebra right, we are forced to conclude that

$$\frac{\partial H}{\partial x} \cdot \frac{dx}{dt} = -\frac{\partial H}{\partial t}$$

However, no one would propose that the

minus sign indicated a causality relationship between $\partial H/\partial x$ and $\partial H/\partial t$.

The last equation never appears in the text books. In the books, one of the terms is first converted into a function of E according to the formula

$$\frac{E}{H} = \sqrt{\frac{\mu}{\epsilon}}$$

The result is either $$\frac{\partial E}{\partial x} = -\frac{\partial B}{\partial t} \qquad (4)$$

or $$\frac{\partial H}{\partial x} = -\frac{\partial D}{\partial t} \qquad (5)$$

The text books say the "solution" to this pair of equations is a sine wave! See references 1 to 5. (In fact, almost anything is a solution to these equations.)

At this stage, the whole subject starts to look sophisticated and profound. Really it is neither. The minus signs have no significance, as we have seen. B and D are introduced on the RHS merely to suppress μ and ϵ. The moves to B and D on the RHS get rid of μ and ϵ and merely suppress the remnants of the substitution for H by the formula

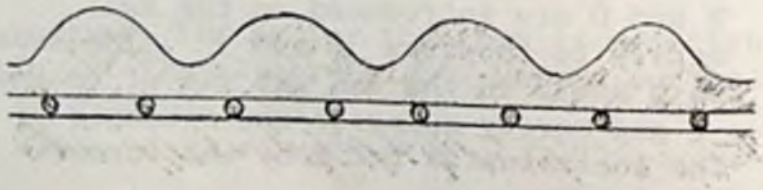
$$\frac{E}{H} = \sqrt{\frac{\mu}{\epsilon}}$$

In fact, the last two equations (4) and (5) are meaningless. If the front of the high speed train were pointed, sloping out sideways as well as upwards, and w were the term given to width (as H stands for height), exactly the same pair of equations could be constructed.

$$\frac{\partial w}{\partial x} = -\mu \frac{\partial H}{t} \,.$$

$$\frac{\partial H}{\partial x} = -\epsilon \frac{\partial w}{\partial t}$$

As with E-M theory, we could conclude with equal validity that a train's height (and width) must vary sinusoidally along its length, making our trains look like the Loch Ness Monster, or more accurately, like a row of short sausages.



It is shocking that this nonsense has survived for a century at the core of a subject as crucial as electromagnetic theory.

We see now that mathematical formulation of E-M theory, far from making the subject more rigorous, has made it ludicrous and false. We see that the mathematicians are incompetent where physical reality is concerned and hide their incompetence and confuse others by conjuring up nonsensical, interrelated formulae.

When Hertz established that electromagnetic waves existed, Maxwell's Equations should have been re-examined and the large rubbish element removed. Instead, physically ignorant mathematicians look over, piling garbage upon garbage, frightening away those with real insight into the subject - the latter day Faradays.

Those who try to build extensions, or additions to, the House of Newton should not assume that since the foundations were good enough for Newton's simpler theory, they are strong enough to support their own more complex constructions. Minkowski's failure to

re-examine the foundations of Newton, in particular his assumption that velocity is positive and the passage of time is positive, makes his constructions useless in the came way as Maxwell's equations are useless.

In the Minkowski sense (reference 6), time really flows from $+\infty$ to $-\infty$, not, as he thought, (and our clock faces, with their ascending sequence of numbers, think,) from $-\infty$ to $+\infty$. Velocity, being the gaining of distance in return for the loss of time, is negative. This points to a fundamental difference between space and time, and means that the "space-time continuum" as Minkowski formulated it is bogus. At best, we see his pronouncements as oracular, similar to the answer that Delphos gave when being asked about the sex of an unborn child, "GIRLNOBOY". This remark could well be interpreted as true, but really it has no content.

Einstein failed to consider the problem of the sign of time and of velocity. Also, he never succeeded in fighting his way through the mass of mathematical garbage surrounding electromagnetic theory.

References.

1. G.W. Carter, The Electromagnetic Filed in its Engineering Aspects, Longmans, 1954, page 268, equations (12.5.1),(12.5.2).

2. A.F. Kip, Fundamentals of Electricity and Magnetism, McGraw-Hill, 1962, page 321, equations (12.19),(12.20).

3. E.G. Cullwick, Electromagnetism and Relativity, Longmans, 1959, page 81, equation 6(2).

4. S.A. Schelkunoff, Electroma netic Waves, D Van Nostrand, 1943, page 39, equation (10-1).

5. Wireless World, August 1979, page 44, equations (i) and (ii).

6. A. Einstein etc., Principles of Relativity, Dover, page 76.

7. I. Catt, Computer Worship, Pitman, 1973, page 71.

THE RELATIVITY ENIGMA

Relativity is so full of anomalies and absurdities that I begin to think that it should not be classed as a serious scientific discipline - like Electromagnetic Theory, for instance. It is difficult to do a hatchet job on Relativity (as we are currently doing on Maxwell) because the phrase "hatchet job" brings to mind the idea of going into a grove of trees and chopping them down. An example of a "tree" is "Displacement Current". However, in the case of Relativity one enters a thicket, and finds that the trees are not standing anyway. One is reduced to merely rolling around prone trees, and it is not clear that this activity significantly changes the view.

Take the Michelson-Morley experiment, for instance.

A "ray", or "pencil" of light is split and sent out and back in two directions at right angles, and the travel time compared. Difference in travel time will

undermine Relativity. Conversely, and for no convincing reason, the failure to detect a difference will be taken to confirm Relativity.

Measurement of difference in travel time is by means of interference fringes.

Use of interference fringes at the destination means that light is regarded as a wave (not a particle). However, during its journey from source to destination, paradoxically, the light is regarded as particulate. It cannot be regarded as a wave, because if it were, the "wave" would have to travel down a channel of constant cross section. Any change in cross section would lead to both forward and backward reflections, in the same way as a logic signal travelling down a transmission line is partially reflected if the characteristic impedance changes. Double (and multiple) reflections would occur, resulting in a change in the phase of the light at the destination.

For the Michelson-Morley experiment to produce useful results, the light would have to have been guided down uniform channels. It was not. However,

use of channels would have destroyed the value of the results anyway because of possible aether drag. Either way, the experiment is useless if sinusoidal (light) signals are used.

Anyone earning his living from Relativity for more than five years should have noticed this, but nobody has. Perhaps the salaries for lecturers in Relativity are too low (- or too high?).

Now let us consider another so-called "acid test" of Relativity. It is asserted that in 1919 during an eclipse it was observed that light from distant stars bent as it passed close to the sun. This purported to prove that light had mass and thence - somehow - that Relativity was vindicated.

Let us look at the assertion that if light passing near to a star bends, it follows that light has mass. Again, it is assumed that light is particulate - made up of billiard ball-like photons. But long before Einstein, light was a wave, an electromagnetic wave. Now Relativity gurus must know that their radios still work when there is no unobstructed line of sight to the transmitter. Do they believe that the

cause is gravity? Again, we see the shallow technical level of the Relativity fruit-machine operators over the last half century. Do they believe that radio waves can only bend round corners downwards, attracted to the centre of the earth? Why is there no mention in all the discussion of the eclipse observations of the bending of light because of its electromagnetic nature? Do Relativists not know (or believe) that light is an electromagnetic wave? If not, why don't they say so, and establish that they are outside the main stream of contemporary science?

NEGATIVE TIME

A misunderstanding lies in mathematical formulations of Newton' Laws of Motion. At the relatively simplistic, commonsense level of Newtpn it is harmless enough, but it has wrought havoc in later developments, by Maxwell and Einstein, where commonsense is not so readily at hand to steer us away from absurdities.

The source of the confusion is the numbering of the hours, from 1 o'clock to 12 o'clock in ascending order. This creates the impression that as time goes by, we gain time; that time increases. This leads to the idea that an interval of time Δt is positive. If (as in Relativity) we assume that all distances travelled are positive, we conclude that velocity, $\Delta s/\Delta t$, being the ratio of positive values, is positive. However, this leads to absurdity, as we demonstrated on page 97.

When we walk across town to catch a train we gain distance as we lose time.

The hour we spend walking five miles is a loss, not a gain, and there is a negative relationship between distance and time. When we have walked the five miles and succeeded in catching the train, we do not then have more time on our hands; we have less. It follows that the universe started at + ∞ time and will end at - ∞ time. In the past we had more time than we do now, and a clock hand points to hours lost, these hours being numbered in an awkward manner.

In Maxwell's equations, as we have seen on page 97, the supposed negative (and thence imagined causality) relationship between E and H fields is spurious, and derives directly from the confusion illustrated on page 98. None of the minus signs in Maxwell's equations are valid, but they have created a lot of nonsensical theorizing about causality. (See Kip and Carter, page 32.)

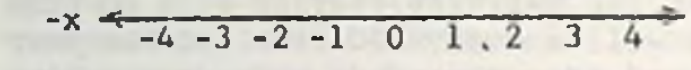
The effect of the misunderstanding is if anything more grave in Relativity, but before we discuss it we should set the scene more carefully. (The text used is "Principles of Relativity, A. Einstein

etc., Dover, page 76.)

There are two conventional world views;

1) The arithmetic, or "polar" view, in which all distances from the origin are positive.

2) The algebraic, or Cartesian view,



where distances to the right are positive and distances to the left are negative.

In the case of (1), which is Minkowski's Relativity view, the previous discussion tells us that whereas conventionally all velocities are regarded as positive this is wrong, and in fact all velocities are negative.

In the case of (2), the new view would make velocities towards the right negative and velocities towards the left positive.

Minkowski, using view (1), was consistent in regarding distances travelled x, y and z as all positive, and he was justified in doing Pythagoras' Theorem calculation with them. Where he went terribly wrong, due to the error in

the sign of t, was in regarding "the fourth dimension" t as fundamentally similar to the space dimensions x y and z. The misunderstanding, which was already (and up until Maxwell's and Minkowski's time harmlessly) buried in Newton's laws, caused Minkowski to think of time as a forward going, positive dimension like the three distance dimensions. We can now see that it is not. Time is diametrically opposed to the three space dimensions. Velocity, ideally the unchanging velocity of light, represents a transaction in which time is lost, or given up, in order to gain space, or distance. This produces the idea of a conservative universe, where space is gained at the expense of time, i.e. when time is lost. There is no evidence for any such transactions between two space dimensions.

Now that we have corrected the sign of time, it becomes clear that we must dismiss ideas of "a four dimensional space-time continuum"; even more if we throw out Relativity's other mainstay, which I like to call "synchroneity-fixation" or "observer-fetishism". (One gets the feeling that the way

Relativity crawls with observers anxiously consulting their watches puts the 1984 police state in the shade.)

Minkowski's diagram of a "world line" in space-time should not indicate an opening up, or increase of freedom, as time flows through the future. Rather, a closing in or increasing limitation should be indicated, at least when all "four dimensions" are being considered. The whole idea that "Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." is seen to be specious, as Maxwell's equations were seen to be specious.

The Rise and Fall of Bodies of Knowledge

IVOR CATT*

It is argued that the self-protecting nature of the knowledge establishment leads to the suppression of new ideas. Proposals are put forward for the establishment of 'Communication nets' which having no central points are incapable of suppression.

Introduction

Although the principle of free communication of ideas is a basic tenet of the scientific community, there are numerous examples of their suppression. Professor Herbert Dingle, who wrote a book on relativity in the 1920s as well as a section on relativity for *Encyclopaedia Britannica*, and was the man chosen by the BBC to give the eulogy on Einstein when he died, developed doubts about the special theory of relativity around 1955. To his astonishment, he found that the scientific journals and institutions suddenly closed their pages and doors when he wanted to write or say something unorthodox; that is, heretical. A scientist might say, 'something that was incorrect'. He describes his experience in his book, *Science at the Crossroads*.[1]

Immanuel Velikovsky painstakingly developed the heretical theory that Venus as a planet is only some 3,500 years old, that it moved for centuries on a very eccentric orbit, and about 1500 BC made its two closest approaches to the Earth. During the eighth and seventh centuries BC, the comet Venus repeatedly approached Mars, and Mars in turn menaced our planet. Only after all these encounters did Venus finally lose its last cometary characteristics and settle down to its present planetary behaviour. Velikovsky believes that the effects of these encounters on the Earth, especially the earlier ones, were truly catastrophic. He wrote a book about his theories, called *Worlds in Collision*.[2]

Without reading Velikovsky's book, the Professor of Astronomy at Harvard warned Macmillan not to publish anything by Velikovsky, saying that if they did, Macmillan would be boycotted by the academic community. Macmillan bowed to the pressure, and fired the editor who had accepted Velikovsky's manuscript, because he had accepted heretical material.[3, 4]

The computer journals and conferences in Britain and the USA consistently evaded 'The Glitch', the way in which computers spontaneously go mad for no apparent reason. The lengthy private correspondence with the editor of *Scientific American* which culminated in his being forced to give 'The Glitch' a passing mention, in April 1973, is very revealing. It took ten years of dedicated hard slog by a group of scientists in the University of Washing-

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ton, St Louis, to get it into the professional journal, the *IEEE Transactions on Computers*, in June 1975.[5]

Many other instances could be cited of the suppression of new or unusual, that is 'heretical', ideas by scientific institutions. The system of refereeing technical articles before publication (and I myself have acted as a referee) is a system of censorship, the censor having no training in how to differentiate between 'wrong' and 'heretical'.

Superficially, it is easy to look at the suppression of free communication in science from the Basil Bernstein point of view,[6] that 'knowledge is property with its own market and trading value', to be protected by the practitioners of that particular brand of knowledge—it may be sociology, mathematics, psychology, or some sub-set of one of these. We might regard the suppression of new ideas and the obstruction of outsiders when they try to trespass into a branch of knowledge as pernicious and retrograde. As one example of many suppressions, digital electronics, otherwise called computer hardware design, can be taught in virtually no college in the world today. It is suppressed by the older knowledge groups of computer science, which means programming, and by electronics, which means telecommunications. Dr Charles Seitz was chased out of the University of Utah when he opened up a laboratory with digital electronic hardware within the Computer Science Department. He then called himself a 'defrocked computer scientist'. (After a long gap, he is now lecturing at CALTECH.)

If we were certain that the suppression of free communication was wrong, it would merely be necessary to expose the fact that editors of scientific publications work to suppress scientific communication, rather than to sustain it; that university faculties work to block new disciplines, rather than to help them to develop, and we would organize methods to prevent editors, professors and conference organizers from suppressing new developments in the future.

The Holt Dictum

However, across this vista, like a blaze of light, comes the dictum of Dr A. W. Holt, 'Without barriers to communication there can be no communication'. This is one of the great profound truths which often appear facile at first sight.

As an illustration of Holt's thesis, when I publish something in a scientific journal, a large part of what I am saying has already been said before the first word of the piece. The fact that I am publishing in that scientific journal means that I accept virtually the whole of what Galbraith calls the 'conventional wisdom' which is accepted by subscribers to that journal and

its editors. This rigidly limits the scope of my communication. I want to publish in that journal because I accept the frame of reference established by that journal and the group of scientists who support it. If something were published in that journal by someone who did not accept virtually all the precepts enshrined in previous issues of the journal, it would carry little or no meaning, or communication, because having broken with the traditional agreed premises of the journal, no reader would any more know what was still agreed; no one would even be sure what the words in the revolutionary article meant. After all, the meaning of a word is a creature of the frame of reference within which it has traditionally been used. (M. Polanyi in *Personal Knowledge* says that every time a word is used, it alters or reinforces its meaning as a result of its being used in a different context.[5])

As further illustration of the Holt dictum, we can take something that the poet Stephen Spender once said. He argued for writing in an already accepted style. He said that if one created a new style, one's own style, one ran the risk of creating merely an 'historical object', and not communicating. Similarly, one could say that if one wrote a revolutionary article in a journal, one would create an historical object; what one said would be unintelligible to the reader. The only meaningful communication is one which only marginally alters the frame of reference.

In the language of T. S. Kuhn[6] it is permissible to write and speak within the limitations of a shared paradigm, and even to marginally modify the shared paradigm. This is an acceptable, meaningful exercise in what he calls 'normal science'. What is *not* permissible is to write or say something which contradicts the shared paradigm, and expect it to be tolerated by the accepted journals, conferences and faculties. In so far as such institutions allowed the ingress of revolutionary ideas, they would be inhibiting the proper flow of very useful communication of the normal kind, of normal science, because the shared paradigm, a necessary frame of reference in normal scientific communication, would be undermined.

Knowledge as Property

Basil Bernstein writes, apparently critically, that a body of knowledge is property, with its own market value and trading arrangements, to be protected by the social group which administers that body of knowledge. However, one can look on such defensiveness in a favourable way. If no one were to defend the integrity of a body of knowledge against assault from laymen outside, the clarity and coherence of that body of knowledge, and in particular the solidity and validity of the shared paradigm which is its foundation, would be undermined.

Any body of knowledge, which embraces both information and understanding, needs its own body of dedicated practitioners, who exercise their knowledge and keep it alive. Also, they put up barriers around it to defend it against confusion. Without these barriers to more or less random communication, giving precedence to communication between the select few within the barriers, within their journals and conferences (and churches), the body of knowledge that they are protecting would lapse into confusion. That is why 'without barriers to communication there can be no communication'.

New Knowledge

From time to time, new knowledge tries to break through the defensive barriers into the main body of knowledge, and an important role of the priests within is to analyse these new ideas and decide whether to accept or reject them. All the while they must defend what they already have. It is therefore important that a limit be placed on the amount of new knowledge attempting to break through to the inner sanctum. If too much were allowed in for analysis at any one time the result would be confusion and damage to the valuable body of knowledge already entrenched within.

However, the new knowledge which attempts to break in beyond the barriers and articulate on to the already established knowledge plays an important role. The existence of such conflicts attracts people of high calibre towards the centre of the knowledge and towards its fringes. Even the rejection of a new piece of knowledge is a useful exercise, because in the process the main body of knowledge is exercised, and the practice of manipulating it will be kept alive among the priests in the inner sanctum.

As a body of knowledge increases in size and complexity, the problem created by each quantum of new knowledge which attempts to break through into the inner sanctum is greater. For this reason, the defences surrounding a large body of knowledge are rightly much higher, more difficult to surmount, than those surrounding one that is smaller, less complex and less mature. However, new knowledge still comes in, and the body of knowledge continues to grow, albeit at a slower and slower rate. Unfortunately, however, when the body of knowledge is bigger and the rate of inflow of new knowledge is smaller, more and more of the activity within the knowledge becomes 'celebration', more and more ceremonial rather than exercise in depth. As a result, a different calibre of person is attracted to the large knowledge, lacking the ability to understand and defend a body of knowledge with many levels of meaning. They are 'maintenance men' rather than 'builders'. The central body of knowledge ossifies,

becomes brittle and distintegrates. This is how civilizations collapse, how religions and cities collapse, and how a scientific community will collapse.

Growth of Knowledge

We can expect bodies of knowledge to grow rapidly at first, grow more slowly when they are large, and then steady to a more or less fixed maximum. After some time at this maximum they will disintegrate.

My recent investigations indicate that our knowledge and understanding of electromagnetic theory reached its zenith in about 1910, and we have since lost most of what we know about the subject. I cannot find anyone in the world today who professes to be an expert on electromagnetic theory, or who is researching into the subject.

The computer art had reached a large size and complexity as a body of knowledge in 1944, which appears to have been its practical limit. Since there has been no advance in the last thirty years,[9] it must be well on its way to disintegration.

In the language of Professor Lehman's theory of growth dynamics[10] 'progressive' work has come to a halt in the computer art and all the activity is 'anti-regressive' maintenance work. Lehman says that at this point, further advance can only be made if the foundations of the knowledge are re-examined and streamlined.

However, it is at this point that the Holt barriers to communication play an unfortunate role. By the time fundamental change is needed, we have seen that there are good reasons why the calibre of the 'guardians of the faith', the high priests, will have sunk to an all-time low, becoming worried, inadequate functionaries holding in reverence their predecessors who engineered the era of fast growth and progress. As the need for fundamental change increases, their blocking of communication of new ideas will become more complete and the established institutions more closed and rigid.

High technology will grind to a halt and even regress unless we fundamentally alter its underlying structure. The key problem is that as a body of knowledge matures, that is, ossifies and becomes decadent, channels of communication are shut off by the vested, mature groups, in a manner vividly described by Dr Charles McCutchen.[11]

Need for a New System of Communication

Clearly, what is needed is a new system of communication between peers which cannot be strangled in the normal way when the relevant body of knowledge reaches maturity. The key to the design of an irrepressible

communication system, which we can call a 'Communication Net', is that it should have no central control point, no single focus whose capture leads to strangulation. This is how the established institutions are easily emasculated. For instance, control of the staff appointments to a college faculty makes it easy to destroy the *élan vital* of that faculty. Control of the reviewing process of a professional journal makes it easy to suppress further constructive communication. Similarly the technical conference, with its small cabal choosing the list of speakers, is easy prey to a decadent clique.

I am not saying that the forces of decadence know that they are strangling their social group's future—indeed the essence of their decadence is their ignorance of what they are doing. Generally, they believe they are maintaining standards.

We must design a system which retains the good intent of the established institutions—search after truth, free communication, appraisal by peers—but does not have their unsound structure, vulnerable to capture by a career- and prestige-oriented clique. One might even go so far as to say that more rugged structures are a prerequisite for the technological revolution, and that the reason for the failure of high technology to generate vast profit is the strangulation of its institutions.

In principle, a communication net contains equal individuals, each of whom keeps an up to date list of articles that he recommends and copies of which he is willing to supply on request at twice the direct cost involved; 25p would be the kind of sum that another member of the net would send in advance when requesting one article. The reason for charging double is that this gives anyone in the net a surplus of funding which he uses to finance the voluntary sending of unrequested articles—for instance an important new article, or articles to someone who is being invited to join the net.

A member includes, in his bibliography of a certain subject, only those articles—by himself and others—which he thinks make a contribution to the subject. Each subject will have its own net, and on request a member will supply his bibliographies to all nets of which he is a member. This will break down interdisciplinary boundaries, which is one of the main problems in high technology.

Since membership of a professional institution costs about £15 p.a., it will be reasonable to expect such members to spend about £5 p.a. on communications nets, that is about twenty communications per year; quite enough in practice.

Once the nets are in operation, a prestige-oriented scientist will aim to belong both to a professional institution *and* to a communication net.

Wide distribution of one's article on a net, particularly if it appeared in bibliographies supplied by a number of eminent experts, would soon become

more prestigious than publication in a professional journal. In job applications it would be useful to show that one's articles were recommended by top people in the field—this is a facility unavailable at present.

A member of a net will include in his bibliography a statement of the hours during which he is available on the telephone. It looks as though two hours per week would be reasonable, and it might be necessary to restrain calls by only allowing trunk calls on the net.

Xerography and the direct dial telephone appeared after the philosophical and organizational structure of professional institutions ossified, and the institutions make no concessions to such technological advances. Communication nets should be able to adjust rapidly to new communication developments and opportunities.

In a BBC programme it was estimated that on average a published technical article was read 1·3 times—that is, articles are read 30 per cent more often than they are published. I asked the editor of *AFIPS*, a leading computing journal, about this, and he said he thought the figure was probably more like four. Whoever is right, it is clear that even after suppression of important articles, the dissemination of what is allowed through by the censors (reviewers) is ineffective and expensive. It seems eminently economical by comparison to Xerox (say) ten copies of an article and mail them to those likely to read it.

I myself am setting up at least three nets—one being on electromagnetic theory, a subject totally suppressed by the journals. Another net that I shall start will be a net giving advice on how to set up nets, and a third net will be one giving advice on what nets exist. Net design can be expected to improve rapidly during the first ten years or so after their inception, and it is important that improvements in their structure are widely communicated as they are conceived.

If communication nets are successful, it may be possible to use their structure as the basis for the design of organizations dedicated to other activities than flow of information. These other activities may develop spontaneously within communication nets, or alternatively they may be consciously started at a later date after some experience has been gained with communication nets.

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This is a cumulative index covering the present volume (E), the two volumes DIGITAL ELECTRONIC DESIGN (D), the Macmillan book DIGITAL HARDWARE DESIGN (M), and some WIRELESS WORLD articles (WW).