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The End of Electric Charge and ELECTRIC CURRENT as We Know Them

Ivor Catt, an engineer and a scientist, presents a two-part article on the matters of electrical charge and current. This is the first part, with the second part to follow in the next issue of *Electronics World*

FOR 43 YEARS it has not been noticed, even by the author, that oscilloscope pictures (reproduced here) in a refereed journal undermine the concepts of electric charge and electric current, and with them a large part of 20th century scientific theory. We see two electric currents travelling in opposite directions down a single conductor. Conventional electric current is not fit for purpose.

Under Faraday's Law $(V = -\frac{d\phi}{dt})$, which forbids superposition and yet whose mathematics permits it, we end up with two electric currents travelling in opposite directions down the same conductor.

In **Figure 1**, I inject a very narrow voltage spike between the left hand surface conductor and the ground plane. The bottom trace in the left-hand **Figure 3** shows the introduced voltage spike, and the bottom trace in the right-hand Figure 3 shows the smaller spike immediately resulting in the right hand conductor. The later second and first traces show how the signal develops further along the pair of conductors. It separates out into, first, an Odd Mode signal with equal and opposite voltage spikes on the pair of lines, followed by a slower Even Mode signal of equal positive spikes.

In **Figure 2**, the case of buried conductors, the two modes travel at the same velocity and do not separate out, as shown in **Figures 5** and **6**. Now let us look at the case of surface conductors when the front end of the right hand passive conductor is shorted to ground so that there can be no voltage there.

In **Figures 7** and **8** we see that in the earliest, bottom traces the initial zero voltage in the right hand conductor must have been two equal and opposite voltages superposed. At the same time, there must have been equal and opposite charges on the surface of the right hand conductor, and equal and opposite electric currents flowing in and out of this conductor. As we see in **Figure 9** in the field patterns, in the Even Mode the right hand conductor is positive and so electric current flows into the paper, generating the field pattern shown. Meanwhile, in the Odd Mode, the right hand conductor is negative so electric current flows out of the paper.

Looking back, this must have been happening in all traces in Figures 5 and 6 and in the bottom traces in Figure 3.

First, assuming a TEM Wave, I mathematically prove that only one voltage/current ratio and one velocity can travel down between a conductor and ground plane.

Properties of a Transmission Line

I've called this section 'Properties of a transmission line' or 'Proof that only one type of wave-front pattern can be propagated down a two-wire system'.

In order to discover how we characterize a transmission line we shall consider an observer watching a step passing him along a two-wire line (see **Figure 10**).

The observer knows: (a) Faraday's Law of Induction and (b) that electric charge is conserved.

Use Faraday's law $(V = -\frac{d\phi}{dt})$ around the loop AA'B'B. Define l as the inductance per unit length of the wire pair, then:

$$l = \frac{\phi}{i} \quad (1)$$

In a time δt, the step will advance a distance δs, such that:

$$\frac{\delta s}{\delta t} = C \quad (2)$$

and the change of flux will be (from **Equation 1**):

$$\delta\phi = l\,\delta s\, i \quad (3)$$

Substitution into (a) Faraday's Law gives the input voltage V across AB

needed to equal and overcome the back e.m.f. $v_{back} = \frac{\delta\phi}{\delta t}$.

From **Equations 2** and **3**:

$$v = v_{back} = l\, i\,\frac{ds}{dt} = l\, iC \quad (4)$$

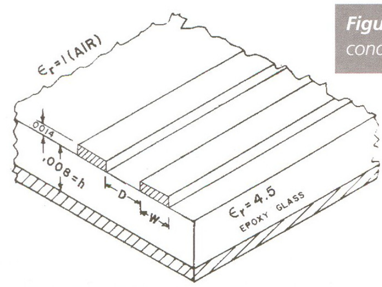


Figure 1: *Surface conductor (Microstrip)*

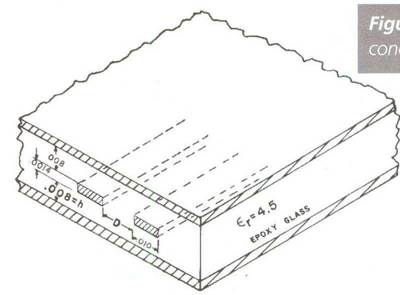


Figure 2: *Buried conductor (Stripline)*

Now we consider the conservation of charge. In a capacitor in general, q = cv. In our case, the charge $i\delta t$ entering the line in time δt equals the charge trapped in charging up the next segment δs of the line, $c\delta s\, v$ where c is the capacitance per unit length between the pair of wires and $c\delta s$ is the capacitance of our section.

$$i\delta t = vc\delta s, \text{ which means that } i = vcC \quad (5)$$

Combining **Equations 4** and **5**:

$$vi = l\, iC\, vcC$$

$$C = \pm \frac{1}{\sqrt{lc}} \quad [= \pm \frac{1}{\sqrt{\mu\varepsilon}}] \quad (6)$$

$$\text{and } \frac{v}{i} = Z_0 = \sqrt{\frac{l}{c}} \quad (7)$$

Thus we see that, knowing only Faraday's Law and that charge is conserved, the observer in Figure 10 concludes that any step passing him must have a single velocity *C* and a single voltage-current relationship given by an 'Ohm's Law' type relation:

$$\frac{v}{i} = Z_0 \quad (8)$$

where Z_0 is a property of (1) the geometry of a cross-section of the wires and (2) of μ and ε characteristics of the medium in which the wires are embedded.

Crosstalk in Digital Systems

This sections is 'Crosstalk in digital systems' or proof that only two types of wave-front pattern can be propagated down a system of two parallel wires and a ground plane.

In **Figure 11** the method of images is used; it is assumed that $i_b=-i_a$, $i_q=-i_p$.

The following terms are defined for steady state conditions:

l = Magnetic flux per unit length between AA' and BB' when unit current flows down AA' and back on BB'.

m = Magnetic flux per unit length between AA' and BB' when unit current flows down PP' and back on QQ'.

c = Charge per unit length on AA' and BB' which produces unit voltage drop between AA' and BB'=l/(coefficient of capacitance).

d = Charge per unit length on AA' and BB' which produces unit voltage drop between PP' and QQ'=1/(coefficient of induction).

This could well be called "Mutual Capacitance".

In order to discover how we characterize the four wire system we shall consider an observer watching a step passing him (**Figure 12**).

The observer knows: (a) Faraday's Law of Induction and (b) that electric charge is conserved.

Now assume that the wave front passing him involves current steps i_a and i_p travelling down the lines with a velocity *C*.

From $v = \frac{d\phi}{dt}$ between AA' and BB', we get (as in Equation 4):

$$v_{ab} = l\, i_a C + m\, i_p C \quad (9)$$

Similarly $v = \frac{d\phi}{dt}$ between PP' and QQ', so:

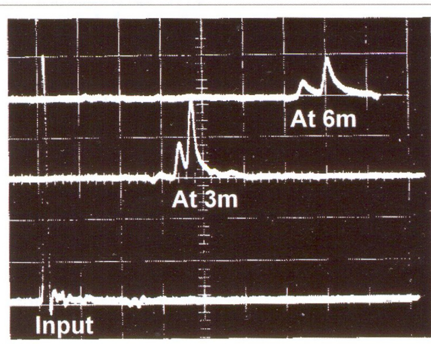


Figure 3a: *Signal on active left hand line*

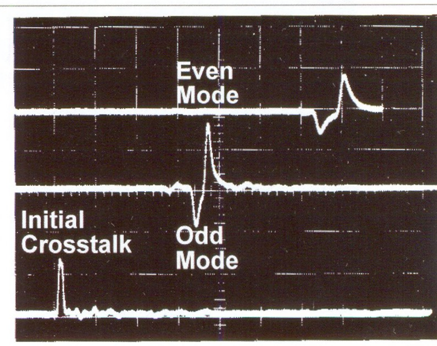


Figure 3b: *Signal on passive right hand line*

Figure 4: Drawings of Figure 3

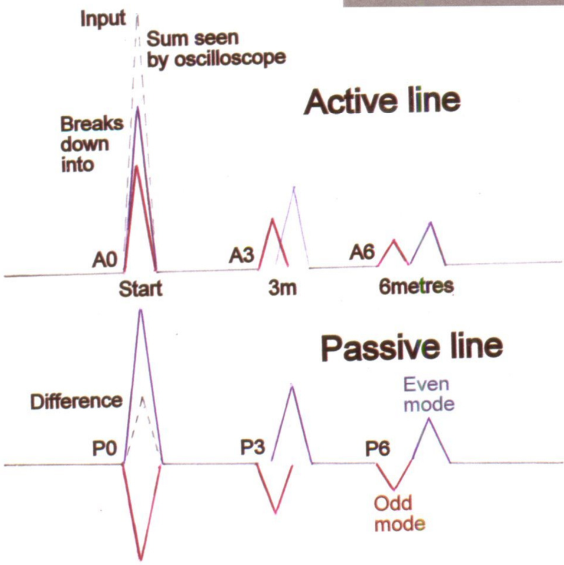


Figure 5: Signal on active left buried line

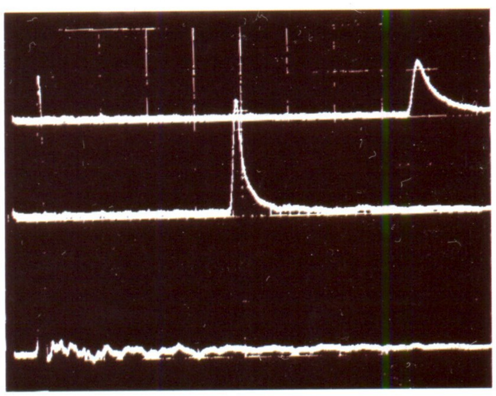
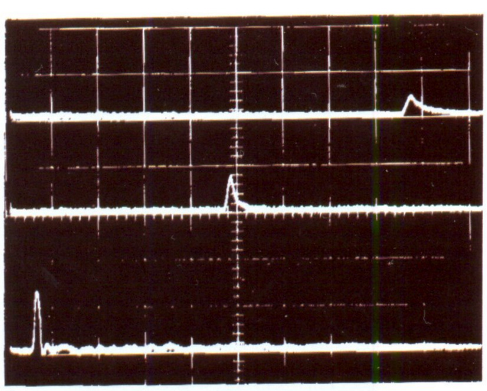


Figure 6: Signal on passive right buried line



$$v_{pq} = l\,i_p C + m\,i_a C \quad (10)$$

Also, from v=q/c (as in Equation 5):

$$v_{ab} = \frac{i_a}{cC} + \frac{i_p}{dC} \quad (11)$$

$$v_{pq} = \frac{i_p}{cC} + \frac{i_a}{dC} \quad (12)$$

First find C. Eliminate voltages from **Equations 9** through to **12**. From Equations 9 and 11 we get:

$$l\,i_a C + m\,i_p C = \frac{i_a}{cC} + \frac{i_p}{dC}$$

$$l\,i_a C^2 + m\,i_p C^2 = \frac{i_a}{c} + \frac{i_p}{d}$$

Therefore:

$$\frac{i_a}{i_p} = -\frac{mC^2 - \frac{1}{d}}{lC^2 - \frac{1}{c}} \quad (13)$$

Similarly, from **Equations 10** and **12** we get:

$$\frac{i_a}{i_p} = -\frac{lC^2 - \frac{1}{c}}{mC^2 - \frac{1}{d}} \quad (14)$$

Eliminate i_a and i_p from **Equations 13** and **14** to get:

$$C = \pm\sqrt{\frac{\frac{1}{c} + \frac{1}{d}}{l + m}} \text{ or } \pm\sqrt{\frac{\frac{1}{c} - \frac{1}{d}}{l - m}}$$

So in the forward direction there are two possible velocities of propagation:

$$C_e = +\sqrt{\frac{\frac{1}{c} + \frac{1}{d}}{l + m}}$$

or:

$$C_0 = +\sqrt{\frac{\frac{1}{c} - \frac{1}{d}}{l - m}}$$

Returning to Equation 13 and using the results for C, we find th following two wave fronts are possible: The EM, or Even Mode, (**Figure 13**) is like a TEM step travelling down between two wire up of A shorted to P and B shorted to Q. It has the higher Z_0 anc case of surface, or stripline, conductors) the lower velocity (beca of its field is in the slower medium of epoxy glass).

$$C_e = +\sqrt{\frac{\frac{1}{c}+\frac{1}{d}}{l+m}}$$

$$Z_{0e} = \sqrt{(l+m)\left(\frac{1}{c}+\frac{1}{d}\right)}$$

$$i_a = i_p$$

$$v_{ab} = v_{pq} \tag{15}$$

OM Wave

The OM, or Odd Mode, wave (**Figure 14**) is like a TEM step travelling down between two wires made up of A shorted to Q and P shorted to B.

$$C_0 = +\sqrt{\frac{\frac{1}{c}-\frac{1}{d}}{l-m}}$$

$$Z_{00} = \sqrt{(l-m)\left(\frac{1}{c}-\frac{1}{d}\right)}$$

$$i_a = -i_p$$

$$v_{ab} = -v_{pq} \tag{16}$$

Our initial assumption in our mathematics was that a stable waveform passed the observer; that is, a TEM wave which was in equilibrium or, as Einstein put it, "at rest". (See *"Einstein's Error"* in the next issue of *Electronics World*).

Following that assumption, we used Faraday's Law and concluded from our calculations that no other waveform may pass the observer other than the Even Mode and the Odd Mode. However, superposed combinations of EM and OM are permissible, as are seen in Figures 5 and 6. They are permissible in the real world, but not permissible according to Faraday's Law, which is therefore not about the real world as photographed here.

This mathematics was "confirmed" by the upper two traces in Figures 3, 7 and 8. However, for 43 years I failed to notice that the bottom traces in these figures, and all the traces in Figures 5 and 6 give an illegal asymmetrical, third mode, which is a combination of an Even Mode and an Odd Mode. On their own, Even Mode and Odd Mode are symmetrical with respect to the four conductors.

At Odds

Clearly, physical reality was disproving a conclusion derived mathematically from Faraday's Law, that only the Even Mode and the Odd Mode were permissible. The mathematics is indifferent as to whether superposition is permissible. It does not cover all the features of the physics.

Faraday's Law (but not its maths) outlaws the superposition of two permissible modes, which become a third, illegal mode. One reason why it is illegal is that the electric currents in the right-hand conductor are in opposite directions for the two modes, and classical theory says there cannot be two electric currents in opposite directions along a single conductor. However, two electromagnetic waves (or light rays) can be in the same point in space, for instance when we shine a torch at another lighted torch pointing in the opposite direction, or when we send two

Figure 7: *Signal on active left line with right line shorted to ground*

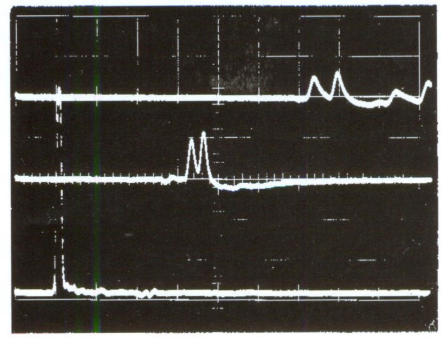


Figure 8: *Signal on passive right line with its front end shorted to ground*

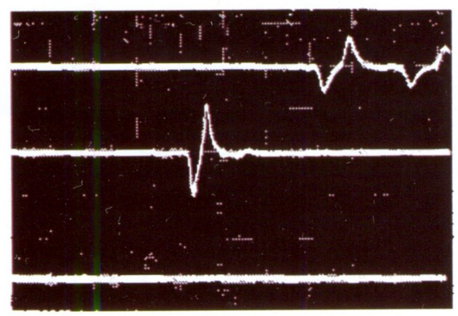


Figure 9: *Field patterns for Even Mode and Odd Mode for surface lines. It is simpler to think of four conductors rather than two conductors and a ground plane*

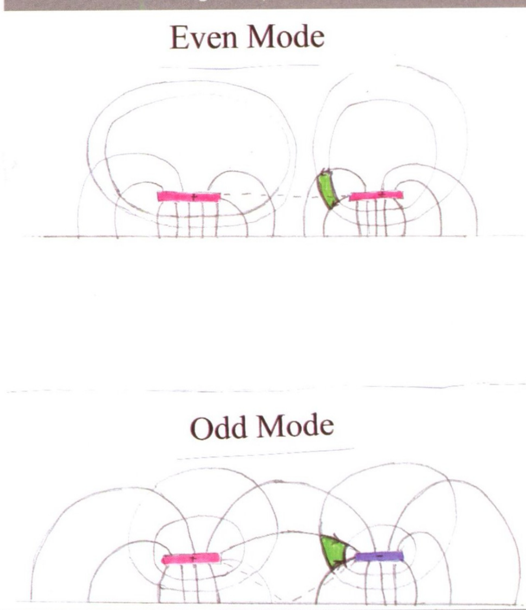


Figure 10: *An observer watching a voltage step passing him along a two sire system*

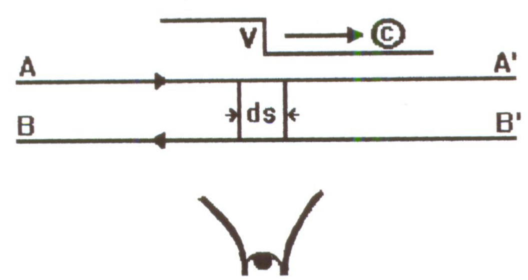


Figure 11: *A pair of parallel surface lines and their images*

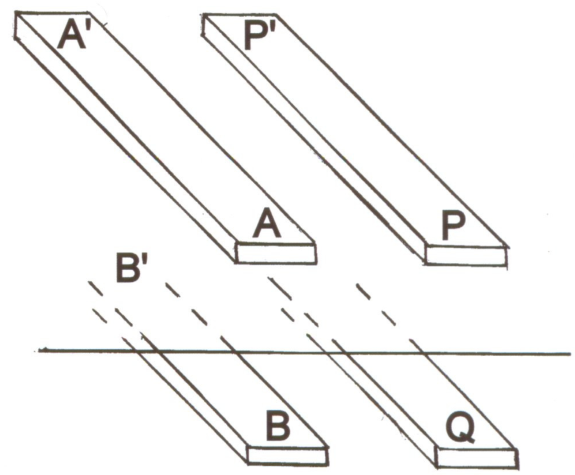


Figure 12: *An observer watching a voltage step passing him along a four wire system*

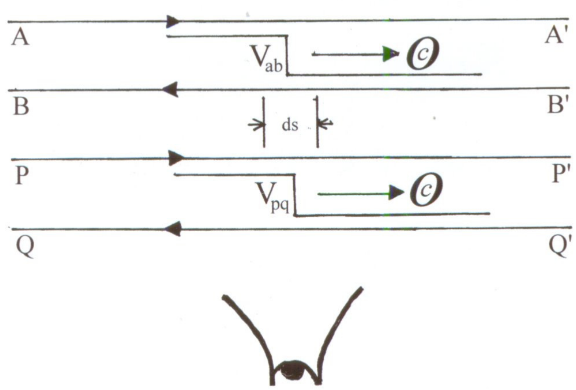


Figure 13: *Illustration of the Even Mode*

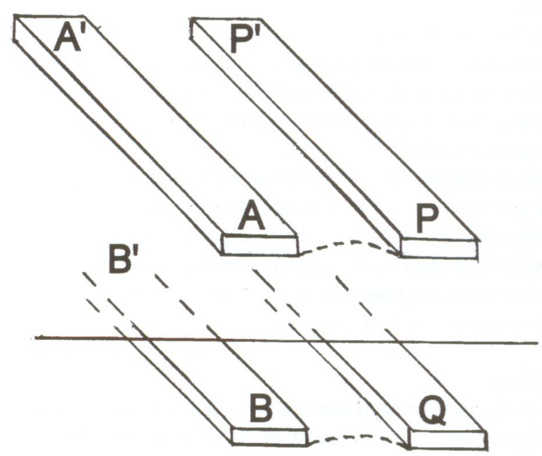
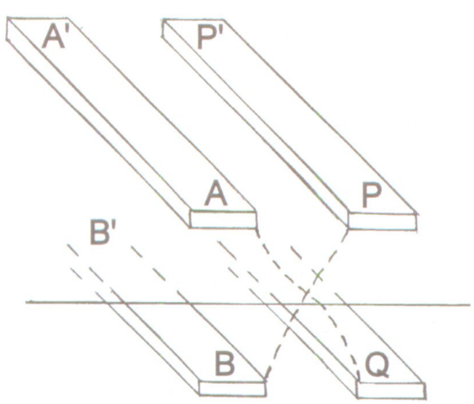


Figure 14: *Illustration of the Odd Mode*



pulses from left and right through each other down a coaxial cable.

The figures show that the Even and Odd Mode TEM Waves can coexi: but not their associated electric charges and currents. To resolve the problem, we study the mathematics of it next month.

The second-part of Ivor Catt's article continues in the next issue of Electronics World magazine.