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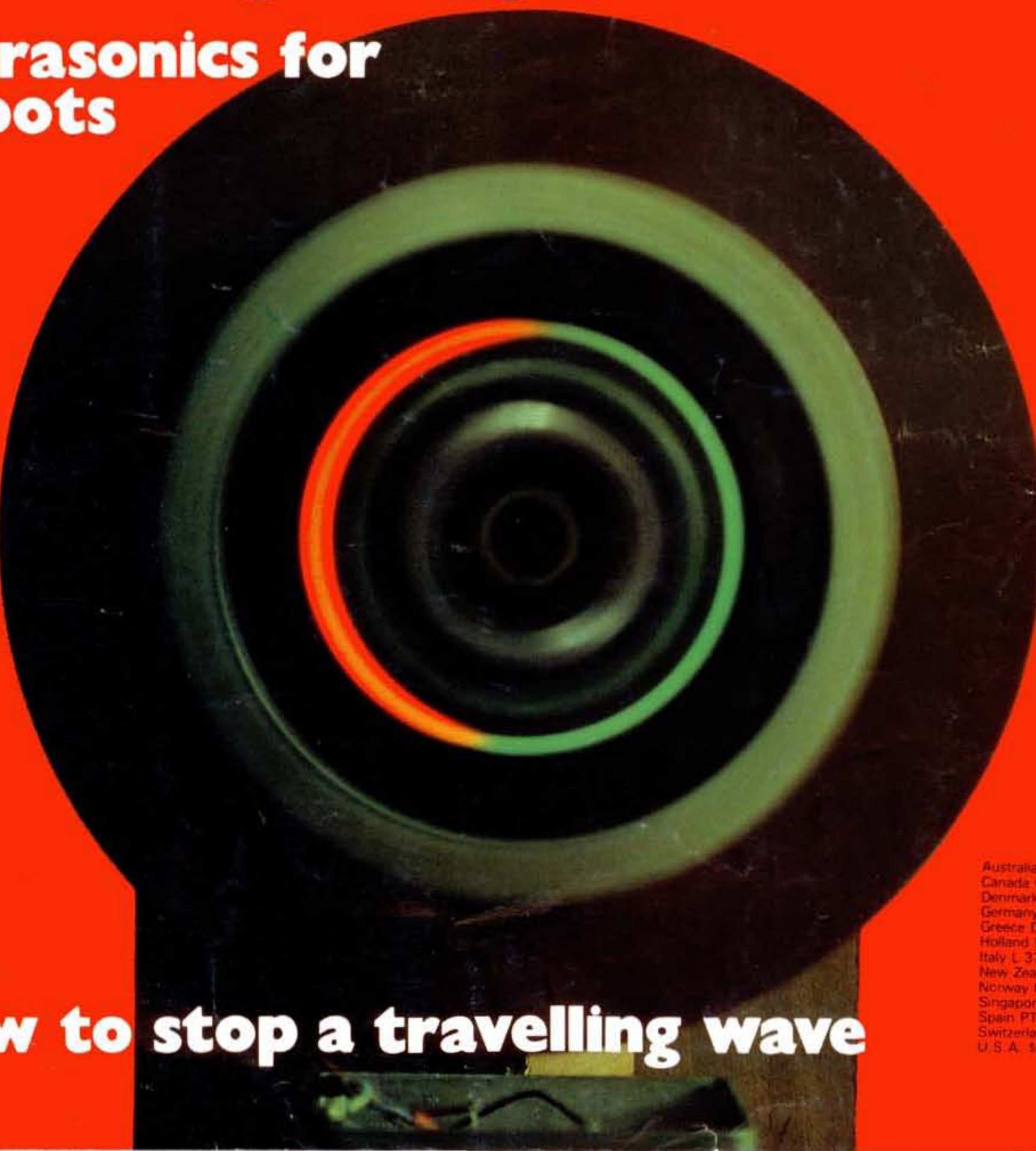

How to stop a travelling wave

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How to make electric charge from a radio wave

A wave in free space can be persuaded to enter a transmission line where its velocity may be reduced whilst still conserving its field pattern. If the transmission line is formed into a closed circle it may be spun at the same angular velocity as that of the wave to produce an electrostatic field in the laboratory, just as from a charged surface, but the primary energy is entirely in the wave field. Which then is the more fundamental, charge or field – do we really need two criminals where one may suffice?

by R. C. Jennison

In recent years there have been a number of controversial articles in *Wireless World* questioning the very basis of the principles which are fundamental to wireless and wired communication. One is often tempted to comment in the letter columns but it is entertaining to sit back and witness battles which, too frequently, are replays of conflicts that one has fought on similar battlegrounds in days gone by. I will not enter directly into the controversies, although it may be clear in which direction my sympathies lie, but I will present a little conundrum and show how a partial solution has been demonstrated with simple apparatus that can be constructed at home by many readers of *Wireless World*.

What is electric charge? What is it made of and why does it have, and appear to behave as the source of, an associated electric field, whatever that may be? If you do not like the concept of an electric field, but prefer to live in my old friend Sandy Scott Murray's particulate world, substitute for the field a horrific flow of virtual photons, whatever they may be. The answer that charge is simply an excess or deficit of electrons, is not sufficiently fundamental. What is the nature of the charge on a single electron? Even if the electronic charge is made of miniscule sub-particles which defy discovery the same question remains: what *is* charge, is it a special sort of green cheese which acts as the source of an electric field? Its only purpose seems to be to support the field, or complex of virtual photons, and couple it to matter, but after all it is a very old concept that predates Friday's work on fields. At the present time we appear to have two separate unknown criminals who travel hand-in-hand, the electric charge and the electric field. Can we not form a model which causes the two criminals to coalesce and thereby remove at least one of the unknowns?

Start by considering an imaginary experiment using some of the radiation that has been around since the time of the 'big bang'. The 3K radiation which pervades our part of the universe is thought to be the dying remnant of immaculately conceived radiation which cannot be associated with the radiation from particulate matter. We can pick up some of this radiation on a millimetre-wave antenna and pop it down a transmission line in which the velocity of propagation of the disturbance depends on the dielectric properties of the line. In principle the dielectric constant can be as high as we wish so that the disturbance moves at a leisurely pace. (Wave velocity in a transmission line is given by the reciprocal of the square root of the product of the inductance and capacitance per unit length, which is

$$c' = (LC)^{-1/2} = (\mu\epsilon)^{-1/2} = c/(\mu_r\epsilon_r)^{1/2},$$

the same as for an electromagnetic wave in the medium when no conductors are present). Coil the line around so that the circumference is precisely one wavelength in the line, Fig. 1(a). We now have to work very quickly but remember that we are discussing an imaginary experiment at this stage! Chop a section out of the line which carries exactly one wavelength and couple the input of the section immediately to the output of the same section, (b). We now have one wavelength trapped in a continuous transmission line of one wavelength circumference. The radiation will quickly decay but we can at least imagine a transmission line with very low losses so that the wave circulates for a finite time.

You may not care for the idea of changing the connection so quickly, so if you wish to be a little more practical, substitute the arrangement in Fig. 2 where two isolators are used to achieve the same result.

Now take stock of the situation. We have a single loop of transmission line which originally contained no energy other than that associated with its rest mass but which now contains an additional packet of pure electromagnetic energy whose origin can be traced right back to the start of our present universe, about 15,000,000,000 years ago. This energy, in the good old-fashioned concepts of wireless, is in the form of an electromagnetic wave comprising a sinusoidal pattern of electric and magnetic fields which are together in phase and are travelling around the loop at the languid velocity c'. The fields are not coming directly from the electrons in the conductors of the transmission line but these electrons mirror the passage of the wave as they are influenced by the induction from the waves whose origin we have traced. The frequency at which the wave circulates around the loop is the same as that of the original received signal, say 300GHz in round figures, whereas the wavelength is reduced by the effect of the dielectric to only a tiny fraction of its original length.

We are now ready to perform the final trick. Take the little loop containing the wave and spin it, about an axis through its centre, in the opposite direction to that in which the wave is travelling, increasing the speed of rotation until it is rotating anticlockwise at exactly the same angular speed as the wave is rotating clockwise. The trapped wave is now precisely at rest in the laboratory although the transmission line is spinning round at high speed. It is in fact spinning at $-c'$, very much less than the free space velocity of light c, so that from the point of view of the mechanics the principle is demonstrable, as indeed we shall shortly see.

If we now examine the space in close proximity to the little loop we find a static electric field. It is not a standing wave but a truly stationary, unvarying field, the intensity of which is a maximum in one

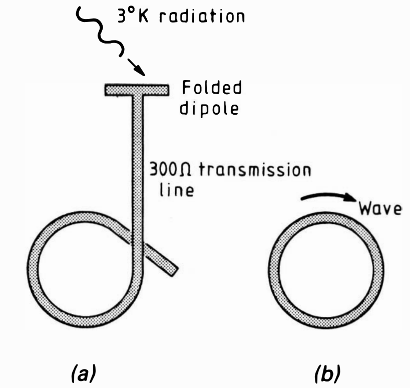

Fig. 1. A wireless wave from the original 'big bang' radiation is picked up on a folded dipole and fed into a 300 ohm transmission line, as shown (a). In principle, the coiled section may be removed and connected full circle whilst the wave is still in the line (b).

direction (say +) in one part of the line, a maximum in the other direction (say −) diametrically opposite and a minimum at the two quadrant points in between. Remember that this is the field that we originally trapped from space and the electrons in the wires are simply slaves to its influence. Relative to the centre of the disc, it is in fact a static dipole field for the particular configuration of the experiment in which both conductors are in the plane of the disc, one of slightly smaller radius than the other. Relative to the laboratory as a whole the vectors are continuous in the upper and lower halves.

Returning to the fundamental point raised at the beginning of this article, we have produced a static field but where are the charges which provide the source of that field? There are none; the electrical energy is the original wave energy and the electronic charges in the conductors are simply catalytic. We have essentially produced a 'charge' from the electromagnetic wave, for one cannot differentiate between the static field that we have produced and another that could be set up by a suitable distribution of 'real' electric charges on a stationary ring in the laboratory.

Practical demonstration

It may well be that you consider that all the above is a lot of academic guesswork and that nothing like it could be achieved in practice. To prove the point I constructed two demonstration systems. One of these uses inexpensive and readily available electronic components and can be built quite easily at home. To this end the frequency is scaled down to the sub-audio range but the apparatus could still, in principle, contain a wave from the virgin past. The apparatus and its implications have been discussed in *Journal of Physics-A* vol. 15, 1982, pp.405-8.

To achieve exceptionally slow velocities of propagation in a transmission line it is usual to increase the permeability and permittivity μ_r and ϵ_r or *equivalently* to increase the capacitance and inductance per unit length by the use of 'lumped' circuits, in which discrete large values of L and C are cascaded to form a continuous line of discrete sections. The physical principles in such a line remain the same electromagnetic principles as those in a continuous distributed line which for an equivalent propagation velocity would require impractical values of permittivity and permeability. Phenomenologically, the set of lumped circuits in the apparatus to be described form a dense medium, whereas at low frequencies the molecules in a 'continuous' dielectric behave, on a microscopic scale, as separate systems below resonance.

The arrangement uses a lumped-circuit transmission line in which there are 32 sections giving a total delay of 120ms. The inductors are small 1:1:1 transistor coupling transformers (RS Components) with their windings connected in series to increase the inductance. The capacitors are 1μF polycarbonate types from the same supplier. There is a small loss of the order of 1dB in each section of the line and small linear repeater amplifiers are included in the circuit to compensate for this loss. These repeater amplifiers consist of an f.e.t. input stage feeding a bipolar output stage and the gain is set to compensate for the loss in the adjoining section of line. The complete line is looped on itself in a geometrically circular configuration as in Fig.3.

Energizing the linear repeater amplifiers in the completely closed circular loop causes an oscillation to build up in which a sinusoidal wave with a period of approximately 120ms propagates around the system in a clockwise direction. A slight roll-off in the response of the system, together with the maintenance of just sufficient gain to compensate for the losses, ensures that the waveform remains sinusoidal for long periods. The continuity of the cycling sinusoidal wave places the system in the general category of phase-locked particles*, the particular mode corresponding to one complete wavelength around an annular system. It is possible to inject a signal into the system to initiate the circulation of the wave but one cannot differentiate such a wave from that resulting from self-oscillation, and the last-mentioned serves equally well to demonstrate the phenomenon under discussion.

The whole system is arranged mechanically in a well-balanced configuration on a strong laminated plastics disc, and power to the repeaters is supplied from two small 9 volt batteries strapped symmetrically behind the disc. At the centre of the disc there is a hub which is firmly attached to a small variable speed electric motor.

Upon energizing the repeater amplifiers, a travelling wave moves round the system in a clockwise direction and the travelling field may be sampled at take-off points associated with each of the capacitors. The 32 elements give a sufficiently close approximation to a continuous line and a reasonably pure sinusoidal wave may be detected passing each of these points. An alternative display system consists of a set of red light-emitting diodes, each of which glows on the passage of the positive crests of the wave, and a set of green light-emitting diodes, each of which glows on the passage of the negative troughs. When at rest the disc then exhibits a circle of rapidly flickering red and green lights corresponding to the circular rotation of the wave system at about 8Hz.

The disc is now spun in an anticlockwise sense at such an angular frequency that it is precisely equal and opposite to that of the wave. At this velocity, the wave, whilst still travelling relative to the disc, becomes stationary in the laboratory. The resulting potentials may be sampled to confirm the stationary state of the field system, but the most vivid demonstration of its state is given by the light-emitting diodes which form two stationary arcs, as shown on the front cover, one of positive (red) and the other of negative (green) potential relative to the centre. With careful adjustment of the speed of rotation, this static dipole electric field may be maintained indefinitely in the laboratory.

It should be stressed that the effect is truly that of a static field and neither a rapidly reversing field, as in standing wave systems, nor a stroboscopic artefact. The crests and troughs of the travelling wave are truly brought to rest in the laboratory and indeed it is possible to reverse the original direction of propagation, without reflection, by increasing the rotational speed of the motor.

An interesting conceptual problem then arises with regard to the magnetic field of the wave. The particular apparatus described here is not designed in such a way that the magnetic field may be sampled and there can be two schools of thought on whether or not it is also stationary. One argument is that as the charges are not moving in the laboratory there ought to be no magnetic component. The other argument is that as the travelling wave has a magnetic field in phase with the electric field this magnetic field should appear stationary when the electric field is ren-

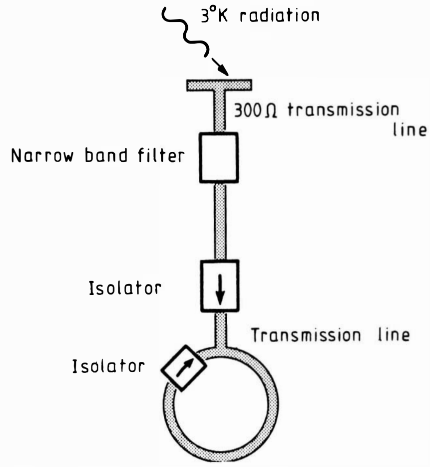

Fig. 2. More practical arrangement for putting the wave into the circular line.

* Jennison, R. C. and Drinkwater, A. J. *J. Phys. A.* vol. 10 1977. pp. 167-79. Jennison, R. C. *J. Phys. A.* vol. 11 1978, pp. 1525-33. *J. Phys. A.* vol 13 1980 pp. 2247-50. Second Oxford Quantum Gravity Conference (London: OUP) pp. 657-69. *J. Phys. A.* vol. 15 1982, pp 405-8. *Wireless World* vol. 85 1979, June pp. 42-7.

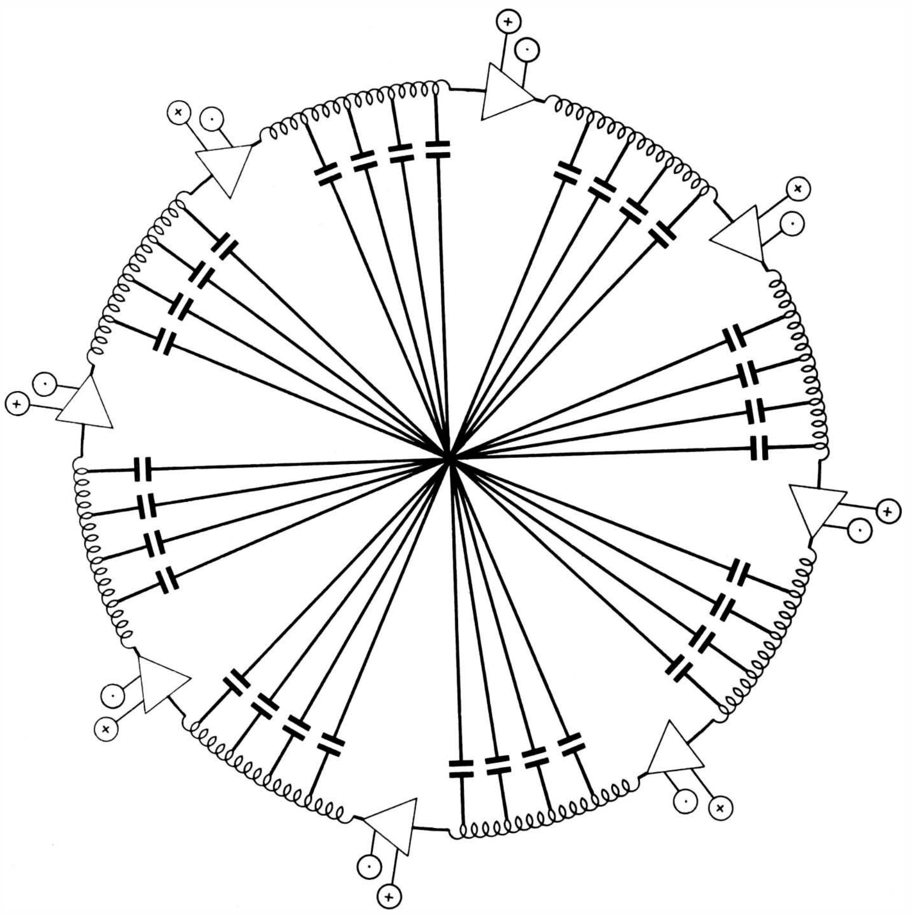

Fig. 3. *Artificial delay line whose construction is described in the text in which a wave runs in the clockwise direction. Rotation of the system in an anticlockwise direction at the same angular frequency as that of the wave produces a static field. Red and green light-emitting diodes, connected at the points marked + and ·, indicate the stationary wave, as on the cover photograph.*

dered stationary. It appears that the first argument is fallacious for it ignores the motion of the system relative to the wave and there is also no known mechanism whereby the Maxwellian property of the wave system should break down even when the velocity, relative to the observer, is reduced to zero.

This demonstration is crude but very enlightening. We have got rid of one of the criminals who were travelling hand-in-hand at the beginning of this article. Nature probably has a much better way of achieving the same thing by so convoluting the electromagnetic field in the unique mechanism of electron-positron pair production that a perfect system is formed which has all the stable and wonderful properties of an electron and merits the concept of charge which is now fully ingrained in our conception of the properties of matter.

Having formed a static field from a travelling electromagnetic wave I am quite content, contrary to other views expressed in *Wireless World*, that if I hurl it around on a string it will give rise to freely propagating electromagnetic waves at the frequency of rotation, the energy coming from my muscles as I whirl the string. If, however, you ask me what these electromagnetic fields are then I must confess, along with Feynman, that I have not the faintest idea. It is a pity that some of the classical apparatus has disappeared from modern teaching. It is my belief that every budding researcher should be given a gold leaf electroscope to contemplate for a few minutes every day. Ultimately someone may really explain the phenomenon which keeps the leaves apart. WW

Professor Roger C. Jennison, B.Sc., Ph.D, C.Eng., FIEE, FIP, FRAS, PPIE, FRSA, was born in Grimsby and studied engineering in Hull before volunteering for aircrew in 1942. Demobilized in 1947, he decided to start again and read physics at Manchester University, graduating with an Honours degree in 1950 and a Ph.D. in radio astronomy in 1954. In this period he deduced that the Cygnus A radio 'star' was double, invented 'closure phase' and a number of other techniques and was successively lecturer in radio astronomy, then senior lecturer in radio astronomy, and later in physics. In 1959 he turned his attention to medium-wave radio astronomy and cosmic dust research. He developed the first foil detectors and with experiments on rockets and the Ariel II satellite he showed that there was no danger to space travel from the cosmic dust which had previously been thought to be a severe hazard. In the early 1960s he became interested in problems of gravitation and rotation and was also elected President of the Institution of Electronics. In 1965 he accepted the chair of physical electronics at Canterbury where he founded the Electronics Laboratories and recently added a chair of radio astronomy to his titles. He has maintained an interest in trying to understand fundamentals and has contributed an alternative explanation of inertia and quantization among his 90 published works.

LITERATURE RECEIVED

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'Magnetic materials and components' is a folder containing information on the Arnold ranges of Mo-permalloy powder magnetic cores, and other iron powder cores, tape-wound cores, and other magnetic materials. Walmore, who issued the folder as well as stocking other manufacturers' magnetic materials, also manufacture ferrite toroidal cores for use in switching power supplied. Walmore Electronics Ltd, 11 Betterton Street, London WC2H 9BS. **WW403**

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Photomultiplier tubes (with high efficiency arc rubidium-caesium types), according to literature from Thorn EMI Electron Tubes Ltd, Bury Street, Ruislip, Middlesex HA4 7TA. The new tubes are plug-in replacements for the older ones in the Thorn EMI range. **WW406**