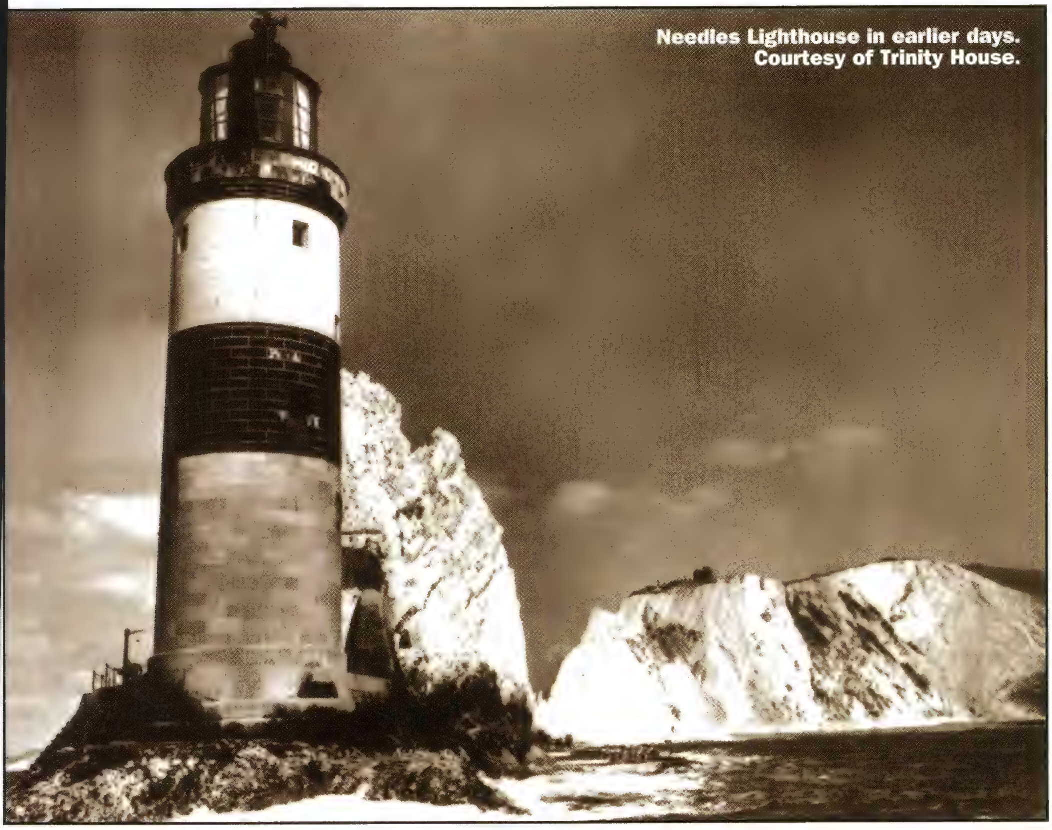


Needles Lighthouse in earlier days.
Courtesy of Trinity House.

the cables where they were brought ashore.

Willoughby-Smith's system overcame the problem by terminating the submarine cable with an electrode on the sea bed, using the sea itself to provide a link with its complementary electrode securely anchored to the rock. The system was reliable, efficient and for a non-Hertzian system, it could not be improved upon.

Current Field Lines

As already mentioned, both systems are based on current field lines; they are, of course, imaginary, but they do provide a means of describing a phenomenon that would otherwise be well nigh impossible. When a current flows between a pair of electrodes in earth or water, it does not take the short, direct path but spreads out in a pattern similar to magnetic field lines extending from the poles of a bar magnet – see Figures 1 & 2.

Pre-Hertzian WIRELESS SYSTEMS PART 1

Water as the Natural Conductor Johnson's System & Willoughbby-Smith's System

by George Pickworth

The term 'wireless' is derived from "electric telegraph without connecting wires" and this study is about two very successful, but virtually forgotten pre-Hertzian wireless systems based on the peculiar characteristics of current field lines in water.

As the water served as a natural conductor, they were, by definition, true wireless systems. In Part 1 of this study, we look at how the pioneers exploited the peculiar characteristics of current field lines to overcome the problem of isolating outgoing and return currents in a single expanse of water. It is supported by small scale reproductions of this early system. In Part 2, we look at the hitherto unrecognised role of polarisation in the operation of these early wireless systems and this is supported by practical experiments which can easily be reproduced on a micro scale with minimal equipment in a large plastic tub or even the domestic bath.

India

The earliest practical wireless system was developed in India to extend the telegraph system across rivers too wide to be spanned by land line wires. At that time, the India telegraph land lines employed galvanized iron wire supported by porcelain insulators attached to wooden poles. It was a 2-wire DC system and receivers were essentially galvanometers; operators read signals by observing the swing of the needle.

Attempts to produce submersible cables by coating galvanized iron wire with tar and pitch were only partially successful as the insulation was soon scoured off; armoured gutta-percha insulated cable was still only a concept. The solution was to abandon the submersible cable approach and terminate the land lines with electrodes inserted into the bank on either side of the river and employ the water itself as a natural conductor. The feasibility of such a system had been demonstrated in 1842 by Morse in North America but he did not develop his system; this was left to O'Shaughessy, Blisset and Johnson working in India.

However, for the purpose of this study, the India system is referred to as Johnson's system. Unfortunately, Johnson's system was limited to rivers a few hundred metres wide, but it enabled the telegraph system to extend to hitherto inaccessible areas and this had a profound effect on the history of the subcontinent.

Needles

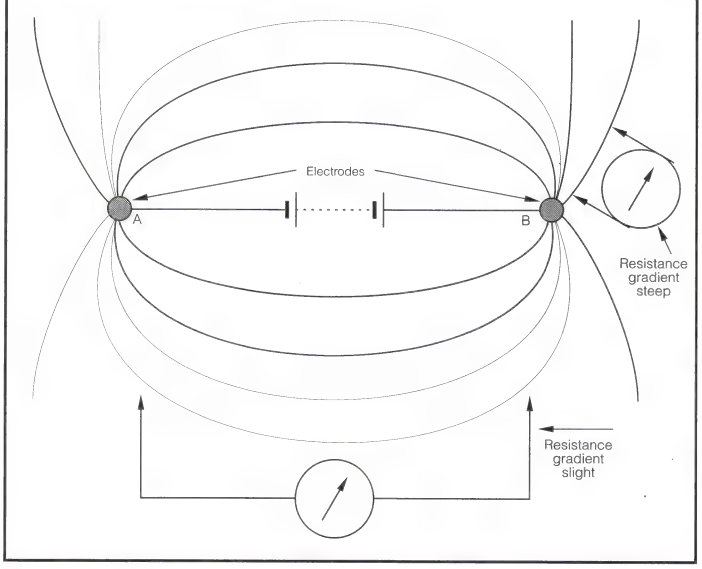
The other system, developed by Willoughby-Smith just before the turn of the century, provided an electric telegraph link with the Needles lighthouse and later with Fastnet lighthouse. Paradoxically, reliable submarine cables were then available, but waves which pounded the rocky islands on which the lighthouses were sited, repeatedly washed away

For clarity, current field lines are depicted in this study in plan view whereas in reality, they form a distorted hemisphere which extends into the earth below the river bed and laterally into the adjacent land. Theoretically, the field lines extend to infinity.

Resistance Wire Analogy

Let us now consider current field lines as lengths of resistance wire and that a potential difference (p.d.) occurs between two points along these wires. However, the

Figure 1. Current field lines, showing variation in resistance gradient.



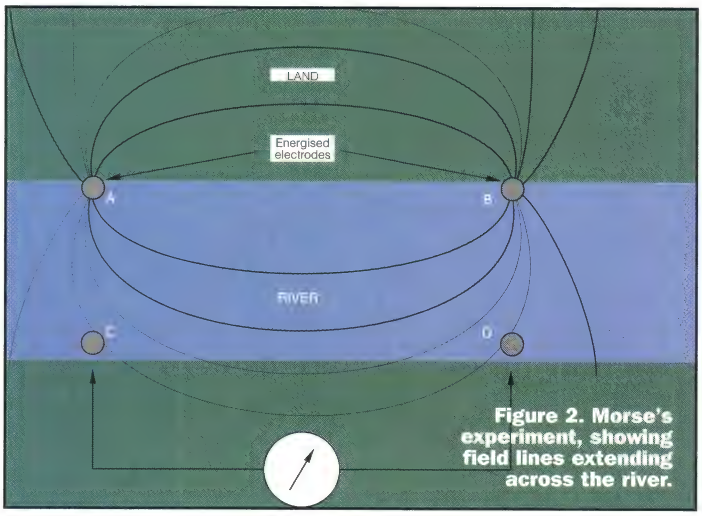


Figure 2. Morse's experiment, showing field lines extending across the river.

The Needles Lighthouse today. Courtesy of Trinity House.

resistance gradient is steepest where field line density is greatest, i.e., where the lines converge on an electrode. The gradient declines exponentially with distance from an electrode.

Indeed, with Johnson's system, the resistance gradient on the opposite side of the river declined to the point where in order to produce a useful p.d., the probes had to be widely spaced, as shown in Figure 3. Indeed, it was this dramatic reduction in the resistance gradient that limited the range of Johnson's system.

Field lines converge on both electrodes from 360°, so a p.d. occurs across a pair of probes aligned radially with either electrode. I have called the above phenomenon the '360° effect'. However, to demonstrate the effect, spacing of the probes must be only a fraction of the energized electrodes. This will be apparent from Figure 1.

Moreover, as the field line resistance gradient is very steep near an electrode, a significant p.d. occurs even when the probes are relatively closely spaced and this was fundamental to Willoughby-Smith's system – refer to Figure 4. It follows that if the current to the energized electrodes is keyed, a meter connected across a pair of distant probes will respond accordingly, thereby providing a basics of practical wireless system.

Complicated

So far, we have considered field lines as a single 'set' extending from a single pair of electrodes, whereas in reality, there are numerous individual 'sets'. Some are man made and some seem to occur naturally. All create electric and magnetic fields which presumably interact, so the actual field line pattern would seem to be very complicated.

However, my experiments have shown that where two or more sets of field lines are present, there is a degree of cancelling with field lines of opposite polarity and the potential developed the probes is set by the collective effect of all the field lines present.

Induction

Field lines in conjunction with electrodes and connecting wires form a single turn loop on an horizontal axis; it therefore responds to changing magnetic fields. By the same token, if the loop is energized with AC or

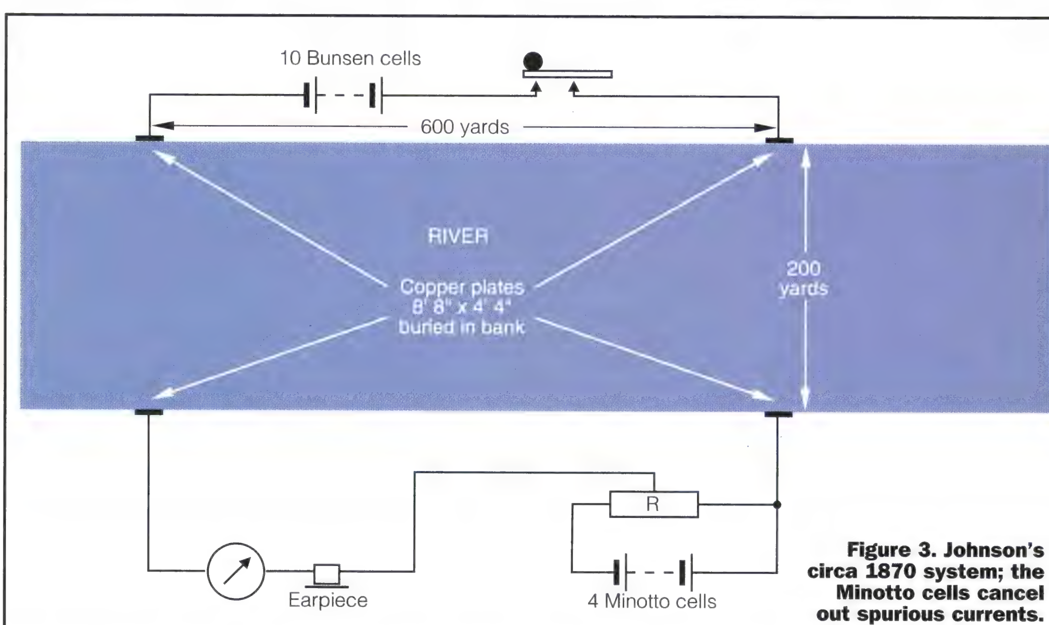


Figure 3. Johnson's circa 1870 system; the Minotto cells cancel out spurious currents.

ised DC, the resultant gnetic field can induce rrents in a distant similar op; this was the basis of World r I 'Earth current' signalling stems. Inductive coupling was nifest with Johnson's system 'clicks' in a telephone rpiece when the key was essed and released; indeed, e of Johnson's innovations s to complement the lvanometer with a telephone rpiece so that operators uld read signals both visually d orally (see Figure 3).

lorse

orse was drawn into perimenting with wireless stems by accident. In 1842, he as demonstrating to the nerican Institute of Science in ew York the practicability of king Governors Island with astle Garden, a distance of 5km, with a submersible sulated with tar and bitumen. though successful, the cable as unfortunately ripped up by ship's anchor.

Morse realised that for a oss-river wireless telegraph stem, range need only be the idth of the river and this otivated him to look at the ossibility of employing the ater as a natural conductor. To nsure clarity and consistency describing Morse's xperiments and indeed all xperiments, the energized lectrodes will from now on be eferred as electrodes AB and he probes as electrodes CD, nless of course, some other erm is more appropriate – efer to Figures 2 & 3. Their oles obviously reverse during -way working.

During his experiments, Iorse used identical 4 × 8ft. opper plates for electrodes AB nd CD which were placed in a anal close to the bank, with ach pair directly opposite each ther. But as electrodes CD vere located where the esistance gradient was slight see Figure 1), the electrodes had to be widely spaced, otherwise the p.d. across CD was too low to operate the galvanometer. Morse found that he spacing of AB and CD should be at least three times he width of the river.

Johnson

Johnson's practical system was essentially the same as Morse's experimental system, except that Johnson buried the electrodes in the river bank, presumably to prevent them being washed away. Branches extended from the land line along the river banks to accommodate the wide spacing of the electrodes. Johnson experienced spurious currents which were cancelled out by applying a small opposing current. Similar currents were experienced during my experiments and were, no doubt, caused by natural field lines.

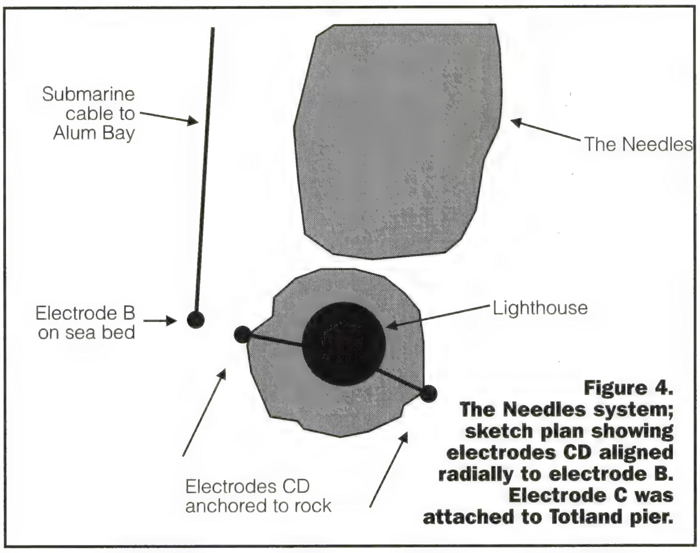


Figure 4. The Needles system; sketch plan showing electrodes CD aligned radially to electrode B. Electrode C was attached to Totland pier.

Willoughby-Smith

The pioneers were aware that field lines converged on an electrode from 360° (see Figure 1). This can easily be reproduced in the domestic bath. However, Willoughby-Smith seems to have been first to find a practical application for the phenomenon.

Willoughby-Smith's original objective was to develop a wireless telegraph system for wooden lightships which swung 360° around their anchors, but these were rapidly being replaced by steel ships. The steel would obviously 'short' electrodes attached to the hull, so Willoughby-Smith directed his attention to lighthouses on small rocky islands, particularly the Needles and Fastnet.

Sunk Light Vessel Courtesy of Trinity House.

The Needles and Fastnet installations, as already mentioned, were based on field line density being high where they converged from 360° on electrode B (refer to Figure 1). The resistance gradient in the vicinity of electrode B was steep enough to produce a p.d. capable of operating the signalling equipment when spacing of electrodes CD was limited to the short distance across the islands. During early trials, a lightship was simulated by a rowing boat on a lake but in later trials, simulated the Needles lighthouse. The trials provided Willoughby-Smith with sufficient data to persuade the Telegraph Construction & Maintenance Company to invest a large amount of money in the Needles system.

Installations

With the Needles installation, electrode B was placed on the sea bed near Lighthouse Rock and connected to the shore station by a submarine cable which came ashore in Alum Bay. However, we have seen that the spacing of CD must be only a fraction of AB, so to attain the required spacing of AB, electrode A was attached below low water level to Totland pier. Electrodes CD were aligned radially to electrode B and securely anchored to opposite sides of Rock, as Figure 4 shows.

The Fastnet installation was basically the same as the Needles system, but electrodes CD were copper rods inserted into sloping holes drilled through the rock, extending into the sea below low tide level, where they were relatively safe from wave damage. The

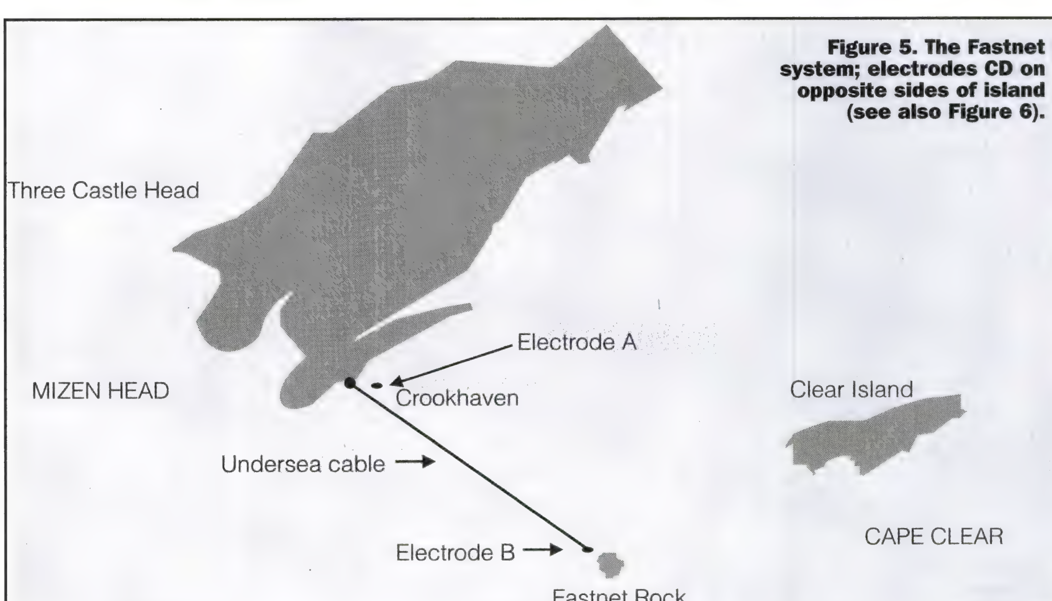


Figure 5. The Fastnet system; electrodes CD on opposite sides of island (see also Figure 6).

wires leading to the lighthouse were buried in deep groves filled with concrete – see Figures 5 & 6. The Fastnet system was very difficult and expensive to install, and was therefore delayed until the Needles system had proved reliable.

Signalling

Signalling equipment was essentially the same on both lighthouse and on shore. However, to avoid having an operator constantly on duty, a relay device, which activated a buzzer, alerted lighthouse staff to an incoming signal – refer to Figure 7. Spurious current, which Willoughby-Smith called 'sea-currents', were experienced with both the Needles and Fastnet installations, so galvanometers were employed which could be easily be compensated for these curre[nts]

Whilst it is not difficult to visualise 2-way signalling with Johnson's system where spaci[ng] of electrodes AB and CD was the same, it is more difficult with Willoughby-Smith's syste[m] where the spacing of CD is much less than AB; nonethele[ss] as we will see, my experiment[s] demonstrated that signalling was possible in either directio[n].

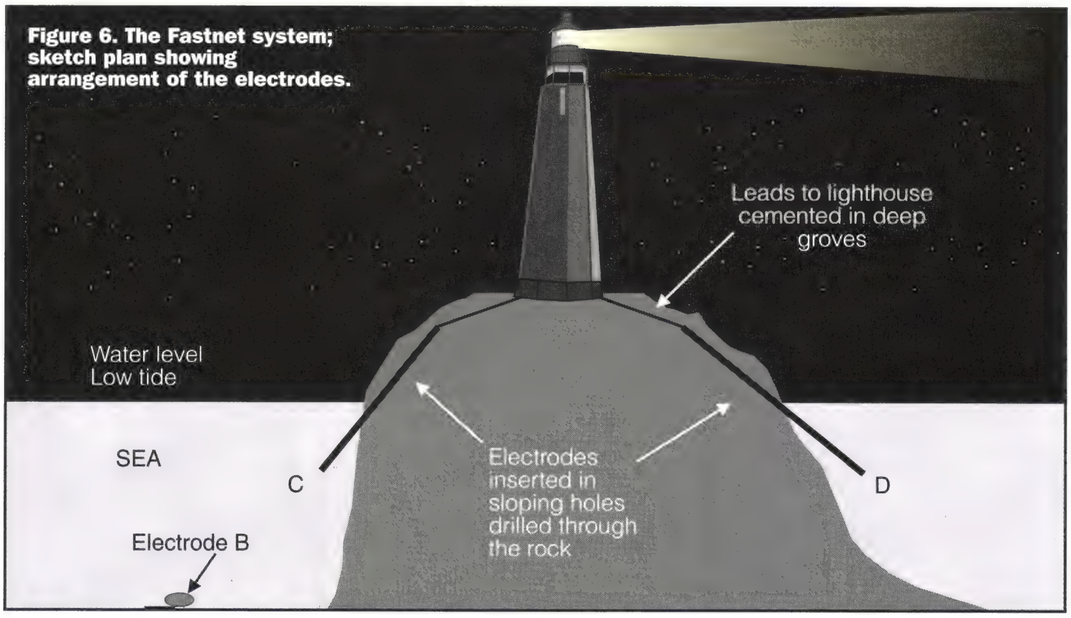


Figure 6. The Fastnet system; sketch plan showing arrangement of the electrodes.

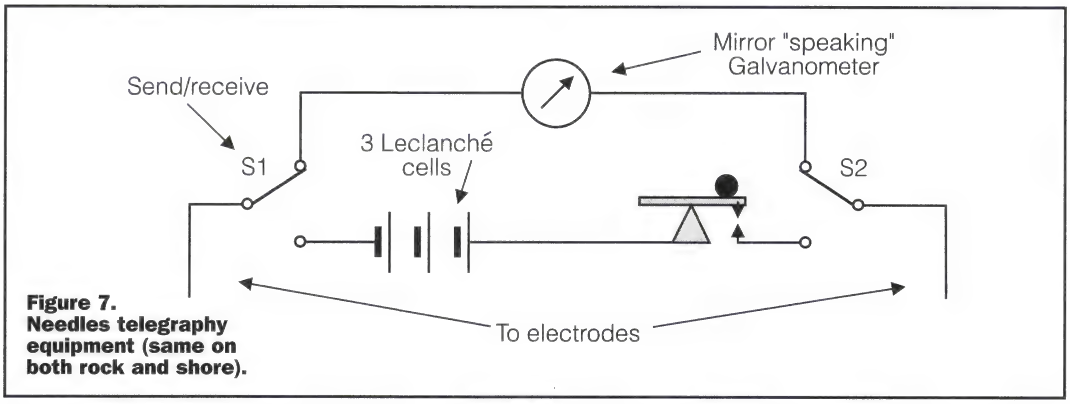


Figure 7. Needles telegraphy equipment (same on both rock and shore).

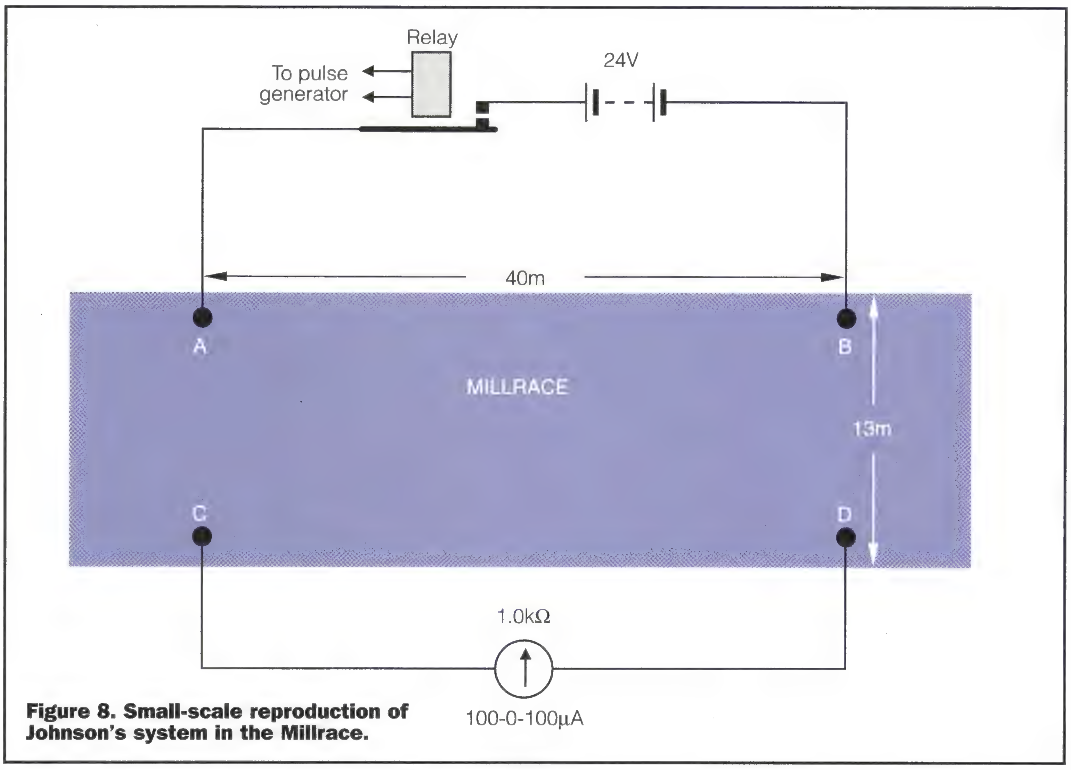


Figure 8. Small-scale reproduction of Johnson's system in the Millrace.

Reproduction of Willoughby Smiths Lake Experiment

I was fortunate in having the use of a GRP (fibreglass) dingh[y] and access to a large but fairly shallow lake on which to reproduce Willoughby Smith's lake experiment. Electrode A was placed in the water close [to] the bank whilst an insulated cable (automotive wire) extended to electrode B. The plastic bottle served as a mark[er] and kept electrode B in the vertical position. A 6V lantern battery supplied the energizing current to AB but a Morse key was inserted in the circuit.

Electrodes CD were suspended from the bow and stern of the dinghy and electrode C was maintained at constant 1·5m from electrode B as the dinghy was swung 360° around this electrode.

Surprise!

During set up, the meter registered virtually zero, but th[e] moment my assistant pressed the key, the meter indicated a transient current of about 200µA, gradually declining to a steady 40µA, which was maintained for as long as the key was held down. I refer to this as the steady current.

More remarkably, when the key was released, there was a reverse transient current of about -200µA then the current slowly fell to almost zero. The above effect remained virtually the same as the dinghy was swung 360° around electrode B.

The steady current demonstrated the '360° effect' and indeed, was expected, but the forward and reverse pulses were quite unexpected and for the sake of a better name, I have called this the 'lake effect'. It opened up a new field of study.

Pulse Generator

During a second series of experiments on the lake, electrodes AB were energized with 6V on/off pulses produced by a relay type switch driven by a pulse generator; this enabled the

/off frequency to be varied
ween 0·1 and 3·0Hz. On the ghy, the meter connected oss electrodes CD was nplemented with an analogue-digital conventor (ADC) and a top computer. The effect was played by the computer – er to GRAPH 1, which with the notations, is self-explanatory. fortunately, it was not possible employ the ADC/computer to onitor pulses transmitted from e dinghy.

The wide spacing of ctrodes AB caused this cuit to behave as a large loop tenna. Consequently, induced , mainly 50Hz, but also VLF, asked the DC pulses. On the her hand, with analogue eter, the inertia of its needle nited its AC response to a aximum of a few Hz. Indeed, th pulse rates up to about 0Hz, the analogue meter gave good visual indication of peak rward and reverse potentials d their duration. The alogue meter was, therefore, lopted to observe the effect hen pulses were transmitted om the dinghy – see Figure 9.

nomaly

uring this second experiment, e magnitude of forward and everse pulses was significantly ss than with the previous xperiment, but the 'lake effect' ill occurred. However, steady urrent increased to almost 0µA. At that time, I attributed he anomaly to the wider pacing of CD, but later xperiments suggest it was aused by electrode A laying on ke edge mud.

mall Scale Reproduction of ohnson's System

was not easy to find a stretch f water free from anglers and oats that was suitable for a mall scale reproduction of ohnson's system, and I am ndebted to the proprietor of he Mill Marina, Thrapston, Northants, for allowing me to onduct experiments on the nillrace. Moreover, there was a onvenient bridge which greatly acilitated the experiments.

Because of the wide spacing f each pair of electrodes, nduced AC precluded the use f the ADC/computer. So, neasurements were made with centre-zero microammeter vith a resistance of pproximately 1kΩ. Readings ould, therefore, be taken as either mV or µA. I used a centre-ero meter to avoid damage if olarity was wrong, but also to note the effect of changing

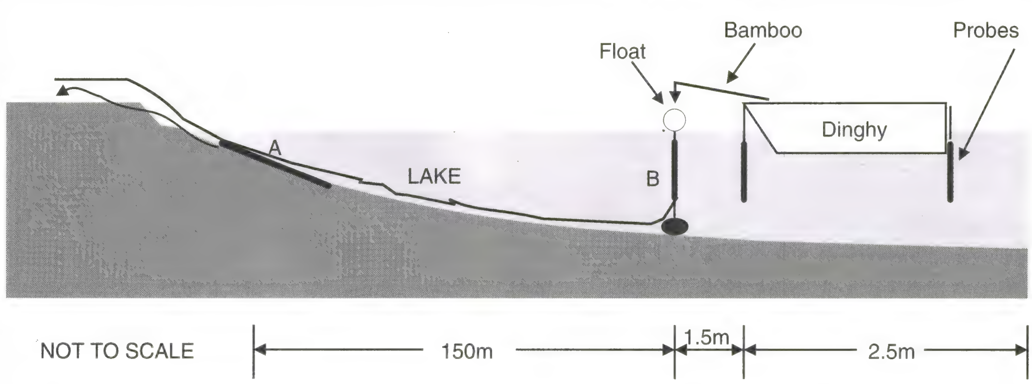


Figure 9. Reproduction of Willoughby-Smith's Lake experiment; electrode B held vertically by float.

polarity of AB in relation to the natural field line. All four electrodes were aluminium tubes 20mm diameter and 750mm long, all the electrodes laying on river bed mud.

Spacing of AB and CD (40m) was approximately equal to three times the river width. Four 6V lantern batteries provided the 24V energizing current for AB; this was periodically interrupted by the same relay/pulse generator as used with the previous experiments. Prior to the experiment, with AB not energized, a spurious current indicated +15µA, but the moment the relay contacts closed, the meter across CD indicated a peak current of +80µA before falling back a steady +50µA.

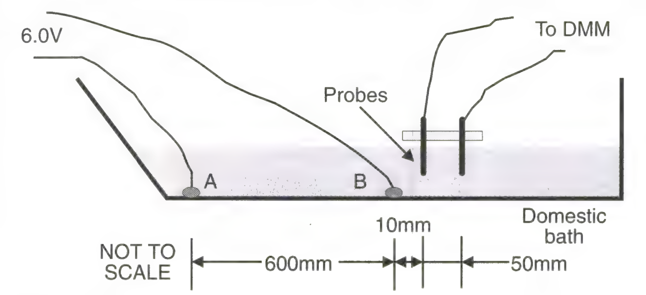
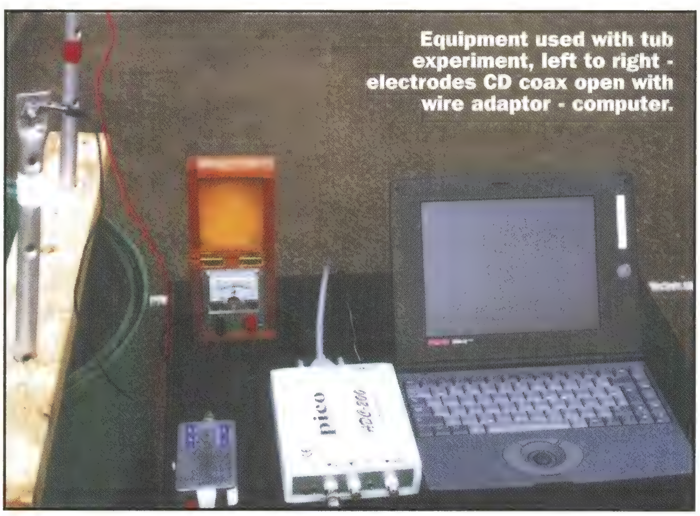
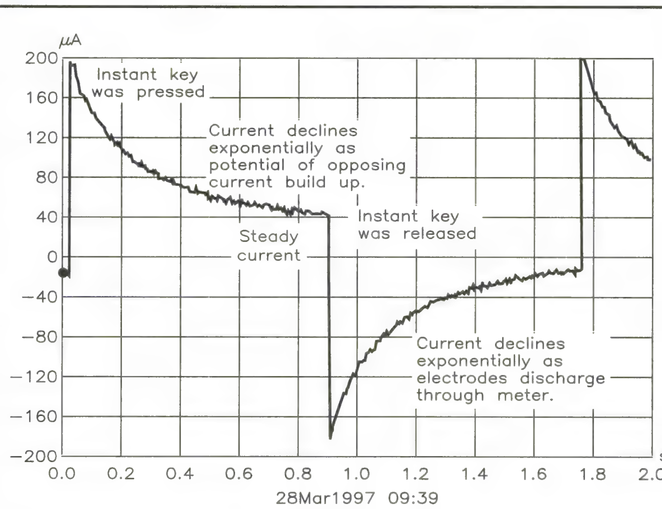


Figure 10. Simple demonstration of the 360° phenomena.



Equipment used with tub experiment, left to right - electrodes CD coax open with wire adaptor - computer.



Graph 1. The 'lake effect'.

When the contacts opened, peak reverse current as indicated by the meter was -85µA, but as needle was offset +15µA by the spurious current, the reverse pulse was a virtual mirror image of the forward pulse. Similar results were obtained when the aluminium tube electrodes were replaced by copper tubes. During a further experiment, electrodes CD were suspended in the water from long bamboo canes; the effect now was that peak forward current dramatically increased to almost +200µA and once again, the reverse pulse was a virtual mirror image of the forward pulse. But, the steady current fell to about 35µA. Indeed, the effect was similar to when electrodes CD were suspended from the dinghy and clearly indicated that the 'lake effect' was not attenuated by the wider electrode spacing.

Polarisation

The logical explanation for the 'lake effect' was that electrodes CD emulated a capacitor or cell and this was caused by polarisation, but in some way, this was suppressed by contact with mud. This phenomena is discussed in Part 2. For home experimenters, Figure 10 demonstrates how to achieve the 360° effect in your bathtub!