Phase-Velocity of Electro-Magnetic Waves along the Ground

IN a recent publication, Colwell and his co-workers have recorded the results of experiments to determine the group velocity of electro-magnetic waves along the ground[1]. These experiments indicated that the speed with which a short pulse of radiation passed along the ground between two points situated some kilometres apart was considerably less than the velocity of light in free space. Their measurements were made on frequencies in the neighbourhood of 2,000 kilocycles per second.

In view of these results, it appeared to us that it would be of considerable interest to measure the phase-velocity of waves travelling along the ground. Apparatus was available at the Radio Research Station, Slough, with which such measurements could be made on a certain band of frequencies.

The apparatus consists essentially of a pair of similar aerials placed a known distance apart in the path of the wave and some means of comparing the phases of the signals induced in the two aerials. In the apparatus used, the output from each aerial was applied, after suitable amplification, to a pair of deflecting plates on a cathode ray tube. The fluorescent spot is thus subject to two deflections at right angles, these deflections being proportional to the signals in the two aerials respectively. The amplifiers and aerial circuits are first adjusted so that when equal and cophasal fields exist at the two aerials, the figure traced out on the oscillograph is a line at 45° to the axes of deflection of the spot. This preliminary adjustment is carried out by radiating a signal on the frequency to be used in the measurements, from an oscillator located midway between the aerials, it being assumed that in these circumstances equal and cophasal fields exist at the aerials. When a C.W. signal is received from a distant point on the line joining the aerials the figure traced out on the oscillograph tube is in general an ellipse, from which it is possible to determine the phase difference between the fields at the two aerials, and hence deduce the phase velocity of the wave passing between the two aerials.

If d = distance between aerials (cm.); f = frequency of wave (cycles per sec.); ψ = phase difference between signals in the two aerials (degrees); c = phase velocity of wave (cm. per sec.), it is easily seen that

$$\psi = \frac{360\,d}{c/f} \quad \text{or} \quad c = \frac{360\,df}{\psi} \text{ cm. per sec.}$$

The aerial system used consisted of a pair of vertical aerials spaced 34·9 metres apart. Measurements were made on signals from a portable transmitter located about a mile from the receiving system, on the line of the aerials. The results are given in Table 1.

TABLE 1.

Frequency		Phase-Velocity
2·50 Mc./sec.		$3{\cdot}05 \times 10^{10}$ cm./sec.
2·90 ,,		$3{\cdot}10 \times 10^{10}$,,
3·29 ,,		$3{\cdot}00 \times 10^{10}$,,
5·95 ,,		$3{\cdot}00 \times 10^{10}$,,
7·60 ,,		$3{\cdot}10 \times 10^{10}$,,
10·92 ,,		$2{\cdot}75 \times 10^{10}$,,
11·70 ,,		$2{\cdot}80 \times 10^{10}$,,
11·70 ,,		$2{\cdot}85 \times 10^{10}$,,
15·05 ,,		$2{\cdot}90 \times 10^{10}$,,
	Average	$2{\cdot}95 \times 10^{10}$,,

Over the range of frequency between 2·5 Mc. per sec. and 15 Mc. per sec. the measured velocity is seen to lie very close to the value $3{\cdot}0 \times 10^{10}$ cm. per sec. There is no indication of a marked change in velocity with frequency, from which we may deduce that the group velocity of waves along the ground is also within a few per cent of $3{\cdot}00 \times 10^{10}$ cm. per sec., that is, the velocity of light.

The accuracy of these results depends on the accuracy with which the distance between the aerials and the frequency can be measured and on the accuracy of the process of 'lining-up' the aerials. The measurement of distance was made to an accuracy better than 0·5 per cent and the measurement of frequency was made with a sub-standard wave-meter to an accuracy better than 1 per cent. It is considered that the accuracy with which the 'lining-up' process could be carried out and the accuracy of the measurements made on the ellipse are such that the overall accuracy is about 5 per cent or slightly better.

It remains to note that the observed values show discrepancies from the value $3{\cdot}00 \times 10^{10}$ cm. per sec. of more than the estimated experimental accuracy. These cannot be due to the effect of waves reflected from the ionosphere since at these ranges such waves would be incident vertically and would not affect the aerial system. The possibility of direct pick-up on the transmission lines coupling the aerials to receiver or on the receiver is ruled out by the negative results of direct experiments to test this. The possibility still remains of re-radiation from disturbing bodies near the receiving aerials.

It should be observed that, while these results are not in agreement with those of Colwell, Hall and Hill, the measurements made by them refer to a pulse which has travelled some kilometres, and which may not have remained quite close to the ground all the way, while our measurements refer to the velocity of the wave actually as it passed between two aerials on the ground.

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[1] Colwell, R. C., Hall, N. I., and Hill, L. R., *J. Franklin Inst.*, **222**, 551–562 (1936).

Cosmic Ray Showers

IN the current theories and experiments, the question whether a cosmic ray shower is produced in a single elementary process or rather in a succession of many elementary processes is still open to discussion. For example, the discussions of Geiger and Fünfer[1], and of Bhabha and Heitler[2] are based on the latter idea, while that of Heisenberg[3] represents the former point of view. In the first case, the shower contribution from different layers of producing material would be linear to its thickness, provided the latter is sufficiently small, while in the second case, on the contrary, a quadratic relation between the shower frequency and the thickness is to be expected.

Using the arrangement *A* of Fig. 1, in which at east three particles are necessary to cause a simultaneous discharge, Morgan and Nielsen[4], later