proximity must accommodate itself to them. A part of the wave, however, really does go off into space with some loss of energy at a sharp corner by its own natural tendency to keep going, but the wire serves to guide the disturbance round the corner as a whole, by holding on to the tubes of displacement by their ends. This guidance is obviously an important property of wires.

There is something similar in "wireless" telegraphy. Sea water, though transparent to light, has quite enough conductivity to make it behave as a conductor for Hertzian waves, and the same is true in a more imperfect manner of the earth. Hence the waves accommodate themselves to the surface of the sea, in the same way as waves do round wires. The irregularities made by the ground, no doubt, but the main waves are pulled round by the curvature of the earth, and do not jut off. There is another consideration.

There may possibly be a sufficiently conducting layer in the upper air. If so, the waves will, so to speak, catch on to it more or less. Then the guidance will be by the sea on one side and the upper layer on the other. But obstructions, on land especially, may not be conducting enough to make waves go round them fairly, though waves will go partly through them.

The effects of the resistance of the guides are very complicated in general, and only elementary cases can be considered.

Consider the transmission of plane waves in the ether bounded by parallel cylinders; first imagine the ether to be electrically conducting. Then

\[
\frac{dE}{dx} = kE + \frac{dV}{dt} \quad \text{or} \quad \frac{dV}{dt} = KV + gV, \tag{4}
\]

expresses the first circuital law, and

\[
\frac{dH}{dx} = kH + \frac{dE}{dt} \quad \text{or} \quad \frac{dE}{dt} = LH + dV, \tag{5}
\]

expresses the second. The additional quantities here are \(k\) the conductivity, and \(K\) the conductance per unit length along the wires. The effect is to waste energy at the rate \(KE\) per unit volume, or \(KV\) per unit length. It is wasted in heating a medium of resistance \(r\), according to Joule's law. Two other effects occur, viz., attenuation of the wave in transit, and distortion, or change of shape, due to reflection in transit. The attenuation cannot be prevented, but the distortion can. For let the medium be conducting magnetically, so that \(gC\) is the waste per unit volume, and \(RC\) the corresponding waste per unit length. This can be analogous to \(k\), and \(R\) to \(K\). Then instead of (5) above, we shall have

\[
\frac{dE}{dt} = gC + \frac{dV}{dt} \quad \text{or} \quad \frac{dV}{dt} = RC + dV. \tag{6}
\]

These are of the same form as (4). So, if there be no electric conductance, but only the new magnetic conductance, the wave of \(H\) will be distorted in the same way as that of \(E\) was before, the wave of \(E\) in the same way as that of \(H\) was before, and there will be attenuation similarly. But if the two conductivities coexist, though the attenuations are additive the distortions are commutative, and may therefore destroy one another. This occurs when \(R_pL = R_pS\), or \(g = k\).

The solution expressing the transmission of a plane wave is now

\[
E = Ce^{-\alpha x} \cos f(t - z/\rho), \tag{7}
\]

\[
V = Le^{-\alpha x} \cos f(t - z/\rho). \tag{8}
\]

The meaning is that signals are transmitted absolutely without distortion, every slab independently of the rest, but with attenuation in transit according to the time factor \(e^{-\alpha x}\).

This is very curious, even if it could only be imagined to be done by means of the imaginary magnetic conductivity. What is even more remarkable, however, is that it can be closely imitated by means of the real electric resistance, not of the medium outside the wires, but of the wires themselves. Abolish \(g\) altogether, but keep in \(K\), which is to maintain the steady resistance of the conducting guides per unit length, previously taken as zero. Then

\[
\frac{dE}{dt} = KV + gV \quad \text{and} \quad \frac{dV}{dt} = RV + gV, \tag{9}
\]

are still the proper equations in certain circumstances, to be mentioned later. Thus equation (8) is still the result, i.e., distortionless propagation along wires. The waste \(RC\) is now in the wires, instead of outside. It equals the other waste \(KV\). It follows that any ordinary telegraph circuit may be made approximately distortionless by adding a certain amount of leakage, or leakage conductance; for it has \(I, S\), and \(R\) already, and a little \(K\). Increase \(K\) until \(R_pS = R_pL\). Then the distortion, which may be excessive at first, will gradually disappear, and the signals will be restored to their proper shape, but at the expense of increased attenuation. If \(K\) be increased further, distortion will come on again, of the other kind; for at first it was in excess, but now it is.

For example, if \(R\) is 1 ohm per kilom., and \(L = 600\) ohms, then

\[
S = \frac{R}{L} = \frac{1}{600} \text{ ohms per kilom.}
\]

This is the insulation resistance required. Also, the attenuation in the distance \(x\) is \(e^{-L/2k}\) or \(e^{-\alpha x}\); that is, from 1 to \(e^{-1}\) in 600 kilom. to \(e^{-2}\) in 1200 kilom., and so on.

To understand the reason of the disappearance of the distortion: concentrate the resistance of the wire in detached lumps, with no resistance between them. Let each resistance be \(r\). Similarly, concentrate the leakage, each leak being \(k\). Then, between the \(r's\) and \(k's\) there is no magnetic windage, no propagation; so we have only to examine what happens to a slab wave in passing by one of the \(r's\), or one of the \(k's\), to see the likeness and dissimilarity of their effects on \(V\) and \(C\).

First let a positive wave be passing. Let \(V, V, V\) be corresponding elements in the incident, reflected, and transmitted waves. Then the conditions are

\[
V_i + V_S = V_i - 2V_C \quad \text{and} \quad C_i + C_S = C_i, \tag{10}
\]

and, since \(V_i = L_C V_i\), then

\[
V_i = \frac{V_i}{1 + 2r/2k}. \tag{11}
\]

The second of these equations shows that the electrification (and displacement) is conserved. The first shows how the transmitted to the incident wave. The incident element, on arriving at \(r\), divides into two, both of the same sign as \(V\); one \(V\) goes forwards, the other \(V\) backwards, increasing the electrification behind. Now suppose a slab wave passes by a resistance in succession in the distance \(x\), such that \(k = r\); then the attenuation produced in the distance \(x\) is the \(k\)'th power of \(V_i\) and \(V_i\), and in the limit, when \(x\) is made \(0\), it becomes \(e^{-k}e^{-r}\). This is when there is no leakage.

Next consider the effect of a single leak. The conditions are

\[
C_i + C_S = C_i + C_S, \tag{12}
\]

and the results are

\[
V_i = \frac{1}{1 + k/2r} \quad \text{and} \quad C_i = C_i + C_S. \tag{13}
\]

Here the second result shows that the induction is conserved, instead of the displacement. A part of \(C\) is thrown back and increases \(C\) behind the leak. The complete attenuation in the distance \(x\), by similar reasoning to the above, is \(e^{-k}e^{-r}\), when there is leakage without resistance in the wires.

To compare the two cases, in the first, part of \(V_i\) is reflected positively and part of \(C_i\) negatively, in increasing a resistance; and in the second, part of \(V_i\) is reflected negatively and part of \(C_i\) positively. The effects are opposite. So if the resistance is the leak coexist, there is partial cancellation of the reflection. This compensation becomes perfect when \(r\) and \(k\) are infinitesimally small and in the proper ratio. Then there is no reflection, though increased attenuation. So with \(R\) and \(K\) uniformly distributed there is no reflection; incident power is transmitted. \(R = L = R_pS\).

The attenuation in the distance \(x\) is now \(e^{-k}e^{-r}\).

If the circuit stops anywhere, what happens to the wave depends upon the electrical conditions at the terminals. If it is a short circuit, then the resultant \(V = 0\) is imposed. This causes complete positive reflection of incident \(V\), and negative of \(C\). If insulated, then the resultant \(C = 0\), and there is positive reflection of incident \(C\) and negative of \(V\). A remarkable case is that of a terminal resistance, say \(R\). Then

\[
V_i = L_x C_0 \quad \text{and} \quad V_i = -L_x C_0 \quad \text{and} \quad V_i = R_0 (C_i + C_S), \tag{14}
\]

are the conditions. So the reflected wave is given by

\[
V_2 = V_1 - R_0 \quad \text{and} \quad V_2 = V_1 + R_0 \tag{15}
\]

\(V\) is reflected positively when \(R_1 > L_x\) and negatively when \(< L_x\). If \(R_1 = L_x\), there is no reflection. The energy of the wave is absorbed by the resistance. So we attain not only perfect transmission, but also perfect reception of signals.

The above method of transmitting resistance and leakage by insulated resistances and leaks may be applied to find out what in general happens when there is either no leakage or else no resistance in a continuous circuit. Suppose, for example, there is no leakage. Given a charge anywhere, initial without current, how will it behave? If there were no resistance, it would immediately split into two; one with positive magnetic force would move to the right, the other with negative magnetic force would move to the left, both at speed \(v\). Now this is also exactly what happens in a resisting circuit at the first moment, namely, the generation of

\[
\text{TELEGRAPHY}
\]

\[
215
\]
<table>
<thead>
<tr>
<th>No.</th>
<th>Date of making the Entry</th>
<th>Title of Book</th>
<th>Name of Publisher and Place of Publication</th>
<th>Name and Place of Abode of the Register of the Copyright</th>
<th>Date of First Publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>40160</td>
<td>December 19, 1902</td>
<td>The New Volumes of the Encyclopaedia Britannica constituting, in combination with the existing volumes of the ninth edition, the tenth edition of that work and also supplying a new distinctive and independent Library of reference dealing with the most recent events and developments: The ninth of the new Volumes in the Parish of St Anne, Blackfriars, in the City of London.</td>
<td>George Edward Wright, 1, Blackfriars Park Road, Blackfriars, London.</td>
<td>Arthur Francis Wilson, Chevenings, Woldingham, Bex.</td>
<td>19th December 1902</td>
</tr>
</tbody>
</table>

I certify that the foregoing is a true and authentic extract.

Assistant Keeper of the Public Records

1st September 1902

Certificate from the British Copyright Office showing that the New Volume of the Encyclopaedia Britannica No. XXXIII containing Dr. Heaviside's suggestion concerning conducting layers was first published on December 19th, 1902.