Experimental Results on Ground Wave Propagation over Mixed-Paths

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Abstract

In this paper, we will show the experimental results performed in the Kanto area including the city of Tokyo and the Tokyo bay for the MF and HF ground wave propagation. By receiving the radio waves transmitted from the three different stations, we have measured the electric field strength as the function of the propagation distance. It is clearly observed that the recovery effect is appeared on the sea path propagation over the land-to-sea mixed-path. It is also observed that the anomalous variation with distance and the unexpected attenuation are appeared in the propagation in the high density urban area. By comparing with the theoretical results, we have confirmed that the propagation phenomena observed in the urban area are occurred due to the interference between the conventional Norton ground wave and the slow wave type surface wave.

1. INTRODUCTION

Medium Frequency (MF) and High-Frequency (HF) ground wave propagation is playing and will continue to play the role of one of the most important means for a long range communications [1] – [8]. The measurements of the ground wave propagation in the urban area have shown the unexpected high attenuation in some parts of cities and the anomalous variation pattern of the electromagnetic field with distance [1], [5] – [8]. It is shown theoretically that the electromagnetic fields are attenuated strongly and are oscillated as the function of the distance when the surface impedance of the earth is highly inductive. These anomalous phenomena are appeared due to the appearance of the slow-wave type surface wave in addition to the conventional Norton ground wave [3], [5] - [11]. Also Wait [3], [12] has shown, by comparing the mixed-path theory [13], [14] with the measurements performed by Millington, that the recovery effect is appeared on the portion of the sea path propagation when the radio wave traverses a coastline from the land to the sea. Furthermore, the measurements have shown that the field strength will be influenced by the tropospheric effects even for the HF ground wave propagation [2], [15].

In this research, we will show that the experimental results obtained from the measurement performed in the Kanto area including the city of Tokyo and the Tokyo bay agree very well with the theories for the ground wave propagation over the homogeneous earth's surface and the land-to-sea mixed-path. We will show experimentally that the recovery effect is appeared on the land-to-sea mixed-path propagation. We will also show that the unexpected attenuation and the anomalous oscillation with distance are observed on a highly inductive impedance surface in the high density urban area.

2. THEORY FOR GROUND WAVE PROPAGATION

Fig. 1 shows a coordinate system (x, v) and the mixed-path consisting of three-sections; the surface impedance of each section is designated as Z_a $(x < d_1)$, Z_b $(d_1 \leq x < d_2)$, and Z_c $(d_2 \leq x)$, respectively. When the vertical transmitting antenna T is located on the impedance surface Z_a, the vertical electric field observed at the receiving antenna R located at the distance $x = d$ on the impedance surface Z_c will be obtained from the following three-section mixed-path theory [3], [7], [8], [12] - [14]:

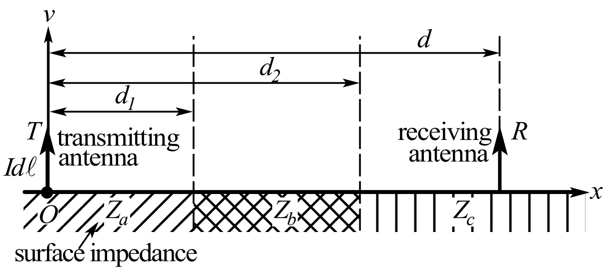

Fig. 1: Three-Section Mixed-Path Consisting of the Surface Impedances Z_a, Z_b, and Z_c and the Coordinate System (x, v). I : Antenna Current, $d\ell$: Antenna Height

$$E_v = E_{v,0} W(d, Z_a, Z_b, Z_c) \quad (1)$$

$$E_{v,0} = -i\omega\mu_0 \varepsilon_r(0) Id\ell \frac{\exp(ikd)}{2\pi d} \quad (2)$$

$$W(d, Z_a, Z_b, Z_c) = W(d, Z_a) - \left(\frac{-ikd}{2\pi}\right)^{\frac{1}{2}} \frac{Z_c - Z_a}{Z_0} \cdot \int_{d_2}^{d} \frac{W(x, Z_a) W(d-x, Z_c)}{\sqrt{x(d-x)}} dx - \left(\frac{-ikd}{2\pi}\right)^{\frac{1}{2}} \frac{Z_b - Z_a}{Z_0} \cdot \int_{d_1}^{d_2} \frac{W(x, Z_a) \widetilde{W}(x, Z_b, Z_c)}{\sqrt{x(d-x)}} dx \quad (3)$$

$$\widetilde{W}(x, Z_b, Z_c) = W(d-x, Z_c) - \left(\frac{-ik(d-x)}{2\pi}\right)^{\frac{1}{2}} \frac{Z_b - Z_c}{Z_0} \cdot \int_{x}^{d_2} \frac{W(d_2 - x', Z_b) W(x' - x + d - d_2, Z_c)}{\sqrt{(d_2 - x')(x' - x + d - d_2)}} dx' \quad (4)$$

where $E_{v,0}$ is the vertical electric field excited by the vertical dipole $Id\ell$ located on the perfectly conducting flat surface and $W(d, Z_a)$ denotes the attenuation function for the homogeneous surface impedance Z_a. The notations and the parameters in equations (1) – (4) are shown in Fig. 1. The definition of the attenuation function $W(d, Z_a)$ has been given in the references [3], [6] – [8], [12].

When the earth's surface consists of two different surface impedances, the attenuation function $W(d, Z_a, Z_c)$ for the two-section mixed-path can be obtained directly from (3) by setting $d_2 = d_1$.

3. Experimental Results

In Fig. 2, we have shown the map of the Kanto area including the Tokyo metropolitan area and the Tokyo bay and the routes I – III along which we have performed the measurements. The route I traverses the rural area (0 km < $d \le$ 32 km) along which the density of the man-made objects is low and the sea portion (32 km < $d \le$ 65 km) extending from Kyonan to the point P_1 on the sea. This route is considered to be the land-to-sea mixed-path [3]-[8], [12]-[14]. The route II, extending from Nagara transmitting station (3925 kHz) to Futtu (0 km < $d \le$ 38 km) and then from Futtu to the point P_2 (38 km < $d \le$ 80 km) on the sea, is also the land-to-sea mixed-path.

The route III consists of three areas; from the Kawaguchi transmitting station (1134 kHz) to the point 10 km (i.e., 0 < $d \le$ 10 km) the area is opened and the transmitting antenna can be seen from the measuring point, from the point 10 km to Higashi Ougishima (10 km < $d \le$ 38 km) the area is the high

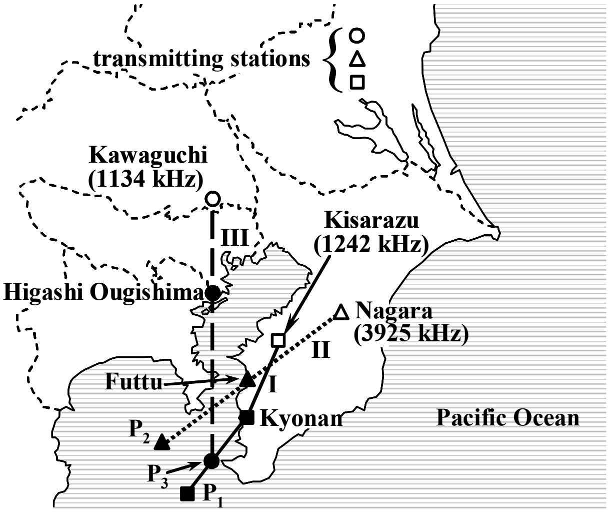

Fig. 2: Rotes I-III for the Measurements in the Kanto Area in Japan

density built up urban area, and from Higashi Ougishima to the point P_3 (38 km < $d \le$ 90 km) the area is over the sea. The surface impedance in each area can be considered as a constant. Therefore, the route III is considered to be the (high density land)-to-(medium density land)-to-sea three-section mixed-path.

In Fig. 3, we have shown the experimental results measured along the route I the land-to-sea mixed-path. The electric field magnitude decreases almost monotonically as the function of the distance d (km) on the portion of the land path. While from the point 32 km, the path becomes the sea path and the electric field magnitude increases gradually as the function of the distance form the coast line. This increase of the field magnitude with distance is known as the "recovery effect" of the electromagnetic field occurring on the portion of the sea propagation over land-to-sea mixed-

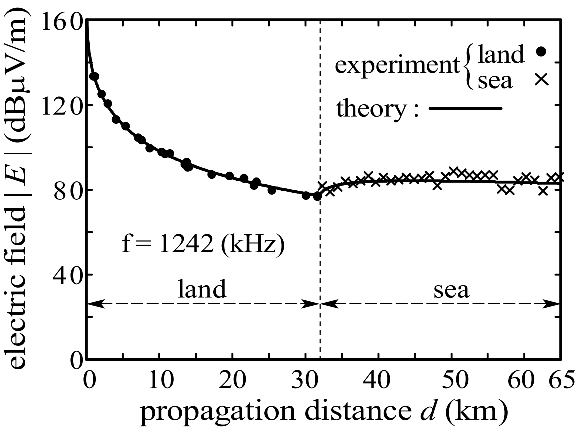

Fig. 3: Land-to-Sea Mixed Path Propagation along the Route I

path. This phenomenon was first observed in the Millington's experiment performed in the North Sea by receiving the radio wave from the BBC transmitting station (3.13 MHz) in the England [3], [12]. In the data in Fig. 3, we can also observe clearly the recovery effect. To the best knowledge of the authors, this is the second time to show the recovery effect observed through the experiments of the radio wave propagation.

In Fig. 3, It is also shown that the experimental results (● ● ●, × × ×) agree very well with the (land-to-sea) two-section mixed-path theory (d_2 = d_1, Z_a = 0.238Z_0exp(−i28°), Z_c = 0.0037Z_0exp(−i45°) in (3). Note that $Z_0 = \sqrt{\mu_0 / \varepsilon_0} = 120\pi$).

In Fig. 4, the experimental results along the route II, the land-to-sea mixed-path, are shown. The frequency of the transmitting station (3.925 MHz) is higher than those used in Millington [3], [12] and in Fig. 3. Therefore, one can observe the recovery effect more clearly than those observed in Millington and in Fig. 3. The experimental results agree also very well with the theory (d_2 = d_1, Z_a = 0.3Z_0exp(−i12°), Z_c = 0.0066Z_0exp(−i45°) in (3)) shown by the solid curve.

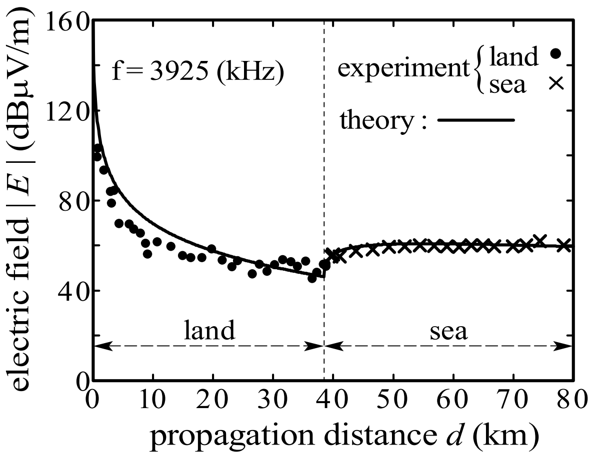

Fig. 4: Land-to-Sea Mixed Path Propagation along the Route II

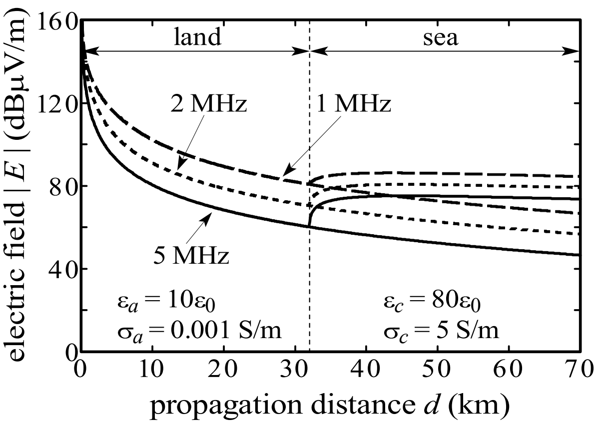

Fig. 5: Theoretical Results over the Land-to-Sea Mixed-Path for Different Frequencies 1MHz, 2MHz, and 5MHz

In Fig. 5, the theoretical results for the three different frequencies (1 MHz, 2MHz, and 5MHz) are obtained by using the two-section mixed-path theory ($Z_{a,c} = \sqrt{\mu_0 / \varepsilon^*_{a,c}}$ $\varepsilon^*_{a,c} = \varepsilon_{a,c} + i\sigma_{a,c}/\omega$, $\varepsilon_{a,c}$: dielectric constant, $\sigma_{a,c}$: conductivity) and are compared to show the strength of the recovery effects. As shown in Fig. 5, the higher the frequency of the ground wave the more strongly attenuated in the propagation over the land path. However, when the ground wave traverses the coast line from the land to the sea at 32 km, the ground wave with the higher frequency increases more rapidly than that with the lower frequency as the distance from the coast line increases. This confirms the stronger recovery effect observed in the experimental results shown in Fig. 4 than that observed in Fig. 3.

Finally, we have shown in Fig. 6 the experimental results performed along the route III in Fig. 2 consisting of the open area, the highly inductive area, and the sea. Thus the route III corresponds to the three-section mixed-path. The solid curve (——) is the theoretical result for the ground wave propagation on the homogeneous impedance surface (ε = 10ε_0, σ = 0.01 S/m) [5] – [14], or on the rural area. Comparing with the theoretical result, an anomalous attenuation and an unexpected oscillation with distance are observed in the region between 10 km and 38 km along the route III. We assume that the surface impedance of the urban area with the high density man-made objects is a highly inductive [10], [11]. It has been shown that, in case of the highly inductive impedance surface, the slow-wave type

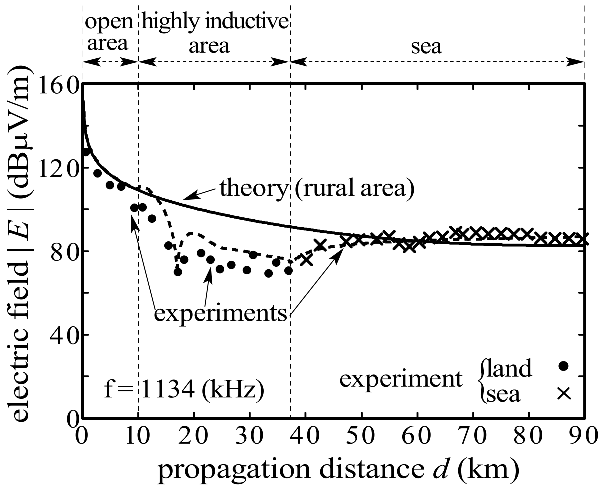

Fig. 6: Three-Section Mixed-Path Propagation along the Route III

surface wave is excited in addition to the conventional Norton ground wave [5] – [8], [10], [11]. The anomalous and unexpected phenomena observed in the experimental results in Fig. 6 can be explained physically as the result of the interference between the Norton ground wave and the slow-wave type surface wave.

The dotted curve in Fig. 6 is obtained from the three-section mixed-path theory [3], [4], [7], [8], [13], [14] assuming the highly inductive impedance surface [7], [8] in the region between 10 km and 38 km. It is observed that the experimental results agree very well with the three-section mixed-path theory in (1) - (4) ($Z_a = 0.079 Z_0 \exp(-i43^o)$, $Z_b = 0.26 Z_0 \exp(-i76^o)$, $Z_c = 0.0036 Z_0 \exp(-i45^o)$). From this result, one may consider that the surface wave is excited in the urban area where the density of the man-made objects is very high. Also shown in Fig. 6 is the recovery effect occurring on the portion of the sea path propagation over the three-section mixed-path.

4. Conclusions

We have performed the experiments in Kanto area for the MF and HF ground wave propagation by receiving the radio waves transmitted from the three different stations. We have observed clearly the recovery effect on the portion of the sea path propagation over the land-to-sea mixed-path. We have also observed the anomalous and the unexpected propagation phenomena on the highly inductive impedance surface in the high density urban area. By comparing with the theoretical result, we have confirmed that the propagation phenomena observed in the urban area are occurred due to the interference between the slow-wave type surface wave and the conventional Norton ground wave.

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