DIRECTION FINDING OF SKY WAVES AT MEDIUM FREQUENCY

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1. INTRODUCTION

The bearing of arrival direction has been so far made by various techniques in the VLF band [1][2]. However, the arrival direction of the sky waves from the ionosphere in the MF band has not been clearly measured mainly due to the difficulty of the accurate measurement of phase and amplitude.

In this paper, we firstly deal with the measurement of both incident angle and azimuthal angle of the MF radio waves transmitted from BC stations. The principle of measurement is based on the NPE method [2] for VLF waves and then the ground effect is considered for the direction finding. The MF wave is received by a set of orthogonal loop antennas and a vertical dipole antenna. The errors in the arrival direction due to the receiver system (transfer function of the antenna and receiver) are estimated. Preliminary results of MF direction finding experiments in Japan are pretested.

2. PRINCIPLE OF DIRECTION FINDING

The wave coordinate system is shown in Fig. 1. A plane wave is assumed to be incident to the receiver at O with incident angle θ measured from zenith, and azimuthal angle ϕ measured clockwise from North. The vertical electric component Ez of wave is measured by a vertical dipole antenna and the two horizontal magnetic field components Hx and Hy are measured by the orthogonal loop antennas. The amplitude ratios of the magnetic fields to the electric field and the phase differences of the two magnetic fields with respect to the electric field are measured. These four quantities are used to obtain the incident angle and azimuthal angles in a similar way as in the NPE method of VLF waves [2]. The electric field on the incident wave can be decomposed into two mutually orthogonal components: $E_{/\!/}$ is the electric field in the plane of incidence: $E_{\perp}$ is the electric field perpendicular to the incidence plane. The wave is reflected by the ground. The electric fields of the reflected wave are defined by $E_{/\!/}^R$ and $E_{\perp}^R$. Assuming that the refractive index of the ground is n, the Fresnel reflection coefficients of the ground for the wave with incident angle of θ are given as follows;

$$R_{/\!/}=\frac{E_{/\!/}^R}{E_{/\!/}}=\frac{n^2\cos\theta-\sqrt{n^2-\sin^2\theta}}{n^2\cos\theta+\sqrt{n^2-\sin^2\theta}} \quad \cdots(1)$$

$$R_{\perp}=\frac{E_{\perp}^R}{E_{\perp}}=\frac{\cos\theta-\sqrt{n^2-\sin^2\theta}}{\cos\theta+\sqrt{n^2-\sin^2\theta}} \quad \cdots(2)$$

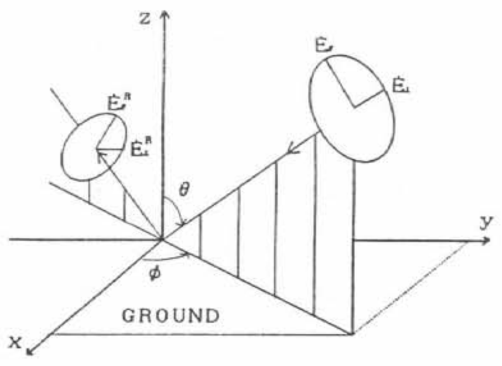

Fig.1 Wave coordinate system

Therefore $R_{/\!/}$ and $R_\perp$ are functions of only θ if n can be measured.

The observable three fields on the ground Ez, Hx and Hy are presented by superposition of those of the incident and reflected waves. If the characteristic impedance of free space is Z, the following relations are obtained;

$$E_z = E_{/\!/}(1 + R_{/\!/})\sin\theta \quad \cdots(3)$$

$$ZH_x = E_\perp(1 - R_\perp)\cos\theta\cos\phi - E_{/\!/}(1 + R_{/\!/})\sin\phi \quad \cdots(4)$$

$$ZH_y = E_\perp(1 - R_\perp)\cos\theta\sin\phi + E_{/\!/}(1 + R_{/\!/})\cos\phi \quad \cdots(5)$$

From Equations (1) through (5) we obtain the quantities θ and Φ as follows;

$$\theta = \sin^{-1}\left(\frac{|E_z|\sqrt{|ZHx|^2\sin^2\alpha_2 + |ZHy|^2\sin^2\alpha_3}}{|ZH_x|\cdot|ZH_y|\cdot\sin(\alpha_2 - \alpha_3)}\right) \quad \cdots(6)$$

$$\phi = \tan^{-1}\left(\frac{|ZHy|\sin\alpha_3}{\sin(\alpha_2 - \alpha_3)}, \frac{|ZHx|\sin\alpha_2}{\sin(\alpha_2 - \alpha_3)}\right) \quad \cdots(7)$$

where α_2, α_3 indicate the phase differences of ZHx and ZHy with respect to Ez, respectively. The quantities a, x, and y are interrelated as $a=\tan^{-1}(x,y)$, $r=\sqrt{x^2+y^2}$, $x=r\cdot\cos(a)$, $y=r\,\sin(a)$.

Equations (3), (4) and (5) are reformed by using the relations (6) and (7) as follows;

$$E_{/\!/} = |Ez| \,/\, \{|1+R_{/\!/}|\sin\theta\} \quad \cdots(8)$$

$$E_\perp = |ZH_x\cos\phi + ZH_y\sin\phi| \,/\, \{|1-R_\perp|\cos\theta\} \quad \cdots(9)$$

$$\arg(E_\perp/E_{/\!/}) = \arg(1+R_{/\!/}) - \arg(1-R_\perp) + \arg(ZH_x\cos\phi + ZH_y\sin\phi) \quad \cdots(10)$$

Thus, the incident and azimuthal angles and polarization are solved by using Eqs.(6),(7),(8),(9) and (10).

3. METHOD FOR DETECTING AMPLITUDE AND PHASE OF MF SIGNALS

We have measured the phase difference and amplitude ratio of the electric and magnetic components of the MF broadcasting carrier signal as follows. A reference signal whose frequency is 5.5 Hz higher or lower than the MF carrier signal is fed to the each receiver relevant to an electric and two magnetic sensors. The carrier and reference signals are mixed and amplified by the superheterodyne receivers. Then the down-converted signals are analyzed to deduce the phase differences and amplitude ratio. This heterodyne techniques has been found to be very effective in the accurate phase measurement of MF signals.

4. DIRECTION FINDER

Fig.2 shows a block diagram of the direction finder. The dipole antenna consists of a pair of brass pipes of size 1 m long and 0.01 m diameter, and is connected to a transformer in a pre-amplifier. The reference signal is transformer-coupled to the carrier signal. One of the orthogonal loop antennas is a rectangular-shaped loop with the size of 0.4×0.4 m, being wound 3 times. The reference signal is added to one-turn

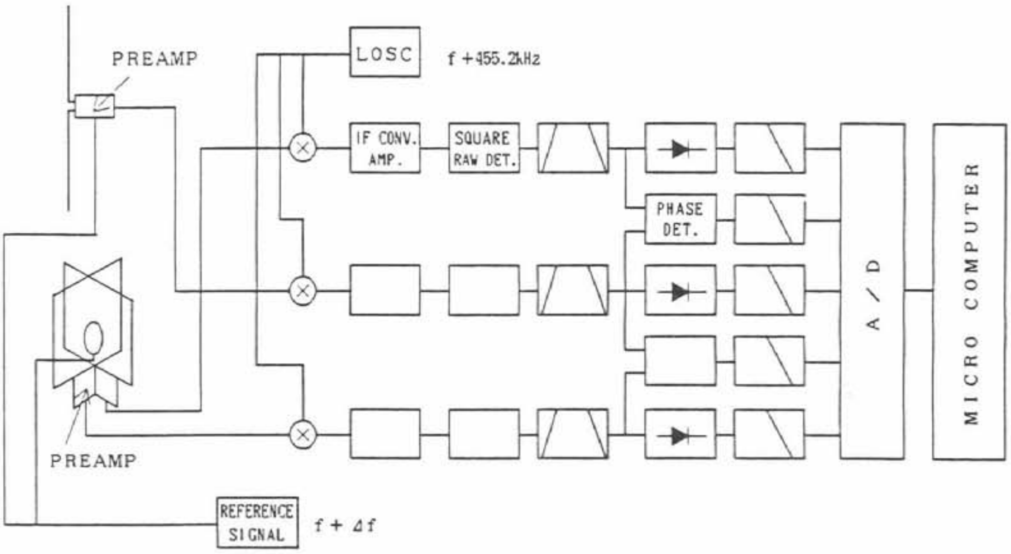

Fig.2 Block diagram of the direction finder

of 0.12 m diameter, placed at the nearly center of the orthogonal loop antennas. The dipole antenna is set with about 1.5 m space from the loop antennas in order to prevent electromagnetic interferences. Each signal of these three sensors is amplified and squared. Then a beat signal of 5.5 Hz is lowpass-filtered and detected. In filtering, the group delay time is nearly constant for 4.5 and 6.5 Hz. Therefore, a wave form with fading frequency less than about 1 Hz is not distorted. The five analogue outputs of these detectors connected with three receivers are digitized into 12-bit string digital data. Finally, the arrival angles and polarization are derived from these data in real time by a microcomputer.

The gain of the loop antenna system is measured by feeding a magnetic flux with known intensity by using a standard loop. The overall gain of the dipole antenna system is measured by using a equivalent vertical antenna circuit. In addition to above-calibration, the overall gains of three receiving systems have been checked by reception of MF broadcasting signals in the neighborhood. The phase characteristics of the antenna and receiver are also calibrated by changing the phase difference of the reference signal. By such a calibration, the measured error of the electric and magnetic field strengths and the phase differences are found to be less than 1 % and 1 $^{\circ}$, respectively. Based on these calibrations, the errors in the incident and azimuthal angles can be estimated. If the incident plane wave is circularly polarized and $\phi=45^{\circ}$, the errors $|\Delta\theta|$ and $|\Delta\phi|$ of θ and ϕ, respectively, are obtained from Eq.(6)(7). These results are shown in Fig.3. It is said from Fig.3 that we can distinguish whether the the incident wave is reflected by the E layer or F layer, if the incident angle is measured with error of less than 5 degrees in the case of incident angle smaller than 73 degrees.

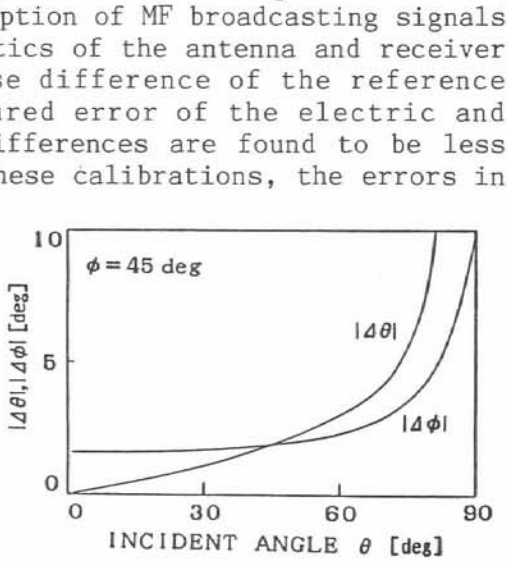

Fig.3 Errors $|\Delta\theta|$ and $|\Delta\phi|$ of θ and ϕ

5. EXPERIMENTAL RESULTS

The receiving site is a flat ground in the Faculty of Technology, Kanazawa University, in Kanazawa, Japan. The receiving antennas are equipped at a height 2 m above the ground. Figure 4(a)(b) show a record of the arrival angles and polarizations of the transmitted wave from Radio Kansai (558 kHz) during the period 19:52-20:22 of November 22, 1988. In Fig.4(a), the concentric circles are isometric lines for θ and the vertical angle is the center. The radial lines show the isogonic lines and N indicates a geographical north. The position of the transmitter is shown by a circle in Fig.4(a). If E and F layers are at the altitude of nearly 100 and 280 km respectively and the wave is reflected like a mirror, the incident angles of the reflected sky waves are mapped on E and respectively F in Fig.4 (a). The number of the measured arrival angle are 200 and are shown by small circles in Fig.4(a). Hence, it is clear that the wave was reflected by the E region. Fig.4(b) shows the field strength and polarization of the incident wave sampled every 2 minutes. The abscissa indicate $E_{\perp}$ while the ordinate indicate $E_{/\!/}$ in linear scale. The arrows show the sense of rotation to an observer looking in the direction of the wave normal.

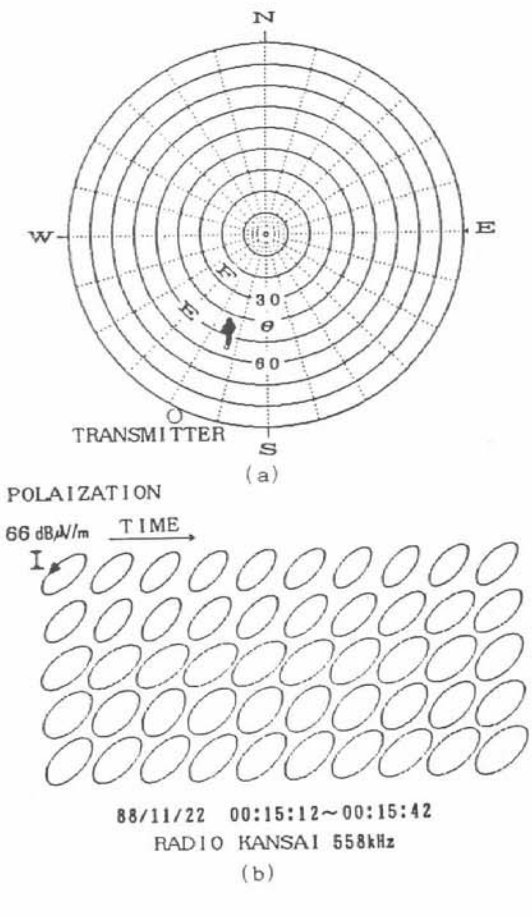

Fig.4 An example of the observed data

6. CONCLUSION

For specifying a reflecting region of MF sky waves, a direction finder at a single ground station has been developed. The principle of the direction finder is similar to that of the NPE method for VLF waves. Arrival angles are automatically measured in real time by a microcomputer. The measured errors in the field strengths and the phase differences are less than 1% and 1°, respectively. With these errors we can recognize whether the wave is reflected from the E region or the F layer.

REFERENCES

1 Leavitt,M.K.: A frequency-tracking direction finder for whistlers and other very low frequency signals" Tech.Rep.3456-2,Radiosci.Lab., Stanford Univ.,Stanford,Calif.(1975)

2 Tsuruda,K. and Hayashi,K.:"Direction finding technique for elliptically polarized VLF electromagnetic waves and its application to the low-latitude whistler" J.Atmos.Terr.Phys.,37,1193(1975)