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TECHNICAL NOTE

VHF DIRECTION FINDER FOR LOCATING LIGHTNINGS AT CLOSE RANGES

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Abstract

A new VHF (74MHz) direction finding ('DF') system using Rocke-type Adcock antenna has been developed to locate nearby lightnings with a bearing error less than 2°. It is found from the DF results that the locations of lightnings are distributed within the region of a causative thundercloud, at ranges less than 120km.

1. Introduction

Many techniques to locate lightning discharges at various distance ranges have been developed at frequencies of VLF to UHF to protect against lightning-caused disasters. VLF triangulation DF network has been operated to locate lightning discharges at distant ranges of more than 1000km (Iwai et al.,1979). To locate nearby lightnings (<500km), the VLF direction finder is not available because of larger polarization errors, and its bearing errors amount to more than 20° for locating lighitnings at range of 200km (Nishino et al.,1973).

While, VHF and UHF have been used to locate lightnings at close ranges. Two principally differrent systems have been proposed; one is based on the measurements of arrival time differences at multiple observing points (Oetzel and Pierce,1969; Cianos et al.,1972), and the other is based on the determination of bearing angles by means of a pair of directive antennas. The former requires a wideband reception to realize highly accurate measurements of arrival time, and hence it is not suitable in Japan because of severe interferences from many communication radio signals. Nishizawa et al.(1980) have designed a DF system for locating lightnings at close ranges using a normal Adcock antenna at 74MHz, and they have carried out one-stationed DFs at ranges of <160km with a bearing error of <3°. It is impossible to realize both an increase in gain and a reduction in bearing error using a normal H-type Adcock antenna. We have developed a two-stationed VHF DF system using Rocke-type Adcock antennas, so that we can fix lightning discharges at ranges less than 200km with a bearing error less than 2°. Our newly developed VHF DF system will satisfy the social demand to protect ultra high voltage (UHV) electric power line systems from lightning-caused interruptions.

On the other hand, another DF technique using a gated wideband magnetic direction finder ('Uman' type) was developed by Uman et al. (1976) for locating nearby lightnings to detect lightning-caused forest fires or to protect against interruptions of electric power distribution systems in the US. In order to examine the availability of the Uman type direction finder in Japan and to compare the measuring accuracy and sensitivity with those of our newly developed direction finder, the Uman type direction finder was also equipped at Gamagohri observing point.

2. DF system for nearby lightnings

2-1 Outline of the equipment

Fig.1 shows the VHF DF equipments at Gifu observing point (geographic coordinates, 35°23'N, 136°43'E), and the antenna was installed on the top of a building. Fig.2 shows the corresponding equipments at Gamagohri observing point (34°51'N, 137°13'E). The antennas were installed on the top of Mt.Tobone (about 400m above the sea level), and the receiving systems were placed inside a mobile. Two bearing angles of a spheric obtained simultaneously at both observing points enabled us to fix the causative lightning by intersecting the two direction lines. Both observing points were linked by VHF (150MHz) FM radio.

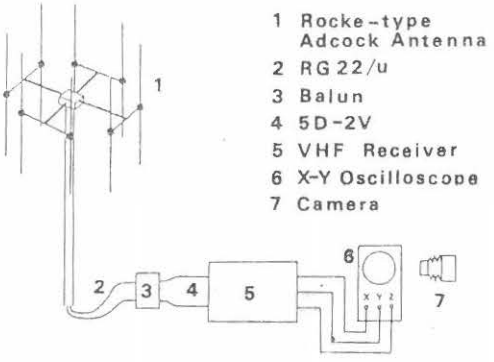

Fig.1 VHF DF equipments at Gifu observing point.

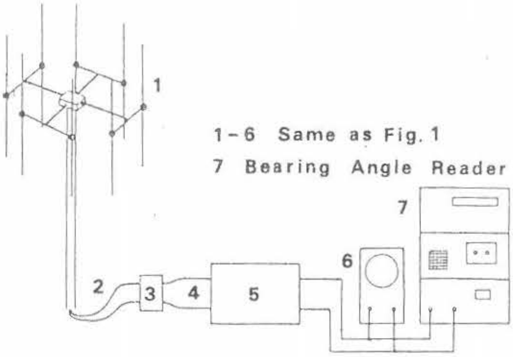

Fig.2 VHF DF equipments at Gamagohri observing point.

2-2 Rock-type Adcock antenna

Fig.3 shows the configuration of the antenna consisting of a pair of parallel vertical dipoles in each of four directions (N,S,E,W). Outputs from the parallel dipoles are fed to the center of both elements, and are led to the feeding point centered in the antenna. The angle (γ) shown in Fig.3 is chosen 29° in the optimum range of 26°~30° where the bearing error ($\Delta\phi$) due to the extension of spacing length (s) between the diagonal elements ('spacing errors') is restricted less than 0.5° (Travers,1957). The spacing errors and gains for Rocke-type Adcock antenna (γ=29°) and the normal Adcock antenna (%=0°) are shown in Figs.4 and 5, respectively. As is shown in Fig.4, the spacing error of the normal Adcock antenna increases with increasing the spacing, and so the spacing error less than 0.5° to be of practical importance forced to restrain the spacing length less than %/8, resulting in the depleted gain of the antenna. Whereas, the spacing error of the Rocke-type Adcock antenna is restricted within 0.5° even for the spacing beyond $\lambda/2$, so the higher gain can be expected. In the case of DFs using both type antennas, the gain of the Rocke antenna is about 20dB higher than that of the normal antenna for the spacing error of 0.5°.

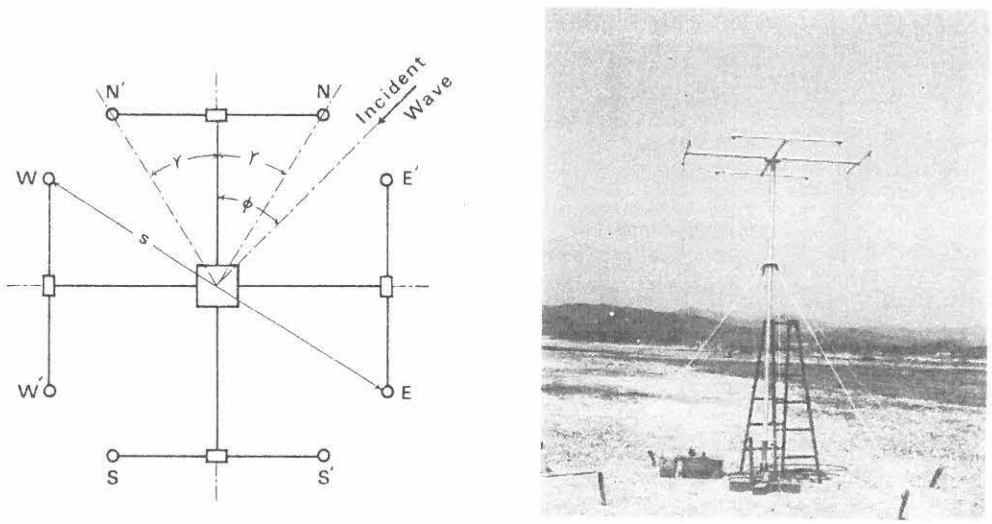

Fig.3 The configuration of the Rocke-type Adcock antenna (seen from the top) and its photo for the field test.

For our present experiments, the following dimensions were chosen; s=2000mm (0.5λ), γ=29°, the length of vertical dipole =1950mm (0.49λ). In the case of the previous DFs by Nishizawa et al.(1980), a normal type Adcock antenna was used, for which s=0.33λ, so that the spacing error was about 3° and the gain was lower by about 5dB than our present experiments, as shown in Figs.4 and 5.

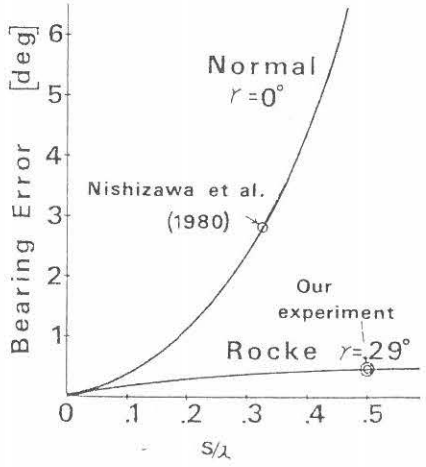

Fig.4 Bearing error vs. spacing for the Rocke (γ=29°) and normal (γ=0°) Adcock antennas.

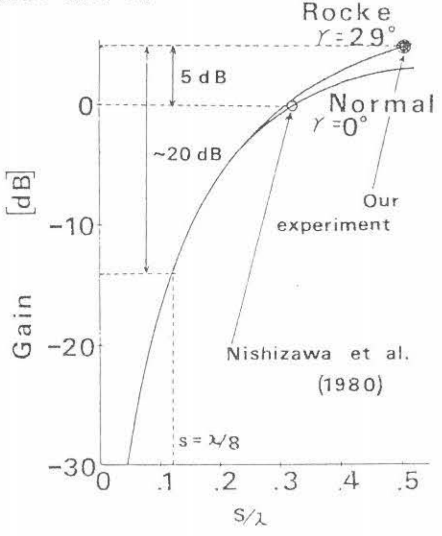

Fig.5 Relative gains of the Adcock antennas to λ/2 vertical dipole vs. spacing.

Our higher gain by about 5dB was expected to enhance the DF range up to 200km, referring to the relationship between the field strength and the propagation distance (-5dB/50km) and the coverage (<160km) of the DF system used by Nishizawa et al.(1980).

2-3 Receiver and data recorder

Fig.6 shows the block diagram of 2-channel (N-S,E-W) VHF (74MHz) receiver which has the same performance as the receiver used by Nishizawa et al. (1980). For DF data recording in Gifu, Lissajous' figures on a CRT screen displayed by the beam intensity modulation circuit were photographed. A digital bearing angle reader was used at Gamagohri, the performance of which is the same as that for VLF atmospherics (Iwai et al.,1979), and then the digital data were recorded on a cassette magnetic tape with the receiving times of atmospherics.

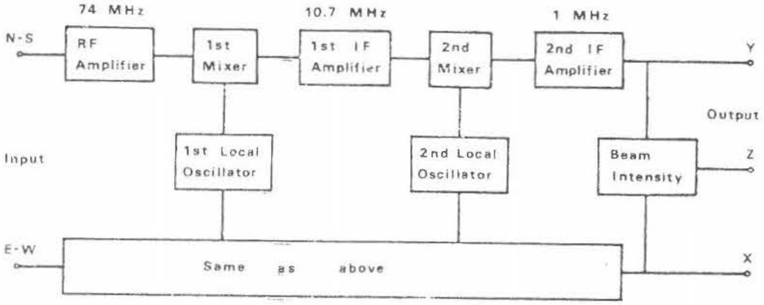

Fig.6 Block diagram of VHF receiver.

2-4 Field test of measuring accuracy

The estimation of the accuracy of the DF system was made in an open field, being remote enough from neighbouring objects. The actual gain of the Adcock antenna relative to that of $\lambda/2$ vertical dipole was 1.5dB, the rejection ratio against the horizontal field component, -35dB and the isolation of both channels, -51dB. The bearing error was measured from a difference between the azimuthal angle of the signals from a testing transmitter and its geometrical direction. Fig.7(a)

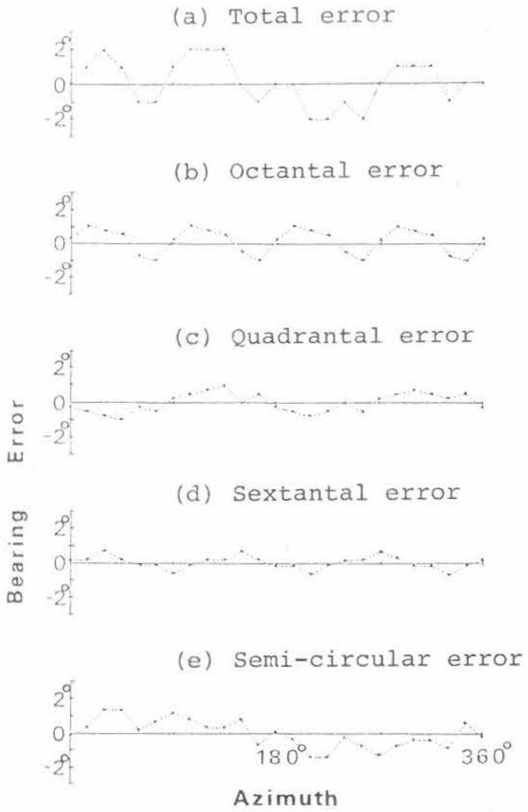

Fig.7 Total bearing error vs. azimuthal direction measured clockwise from the north (a), and harmonically analyzed components (b-e).

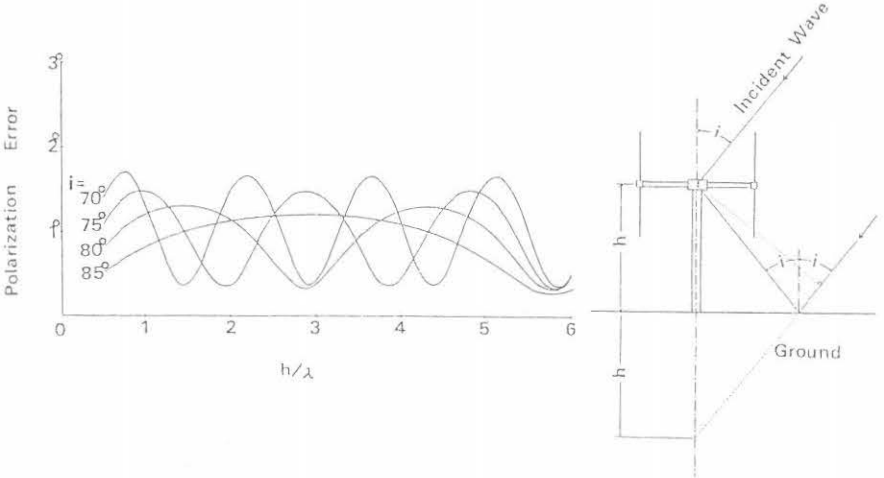

Fig.8 Variation of the estimated polarization error with height of the antenna (h) given as the ratio (h/λ) (λ:wavelength). The parameter is incident angle (i).

shows the total errors of our VHF DF system, the maximum of which was less than 2°. The harmonic analysis was done for the error curve of Fig.7(a), and the analysed results are represented in Figs.7(b)~(e). There are measuring and personal errors; semi-circular error about 1° and sextantal error less than 1°. Residual instrumental errors are quadrantal and octantal of about 1°. The quadrantal error is due to the unbalance in gains between both channels, and the octantal to the coupling between both channels including the antenna system. The errors except the measuring and personal ones are small enough (<1°). The horizontal component rejection ratio of -35dB causes still a small polarization error. The polarization error is estimated to be less than 2°, as shown in Fig.8. According to Nishizawa et al. (1980), the horizontal electric field component of atmospherics propagated more than 100km becomes lower by about 5dB than the vertical one due to the propagation effect. Then, as a total, we have -40dB for the horizontal component rejection ratio and we may be able to fix atmospherics at the range of more than 100km with the polarization error less than 1°.

3. Observed results

The DF observations of nearby lightnings were carried out in mid-August, 1982 simultaneously at both observing points. As it was rather cool in this summer, less activities of thunderstorms supplied fewer DF data than expected. During the observing period, it thundered for several days, and the DF data were obtained for only 4 days. Figs.9 and 11 show the locations of lightnings as given by dots at ranges of 50~60km on August 12, and 40~70km on August 19, respectively. Figs.10 and 12 indicate the radar echo data during the corresponding periods. It is found from Figs.9-12 that the lightnings were located within the range of a causative thundercloud encircled by a thick line. Even from fewer DF data for other 2 days, lightnings were fixed within the region of causative thunderclouds at ranges of 50~120km.

On the other hand, the observed results by the Uman type DF system are indicated in Fig.13, where the occurrence distribution of bearing angles is shown in every 5° for lightnings fixed from 14:10 to 14:26 LT on August 19, 1982. From this figure and the corresponding radar data in Fig.12, there appears to be not always the corresponding thunderclouds in the regions expected from the bearing angles of

Fig.9 Lightnings fixed by the DF system on August 12, 1982.

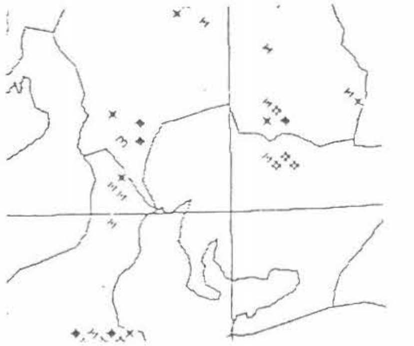

Fig.10 Radar echo data at 14:00 LT on August 12, 1982. Echo intensities: 〃 < × < ✱ < ◆

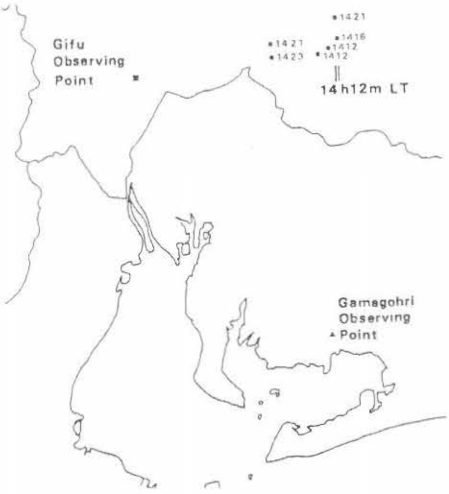

Fig.11 Lightnings fixed by the DF system on August 19, 1982.

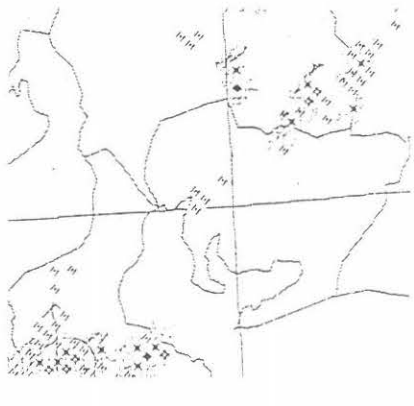

Fig.12 Radar echo data at 14:00 LT on August 19, 1982. Echo intensities: 〃 < × < ✱ < ◆

lightnings. The similar trend is found in the data for other days. These unexpected results may be due to the followings; (1) a different characteristic of lightning discharges in Japan (not straight and vertical return strokes), (2) a wrong settig of the start time and interval of the display gate (induction of polarization errors), (3) configuration of mountainous terrain. These are significant problems to be examined in the future.

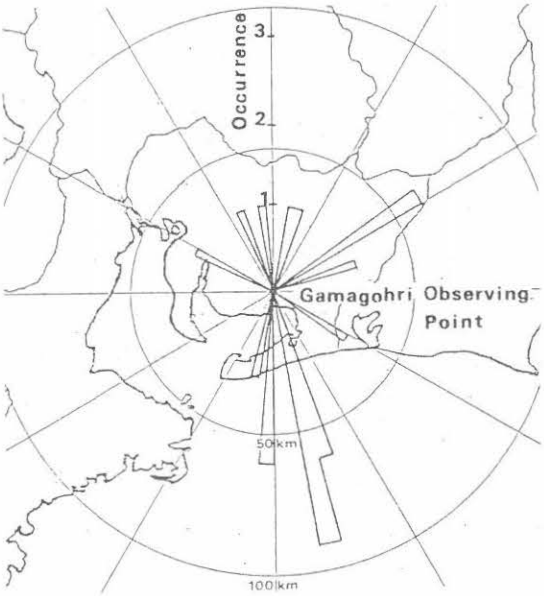

Fig.13 Occurrence distribution of bearing angles by the Uman-type DF system at Gamagohri at 14:10-14:26 LT on August 19, 1982.

4. Concluding remarks

Gifu observing point is situated beside a road and Gamagohri point is located near a parking area, so the gains of the receivers were obliged to be reduced by 10~20dB from the maximum gain because of the interference of automobile ignition noises. As the result, the coverage was reduced at less than 120km. However, our newly developed VHF DF system using the Rocke-type Adcock antenna has been confirmed to be able to locate nearby lightnings at ranges of 120km with bearing errors less than 2°. For the DF at ranges of more than 120km (<200km), it is significant to install the direction finder in an observing site satisfying the followings; (1) it is free from artificial (mainly automobile) noises, and (2) it should be installed on the top of an isolated mountain for no site error and unlimited visibility.

5. Acknowledgements

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