Proceedings of the Research Institute of Atmospherics,
Nagoya University, vol. 27(1980) –Research Report–

VHF DIRECTION FINDING FOR LIGHTNINGS AT CLOSE RANGES

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Abstract

We have obtained the basic data for the design of VHF direction finder locating lightnings at close ranges. As a first step, the field strengths of lightning discharges on 48MHz and 78MHz were measured, then we have chosen a frequency of 74MHz for the direction finding operation and measured the horizontal and vertical field strengths on 74MHz. The VHF direction finder using the Adcock antenna is found to be able to determine the bearing of lightnings at the range less than 160km with a bearing error less than 2°. The obtained directions by the VHF direction finder (200kHz bandwidth) showed a good agreement with the radar data.

1. Introduction

Many techniques to locate lightning discharges at various distance ranges have been studied using the frequencies from VLF to UHF. A fixing network by three-stationed VLF direction finders is in operation on a routine basis to locate the thunderstorms at long ranges (≥1000km) (Iwai et al.1978;Iwai et al.1979). However, there is not so much work on the direction finding (DF) for nearby thunderstorms, which is of practical importance such as the protection of power lines and human bodies and also of academic interest such as the discharge process in thunderclouds, and the establishment of an observation system on a routine basis is highly demanded.

Principally, there are two different techniques to find the arrival direction of the lightning discharges. The first is the use of a pair of directive antennas, which enable us to determine the bearing of the incident atmospherics. The second is based on the measurement of the difference in the time of arrival of an atmospheric pulse at a few stations, which provides us with the information on the cosine of the bearing angle of atmospherics. Oetzel and Pierce(1969) and Cianos et al.(1972) have proposed a VHF time-of-arrival method for locating lightnings at close ranges. Proctor(1971), Murty et al.(1973), and Taylor(1978) have adopted the same principle to locate the VHF emissions from lightnings and obtained important results on the process of discharges in thunderclouds with a high spatial and temporal resolution. But this time-of-arrival method requires a wide bandwidth of receivers (4MHz-40MHz) to realize a highly accurate measurement, and it can easily be interfered by the TV and other communication signals. This is the reason why this technique is not available in our country, where many transmitting stations coexist in a small district. So under these situations, the technique by means of a pair of directive antennas seems to be more efficient for locating lightnings at close ranges than the time-of-arrival method.

The purpose of the present paper is to make a design of the direction finder system for lightnings at close ranges ($\leq$200km) using an Adcock antenna and receivers with a narrow bandwidth. As a first step, we have measured the field strength of nearby atmospherics in order to obtain the basic data for the DF system, and then tested a direction finder using an H-type Adcock antenna. We report the results of these experiments, describe the covering area of our system, and estimate the bearing error due to the wave polarization.

2 Measurement of Field Strength of Lightning Discharge on VHF

A lightning discharge radiates strong pulses at frequencies ranging from ELF to UHF, but for DF of close lightnings, the VHF signal is suitable because of no propagation effect due to the ionosphere. On the basis of the estimation of the signal-to-noise ratio, Oetzel et al. (1969) have suggested that a frequency in the range between 40MHz and 100MHz is suitable for the DF of close lightnings. As their estimation was for lightning flashes at a range of 100km, we made a trial to extend a measurement for the atmospherics occurring over a wider distance range around 100km. Then, to decide a frequency for DF of close lightnings, we measured the signal strength of atmospherics on 48MHz and 78MHz, and obtained the relationship between the field strength and the propagation distance.

A block diagram of the measuring equipment of field strength is shown in Fig. 1. Signals at the two frequencies of 48MHz and 78MHz are received with dipole antennas with a half-wavelength and amplified by the receiving units for FM radio. These signals are fed to peak detectors and then go to a 2ch pen recorder through hold circuits with a discharge time constant of 0.5sec. The bandwidth of the receivers is 200kHz, and their dynamic range is about 50dB. Installing two dipole antennas vertically on the top of the building(15m high above the ground) of our Institute, we measured the field strength of atmospherics in July and August of 1978. Both the radar data and the local storm reports supplied by Nagoya Meteorological Observatory enabled us to know the distance from the receiving point to the active thunderclouds. When many groups of thunderclouds are very active at the same time, the nearest cloud to the observation point is regarded as the source of the relevant atmospherics. During our observation period, we encountered 21 days with thunderstorms. Based on the data from those days we obtained the relationship between the received field strengths of atmospherics and the propagation distance, and the results are shown in Fig. 2. As is seen from the figure, the field strengths at two

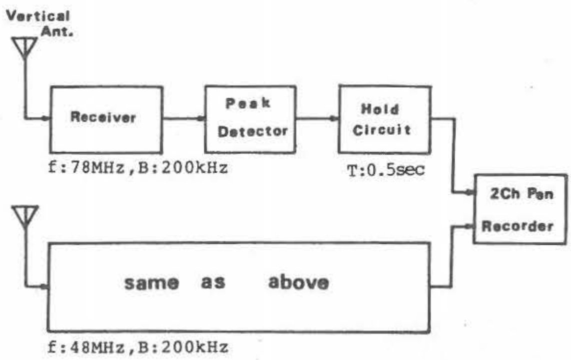


Fig. 1 Block diagram of the equipment for the field strength measurement

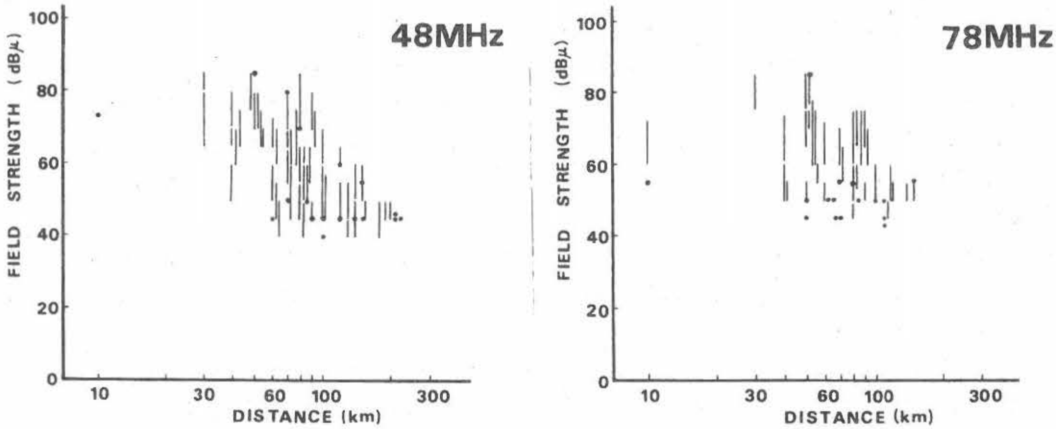
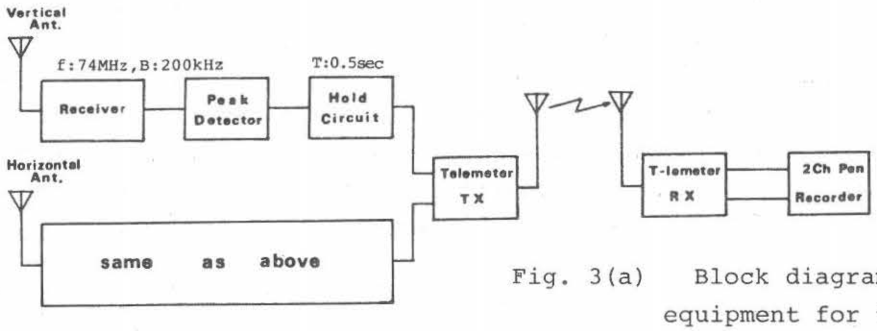


Fig. 2 Field strength (vertical component) on 48MHz and 78MHz versus propagation distance. Vertical lines indicate a variation in the strength.

frequencies of 48MHz and 78MHz decrease approximately inversely with propagation distance. The field strength is about 70dBμ±10dBμ at 50km and 60dBμ±10dBμ at 100km. A small difference between the two frequencies seems to be that the signal intensity on 78MHz decreases slightly more than that of 48MHz at a distance more than 100km.



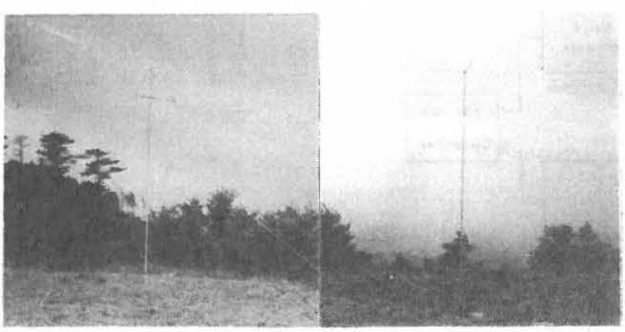


Fig. 3(a) Block diagram of the equipment for the field strength (vertical and horizontal) measurement.

(b) Picture of the vertical and horizontal antenna.

We use an H-type Adcock antenna for VHF DF. If the two elements of the Adcock antenna is unbalanced, the horizontal component of the incident signal will yield the error for the measurement of azimuthal angle. For the sake of the estimate of polarization error, we have measured the horizontal and the vertical field strengths of atmospherics. The block diagram for this measuring system is shown in Fig. 3. The receiver is the same one as shown in Fig. 1,with the receiving frequency of 74MHz. The antennas for the horizontal and vertical field strength measurement are a turnstyle and a half-wavelength dipole. They were installed 5m high above the ground as shown in Fig. 3(b). The measurement was carried out on the top of Mt. Hongu(789m above the sea level), that is 10km north of our Institute, and the obtained data of field strength were sent to the Institute at Toyokawa by a VHF telemeter link and recorded on charts of the pen recorder. The period of observation was July and August of 1979, and we encountered 28 days with high thunderstorm activities.

The results of the field strength measurement are shown in Fig. 4. We have also determined the distance to the thundercloud in the same way as aforementioned. The horizontal field strength versus distance is shown in Fig. 4(a), and the vertical field strength versus distance in Fig. 4(b). The ratio of horizontal to vertical field strength (Eh/Ev) of atmospherics received at the same time is shown in Fig. 4(c). These figures indicate that the vertical field

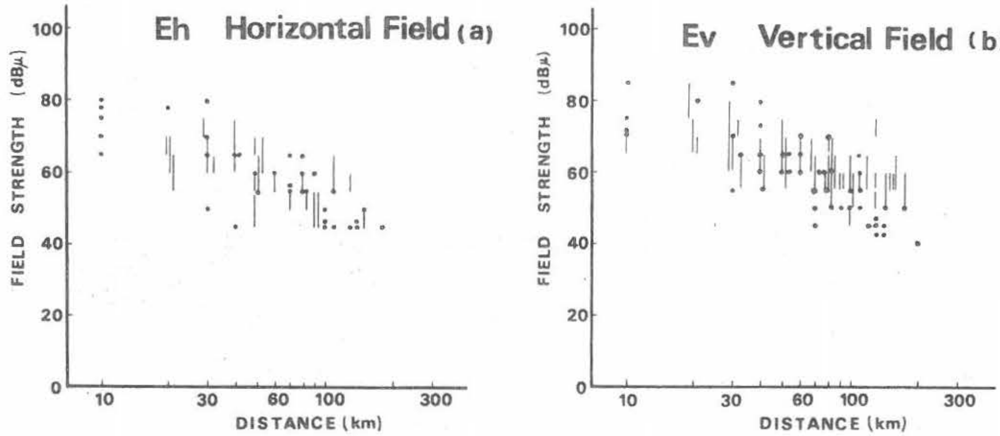


Fig. 4 Relationship between the field strength (horizontal (a) and vertical(b)) on 74MHz and the propagation distance.

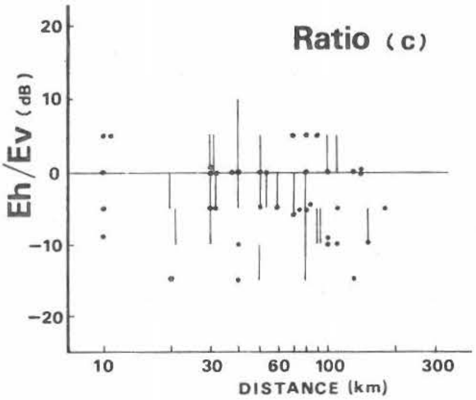


Fig. 4(c) Relationship between the ratio of horizontal to vertical field strength (Eh/Ev) and the propagation distance.

strength is, on the average, about 65dBμ at the distance of 50km, about 60dBμ at 100km, and about 55dBμ at 150km, while the horizontal field strength is 60dBμ at 50km, and about 55dBμ at 100km. The ratio of horizontal to vertical field strength is widely scattered in the range between +5dB and -10dB, but the Eh/Ev value seems to be distributed mainly below 0dB. Especially, at the distance more than 100km, the Eh/Ev value tends to take larger negative values.

3 Direction Finding by Adcock Antenna

A direction finder using an Adcock antenna was tested in the field on the top of Mt. Hongu in August of 1979. The block diagram of the VHF direction finder is shown in Fig. 5(a), and an H-type Adcock

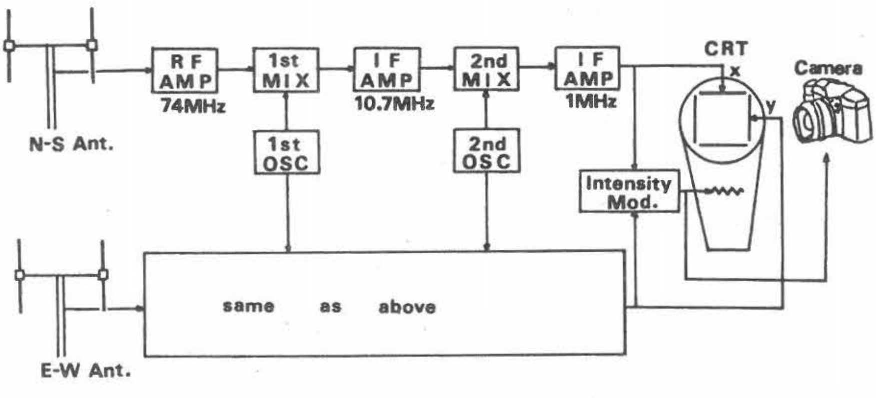
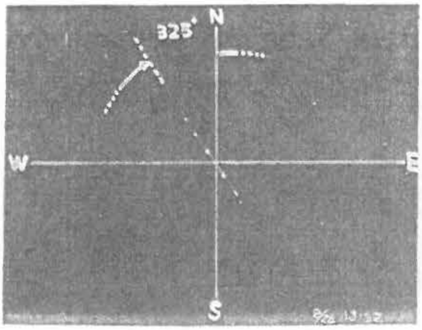


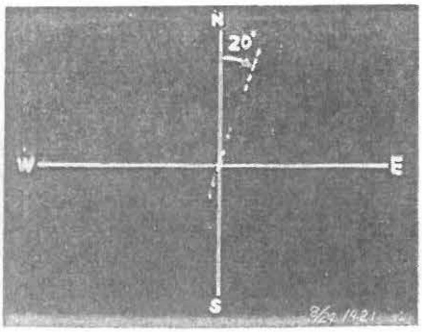
Fig. 5(a) Block diagram of the VHF direction finder.

Fig. 5(b) Picture of Adcock antenna and mobile van.

antenna used is shown in Fig. 5(b). The frequency adopted for DF is 74MHz. The reason of this selection will be discussed in detail in Section 4. The spacing of the elements is about one third of a wavelength (1.28m), and two pairs of Adcock antenna are oriented in the north-south and the east-west directions, respectively. The gain of this antenna is greater by 4.8dB than that of half wavelength dipole. The two output signals at 74MHz from the N-S and E-W antennas are separately fed to the RF amplifiers by the coaxial cables of 15m long. The RF signals are converted to the IF signals of 10.7MHz and amplified. The IF signals are fed to the 2nd mixers and converted down to 1MHz. Two output signals of 1MHz go to the X and Y axes of CRT. The gain and dynamic range of the receivers are 63dB and about 50dB, respectively, and the bandwidth of IF amplifier is 200kHz. In order to take a picture of Lissajous pattern on the CRT screen, the intensity modulation circuit is driven by the 1MHz output signal, which has also a function to close the shutter of the camera in front of the CRT screen at the end of an initial cycle of 1MHz signal. But because of its mechanical delay, a few cycles of the signal were picked up. The antenna was installed on the roof of a mobile van and these equipments were inside it. Before the observation, the VHF direction finder was adjusted and calibrated by means of the calibration oscillator about 50m away from the Adcock antenna. A few examples of photographic records are illustrated in Fig. 6. The present direction finder has no sensor for the omni-directional measurement, so that we have an ambiguity of 180° in azimuth, but this ambiguity can be eliminated in comparison the radar data.

During our experimental period, the strongest thunderstorm activity accompanied by heavy damage in Chubu area took place in the afternoon on August 24, 1979. The results of the bearing angles on that day are summarized in Figs. 7(a)-(d). We can see the bearing





13:52LT 14:21LT

August 24 1979

Fig.6 Photographic records by the VHF direction finder

distribution of atmospherics in every one hour. The bearing is plotted in every 5°. The radar data during the corresponding period are given on the upper panels, in which the shaded regions indicate the location of clouds and the dark portions correspond to the region of thunderstorms identified by the local storm reports. During 13:40-14:30 LT in Fig. 7(a) on 24 August, the distribution of bearing angles have a maximum in an azimuth around 330°, and in this direction we can find the dark thunderstorm regions on the radar data. Then during 14:30-15:30 LT in Fig. 7(b), we can find extremely good agreement between the DF results and the radar data. Corresponding to a few main peaks in the range from 330° to 0° (north), we can recognize the regions of thunderstorms. But during 15:30-16:20 LT in Fig. 7(c), no thundercloud corresponding to the peak in an azimuth around 20° is found in the radar data. This fact seems to be due to the movement of the thunderstorms, because the thunderclouds' echoes were observed by the radar to move from the north to the south-west during this observation. During 16:40-17:00 LT in Fig. 7(d), a large peak of bearing angles around 5° is obtained, and in this direction we can also find the active thunderstorm echoes within a range of 50km, and the flashes were actually seen from the observing point at the end of this observation. Hence we may conclude that the good agreement obtained is very useful for future experiment.

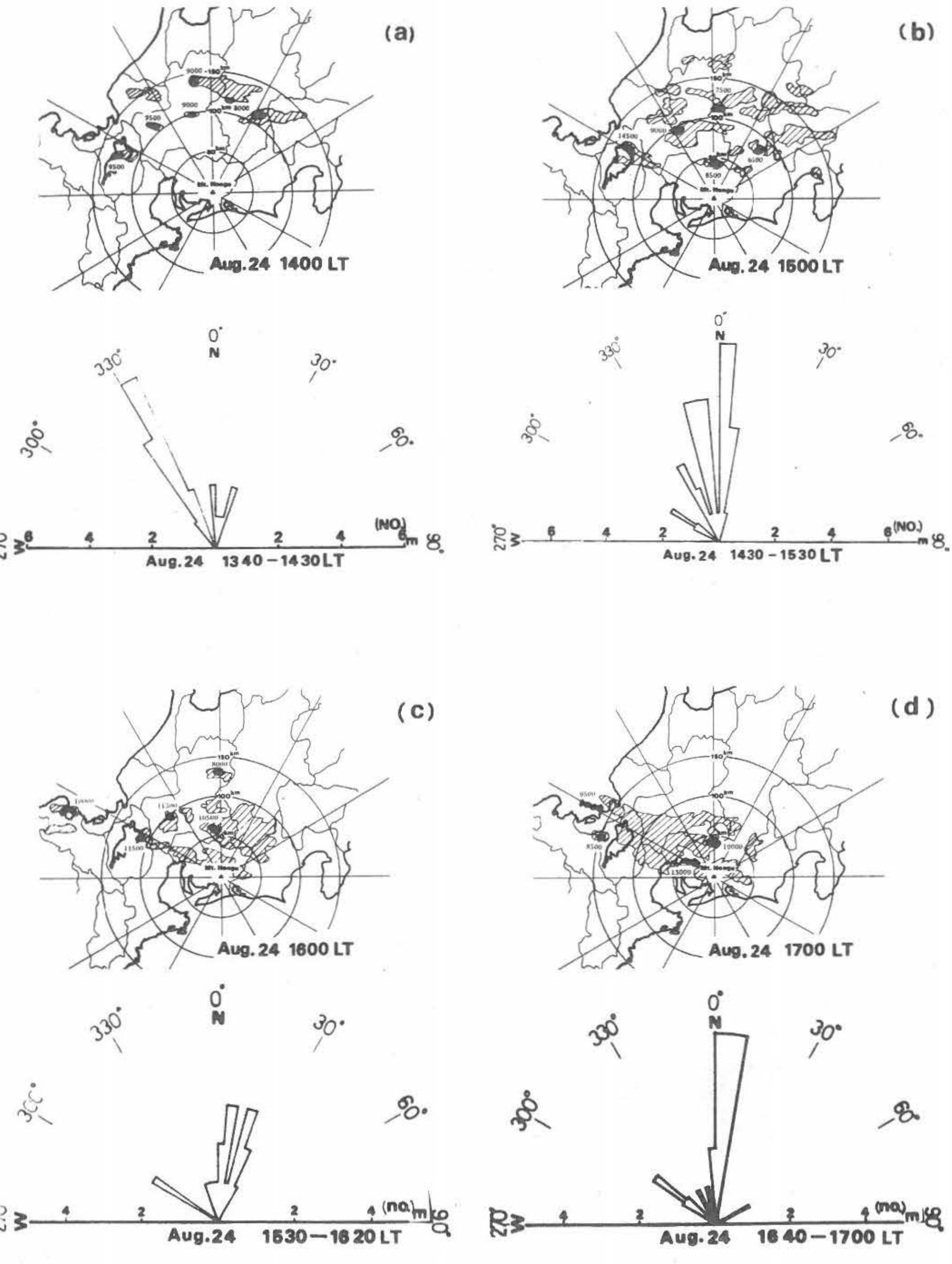


Fig. 7 Polar plot of the occurrence distribution of bearing angles measured by the VHF direction finder and associated radar data on August 24, 1979.

4 Discussion

Comparing with the field strength measured by other investigators (Cianos et al.,1972), the strength of our measurement in July and August of 1978 is more enhanced by more than 10dB. This may be due to the different detector of the receiver, and also due to the wide fluctuation in the received field strengths of lightning discharges themselves. The frequency dependence of the field strength showed a good agreement with the data of previous investigators. The difference of field strength of signals between 48MHz and 78MHz is not remarkable at a distance less than 100km, and the field strength on 78MHz showed a rapid decrease at a range larger than 100km. This may be related with the topographical effect on the VHF propagation. The topographical horizontal and vertical maps to the north from the observing station are shown in Figs. 8. Fig. 8(a) indicates that mountains of 300m or 500m high stand at a range of 10km from the observing station, so the signal visibility is the serious problem. The VHF emission from the lightning discharges seems to have been radiated at a height of 5km above the ground (Taylor,1978). As is seen Fig. 8(b), the propagation paths are blocked by the mountains and we can not obtain any visibility to the VHF emission from the lightning discharges at a range more than 100km. Then, the decrease of a signal intensity to be received from the distance more than 100km seems to be due to the diffraction by the mountains. Treating a mountain as a knife edge, we can calculate the diffraction effect on the assumption that a mountain 300m or 500m high is present at a range of 10km and the receiving point is 15m

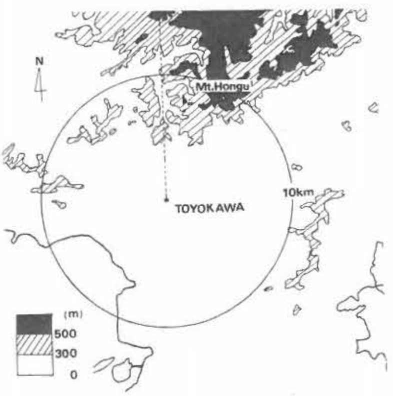


Fig. 8(a) The topographical map around the observing station. Dotted line indicates the path corresponding to the profile map shown in Fig. 8(b). VHF signal seems to be diffracted by the mountains which distribute around 10km north from the station.

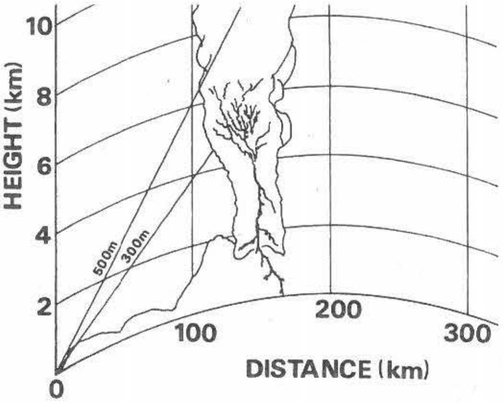


Fig. 8(b) Profile map from the station in Toyokawa. As the mountains 300m or 500m high above the sea level are present at a distance of 10km, lightning at a distance of more than 100km are out of sight.

high. The radiation power is calculated backwards based on the received signal strength of 65dB at a distance of 80km. The signal from a distance of 80km has no effect of diffraction, because the signal visibility is good at a range within 100km. The calculation model is shown in Fig. 9(b). Varying the distance from the receiving point to the source, we have calculated the field strength with the effect of diffraction. The result of calculation on 78MHz is shown in Fig. 9(b). From Fig. 9(b) the experimental results at range more than 100km seem to agree with the calculated field strength.

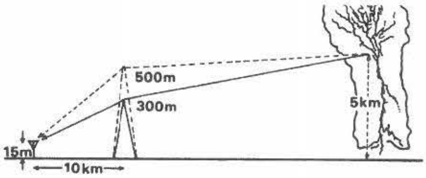


Fig. 9(a) The model of the calculation for the effect of the diffraction.

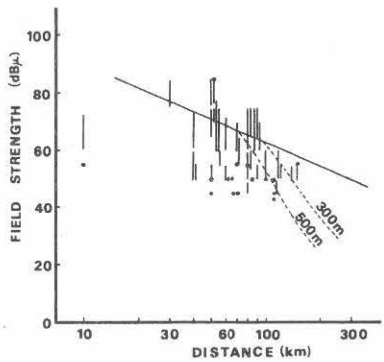


Fig. 9(b) The calculation results of the diffraction on 78MHz. Two dotted line indicates the field strength variations when the diffraction is corresponds to the signal variation without a diffraction.

The frequency of 48MHz seems to be more suitable for DF than that of 78MHz from the view-point of the signal intensity variation for the distance, but the interference due to the reflection from sporadic E layers in summer season is serious for 48MHz signals and also a wider spacing is required for the antenna site for 48MHz. Although the signal on 78MHz is slightly weaker than that on 48MHz, the DF on 78MHz will be useful for the lightnings at a range more than 100km, if we can find out a suitable field site free from the diffraction effect mentioned above. After these considerations, we have chosen 74MHz for the DF, and have measured the horizontal and vertical field strengths of atmospherics at that frequency.

The results obtained during 1979 are already shown in Figs. 4. We installed two antennas on the top of Mt. Hongu to avoid the influence of topography as met in the 1978's observation and to receive 74MHz impulses from the lightning at a distance more than 100km. From Fig. 4(b) it is found that the lightning at a range of 160km has a vertical field intensity more than 50dBμ. As the signal-to-noise ratio at an antenna output is required more than 40dB for a normal DF, our VHF direction finder will be able to determine the bearing of lightnings within the range of about 160km, because the background noise is less than 10dBμ at the observing point. As shown in Fig. 4(c), the value of Eh/Ev is widely scattered, but the vertical field tends to exceed the horizontal field by about 5dB. Especially, at a range more than 100km, the vertical field strength is stronger than the horizontal one. Takagi(1975) has reported that the value of Eh/Ev for atmospherics within 20km range is scattered between -2dB and +8dB. The difference between his result and ours seems to be caused by the difference in propagation distance.

The experimental fact that the vertical field strength exceeds the horizontal one is favorable for the DF. We tried to estimate the relationship between the value of Eh/Ev of the received signals and the bearing error(Itoh et al.,1957). The result of this calculation is shown in Fig. 10(a). This figure shows that the bearing error becomes smaller when the value of Eh/Ev is smaller and the incident angle is larger. For example as shown in Fig. 10(b), the incident angle of the flash at 5km high is larger than 85° at a range more than 50km. The value of Eh/Ev of that incident signal is -5dB according to the observed result shown in Fig. 4(c). Two elements of our Adcock antenna are not completely balanced, but the factor of the rejection against the horizontal component of the incident signal is

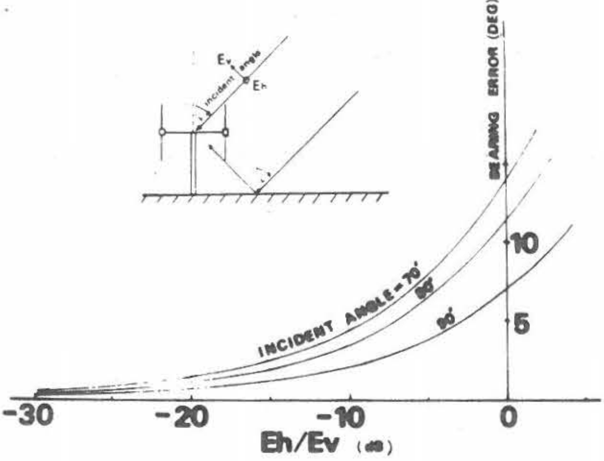


Fig. 10(a) Estimated bearing error versus Eh/Ev value of the incident signals.

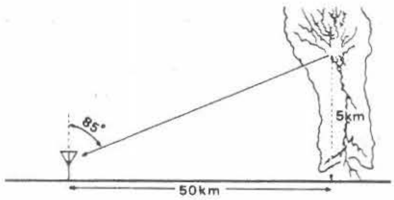


Fig. 10(b) The incident angle of the lightning discharges at a distance more than 50km is larger than 85°.

more than 15dB. So the ratio of the horizontal and vertical received signal is less than -20dB. From Fig. 10(a), the error seems to be less than 2°. The bearing error will be reduced by an improvement of the rejection characteristics of the Adcock antenna against the horizontal field component.

5 Conclusion

As we have not obtained so many data of DF measurement, we would not conclude that our system is the best for DF of lightnings at close ranges (≤160km). But, the bearing of lightnings by means of our VHF direction finder showed a good agreement with the radar data. We believe that the location of the thunderstorms at close ranges can be accurately fixed by the simultaneous measurements using the same DF systems at more than two stations, which would be our future work.

6 Acknowledgment

We wish to express our sincere thanks to Nagoya Meteorological Observatory for supplying with us the radar data and local storm reports.

References

Cianos,N.,G.N.Oetzel and E.T.Pierce; A Technique for Accurately Locating Lightning at Close Ranges,J.Appl.Meteorol.,11,1120-1127,1972.

Itoh,Y. and M.Gotoh; Radio Direction Finder,Corona Publishing Co.,37-54, 1957.(in Japanese)

Iwai,A.,M.Nishino,M.Kashiwagi and M.Satoh; A Locator System of Lightning Discharges using the Triangulation of Direction Finders for Atmospherics, Trans.Inst.Elect.Engrs.Japan,98,c-6,43-50,1978.(in Japanese)

Iwai,A.,M.Kashiwagi,M.Nishino and M.Satoh; Triangulation Direction Finding Network for Fixing the Sources of Atmosperics, Proc.Res.Inst.Atmospherics Nagoya Univ.,26,1-16,1979.

Murty,R.C. and W.D.MacClement; VHF Direction Finder for Lightning Location J.Appl.Meteorol.,13,1401-1405,1973.

Oetzel,G.N. and E.T.Pierce; VHF Technique for Locating Lightning,Radio Sci.,4,199-201,1969.

Proctor,D.E.; A Hyperbolic System for Obtaining VHF Radio Pictures of Lightning, J.Geophys.Res.,76,1478-1489,1971.

Shibuya,S.; Basic Atlas of Radio-Wave propagation Systems, Corona Publishing co.,281-326,1976.(in Japanese)

Takagi,M.; Polarization of VHF Radiation from Lightning Discharges,J. Geophys.Res.,80,5011-5014,1975.

Taylor,W.; A VHF Technique for Space-Time Mapping of Lightning Discharge Processes, J.Geophys.Res.,83,3575-3583,1978.