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Wide-Area Monitoring and Direction Estimation of UHF Pulses from Lightning Discharges Using a Yagi Antenna

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In recent years, the rapid advancement of the information society has heightened the importance of a stable power supply. One of the factors hindering stable power transmission is damage to transmission facilities caused by lightning strikes. To minimize this impact, it is essential to accurately observe lightning occurrences over a wide area, detect damage at an early stage, and implement countermeasures. However, conventional lightning discharge observation systems(1) use omnidirectional antennas, limiting the observation coverage to several tens of kilometers. To address this issue, this study aims to develop a UHF pulse observation system using a directional antenna, enabling the detection of lightning activity over a range of more than 100 km. The introduction of this system is also expected to contribute to the efficiency of maintenance operations, considering the declining workforce due to an aging population.

The proposed observation system records the arrival time and direction of impulsive UHF electromagnetic pulses emitted from lightning discharges. It uses a Yagi antenna, which is well known as a directional antenna, with a half-power beamwidth (HPBW) of 23° in the E-plane. UHF pulses received by the antenna are transmitted to the down converter through a band-pass filter (BPF) and a low-noise amplifier (LNA). They are then converted to an intermediate frequencies (IF) of 50 MHz or 10 MHz, digitized by analog-to-digital conversion (ADC) with the sampling frequencies of 200 MHz or 31.3 MHz, and recorded on a PC. A frequency of 325 MHz is selected as the observation target, as it is protected band for radio astronomy and is expected to have less interference from artificial radio signals.

For direction-of-arrival (DOA) estimation, the same two Yagi antennas are installed facing different directions. The voltage ratio between the peak voltages of recorded UHF pulse by the antennas 1 and 2, V_1 and V_2, corresponds to the gain ratio of the two antennas, G_1 and G_2. The direction of arrival of each UHF pulse is estimated from the received voltage ratio with reference to the known gain ratio.

Continuous lightning discharge observations have been conducted since the summer of 2022. Observations were conducted mainly in inland areas (Osaka and Aichi) during the summer and the Sea of Japan coast areas (Toyama and Niigata) during the winter seasons. The detection rate and direction estimation accuracy were evaluated while considering seasonal characteristics of lightning discharges. The detection rate was defined as the proportion of lightning strikes recorded in a lightning location system (LLS) for which at least one UHF pulse was detected within 1 second of the lightning strike. The results confirmed that UHF pulses from lightning discharges could be detected up to 150 km away.

During observations in Osaka in the summer of 2023, the detection rate within a 0–100 km range was 63%. In contrast, the detection rates during winter observations in Toyama and Niigata, were 12% and 17%, respectively. Additionally, observations in Aichi, in the summer of 2024 resulted in a detection rate of 17%. These findings indicate that summer lightning can be detected over longer distances compared to winter lightning. Since installation heights varied by observation site, further investigation will be conducted to assess the impact of this factor on observation results.

The DOA estimation results showed a strong agreement between the estimated lightning strike locations and the LLS records in most cases. However, in some cases, the estimation error exceeded 15°. Possible causes of these errors include antenna installation conditions and surrounding noise. Moving forward, we will continue to optimize polarization patterns and installation angles based on real observation data, with the goal of further improving accuracy in 2025.

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