An Operational VHF Broadband digital Interferometer for Lightning Observations

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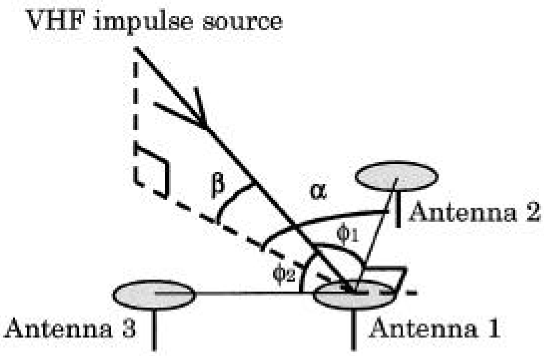
The autors have been developing a new type of lightning location and monitoring system based on a technique of VHF broadband digital interferometry. The basic principle of the broadband digital interferometry is the relative phase estimation of Fourier component of VHF impulse signals detected by several separately equipped antennas, like an antenna array. Since it is known that VHF/UHF impulses are mainly radiated from the tip of the breakdown, the location for their radiation source is equivalent to imaging the lightning channel development and is able to give us information on positive charge distribution inside thunderclouds as well.

A remarkable feature of the broadband interferometer is its wide detection frequency range. The Fast Fourier Transform is applied to calculate Fourier components of the received EM pulse. Computed phase difference for each Fourier component between two antennas is a function of the incident angle of the EM pulse against the baseline. A couple of antennas as a two-element-array of the broadband interferometer enable to estimate the incident angle. Two pairs of antennas and two independent baselines lead to two-dimensional mapping of sources, like in azimuth and elevation format. In our system, we use three sensors, which are equipped at three apexes of a level isosceles right-angled triangle, and we define linearly independent two couples of sensors with 10m distance. We use circular flat-plate antenna, which has a diameter of 30cm as a VHF receiver. The received broadband signal is limited its bandwidth and amplified by band-pass filter and amplifier equipped just beneath antenna, respectively. Then the transmitted signal through a coaxial cable is digitized with synchronization with the signals from other antennas by a three-channel analog-to-digital converter (ADC), and stored to a personal computer. Fig.1 shows the antennas arrangement and the schema of the VHF impulse source location. A synchronized operation of tow units with a proper distance separation by GPS enables the three-dimensional mapping of VHF impulse sources.

As a first step of developing, we install an experimental system using a commercial high-speed digital oscilloscope having 500MHz sampling rate and 8-bit resolution. The band-pass filter with the pass band of 10-250MHz and a logarithmic amplifier to compensate for the insufficient resolution are equipped. After the verification of the performance of the experimental system as described later, the advanced system is developed on the recent progress of electronics. The striking improvement is its specially developed ADC, which has 200MHz sampling rate and 10-bit resolution. The three-channel ADC is on one board and plugged in to ordinary PCI-bus of a PC. The band-pass filter with the pass band of 25-100MHz and a linear amplifier are also manufactured. The specifications of experimental and advanced systems are given in Table 1. Because of such high-speed digitization, the whole VHF radiation from a lightning flash cannot be recorded continuously. As a measure to overcome this difficulty we applied a sequential triggering technique, namely the memory on the digitizer is divided into 2000/2048 segments to store signals for 1/2.5 microseconds. Dead time in Table 1 means the instrumental interval between segments when signal cannot be recorded. We apply the mapping process to each VHF impulse, which has at most 500 nanoseconds pulse width.

We have conducted lightning observation campaigns, and imagings of lightning progression is realized. In order to verify the application the broadband digital interferometric technique for lightning monitor we compared our observations with observations by other methods. The results show consistencies with previous studies. It is concluded that the function of the system is working well, and the VHF broadband digital interferometer for lightning monitor is accomplished with high accuracy from the aspects of time and space.



$$\alpha = \tan^{-1}\frac{\cos\phi_2}{\cos\phi_1}$$

$$\beta = \cos^{-1}\frac{\cos\phi_1}{\cos\alpha}$$

$$= \cos^{-1}\frac{\cos\phi_2}{\sin\alpha}$$

Fig. 1. The antennas arrangement and the schema of the VHF impulse source mapping.

Table 1. specifications of the experimental and advanced broadband interferometer systems.

		Experimental system	Advanced system
Band-pass filter	Pass band	10 — 250MHz	25 — 100MHz
Amplifier	Input range (in)	-70 — 5dBm	-85 — -15dBm, -75 — -5dBm -65 — 5dBm, -55 — 15dBm (with 10dB-step variable attenuator)
	Output range (out)	out[-mV] = 3.33[dBm]+300 (logarithmic amplification)	out[dBm] = in[dBm]+25 (linear amplification)
ADC	Sampling rate	500MHz	200MHz
	Resolution	8-bit	10-bit
	Time of data acquisition	1μs × 2000segments	2.5μs × 2048segments
	Memory	1MW/ch (8-bit)	1.024MW/ch (16-bit)
	Dead time	~70μs	~1μs