Fine structure of magnetic field waveforms from the first return stroke of inland lightning

O. Santolík[1, 2], I. Kolmašová[1], P. Novák[3]

[1] *Institute of Atmospheric Physics AS CR, Prague, Czech Republic*
[2] *Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic*
[3] *Czech Hydrometeorological Institute, Prague, Czech Republic*

Abstract We analyze a fine structure of the *dB/dt* and *B* waveform of the first return stroke near its dominant peak. The broadband waveform of the magnetic-field derivative from a lightning discharge is measured in the frequency range of 5 kHz – 37 MHz. The sampling frequency of 80 MHz allows us to examine the timing properties of the onset and decay of the return stroke dominant peak. We examine different types of discharges, both positive and negative cloud-to-ground flashes and also intracloud flashes. The data have been collected during an observational campaign in summer 2011 in Prague, Czech Republic. The recorded data originate from four thunderstorms that occurred in the vicinity of the receiving station. We have obtained about 20 return stroke waveform records. We have completed our records with the return stroke data obtained from the lightning detection network CELDN.

1. Introduction

The submicrosecond-scale measurements of the electric field radiated during the onset of return strokes in the cloud-to-ocean lightning were studied by Weidmann and Krider [1, 2]. The data set measured by Krider in 1984 was corrected for the effect of propagation and reported by Willet et al. [3]. Murray et al. [4] described fine structures of the same data on time scale of tens to hundreds of nanoseconds. Willet et al. [3] noted that the typical field waveforms from return strokes begin with a relatively slow front lasting for several microseconds. The front is followed by a fast transition to the peak. There are often various subsidiary peaks and other structures in the return stroke waveforms. These peaks and structures are believed to be connected with the effect of branches, with the geometry of the channel, or with the current waves travelling during the attachment process. Willet et al [3] estimated the FWHM (Full Width at Half Maximum) of the initial half cycle of *dE/dt* in the first return stroke to 64±22 ns.

In our study we present examples of the shapes of radiated magnetic fields produced by first return strokes measured in the inland by a newly developed broadband digital analyzer.

2. Instrumentation

The measurements have been done using a ground-based version of a broadband high-frequency analyzer which is being developed for the TARANIS spacecraft. The analog part of the analyzer includes two fully differential input amplifiers, two anti-aliasing filters and a set of twelve band-pass filters with amplifiers and RMS detectors. The signals from these detectors are used as input data of a flexible event detection algorithm. The core of the digital part of the electronics is a Virtex-4 FPGA, where the sampled and digitized signals are processed The analyzer produces selected waveforms sampled to 12 bits per sample at 80 MHz. The analyzed frequency band is from 5 kHz to 37 MHz. The time assignment is done by a GPS receiver connected to the analyzer.

We have connected the analyzer to a broadband magnetic-field antenna. The antenna is formed by a single loop of a 50-Ω coaxial cable with a loop diameter of 1 m. The voltage induced in the antenna loop is proportional to the magnetic-field time derivative *dB/dt* and to a geometrical factor which depends on the loop area and on the angle to the discharge. Similar antenna system was used by Krider et al [5].

3. Results and discussion

During an observational campaign in summer 2011 in Prague, Czech Republic, we have collected measurements for several thunderstorms that occurred in the vicinity of the receiving station. A precise time assignment of our recorded return stroke events (with an accuracy of 3 μs) allowed us to search for the corresponding records in the CELDN (Central European Lightning Detection

Network) database [6]. Here, we have obtained the information about the type, position and peak current of our recorded discharge. The peak current of CG discharges is estimated with an accuracy of about 30%, the location of CG discharges is given with an accuracy of about 1km. The accuracy of the location and peak current of IC discharges is disputable. We have analyzed 11 negative cloud-to-ground discharges, 1 positive cloud-to-ground discharge, and 3 intracloud discharges which occurred during four thunderstorms. To minimize the distortion of the submicrosecond field variations due to effects of ground-wave propagation we have included only close lightning flashes up to a distance of 8 km. We have numerically integrated our waveform records to obtain the *B* shapes. A time interval of 15 μs (9 μs before and 6 μs after the dominant peak) was chosen for the study of the *B* and *dB/dt* waveform shapes.

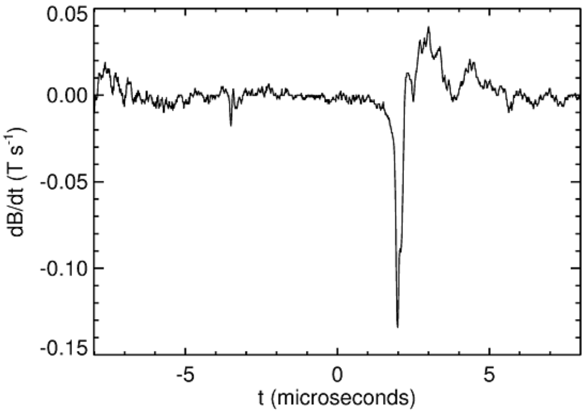

Fig. 1 Negative cloud-to-ground discharge recorded on June 6, 2011, at 20:57:30.744 UT.

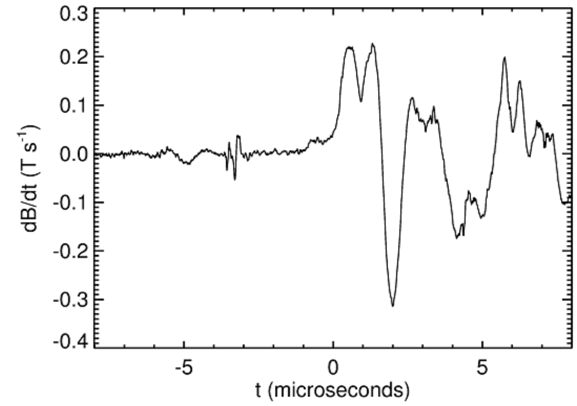

Fig.2 Negative cloud-to-ground discharge recorded on June 6, 2011, at 21:03:42.979 UT.

Fig. 1 shows an example of a single-peak *dB/dt* waveform from the first return stroke (CG-, 13 kA, 3 km from the receiving station). We have also recorded a multiple-peak *dB/dt* waveform during the same thunderstorm 6 minutes later (CG-, 21 kA, 3 km from the receiver). The shape of the waveform shown in Fig. 2 probably indicates occurence of multiple channels at the time of the attachment. The cluster of pulses at -3,5 μs corresponds to a “leader burst”, observed also by Jerauld el al [7].

The FWHM estimation of the initial fast part of the dominant *dB/dt* pulse was done only for the records, where the border between the slow front and the fast transition was clear. The FWHM varies from 116 ns to 333 ns. These numbers are two to five times larger than the values reported by Willet et al [3]. This significant difference was probably caused by the distortion effects of the ground-wave propagation.

4. References

[1] Ch. D. Weidmann and E. P. Krider, The fine structure of lightning return stroke waveforms, J. Geophys. Res. 83, 6239-6247 (1978)

[2] Ch. D. Weidmann and E. P. Krider, Submicroseconds risetimes in lightning return stroke fields, Geophys. Res. Lett. 7, 955-958 (1980)

[3] J. C. Willet, E. P. Krider and C. Leteinturier, Submicrosecond field variations during the onset of first return strokes in cloud-to-ground lightning, J. Geophys. Res. 103, 9027-9034 (1998).

[4] E. P. Krider and R. C. Noggle, Broadband antenna system for lightning magnetic fields, Journal of Applied Meteorology 14, 252-256 (1974)

[5] N. D. Murray, E. P. Krider and J. C. Willett, Multiple pulses in dE/dt and the fine-structure of E during the onset of first return strokes in cloud-to-ocean lightning, Atmos. Res. 76, 455–480 (2005)

[6] P. Novák, H. Kyznarová, Climatology of lightning in the Czech Republic. Atmos. Res., 100, 318-333 (2011)

[7] J. Jerauld, M. A. Uman, V. A. Rakov, K. J. Rambo, D. M. Jordan and G. H. Schnetzer, Electric and magnetic fields and field derivatives from lightning stepped leaders and first return strokes measured at distances from 100 to 1000 m, J. Geophys. Res. 113, D17111 (2008)