The submicrosecond structure of unipolar magnetic field pulse trains generated by lightning discharges

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Abstract We analyze the fine structure of the trains of regular unipolar microsecond-scale magnetic-field pulses produced by lightning discharges. Waveforms of the broadband magnetic-field derivative were measured in a frequency range of 5 kHz – 37 MHz. We found more than 40 trains of regular unipolar pulses in the waveforms of integrated magnetic field. A sampling frequency of 80 MHz allowed us to examine in detail the shapes and timing properties of the individual pulses. The data were collected during an observational campaign in summer 2011 in Prague, Czech Republic. The recorded data originated from three thunderstorms that occurred in the vicinity of the receiving station.

1. Introduction

Trains or bursts of electric and magnetic-field microsecond-scale pulses were reported many times in the lightning literature [1, 2, 7, 8, 9, 10]. Some types of trains were identified to be connected with specific lightning phenomena. Preliminary breakdown pulses, stepped leader pulses, dart-stepped leader pulses, and bursts associated with either K-changes or M-component were observed. The bursts of regular unipolar pulses occurring in cloud flashes were first studied by Krider et al [1]. Similar bursts in cloud-to-ground and in intracloud lightning electric-field waveforms were observed and reported by Rakov et al [2]. According to these studies, the regular unipolar pulse bursts can occur in a part of the ramp-like field variation characteristic for the K-change or in a hook-shaped field variation characteristic for the M-component. Wang et al [3] introduced four types of bursts according to the wave shape of the burst – normal, backward, symmetrical and reverse pulse burst.

The aim of our work was to analyze and describe the fine structure of bursts of regular unipolar pulses measured by a newly developed digital broadband analyzer.

2. The measurement method

For our measurements we have used 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 signal is processed. The analyzed frequency band is from 5 kHz to 37 MHz. The signal is sampled at 80 MHz. Selected interesting parts of the waveforms are recorded. 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 1m. The voltage induced in the antenna loop is proportional to the magneti-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 [4].

Our data were recorded during an observational campaign in summer 2011 in Prague, Czech Republic.

3. Data analysis and discussion

We have analyzed more than 40 bursts of regular pulses. All bursts which contained bipolar or chaotic pulses have been excluded from our statistics. We have numerically integrated our waveform records to obtain the *B* shapes. The smallest pulse amplitude included in our analysis was about 1 nT. The duration of the bursts varied from 48 to 446 μs, the number of pulses from 13 to 109. The average time interval between pulses was about 4 μs. The average ratio between the largest and smallest pulse amplitude in each individual burst was about 7. The amplitudes of the pulses are often decreasing and the spacing between the pulses is increasing with time within a given burst (Fig.1).

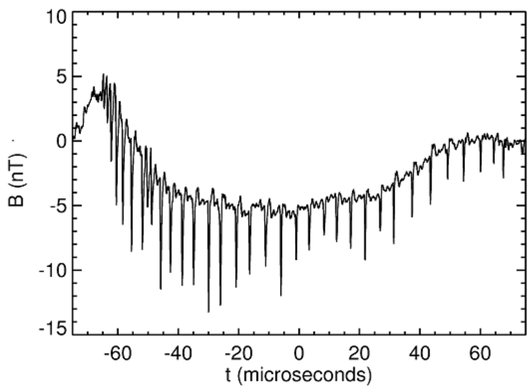

Fig. 1 An example of the most frequently measured burst type

Our high-resolution measurements with a sampling interval of 12.5 ns allow us to analyze the timing properties and the shape of individual pulses in detail. Analysis of the pulse shapes shows that, in most cases, the leading edge is twice shorter than the trailing edge. Typically, every isolated pulse is followed by an overshoot of the opposite polarity (Fig.2).

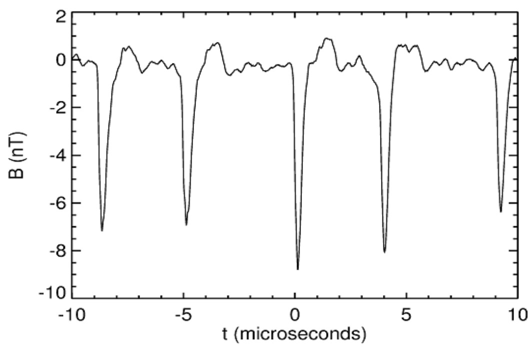

Fig. 2 A typical shape of negative unipolar pulses

The usual position of the K-change and of the M-component in relation to the strokes was reported by Rakov et al [5] and Thottappillil et al [6]. The duration of the individual bursts and the interval between the bursts in our data set correspond to the usual time properties of the K-change sequence.

We plan to complete our high-frequency measurements with observations of low-frequency electric and magnetic fields in the next ground-based observational campaign in summer 2012.

4. References

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