The importance of the receiver transfer function in the interpretation of ELF pulses related to Transient Luminous Events

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Electromagnetic waves originating from TLE-related lightning discharges can be observed in the ELF range even several thousand kilometers away from the individual discharge. Based on the recorded signal it is possible to reconstruct the complete current moment waveform of a discharge. Most ELF stations worldwide have been designed for spectral observations and are equipped with an anti-aliasing filter that is optimized for this purpose. It is very important to realize that the waveforms recorded with this type of receiver can be highly distorted. The receiver's transfer function must be taken into account when analyzing the data and reconstructing the current moment waveform of a discharge. Otherwise the distortions introduced by the receiver might be misinterpreted as actual external events. In this paper we illustrate this issue using recent data from the Hylaty ELF station.

1. Introduction

Two components dominate in the ELF (Extremely Low Frequency) electromagnetic field observed on the Earth surface: ELF field pulses (ELF transients) and Schumann resonance background. Most of the observed ELF pulses have a form of short spikes, accompanied by more or less visible resonant responses of the Earth-ionosphere cavity. They originate form cloud-to-ground lightning discharges generated by thunderstorms located over distances up to 1500 km or from strong discharges, such as upward discharges related to TLE, located over distances up to about 6000 km. In the case of extremely strong discharges, such as associated with Gigantic Jet, the system range for individual pulse observation can be up to 15000 km. The actual range of observation of individual pulses depends on the ratio between their amplitude and the background noise formed by the Schumann resonance components.

2. Sprite associated electromagnetic signature recorded at Hylaty ELF station

TLEs are large-scale optical events that occur at stratospheric and mesospheric altitudes and are directly related to the electrical activity in underlying thunderstorms [1]. Several different types of TLEs have been documented and classified. These include Sprites and Gigantic Jets. The return stroke phase of upward discharges is often followed by a continuing current phase, which is so slow that it can be observed only in the lower part of the ELF range. This makes the ELF a very useful tool for TLE studies.

Figure 1 shows the first of four Sprites observed optically near Nydek in Czech Republic on 27 August 2011 by Martin Popek [2]. Figure 2 shows the magnetic field components recorded at the same time by the Hylaty ELF station.

Fig. 1. A photograph of the first of four Sprites observed optically near Nydek [2]

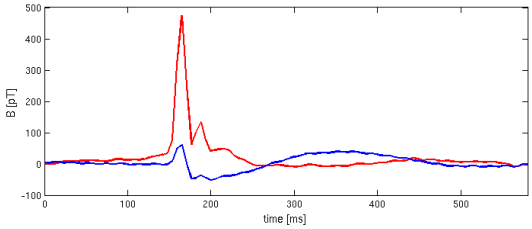

Fig. 2. Magnetic field components recorded at the Hylaty ELF station by the NS (red line) and EW (blue line) antennas, associated with the Sprite shown in Fig 1.

3. Signal analysis

The spectrum of the recorded magnetic field component at the distance r from the source can be written:

$$\overline{B}(f,r) = \overline{s}(f) \cdot \overline{w}(r,f) \cdot \overline{g}(f)$$

where $\overline{s}(f)$ is the spectral density of the source current moment, $\overline{w}(r,f)$ is the transfer function of the Earth-ionosphere waveguide, and $\overline{g}(f)$ is the receiver's transfer function. Using this relationship and calculating all the required parameters, it is possible to reconstruct the current moment waveform of the discharge $s(t)$. The details of the method we have developped for this purpose can be found in [3]. In this paper we focus on removing the distortions related to $\overline{g}(f)$ from the recorded magnetic field components.

As an example we take the waveform registered by the Hylaty ELF station (Fig. 2) associated with the Sprite shown in Fig. 1. It can be clearly seen in the signal recorded by the NS antenna that the first impulse recorded by the NS antenna is followed by the second impulse, delayed by about 23 ms. Base on this plot a hypothesis might have been made that the first discharge was followed by another discharge, or that the discharge process of the Sprite itself was unusual, but this would not be a correct interpretation.

Most ELF stations have been designed for spectral observations and are equipped with an anti-aliasing filter that is optimized for this purpose. The impulse waveforms recorded with this type of receiver are distorted, due to ripples in the impulse response caused by a steep roll-off in the receiver's frequency response.

Figure 3 shows the impulse response of the Hylaty receiver and Figure 4 the block diagram of the Hylaty ELF station. The anti-aliasing filter can be found in the middle of the diagram.

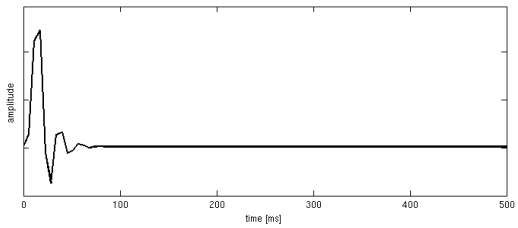

Fig. 3. A response of the receiver to the Dirac delta function

Analyzing Figure 3 and Figure 4 one can clearly see that the second impulse in Figure 2 and 3 might have been created by the receiver and had nothing to do with the Sprite's discharge process.

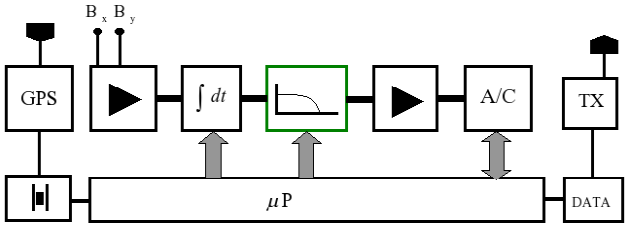

Fig. 4. Block diagram of the Hylaty ELF station

For the given receiver's transfer function $\overline{g}(f)$ and the spectrum of the recorded magnetic field $\overline{B}(f)$, the input signal can be obtained using the relationship:

$$\overline{B}(f) = \overline{B}_{in}(f) \cdot \overline{g}(f)$$

Figure 5 shows the Sprite's electromagnetic signature obtained after removing the distortions introduced by the receiver. It is clearly seen that the Sprite wasn't followed by any other discharge.

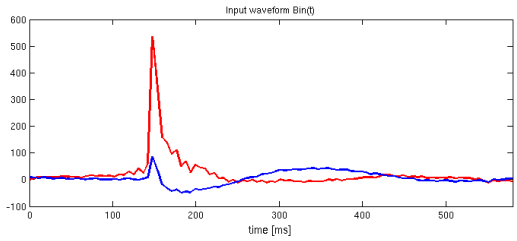

Fig. 5. Magnetic field components at the receiver's input from the Sprite-related discharge

3. Conclusions

The receiver's transfer function has to be taken into account when analyzing impulse signals recorded by ELF stations and reconstructing the current moment waveforms of the discharges. Otherwise the oscillations related to the impulse response of the receiver might be misinterpreted as external events related to the discharge process.

4. References

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