Introduction

In the past a lot of electric field derivative measurements of return strokes, stepped leaders and intracloud discharges in the near distance range were made (e.g. 1, 2). However, difficulties remain in determining distance and type of the signal source. Hence in the past a lot of electric field derivative data to discriminate signals from return strokes were made (e.g. 1, 2, 4, 5). The interesting E-signals of return strokes which are of main interest show a typical bipolar impulse with dominant frequencies up to a few MHz. To avoid triggering on very fast impulses, e.g. produced by stepped leaders, an external trigger generator in combination with a separate similar rod antenna is used. It works as a bipolar trigger with an upper cutoff frequency of 5 MHz.

Experiment

The fully automatically working measuring station consists of two components, firstly the measuring devices for obtaining the electrical signals of a lightning discharge and secondly the so called all sky video camera system. Figure 1 shows an overview of the measuring station with the HP 9836 computer as the controller.

The electric field derivative E is registered by a capacitive 0.5 m rod antenna with a spherical termination at the top. Combined to a coaxial cable with a surge resistance of 50 Ohm it leads to a bandwidth of at least 50 MHz. Using a digital storage oscilloscope LeCroy 9450 with a sample rate of 10 ns it is possible to record at maximum 20 E-waveforms of 20 µs duration, which are separately to be triggered, within one lightning event.

A DSO Gould 4072 samples at a rate of 1 ms both the electrostatic field measured by a slow field mill (bandwidth = 10 Hz) and the maximum E-signals using peak detection during 1 ms. A positive change of the electrostatic field points at a negative flash, a negative change at a positive flash, if it is produced by a cloud-to-ground flash. The peak detection of the E-signal and a time period of 1 ms gives information about the duration of one whole event and the maximum amplitudes of the electric field derivative.

As it is reported from near field measurements (1, 2, 4, 5) the interesting E-signals of return strokes which are of main interest show a typical bipolar impulse with dominant frequencies up to a few MHz. To avoid triggering on very fast impulses, e.g. produced by stepped leaders, an external trigger generator in combination with a separate similar rod antenna is used. It works as a bipolar trigger with an upper cutoff frequency of 5 MHz.

Only if type and distance of the signal source are certainly established criterions can be worked out derived from the measured electric data to discriminate signals from return strokes from other signals. To achieve this aim analysis in the time domain, as well as in the frequency domain down to low frequencies of 50 kHz, are performed.
Fig. 1 Block diagram of the automatically working electric field measuring station used in 1989.

cloud-to-cloud discharges (Fig. 4b). Thereby the horizon appears as the inner circular disk surrounded by the sky as an enlightened annular ring. With the video image repetition rate of 40 Hz it is possible to resolve even subsequent strokes. During the automatic operation the computer starts the video recorder after the first trigger impulse and stops it 7.5 min after the last trigger impulse in order to make the most of the video tape with a recording time of 180 min.

Fig. 2 All sky video camera system with an azimuth angle of 360° and an elevation angle of 50°.

Fig. 3 Convex aluminum mirror used in the all sky video camera system for wavelengths of 380 nm to 760 nm.

Measurements

In 1989 of altogether 604 lightning flashes creating 5044 E-signals 111 flashes with 1219 E-signals were registered on video tape (Table 1). Triggering to a certain threshold of the E-signals explains the relatively small number of 54 obtained return stroke waveforms compared to 2165 single impulse waveforms produced by stepped leaders and intracloud discharges. In the following E-signals are examined with a single characteristic impulse within 20 μs. Figure 5 shows the interesting parameters, that is the impulse width (T50) and the maximum peak of the E-signals (Emax), resp. the initial peak of the computed electric field (Emax). 2813 E-waves without a regular structure or with multiple characteristic impulses within 20 μs are ignored.
Results

In agreement with former measurements [1] the maximum peaks of the electric field derivative \( E_{\text{max}} \) with a mean value of 128 (V/m)/µs for all measured data of stepped leaders and intracloud discharges, resp. 7.59 (V/m)/µs for determined distances normalized to 100 km by the inverse distance relationship, lie in the same order as those of return strokes with a mean value of 109 (V/m)/µs for all data, resp. 5.53 (V/m)/µs for determined distances normalized to 100 km (Fig. 6).

Against that the electric field initial peaks \( E_{\max} \) differ with a mean value of 4.82 V/m for all measured stepped leaders and intracloud discharges, resp. 0.247 V/m for determined distances normalized to 100 km, from return strokes electric field initial peaks with a mean value of 88.6 V/m for all data, resp. 3.95 V/m for determined distances normalized to 100 km (Fig. 7). The mean value of 3.95 V/m for \( E_{\max} \) of return stroke waveforms normalized to 100 km is also found in [3] and [7].

The comparison of \( T_{50} \) shows the most obvious difference between stepped leaders and intracloud discharges on the one hand with a mean value of 26.2 ns for all acquired data, resp. 23.1 ns for determined distances, and return stroke signals on the other hand with a mean stroke signals on the other hand with a mean value of 606 ns for all data, resp. 564 ns for determined distances (Fig. 8).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All measured data</th>
<th>Data with determined distances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive single pulses</td>
<td>2825</td>
<td>704</td>
</tr>
<tr>
<td>Negative single pulses</td>
<td>973</td>
<td>233</td>
</tr>
<tr>
<td>Stepped leaders</td>
<td>1192</td>
<td>271</td>
</tr>
<tr>
<td>Intracloud discharges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neg. single pulses of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>stepped leaders and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>intracloud discharges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pos. single pulses of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>return strokes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>5044</td>
<td>1219</td>
</tr>
</tbody>
</table>

Table 1: Overview of 5044 \( E \)-signals (20 µs, 10 ns sample interval) in 604 flashes, resp. 1219 \( E \)-signals in 111 flashes with determined distances measured in 1989.
Fig. 6: Histograms of maximum peaks $E_{\text{max}}$ (pos. and neg.)

Fig. 7: Histograms of electric field initial peaks $E_{\max}$ (pos. and neg.)
Discussion

The results show that for the discrimination of electric field derivative signals of the return strokes from those of stepped leaders and intracloud discharges in the range to 15 km both the impulse width and the electric field initial peak by a factor of 15 seem to be appropriate criterions. The evident difference of $T_{50}$ in the time domain points at a significant difference also in the frequency domain.

In Fig. 9 the two average amplitude density spectra of the $E$-waveforms produced by return strokes (solid) resp. stepped leader and intracloud discharges (dotted) are presented [8]. Before computation of the Discrete Fourier Transform in the frequency range from 50 kHz to 10 MHz is performed the data are normalized to 100 km. Up to frequencies of 500 kHz the average amplitude density spectrum of 11 $E$-signals originating from return strokes lies by a factor of 10 above that of 504 $E$-signals produced by stepped leaders and intracloud discharges. For frequencies higher than 2 MHz no such difference is recognizable as also reported in [9]. This corresponds to the relatively long $T_{50}$ of return strokes, which is caused by the massive removal of charge from the lightning channel at the beginning of the return stroke phase.

Deduced from Fig. 9 a bandwidth limitation of the $E$-measuring system, that means of the trigger device, by a lowpass filter with a cutoff frequency of 500 kHz leads to an appropriate discriminator for return stroke signals produced by cloud-to-ground flashes in the 15 km range.

In order to eliminate strong stepped leader pulses of near cloud-to-ground discharges or signals of cloud-to-cloud discharges the $E$-signals filtered by a 4th order Butterworth lowpass filter with a 3 dB cutoff frequency of 500 kHz is compared to the unfiltered $E$-signals. Fig. 10 shows the ratios of the maximum peaks within the 20 $\mu$s time window of the filtered and unfiltered $E$-signals.
produced by return strokes. The 4th order Butterworth lowpass filter was simulated by a digital recursive filter using the bilinear transform. For all return stroke signals the ratio is greater than 25% with a mean value of 61.2%, resp. 57.8% for signals with determined distances. Against that the ratio for all other acquired signals lies under 35%.

Fig 10: Histograms of ratios of maximum peaks of filtered E-signals \( \frac{E_{\text{max}}/500\,\text{kHz}}{E_{\text{max}}} \) with determined distances. The histograms show the distribution of the ratio for return strokes and for other signals.

Conclusion

The comparison of E-signals with determined distances by the use of the all sky video camera system results in significant differences both in the time and the frequency domain for return strokes on the one hand and all other signal sources on the other hand.

To achieve the discrimination of return stroke signals in the 15 km range two criterions have to be fulfilled. First the E-signal filtered by a 4th order lowpass filter with a cutoff frequency of 500 kHz must exceed a certain level, which affects the effective range of the measuring system. Second the ratio of the maximum peaks of the filtered and unfiltered E-signal \( \frac{E_{\text{max}}/500\,\text{kHz}}{E_{\text{max}}} \) has to be greater than 35% in order to register at least 90% of the return stroke E-signals (first and subsequent) in the 15 km range and to exclude predischarges, stepped leader and cloud-to-cloud pulses.

References


Adress of author:

Ch. Hopf
Universität der Bundeswehr München
ET / 7
Verner-Heisenberg-Weg 39
D-8014 Neubiberg, Germany