

## ZERO-CROSSING TIME AND PULSE WIDTH OF RADIATED FIELDS FROM LIGHTNING TO ELEVATED OBJECTS

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**Abstract** – In this paper we present the analysis of the width values reported by lightning location system (LLS) sensor for three different subsets of lightning events. The three data sub-sets are (1) lightning to the Gaisberg Tower (GBT), (2) lightning located near the GBT and (3) lightning located near Vienna where correlated video images are available. Median width values for these three data sets are 11  $\mu\text{s}$ , 20  $\mu\text{s}$  and 27  $\mu\text{s}$ , respectively. The sensor reported width of the field pulses from lightning to the GBT is significantly smaller than the sensor reported field pulse width from lightning to ground near the GBT and near Vienna, respectively. This is in agreement with the observations of Pichler *et al.* [1] reporting peak-to-zero values of electric field pulses radiated by GBT strokes being significantly shorter than typically zero crossing times observed in natural cloud to ground lightning.

### 1 – INTRODUCTION

Zero crossing time or peak-to-zero time ( $T_{PTZ}$ ) of radiated fields from cloud-ground lightning was the subject of some recently published papers [2, 3].  $T_{PTZ}$  is one of the field waveform criteria that are used by some lightning location systems to discriminate between cloud-to-ground (CG) and intra-cloud (CC) lightning. Shoory *et al.* [2] have compared various return stroke models in their capability to reproduce zero crossing time. They identify three mechanisms responsible for the time of occurrence of the reversal of polarity in the model calculated far fields: (1) the current attenuation along the channel, (2) the duration of the return stroke current, and (3) the return stroke speed. The higher the attenuation of the current along the channel, the earlier the polarity reversal of the vertical electric field occurs. On the other hand higher propagation speeds correspond also to earlier polarity reversal times.

Pavanello *et al.* [3] extended five engineering models to calculate the radiated fields from lightning to an elevated object. For the considered case of a 168-m tower-initiated return stroke and the assumed 'undisturbed current' none of the models predicted any zero crossing within a time window of 50  $\mu\text{s}$ . Typically, the zero crossing time of lightning radiated fields is about 50  $\mu\text{s}$  for the first return-stroke and about 35  $\mu\text{s}$  for subsequent return-strokes [4].

Pichler *et al.* [1] analyzed simultaneous measurements of current pulses from lightning strikes on the instrumented Gaisberg Tower (GBT) in Austria and their correlated vertical E-field components recorded at a distance of 78.8 and 108.7 km, respectively.

Instrumentation of the GBT for the direct measurement of lightning current is described in detail in Diendorfer *et al.* [5]. Since May 2006 the vertical E-field radiated from GBT strikes was measured at a distance of 78.8 km (site #1 in Fig.1) with a fast flat plate antenna and digitized with a sampling rate of 5 MS/s. Integrator decay time constant is 0.5 ms equivalent to a lower cutoff frequency of about 300 Hz. For operational reasons, in May 2008, the field recording system was moved from Wels (site #1 in Fig.1) to Neudorf (site #2 in Fig.1) at a distance of 108.7 km from the GBT. Field propagation between the GBT and both antenna sites is more or less over flat area of moderate ground conductivity.



Figure 1 – Location of the GBT and the two sites of vertical E-field measurement in Wels (#1) and Neudorf (#2) [1]

Figure 2 shows an example of a current pulse measured at the GBT and the correlated E-field waveform recorded at the site #1 in Wels. The observed propagation time of 263  $\mu\text{s}$  corresponds to the distance of 78.8 km between the GBT and the antenna site #1 in Wels and the speed of light.

Pichler *et al.* [1] analyzed a total of 218 sets of correlated current and field pulses, 145 of them were initial continuing current (ICC) pulses, and 73 were return stroke (RS) pulses. They determined a mean Peak-to-Zero time  $T_{PTZ}$  for the E-field in the range from 7.0  $\mu\text{s}$  (fields from ICC pulses recorded in Neudorf) to 10.2  $\mu\text{s}$  (fields from RS recorded in Wels). Table 1 shows a summary of the results found by Pichler *et al.* [1].  $T_{PTZ}$  does not include the front portion of the wave form, as it is the case in the zero-crossing time estimates in [6]. But

nevertheless, by the fact, that in the subsequent stroke fields the slow front is either absent or of short duration [8] the zero-crossing time of fields resulting from strokes to the GBT is significantly shorter than the typical values of 30 – 40  $\mu\text{s}$  observed for natural CG lightning [6].

	N	$T_{E\_PTZ}$ ( $\mu\text{s}$ )	
		Mean	MED (GM)
Wels ICC pulses	103	9.7	8.6 (8.6)
Neudorf ICC pulses	42	7.0	7.6 (6.3)
All ICC	145	8.9	7.9 (7.9)
Wels RS	42	10.2	9.8 (9.5)
Neudorf RS	31	8.3	7.5 (7.4)
All RS	73	9.4	9.5 (8.6)

Table 1 – Peak-to-zero times of far fields radiated by lightning to the GBT (adapted from [1])

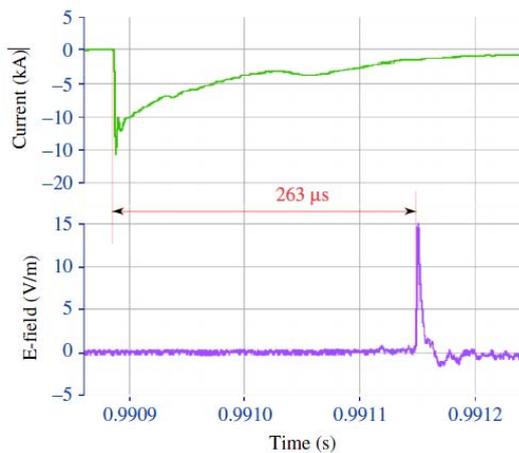


Figure 2 – Current and correlated E-field measured at a distance of 78.8 km of a typical RS-pulse (pulse #554-10).  
 $I_p = -15.9$  kA,  $E_p = +15$  V/m (according to the ‘atmospheric electricity sign convention’, a negative stroke produces a positive E-field pulse) [1]

## 2 – DATA

In this paper we analyze the “width” field parameter reported by the sensors of a lightning location system (LLS) for strokes to the instrumented GBT. The width parameter reported by the LLS sensor is actually the peak-to-zero time of the lightning far field pulses and represents a data source completely independent from the field measurements described by Pichler *et al.* in [1]. Sensors employed in the LLS network and used for this study report pulse widths values of up to 30  $\mu\text{s}$ . For field pulse widths being greater than 30  $\mu\text{s}$  the LLS sensors assign a fixed pulse width of 30.1  $\mu\text{s}$ .

In this study we statistically compare three different LLS sensor data sets:

(A) LLS sensor reported widths values for lightning strokes to the GBT. Those strokes are clearly identified by the GPS time synchronization of the LLS sensor data and the GBT current records.

(B) Sensor reported widths values for CG lightning strokes located in a ring area of a radius from 2 km to 10 km around the GBT and therefore excluding the GBT strikes. A period from June and July 2006 is used because this was a period of high lightning activity in the particular area. By selecting this ring area we create a subset of LLS sensor reports (N=1 685) where the field pulses propagated more or less along the same propagation paths to the different sensors in order to minimize any propagation effects on observed differences in the pulse width. In this dataset we have used LLS reports from the 3 sensors DF1, DF4, and DF8 at distances of 33 km, 77 km, and 204 km, respectively, from the GBT. Field propagation paths to those sensors is similar to the field propagation path of data set “A”

(C) We have also selected the sensor reported widths values (N = 201) from a particular set of 94 CG lightning strokes located near the city of Vienna. For those selected strokes field and video records are available and their classification as CG events was validated by the video records [7]. Again for each stroke only 2 or 3 sensor reports from the closest sensors were selected to minimize propagation effects.

## 3 – RESULTS

We determined a median of 11  $\mu\text{s}$  (N= 15 314) for the reported width by the LLS sensors for the strokes to the GBT (data set “A”). This value is very similar to the 9.5  $\mu\text{s}$  reported by Pichler *et al.* [1]. A histogram of the LLS sensor reported widths values is shown in Figure 3.

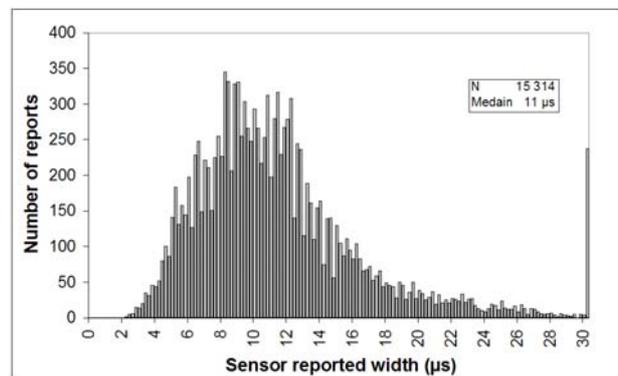


Figure 3 – Histogram of sensor reported width for strokes to the Gaisberg Tower (2000 – 2009). Note: All width values exceeding 30  $\mu\text{s}$  are summarized in the last bar of the chart

For CG lightning strokes located in the ring area from 2 km to 10 km around the GBT (data set “B”) we determined a median width value of 20  $\mu\text{s}$  (N=1 685) which is about two times the value estimated for data set “A” and the histogram is shown in Fig.4. We have to note, that data set “B” is possibly contaminated by some pulses from intra-cloud lightning as the data set was selected solely on the LLS provided stroke type classification (CG versus CC). We can assume that misclassified strokes will result in a bias to smaller width values and hence the observed significant difference between data set “A” and

“B” in terms of median width value for an “uncontaminated” data set B would be even larger.

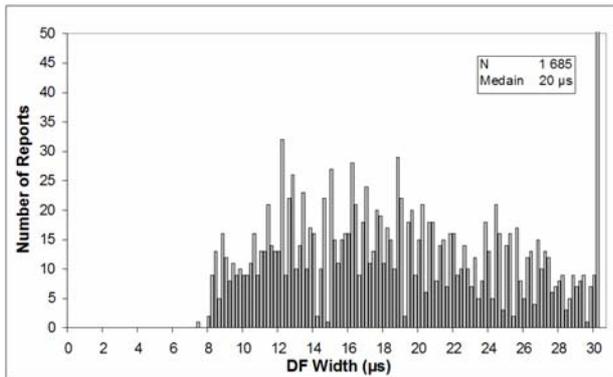


Figure 4 – Histogram of sensor reported width for strokes to the 2-10 km ring area around Gaisberg Tower. Note: All width values exceeding 30 µs are summarized in the last bar of the chart.

For the width values of 201 sensor reports from CG lightning near the city of Vienna (data set “C”) we determined a median of 27 µs. This is again significantly higher than the median of 11 µs observed for the GBT strikes shown in Fig.3. We have to note that the sample size of data set “C” is relatively small compared to the other two data sets and one third (67 out of 201) of the pulse width reports exceeded 30 µs.

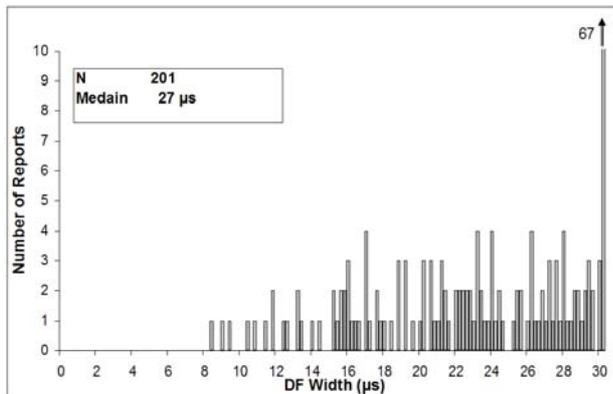


Figure 5 – Histogram of sensor reported width for strokes located near Vienna with correlated video records available (data set “C”) Note: All width values exceeding 30 µs are summarized in the last bar of the chart.

#### 4 – SUMMARY AND DISCUSSION

Based on the widths values reported by LLS sensors we determined significantly smaller pulse width for strokes to the GBT (11µs median width) than for two groups of strokes to ground with a median width of 20 µs and 27 µs, respectively. All the results presented in this paper support the conclusion, that the significantly shorter peak to zero times  $T_{PTZ}$  reported by Pichler et al. [1] are typical for the GBT lightning and not a result of either the field measuring system used by Pichler *et al.*[1] or the specific propagation path and distance between the GBT and the field measuring station at about 100 km. The reasons for these observed shorter pulse durations for lightning to the GBT are still unclear and subject of further research.

#### 5 – REFERENCES

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