

SUB-MILLISECOND TIME DIFFERENCES BETWEEN LOCATED STROKES: WAVEFORM ANALYSIS

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Introduction

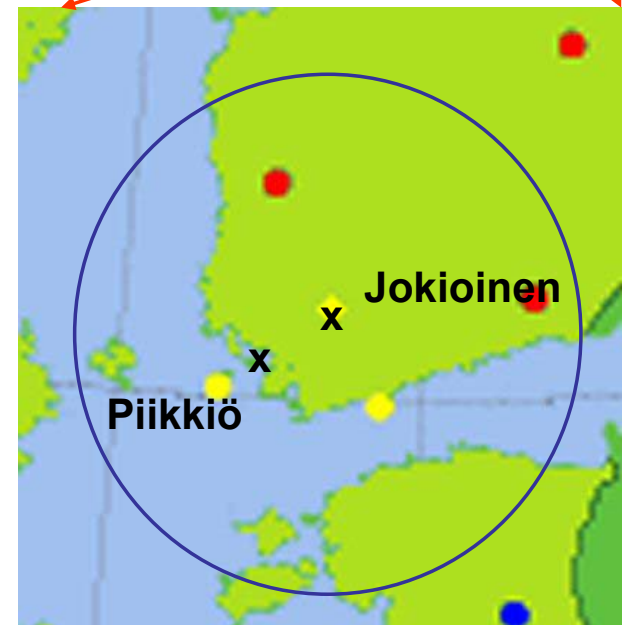
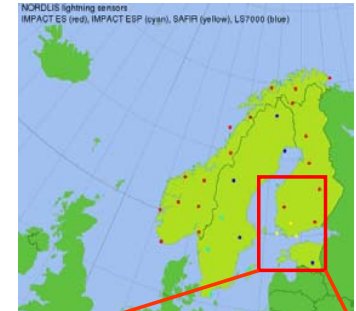
- **Relatively few direct comparisons of IMPACT versus broadband have been made**
- **The detection efficiency for flashes is considered good enough for most practical applications**
- **At general level, various effects are accepted to cause errors in lightning networks, but no waveforms have been published nor exact error mechanisms discussed**

Introduction

- **We focus on one particular anomaly: sub-millisecond return stroke pairs of both polarities observed in Finland**
- **By themselves, the anomalies are only mildly interesting, but they are a good sample set to study error mechanisms more generally**
- **Statistics discussed in companion presentation (Tuomi and Mäkelä); we present electric field waveforms for a subset of these events.**

Waveform measurement sites

- In summer 2006, two identical measurement sets in Piikkiö and Jokioinen (80 km distance), near south edge of IMPACT network
- Vertical electric field measured with flat-plate antenna with a broadband buffer amplifier with response from 1kHz-100MHz
- Attached to Agilent oscilloscopes; automatic triggering and saving to external HDD. Dead time of 2-4 minutes, so only small percent of IMPACT flashes caught.
- Range several hundred km (more over ocean).



Statistics

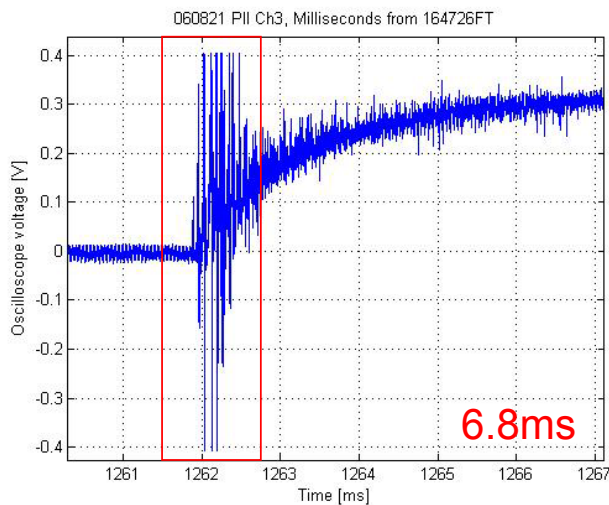
	Neg- neg	Neg- neg	Bipolar	Bipolar	Pos- pos	Pos- pos
	26		26		9	
RS with fine structure	13	50%	5	19%	--	
PBP	3	11%	7	26%	8	88%
Narrow pulse(s)	4	15%	6	23%	--	
Unclear	6	23%	8	30%	1	12%

Positive-positive pairs	9	
Misidentified PBP	8	88%
Unclear	1	12%

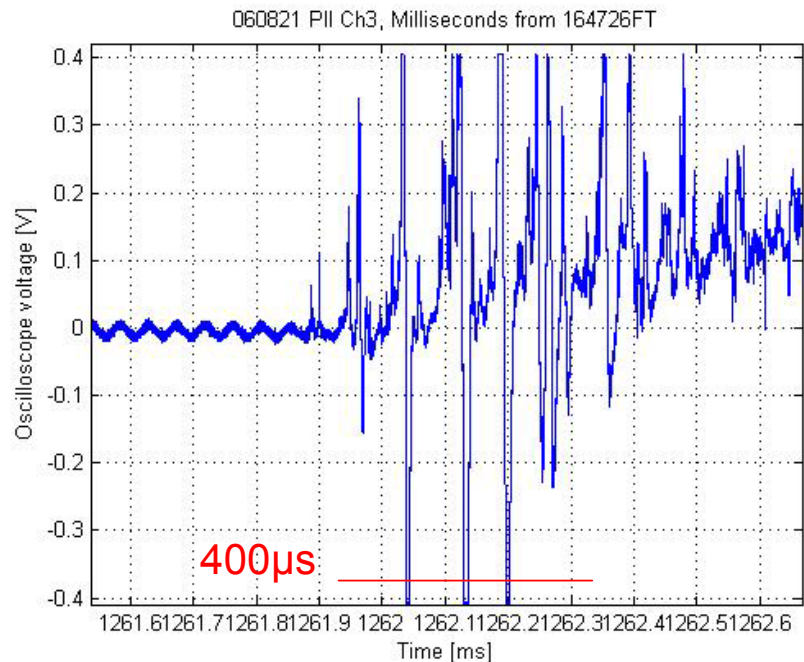
- Identifications have no ambiguity
- Essentially all positive-positive pairs are preliminary breakdowns
- In some cases, there is no RS at all (this is a pure intra-cloud event)
- Note: In some cases, the actual negative RS is missed altogether, so that it is not sufficient to reject all these cases

Positive-positive pairs: breakdowns

- **IMPACT: 16kA/14kA pair separated by 0.1 ms located 20 km from Piikkiö**
- **Waveform: A very intense breakdown (without an RS)**



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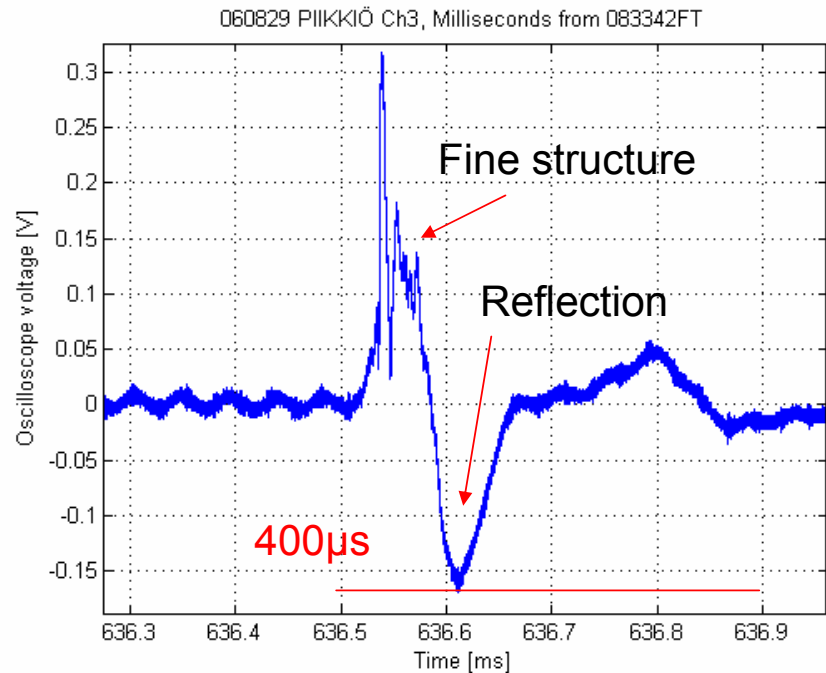
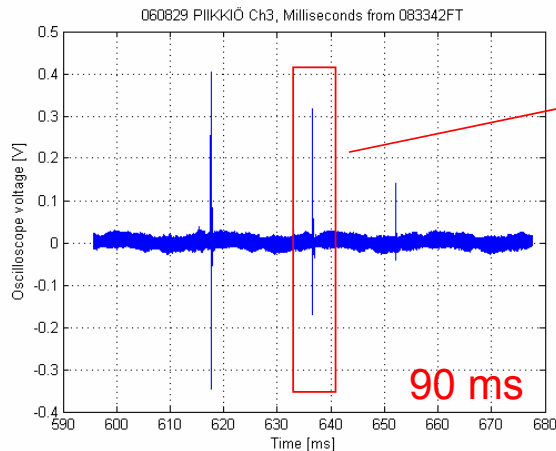


Bipolar pairs	26	
RS with fine structure	5	19%
PBP	7	26%
Narrow pulse(s)	6	23%
Unclear	8	30%

- There is no single dominating phenomenon
- In 30% of cases, no clear mechanism seen in waveform
- Ionospheric propagation can often be seen, but cannot be quantified exactly

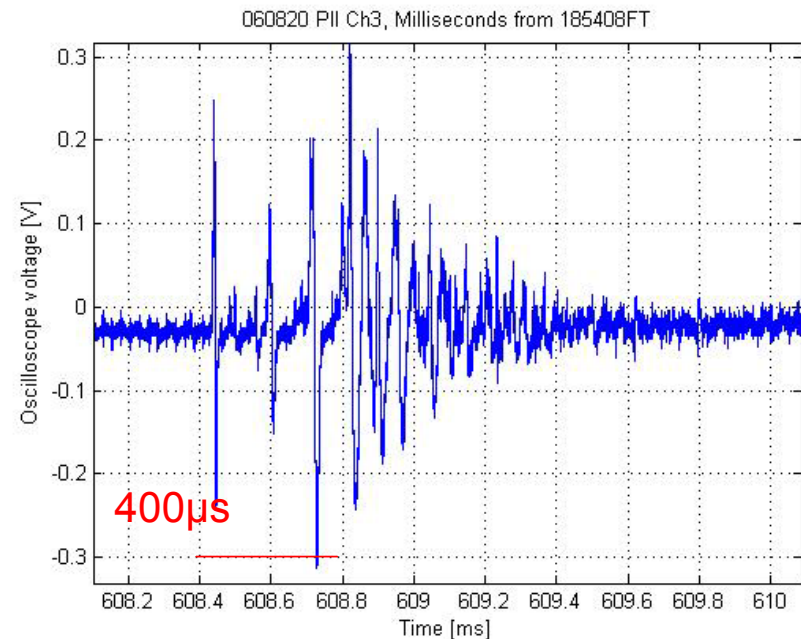
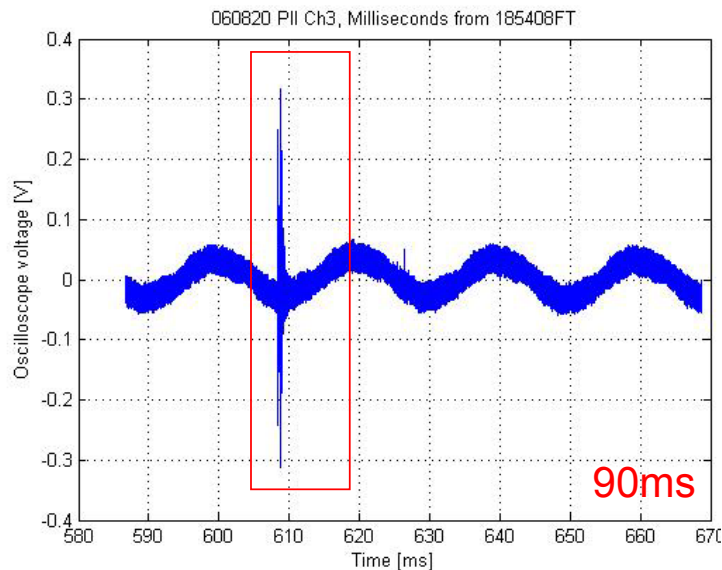
Bipolar pair: RS with fine structure

- **IMPACT: Multi-stroke flash with first RS -75kA, 170 km from Piikkiö. Second RS is +44/-43 pair, separation 0.1 ms, with long baseline**
- **Waveform: Weak reflection exists. The misidentified stroke has multiple terminations.**



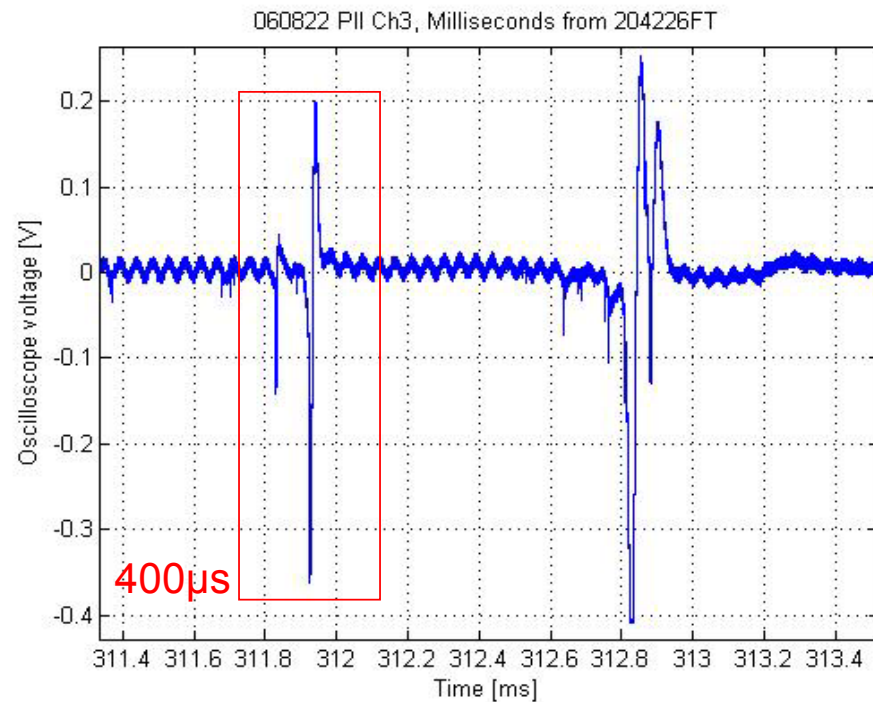
Bipolar pairs: preliminary breakdown

- **IMPACT: -15kA/+20kA pair, 0.1 ms delay**
- **Waveform: Preliminary breakdown (without RS)**



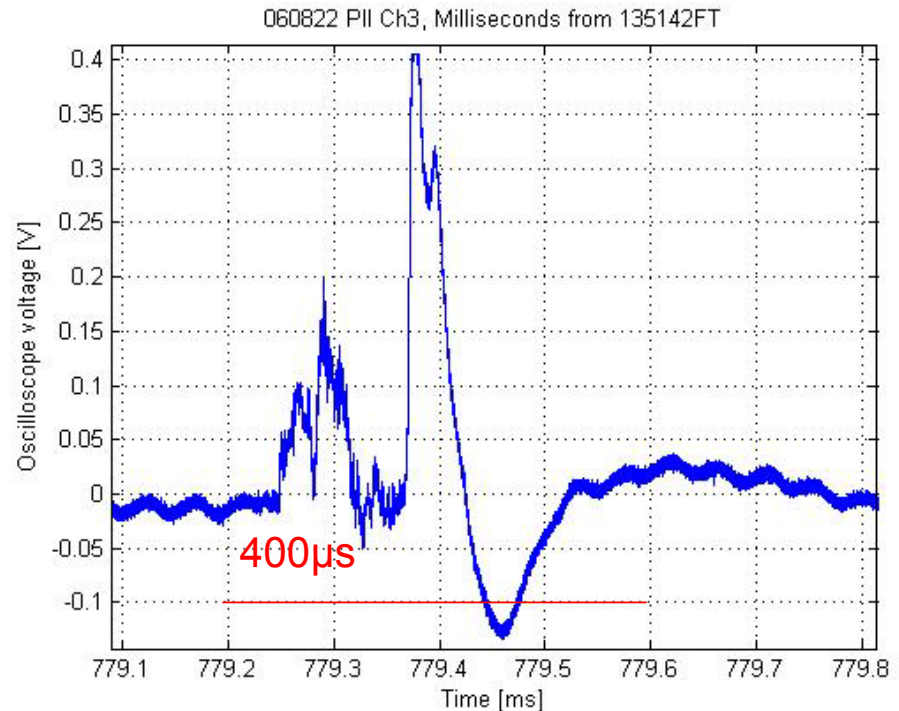
Bipolar pairs: narrow pulses

- **IMPACT: -**
18kA/+44kA pair,
0.1 ms delay, 100
km south of
Piikkiö, nighttime
propagation
- **Waveform: Two**
narrow bipolar
pulses, only one
of which
observed



Bipolar pairs: unclear

- **IMPACT: --**
25kA/+54kA pair,
0.1 ms delay, 50
km SW of Piikkiö,
daytime
- **Waveform:**
possibly an RS
with an
attempted RS?

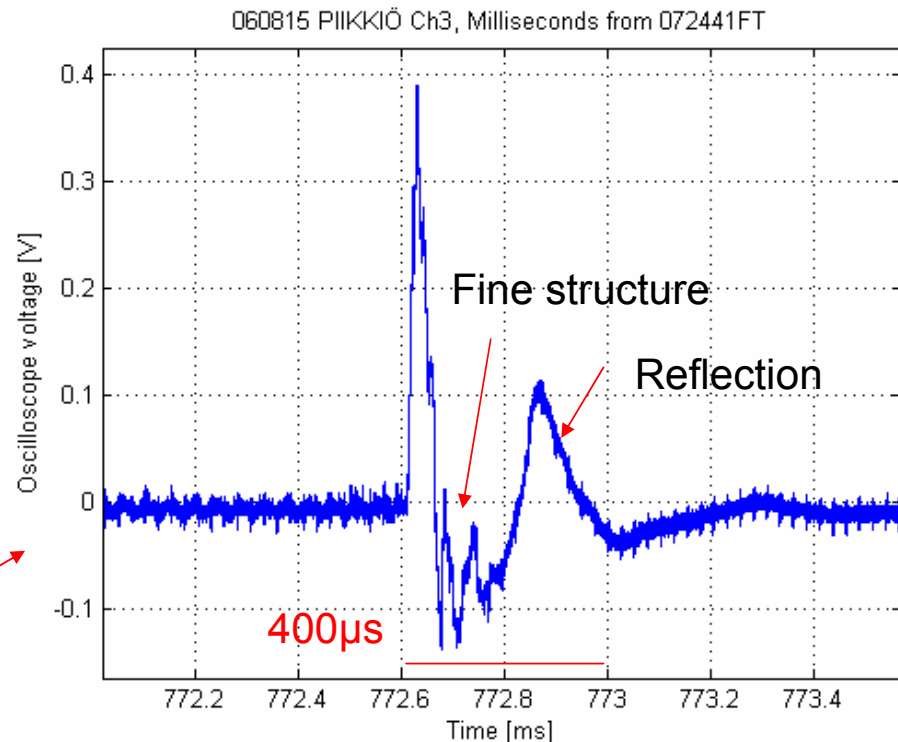
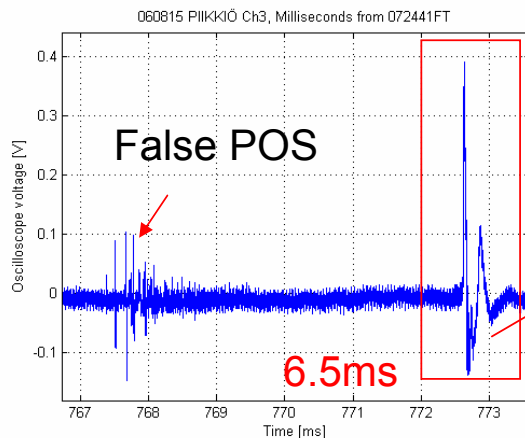


Negative-negative pairs	26	
RS with fine structure	13	50%
PBP	3	11%
Narrow pulse(s)	4	15%
Unclear	6	23%

- **Up to half of the return strokes have structure that suggests a physically genuine sub-millisecond stroke pair**
- **However, these are only observed because of the different dead times in the sensors.**

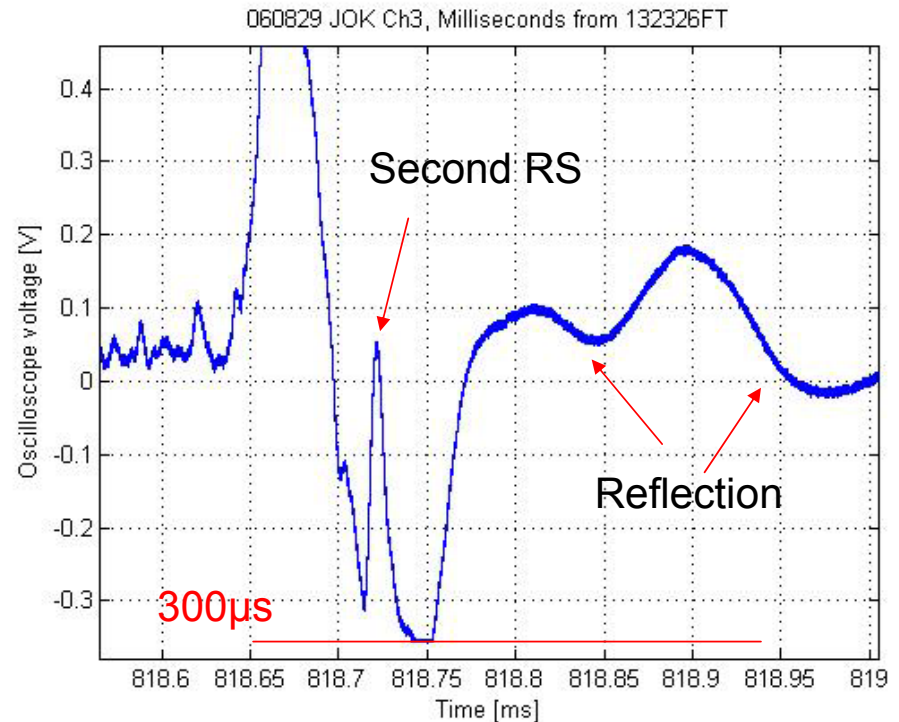
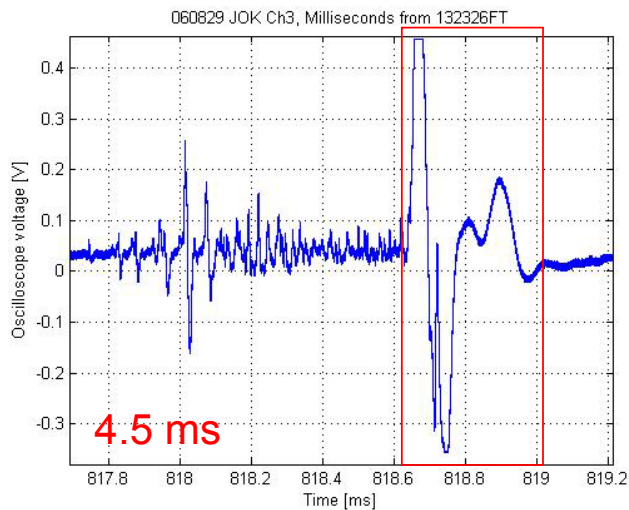
Neg-neg pairs: RS with fine structure

- IMPACT: Positive first RS, then a -71kA/-61kA double negative, 300km to SW, daytime
- Waveform: First positive is a misidentified PBP. The stroke pair RS has multiple terminations



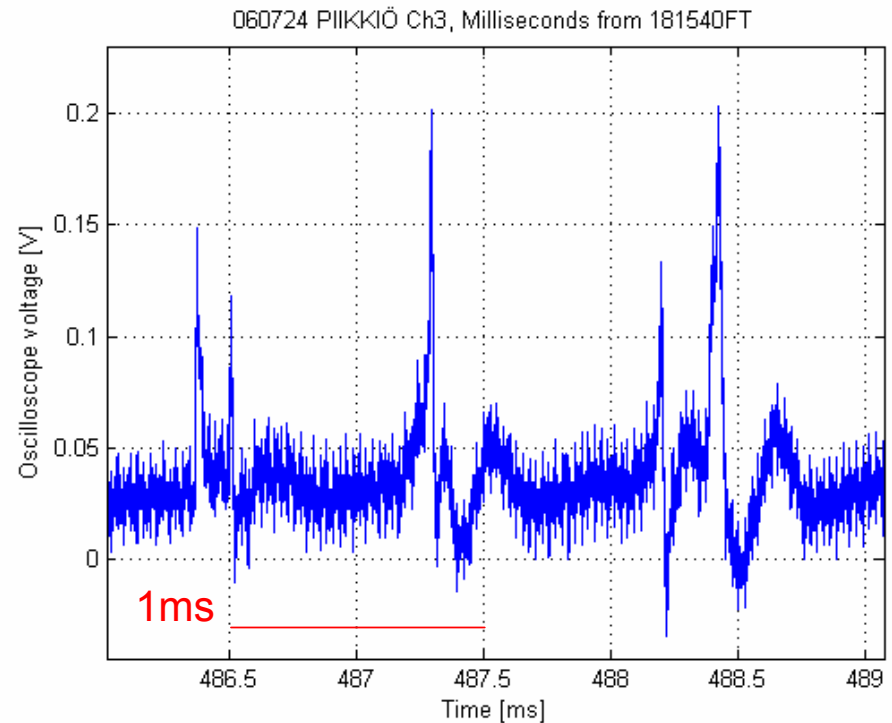
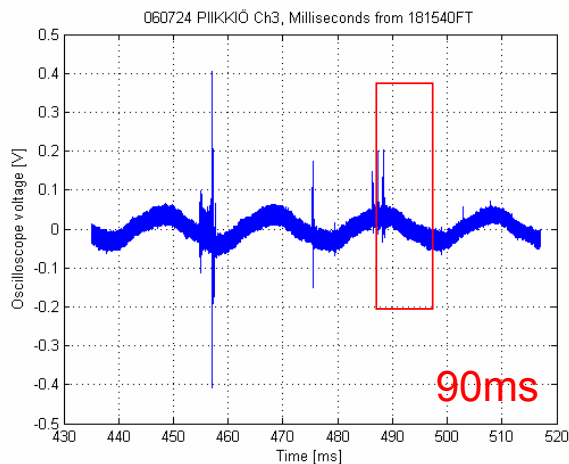
Neg-neg pairs: RS with fine structure

- **IMPACT: -18kA/-10kA pair, 0.2 ms time difference**
- **Waveform: double RS, and ionospheric reflection**



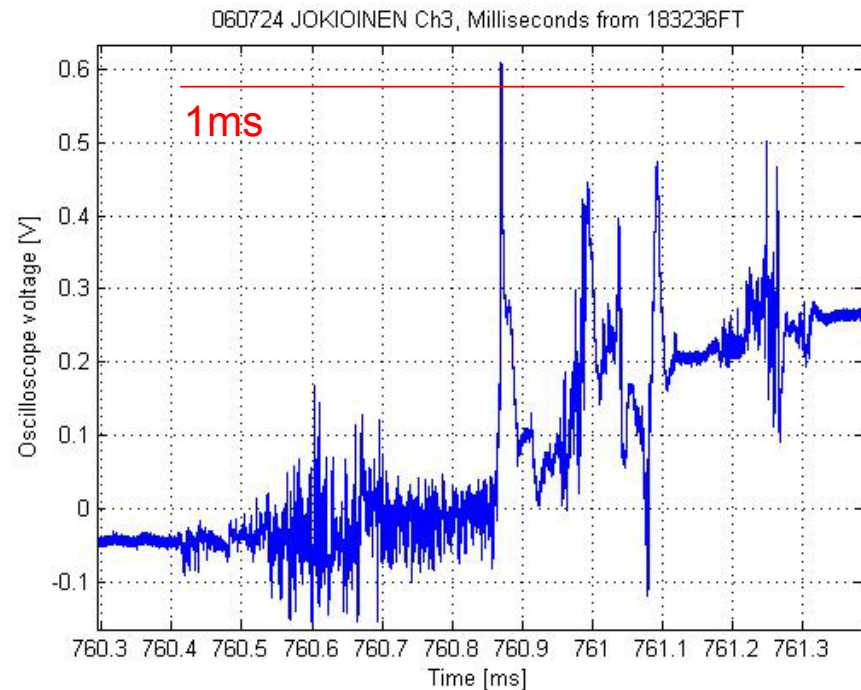
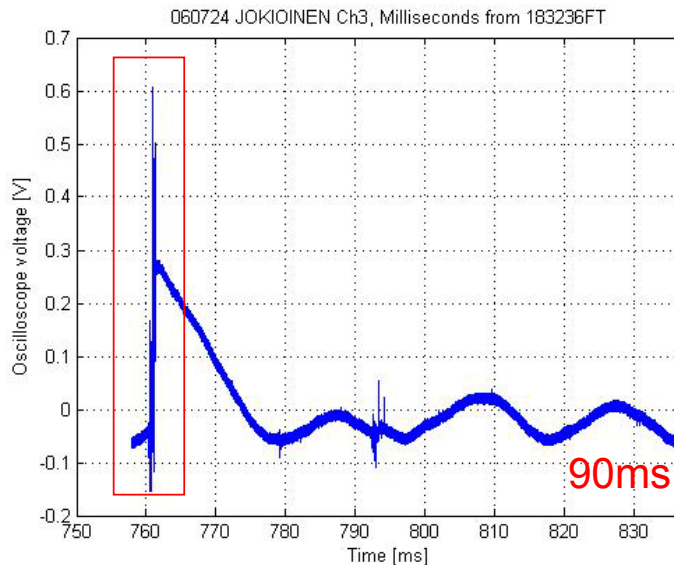
Negative-negative pairs: Pulse train

- **IMPACT: -13kA/-13kA pair**
- **Waveform: pulse train**



Negative-negative pairs: Miscellaneous

- **IMPACT: -17kA/-16kA pair, separation 0.1 ms**
- **Waveform: chaotic process**



Main causes of error

- **Preliminary breakdown: almost 100% of pos-pos cases, about 20% of the others.**
- **Return strokes with fine structure (“real” double return strokes): About 50% of neg-neg cases, 20% of bipolars**
 - **But note that this is an instrumental anomaly caused by multiple sensor types.**
- **Narrow pulses or pulse trains: About 20% of all cases**
- **Other processes: About 25% of all cases**

Comparison to the larger data set

- **Since reflection does play a role, the majority of errors should be at the edges of the network. This is observed**
- **The presence of two populations (short and long baseline) is easily explained. The physics are much the same, but when ionosphere reflects, long baselines can be seen.**

Conclusions on the IMPACT data

- **The sub-millisecond pairs are almost all instrumental anomalies, but the physical phenomena causing them can often be understood**
 - **Preliminary breakdowns are the largest single error source, though others exist**
- **Even where the return stroke has a genuine double structure, the network only observes the double because of the instrumental effects**

General conclusions

- **Waveforms can (and should) be used to identify error mechanisms**
 - **“Relatively easy” to set up**
 - **Unlike e.g. video records, can reveal in-cloud processes and are not limited to evaluating CG accuracy**
- **Main physical conclusion: We suggest that PBP’s can be a significant error source at high latitudes**

Next steps

- **A larger study is needed to evaluate the identification accuracy in “ordinary” flashes**
- **Evaluate whether the preliminary breakdown errors are specific to high latitudes**
 - **PBP’s are suggested to be strong in Scandinavia, weaker at lower latitudes, but more data needed.**