International Lightning Protection Association Symposium

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Artificially Triggered Lightning in Guangdong, China

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CONTENTS

Introduction

Overview of GCOELD

- **GCOELD:** Guangdong Comprehensive Observation Experiment on Lightning Discharge.
- **Duration:** Every summer from 2006 to now.
- **Organizers:**
  - Chinese Academy of Meteorological Sciences
  - Guangdong Meteorological Bureau
- **Contents:**
  - Discharge process in triggered lightning and natural lightning
  - Effects of lightning discharge on other objects.
  - Testing of lightning detection equipment.
  - Lightning striking the high structures.
  - Investigations into lightning location technology.

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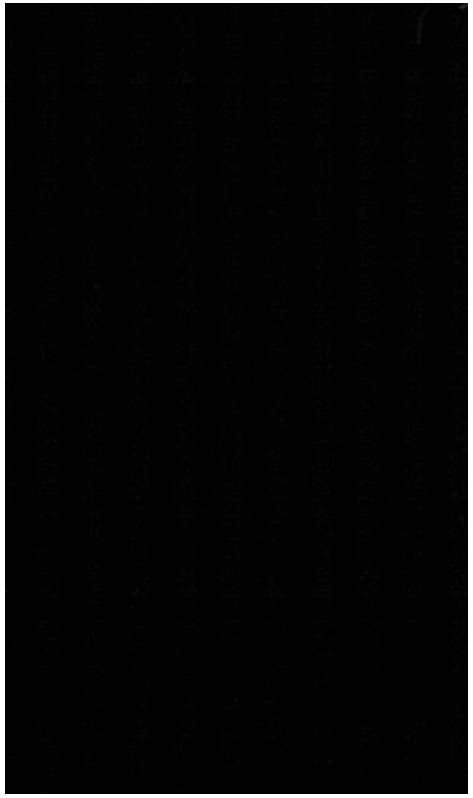
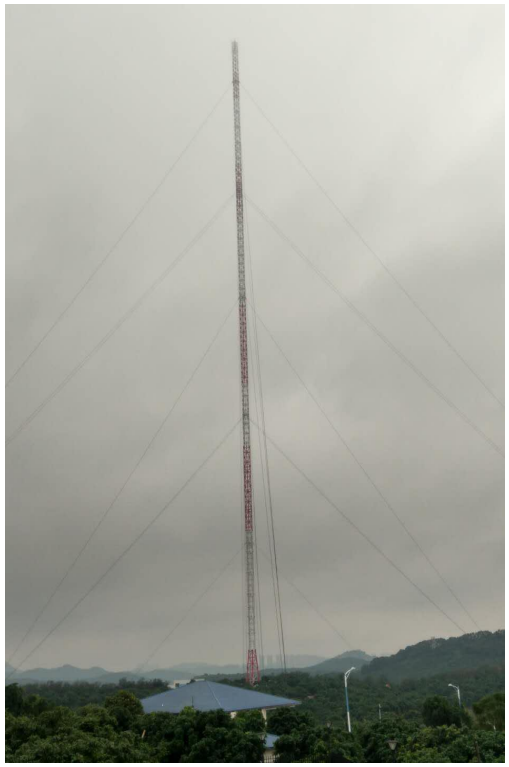
Introduction

Triggered lightning in Conghua, Guangzhou



Lightning on high buildings in Guangzhou
TV Tower: 600 m
upward leader: 394 m



Lightning on tower in Shenzhen(360m):
a lightning current system on the top of the tower

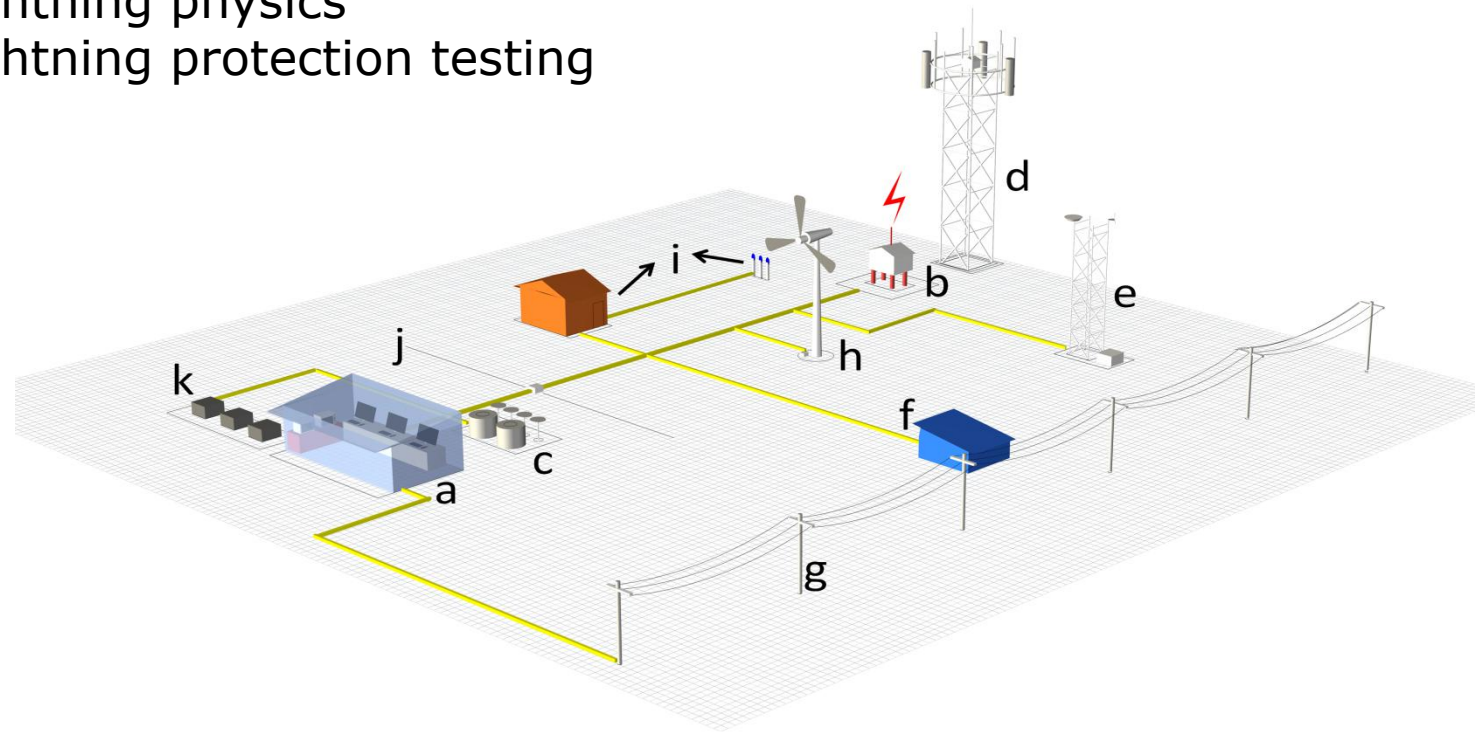
70km

120km

Experiment of triggered lightning

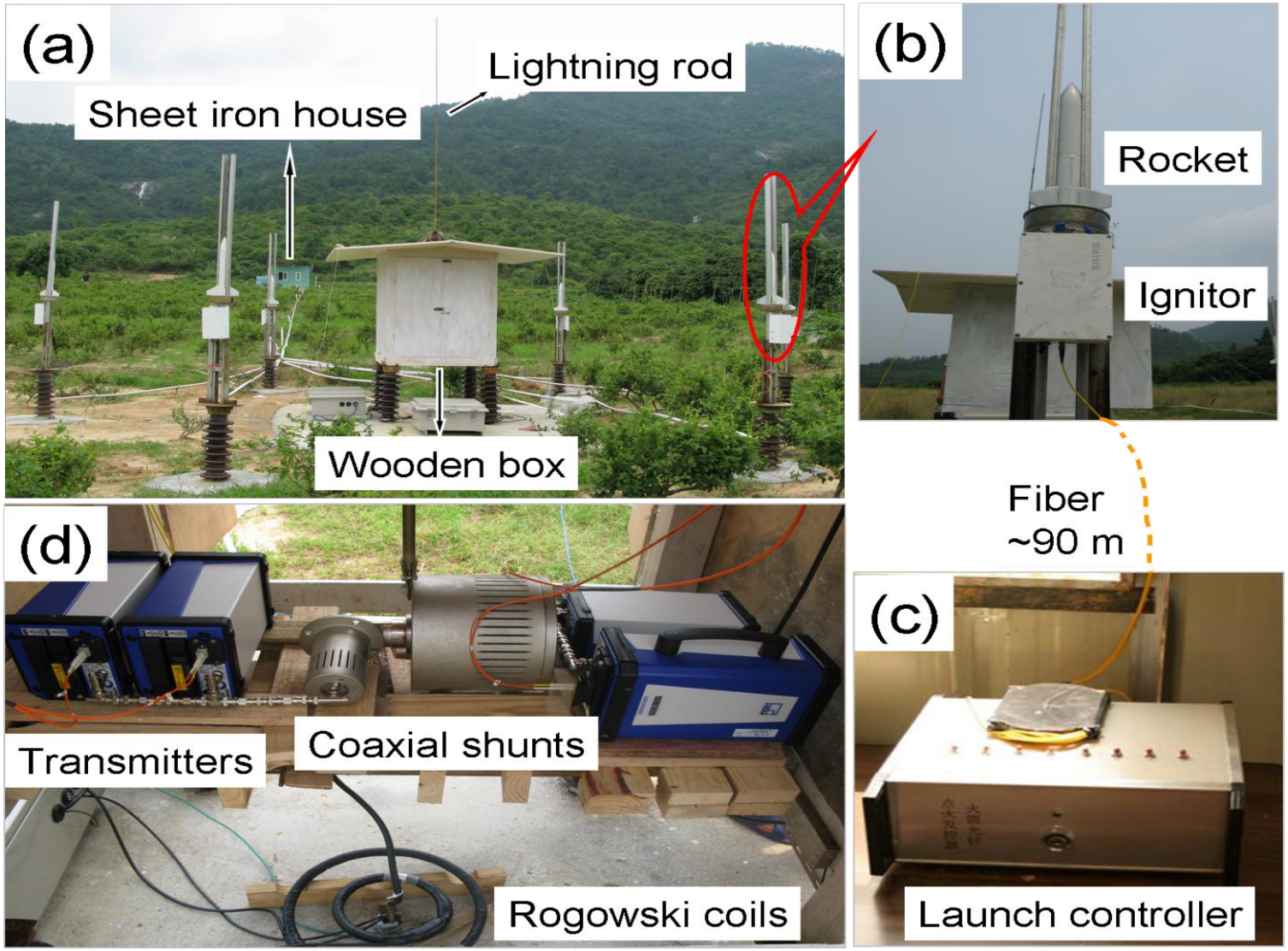
Field experiment site

- Triggering lightning
- Lightning physics
- Lightning protection testing



Layout of the test equipment at the TLF field site. (a): Control room (rocket launches and data acquisition are conducted from here). (b): Wooden house (the lightning rod is installed above it and the current-measuring equipment is covered by it). (c): Region for measurement of electric parameters. (d): Iron tower (a model of a communication tower). (e): Automatic weather station. (f): Region for test of surge protection devices. (g): 10 kV overhead line. (h): Wind turbine. (i): Petrochemical instrument (sensor and power of distribution control system). (j): Buried cables. (k): Shields constructed by brick, concrete and steel mesh.

Experiment of triggered lightning



Experiment of triggered lightning

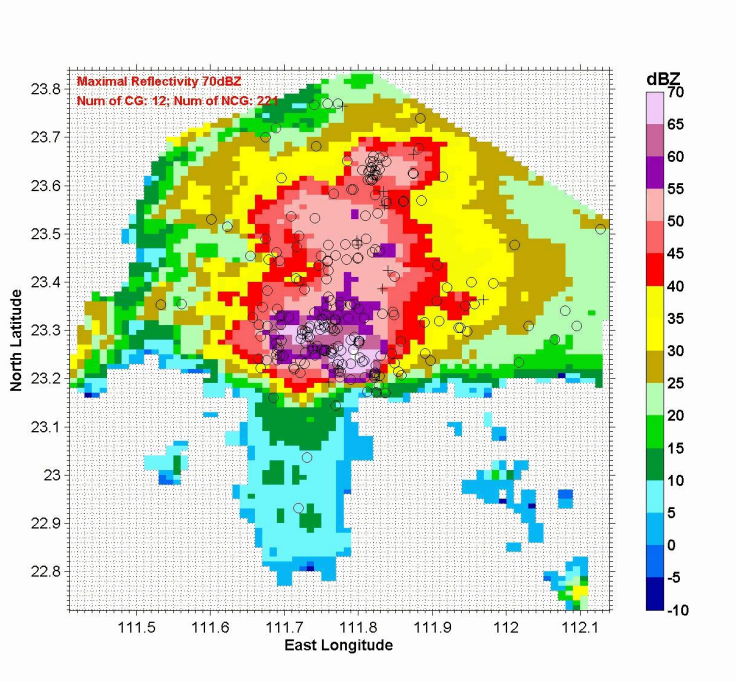
Classical Triggering lightning

Triggering lightning on tower

Experiment of triggered lightning

✓Type: CS110 (Campbell Scientific, INC.)

✓Sampling rate: 1 Sa s^{-1}



Radar echo（30dBz）
electric field mill（》8kV/m）

Experiment of triggered lightning

- ✓ Fast antennae with a time constant of 2 ms and a band-width of 1 kHz–2 MHz,
- ✓ Slow antennae with a time constant of 6 s and a band-width from 10 Hz to 3 MHz,
- ✓ Loop magnetic antennae with a band-width of 100 Hz–5 MHz.
- ✓ Collected by the DL750
- ✓ Sampling length: 2 s
- ✓ Sampling rate: 10 M Sa s^{-1}

Observation of electric and magnetic field

Experiment of triggered lightning

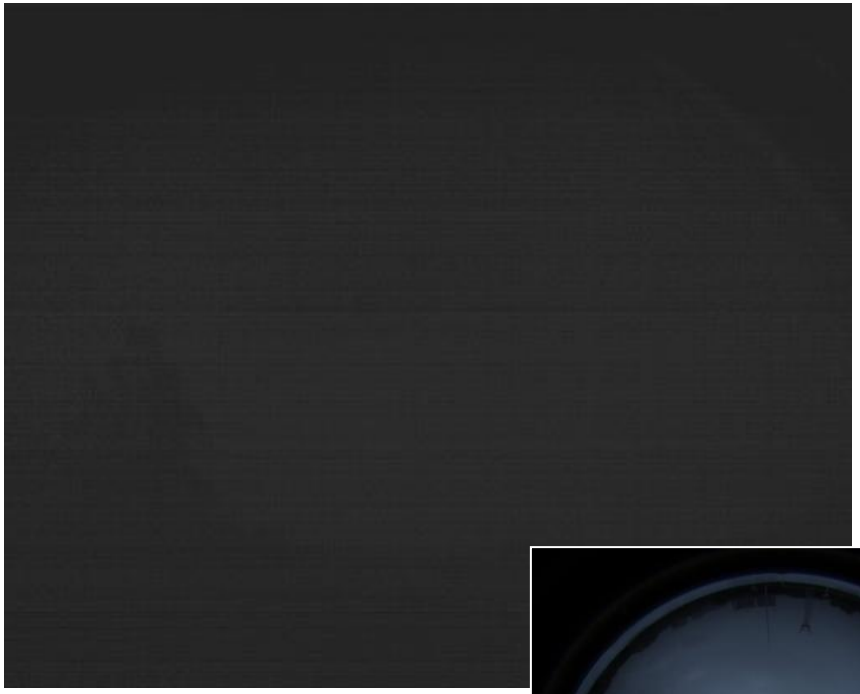
Type: MotionPro Hs-4

Photographic panel: 512 × 512 pixels

Pixel size: 16 × 16 μm

Shooting rate: 5000 fps

Exposure time: 197 μs



High speed camera

Total-sky lightning channel imager
Shooting rate: 50 fps

Optical observation

Experiment of triggered lightning

- Current measurement:, Pearson coil, Bandwidth, 150Hz~150MHz
- a resistive–capacitive voltage divider to measure the induction voltage, divider voltage ratios, 204.9:1 and 203:1

- GPR measurement： voltage divider, divider voltage ratio, 1:2500。

Experiment of triggered lightning

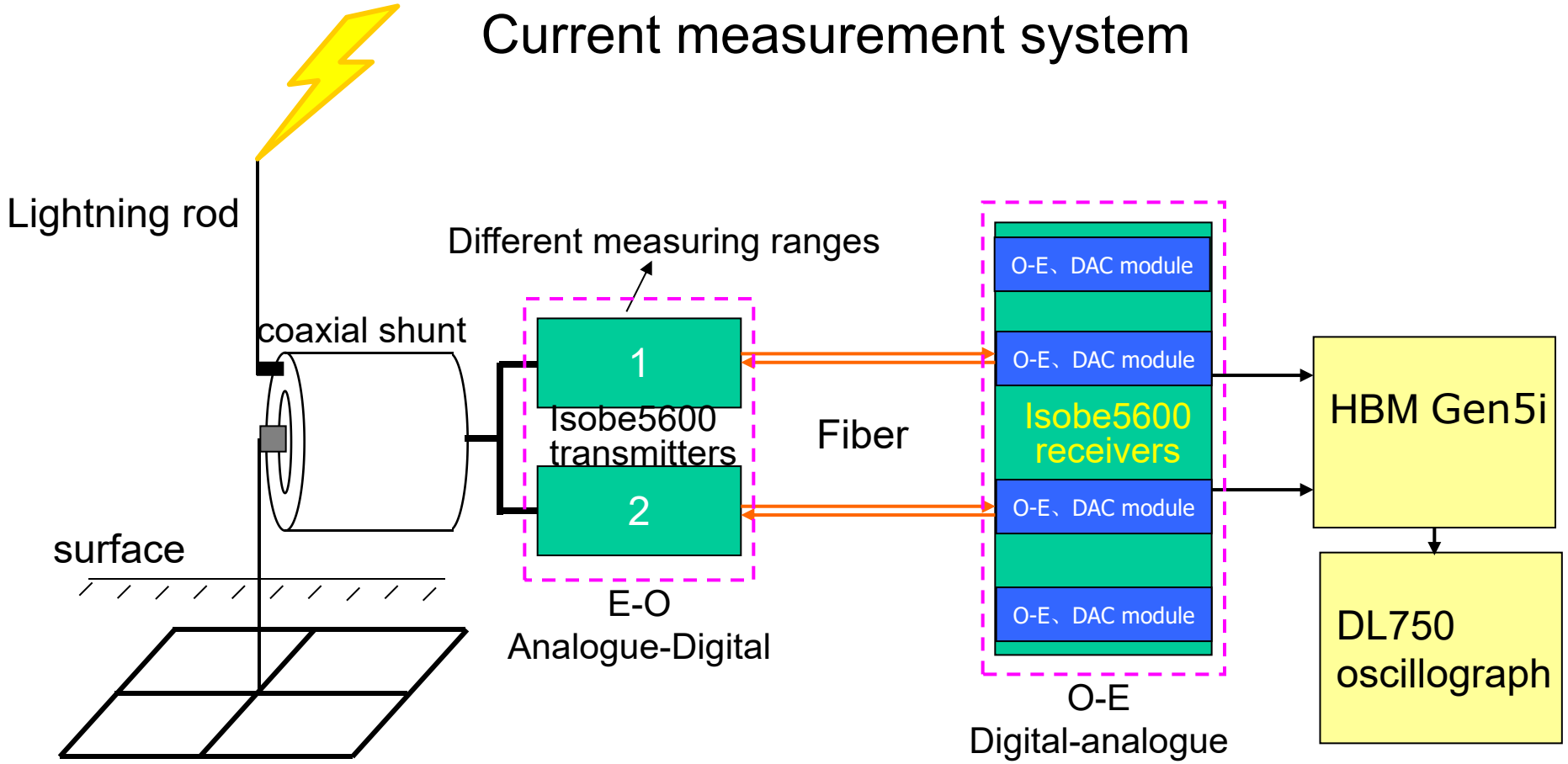
Year	No. of triggered lightning	No. of launched rockets	Altitude/classical triggering	Succeeful Rate
2006	6	18	0/6	33%
2007	12	21	2/10	57%
2008	5	22	1/4	23%
2009	7	28	2/5	25%
2010	6	28	3/3	21%
2011	13	23	2/11	56%
2012	2	14	1/1	15%
2013	8	28	0/8	28%
2014	15	24	0/15	63%
2015	20	24	1/19	83%
2016	13	19	1/12	68%
2017	16	20	1/15	80%
2018	27	43	1/26	63%
total	150	312	15/135	48%

2006-2018

- 150 triggered lightning discharges
- 148 negative polarity (135 classical triggering ; 15 altitude triggering ）
- 2 positive polarity without return strokes

Experiment of triggered lightning

Current measurement system



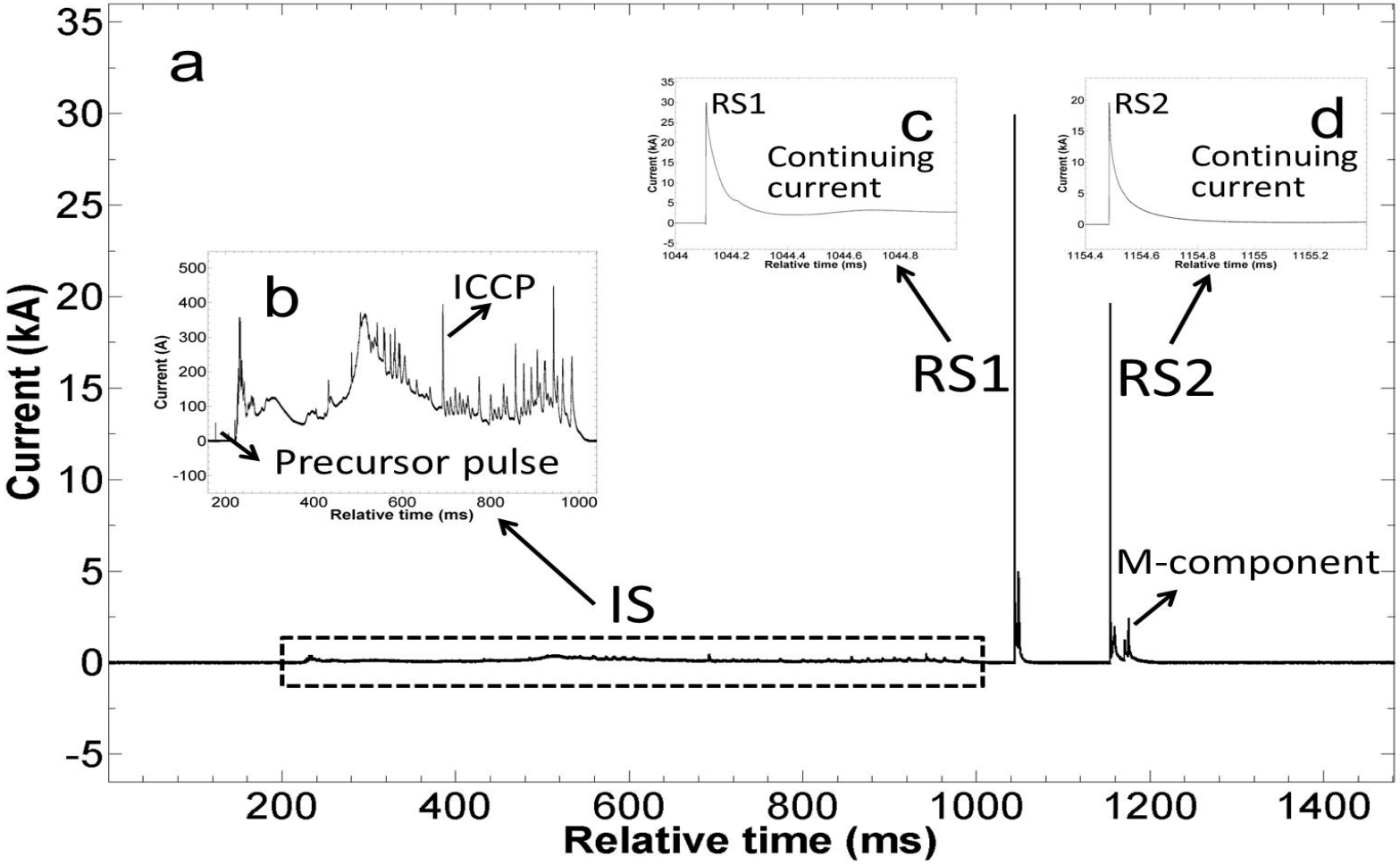
Grounding grids

10 m in side length
5 m in side length of each grid
grounding resistance of 6.7 Ω

Advantages:

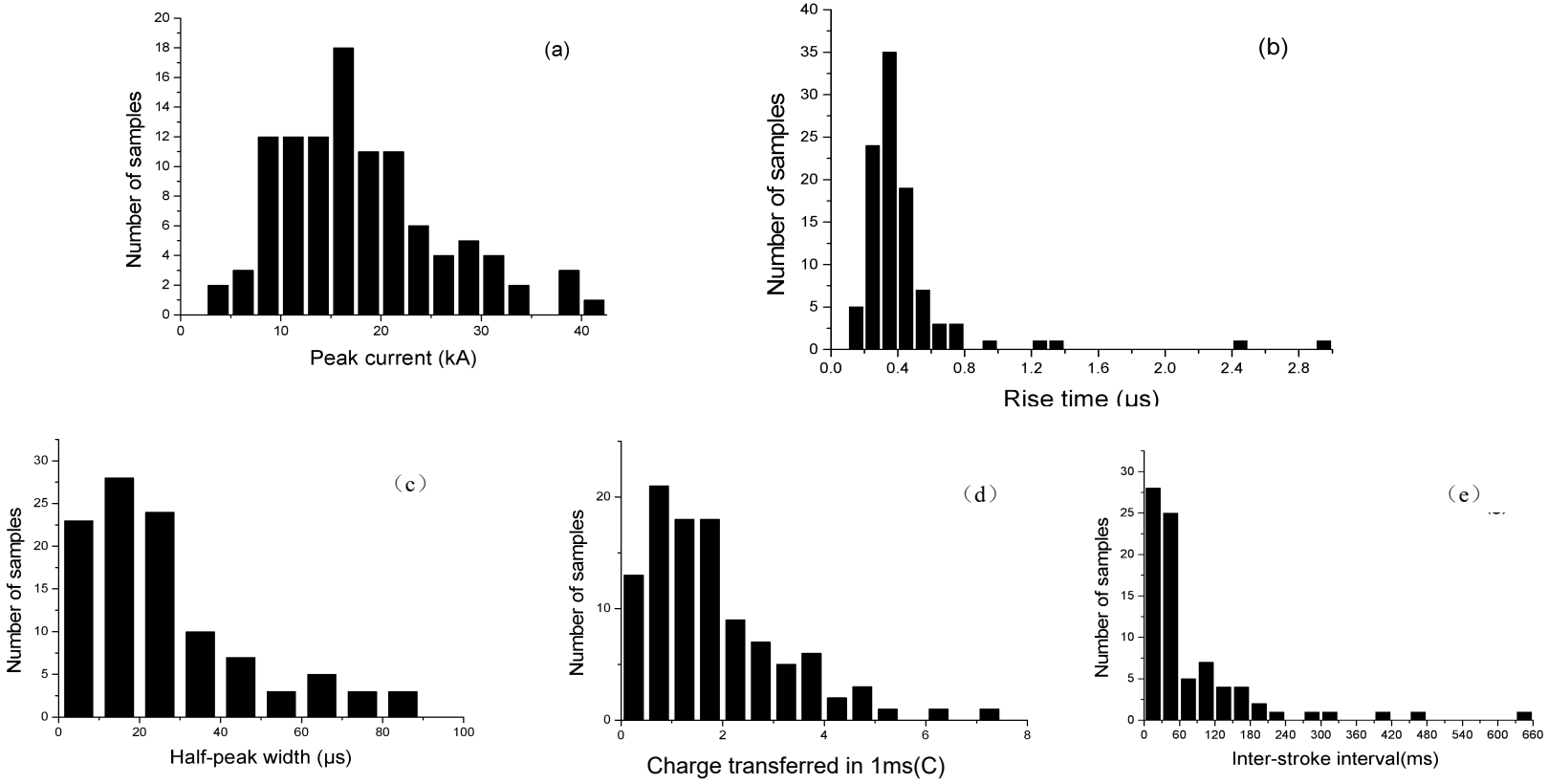
- Excellent anti-interference capability
- High accuracy (error range: 0.3%)
- Coverage of different magnitudes of current

Results of triggered lightning current



An example of the current waveform of a classical TLF (T150612161626). (a): Whole current waveform. (b): The IS current. (c) and (d): Partial enlarged details of the first and second RS current waveforms and the following continuing currents, respectively. The current waveforms shown in a, c, and d were recorded using the channel with a ±50 kA measuring range, whereas that shown in b was recorded using the channel with a ±2 kA range. ICCP: Initial continuous current pulse.

Results of triggered lightning current

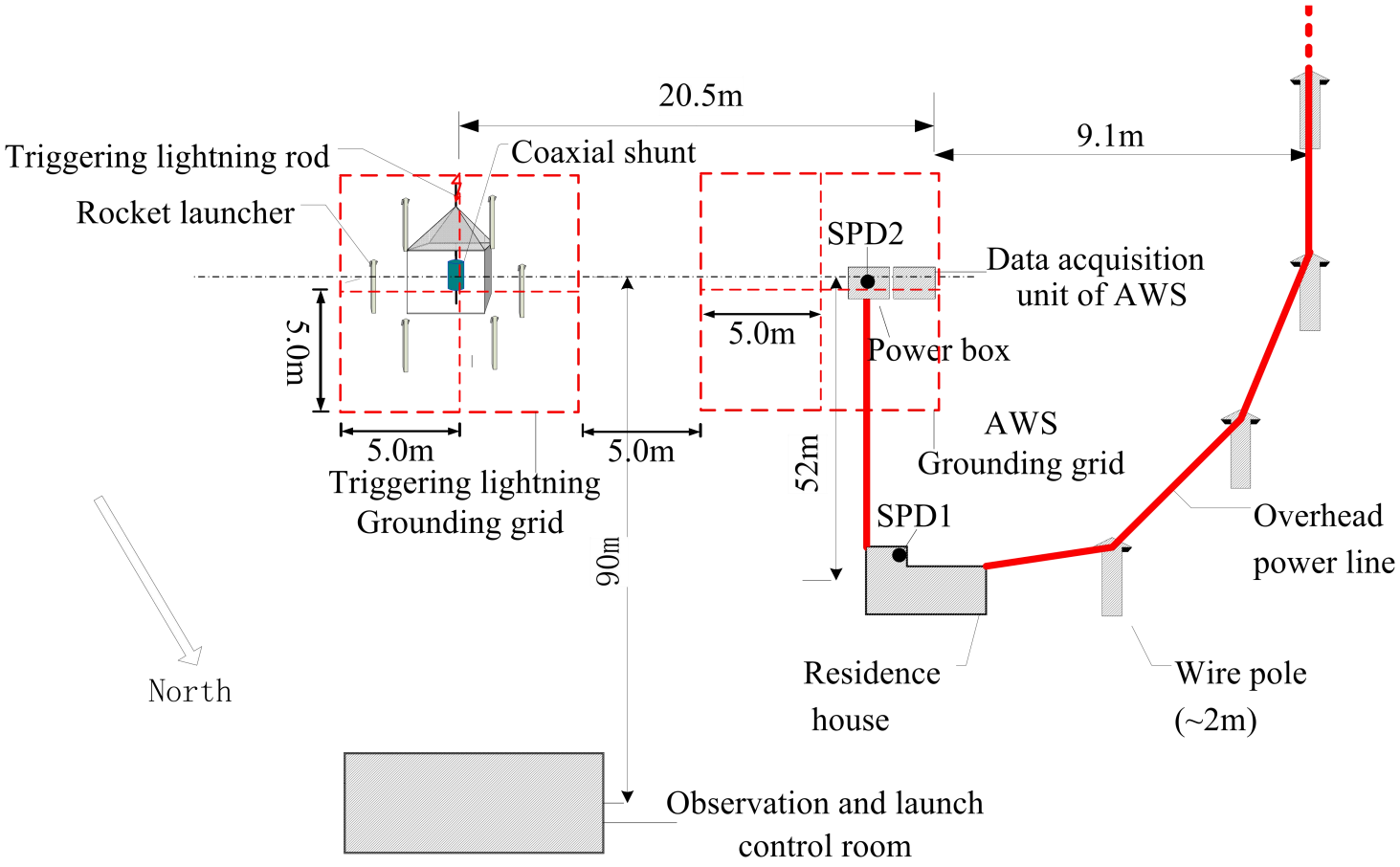


Distributions of the main parameters of return strokes（n=106）.

The peak current of most return strokes is between 7.5 and 22.5 kA, and the rise time is between 0.2 and 0.6 μs. The half-peak width is between 10 and 30 μs, and the amount of charge transferred in 1 ms is between 0.5 and 2 C.

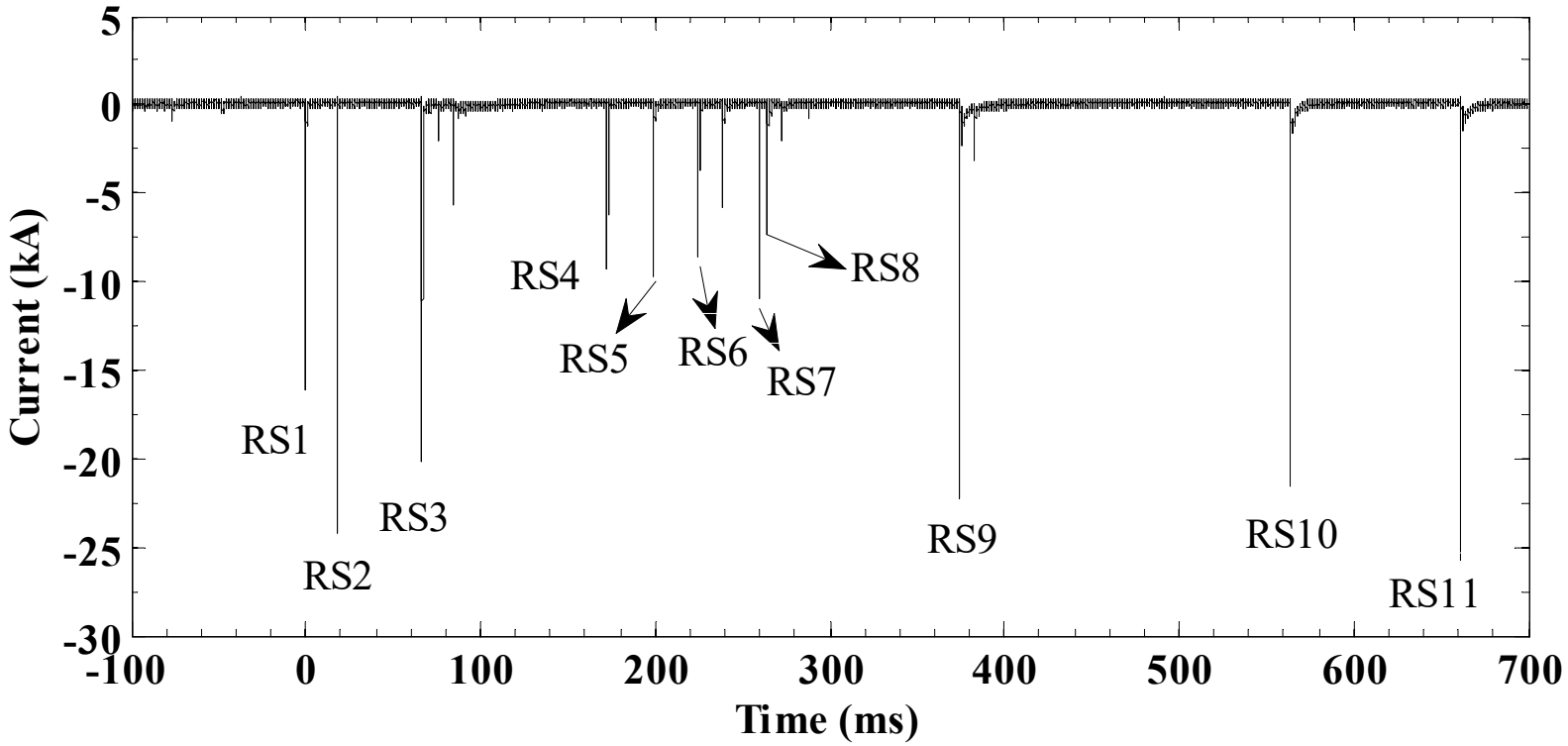
Results of SPD testing

Observation arrangement



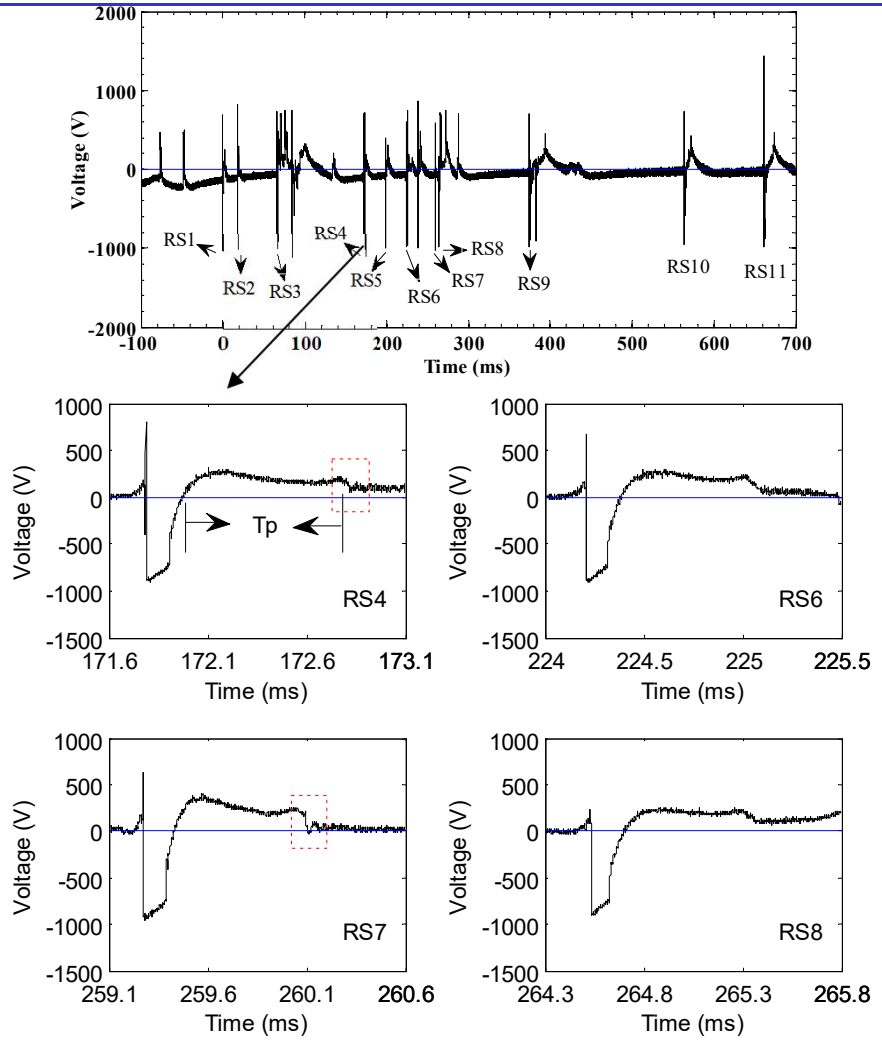
Results of SPD testing

Case one (2014-06-20 15:05:06), 40m away from SPD1



Channel-base current waveform of T201404 (except the return strokes; the others were M-components)

Results of SPD testing



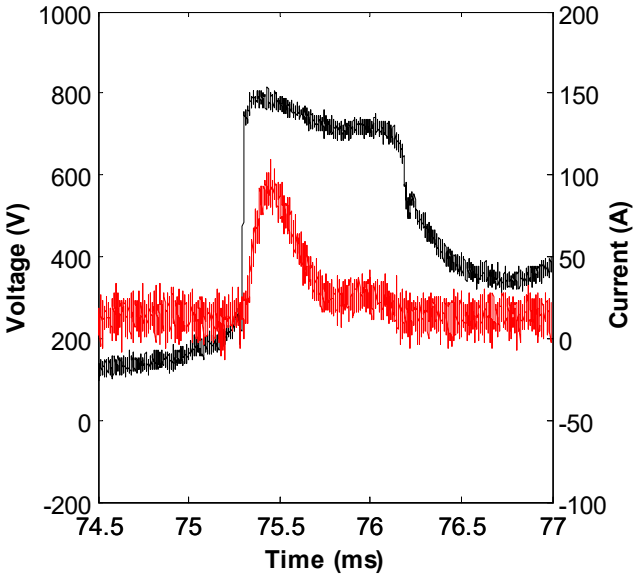
Expanded voltage waveforms between two terminals of the SPD in residence house for RS4, RS6, RS7 and RS8 during T201404
Tp : the time interval between the first time the residual voltage reaches zero and the first time the voltage suffers the recoil features

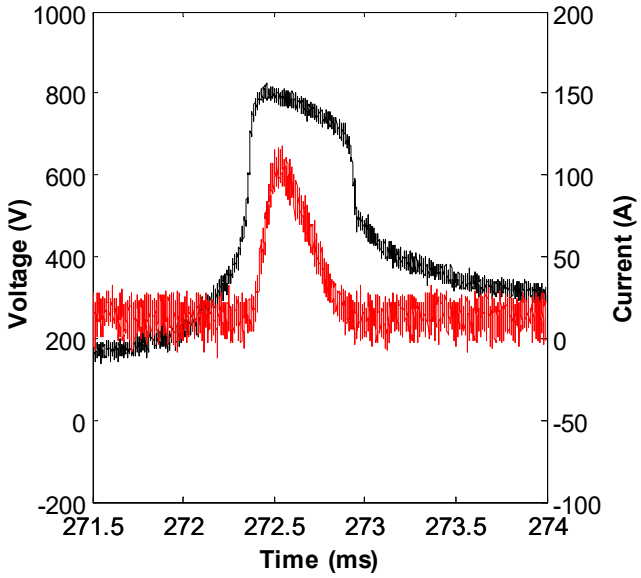
The voltage waveforms between two terminals of the SPD1 during T201404.

- all of the voltage waveform show bipolar pules first, due to the electric field variation caused by the preceding leaders and return strokes
- When the negative residual voltage recovers to zero, the voltage of the positive voltage appears.
- The Tp of the four return strokes ranges from 623.4 μs to 829.4 μs, with the average being 683.8 μs.
- the ground potential rise (GPR) maybe play a key role.

Results of SPD testing

M-components with minor current



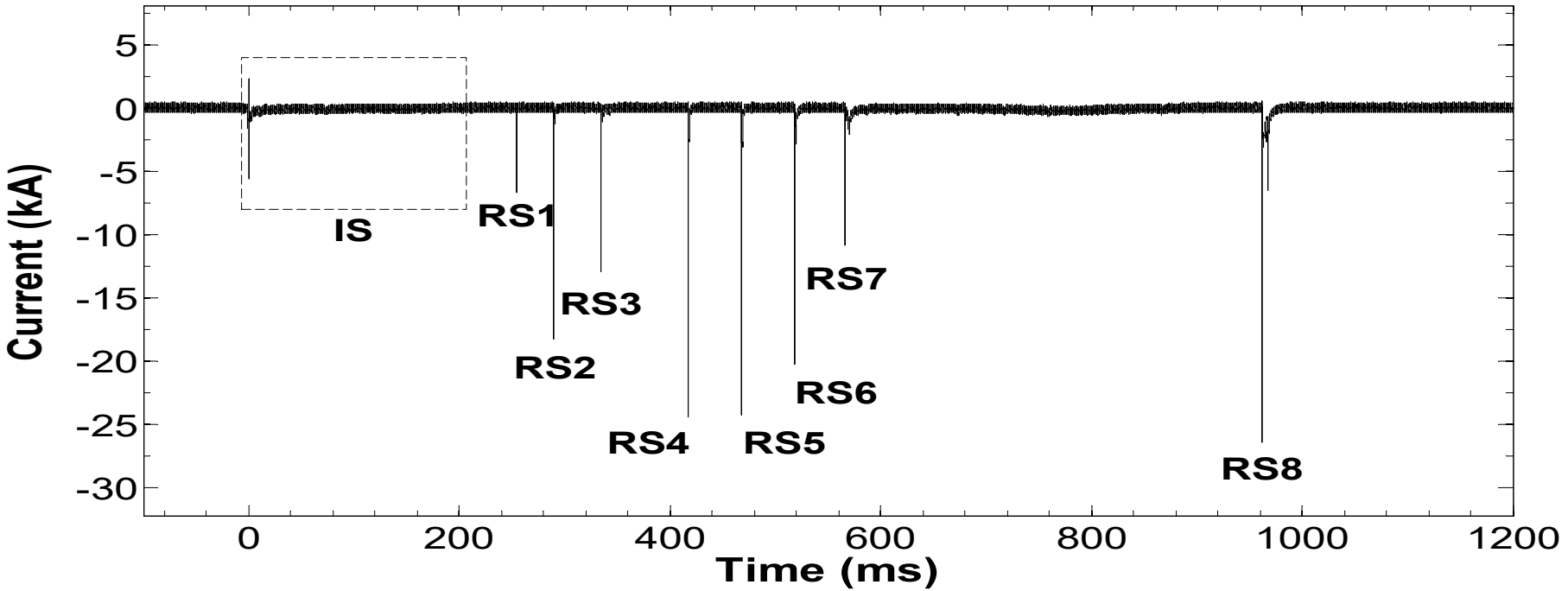


Residual voltage waveform (black lines) of the SPD1 and the corresponding current waveform (red lines) flowing through the SPD1 during two minor M-components (3,5kA) in T201404.

- contrary to the return strokes, the residual voltages of the SPD1 due to the minor M-components are of positive polarity.
- The amplitude of the GPR may be larger than that of the induced voltage at the overhead line.
- in T201404, the SPD1 acted for the 11 return strokes and 13 M-components, and the lightning current via the SPD ranged from 0.2-0.9 kA(AM=0.5 kA)
- The SPD was not damaged. The average duration time of the residual voltage was 157.3us.

Results of SPD testing

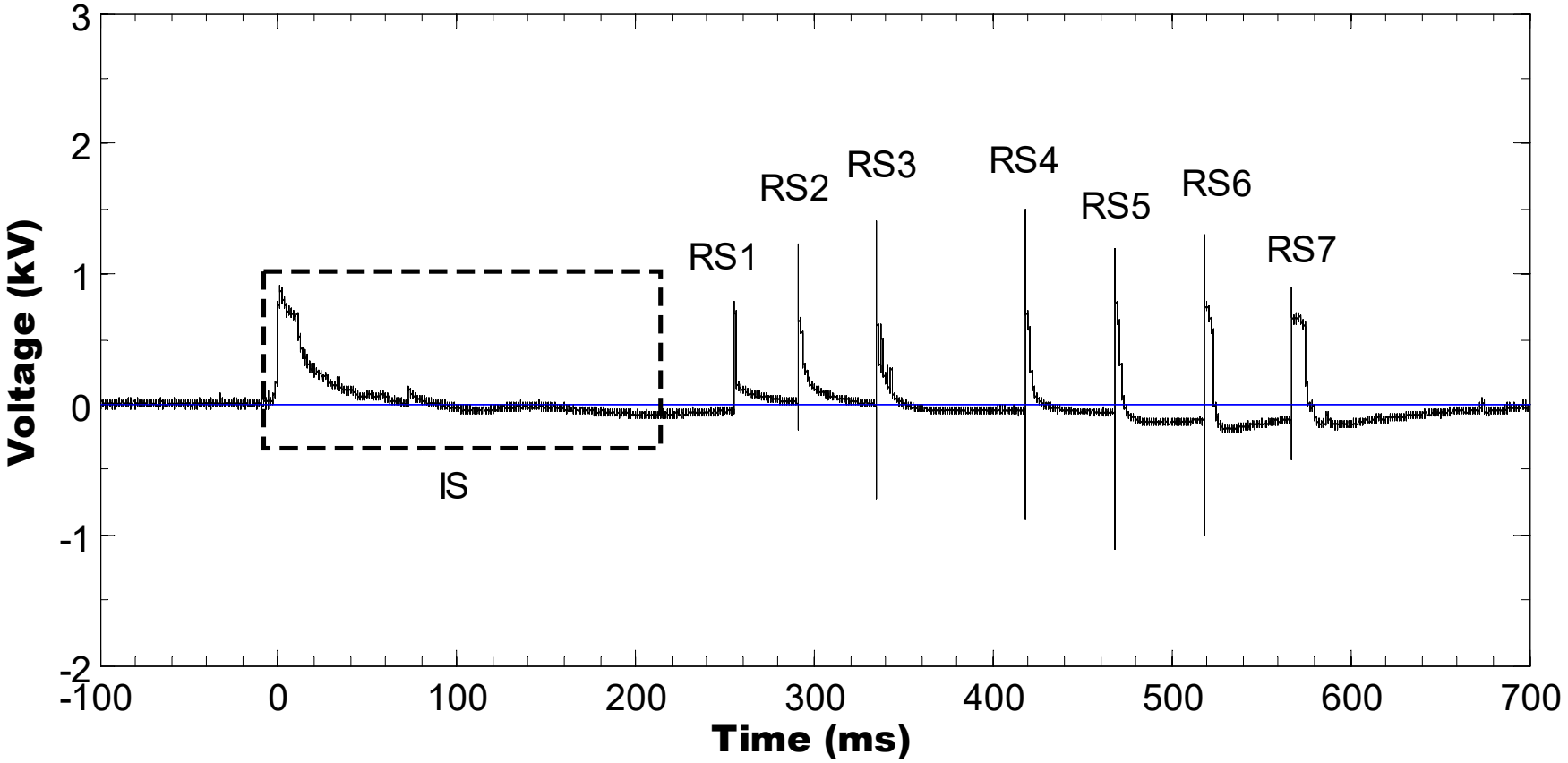
Case 2, (2008-08-12 17:09:21), 5m away from SPD2



Channel-base current waveform of T200804

This lightning contained an initial stage (IS) and eight return strokes

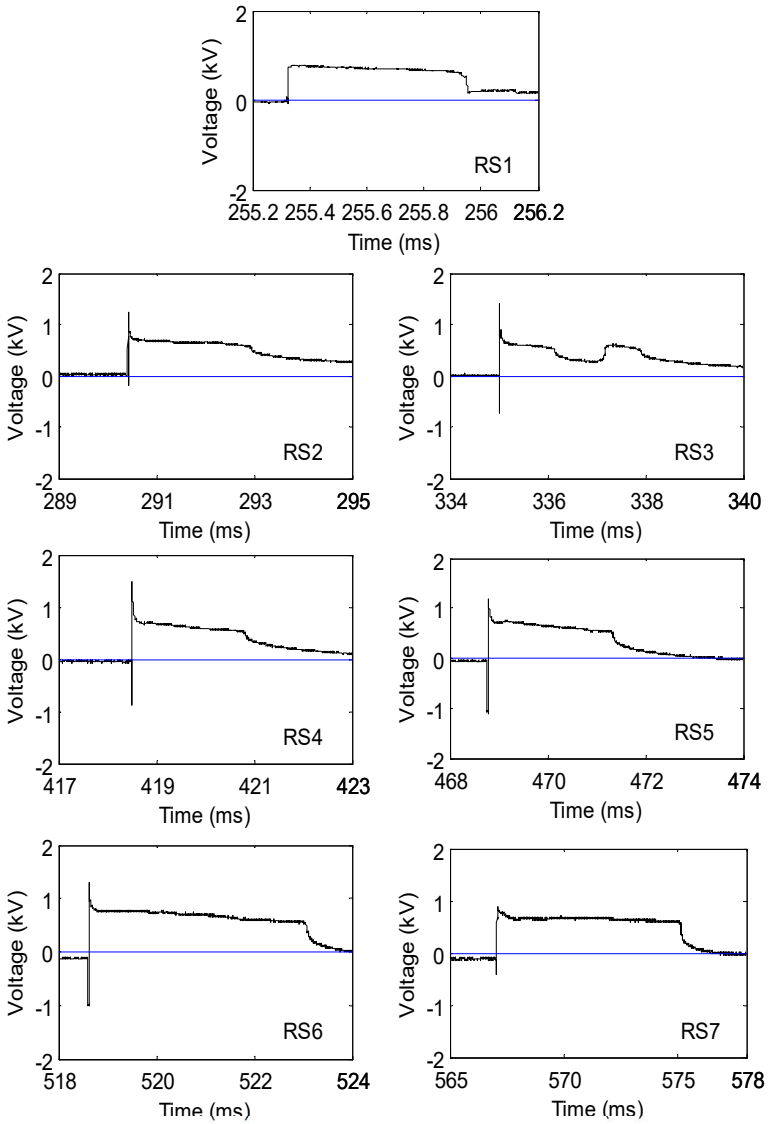
Results of SPD testing



The voltage waveform of the SPD for T200804

Due to the limitation of the recording length, only the waveform of the voltages induced by the IS and the first seven strokes were recorded.

Results of SPD testing



Expanded voltage waveforms for the seven return strokes during T200804

- SPD2 was installed 5 m from the earthing system of rocket launcher.
- the polarity of the residual voltage is positive
- there is a negative pules before the residual voltage.
- the voltage tends to decrease to zero when the positive residual voltage of the SPD ends.
- The residual voltages of the SPD2 during T200804 were produced by the GPR.

Results of SPD testing

- In T200804, the SPD2(Imax=20 kA) was damaged.
- The SPD2 acted for the 7 return strokes and lightning current via the SPD2 ranged from 0.22-1.64 kA(AM=0.77 kA)
- the average duration of the residual voltage was 2.1ms.

Results of SPD testing

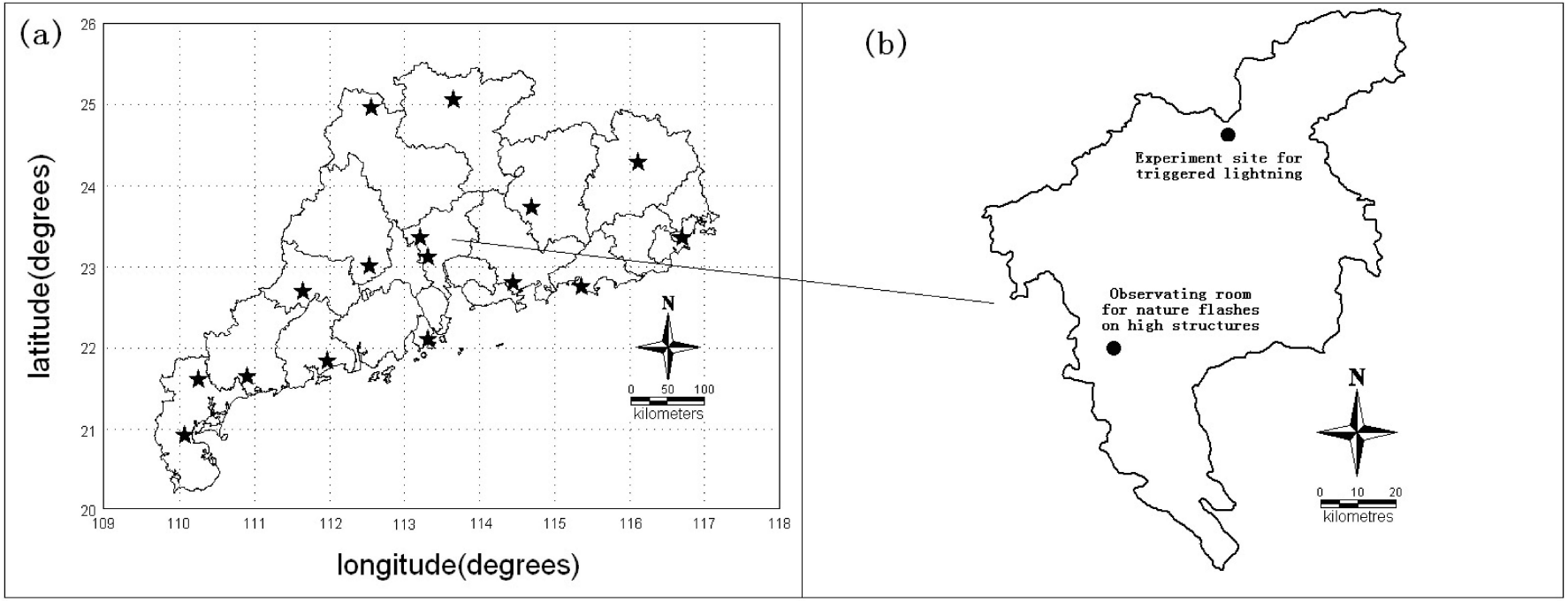
1）When the distance between lightning discharge and SPD was about 40m, the residual voltage of the SPD is determined by the voltage induced on the overhead line for processes with large current.

2）When the distance between lightning discharge and SPD was about 5m, the residual voltage of the SPD produced by the GPR.

3） The residual voltage of SPD can be influenced by the GPR when lightning discharge occur near SPD.

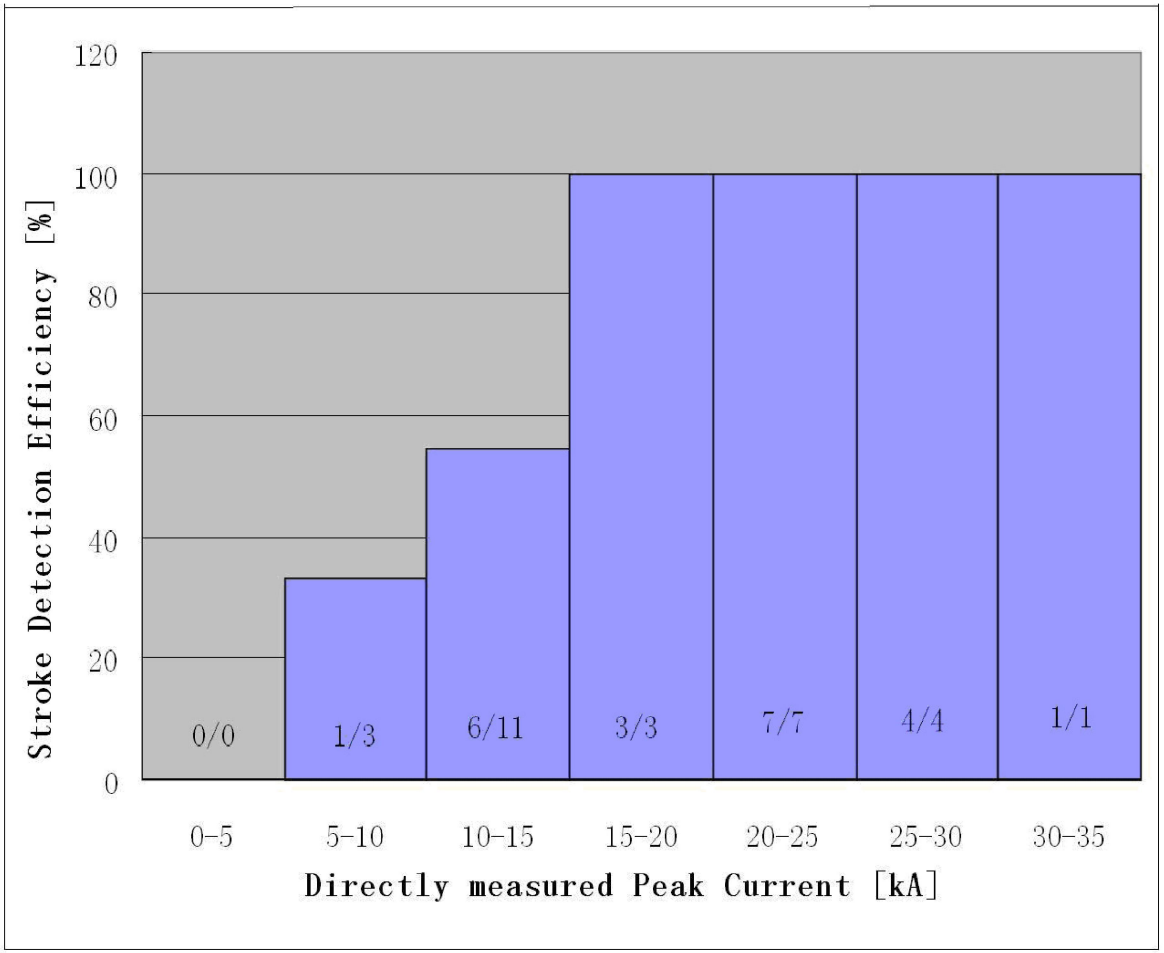
4)The more long durations of residual voltage may damage to SPD if the lightning involve more return strokes.

Performance of lightning location systems



- 16 sensors of LLS in Guangdong Province
- Operating for 15 years
- The detection efficiency and locating accuracy of LLS need to be evaluated
- Experiment site of triggered lightning and observation site of natural lightning on high structure were set up

Performance of lightning location systems

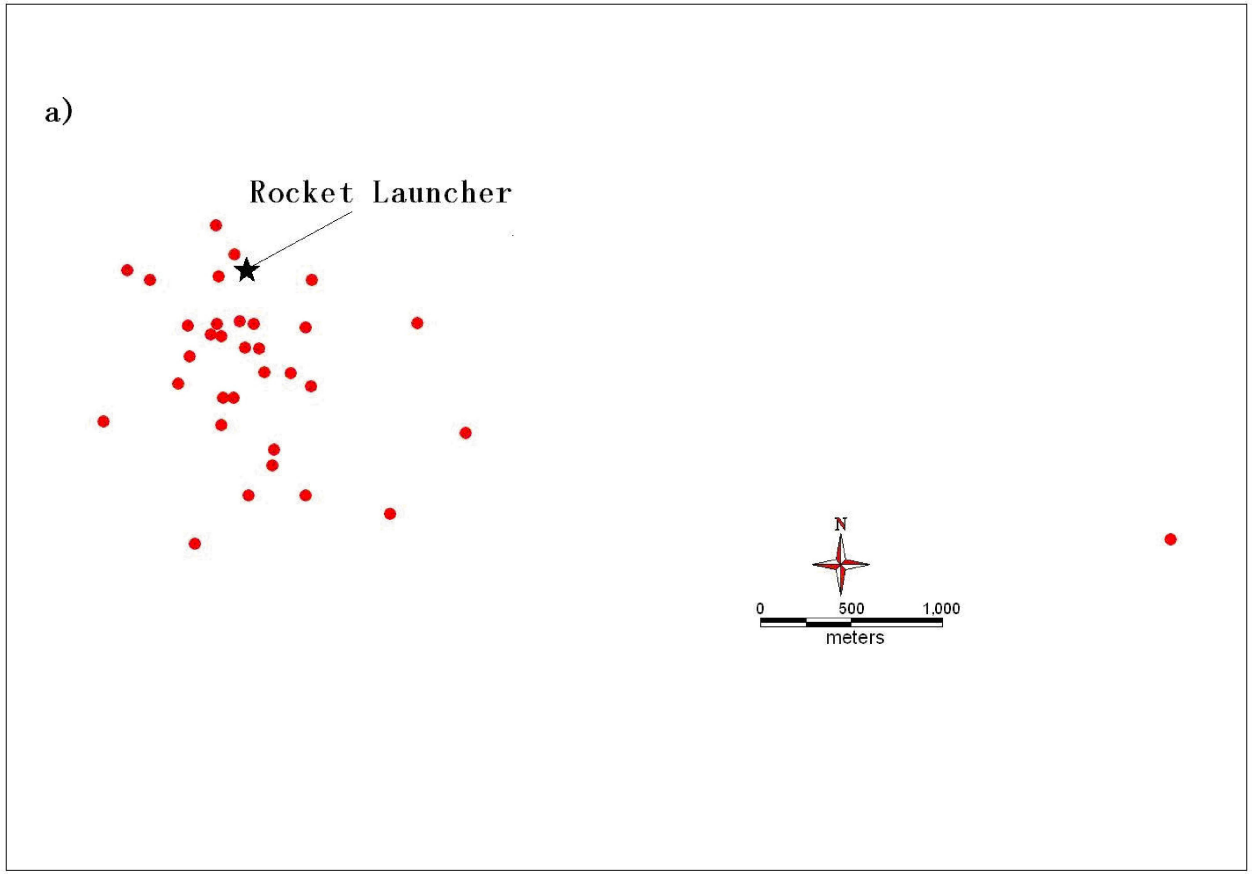


The arithmetic mean values of the flash detection efficiency and stroke detection efficiency were around 94%, 60% respectively.

Stroke detection efficiency as a function of peak current measured directly in the triggered lightning experiment

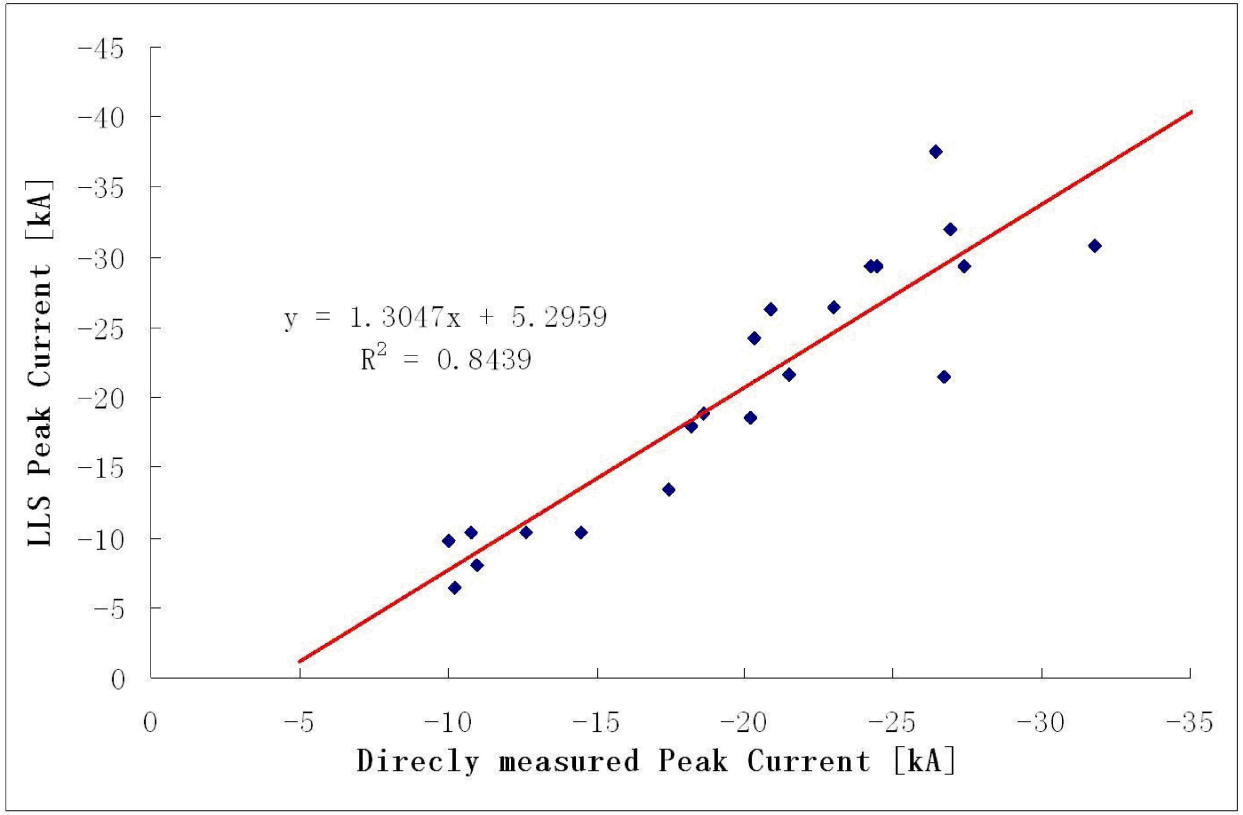
Performance of lightning location systems

Locating Accuracy for classical triggered lightning



33 strokes in classical-triggered lighting were detected with more than 2 reporting sensors Locating accuracy ranged from 111 to 5,250m, with mean value of 710m

Performance of lightning location systems



From 2008 to 2011, for 22 return stroke processes of artificially triggered lightning, both the directly measurement of peak currents and the corresponding LLS records were obtained.

Absolute percentage errors of peak current estimation ranged from 0.4%-42%, with mean value of about 16.3%.

Summary

- the technology of rocket-wire artificially triggered lightning has been improved, and has successfully triggered 150 lightning flashes, with a mean successful rate of 48%.
- Through the direct lightning current waveform measurements, an average RS peak current of 16 kA was obtained.
- The mechanism causing damage to lightning protection devices (i.e., ground potential rise within the rated current) was established.
- Quantitative assessments of the performance of lightning monitoring systems in Guangdong Province have been conducted.

Thank You for your attention

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