Lightning Research at the University of Florida

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The content of this presentation are for educational purpose. You are welcome to use these materials as long as you acknowledge the source.
The phenomenon of lightning occurs through a set of complex processes. In the subsequent slides, some of the details are abstracted in order to present the fundamental aspects of these processes in a simple way. To learn more about lightning, please refer to the books/papers in the reference slide (at the end) or contact

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- Dr. Martin A. Uman (Email: uman@ece.ufl.edu)

For information regarding UF Lightning Research Group, visit http://www.lightning.ece.ufl.edu
Introduction
What is Lightning?

Lightning is the discharge of atmospheric electricity.
Cloud-to-cloud flash (intracloud)

Cloud-to-cloud flash (intercloud)

Cloud-to-air flash

Cloud-to-ground flash

TLE or Transient Luminous Events (sprites, elves)
Depending on direction of propagation and polarity of charges
(Adapted from Lightning Physics & Effects by V. A. Rakov & M. A. Uman)
Objects on Ground

Thundercloud

Charges in Cloud

Streamer

Dart/Dart-Stepped Leader

Stepped Leader

Ionized Air

1st Return Stroke

2nd Return Stroke

3rd Return Stroke

Attachment

Striking Distance

Current

Upward Leaders

Negative downward natural lightning

Objects on Ground

Image Charges on Ground
Natural lightning at Camp Blanding
Photograph by: Dustin Hill
Still-camera image

Streak-camera image

Channel-base current

(Adapted from Lightning Physics & Effects by V. A. Rakov & M. A. Uman)
Various Steps of Lightning Discharge Process over Time

(Adapted from Lightning by M. A. Uman)
M-component

(Adapted from Lightning Physics & Effects by V. A. Rakov & M. A. Uman)
Negative Lightning for Cloud-to-Ground

- **Overall duration:** 200-300 ms
- **Peak current:**
  - 1st stroke = 30 kA
  - Sub. stroke = 10-15 kA
  - M-comp. = 100-200 A
- **10-90% current rise-time:**
  - 1st stroke = 5 µs
  - Sub. stroke = 0.3-0.6 µs
  - M-comp. = 300-500 µs
- **Current duration to HPW-value on tail:**
  - 1st stroke = 70-80 µs
  - Sub. stroke = 30-40 µs
- **Max. current rate of rise:**
  - 1st stroke = ≥10-20 kA/µs
  - Sub. stroke = 100 kA/µs

(Adapted from Lightning Physics & Effects by V. A. Rakov & M. A. Uman)
## Parameters of downward negative lightning based on channel-based current. Adapted from Berger et al. (1975)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Sample size</th>
<th>% exceeding tabulated values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>Peak current (min. 2 kA)</td>
<td>1(^{st}) strokes</td>
<td>kA</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>Sub. Strokes</td>
<td>kA</td>
<td>135</td>
</tr>
<tr>
<td>Max. (dI/dt)</td>
<td>1(^{st}) strokes</td>
<td>kA/µs</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>Sub. Strokes</td>
<td>kA/µs</td>
<td>122</td>
</tr>
<tr>
<td>Front duration (2 kA to peak)</td>
<td>1(^{st}) strokes</td>
<td>µs</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Sub. Strokes</td>
<td>µs</td>
<td>118</td>
</tr>
<tr>
<td>Stroke duration (2 kA to HPW-value on tail)</td>
<td>1(^{st}) strokes</td>
<td>µs</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Sub. Strokes</td>
<td>µs</td>
<td>115</td>
</tr>
<tr>
<td>Flash duration</td>
<td>1(^{st}) strokes</td>
<td>ms</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>Sub. Strokes</td>
<td>ms</td>
<td>39</td>
</tr>
<tr>
<td>Time interval between strokes</td>
<td></td>
<td>ms</td>
<td>133</td>
</tr>
</tbody>
</table>
Ground-Based Tall Object

Thundercloud

Charges in Cloud

Streamer

Initial Continuous Current

Dart/Dart-Stepped Leader

Ionized Air

Upward Positive Leader

Subsequent Return Stroke

Upward lightning

Image Charges on Ground

Ground-Based Tall Object
Lightning striking Burj Khalifa in Dubai (unknown source)
Still-camera image

Streak-camera image

Channel-base current

Note initial continuous current in place of first return stroke

(Adapted from Lightning Physics & Effects by V. A. Rakov & M. A. Uman)
Triggered lightning using rocket-and-wire technique

Thundercloud

Charges in Cloud

Wire connected to Ground

Image Charges on Ground

Rocket Launcher

Dart/Dart-Stepped Leader

Initial Continuous Current

Streamer

Natural Channel

Upward Positive Leader

Ionized Air

Subsequent Return Stroke

Exploded Wire

+ Charges in Cloud

Image Charges on Ground
Rocket Triggered Lightning at Camp Blanding
Subsequent strokes in triggered lightning are similar to those in natural lightning

(Adapted from Lightning Physics & Effects by V. A. Rakov & M. A. Uman)
Interceptor Rocket Launcher

Thundercloud

Charges in Cloud

Current

Streamers

Wire not connected to ground

Rocket Launcher

Interceptor

Image Charges on Ground

Altitude triggered lightning

Return Stroke
Lightning strikes plane while take off in Japan (unknown source).

(classical example of altitude triggered lightning)
UF Lightning Research Group
Facilities

• The Lightning Center for Lightning Research and Testing (ICLRT) at Camp Blanding, FL
  – Rocket-Triggered Lightning Experiments

• The Lightning Observatory in Gainesville, FL (45 km from Camp Blanding)

• Starke Site (3 km from Camp Blanding)

• The Lightning Research Laboratory
Activities

• Studying the various physical processes in natural and rocket-triggered lightning
  – Current shunts/Pearson coil
  – Electric and Magnetic field antennas
  – X-Ray detectors
  – HF and VHF systems
  – Optical equipments
ICLRT at Camp Blanding, Florida
Rocket Triggered Lightning

(Click on the photograph to start video)
Rocket Triggered Lightning

(Click on the photograph to start video)
LOG is located 45 km from CB. Starke site, which is located 3 km from CB, is not shown on the map.
Lightning Observatory in Gainesville

Single-station expt. (Natural lightning around Gainesville)
Lightning Observatory in Gainesville

Multi-station expt. (RTL at CB; far-field measurements at 45 km)
Near and far field measurement
Starke Site

Multi-station expt. (RTL at CB; far-field measurements at 3 km)
Single-station expt. (Natural lightning around Starke)
Study on distribution line done at Camp Blanding
Study on underground cable done at Camp Blanding

(a) Cable A

(b) Cable B

Fulgarite
Study on underground cable done at Camp Blanding

Cable C
Study on residential house done at Camp Blanding

(Click on the photograph to start video)
Case Study

Triggered-Lightning Testing of Lightning Protective System of a Residential Building

Experimental set-up

Test House
Lead conductor
Test Runway
Test
3-Phase
Distribution
Line
IS1
600 V
Underground Cable
Launch Control Tower
Launcher Office

Experimental set-up
The test house at the ICLRT whose LPS was subjected to direct lightning strikes in 2004 and 2005. Approximate dimensions of the house are 10 x 7 x 6.5 m³. Photo from 2005.
Diagram of the LPS of the test house in 2004. All conductors below the plane labeled “Ground Level” are buried (in direct contact with earth).
Note: Return stroke current only was injected in 2004.
Electrical diagram of test system configuration for 2004. Currents A, B, C, D, and K were measured at the test house, and current G was measured at IS1, 50-m away.
Return-stroke currents for stroke 0401-3, displayed on a 10 µs time scale. (a) injected current and currents at points A, B, C, D, and K; (b) currents for flash 0401-7.
Diagram of the LPS of the test house in 2005. All conductors below the plane labeled “Ground Level” are buried (in direct contact with earth).
Note: Both initial-stage and return-stroke currents were injected in 2005.
Electrical diagram of test system configuration for 2005. Currents A, A1, B, B1, and D were measured at the test house, and Current G was measured at IS1, 50 m away.
(a) Return stroke currents in four downleads (A, A1, B, and B1),
(b) The sum of the four downlead currents (A, A1, B, and B1) vs. the injected current waveform displayed on a 110 µs time scale for stroke 0521-1.
(a) Injected current versus the difference between the sum of the four downlead currents and current D, labeled (Sum – D). The (Sum – D) waveform is scaled so that its peak is equal to that of the injected current and represents the current going to the grounding system (local) of the test house. (b) Current D versus current G.
Current division results, 2004 vs. 2005

Peak value of current D (current to electrical circuit neutral) vs. injected peak current for return strokes in flashes triggered in 2004 and 2005.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Injected current, kA</th>
<th>Current D, kA</th>
<th>Current D relative to Injected current, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>3.6</td>
<td>6.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Maximum</td>
<td>17.8</td>
<td>34.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Arithmetic Mean</td>
<td>9.4</td>
<td>14.4</td>
<td>2.1</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>4.1</td>
<td>8.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Geometric Mean</td>
<td>4.7</td>
<td>12.7</td>
<td>1.9</td>
</tr>
<tr>
<td>Sample Size</td>
<td>11</td>
<td>8</td>
<td>11</td>
</tr>
</tbody>
</table>

Over 80% of the injected peak current was observed to enter the electrical circuit neutral in similar 1997 tests at the ICLRT (Rakov et al., 2002).
Damage to the system

Damage to the insulation of the 600-V cable,
(a) puncture of the insulation of one conductor of the 600-V cable,
(b) damage to all three conductors of the cable.
Bar charts of peak current of injected (Inj.) current, currents in ground rod A, ground rod A1 (2005), ground rod B, ground rod B1 (2005), ground rod C (2004), and current D for events LSA-0401-1 and LSA-0521-1.
Current division results (2004 vs. 2005)

Bar charts of half-peak width of injected (Inj.) current, currents in ground rod A, ground rod A1 (2005), ground rod B, ground rod B1 (2005), ground rod C (2004), and current D for events 0401-1 and 0521-1.
Summary

- The primary objective was to examine current division between local (at the test house) and remote grounding systems.

- Current entering the electrical circuit neutral in percent of the injected current:
  - 1997 – >80%
  - 2004 – 22%
  - 2005 – 59%

  Better grounding at the test house than in 1997.

- Roughly a factor of two to three larger current in 2005 than in 2004 was forced to search its way to remote ground.

- Overall, configuration tested in 2004 (RS only; SPDs installed) performed better than the configuration tested in 2005 (IS + RS; SPDs disconnected).

- In absence of SPDs in 2005, the watt-hour meter incurred damage, similar to the no-SPD configuration tested in 1997 (Rakov et al., 2002).
QUESTIONS?

For information regarding UF Lightning Research Group, visit

http://www.lightning.ece.ufl.edu
References


• Lightning, M. A. Uman, Dover Publication, 1969
