Chapter 9

A Lightning Primer

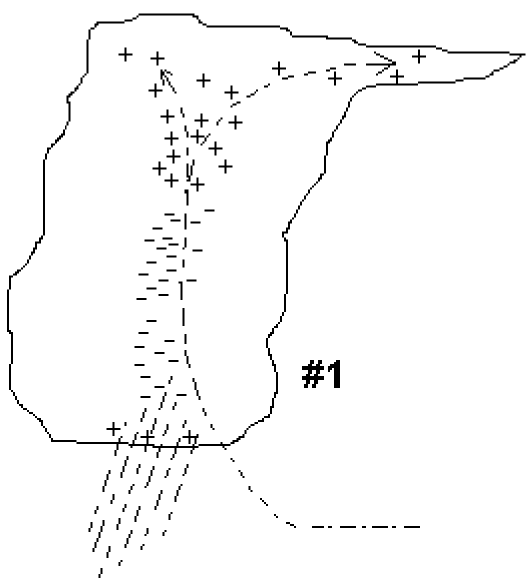
Thunderstorms and Lightning Types • Recognizing Patterns of Strokes • Lightning as an Indicator of Storm Behavior • The Stroke Sort Process and Other Limitations • Additional Information Sources

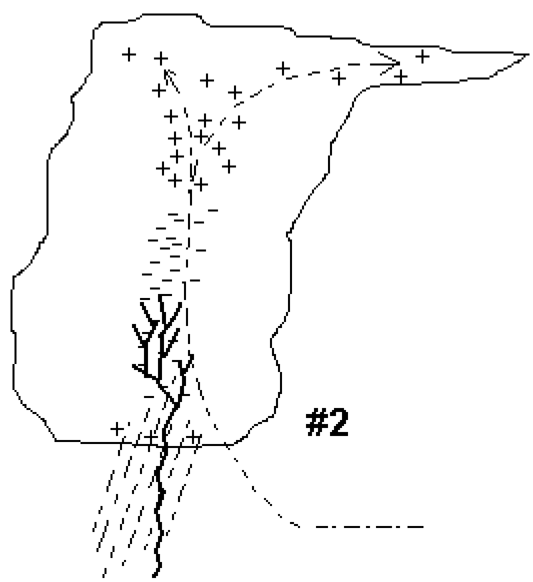
Thunderstorms and Lightning Types

Isolated Thunderstorm Cell

This examination of thunderstorms will focus on the charge distributions and as a result the types of lightning produced.

The charge distribution on the next page (#1) is considered to be the normal charge distribution in a normal single cell storm. In the figure there are two main charge layers, an upper positive charge above the main lower negative charge. This pair is called a **normal dipole**. There is a smaller positive charge below the main negative charge, so the whole charge structure could be called a **tripole**, but we'll ignore the lower positive charge for now.





The most common type of lightning that most people are familiar with is the **negative cloud to ground** discharge (**-CG**). This type of lightning originates in the main negative layer (in figure #1).

The lightning discharge begins with **step leaders**, a sequence of discrete branched steps from below the negative charge in the cloud to the ground, which ionizes the path. As it approaches the ground (within 100 meters or more) an induced positive charge in the ground creates a streamer which bridges the gap and a **return stroke** moves up the path created by the stepped leader. Figure 2 shows a typical –CG stroke.

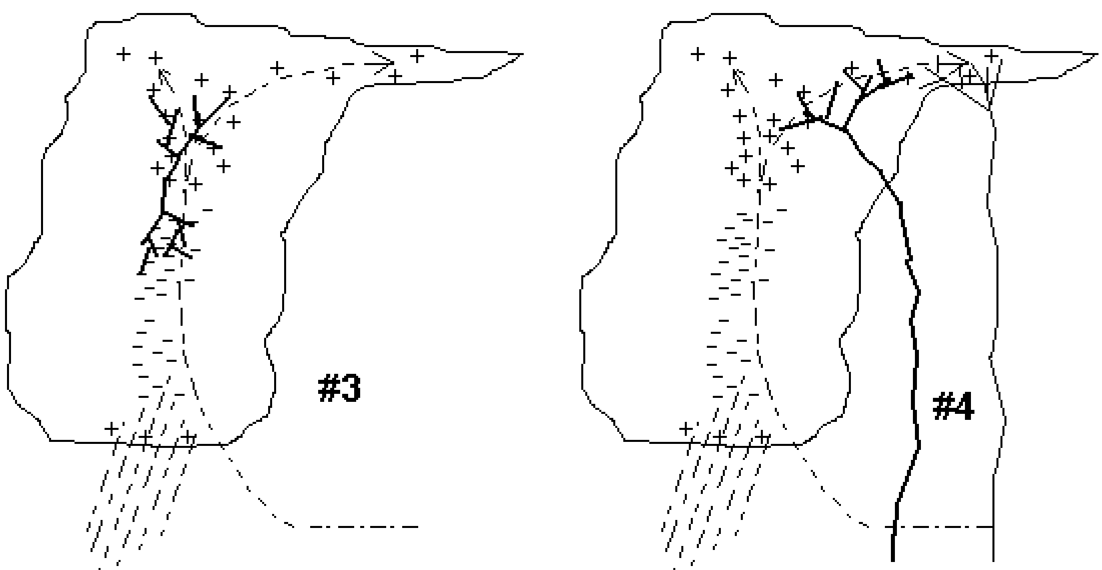
Both the stepped leader and the return stroke create electromagnetic waves (a low frequency radio signal) that can be heard on an AM radio as static. These signals and others are picked up by the Boltek hardware and used in plotting the location of the –CG stroke. It is the vertical section of the –CG stroke near the ground that generates the signal that allows the most accurate location of the stroke's angular position from the low frequency electromagnetic waves.

In most cases the path created by the stroke allows subsequent strokes to discharge additional negative charge from the cloud. Multiple strokes create the flickering '**flash**' of lightning. The initial and subsequent –CG strokes comprise a lightning flash.

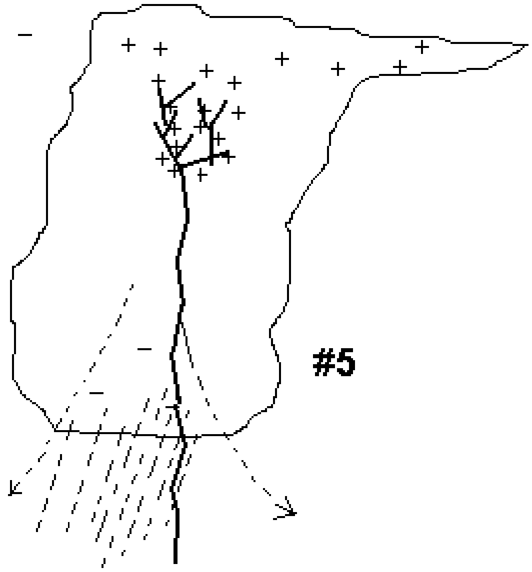
Another type of more frequently occurring lightning is the **intracloud** (**IC**) stroke. This type of stroke is shown in figure 3. It occurs between the main negative charge and the overlaying positive charge. The stroke shown is a positive intracloud stroke (+IC). In this case the main stroke channel is shown as a vertical path.

In many cases the stroke channel has long horizontal segments. The horizontal segments of the stroke create distortions (phase errors) in the signals received and errors in the location of the angular position can be as much as +/- 10 degrees. The IC stroke lacks the single large pulse of charge flow that the –CG return stroke has so that the signals from the +IC strokes are much weaker than –CG strokes, by a factor that varies from 10 to 100 times smaller.

An additional type of stroke is the **positive cloud to ground** discharge (+CG) with two possibilities shown in figure 4. This stroke originates in the upper layer of positive charge or the anvil and is usually stronger than the typical –CG stroke, but not always. This type of stroke occurs less frequently than the –CG stroke in the typical thunderstorm. A +CG stroke is usually not followed by additional +CG strokes as is the case for an initial –CG stroke.



During the dissipating stage of thunderstorms the lower negative charge may have been mostly removed by –CG strokes leaving the main positive charge. At this stage of the storm there will be a larger number of +CG strokes than –CG strokes. This condition is shown in figure 5.



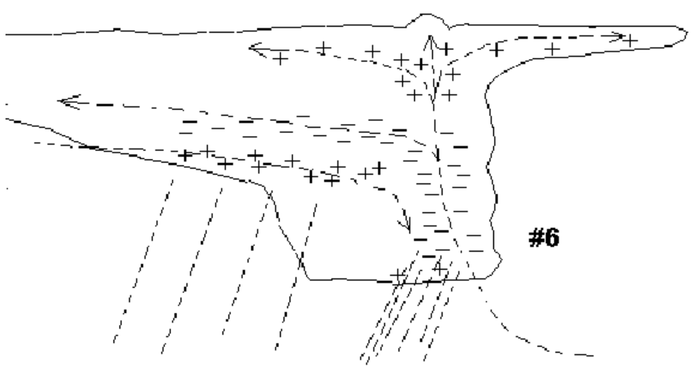
#5

The primary stroke types in well-developed thunderstorms with charge distributions shown in figure 1 are +IC and –CG. Even at close range a sizeable percentage of the IC strokes will not be detected due to the orientation of the stroke channel. And at larger ranges the smaller signal of IC strokes will prevent their detection. At very large distances it may not be possible to detect any IC strokes.

The –CG strokes will be concentrated near the **convective core** (**updraft**) of the storm cell. The +IC (and –IC discussed in the next section) strokes will be more spread out and most likely occupy a major part of the volume of the storm cell between the two main bodies of negative and positive charge.

Organized Cell Complexes

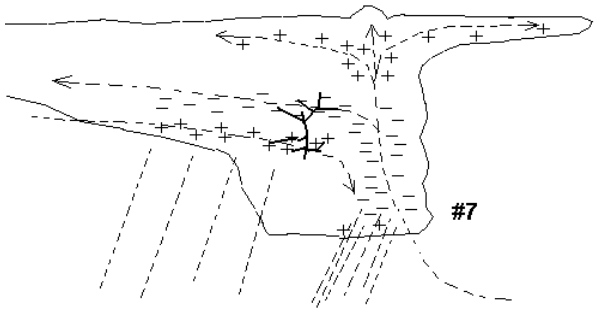
If a cell is part of a **squall line** or a **mesoscale convective system** (**MCS**) then it may have a charge distribution similar to figure 6. Near the convective core there are two main charge layers, an upper positive charge above the main lower negative charge, just as in figure 1. There is a smaller positive charge below the main negative charge. In the **trailing stratiform** region there is an upper thin layer of negative charge over a thin layer of positive charge.



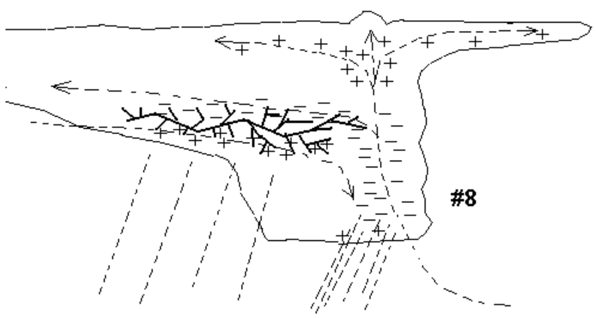
#6

The additional thin layers of negative over positive charge can give rise to a few additional ways that both CG and IC strokes can occur.

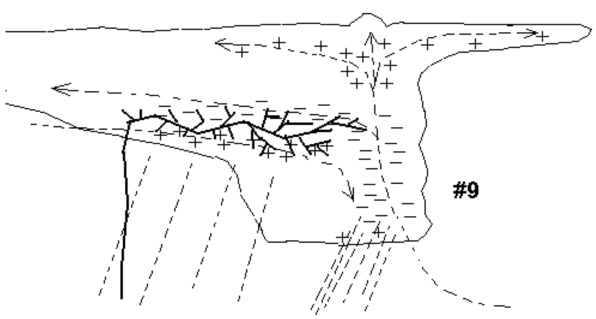
Figure 7 shows a –IC stroke between the thin negative charge and the positive charge below it. The –IC stroke will have many of the same characteristics as the +IC stroke (stroke channel orientation, strength of the electromagnetic wave).



Another type of intracloud stroke seems to crawl (spider lightning) below the bottoms of the stratiform area or in other cases below the anvil formations of thunderstorms. This type of stroke can produce a movement of charge that can be seen as –IC or as +IC depending on whether the charge is carried to or away from the detector, and in some cases be undetected if the orientation of the charge movement relative to the detector is entirely horizontal. This occurs as an extended stroke between the charge layers in the stratiform area. This is shown in figure 8.



The stratiform charge layers can also lead to a CG stroke (usually a +CG) as a result of the spider lightning stroke. This is shown in figure 9.



Recognizing Patterns of Strokes

The direction of movement of a storm cell relative to the single station detector can supply additional information in many cases.

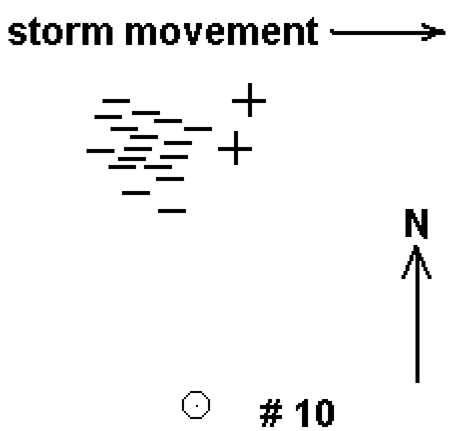
Consider the case of a single storm cell due north of the detector where the storm cell is moving due east. If the storm is producing mostly –CG strokes (near the convective core) and a few +CG from the anvil the pattern could look like figure 10.

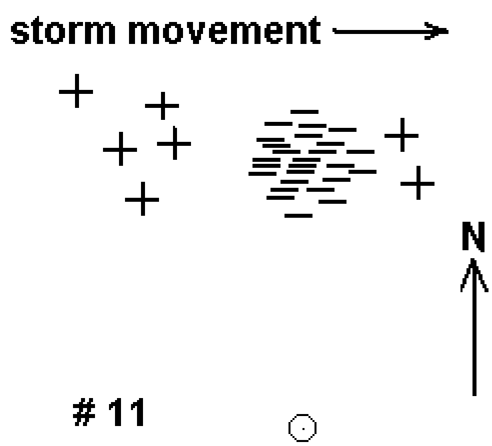
When the numbers of –CG strokes are far larger than the numbers of +CG strokes then the storm is considered to be negative stroke dominated (NSD). As the storm ages more positive charge will move into the anvil and increase the possibility of a larger number of +CG strokes. When the storm dissipates the –CG strokes would decrease in number and the positive charge in the upper part of the cell could generate a larger number of +CG strokes.

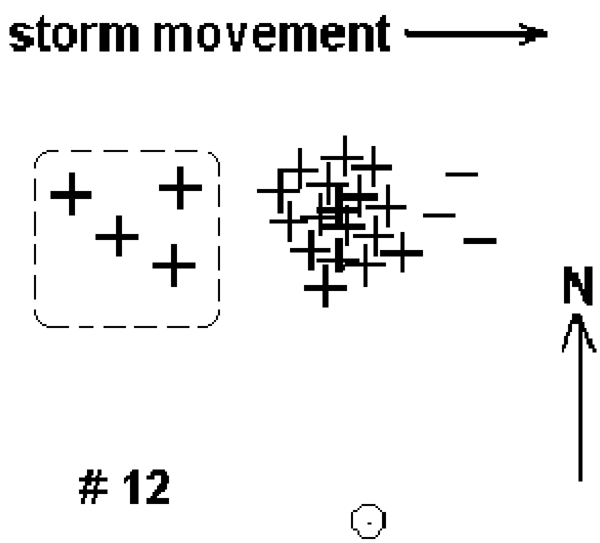
Another case to consider is the pattern of strikes generated by a single cell that is part of a mesoscale convective system (MCS). Assume the same conditions as for the storm movement and position of the detector as above. Again the storm would be producing a larger number of -CG strokes with a few +CG out in front. But there would also be an additional number of +CG strokes trailing the storm's movement (a larger number than from the anvil). This condition is shown in figure 11.

Published research discloses that a few measurements of charge distributions show apparent inverted structures (**inverted dipole**) in some severe storms. In this condition the positions of the main positive and negative charges are reversed, with the main positive charge below the main negative charge. In this case the positions of the +CG strokes are positioned near the convective core (and below the stratiform area, dashed box, if this **positive stroke dominated** (**PSD**) cell were part of a larger complex, a rare occurrence) while the strokes from the anvil will show up as –CG. The pattern this would produce is shown in figure 12.

Depending on the range of the storm cell, the separation of the stroke plots may not be as clear as in figures 10 to 12. Also these cases consider the best possible orientation of the storm's movement relative to the detector. If the storm were moving directly toward or away from the detector the positions of the +CG and –CG strokes would most likely be mixed so that it would not resemble what is shown. This is caused by the fact that the angular resolution of a single station detector is much better than the range resolution.







Lightning as an Indicator of Storm Behavior

The following description of a thunderstorm's intensity relates to a thunderstorm's development of an updraft in a single storm cell. In each of these cases one can think of them as a continuum of storm cell severity.

1. When the updraft of a cumulus cloud pushes beyond an altitude where the temperature is at –20 C electrification of the cloud starts, with negative charge between the –10 C and –20 C isotherms and the positive charge above that. When the charge becomes large enough IC lightning will start to occur. As the updraft gains strength the charges build to larger values and the lower negative charge becomes sufficiently large to induce a positive charge on the ground below the cloud. At this point –CG strokes will start to occur. If the updraft does not increase in strength then the storm cell will produce mainly IC (both +IC and –IC) flashes with –CG lightning. The ratio of these types (IC to –CG) will be somewhere between 1 to 1 and 4 to 1. A normal ratio for –CG and +CG would be around 10 to 1.
2. If the updraft continues to gain strength, then not only does the IC flash rate increase, but the updraft starts shifting the area of negative and positive charges to a higher altitude (elevated dipole). This has the effect of increasing the distance to the ground and as a result the –CC lightning rate decreases. At this point the storm cell is borderline supercell.
3. If there is sufficient vertical shear at high altitudes, then the top of the storm cell will be offset from the bottom, as will the updraft. This may cause an increase in the number of +CG strokes as the positive charge is not shielded from the ground by the lower negative charge. The shear also prevents any accumulation of hail/rain in the area of the top of the updraft that falls from choking the updraft and the storm cell. Rotation of the updraft (**mesocyclone**) is also a major contributor to the cell's stability. This can increase the lifetime of the cell to hours from the normal 20 to 40 minutes of a typical thunderstorm. This is a **supercell** storm.

Using these, one can classify storms into several categories.

1. minimal IC lightning – this is a weak or recently formed cell

2. minimal IC lightning and a few +CG strokes – this is possibly a dying storm cell
3. IC and CG lightning in a ratio of 1-1 to 4-1 and –CG and +CG in a ratio of 10-1 – this is a normal storm cell
4. Heavy IC lightning and minimal –CG lightning, ratio of IC to CG lightning is 6-1 to 20-1, the ratio of –CG to +CG is about 1-1, and the IC rate approaches 40 to 50 flashes a minute – this storm cell is borderline supercell
5. Very high IC lightning and moderate +CG, there may be little or no –CG lightning, the IC rate in this cell is well over 50 flashes a minute and 5 to 7 +CG strokes a minute, but in some cases the +CG rate may also be zero – this is a supercell storm

In borderline supercell and supercell storms there is another lightning anomaly that indicates that related severe cell activity is about to start or has already started. This is the **lightning jump**. This is an increase over a short interval (5 minutes) in the total flash rate (all types of lightning) of 50 to 100 flashes per minute for the five minute period. If this is followed by a decrease to previous high levels then several types of **severe events** have occurred or are about to occur: a **microburst**, **large hail**, or a **tornado**. In the absence of IC stroke information (storm at long range) significant pulsing in the –CG or +CG flash rates can be used with less precision in place of the lightning jump.

Another indicator is if a supercell storm that was producing mostly +CG lightning switches to mainly –CG lightning. This **polarity reversal** is another indicator that the basic nature of the cell has changed and may indicate that a severe weather event has occurred or will occur.

It should be noted that the ratios in stroke types/polarities and flash rates will be affected by the terrain below the storm, mountains vs. flat plains, the type of interface between dry and moist air, as well as the season, summer vs. winter.

A storm cell over a high mountain peak could be the cause of a higher –CG count (the distance from the peak to the negative charge is smaller). This may result in a reduced IC stroke count, and as a result of the excess positive charge remaining also a higher +CG stroke count.

If there were mountains to the west and a flat plain to the east, then the character of storms in these two directions most likely would be different and the interpretation of the ratios/flash rates would be different.

Each user needs to keep careful records of ratios and flash rates of the storms in their area and match these with the weather service's classification of the storm. In this way the display of future storms will convey more meaningful information about the storm's nature/severity.

Another Stroke Subtype

Other discoveries by researchers have found that some IC flashes radiate electromagnetic energy (at **very high frequencies**, **VHF**) more intensely than CG strokes and other IC flashes. This distinct class of IC flash occurs in more active thunderstorm cells. These are the **narrow positive bipolar pulse** and the **narrow negative bipolar pulse** (**NPBP** and **NNBP**). Together these are called the **compact intracloud discharge** (**CID**).

These flashes are short (1 km in length or less), oriented vertically and singular. Because of their vertical orientation, the signals from these flashes allow their angular location to be more precise than most IC flashes. But their distribution is variable; they may be clustered around the updraft (most likely) or spread throughout the volume of the cloud between the positive and negative charges. In some severe cells the CID may account for as much as 20 percent of the total IC flashes. There is some speculation that CIDs may be the initial trigger for most IC stroke sequences.

Other Storm Types

In limited cases lightning can also indicate a change in the character of a **hurricane**. Lightning production in hurricanes is usually minimal except during intensification of the storm as it passes over warmer water, then there will be bursts of lightning activity in the inner wall near the eye. Or if the hurricane changes in structure as it comes onshore, then a tornado producing cell may be generated in the outer wall.

Winter storms also have a different lightning characteristic. In winter storms the freezing level occurs at a lower altitude than in a summer storm, so both the negative and positive charge centers occur at a lower altitude. In addition the positive charge is offset from the negative charge. In this case there will be a larger number of +CG flashes, 25% to 40% in a normal winter thunderstorm cell but the total flash count (all types and polarities) will usually be smaller than for a summer storm.

In all of these cases above, the numbers apply to a single storm cell. In multicell storms the separation of the statistics of individual cells may not be possible.

The Stroke Sort Process and Other Limitations

There are a few limitations in the method of stroke classification in Lightning/2000. The classification between –CG and –IC will be generally about 70-90% accurate. Differentiation between +CG and +IC can be less accurate (a +IC will masquerade as a low amplitude +CG, just as in some networks of lightning detectors).

If there are major distortions in the signal caused by large horizontal segments in the stroke, the classification accuracy will suffer. Also, at large distances the signal will degrade and some of the information content of the signal necessary for stroke classification will be lost in the background noise. This will vary from stroke to stroke. At extreme range, reflections from the ionosphere can cause an inversion of the information used to determine the polarity of the stroke type which will in turn cause the stroke to be plotted 180 degrees from its true location.

The stroke rate can also cause some errors in the stroke sorting process. In cases of very high stroke rates from several storms (stroke count over 1000/minute) the occasional loss of information at the beginning of a signal may cause an error in stroke classification.

The distance that IC strokes can be detected can also be a problem. At larger distances the total stroke counts will not be a true indicator of storm activity due to the limited range at which IC strokes can be detected. An example of this would be a supercell storm over 200 miles away. At that distance a much smaller percentage of the IC strokes would be detected (if any) and the storm's type could be hard to classify based on just CG activity. An extreme case of this would be a supercell storm that is producing only IC lightning. At long range (200+ miles), such a storm may not be detectable or look like a normal weak storm cell.

The **detection efficiency** (**DE**) of the hardware has been estimated with a series of measurements with the data sets of several storms. The DE for CG strokes is about 85% +/- 6% and the DE for IC strokes is about 20% +/- 5%. An additional factor that effects the DE is the percentage of IC and CG that can not be classified into stroke types. This may result in the stroke type being classified as unknown or as noise. Typical percentages seen (from a 108,000+ stroke summer storm) are:

Type	% of all Records	% of recognized stroke records
Noise	25.0	---------
-CG	42.8	56.9
+CG	19.5	25.9
-IC	3.7	4.9
+IC	7.6	10.1
+CID	0.9	1.2
-CID	0.5	0.67

Additional Information Sources

Additional information about lightning can be found on the internet by searching for published works by the following authors. References in these should lead you to additional authors and topics in lightning and storm research. Some of the information contained in this primer comes from papers published by the following authors and also from the two web pages noted.

D. J. Boccippio

E. P. Krider

D. R. MacGorman

R. C. Noggle

V. A. Rakov

W. D. Rust

D. A. Smith

M. A. Uman

C. D. Weidman

And an excellent look at a lightning locator design in detail can be found on the internet at the following location.

http://bub2.met.psu.edu/default.htm

A very good tutorial on basic electrification and lightning activity can be found at the indicated location and a second tutorial on anomalous lightning behavior should become available soon.

http://www.cira.colostate.edu/ramm/visit/ltgmet1/01_title.asp