# MEASUREMENTS OF LIGHTNING RADIATION FIELD AND ESTIMATION OF FIRST RETURN STROKE PARAMETERS

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Received September 29, 1989

ABSTRACT

This paper briefs a method of measuring lightning radiation field with a fast antenna and narrow bandwidth receivers, the first return stroke parameters and the spectrum distribution from 2 kHz to 20 MHz for both ground discharges and cloud discharges are calculated.

The peak radiation field of first return stroke, normalized to 50 km, is $(15.2\pm8.4)$V/m. Below 1 MHz, the total energy radiated by the first return stroke is $(0.8\pm1.6)\times10^5$J, the peak power is $(0.8\pm1.0)\times10^{10}$W, the peak current is$(27.8\pm17.1)$kA, and the peak current derivation is $(109.3\pm91.5)$ kA/$\mu$s.

The peak spectral amplitudes appear between 4 kHz to 10 kHz for ground discharges and 20 kHz to 80 kHz for cloud discharges. From 10 kHz to 3.0 MHz, the spectral amplitudes of the ground discharges decrease in $1/f$, and from 3.0 MHz to 20 MHz, in $1/f^2$. Below 40 kHz, the ground discharge is the main lightning radiation source; and above 40 kHz, both discharges behave similarly.

A few special phenomena were found and explained preliminarily.

**Key words:** lightning, electric radiation from lightning, lightning parameters

## I. INTRODUCTION

The measurements of electromagnetic field radiated by lightning are significant for both the understanding of the lightning physical process and the improvement of lightning location technique and protection.

We measured the lightning radiation field over a wide frequency band for both cloud discharge and ground discharge from the same storm by combining two different methods in east Gansu, Nanning and Beijing in summers, 1986—1989. For lower frequencies, we used a wide bandwidth receiver (fast antenna) to get the time domain field data and then the resulting wave-forms are subjected to Fourier analysis to get the spectral amplitude distribution from 2 kHz to 800 kHz. For higher frequencies, we used two narrow bandwidth receivers to sample the radiation field at the fixed frequencies to get the spectral amplitude distribution from 1 MHz to 20MHz. A slow antenna is used to distinguish the different discharge process in ground flashes.

From the radiation field of the first return stroke received by fast antenna, the discharge parameters including the peak electric field ,the total radiation energy, the peak radiation power, the electric current and its derivation in discharge channel are estimated.

There are two direct methods to measure the electric current in ground flashes for engineering—magnetic link put on the high voltage transmission tower and the measurement meter put on the high tower on mountain top. But both of them are limited by the randomness of lightning for they must wait to be stricken by lightning. Thus, it is difficult to obtain enough data. In this paper, we try to estimate the current and other parameters of lightning by measuring the radiation electric field radiated by lightning return strokes.

## II. RECORDING TECHNIQUE AND DERIVATION OF LIGHTNING PARAMETERS

The fast antenna and slow antenna made by ourselves are similar to those first used by Fish and Uman(1972).The relationship between the output voltage $V_{out}$ and ambient field $E$ is,

$$V_{out}=\varepsilon_0 AE/c,$$

where $c$ is the integrating capacity, $\varepsilon_0$ is the permittivity of the air, $A=0.2\text{m}^2$ is the effective area of the fast antenna, the frequency bandwidth of the fast antenna is 1 MHz, its time constant is 2 ms, and the time constant of slow antenna is 4 s.

The output of the fast antenna is connected to a microcomputer via a model TCCJ-2000 transient converter.

Two narrow bandwidth receivers are used at 3.0 MHz and 20 MHz, respectively. The output after detection is directly recorded to a tape recorder with a bandwidth of 60 kHz, The output of the slow antenna is recorded simultaneously with FM record mode to distinguish the radiation of the first return stroke.

Four receivers as described above and weather radar have been used to measure the lightning radiation field and monitor the storm movement for three summers in east Gansu, Nanning and Beijing 56 ground discharges and 101 cloud discharges were selected from a wealth of lightning data.

To estimate the return stroke current and its derivation from the field, it is assumed that the initial fast rising portion of the return stroke fields and the return stroke current can be described by transmission line model (Uman and Mclain, 1983), i.e., the return stroke current measured at the ground propagates upward along the channel at a constant velocity $V$ and without distortion. In this model, the relation between the electric radiation field and current is

$$I(t)= (2\pi\varepsilon_0 c^2 R/V) \quad E(t+R/c),$$

furthermore

$$\frac{dI(t)}{dt}= (2\pi\varepsilon_0 c^2 R/V) \quad \frac{dE(t+R/c)}{dt},$$

where $c$ is the light velocity, $R$ is the distance from the lightning source to the instrument, $V$ is the return stroke velocity. here we use $V=1.5\times10^8$m/s, which is the best measurements of the return stroke velocity made by Idone and Orville (1982) in Langmuir Laboratory,New Mexico, using a streaking camera.

To estimate the radiation energy and the power of the return stroke, it is supposed that the first return stroke channel can be represented by a vertical dipole, the lightning current is positive and propagates upward ,and the electric field on the ground, which is $R$ km from the dipole ($R\gg$ the height of the source), is $E(t)$, thus the electromagnetic energy of the first return stroke, given by Taylor (1963), is

$$\text{ENERGY}=(R^2/90)\int_0^t E^2(t)dt.$$

The peak power radiated by the first return stroke, given by Krider and Guo (1982), is

$$\text{PEAK POWER}=(\text{R}^2/90)\text{E}^2(\text{max}).$$

The fast Fourier transform (FFT) of a finite sequence of the sample points, $E(t)$, is defined by $F(mf)$ at frequency $mf$,

$$F(mf)=T\sum_{n=0}^{N-1}E(nT)\exp(-j2\pi mnfT),\quad (\text{in V s/m})$$

where $m=1,\ldots,N/2$, $N$ is the power of 2, $T$ is the sampling interval, $f=1/(NT)$, and the spectrum extends from $1/(NT)$ to $f=1/(2T)$.

To combine the data from each narrow bandwidth receiver with the spectrum obtained by using FFT algorithm, we normalize all measured results to 1 kHz bandwidth. Here, the peak response of the receiver to lightning pulse is assumed to be directly proportional to the square root of the receiver's bandwidth (Luis, 1969).

In addition, the results are normalized to 10km, according to the assumption that the variation of the field strength follows the inverse distance law.

## III. RESULTS AND DISCUSSIONS

### 1. *Parameters of the First Return Stroke*

The average peak radiation electric field of the first return stroke, normalized to 50km, is 15.2 V/m with a standard deviation of 8.4V/m. Below 1MHz, the total radiation energy is $0.8\times10^5$J, with a standard deviation of $1.6\times10^5$J, the peak power is $0.8\times10^{10}$W, with a stand- of 17.1 kA, the peak current is 27.8 kA with a standard deviation of 17.1kA, and the peak ard deviation current derivative is 109.3 kA/$\mu$s with a standard deviation of 91.5 kA/$\mu$s.

The results are well in agreement with those of other workers, and the peak current is also well in agreement with that measured by using magnetic link.

Some simple models are supposed in order to estimate the discharge parameters, the results show the reasonableness of these models. In fact, the peak electric field we used occurred about 100m above the ground, at the strike point or nearby, and the observations show that the closer the return stroke is to the ground, the more vertical it will become, the simple hypothesis is proven to be reasonable again.

### 2. *Spectrum*

Tables 1 and 2 show the average spectral amplitude distributions and derivations of the 56 ground discharges and the 101 cloud discharges, normalized to 10km range and 1kHz bandwidth, respectively. Figs.1 and 2 give the corresponding spectral distribution.

**Table 1.** The Average Spectrum and Derivation of the 56 First Return Strokes Normalized to 10 km and 1 kHz

| $F$ (MHz) | 0.005 | 0.010 | 0.020 | 0.040 | 0.060 |
|---|---|---|---|---|---|
| $E(f)$ (dB) | 129.2±53.9 | 133.2±56.8 | 125.5±50.7 | 119.8±46.6 | 116.9±51.4 |
| $F$ (MHz) | 0.100 | 0.300 | 0.600 | 3.000 | 20.000 |
| $E(f)$ (dB) | 109.5±50.2 | 101.3±41.2 | 89.2±34.7 | 68.5±20.4 | 44.5±8.7 |

**Table 2.** The Average Spectrum and Derivation of the 101 Cloud Discharges Normalized to 10 km and 1 kHz

| $F$ (MHz) | 0.005 | 0.010 | 0.020 | 0.040 | 0.060 |
|---|---|---|---|---|---|
| $E(f)$ (dB) | 114.8±59.8 | 116.7±61.2 | 119.8±62.3 | 122.4±60.3 | 117.7±55.3 |
| $F$ (MHz) | 0.100 | 0.300 | 0.600 | 3.000 | 20.000 |
| $E(f)$ (dB) | 111.0±52.0 | 100.4±46.6 | 88.0±44.0 | 69.7±25.3 | 46.2±15.4 |

Usually, the peak spectral amplitudes of the ground discharges appear between 4 kHz and 10kHz, mostly around 9 kHz, and from 10kHz to 3.0MHz, the spectral amplitudes decrease in $1/f$, and from 3.0MHz to 20MHz, decrease in $1/f^2$.

Curves 1—3 in Fig.1 are from Serhan et al. (1980), Weidman et al. (1981) and Weidman (1982), corresponding frequencies are 2—300kHz, 100k—1MHz, 1—20MHz, respectively. There is a little difference between our results and those of Serhan et al. (1981), the peak amplitude of his appears at 4 kHz and the spectral amplitudes at the frequencies after the peak amplitude are also smaller than those of ours, but the tendency is nearly the same. If we regard the discharge channel as a radiating antenna, the difference of the frequencies at which the peak spectral amplitudes appear suggests the difference of the effective radiating length of the discharge channel.

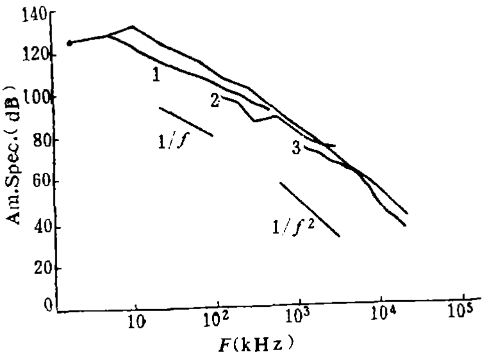


Fig. 1. The spectral distribution for 56 first return strokes normalized to 10 km and 1 kHz. Also shown here are the other results by curves 1—3 from Serhan et al. (1980),Weidman et al. (1981), Weidman(1982), respectively.

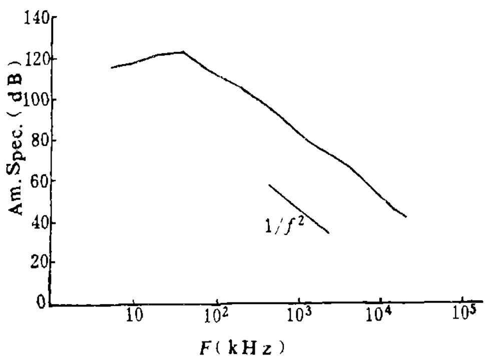


Fig.. 2. The spectral distribution for 101 cloud discharges normalized to 10 km and 1 kHz.

3. *Lightning Radiation at* 20 *MHz and Discharge Process*

Figs.3 and 4 show the electric field change of a ground discharge and a colud discharge, respectively, occurring in Beijing on August 2, 1988 and the associated 20 MHz radiation.

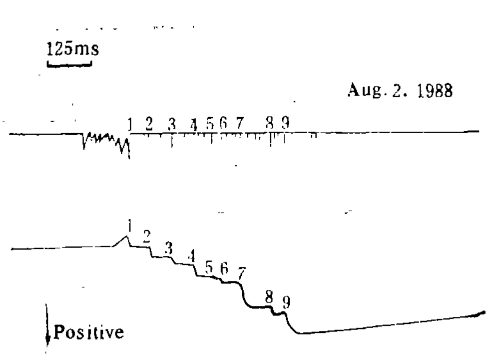


Fig. 3. Electric field change of a ground discharge and its corresponding 20 MHz radiation.

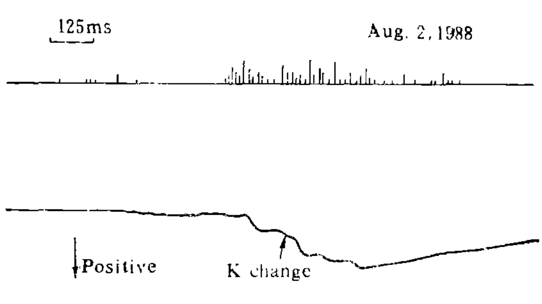


Fig. 4. Electric field change of a cloud discharge and its corresponding 20 MHz radiation.

The small changes between the return strokes are neglected for we do not pay attention to them. The ground discharge contains 9 strokes which are marked with 1, 2, ..., 9, respectively, the range is about 10km. The continuous change before the first return stroke is due to the increase of a number of radiation pulses in stepped leader. The pulses between strokes are due to C-process and J-process, and the K-process provides the largest radiation field.

**Table 3.** The Largest 20 MHz Radiation Intensity for Each Discharge Process

| Discharge Process | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_5$ | $>R_5$ | Cloud Discharge (K-change) |
|---|---|---|---|---|---|---|---|
| 20 MHz Radiation (dB) | 44.5±8.7 | 38.7±8.0 | 31.6±10.6 | 31.0±9.8 | 31.3±8.7 | 26.8±12.0 | 46.2±15.4 |

Table 3 shows the largest 20 MHz radiation intensity for each discharge process. The radiation before and after the first return stroke and K change of the cloud discharges are the strongest radiation source at 20 MHz. The radiation decreases gradually following subsequent strokes, this is related to the breakup at the top of the return stroke channel.

## 4. *Return Stroke Waveforms*

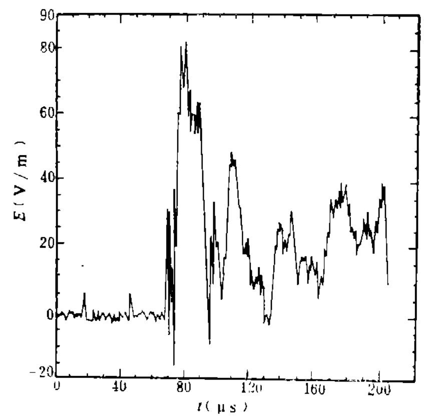


Fig. 5. A first return stroke waveform in east Gansu ($R=15$km).

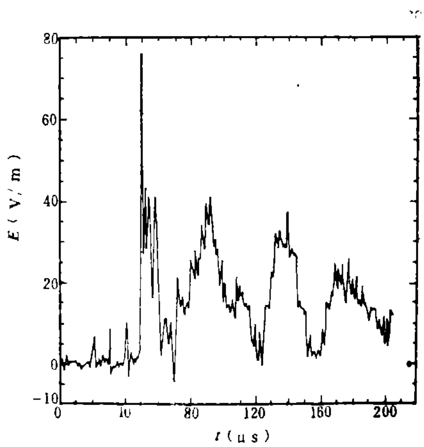


Fig. 6. A first return stroke waveform in Nanning ($R=10$km).

It can be seen from the first return stroke waveform obtained with the fast E-field change meter in east Gansu that oscillations occur before the main peak value (see Fig.5). The typical return stroke waveform is shown in Fig.6.

The oscillation before the main peak value occurs in the process of slow front or R process, this shows that the discharge channel has been set up, but the return stroke from the ground may not start or very near the ground, the channel no longer extends, but charges are still transported to the channel from the center of negative charge area, which results in an increase of charge density at the upper part of the channel. The measurements of recent years in east Gansu show that the positive charges close to the cloud base spread much wider and have larger magnitude than that of a typical one, so the discharge between this positive charge region and high charge density region in the upper part of the channel is possible, this kind of discharge has the feature of cloud discharge, and the polarity is opposite to that of return stroke.

The oscillation may be the coincidence of the return stroke and the cloud discharge in time, the return stroke occurs near the ground and the oscillation occurs between the small positive charge region and the negative charge region. Further measurements and studies are needed to get a satisfactory answer.

The lightning radiation field detected at a given distance depends on the antenna property of the channel, for example, the current distribution, the orientation and geometric structure of the channel, the dispersion property of propagation medium between the ground and ionosphere, and the propagation effect on the ground and so on, some errors introduced for these factors are not taken into account.

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