# Far Electric Field of M-Component Recorded by Lightning Locating System in Foshan (FTLLS)

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***Abstract*—Ten far electric field waveforms of M-component produced by rocket-triggered lightning have been observed by 9 sites of the lightning locating system in Foshan (FTLLS), Guangzhou, China, at a distance range 68km-126km from the lightning channel. There are two evidence to prove this, one is the interval time between of the M component and the return stroke just adjust before of 9 sites are comparable, the other one is all these 10 M-components have attenuation exponent, nearly -1.0. Our study expands on work of Rakov's (2001), which reported electric field of M-component at distances in relatively wide ranges.**

***Keywords- M component; electric field ; lightning locating system; rocket-triggered lightning;***

## I. INTRODUCTION

Malan and Schonland (1947) reported the hook-like shape of electric field changes produced by 199 return strokes in 37 natural lightning in the range 6km or less. This hook field changes were defined as M component, which the overall durations were about 200-800us. Electric field changes of M component, carried negative charge to ground, was started with negative change and then followed by slightly larger positive changes. The responding electrostatic field of M-component was between one-fifth and one-hundredth of return stoke in quantities.

Thottappillil et al. (1990) analyzed 88 M changes (hooks) from 16 natural lightning at distances between 2.5km and 12.0km. The data were recorded in the Tampa Bay area of Florida and all located by network of TV cameras and thunder ranging. They found that 40% of the 38 first M changes following return strokes occurred within 3ms of the return stroke peak. They also reported that most frequent interval between the return stroke peak and the first M change was less than 1ms.

Rakov et al. (1992) observed electric field pulses in the microsecond scale preceding the electric field hook of M components from 27 ground flashes near Tampa, Florida and 19 ground flashes at NASA Kennedy Space Center (KSC). Using the multiple-station TV network and thunder ranging and the KSC Lightning Location and Protection (LLP), the distance between the field measurement site and return strokes locations in Tampa and KSC were ranging 5- 27km, and 2.5-12km, respectively. From a total of 118M changes, they classified them as various categories, namely bipolar pulses with the same initial polarity as initial polarity of the hook, unipolar pulses of the same polarity as that of the hook bipolar pulses with initial polarity opposite to that of the hook, unipolar pulses with initial polarity opposite to that of the hook and irregular pulse activity.

For rocket-triggered lightning, Rakov et al (2001) published that the M component electric field at 45km appeared as a bipolar, microsecond-scale pulse that stared prior to the onset of the M-component current at the channel base. However, far electric field of M-component produced by triggered-lightning field measurements is very rare.

In this paper, ten far electric field waveforms of M-component produced by rocket-triggered lightning have been observed by 9 sites of the lightning locating system in Foshan (FTLLS), Guangzhou, China, at a distance range 68km-126km from the lightning channel. Further, this is the first time that the far electrical fields of M-component have been measured in the range of distance 68 km to 126 km in rocket-triggered lightning.

## II. DATA AND EXPERIMENT

During the summer of 2014, many results of electric field (essentially radiation) have been obtained through artificially-triggering lightning at Guangdong Comprehensive Observation Experiment on Lightning Discharge (GCOELD), including 38 strokes in 8 flashes. Ten M components, interval time between the peak time of prior return stroke and the peak time of M-component were within 500μs, associated with 4 flashes were selected for this analysis.

The data were collected in and around the Foshan, China, in the summer of 2014. Electric fields used in this study were measured by 9 sites of the lightning locating system in Foshan (FTLLS) at the Guangdong province, China during the months of April and September in 2014. Geographical distribution of FTLLS and GECOELD are shown in Fig.1.A parallel plate antenna system, which was equipped in each site with 1 MHz bandwidth, was used to drive the signals to a 4 channel digital high-speed data acquisition card which digitized and recorded it with 10 M sampling rate with 12-bit resolution. Triggers occurred when a floating trigger threshold was exceeded. Typically, 500 μs of data were recorded for each trigger.

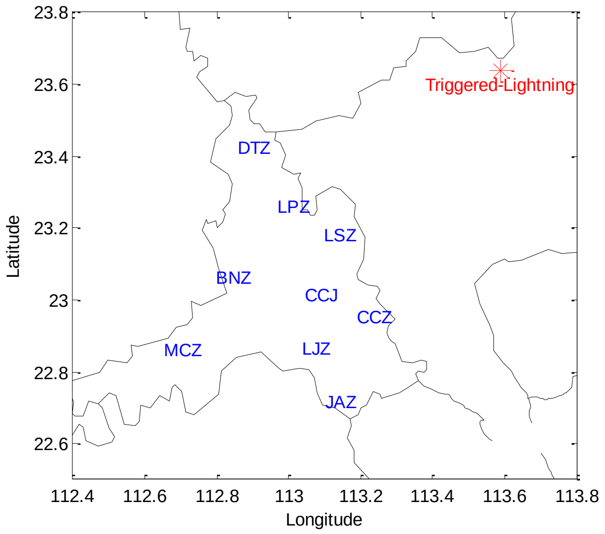


Fig. 1 Distribution of sensors at the lightning locating system in Foshan (FTLLS) and observation experiment sites for lightning.

## III. RESULTS

During the summer of 2014, both peak currents and electrical field of location systems data were obtained on 47 triggered lightning return strokes in 8 lighting flashes. Note that there were 37 return strokes detected in 5 flashes successfully. And 10 M-components within 500 microseconds after return stroke were examined in this paper.

### *A. M-component characteristics*

The parameters of electric field waveforms, recorded at each site (at a distance rang 68-126km from GCOELD), examined in this study are zero-to-peak risetime (*Tp*), 10-to-90% risetime, half- peak width (*Tphw*), the value of the continuing current immediately preceding the M current pulse(*ICC*), the difference between the maximum value of the M-component and ICC (*Im*), charge transferred of the time integral of the current above ICC (*Qm*).The definitions are similar to those used in Thottappillil et al. (1990).

Data of characteristics of M-component were listed in Table 1. The *Q1* was defined the amount of charge from the peak of the return stroke to the begin of the M-component. *T1* means the interval time between the peak of return stroke and the begin of the M-component, and *T2* shows the interval time between the peak of return stroke and the peak of the M-component. $T_{phw}$ was defined the Half wave width of M-component. The average magnitude of the continuing current (M-component) in our work is 2.09kA, and the average $T_{phw}$, 10-90% risetime and $T_{Rw}$ are 60.1μs,50.6μs and 311.3μs, respectively. The average *Qm* is 0.5C.

### *B. Far electric field waveforms of M-component*

Rakov et al (2001) measured the electric field 45km from the lightning channel using a 1.5m whip antenna on the roof of the five-story Engineering Building at the University of Florida Campus in Gainesville. The M-component electric field at 45km appears to be a bipolar microsecond-scale pulse that begins prior to the onset of the M-component current at the channel base.

The interval time between return stroke and the M-component of each site appeared to be comparable. This suggests that all these ten M-component were produced at the same position, GCOELD. Otherwise, if M-component were not produced at GCOELD like return stoke, there will be great variations recorded by each site of this value. It should be noted that all this value was calculated using the peak value of return stroke and M-component.

In Table II there are 10 M-components that were detected by seven or nine fast antennas. By plotting the amplitudes from columns 1-10 and fitting a power curve of the form $y=ax^b$, where y is the amplitude and x is the distance D from the triggered lightning flash, we obtain values for a and b. One result is shown in Figure 2 for M6 in triggered lightning flash F081901. The power fit produces an attenuation exponent, b, of -1.107 and the regression fit has a correlation coefficient of 0.58. The coefficient, a, has no physical meaning and is not listed. The other nine attenuation curves are similar to Figure 8 and are not reproduced in this paper, the attenuation exponents range from -0.699 to -1.674 with a mean of -1.012 and the correlation coefficients range from 0.38 to 0.71.

Note that all propagation paths are over land, more detail about the empirical attenuation exponent for the geographical area of Foshan, China will be published further. Even the attenuation, which depends mostly on ground conductivity, may varies as geographical area, we must recognize that it was probably the M-component triggered in Conghua, China that produced the far electric field.

In Fig 3 the current and coreponding far eletrical filed of ten M-componennts including return stroke (RS) followed by the M component are shown in left half and right half, respectively. (a)~ (j) in the left half represent continuous current of M1~M10 in four rocketed-triggered lightning flashes at the GCOELD in 2014.Simialrily, (a) ~ (j) in the right half represent vertical electrical field of M1~M10 recorded by CCJ in four rocketed-triggered lightning flashes. It suggests that the waveform of far electrical field of M2, M3 and M8 in right half (b), (c) and (h) are bipolar microsecond-scale pulses, which M2 and M3 are bipolar pulses with the same initial polarity as initial polarity of the hook and M8 is opposite to that of the hook. The waveform of far electrical field of M4 and M10 are unipolar pulses of the same of polarity as that of the hook. The remanding five waveforms of M-component appear to be irregular pulses.

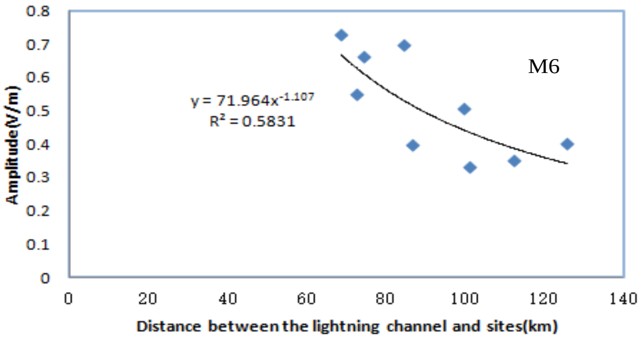


Fig. 2 Nine fast antennas recorded the M6 in triggered lightning flash F081901.Their received signal strength amplitudes are plotted at the distance of the fast antenna from the triggered lightning site. A regression power curve of the form, $y=ax^b$ is fitted with a correlation coefficient of 0.58. The attenuation exponent b is -1.107 for this M-component. Similar plots can be obtained for nine other M-component.

Rakov et al. (1992) reported four types of waveforms of electrical field of 118 M component in natural lightning. There are following main difference: 1) In Tampa and KSC the distance was ranging 5-27km, and 2.5-12km, respectively. In this work, our distance ranging in a relativity wide range ,68.5km~125.7km, which electrical filed are entirely radiation field. 2) The time constant of our fast antenna are all 1 microsecond. different time constant of sensor may result in variations of waveforms. 3) Difference between natural lightning and rocket-triggered lightning may also lead to somewhat dissimilar to Rakov. et al. (1992)

TABLE I CHARACTERISTICS OF M-COMPONENT RECORDED

| | Q1(C) | Magnitude(kA) | ICC(kA) | Zero-to-peak rise time(μs) | 10-90% rise time(μs) | Tphw(μs) | Qm(C) | T1(μs) | $T_{RM}$(us) |
|---|---|---|---|---|---|---|---|---|---|
| M1 | 0.744 | 2.67 | 3.73 | 35.6 | 15.3 | 21 | 0.248 | 80.4 | 116 |
| M2 | 0.487 | 1.63 | 1.1 | 117.8 | 79.3 | 63.5 | 0.384 | 168.1 | 285.9 |
| M3 | 1.523 | 1.13 | 1.83 | 138.6 | 81.6 | 74.9 | 0.511 | 381.3 | 519.9 |
| M4 | 0.3 | 4.33 | 0.47 | 24.1 | 10.8 | 53.2 | 0.421 | 131.2 | 155.3 |
| M5 | 0.95 | 2.5 | 1.77 | 93.7 | 68.3 | 51.2 | 0.457 | 165.1 | 258.8 |
| M6 | 0.81 | 1.77 | 2.03 | 76.7 | 50.9 | 51.1 | 0.383 | 178.9 | 255.6 |
| M7 | 1.908 | 2.63 | 3 | 151.6 | 83 | 85.1 | 1.082 | 203.6 | 355.2 |
| M8 | 3.577 | 1.43 | 3.53 | 56.4 | 41 | 60.8 | 0.536 | 279.2 | 335.6 |
| M9 | 1.549 | 0.79 | 1.71 | 110 | 90 | - | - | 370.0 | 480.0 |
| M10 | 2.404 | 2.13 | 1.4 | 157.8 | 96.2 | 142 | 0.948 | 354.5 | 512.3 |

TABLE II STASTICAL POWER LAW REGRESSION FIT ELECTRICAL FIELD VERSUS RANGE.

| M-component | Field(V/m) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | LSZ 68.5km | LPZ 72.4km | DTZ 74.3km | CCZ 84.5km | CCJ 86.5km | BNZ 99.8km | LJZ 100.8km | JAZ 112.4km | MCZ 125.7km |
| M1 | 1.015 | 1.007 | - | 0.933 | 0.621 | 0.974 | - | 0.598 | 0.644 |
| M2 | 0.690 | 0.580 | - | 0.642 | 0.443 | 0.550 | - | 0.381 | 0.376 |
| M3 | 0.731 | 0.702 | - | 0.467 | 0.410 | 0.593 | - | 0.462 | 0.349 |
| M4 | 0.487 | 0.519 | - | 0.292 | 0.388 | 0.508 | - | 0.381 | 0.268 |
| M5 | 1.218 | 0.946 | 1.108 | 0.992 | 0.543 | 0.720 | 0.539 | 0.652 | 0.563 |
| M6 | 0.731 | 0.549 | 0.665 | 0.700 | 0.399 | 0.508 | 0.334 | 0.353 | 0.402 |
| M7 | 1.664 | 1.403 | 1.773 | 1.225 | 1.075 | 1.397 | 0.847 | 0.843 | 0.832 |
| M8 | 4.019 | 3.111 | 3.768 | 2.041 | 1.873 | 2.244 | 1.463 | 1.631 | 1.449 |
| M9 | 0.934 | 0.671 | 0.831 | 0.817 | 0.432 | 0.550 | 0.488 | 0.598 | 0.563 |
| M10 | 1.380 | 1.251 | 1.884 | 1.225 | 0.997 | 1.270 | 0.975 | 1.033 | 0.939 |

Note that There were only seven sites recorded for M1~M4 successfully. DTZ and LJZ were not included for some reasons.

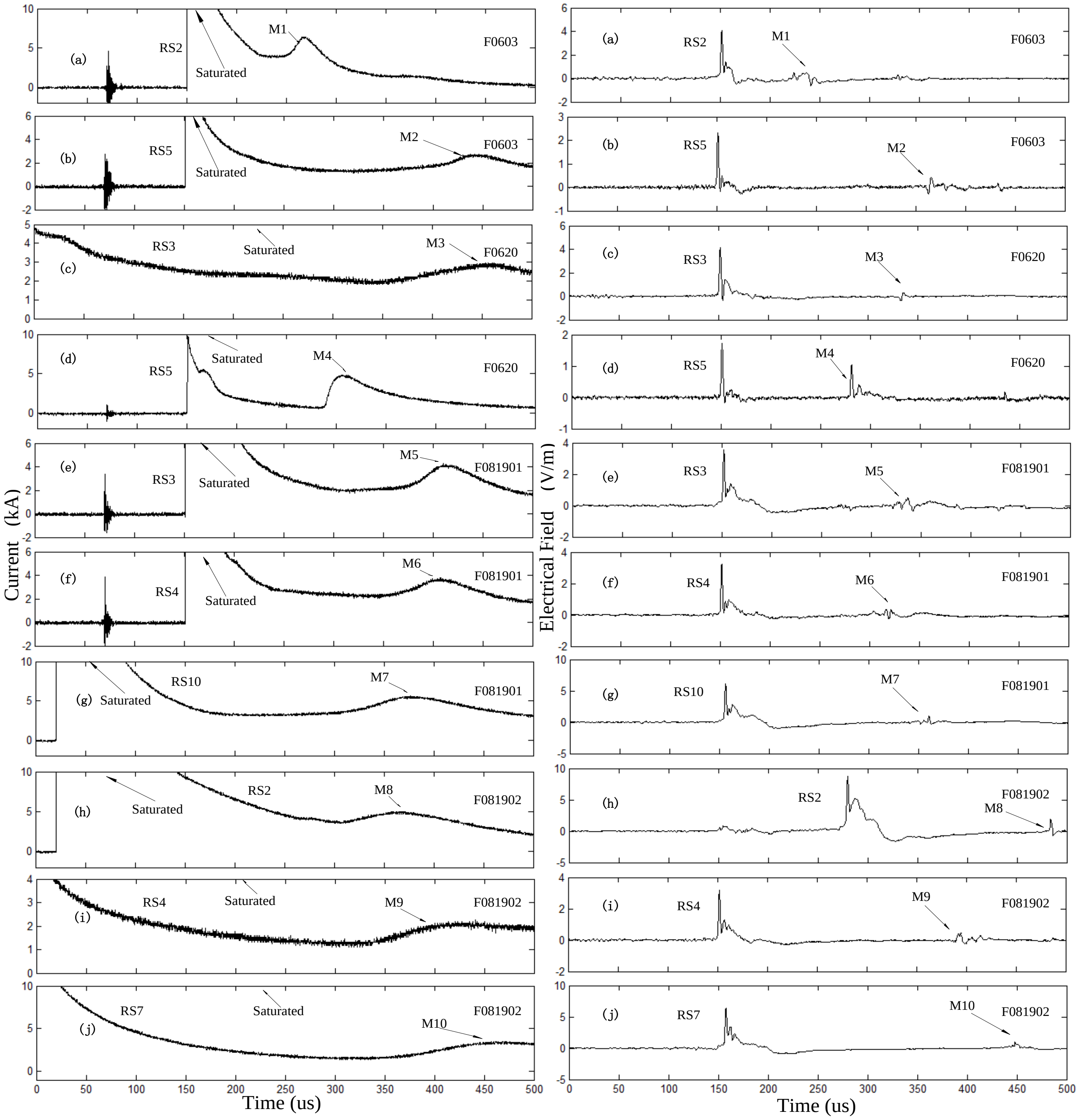


Figure 3 Return strokes (RS) followed by an M component initiated using the classical rocket-and-wire technique at the GCOELD in 2014.The left half were current and the right half were vertical electrical field. Both were in 500 microsecond scale. For example， there were 2th return stroke(RS) in flash F0603,followed M1, in the left half (a) and the corresponding far electrical filed recorded by CCJ were displayed in right half. Note that all this far electrical field were recorded by CCJ and were essentially radiation filed. As expected, the waveforms measured by other sites are very similar to CCJ and not reproduced in this paper. Saturated happened in the left half (a) ~ (j).

## IV. SUMMARY

In this study, effective effort has been made by trying to prove the far electrical filed was produced by M component in rocket-triggered lightning at GCOELD in 2014.Charatertics of these ten M-component have been analyzed and compared with previous studies. Ten far electric field waveforms of M-component produced by rocket-triggered lightning have been observed by 9 sites of the lightning locating system in Foshan (FTLLS), Guangzhou, China, at a distance range 68km-126km from the lightning channel. There are two evidence to prove this, one is the interval time between of the M component and the return stroke just adjust before of 9 sites are comparable, the other one is that we derived a power curve of the form $y=ax^b$ by fitting the far electrical field versus rang. The average attenuation exponent, b, is -1.012 ranging from -0.699 to -1.674. Finally, we group our waveform of far electrical field in to four types as proposed by Rakov et al. (1992).


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