International Conference on Lightning Protection
33rd International Conference on Lightning Protection
25 - 30 September 2016
Estoril, Portugal

Regular Pulse Trains in Chaotic pulse Bursts

R.Abeywardhana, M.Fernando, U. Sonnadara
Department of Physics
University of Colombo
Colombo 3, Sri Lanka

V. Cooray
Department of Engineering Science
Uppsala University
Uppsala, Sweden.

***Abstract*— Electric field pulse bursts generated by lightning flashes are considered as sources of high radio frequencies. In this study, an analysis of pulse bursts in electric field records of 30 negative cloud to ground lightning flashes recorded in the southern coastal area of Sri Lanka is presented. Sixty-four percent (64%) of pulse bursts are typical chaotic pulse trains (CPT). Twenty-four percent (24%) of pulse bursts exhibit CPT characteristic while containing regular pulses within the burst. These are termed as "semi-regular pulse bursts" in this study. The regular pulses within CPTs show characteristics similar to dart stepped leaders or stepped leaders, and in some cases, more than one regular pulse trains with different characteristics are observed within a single burst. The intra-cloud lightning activities associated with CPT such as K changes, leader processes, and isolated pulses bursts also exhibit regular pulse bursts or semi-regular pulse bursts. CPT and regular pulse trains always show similarity in occurrence, and semi-regular pulses have the characteristic of both type of pulse bursts. Hence CPT and semi-regular pulse bursts may be formed by superposition of two or more regular pulse bursts which represent dart stepped leader or stepped leader type activities.**

Keywords-lightning; pulse bursts; chaotic pulses; regular pulses; superimposition;

I. INTRODUCTION

In decades of studies conducted on lightning, electric field signatures were used to identify intra-cloud activities that are not recognizable with visual evidence. So-called CPT is an example of intra-cloud activity in which its physical process is yet to be identified. CPT is known to produce strong radio frequencies signal that may affect on sensitive electronic devices.

A. Regular pulse burst

In 1975, Krider et al. [1] observed regular pulse bursts in intracloud discharges which start with a fast, large amplitude pulse portion followed by a slow, small amplitude pulses. Typical regular pulse burst duration was around 100-400 μs. The time interval between successive pulses was in the range of 1-20 μs with a mean value of 5-6 μs. The Full width at half maximum (FWHM) of individual pulses distributes in the range of 0.2-2 μs with a mean of 0.74 μs.

In 1996 Rakov and Uman [2] studied regular pulse bursts in electric field signatures of the cloud to ground (CG) flashes as well as intra-cloud flashes measured with a 12-bit digitizer in 0.5 μs sampling interval. They observed regular pulses in K changes and M components, although all the K changes or M components does not contain detectable regular pulse burst or CPT. According to their study, typical regular pulse burst duration is around 173-235 μs while average pulses per burst lay between 28 and 39. The average inter-pulse interval is in the range of 6.1-7.3 μs. Those observations do not differ significantly for cloud flashes or ground flashes which suggest the physical process based on the regular pulse in intra-cloud flashes and cloud to ground flashes are same. The amplitude of the regular pulse in a burst often increases and then decreases. They listed characteristics of radiation field pulse in the natural lightning environment. Table I show some of their listed details.

B. Chaotic pulse burst.

Weidman [3] reported chaotic leaders (CL) that are a train of pulses, irregular in pulse shapes, pulse width and pulse separation, preceded by subsequent return strokes. K-changes and [4][5] M-components [6] are identified intra-cloud lightning activities that are associated with chaotic pulses. Pulse trains of irregular pulse characteristics and erratic amplitudes in lightning flashes are termed ''chaotic pulse trains'' [4]. The peaks in the electric field signature of CPT are larger than the peaks of dart leaders and dart step leaders [7].

Gomes et al. studied [4] 95 CPTs, most of them preceded subsequent return stroke. They observed that CPT occurred in intracloud discharges same as in CG discharges. In CG flashes CPTs may occur after the last RS or precede another CPT. The most probable value of pulse width is 2-4 μs, while pulse separation is in the range of 2-20 μs. When considering pulse duration, it shows a nearly normal distribution with the most probable value around 400-500 μs and range of distribution of 100-2000 μs. In their study 65, CPTs out of 84 CPTs that occurred prior to subsequent return strokes were immediately preceding the return stroke. Nineteen CPTs exhibited a pause period between the end of CPT and return stroke with separation time in the range of 0.35-73 ms. They also reported a pulse train that showed chaotic nature during the first couple of hundred milliseconds, which turn into more regular in pulse shape similar to regular pulses at the later part of the pulse train as seen in [2]. With observations in the study, Gomes et al. Suggested that CPT has some relation to dart leader.

TABLE I. LIGHTNING TEST STANDARD FROM RAKOV'S [2] STUDY.

Type of pulses	Typical pulse duration (µs)	Typical time interval between pulse (µs)
Stepped leader	1-2	15-25
Dart-stepped leader	1-2	6-8
Regular pulse burst in both cloud to ground flashes	1-2	5-7
Initial breakdown in ground flashes	20-40	70-130
Initial breakdown in cloud flashes	50-80	600-800

Ismile et al. have observed that CPTs were often contained with trains of regular pulses within the pulse burst [8]. The present study investigates of the occurrence regularity and characteristic of irregular and regular pulse trains within pulse bursts in electric field signature of negative CG lightning flashes recorded in Sri Lanka. The study also includes a comparison of the characteristic of regular pulse bursts, CPTs and pulses burst with both regular and irregular characteristics. Additionally, we were able to examine the relationship between these three types of pulse bursts and to suggest how the chaotic pulse bursts are formed.

II. DATA

The measurement of electric fields generated by lightning flashes was conducted in Matara on the southern coast (5.9500º N, 80.5333 º E) of Sri Lanka during the southwest monsoon period in 2013. Measuring station was situated 200 m away from the Indian Ocean. The measuring system was similar to the one used in [9] with a 30 MHz bandwidth. Decay time constant of the one integrating amplifier was set to 1.0 s (for the slow field) while fast integrating amplifier had 150 µs decay time constant. Electric field measurements were recorded by a digitizer with 12-bit resolution. Data were recorded with a 6.4 ns sample interval allowing 200 ms sample window to be recorded from a single trigger mode. The pre-trigger delay time was set to 60ms. The bandwidth of the digitizer (PicoScope 6402B) was 250 MHz. Most of the flashes occurred over the sea, so the path of propagation was over the sea, except for the last few tens of meters. Hence the propagation effects on the measured fields were minimal.

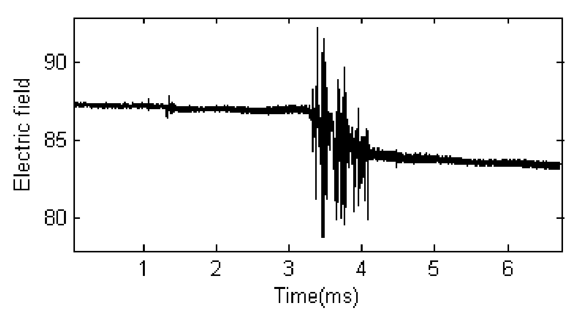
III. RESULTS AND OBSERVATIONS

In this study, electric field signatures of a sample of 30 CG lightning flashes have been analyzed. In the sample, there were 90 pulse bursts including 59 CPTs, 10 regular pulse bursts and 21 pulse bursts exhibiting characteristic of CPT having regular pulses within the burst that we termed "semi-regular pulse burst". Fourteen pulse bursts out of all 90 bursts in this study were associated with clear K-changes and 33 bursts were preceding subsequent return strokes, while 22 isolated bursts had no electric field signatures of any recognized intra-cloud activity or preceding subsequent return stroke. Observed semi-regular pulse bursts were associated with K-changes, pulse bursts preceding subsequent return strokes as well as isolated pulses. There was no pulse burst associated with electric field signatures of M-components in the selected sample of electric field data. The polarity of regular pulses was the same within a given pulse burst for all 10 regular pulse bursts and 22 semi-regular pulse bursts. Also, the polarity of regular pulses did not show a significant bias of been either positive or negative polarity. Electric field signatures type and regular pulse polarity distribution of pulse bursts are summarized in table 2.

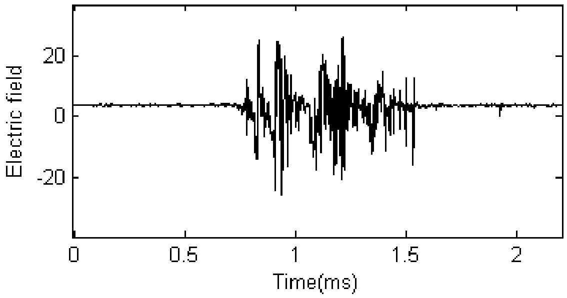
Five pulse bursts out of 23 semi-regular pulse bursts showed characteristic of K-changes. The microsecond scale pulse burst in Fig. 1, which occurred in a CG flash associated with a characteristic of a K-change. In the slow antenna trace shown in Fig. 1(a) pulse burst occurred with a ramp like static field change. In the fast antenna trace shown in Fig. 1(b) the ramp was not visible with pulse burst. Fig. 2(a) and Fig. 2(b) show the start and end portions of the pulse burst in the fast antenna trace. Start portion of the pulse train in Fig. 2(b) consistent with irregular amplitude and pulse shape. However, in Fig. 2(b) the end of the pulse burst, pulse change into regular in shape. Also in Fig. 2(b), the average interpulse duration for first few regular pulses were 7.1 µs, which is in the range of typical inter-pulse duration of dart-step-leader or regular pulse bursts (table 1). But the few regular pulses in the end of bursts have increased average inter-pulse durations of 24.1µs. This characteristic of the regular pulse is hard to categorize as dart-step-leader or intracloud dart-leader [1] but as stepped leader.

TABLE II. CHARACTERISTICS OF PULSE BURST IN 30 GROUND FLASHES.

Burst type	Total	Polarity		Event type		
		Negative	*Positive*	*K-change*	*Leader*	*Burst*
Chaotic pulses	58	-	-	9	26	2
Semi-regular pulses	22	17	5	5	7	10
Regular pulses	10	2	8	-	-	10
Total	90	19	13	14	33	22

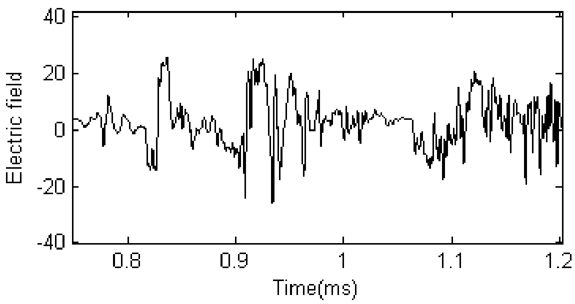


(a)

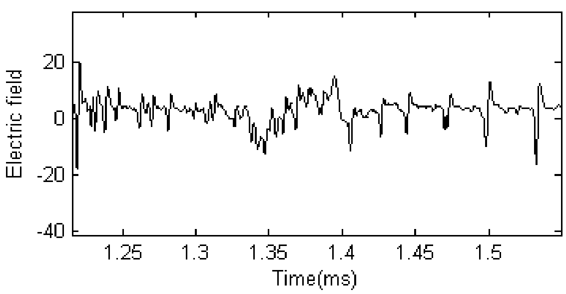


(b)

Figure 1. A semi-regular pulse burst of microsecond scale pulse associated with a K–change in ground flash; (a) slow electric field signature; (b) Fast electric field.

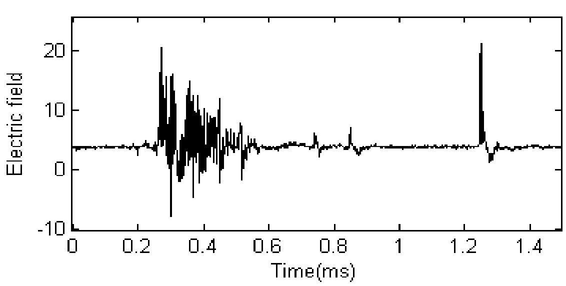


(a)

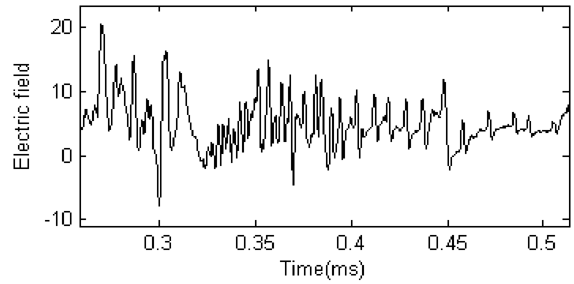


(b)

Figure 2. The Same pulse burst in Fig. 1, but displayed on an expanded time scale (a) beginning of pulse train with an irregular pulse; (b) the last portion of pulse train with regular pulses.



(a)



(b)

Figure 3. A semi-regular pulse burst of microsecond scale pulse associated with a chaotic leader; (a) fast electric field signature; (b) expanded time scale.

Irregular pulses preceding subsequent return stroke was termed as CL by Weidman [3]. In the selected sample of 30 cloud-to-ground flashes, 26 irregular pulse bursts, and 7 semi-regular pulse burst are observed preceding subsequent return strokes. Fast electric field of such a semi-regular pulse burst is presented in Fig. 3(a). The pulse burst occurred 700 μs prior to subsequent return stroke. The time between the end of the pulse burst and return stroke for all seven semi-regular burst distributed in a range of a few hundreds of microseconds. Gomes et al. [4] reported that the pause period for CPT is able to extend from few hundreds of microsecond to few milliseconds. Pulse burst shows irregular characteristic in the beginning (Fig. 3. (b)), which tends to be regular in pulse shape towards the end.

IV. Discussion

Duration of semi-regular pulse bursts is distributed in a range of 200 μs – 2000 μs with a most probable value of 400–600 μs. This distribution is same as the CPT duration reported in [4]. Semi-regular pulse burst contains regular pulses with a typical pulse width of 1.2 μs and 2.5 μs and most probable value of 1.0 μs. FWHM of those pulses distributed in the range of 0.74 μs – 1.56 μs. Fig. 4 shows the distribution of average inter-pulse duration. Most of the regular pulse trains in semi-regular pulse bursts have a typical inter-pulse duration in the range of 2 μs – 11 μs, while two of pulse trains have interpulse duration higher than 20 μs. According to the Table 1, these two pulse trains belong to electric field signature of step leader while other regular pulse trains associated with dart step leader or intra-cloud dart step leader process.

Gomes et al. [4] reported some of CPTs end with train of regular pulses. In the present study regular pulse trains are observed even in the middle portion of pulse burst with chaotic pulse characteristic, as well as at the end portion. In most of semi-regular pulse trains, regular pulses are detected at the end portion of pulse burst. Also, five of CPTs contain more than one regular pulse trains within a burst. All the semi-regular pulse bursts which precede subsequent return strokes are ended with regular pulse trains in which electric field signatures are similar to dart-stepped leader, stepped leader or regular pulse burst.

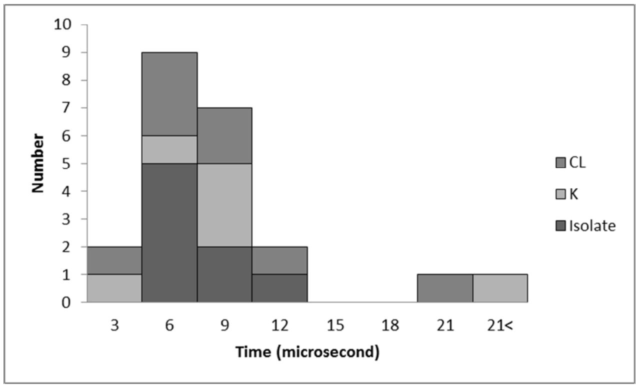


Figure 4. Distribution of inter-pulse duration of regular pulses in semi-regular pulse bursts

In the present study, no pulse bursts associated with electric field signatures of M-component was observed. However, in previous studies, M-components were reported to occur with regular pulse bursts [2] as well as CPTs [6]. Nine CPTs and 5 semi-regular pulse bursts out of a sample of 90 pulse bursts are associated with electric field of K-changes. It has been reported regular pulse bursts [2] and CPTs [4], [5] associated with K–changes. Also, CPTs [4] and regular pulse bursts [2] have been observed as isolated pulse bursts with no special electric field characteristics. We observed isolated pulse bursts including 2 CPTs, 10 semi- regular pulse bursts and 10 regular pulse bursts. The observations of the present study and previous studies suggest that the intra-cloud activities associate with regular pulse bursts also observable with CPTs or semi-regular pulse bursts.

V. Conclusion

We have analyzed 90 pulse bursts in a sample of 30 CG lightning flashes to investigate characteristics of pulse bursts that termed as semi-regular pulse bursts. The measurements were taken in tropical monsoon thunderstorm in Sri Lanka.

Semi-regular pulse bursts exhibit both regular and irregular pulse train within the same pulse burst. Some of the semi-regular pulse bursts start with chaotic shape portion and end of the bursts show regular pulses with decaying amplitude. Some bursts show almost chaotic characteristics but there are detectable regular pulses within the burst, and it is possible to observe more than one regular pulse trains with different characteristics.

K-changes [5], M component [6] and leader breakdown [3] often associated with CPTs, however, this CPT can be replaced with regular pulse bursts or semi-regular pulse bursts. These observations suggest that all three types of bursts have a similar physical activity in common.

According to observations in the present study and previous studies, all three burst types have similarities in occurrence. Semi-regular pulse bursts exhibit evidence of superimposing of two or more regular pulse trains and characteristics of both CPTs and regular pulse bursts. Considering these observations, we conclude that semi-regular pulse burst, which is similar to stepped or dart stepped leader type activities, should be an intermediate situation of forming CPT. Ultimately CPTs are formed by superimposition of two or more regular pulse bursts which represent dart stepped leaders or stepped leaders.

Acknowledgment (Heading 5)

This research was funded by the University of Colombo research grant AP/3/2014/RG/09. Additional support was provided by the research grant AP/3/2012/CG/24 and the assistance given by S.Nanayakara, U Mendis, S Jayalal and JAP Bodhika in data collection is highly appreciated.

References

[1] E. P. Krider, G. J. Radda, and R. C. Noggle, "Regular radiation field pulses produced by intracloud lightning discharges," J. Geophys. Res., vol. 80, pp. 3801-3804, 1975.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[2] Vladimir A. Rakov, Martin A. Uman, Fellow, IEEE, Glen R. Hoffman, Michael W. Masters, and M. Brook, "Burst of pulses in lightning electromagnetic radiation: observations and implications of lightning test standards,IEE transactions on electromagnetic compatibility,38(MAY 1996).

[3] Weidman, C.D., 1982. The submicrosecond structure of lightning radiation fields. Ph.D. Dissertation, University of Arizona.

[4] Chandima Gomes, Vernon Cooray, Mahendra Fernando, Raul Montano, Upul Sonnadara, "Characteristics of chaotic trains generated by lightning flashes", Journal of Atmospheric and Solar-Terrestrial Physics, 66 (2004) 1733-1743.

[5] Sankha Nanayakkara, S.P.A.Vayanganie, T.A.L.N. Gunasekera, M. Fernando, V. Cooray "'K – change: Is it a static field of a chaotic pulse burst?" International Conference on Lightning Protection (ICLP), Shanghai, China(2014)

[6] S.P.A.Vayanganie, T.A.L.N. Gunasekera, S. Nanayakkara, M. Fernando, V. Cooray "Electric Field Change of M Component" International Conference on Lightning Protection (ICLP), Shanghai, China(2014)

[7] Rakov, V.A., Uman, M.A., 1990. Waveforms of first and subsequent leaders in negative lightning flashes. Journal of Geophysical Research D-10, 16,561–16,577.

[8] M. M. Ismail, V. Cooray, P. Hettiarachchi, M. Rahman, M. Fernando, D. Johari 'On the possible origin of chaotic pulse trains in lightning flashes' International Symposium on Lightning Protection (XIII SIPDA), Brazil (2015)

[9] M Fernando and V Cooray, Measurements of lightning generated electromagnetic fields, Lightning Electromagnetics, Edited by V Cooray, IET, pp 576-581, 2012