ELECTRIC FIELD PULSE BURSTS IN CLOUD-TO-GROUND LIGHTNING DISCHARGES

V. A. Rakov, M. A. Uman, G. R. Hoffman

Department of Electrical Engineering
University of Florida, Gainesville, FL, USA

M. Brook

New Mexico Institute of Mining and Technology
Socorro, NM, USA

Abstract
Regular bursts of electric field radiation pulses produced by three multiple-stroke cloud-to-ground discharges recorded in 1991 at the NASA Kennedy Space Center are analyzed. The bursts are similar in the number of pulses per burst and inter-pulse intervals to the "multiple burst" component (so-called component H) of the standard lightning environment for the design and testing of aerospace vehicles [1]. The relation of the regular pulse bursts to various lightning processes is discussed. Comparison of the pulse bursts in ground flashes to similar bursts in cloud flashes is given.

Introduction

Krider et al. [2] observed sequences or bursts of microsecond-scale (essentially radiation field) pulses in a large fraction of their measured electric and magnetic fields from distant cloud lightning in Florida and Arizona. Each burst had a typical duration of 100 to 400 μs, and the time intervals between individual pulses in the burst were typically 5 μs. The initial half cycle of a pulse had a full width at half maximum of typically 0.75 μs (total duration typically 1-2 μs), and was followed by a relatively small and slowly varying overshoot. Based on their observations that (1) the pulse bursts tend to occur toward the end of the intracloud discharges, where the K changes are known to occur (e.g., Ogawa and Brook [3]), and (2) the waveshape of the pulses is similar to that produced by steps in the stepped leader process, Krider et al. [2] suggest that the bursts are due to "an intracloud dart-stepped leader process", possibly associated with K recoil streamers [3] developing in the previously formed channels. The rise times of individual pulses were reported by Krider et al. [2] to be sometimes at the measuring system limit of 0.1 μs. The latter observation taken together with the high repetition rate of the pulses indicates that these pulses may cause interference or upset to microelectronic systems. The pulse bursts observed by Krider et al. [2] are similar in their duration and inter-pulse intervals to the "multiple burst" component (so-called component H) of the standard lightning environment for the design and testing of aerospace vehicles [1]. The "multiple burst" component consists of 24 pulse trains, each containing 20 pulses separated by 10-50 μs; that is, the duration of each train is 200-1000 μs. The trains are distributed, 10-200 ms apart, over a period of up to 2 seconds. Individual pulses within the train, characterized in terms of current, are defined to have a relatively low amplitude of 10 kA (compared to other components of the standard lightning environment [1]), a risetime of 240 ns, and a decay time to half-peak value of 4 μs.

Since Krider et al. [2] used a triggered field-measuring system with a 200-μs oscilloscope sweep, they could not determine the relation of the bursts to K changes or to any other known lightning processes. Further, Krider et al. [2] analyzed primarily intracloud lightning flashes and only briefly state that the pulse bursts were also observed during about 10% of cloud-to-ground flashes. The present study is an extension of that of Krider et al. [2] to cloud-to-ground discharges and is primarily focused on the relation of the regular pulse bursts to known lightning processes identifiable in electric field records. We also compare the characteristics of the regular pulse bursts in ground flashes to corresponding characteristics of similar bursts in cloud flashes.

Data and Results

The electric field records of three multiple-stroke cloud-to-ground discharges recorded in 1991 at the NASA Kennedy Space Center (KSC) are analyzed here. The data were acquired with a multiple-channel 12-bit digitizing system [4] characterized by a 500-ns sampling interval with individual record lengths up to a few seconds. Two channels of the digitizer were used, each fed from a flat-plate antenna via an integrator and a low-pass anti-aliasing filter. The overall response time to a step function input for both channels was about 700 ns. One integrator had a decay time constant of about 10 s so as to reproduce faithfully the millisecond-scale, predominantly electrostatic, field changes. The other integrator had a decay time constant of about 150 μs and a much higher gain so as to accentuate the microsecond-scale, predominantly radiation field, variations. The system noise level was as low as ±1 bit (about 5 mV on a 5-V scale). No smoothing was applied to any records involved in this study. Only those pulse bursts that contained more than 5 pulses separated by time intervals shorter than 30 μs or so are included in this analysis.

A summary of the pertinent information on the three KSC ground flashes is given in Table 1. Examples of regular pulse bursts in ground flashes are given in Figs. 1 through 4. About half of all measured pulse bursts could not be associated with specific lightning processes. The microsecond-scale pulse burst shown in Figs. 1 and 2 appears to be associated with the later portion of a ramp-like millisecond-scale field change characteristic of a K change (Kitagawa and Brook [5]; Thottappillil et al. [6]), while the bursts in Figs. 3 and 4 appears to culminate in a hook-shaped field change characteristic of an M component (Malan and Schonland [7]; Thottappillil et al. [6]).

The results of our analysis of the three KSC ground flashes are as follows.

1. The regular pulse bursts show a clear tendency not to occur before the first return stroke or during the first interstroke interval (between the first and second strokes). After the fourth stroke the occurrence of bursts gradually decreases.
2. Most of the regular pulse bursts were observed to occur when there is no detectable millisecond-scale, predominantly electrostatic field change (55% of all the cases) or there is a ramp-like millisecond-scale field change indicative of a charge transfer associated with a K process (39% of all the cases). Two consecutive bursts occurred just prior to a hook-shaped millisecond-scale field change superimposed on continuing current field change, characteristic of an M component. The bursts apparently associated with K changes typically occur during the second half of the K field ramp (see Fig. 1). Note that many millisecond-scale ramps do not contain regular pulse bursts, only irregular (if any) pulse activity, consistent with observation of Rakov et al. [8].
3. Except for the bursts apparently associated with M component, there is usually a delay in excess of 10 ms between the pulse burst and preceding return stroke.
4. Usually all pulses within a burst have the same polarity. Negative and positive polarities appear to be about equally probable.
5. Amplitudes of the pulses in the burst are usually less than a few percent of the average return-stroke initial field peak in the same flash.

Discussion

The observation that the bursts usually do not occur until after the second stroke possibly indicates that these bursts are associated with processes in previously conditioned sections of the lightning channel, similar to a dart-stepped leader, as first suggested by Krider et al. [2]. It appears that a channel sufficiently conducive for the dart-stepped propagation mode usually is not created until two strokes have contributed to the channel conditioning.

The characteristics of pulse bursts in ground flashes appear to be similar to those in cloud flashes. Table 2 gives pertinent information on three KSC cloud flashes recorded at the same site and using the same instrumentation. These cloud flashes were previously analyzed by Villanueva et al. [9], primarily for the larger pulses that were found to occur early in the flash. The similarity between the pulse bursts in cloud and ground flashes implies that the same physical process creates this lightning radiation field signature, which is apparently independent of the presence of a channel (or its remnants) to ground. Cloud flash 9123164 and cloud-to-ground flashes 91231107 and 91231111 occurred during the same storm, within 45 minutes of each other. For these three flashes, the values of maximum pulse amplitude in the burst, averaged over all the bursts in the flash, are similar (excluding the burst shown in Fig. 4b, whose maximum amplitude is 2-3 orders of magnitude larger than that in the majority of bursts analyzed here). If we assume that the distances to these three discharges do not differ significantly, the similarity of amplitudes probably indicates that the burst processes in the two types of flashes involve similar currents and propagation speeds.

The pulse bursts we observed in both ground and cloud flashes are similar to the bursts studied by Krider et al. [2] and appear to be similar in the number of pulses per burst and inter-pulse intervals to the "multiple burst" component of the standard lightning environment for the design and testing of aerospace vehicles [1]. Although in our data the number of pulses per burst is somewhat greater (18 to 39 vs. 20 in the standard lightning environment) and the intervals between the pulses are somewhat shorter (6.1 to 7.3 μs vs. 10-50 μs in the standard lightning environment).

The "multiple burst" component in the standard lightning environment is apparently based on current and field measurements taken on an instrumented aircraft flying through thunderstorms. It is not clear if the radiation field pulse bursts analyzed here and in [2] are due to the same physical process as that involved in the in-flight measurements. However, the similarity of the most easily identifiable features, number of pulses and inter-pulse intervals, suggests a common origin. Besides that, among all presently

Table 1. Summary of the characteristics of regular pulse bursts in three KSC ground flashes

Flash ID	Number of Strokes	Number of Pulse Bursts			Characterization of Bursts		
		Only Positive	Only Negative	Total	Average Burst Duration, μs	Average Number of Pulses	Average Inter-Pulse Interval, μs
9122246	7	15	20	35	173	30	6.1
91231107	9	21	12	34*	192	28	7.3
91231111	3	10	10	20	235	39	6.1

* One burst shows polarity reversal.

Table 2. Summary of the characteristics of regular pulse bursts in three KSC cloud flashes

Flash ID	Number of Pulse Bursts			Characterization of Bursts		
	Only Positive	Only Negative	Total	Average Burst Duration, μs	Average Number of Pulses	Average Inter-pulse Interval, μs
91225297	11	16	28*	161	18	6.8
9123164	3	5	8	133	24	6.4
912366	31	6	37	117	20	7.2

* One burst shows polarity reversal.

known lightning radiation field signatures, summarized in Table 3, there is no better match to the "multiple burst" component in the standard lightning environment than the regular pulse burst analyzed here.

Recently [10], SAE (the U.S. Society of Automotive Engineers) Committee AE-4L (Lightning) and EUROCAE (the European Committee for Aerospace Electronics) Working Group 31 (Lightning) revised the description of the "multiple burst" component for the standard lightning environment changing (a) the number of pulse trains from 24 to 3, (b) the inter-pulse intervals from 10-50 μs to 50-1000 μs, and (c) the separation between trains from 10-200 ms to 30-300 ms. These radical changes, although not adequately explained, are recommended [10] for inclusion in future revisions of all the documents that specify the standard lightning environment for the design and testing of aerospace vehicles. The new multiple burst description matches best the radiation field signatures of the initial breakdown in ground and cloud flashes (see Table 3). The initial breakdown pulses in both cloud and ground discharges occur in sequences each lasting for some milliseconds [4,9]. However, the time intervals between the initial-breakdown pulses exhibit significantly more variation than inter-pulse intervals in the regular pulse bursts analyzed here. Note that the former are significantly wider and have larger amplitudes (sometimes comparable to those of return-stroke pulses [4]) than the latter. The initial breakdown pulses, occurring at the beginning of the flash, are likely to be a manifestation of the formation of new in-cloud channels, whereas the regular pulse bursts, occurring in the later part of the flash, are probably associated with processes in previously formed channels. Thus, it appears to us that the new description of the "multiple burst" component [10] may well reflect a change to a different lightning process, rather than an improved characterization of the same process.

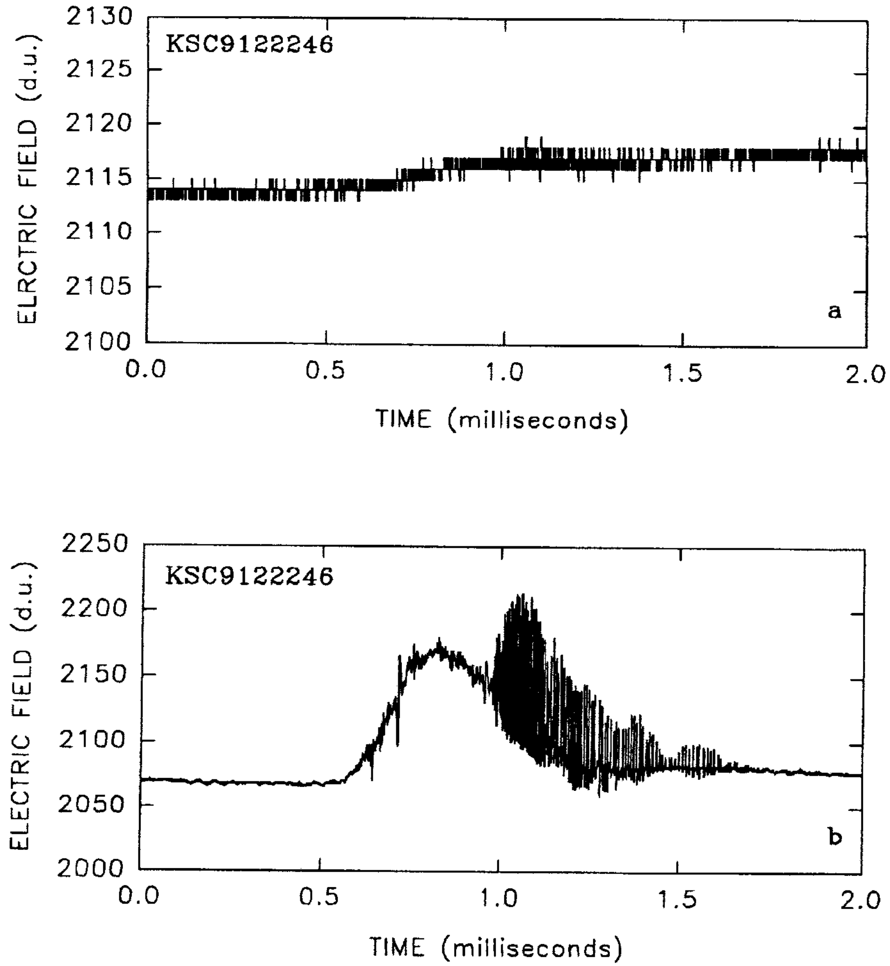

Fig. 1: An example of a regular burst of microsecond-scale pulses associated with a ramp-like millisecond-scale field change (K change), a - low gain, decay time constant of 10 s; b - high gain, decay time constant of 150 microseconds. The pulse burst is shown on an expanded time scale in Fig. 2.

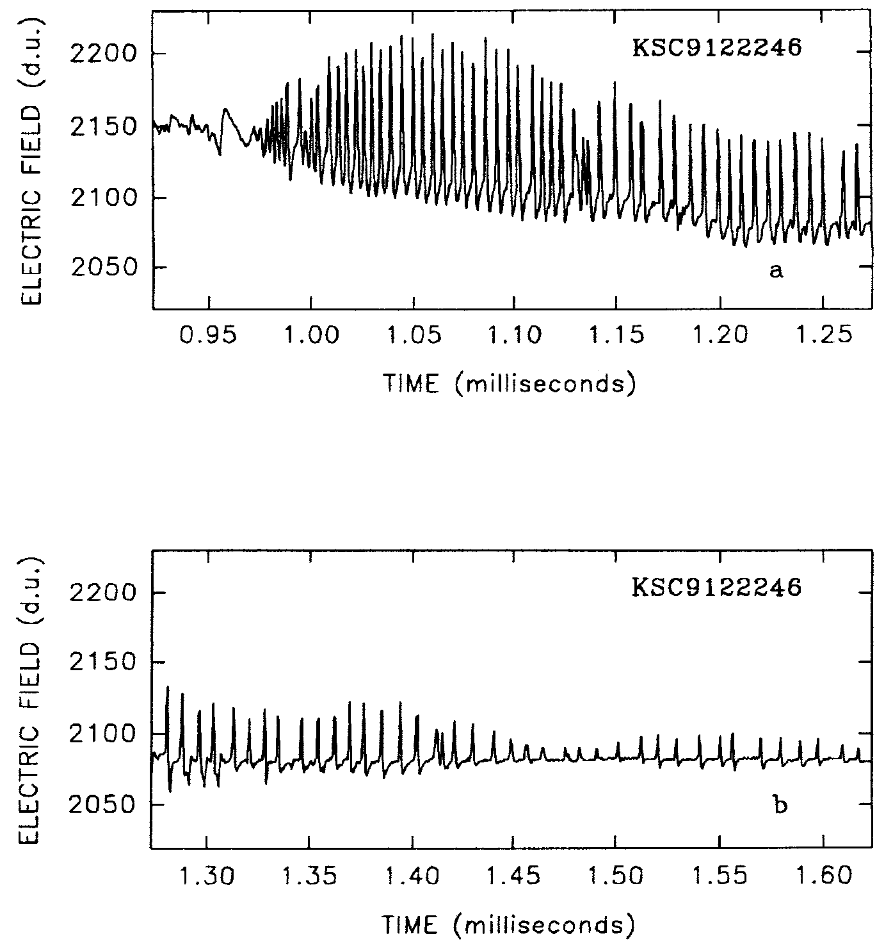

Fig. 2: Same as Fig. 1b but displayed on an expanded time scale (50 microseconds per division). End of time scale in a is the beginning of time scale in b. Positive field change deflects downward.

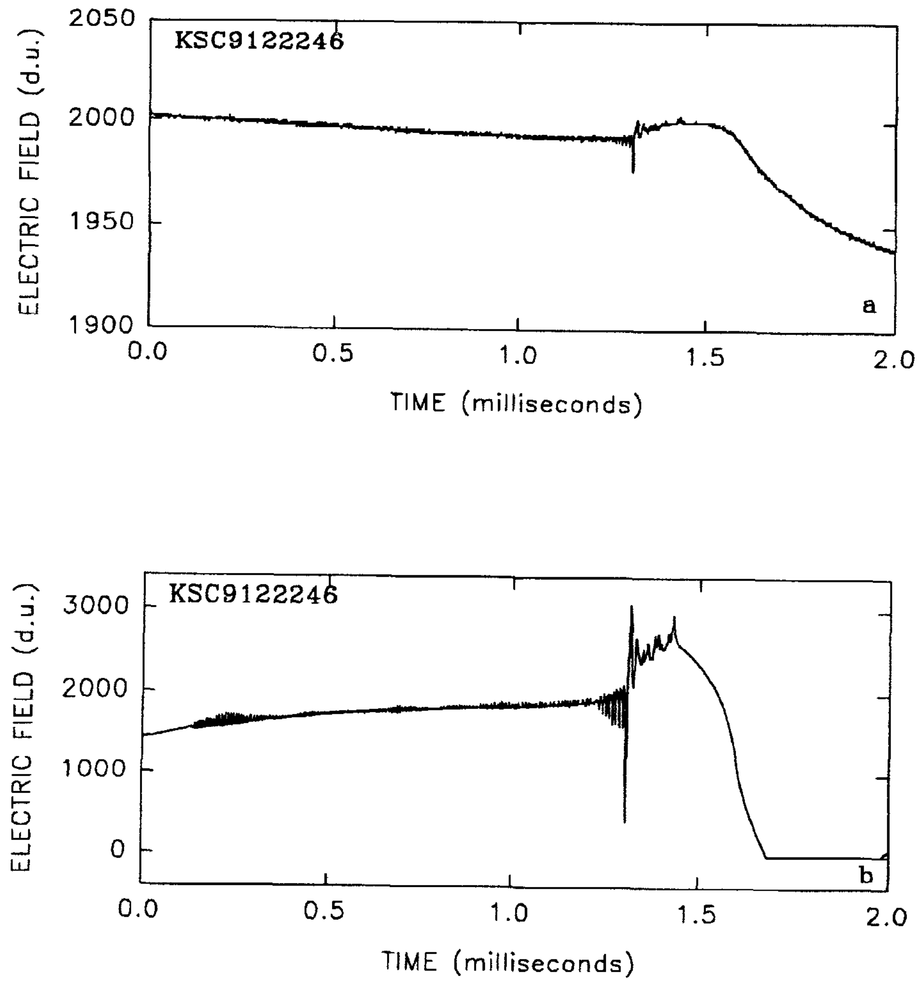

Fig. 3: Regular bursts of microsecond-scale pulses associated with a hook-shaped millisecond-scale field change (M change), a - low gain, decay time constant of 10 s; b - high gain, decay time constant of 150 microseconds. The pulses are shown on an expanded time scale in Fig. 4.

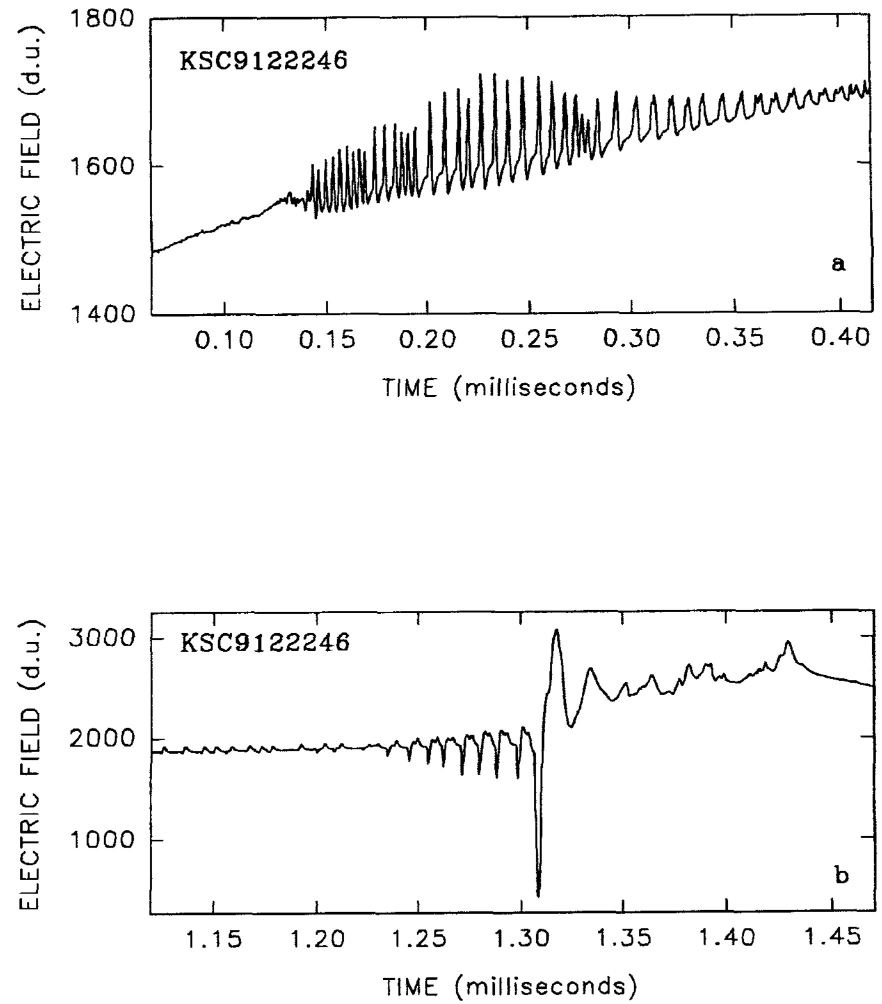

Fig. 4: Two fragments of the field record shown in Fig. 3b but on an expanded time scale (50 microseconds per division). Positive field change deflects downwards.

Table 3. Characterization of radiation field pulses associated with various lightning processes

Type of pulses	Dominant polarity (atmospheric electricity sign convention)	Typical total pulse duration, μs	Typical time interval between pulses, μs	Comments
Return stroke	Positive	30-90 (zero-crossing time)	60×10^3	3-5 pulses per flash
Stepped leader	Positive	1-2	15-25	Within 200 μs just prior to a return stroke
Dart-stepped leader	Positive	1-2	6-8	Within 200 μs just prior to a return stroke
Initial breakdown in ground flashes	Positive	20-40	70-130	At least several milliseconds before a return stroke
Initial breakdown in cloud flashes	Negative	50-80	600-800	The largest pulses tend to occur within a few tens of milliseconds
Regular pulse burst in both cloud and ground flashes	Both polarities are about equally probable	1-2	5-7	20-40 pulses per burst
Isolated pulses	Negative	10-20	-	Reportedly not related to any known lightning process

Notes:
1. Polarity refers to polarity of the initial half cycle in the case of bipolar pulses.
2. Typical values are subjectively synthesized from a comprehensive literature search and from our unpublished experimental data.
3. As shown by Rakov et al. [8], there is no characteristic radiation pulse signature associated with lightning K and M processes.

References

[1] "Protection of aircraft electrical/electronic systems against the indirect effects of lightning," Advisory Circular No. 20-136, Federal Aviation Administration, U.S. Department of Transportation, March 5, 1990.

[2] 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.

[3] T. Ogawa and M. Brook, "The mechanism of the intracloud lightning discharge," J. Geophys. Res., vol. 69, pp. 5141-5150, 1964.

[4] M. Brook, "Breakdown electric fields in winter storms," Res. Lett. Atmos. Electr., vol. 12, pp. 47-52, 1992.

[5] N. Kitagawa and M. Brook, "A comparison of intracloud and cloud-to-ground lightning discharges," J. Geophys. Res., vol. 65, pp. 1189-1201, 1960.

[6] R. Thottappillil, V.A. Rakov, and M.A. Uman, "K and M changes in close lightning ground flashes in Florida," J. Geophys. Res., vol. 95, pp.18,631-18,640, 1990.

[7] D.J. Malan and B.F.J. Schonland, "Progressive lightning, Pt. 7, Directly correlated photographic and electrical studies of lightning from near thunderstorms," Proc. Roy. Soc. (London), vol. A191, pp. 485-503, 1947.

[8] V.A. Rakov, R. Thottappillil, and M.A. Uman, "Electric field pulses in K and M changes of lightning ground flashes," J. Geophys. Res., vol. 97, pp. 9935-9950, 1992.

[9] Y. Villanueva, V.A. Rakov, M.A. Uman, and M. Brook, "Microsecond-scale electric field pulses in cloud lightning discharges," J. Geophys. Res., vol. 99, pp. 14,353-14,360, 1994.

[10] "Change in multiple burst environment agreed upon," in The Lightning Flash, published by Lightning Technologies, Inc., vol. 14, No. 3, p.1, May/June 1992.