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Fine Structure Signatures in Ground Flashes as a Source for HF Radiation

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ABSTRACT

Lighting radiation fields below 10 MHz are of considerable interest since these frequencies correspond to the natural resonance of structures with dimensions of a few meters to tens of meters. In this paper we present the fine structure signatures of sub-microsecond range pulses appeared at the leader phase and after the return stroke in negative ground flashes which act as a source for HF radiations at 10 MHz, 5 MHz and 3 MHz observed in Sri Lanka, in the tropics. Of the total sub-microsecond range pulses analyzed, 298 were due to positive field changes and 228 were due to negative field changes. The average rise time of those pulses for both polarities is 127 ns and it was found to be varying from 110-160 ns. The peak amplitude is in the range of 0.65-2.19 V/m. For the total 526 pulses analyzed for this study, the FWHM was between 190-310 ns with an arithmetic mean of 238 ns. Signatures of these pulses are similar to the leader like electric field pulses which acted as a strong source for HF radiations at 10 MHz, 5 MHz and 3 MHz. The initiation process of pulses reported in this study could be similar to the initiation process of leader like pulses.

***Keywords*:** HF radiation; Lightning; Return stroke; Ground flash

1. INTRODUCTION

Lighting radiation fields, especially in the frequency range from 1.5 MHz to 15 MHz, are of considerable interest since these frequencies correspond to the natural resonance of structures with dimensions of a few meters to tens of meters [1]. Lightning RF emissions are impulsive and there large amplitudes represent a potential hazard to any system which is sensitive to transient fields [2]. For example RF signals generated during lightning discharges might perturb radio or microwave telecommunication links. In addition, knowledge of these radio frequency (RF) emissions in lightning can improve the understanding of the physical process that takes place during lightning discharges. Therefore, the knowledge of radiation from lightning in the RF spectrum is important both for scientific investigations of lightning and engineering assessments of the interference environment during thunderstorms [3].

A few studies have been carried out to understand the characteristics of lightning HF radiation [1,3-14]. Two methods have traditionally been used to measure HF spectrum. In one method, the spectrum is obtained by Fourier transforming the broadband electric field. However this requires wide bandwidth recording devices and large dynamic range [3]. The second technique measure directly the energy radiated at a particular frequency using a filter-detector system, tuned to the interested frequency. The major difficulty with measurements of this type has been in identifying the corresponding stages of the lightning flash (leader, return stroke, etc.) which is the source of the radiation [3]. The problem occurs because of the inherent conflict between the requirement that the signal measured be truly representative of the power radiated at the frequency under investigation (a narrow bandwidth requirement) and the time resolution needed to distinguish between events in the flash (a large bandwidth requirement) [3]. A narrowband RLC tuned receiver was used successfully as a HF measuring system by [7] followed by [11-14]. For this study we have used narrowband RLC tuned receiver system, similar to [7] to detect HF radiation simultaneously with broadband electric field signal.

According to the results obtained by the previous researches [5,7-8,10-12], return strokes are the strongest sources of radiation of ground flashes. On the other hand, according to [1,11] preliminary breakdown process has been seen to be strong source below 10 MHz, comparable to return strokes. As in [4,6], stepped leaders are also known to be an HF source. According to [5], the events producing the strongest RF radiation are characterized by fast negative-going electric field changes. These pulses are typically 10-20 μs duration and generally are associated with a positive overshoot. The available evidence suggests that these pulses are associated with cloud processes, and a reasonable case can be made for there being a recoil streamer similar to that proposed for K changes but of much shorter duration [5]. As reported in [13], using measurements of HF at 10 MHz, shown that the “chaotic leaders” associated with subsequent return are a strong source of HF radiation.

As reported in [9], the basic structure which causes lightning to generate VHF-UHF radiation consists of pulses with a very steep leading edge which originate in the fundamental mechanisms involved in air discharges. These observations [9] showed up pulses with a very short rise time of approximately 5 ns and were found to be repeated at a rate of 1 to 20 per microsecond.

In this paper we present data describing the temporal behaviour of HF radiations at 10 MHz, 5 MHz and 3 MHz generated during leader and first return strokes stage of negative ground flashes together with corresponding electric field changes observed in Sri Lanka, in the tropics. Simultaneous measurements of HF radiations at 10 MHz, 5 MHz and 3 MHz with the broadband electric field signal generated by negative ground flashes are not available in the literature. In this study, the behavior of HF radiation with lightning electric fields was analyzed in order to have a better characterization of the sources which generate radiation from lightning flash.

2. MEASUREMENT SETUP

The experiment was performed on the premises of Colombo University, close to the west coast in Sri Lanka (6.91ºN, 79.86ºE) in May 2005 during the south-west monsoon period. Simultaneous signatures of the broadband electric field, and HF radiations at 10 MHz, 5 MHz and 3 MHz were recorded in 100 Ms/s resolutions for lightning ground flashes. Data were obtained for lightning occurring both over land and sea. During the experiment, the recording length was kept at 40 ms with a sampling rate of 100 Ms/s which is the maximum for the oscilloscope.

The broadband signal was measured using a flat plate antenna system similar to the system described by [7]. Another three flat plate antennas were used to measure the high frequency radiation fields. The resonance frequencies of the HF antenna system were at 3 MHz, 5 MHz and 10 MHz with the bandwidth of 264 kHz, 471 kHz and 2020 kHz respectively. The output from the HF receivers and the broadband electric field measuring system was recorded by a 4-channel digital storage oscilloscope (Agilent Infiinium 54832B) working in pre-trigger mode.

3. THE HF ANTENNA SYSTEM

The HF antenna system is similar to the one described in [7] and elements connected at the base of the flat plate antenna together with the antenna capacitance form a tuned RLC circuit as shown in Fig. 1, Table 1 shows the tuned circuit parameters. The authors believe that the experimentally observed values for the resonance frequencies of the tuned circuits and its bandwidth were reasonably matched for this study.

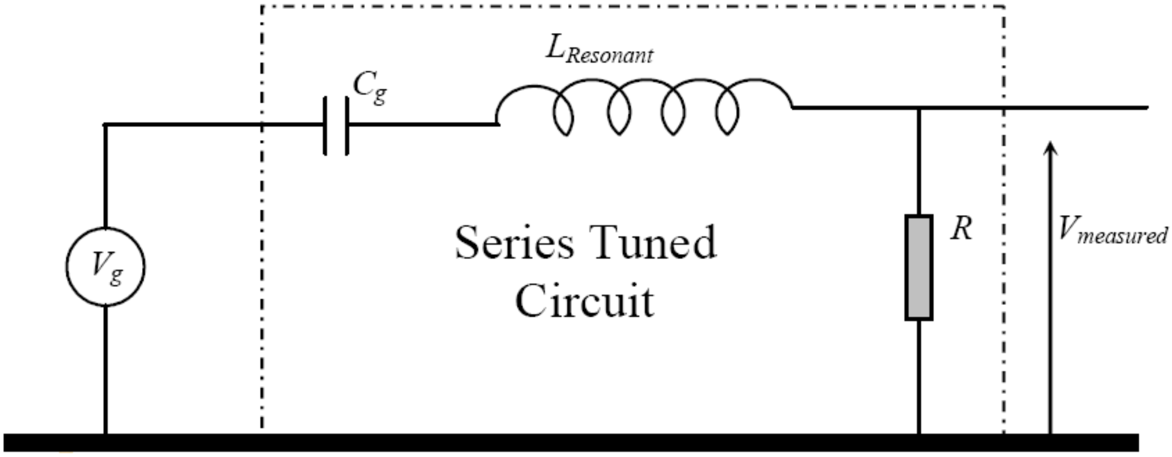

Fig. 1. Equivalent circuit for the HF antenna system. C_g is the antenna capacitance (59 pF) and resistance R is 50 Ω.

Table 1. Tuned circuit parameters.

Tune Frequency (MHz)		Inductance (µH)		Bandwidth (kHz)	
Theoretical	Experimental	Theoretical	Experimental	Theoretical	Experimental
3	3.77	47	30	166	264
5	5.05	17	16	463	471
10	10.44	4.29	3.9	1850	2020

4. RESULTS AND DISCUSSION

In this study, we have analysed 46 negative ground flashes recorded during two thunderstorms occurred during two days in May 2005. We have analysed 14 flashes from May 02nd, and 34 flashes from May 03rd. Several examples of simultaneous records for the signatures of the lightning HF radiations at 10 MHz, 5 MHz and 3 MHz associated with leader and return stroke process together with corresponding broadband electric field are shown in Fig. 2 (flash number 20050502002), Fig. 3 (flash number 20050502003) and Fig. 4 (flash number 20050502004).

First, note that the HF radiation was present continuously before and during the return stroke stage and even after the return stroke too. However, the intensity of HF radiation in the leader phase is strong in some cases (see Fig. 3); while in some other cases HF radiation was strongest at the beginning of the return stroke (Fig. 2 and Fig. 4).

For 40 flashes (87 %), strongest HF radiation was observed at the beginning of the return stroke and onset of the return stroke was given rise to those strong HF radiations. For six flashes (13 %), strongest radiation was at during the leader phase of the return stroke.

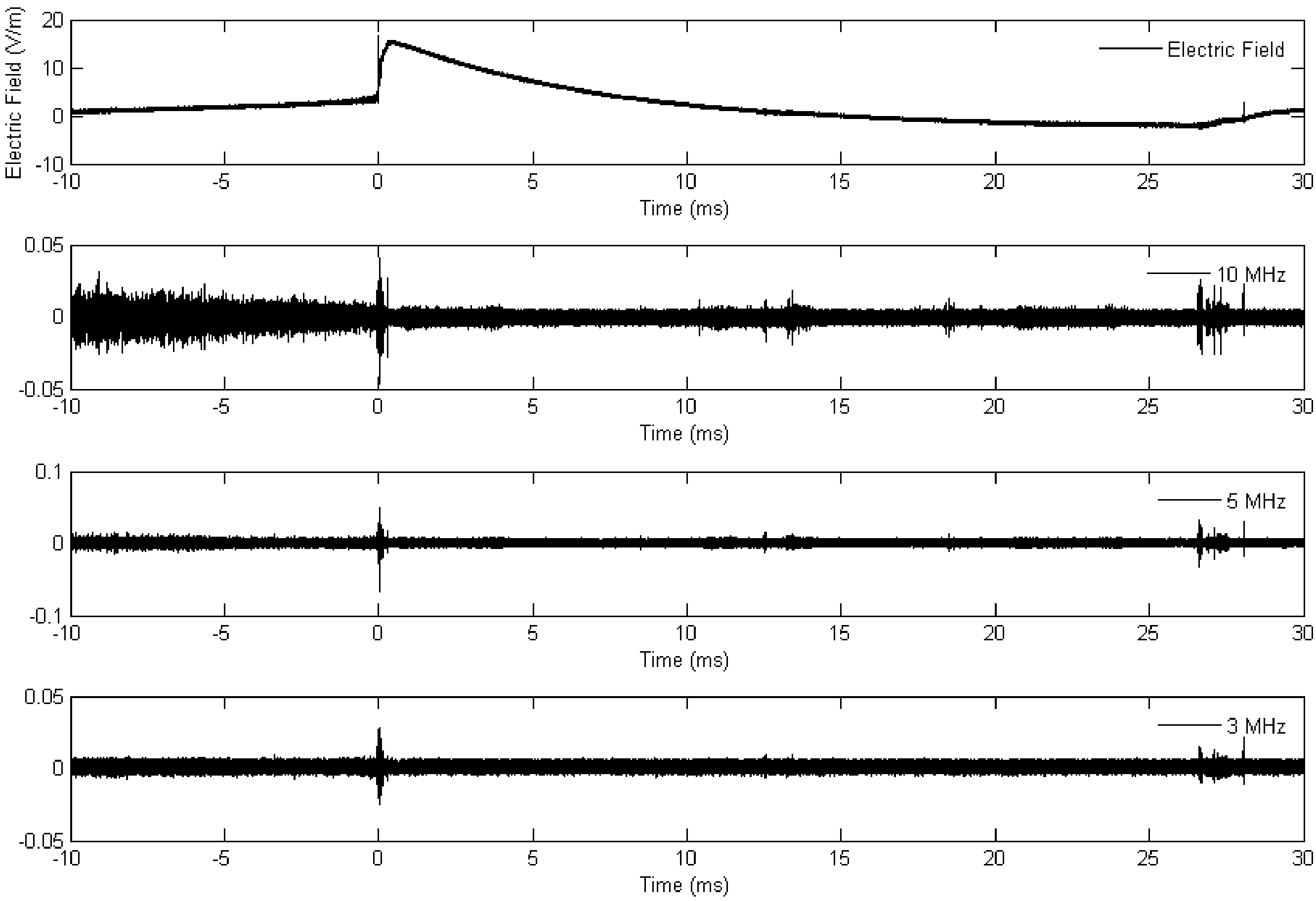

Fig. 2. Simultaneous records of the electric Field and HF radiations at 10 MHz, 5 MHz and 3 MHz for the flash number 20050502002.

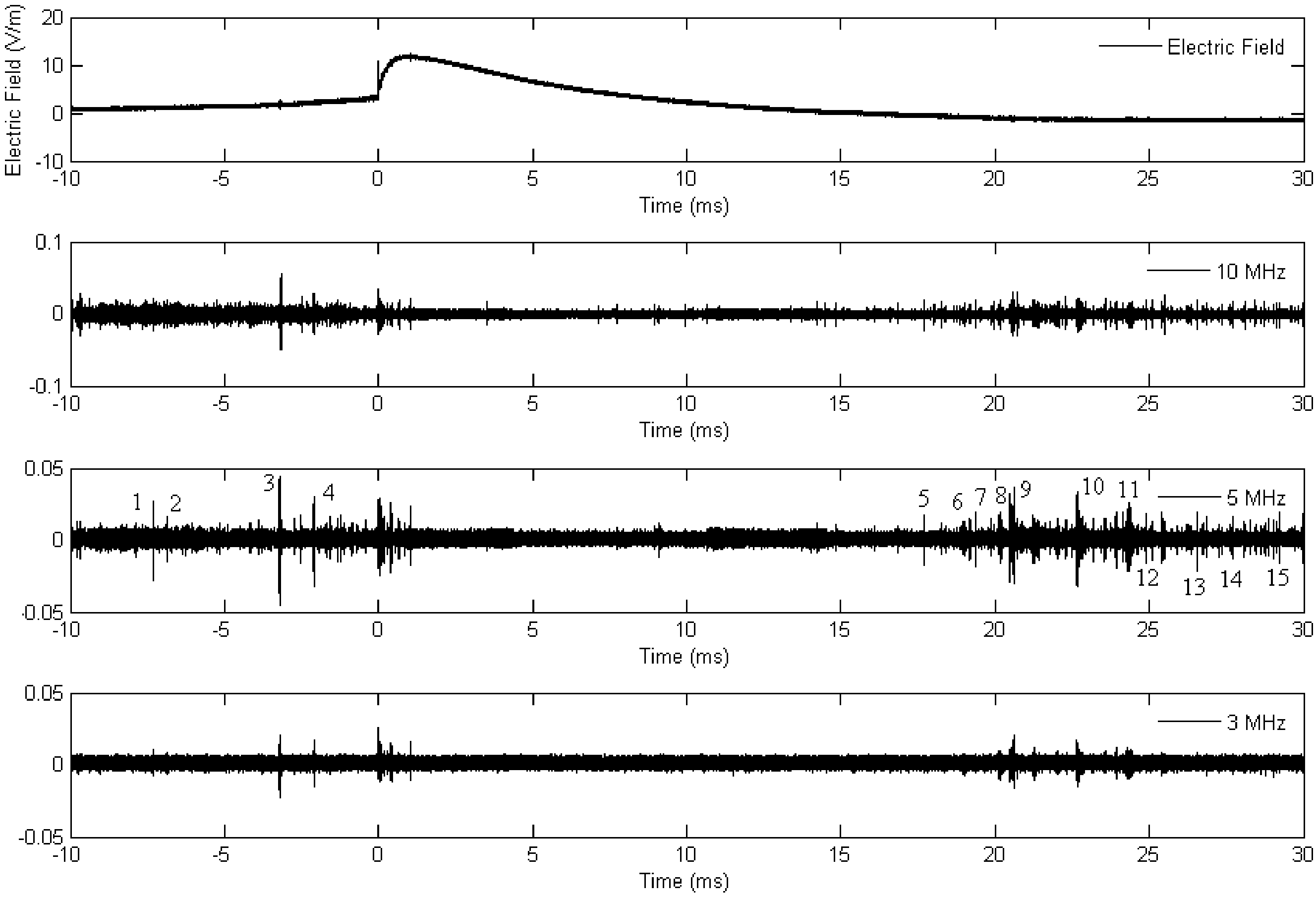

Fig. 3. Simultaneous records of the electric Field and HF radiations at 10 MHz, 5 MHz and 3 MHz for the flash number 20050502003.

On the other hand, during the tail of the return stroke we have not observed an active period for HF radiation. It was also observed that in the majority of the recorded signals after the initial burst associated with the onset of the negative return strokes, the intensity of the HF radiations at 10 MHz, 5 MHz and 3 MHz increase again after several milliseconds (15 ms to 20 ms). Similar results have being obtained for 3 MHz radiations by [11]. The authors believe that, this could be due to possible cloud activity. In between it is almost idle period (15 ms to 20 ms) for all HF radiation signals observed.

An acceptable way to identify HF sources is to single out high intensity peaks of the measured HF radiation and correlated them with the corresponding broadband signal. As shown in Fig. 2–4, we have observed that negative return strokes are strong sources of HF radiation from ground flashes since corresponding HF sources gives high intensity peaks. In addition to that within the 40 ms window of each and every measurement, we can very easily identify 10-15 high intensity HF peaks within the leader phase and after the return stroke. However when we correlate those high intensity HF peaks (as mark in 5 MHz signal in Fig. 3) to the broadband signal, we have observed a sub-microsecond range pulses appeared during leader phase and after the tail of the return strokes. These sub microsecond pulses could be the source for HF radiations at 10 MHz, 5 MHz and 3 MHz appeared at leader phase and after the return stroke.

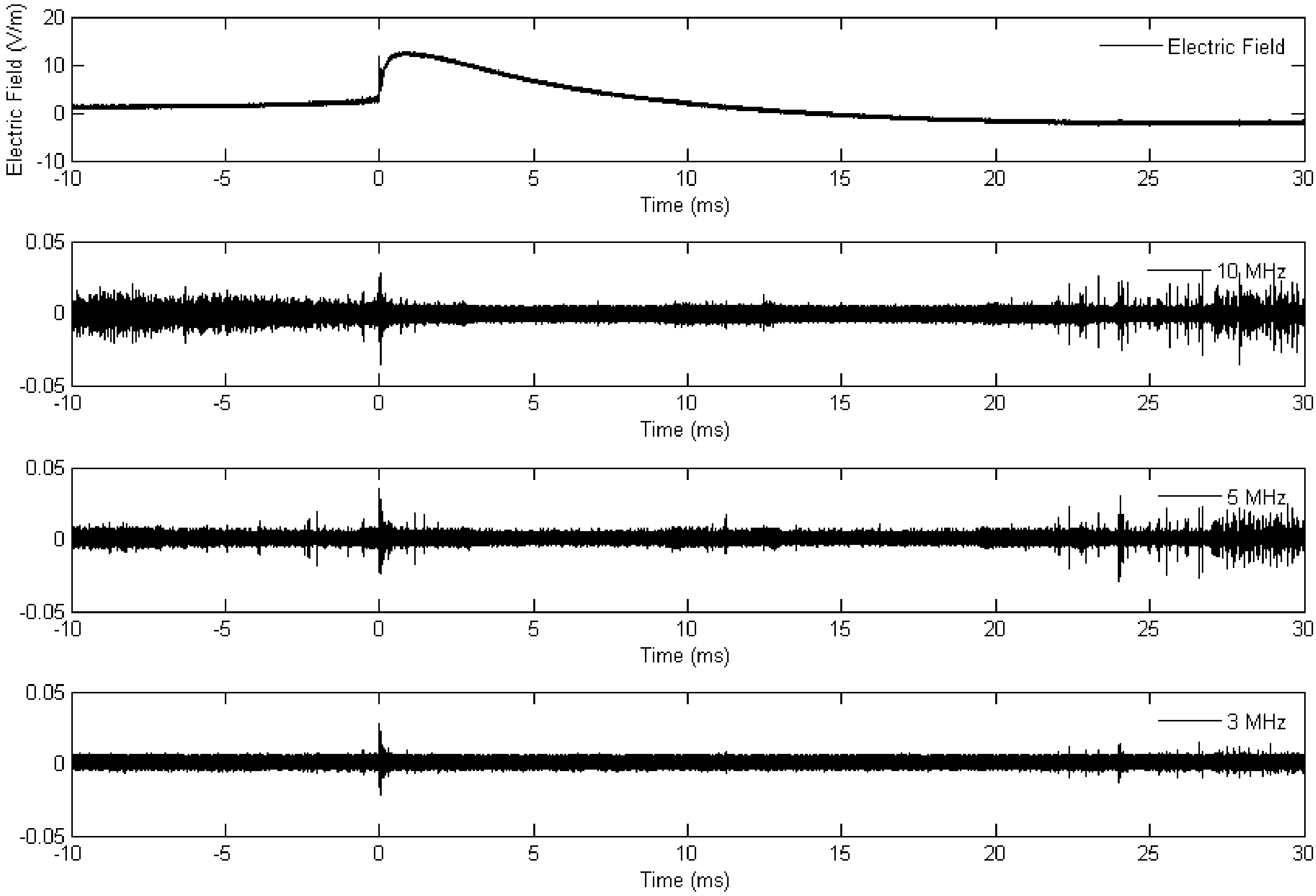

Fig. 4. Simultaneous records of the electric Field and HF radiations at 10 MHz, 5 MHz and 3 MHz for the flash number 20050502004.

Fig. 5 shows the typical sub-microsecond range pulse that we have observed. Fig. 5(a) shows the raw broadband signal which corresponds to the pulse number 3 marked in Fig. 3. Since the signal is affected by background noise signals as shown in Fig. 5(a), moving average technique was performed to smooth the signal.

According to the sensitivity analysis carried out by the authors, it was found that optimal step is to use moving average method with the span value of 11 samples as shown in Fig. 5(e). Hence all the analysis were done based on smoothed data by using moving average method with the span value of 11.

Fig. 6 and Fig. 7 show two examples of those pulses together with corresponding HF radiations at 10 MHz, 5 MHz and 3 MHz. It is very clear that steep rising part of the pulse gives rise to HF radiations at 10 MHz, 5 MHz and 3 MHz. Further, we have observed both positive and negative field change pulses with similar shape as shown in Fig. 6 and Fig. 7. In total of 526 pulses appeared at leader phase and after the return stroke were analyzed.

Altogether 203 pulses were observed at leader phase with both positive and negative field change. The rise time (10-90%) of these pulses was found to be varying from 130 to 160 ns with an arithmetic mean of 141 ns, geometric mean of 141 ns and a standard deviation of 9.5 ns. Out of 203 pulses, 42% were found with the rise time of 140 ns as shown in Fig. 8(a).

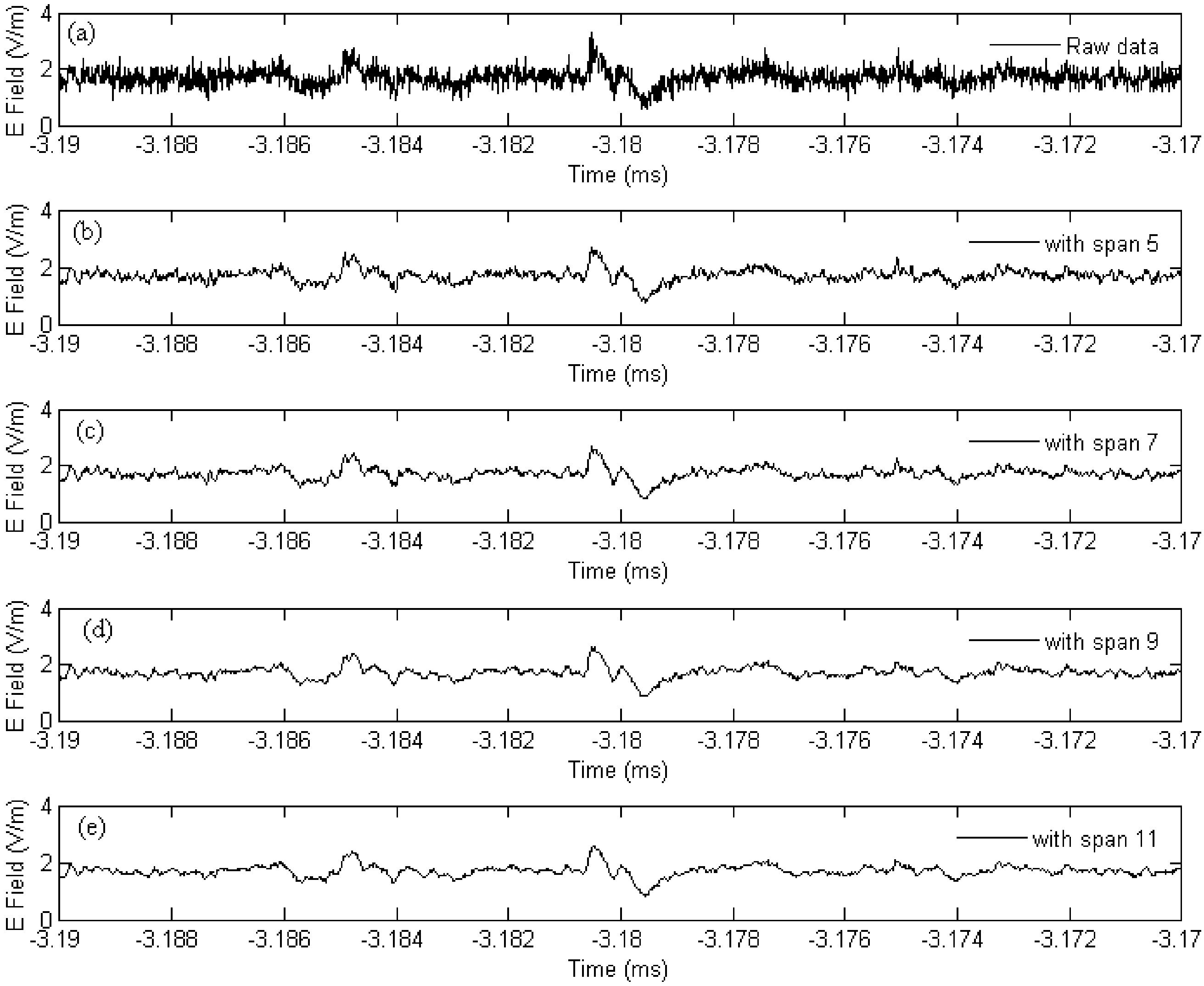

Fig. 5. Smoothing of the broadband signal using moving average method (a) shows the raw data for the corresponding sub-microsecond pulse in the broadband signal for HF high intensity peak number 3 marked in Fig. 3 and other (b)–(e) show the smoothed lines with the span of 5, 7, 9, and 11 respectively.

In addition to this, 323 pulses were observed after the first return stroke with both positive and negative field change. The rise time (10-90 %) of these pulses was found to be varying from 100 to 130 ns with an arithmetic mean of 118 ns, geometric mean of 118 ns and a standard deviation of 9.5 ns. Out of 323 pulses, 40 % of the pulses as highest number of observations were found to be with the rise time of 140 ns as shown in Fig. 8(b). Of the total 526 pulses which appeared at leader phase and after the return stroke, 298 were due to positive field changes and 228 were due to negative field changes. For positive field changes, the rise time is varying from 100 to 160 ns with an arithmetic mean of 131 ns, geometric mean of 130 ns and a standard deviation of 14.7 ns.

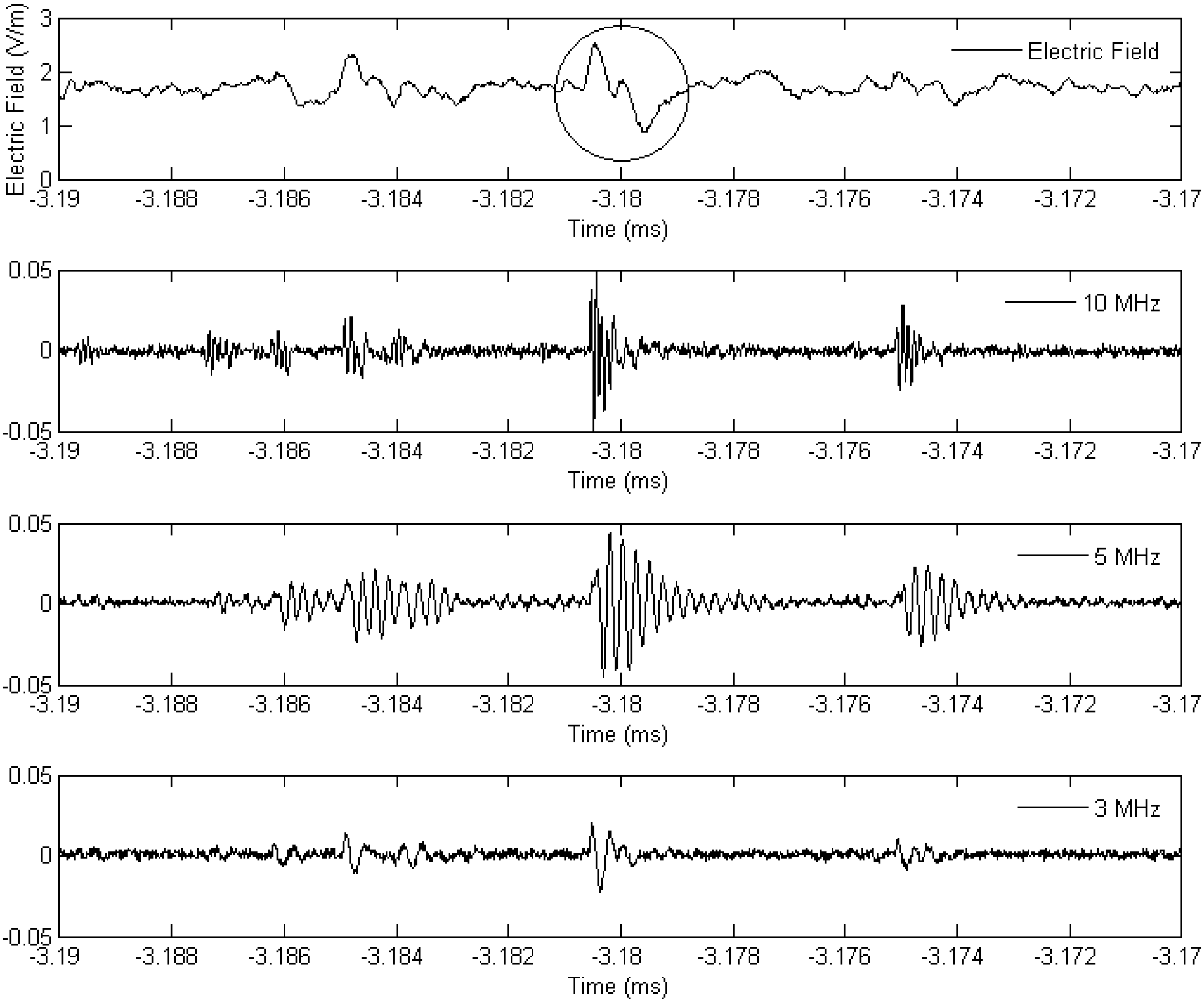

Fig. 6. Sub-microsecond electric field pulse (shown in the circle) and corresponding HF radiations at 10 MHz, 5 MHz and 3 MHz for the High intensity HF peak number 3 marked in Fig. 3.

Whereas, for negative field changes, the rise was found to be varying from 100 to 160 ns with an arithmetic mean of 122 ns, geometric mean of 121 ns and a standard deviation of 13.2 ns. The frequency distribution of the rise times for the pulses with positive field changes is shown in Fig. 9(a) and 26 % of the pulses as the highest number of observations were found to be with the rise time of 130 ns. The frequency distribution of the rise times for the pulses with negative field changes is shown in Fig. 9(b) and 32 % of the pulses as the highest number of observations were found to be with the rise time of 120 ns. For both polarities, the rise time (10-90 %) was found to be varying from 100 to 160 ns with an arithmetic mean of 127 ns, geometric mean of 126 ns and a standard deviation of 14.7 ns. The frequency distribution of the rise times for these 526 pulses is shown in Fig. 9(c) and 27 % of the pulses as the highest number of observations were found to be with the rise time of 130 ns.

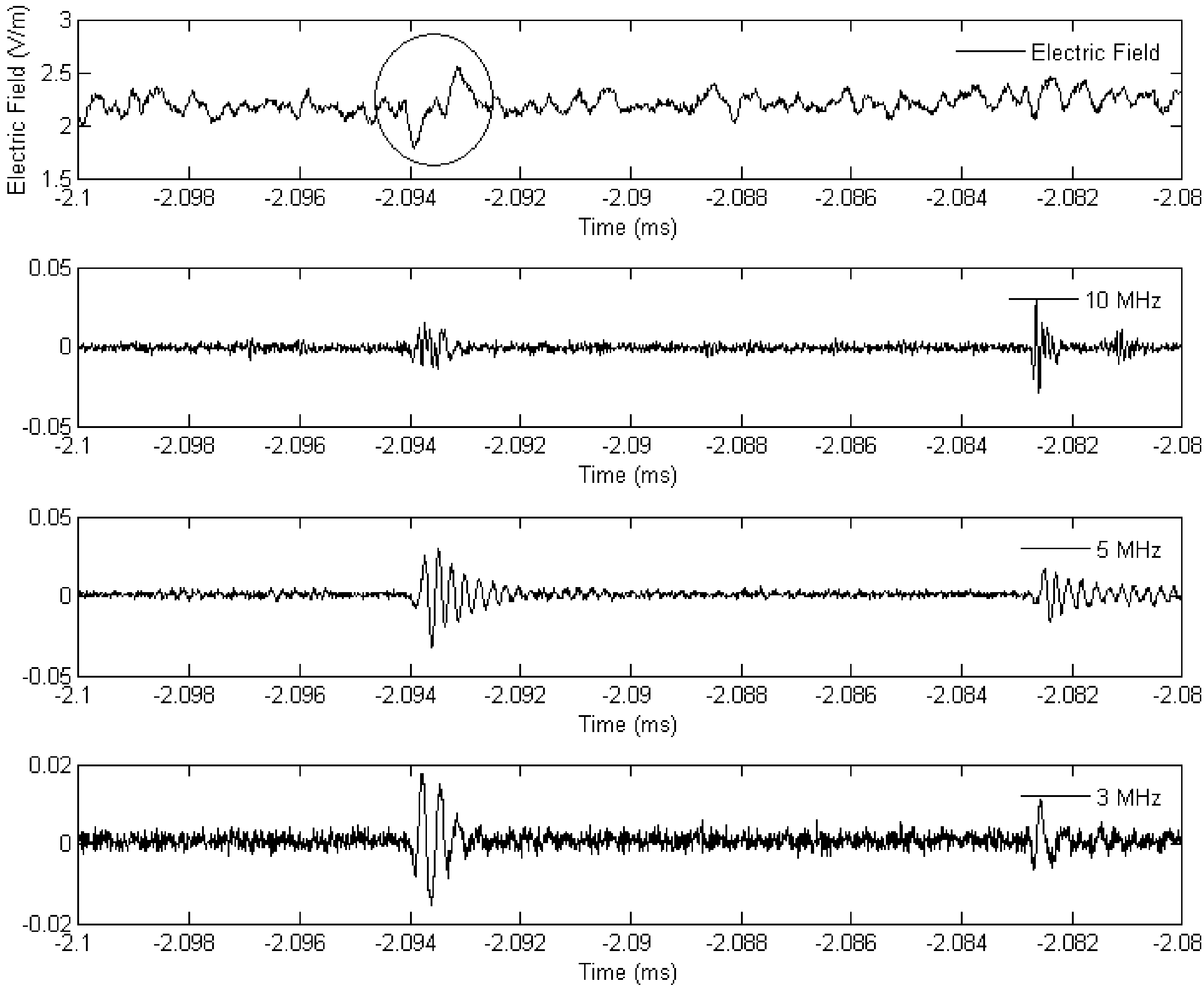

Fig. 7. Sub-microsecond electric field pulse (shown in the circle) and corresponding HF radiations at 10 MHz, 5 MHz and 3 MHz for the High intensity HF peak number 4 in Fig. 3.

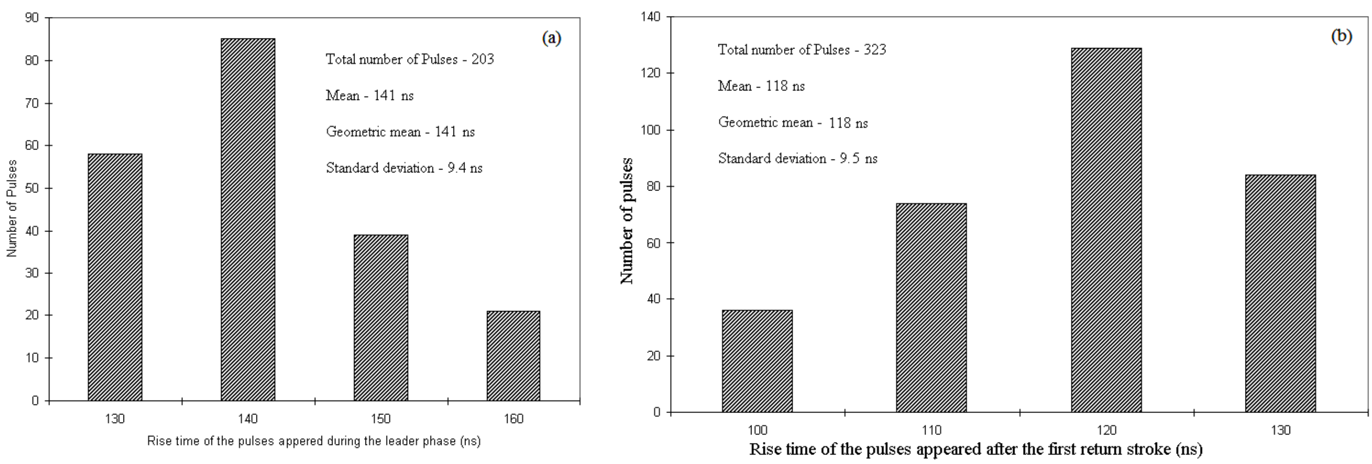

Fig. 8. Histogram of the rise time of the pulses (for both positive and negative field change pulses) (a) appeared during the leader phase (b) appeared after the first return stroke.

For the pulses observed at leader phase with both positive and negative field changes, the full-width at half-maximum (FWHM) was between 230-310 ns with an arithmetic mean of 277 ns, a geometric mean of 267 ns and a standard deviation of 23.6 ns.

For the pulses observed after the first return stroke with both positive and negative field changes, the FWHM was found to be varying from 190-250 ns with an arithmetic mean of 220 ns, a geometric mean of 220 ns and a standard deviation of 14.3 ns.

For the pulses due to positive field changes, the FWHM was found to be varying from 190-310 ns with an arithmetic mean of 247 ns, a geometric mean of 245 ns and a standard deviation of 33.5 ns.

For the pulses due to negative field changes, the FWHM was found to be varying from 200-290 ns with an arithmetic mean of 227 ns, a geometric mean of 226 ns and a standard deviation of 18.4 ns. For the total 526 pulses analyzed for this study, the FWHM was found to be varying from 190-310 ns with an arithmetic mean of 238 ns, a geometric mean of 237 ns and a standard deviation of 29.7 ns.

For the 165 pulses with positive field changes observed at the leader phase, the peak amplitude was found to be varying from 1.60-2.90 V/m with an arithmetic mean of 2.22 V/m, a geometric mean of 2.19 V/m and a standard deviation of 0.375 V/m. It was found to be varying from 0.60-2.8 V/m with an arithmetic mean of 1.56 V/m, a geometric mean of 1.39 V/m and a standard deviation of 0.690 V/m due to 38 pulses with negative filed changes observed at the leader phase.

For the 133 pulses with positive field changes observed after the first return stroke, the peak amplitude was found to be varying from (-1.20)-(-0.30) V/m with an arithmetic mean of -0.71 V/m, a geometric mean of -0.65 V/m and a standard deviation of 0.291 V/m. It was found to be varying from (-2.20)-(-1.50) V/m with an arithmetic mean of -1.80 V/m, a geometric mean of -1.79 V/m and a standard deviation of 0.212 V/m due to 190 pulses with negative filed changes observed after the first return stroke.

Even though all the flashes recorded are within 20 km distance (we have selected 46 flashes which gave the thunder sound to the measurement site) there could be slight influence to the summary given in Table 2 due to the finitely conducting ground. However, it is assumed that propagation effect due to the ground conductivity does not affect the conclusions of this study.

Looking at the filtered signal in Fig. 3.12(e), it can be assumed that it is smoother since a lot of the noise was removed. There is a slight delay in the filtered signal from the original, but that is characteristic of filtering. Also, note that an even smoother signal can be obtained if span value is increased, but realize that this will further increase the delay in the filtered signal.

An interesting observation on the experimental result is that those pulses give rise to HF radiations starting with similar field change. (ie. pulses with negative field changes give rise HF starting with negative field change and similar behavior for pulses with positive field changes give rise to HF starting with a positive field change).

As summarized in Table 2, at the leader phase we have observed more pulses (165) with positive field change than the pulses (38) with negative field change.

But after the return stroke we have observed more pulses (190) with negative field changes than the pulses (133) with positive field changes.

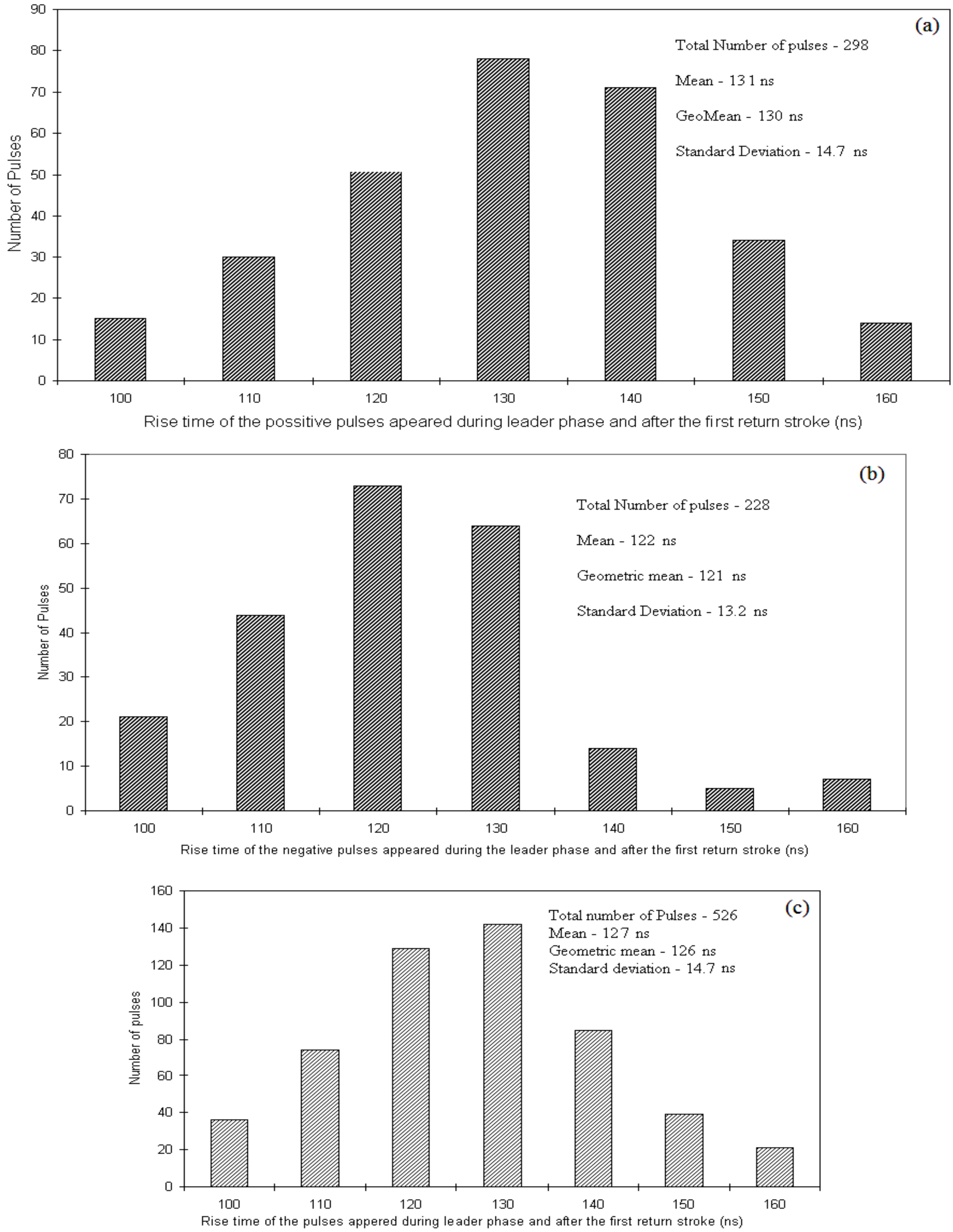

Fig. 9. Histogram of the rise time of the pulses appeared during the leader phase and after the first return stroke (a) pulses with positive field change (b) pulses with negative field change (c) for both positive and negative field change pulses.

Table 2. A brief statistics of the parameters of the sub-microsecond range pulses as a source of HF radiations in ground flashes.

Pulse parameter	Number of Observations		Range (Min-Max)	Arithmetic Mean	Geometric Mean	Standard Deviation
Rise Time (10-90%)	Positive	298	100 – 160 ns	131 ns	130 ns	14.7 ns
	Negative	228	100 – 160 ns	122 ns	121 ns	13.2 ns
	At leader phase (for both positive and negative pulses)	203	130 – 160 ns	141 ns	141 ns	9.4 ns
	After the 1st Return stroke (for both positive and negative pulses)	323	100 – 130 ns	118 ns	118 ns	9.5 ns
	Total	**526**	**100 – 160 ns**	**127 ns**	**126 ns**	**14.7 ns**
Full-width at half-maximum	Positive	298	190 – 310 ns	247 ns	245 ns	33.5 ns
	Negative	228	200 – 290 ns	227 ns	226 ns	18.4 ns
	At leader phase (for both positive and negative pulses)	203	230 – 310 ns	268 ns	267 ns	23.6 ns
	After the 1st Return stroke (for both positive and negative pulses)	323	190 – 250 ns	220 ns	220 ns	14.3 ns
	Total	**526**	**190 – 310 ns**	**238 ns**	**237 ns**	**29.7 ns**
Peak Amplitude	Positive (at leader phase)	165	1.60 – 2.90 V/m	2.22 V/m	2.19 V/m	0.38 V/m
	Negative (at leader phase)	38	0.60 – 2.80 V/m	1.56 V/m	1.39 V/m	0.69 V/m
	Positive (after the 1st Return stroke)	133	-1.20 – -0.30 V/m	-0.71 V/m	-0.65 V/m	0.29 V/m
	Negative (after the 1st Return stroke)	190	-2.20 – -1.50 V/m	-1.80 V/m	-1.79 V/m	0.21 V/m

According to [4,15-17] broadband measurements of leader fields indicate that small field pulses with an amplitude in the range of about 0.5-1 V/m at 100 km occur in the electric fields preceding the return stroke.

As in [4,18] the rise time of those pulses is about 0.1 μs and their duration is about a microsecond. On the other hand, Table 2 shows brief statistics of the parameters of the sub-microsecond range pulses which we observed as a source of HF radiations in ground flashes. The average rise time of those pulses is 0.127 μs and peak amplitude is in the range of 0.65-2.19 V/m. According to the statistics we have observed, those sub-microsecond range pulses are similar to the electric field pulses reported in [4,15-18] which acted as a strong source for HF radiations at 10 MHz, 5 MHz and 3 MHz.

5. CONCLUSION

The temporal behaviour of HF radiations at 10 MHz, 5 MHz and 3 MHz generated during leader and first return strokes stage of negative ground flashes together with corresponding electric field changes observed in Sri Lanka, in the tropics are presented in this paper Out of 46 negative ground flashes analyzed, 40 flashes (87 %), shows the strongest HF radiation was observed at the beginning of the return stroke and onset of the return stroke was given rise to those strong HF radiations. For other six flashes (13 %), strongest radiation was observed at the leader phase.

We found sub-microsecond range characteristic pulses appeared at leader phase and after the return stroke act as a strong source for HF radiations at 10 MHz, 5 MHz and 3 MHz. Signatures of these sub microsecond pulses were analyzed in order to get a better knowledge on the sources which generate HF radiation from lightning flash. Of the total 526 pulses which appeared at leader phase and after the return stroke, 298 were due to positive field changes and 228 were due to negative field changes. The average rise time of those pulses (for both polarities) is 0.127 μs and it was found to be varying from 110-160 ns. The peak amplitude is in the range of 0.65-2.19 V/m. For the total 526 pulses analyzed for this study, the FWHM was found to be varying from 190-310 ns with an arithmetic mean of 238 ns. It is important to note that the signatures of sub microsecond pulses observed in this study are similar to the leader like pulses observed by [4,15-18] which acted as a strong source for HF radiations at 10 MHz, 5 MHz and 3 MHz. Therefore, the initiation process of pulses reported in this study could be similar to the initiation process of leader like pulses.

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