On comparison between initial breakdown pulses and narrow bipolar pulses in lightning discharges with special attention to electric field derivative characteristics

M.M.Ismail, V.Cooray, M.Rahman, P.Hettiarachchi, D.Johari
Ångstrom Laboratory, Division of Electricity
Department of Engineering sciences
Uppsala University, Sweden
Muzafar.Ismail@angstrom.uu.se
Vernon. Cooray@angstrom.uu.se

M.M.Ismail
Faculty of Electronics and Computer Engineering
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, Durian Tunggal, Melaka
Malaysia

***Abstract*—Physical mechanism of initial breakdown pulses and narrow bipolar pulses in lightning discharges is not well understood. There are different opinions about the origins of these two phenomenology. In this study, we make an attempt to compare this two phenomenology based on their electric fields and field derivatives produced by them. The comparison shows that the electric field derivative characteristics of these two phenomenology are different which makes us to believe that the origin of these two kinds of pulses may not be the same.**

Keywords-IBP; NBP; electric field from lightning; field derivative from lightning; cloud discharges; lightning discharges

I. INTRODUCTION

Narrow bipolar pulses (NBPs) and initial breakdown pulses (IBPs) were electromagnetic field radiation in lightning discharges. NBPs are electric field produced by a distinct category of intra-cloud (IC) flashes. They were first reported by [1] and NBPs were the strongest source of HF radiation and later NBPs were described in more details by [2-7]. NBPs differ from the radiation fields produced by return strokes in several ways. The zero crossing time (ZCT) of these pulses are much narrower than that of strokes in a few microseconds and tend to the bipolar. They also tend to occur in isolation, without any electrical activity immediately before or after the pulses. In the case NBPs occur as part of ordinary IC flash, they usually initiate the flash [8-9]. Recently NBPs were reported to occur as part of cloud –to-ground (CG) flashes [7,10-12]. Meanwhile, [13] found that NBPs are not common in temperate region (Sweden for instance) compared to tropic region (Sri Lanka for instance) based on their experimental finding in both region during June to August 2006.

Initial breakdown (IB) are an electrical breakdown between negative charge center and Lower Positive Charge Pocket (LPCR) located below it as suggested by [14]. Recent result by [15] reported that IBPs should be observable in all lightning discharges. Meanwhile, [16] reported that the average pulse duration of IBP was 17 (µs) within the range (1-91) (µs) out of 33 samples. Further, [17] classified IBPs as two types which are “classical” IBP and “narrow” IBP. Classical IBP pulses had the average pulse duration of 4.8 (µs) for cloud to ground discharges pulses train and 17 (µs) for attempted cloud to ground leaders whereas narrow IBP pulses had pulse duration less than 4 (µs).

Meanwhile, some researcher analyzed IBPs and NBPs together and found that IBPs and NBPs are a consequence of the initial lightning leader development [18]. Beside that [19] compared NBPs with IBPs and based on the similarity in temporal characteristics of both pulses they claimed that NBPs and IBPs were resulted by leader discharge. Although we see there are similarities between NBPs and IBPs in their temporal characteristics but NBPs and IBPs are different pulses. This is because NBPs and IBPs are produced by different process in lightning flashes [20-21].

In this study we compare the electric fields and the electric field derivatives of both types of pulses (IBPs and NBPs) with each other to know more about their origin. For this purpose, we use data from measurements both in Sweden and Malaysia.

II. METHODOLOGY

As mentioned before we used experimental data in this study. In summer 2015 we conducted a measurement campaign at Uppsala where we measured simultaneously the electric field for wideband, electric field derivative and 3-MHz radiation. We took 20 negative cloud-to-ground flashes from this campaign for this analysis. Moreover, in 2009 there were another measurement campaign in Johor, Malaysia where the electric field for wide band were measured. We took 20 negative cloud-to-ground flashes from that campaign too.

Note that in Swedish data there are no NBPs. Both IBPs and NBPs appearing in Malaysia data.

III. RESULT AND DISCUSSION

The purpose of this paper is to compare IBPs with NBPs. In figure 1, a typical wideband electric field pulses identified as initial breakdown pulse is shown together with the corresponding measured electric field derivative pulse. Unfortunately, NBPs are very rear in Swedish thunderstorm [13]. For this reason we compare our wideband electric field pulse generated by narrow bipolar pulses adapted by Willet et al. (1989) [5]. We also compare our measured electric fields derivatives generated by initial breakdown pulses with Willet et al. (1989) electric field derivatives generated by narrow bipolar pulses. Pulses from [5] are shown in figure 2. This comparison shows very similar pulses of electric fields but their derivatives are very different. One major difference is that the derivatives generated by NBPs are very oscillating.

To study this further we analyzed the measured electric field data from Malaysia. In Malaysian data there are both IBPs and NBPs. An example of this pulses are shown in figure 3. As before, they appear to be very similar. In figure 4 the derivatives of both types of pulses are shown which were theoretically derived from their measured electric field records respectively. We do see again that the derivative for NBPs is oscillating more than that of the initial breakdown pulses.

We went further in our analysis where we compared the IBPs (the E-field) recorded in Sweden with NBPs (the E-field) Recorded in Malaysia as shown in figure 5. As there were no electric field derivatives data available from Malaysia, we theoretically derived the derivatives from respective electric field measurements conducted in these two places. Even though the derivative was measured at Uppsala, we compared the estimated data with estimated data as shown in figure 6. That comparison again shows the similar trend. In order to show the validity of this comparison, we show in figure 7, a measured and theoretically derived waveforms for the electric field derivatives together with measured wide band field signature from Swedish thunderstorms. It is clear that the derived waveform can represent the measured waveform satisfactorily.

IV. CONCLUSION

Based on the comparison made in this analysis it is clearly shown that the characteristics of electric field derivatives for NBPs and IBPs are not the same. It is suggested that the origin of IBPs and NBPs are different inside the cloud. This conclusion may help to understand the discharge mechanism of lightning initiation inside the cloud.

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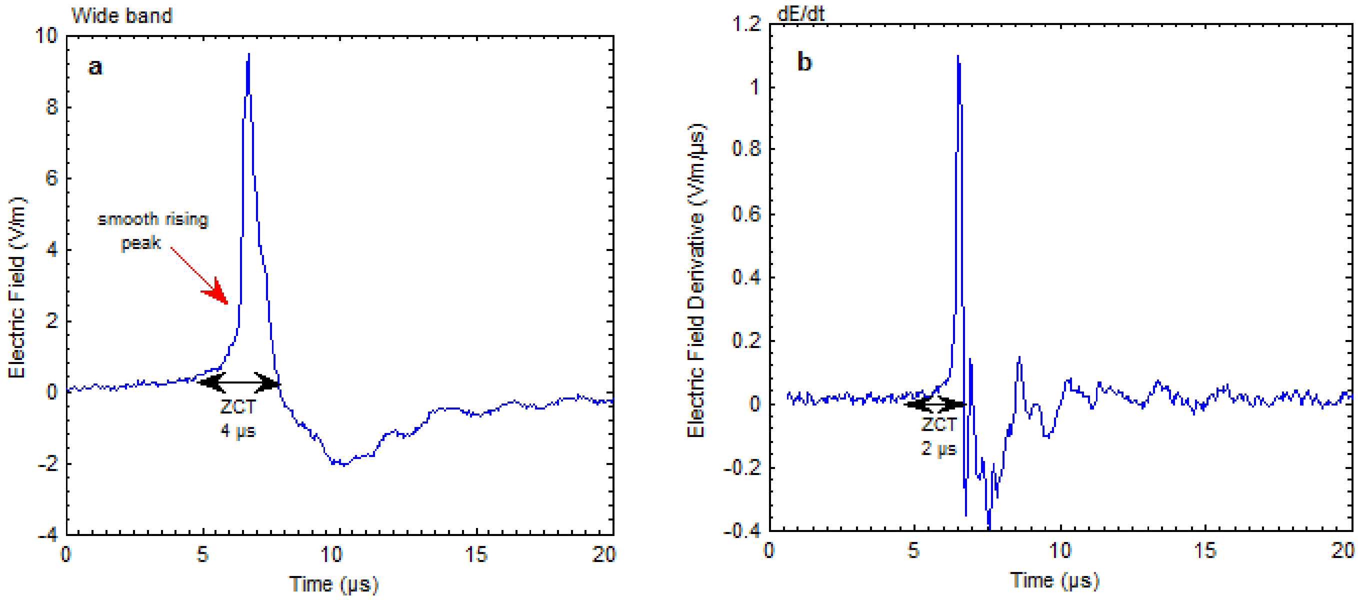

Figure 1: Initial breakdown in Sweden (a) Electric field with smooth rising peak in wideband measurement (b) Electric field derivative with less oscillating.

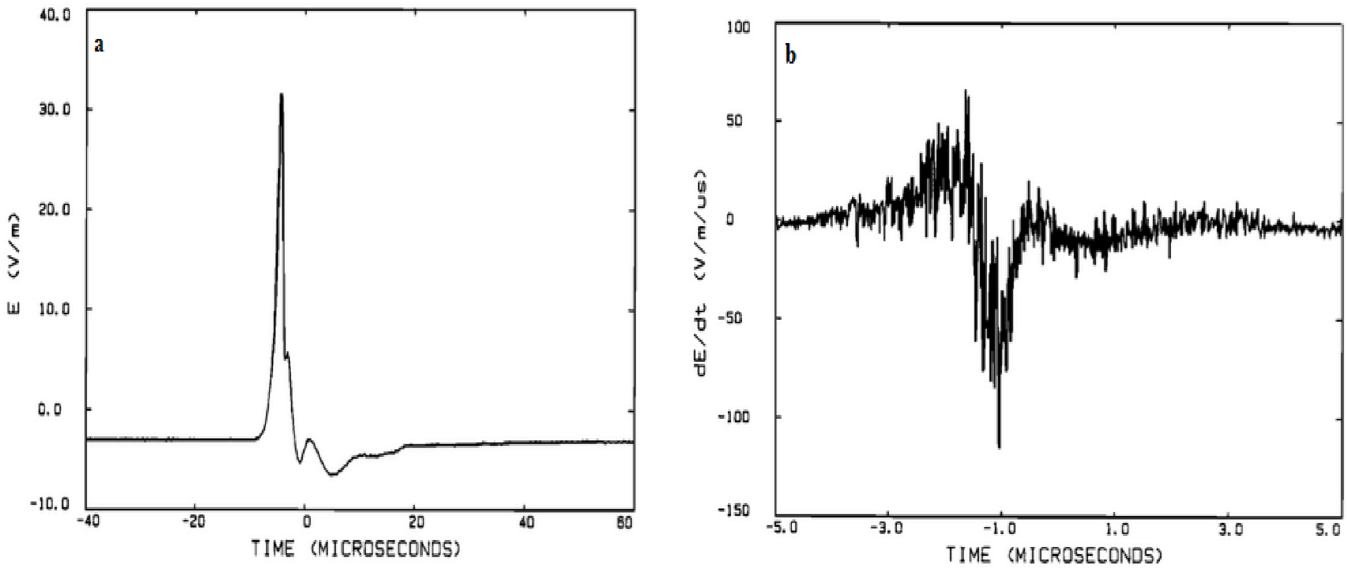

Figure 2: Narrow Bipolar Pulses adapted by Willet et. al (1989)[5] (a) Electric field in wideband measurement (b) Electric field derivative with noisy and very oscillating shape.

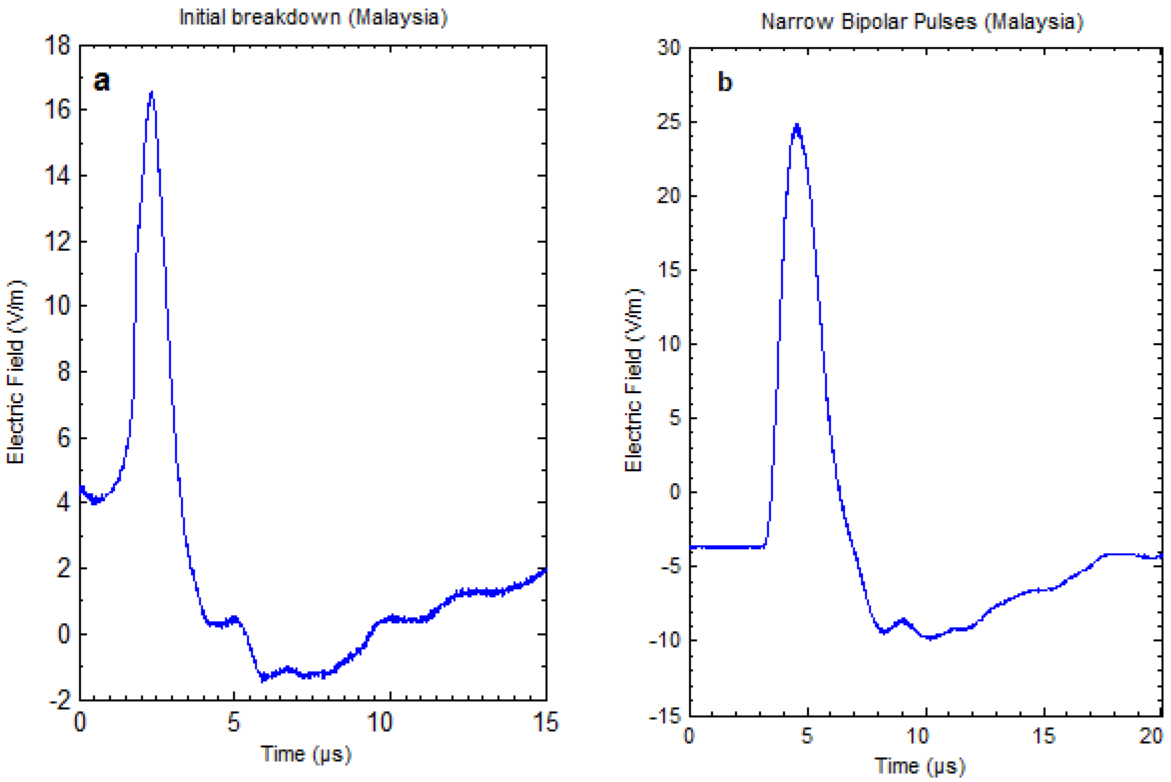

Figure 3: Similarity Characteristic between initial breakdown and narrow bipolar pulses located in Malaysia. The zero crossing time of both pulses less than 10 (µs) and have smooth rising peak from slow front to highest peak.

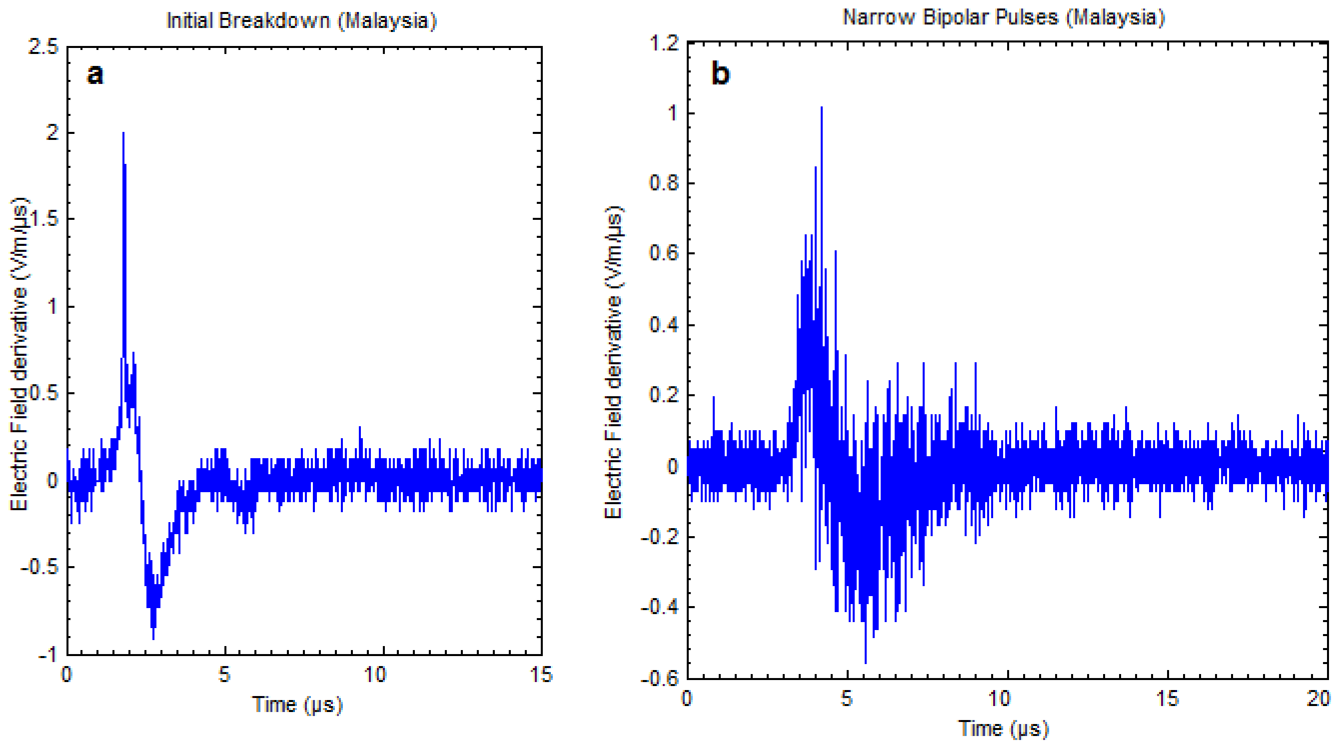

Figure 4: A comparison between initial breakdown and narrow bipolar pulses located in Malaysia based on electric field derivative (theoretically derivation).

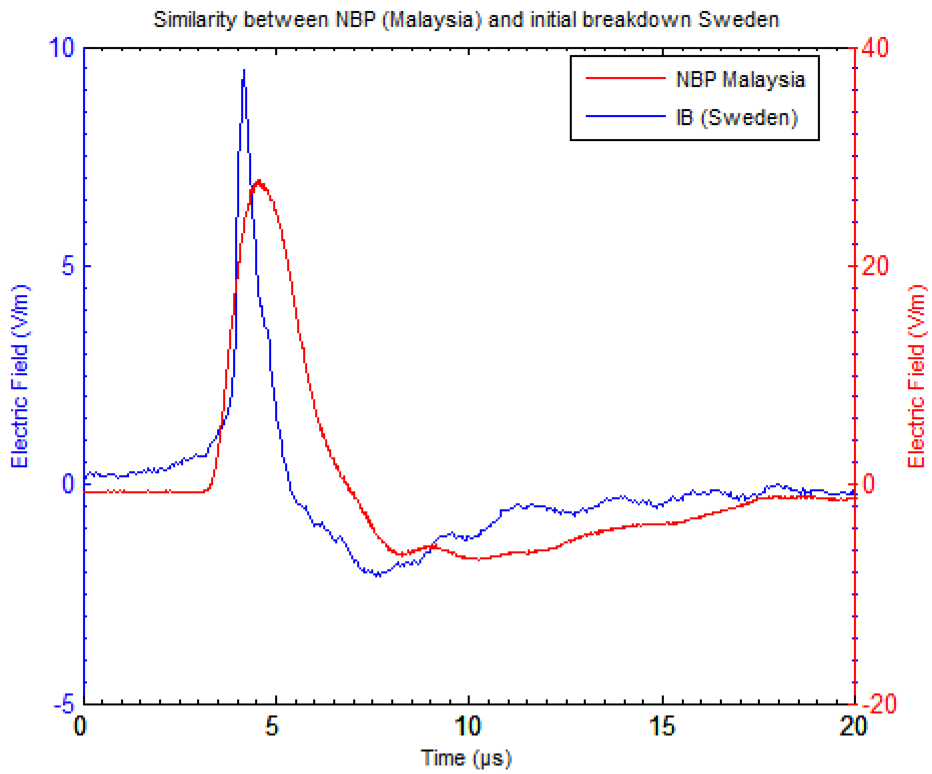

Figure 5: Similarity characteristic with smooth rising peak and zero crossing time less than 10 (µs) between narrow bipolar pulses in Malaysia and initial breakdown in Sweden.

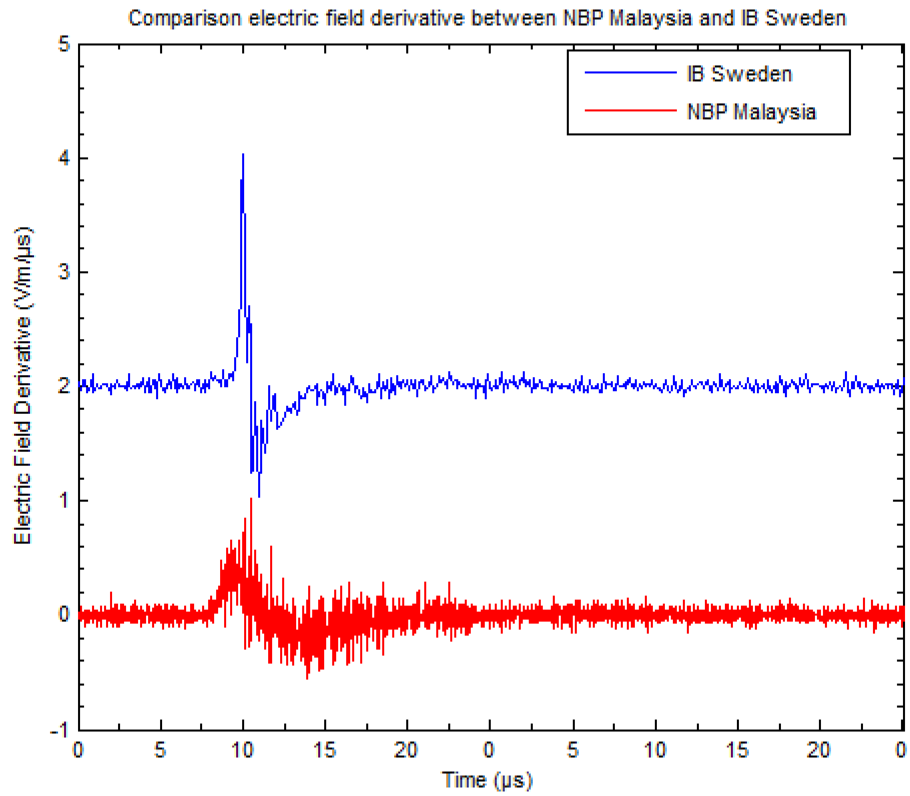

Figure 6: A comparison electric field derivative (theoretically derivation) between narrow bipolar pulses in Malaysia and initial breakdown in Sweden.

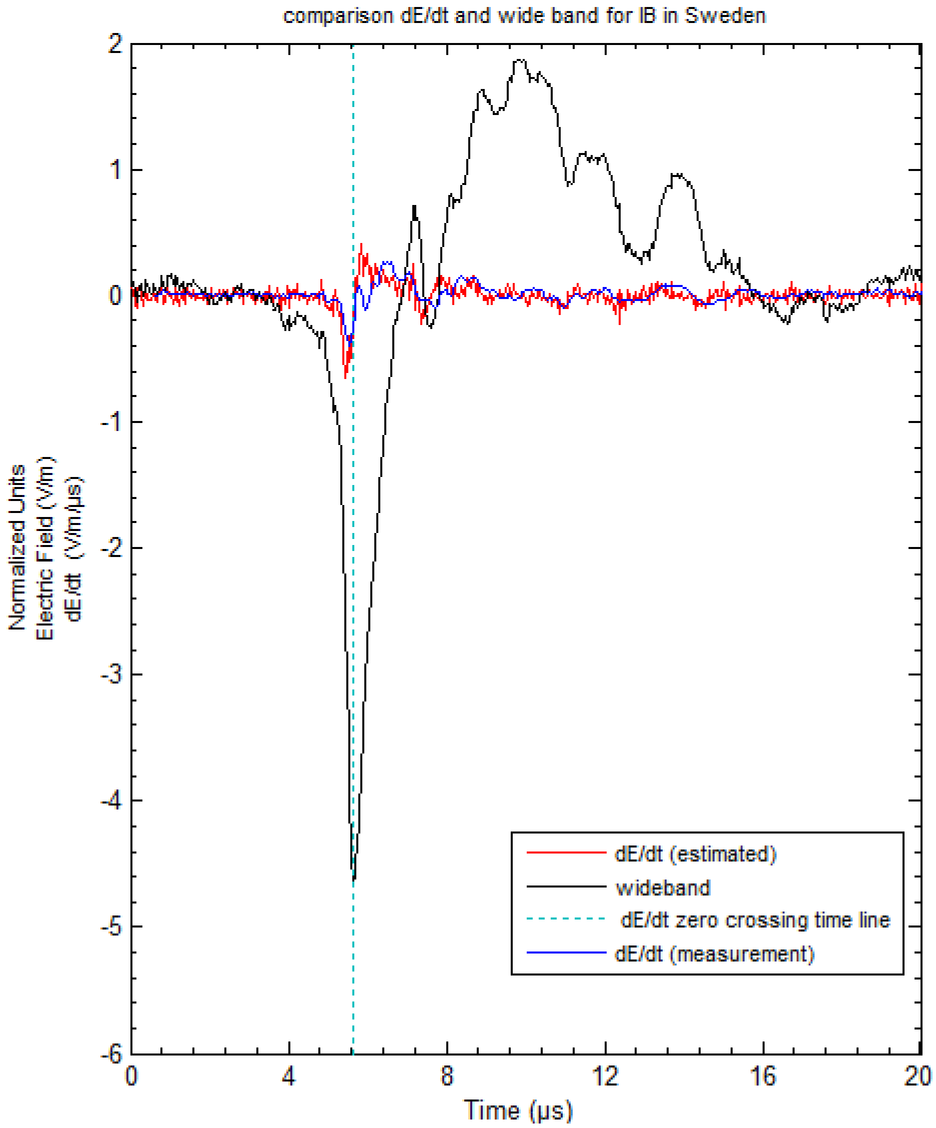

Figure 7: A comparison between Electric field in wide band, Electric field derivative (dE/dt) measurement and electric field derivative estimated by theoretically derivation for positive IB in Sweden.