

## Characteristics of Diurnal and Nocturnal Lightning Activities in Sarawak, Malaysia

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**Abstract:** Malaysia has a very high lightning activities rate that had been recorded every year. Yet, there are still too many lightning features that have not been explored in Malaysia especially in the eastern part of the country. This study presented diurnal and nocturnal lightning characteristics recorded in Sibu, Sarawak. The lightning electric field signal was detected using parallel plate antenna. The waveform was analyzed using PicoScope Software. Four important parameters of negative first and subsequent return stroke were measured namely normal electric field peak voltage, zero crossing time, zero to peak rise time and 10 to 90% rise time. Ten samples of diurnal first return stroke and 10 subsequent return strokes were presented in this study. Same amount of samples were measured for nocturnal lightning. Averagely, normal electric field peak voltage and zero crossing time for diurnal lightning were higher for both first and subsequent return strokes compared to nocturnal lightning. Contrarily, zero to peak rise time and 10 to 90% rise time of diurnal lightning were shorter for both first and subsequent return strokes compared to nocturnal type of lightning. The findings in this research conspicuously enhanced the knowledge about the variations of lightning characteristics in Malaysia.

**Keywords:** Negative lightning, Return stroke, Parallel plate antenna, Lightning characteristics.

### INTRODUCTION

Lightning is one of the Mother Nature on earth. Each bolt of the lightning contains up to 1 billion volts of electricity [1]. Lightning normally associated with thundercloud which brings destruction to the earth [2, 3]. It occurs when air fluctuates in the cloud resulting in the separation of positive and negative charges. Lightning has a bright light that is formed during the release of electricity into the atmosphere. It can occur during electric stretching at two separate points in one cloud, between the two clouds, between cloud and air, and also between the cloud and the ground. Cloud to ground (CG) lightning is the most hazardous to living things on earth. The electrical discharge or lightning is produced when electrical charges on the ground and the atmosphere are large enough to overcome the effect of air insulation. CG lightning can be categorized into positive and negative type based on their initiating charges [4]. The negative CG is a typical compared to positive CG [5]. Most of the lightning investigation conducted around the world observed only less than 10% of the positive lightning events [6-8] that make them very scarce. There are several lightning parameters that are vital in estimating a lightning protection system sensitivity or accuracy such as the operating threshold

voltage or current. This includes normal electric field peak voltage ( $E_n$ ), zero crossing time ( $T_{zc}$ ), zero to peak rise time ( $T_{zr}$ ) and 10% to 90% rise time ( $T_{10-90}$ ) which measured in this study. These parameters reflect to the maximum possible peak and energy produced in a lightning events [9]. Thus, lightning studies are considered important to produce a better design of lightning protection system that can be applied in Malaysia.

In Malaysia, various studies had been conducted to investigate effect of locations to the characteristics of lightning. Wooi et al. [10] analyzed lightning parameters in Johor and Malacca located in the peninsular Malaysia. They measured lower value of the lightning parameters compared to those generated in the temperate regions. Even lightning characteristics in the tropical region itself varies according to the geographical location of the lightning events and type of thunderstorm [11, 12]. Apart from that, there are also studies that have been conducted to analyze lightning characteristics based on different lightning types such as negative and positive narrow bipolar pulses [13], negative lightning flashes [14, 15], and positive lightning flashes [16]. Besides, lightning data obtained from Malaysia was compared to other regions with

different meteorology as reported in [10, 17, 18]. All of the studies conducted in Malaysia were set up in West Malaysia. Due to that reason, this study intends to analyze the lightning characteristics in different geographical region that is in Sibul, Sarawak, located in the eastern part of Malaysia. It focuses to investigate the diurnal and nocturnal lightning characteristics variation. Diurnal is related to activity occurs during day time only and on the contrary, nocturnal related to activity which only occurs during night time [19]. It was hoped that the data analyzed in this research will be able to enhance the understanding on the lightning characteristics occurred throughout Malaysia. The diversity of lightning studies in Malaysia will definitely reduce the literature gap between Malaysia and other advanced countries in the world.

### INSTRUMENTATION

A measurement field campaign was set up in the vicinity of University College Technology Sarawak (UCTS) (2°20'29.0"N 111°50'38.8"E). The vertical electric field from lightning flashes were captured by using one parallel plate antenna, similar to the one developed by Garvan and Fernando [20]. The block diagram of the measurement set up is illustrated in Figure 1.

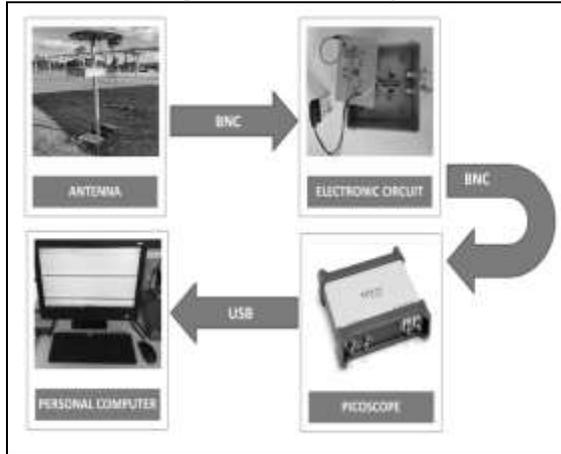


Figure 1: Block diagram for the measurement set up connection.

The electric field data was recorded using PicoScope which is an advanced oscilloscope and displayed using its pre-installed software in a personal computer via universal serial bus (USB) cable. A RG58 coaxial Bayonet Neill-Concelman (BNC) cable was used to connect the antenna and buffer circuit and also to connect the output of the buffer circuit to the oscilloscope. The parallel-plates antenna is composed of two parallel metallic plates, separated by a 3 cm thickness of insulator and was perpendicularly oriented to the direction of vertical electric field. The bottom plate was connected to the ground by insulated pure copper grounding cable. The antenna was placed at

approximately 30 meters away from the control room. Due to the mismatch of the output impedance of the antenna and the input impedance of the oscilloscope, there is a need to insert a buffer circuit in between the antenna and oscilloscope. This is because buffer circuit is a device which has very large input impedance and small output impedance. The antenna has larger output impedance compared to the input of the impedance of the oscilloscope. The oscilloscope might be damaged if the induced voltage on the antenna is too high. Plus, the antenna has frequency-dependent output impedance that is an extremely large frequency will further increase the output impedance of the antenna. The voltage drops at the oscilloscope will vary with the frequency of the detected electric field, so the buffer circuit will also protect the oscilloscope against extreme voltages as well. Output of the buffer amplifier were digitized at rates of 20 MS/s with a vertical resolution of 12-bit, 200 MHz PicoScope. In this study, a negative return stroke was identified as a positive field change as applied in atmospheric sign convention concept. Diurnal lightning activity was observed starts from sunrise time until sunset time, whereas it was vice versa for the nocturnal activity. According to [21], average sunrise time in Malaysia is at 6 am and sunset is at 7 pm. Thus, this study was conducted based on the timeline.

### DATA ANALYSIS

Figure 2 displays the first sample of electric field waveform of FRS (first negative return strokes) from diurnal lightning which was retrieved from PicoScope Software. The measured peak voltage ( $V_m$ ),  $T_{ZC}$ ,  $T_P$  and  $T_{10-90}$  were carefully analysed from the waveform. The normal electrical field,  $E_n$  and the voltage measured,  $V_m$  is related to measuring system factor,  $F_{meas}$  as shown in Equation (1). Based on the calibration procedures done by Galvan and Fernando, different effective antenna height,  $d_{eff}$  generates various measuring system factor,  $F_{meas}$  as shown in Equation (2). All the equations derivation were comprehensively discussed in [20]. From the reference,  $F_{meas}$  produced by 1.5 m of antenna height is 20.6037 and this value was employed in this current experimental set up. Thus, the equation for the normal electric field,  $E_n$  in this study is stated in Equation (3). This study analyzed 10 samples of FRS diurnal, 10 samples of subsequent return stroke (SRS) diurnal, 10 samples of FRS nocturnal and 10 samples of SRS nocturnal obtained in March and July 2020, respectively.

$$F_{meas} = \frac{E_n}{V_m} \quad \text{Equation (1)}$$

$$F_{meas} \propto \frac{1}{d_{eff}} \quad \text{Equation (2)}$$

$$E_n = 20.6037 (V_m) \quad \text{Equation (3)}$$

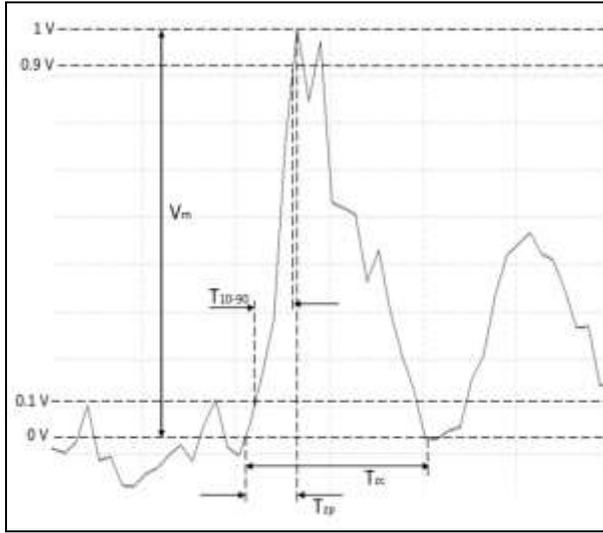


Figure 2: Negative lightning electric field for Sample 1

a) Comparison Between Diurnal And Nocturnal For FRS AND SRS

Day and night are meteorology phenomenon with variation of temperature and humidity and that probably influence lightning activities and characteristics. Generally, temperature is higher during diurnal activity in daytime compared to nocturnal in nighttime. As in Sibu, daytime temperature is averagely 30°C and can be up to 40 °C, whereas night temperature is 23°C [22]. Thus it can be considered reasonable if diurnal lightning consists of higher FRS peak amplitude because of higher temperature compared to nocturnal. As presented in Figure 3, the  $E_n$  value of FRS for diurnal lightning is 15% higher related to FRS of nocturnal lightning. Besides, warmer season produced higher lightning electric field amplitude as reported in [23, 24]. However, these findings are not in agreement with data measured in Guangdong Province in southern China analyzed by Zheng et al. [25] . Most of the high peak amplitude lightning events were observed during cold season compared to summer monsoon. This discrepancy is most likely due to climate difference. Guangdong is located at subtropical monsoon climate with rainy

summer and dry winter. Besides, United State of America (USA) has various climate zones. By using data collected across the entire continent, Chronis et al. [26] found that nocturnal lightning produced higher peak amplitude compared to diurnal events which is also dissent from the results in this study. The highest difference parameter between FRS for diurnal and nocturnal is their mean value of  $T_{zc}$ . Figure 3 shows that FRS for diurnal produced 72% higher value than FRS for nocturnal lightning. This was most probably due to the higher cloud base height during the day. According to [27], the cloud base height is directly proportional to the gap between surface temperature and the dew point. Based on data presented in [21], diurnal lightning for this study was acquired when the surface temperature and the dew point was averagely 3.2°C in difference. Meanwhile, it was averagely 1.2°C gap between the surface temperature and the dew point during nocturnal lightning observation. As inferred by Cooray, the vertical length of the lightning channel that initiates the discharge can affect the  $T_{zc}$  [28]. The vertical channel for lightning is approximately equal to the height of the initial charge layer in the thundercloud. Thus, longer vertical lightning channel produces longer  $T_{zc}$ . Generally, daytime is warmer than at night. Thus, it's not surprising when Ishii and Hojo also found  $T_{zc}$  was 97.5% longer during summer compared in winter [29]. As observed in Nag and Rakov [30] ,  $T_{zp}$  and  $T_{10-90}$  were tend to be shorter in a warmer climate which having higher temperature and vice versa. As in [31], lightning data from Brazil as a warmer country was compared to Japan. It was observed that  $T_{zp}$  and  $T_{10-90}$  in Brazil were 57% and 15% respectively shorter compared to Japan lightning data. It can be seen that result of present study is in agreement with their findings as can be observed in Figure 3.  $T_{zp}$  for FRS obtained in day time with higher temperature is 27% shorter than FRS in night time. Meanwhile the  $T_{10-90}$  for diurnal FRS is 9% shorter compared to nocturnal FRS. Figure 4 shows the comparison of SRS data for diurnal and nocturnal lightning. It can be observed that SRS data produced similar pattern with FRS lightning for diurnal and nocturnal as discussed previously. SRS for diurnal samples are having only slightly higher  $E_n$  value which is 5% than nocturnal. The SRS  $T_{zc}$  mean value for diurnal is 89% higher than nocturnal. The difference is huge compared to FRS samples. The mean value for diurnal SRS  $T_{zp}$  and  $T_{10-90}$  are 32% and 9%, respectively, shorter compared to SRS for nocturnal lightning.

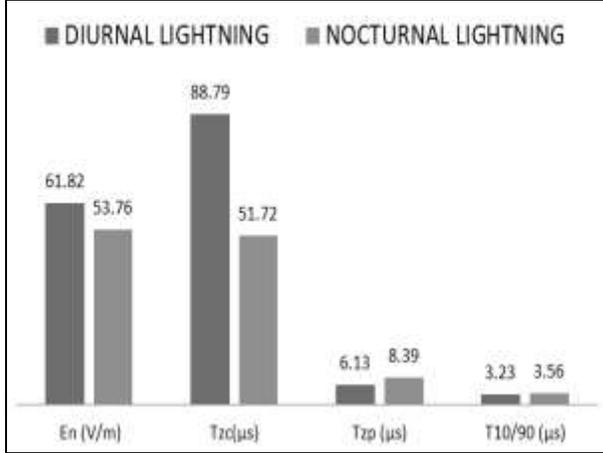


Figure 3: Comparison for FRS Parameters

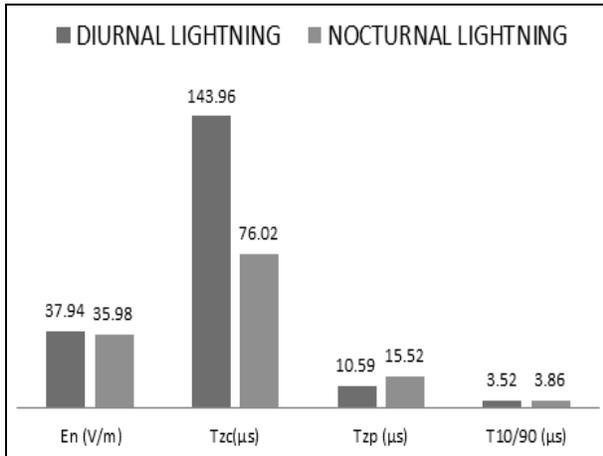


Figure 4: Comparison for SRS Parameters

b) Comparison Between FRS And SRS Parameters For Diurnal And Nocturnal

Figure 5 and Figure 6 show the comparison between FRS and SRS parameters average value for diurnal and nocturnal lightning events respectively. The largest difference is observed between their  $E_n$  values. FRS  $E_n$  value was 63% higher than SRS in diurnal whereas for nocturnal, FRS  $E_n$  value was 49% higher than SRS. FRS amplitude is normally higher than SRS because it was the first excessive charges burst from the thundercloud. After the first discharge, the thundercloud consists less charges and produced lower peak amplitude for the following SRS. This finding was similar to the investigations conducted by Wooi et al. [15] and Baharudin et al. [14]. In their studies, the data were obtained from Johor, located in the southern part of Peninsula Malaysia. However, there were 3% of SRS with  $E_n$  higher than FRS observed in this study which will be discussed in future report. This was also observed in other studies such as by Qie et al. in China

[32] while Nag et al. [33] analyzed data obtained from Florida, Austria, Sweden and Brazil. This is most probably because of the ohmic heating effect when a larger energy transpired into the channel after the return stroke pulse [34]. The  $T_{zc}$  mean values for both diurnal and nocturnal data were found in the same variation. Whereby, SRS samples were 62% and 47% higher than FRS  $T_{zc}$  for diurnal and nocturnal lightning, respectively. This was due to the decreasing speed of the lightning after the first return stroke occurred. Shooray et al. suggested that lower lightning speed produced higher  $T_{zc}$  [35]. Basically, the lightning speed influenced by the charge capacity which generated the lightning electric field amplitude. The higher the charge capacity the higher the peak amplitude produced in the lightning channel and vice versa [36]. According to Cooray [37] and Rakov et al. [38], the higher the total charges, the higher the lightning speed and the lower the rise time of the lightning produced. Result of this study is in agreement with the aforementioned inferences. However, zero crossing and rise time parameters variation are also influence by other factors such as soil conductivity and propagation distance as discussed in [39, 40]. It is interesting to note that, our finding is in contrast to Wooi's work [15] which was conducted in Johor as can be seen in Table I. The  $T_{zc}$  for FRS observed in Johor was 4% higher than SRS. Besides, the mean value for FRS  $T_{zp}$  was 6% higher than SRS whereas  $T_{10-90}$  for FRS and SRS were 100% similar in his work. Meanwhile, this current study observed that  $T_{zp}$  and  $T_{10-90}$  mean value for FRS diurnal data are 42% and 8%, respectively, shorter than SRS. Nocturnal data also displays similar pattern when the FRS is shorter than SRS as much as 46% and 8% for its  $T_{zp}$  and  $T_{10-90}$  mean value, respectively.

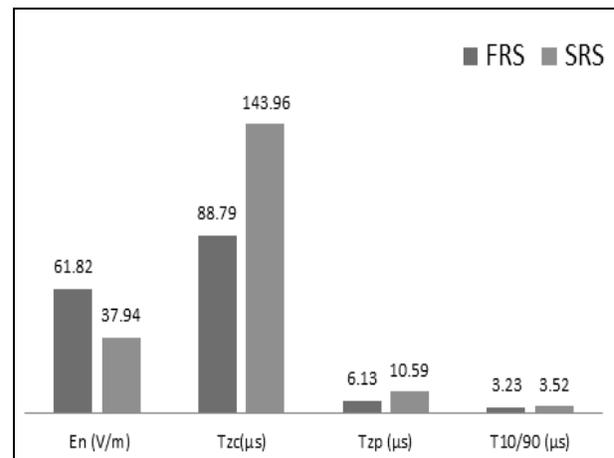


Figure 5: Average Value of Lightning Parameters for Diurnal Events

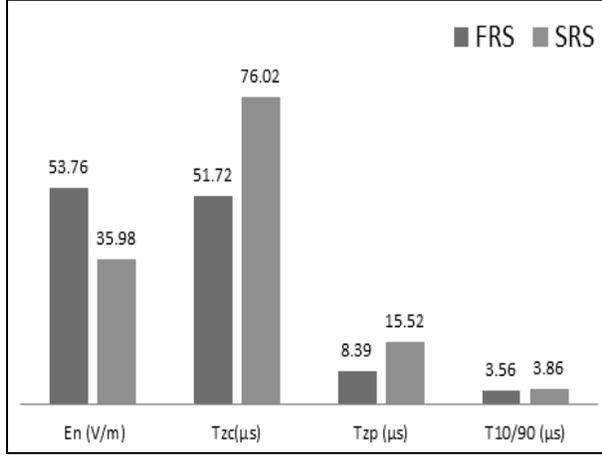


Figure 6: Average Value of Lightning Parameters for Nocturnal Events

Table 1: Lightning Parameters Comparison

| Author     | Activity  | Return Stroke | $E_n$ (V/m) | $T_{zc}$ (µs) | $T_{zp}$ (µs) | $T_{10/90}$ (µs) |
|------------|-----------|---------------|-------------|---------------|---------------|------------------|
| This study | Diurnal   | FRS           | 61.82       | 88.79         | 6.13          | 3.23             |
|            |           | SRS           | 37.94       | 143.96        | 10.59         | 3.52             |
|            | Nocturnal | FRS           | 53.76       | 51.72         | 8.39          | 3.56             |
|            |           | SRS           | 35.98       | 76.02         | 15.52         | 3.86             |
| Wooi [15]  | NA        | FRS           | 21.80       | 50.70         | 6.60          | 3.90             |
|            |           | SRS           | 12.70       | 48.90         | 6.20          | 3.90             |

In a nutshell, temperature and humidity differences are the most influencing factor when discussing about diurnal and nocturnal lightning data variations. Higher temperature tends to produce lower humidity and creates drier air. This combination leads to a higher electrostatic discharge like lightning phenomenon [41]. Therefore, diurnal lightning tends to generate higher  $E_n$  because of higher surface temperature compared to nocturnal. Yet, there were some lightning events that produced higher  $E_n$  during cold and nighttime. It was most probably due to drier cold season and nighttime compared to summer and daytime respectively. FRS normally produced higher  $E_n$  than SRS comparatively. This is because the first lightning discharge contents more electrical charges compared to the following events. There is a condition called ohmic heating effect, when more charges burst into the lightning channel after return stroke. This condition might produce higher SRS amplitude than FRS. Based on Heidler’s work [39], lightning propagation distance substantially

influence the signal  $T_{zc}$ . Thus, for a vertical channel termination lightning event, the higher the cloud base height the longer the  $T_{zc}$ . Cloud base height can be estimated by using surface temperature and dew point as comprehensively derived in [42]. The more the difference between those temperatures the higher the cloud base height which is normally occurred during daytime. Thus, diurnal lightning tends to produced longer  $T_{zc}$ . Besides, than lightning propagation distance, this parameter also affected to the speed of lightning propagation. The higher the speed of lightning the shorter the value of  $T_{zc}$ . High speed lightning is produced by high total charges consist in the lightning channel. Thus FRS which content more electrical charges than SRS produced shorter  $T_{zc}$ . Similarly, due to the decreasing charges and speed after the FRS,  $T_{zp}$  and  $T_{10-90}$  in SRS are likely to be longer than FRS. Besides, both parameters are also influenced by temperature variations. Lightning occurred during higher temperature as in daytime tends to produce shorter  $T_{zp}$  and  $T_{10-90}$  compared to the lightning occurred at night.

## CONCLUSION

Analysis of the characteristics between FRS and SRS occurred during the day and night was conducted. Four important parameters namely normal electric field peak voltage ( $E_n$ ), zero crossing time ( $T_{zc}$ ), zero to peak rise time ( $T_{zp}$ ) and 10% to 90% rise time ( $T_{10-90}$ ) were analyzed from 40 samples in total. The variation pattern of FRS and SRS for diurnal was similar to nocturnal. Mean value for  $E_n$  of FRS is higher compared to SRS by a factor of 1.63 and 1.53 for diurnal and nocturnal respectively. All the rise time parameters in diurnal and nocturnal events, namely the  $T_{zc}$ ,  $T_{zp}$  and  $T_{10-90}$  were shorter for FRS compared to SRS by a factor in range of 0.55 to 0.96. Besides, the samples also used to identify the variation of FRS characteristics in diurnal and nocturnal events and SRS characteristics in both aforementioned lightning events. Again, the variation pattern of FRS for diurnal and nocturnal was similar to the variation in SRS. Both parameters of  $E_n$  and  $T_{zc}$  are higher in FRS for diurnal lightning compared to nocturnal. Further, diurnal FRS peak is higher by a factor of 1.12 compared to nocturnal FRS whereas the  $T_{zc}$  for diurnal FRS is a factor of 1.83 higher from nocturnal FRS samples. Another two rise time characteristics for FRS diurnal lightning events were shorter compared to nocturnal. It was obtained that the  $T_{zp}$  and  $T_{10-90}$  mean value were shorter by the factor of 0.68 and 0.91 respectively. Similarly, the  $E_n$  and  $T_{zc}$  for SRS in diurnal events were higher than nocturnal SRS. The differences were by the factor of 1.05 for the  $E_n$  and 1.89 for the  $T_{zc}$  mean value. The  $T_{zp}$  and  $T_{10-90}$  for diurnal lightning SRS were also shorter compared to nocturnal. By the factor of 0.68,  $T_{zp}$  for SRS diurnal

samples was shorter than nocturnal whereas the  $T_{10-90}$  in SRS diurnal was shorter by 0.91 than nocturnal.

Interestingly, this experimental work had enhanced the understanding on the variations of diurnal and nocturnal lightning important characteristics. The most obvious difference features of days and nights are temperature and humidity. Therefore, most probably those factors highly influenced the lightning characteristics variations as observed in this study. Significantly, the peak electric field of the first return stroke in diurnal events was considered as the strongest peak and this observation is important to a better design of the lightning protection system.

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