

# Development of Slowly-varying Electric Field Sensor in Legoland Malaysia Resort

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**Abstract**— Data Transmission Network and Dataline (DTN), is a private company specializing in subscription-based services for the analysis and delivery of real-time weather. This service is used by LEGOLAND to keep up with weather information and lightning development. With the DTN system's unknown location, distance, and reliance on email for data transmission, gaining control over information flow and ensuring prompt delivery to end users becomes a major hurdle and delay. Besides, the DTN caused LEGOLAND high costs in purchasing DTN services, despite all the drawbacks. The fast and slowly-varying electric fields buffer circuits have been established as sensors for characterizing various lightning types, capable of detecting both near and far lightning. Special attention is directed towards the development of the slow electric field buffer circuit, designed to serve as a lightning warning system for detecting nearby lightning in crowded areas, such as the waterpark within LEGOLAND Resort in South Malaysia. This study focuses on analyzing the slow atmospheric electric field and perform waveform analysis for determining the estimated distance and radius of lightning events at LEGOLAND Malaysia Resort. The newly installed lightning detection system at LEGOLAND features a straightforward and cost-effective setup, incorporating a capacitive antenna, slow and fast atmospheric electric field sensors, and dedicated data analysis software. Its effectiveness and precision will be thoroughly compared with LEGOLAND's existing online service.

**Keywords**—LEGOLAND Malaysia Resort, Lightning Localization, Lightning Electric Field Waveform

## I. INTRODUCTION

Slow and fast components of the atmospheric electric field have been an active area of research in various fields, including atmospheric physics, thunderstorm electrification, and lightning detection [1]. Previous work has explored their distinct characteristics and contributions to electrical phenomena in the atmosphere. Fast electric field, with variations occurring in milliseconds, arises from lightning discharges and other rapid changes in the charge distribution within clouds. Previous studies have focused on measuring its precise dynamics using high-speed sensors, analysing its relationship to lightning leader propagation and branching, and exploring its role in initiating and triggering subsequent lightning strokes. Slow electric field, on the other hand, with changes occurring over minutes or hours, reflects the overall charge distribution in the atmosphere and is influenced by factors like solar radiation, cosmic rays, and global atmospheric circulation. Previous work has investigated its spatial and temporal variations across different regions and

altitudes, its link to thunderstorm development and cloud electrification processes, and its potential for long-range weather forecasting.

The electric field emitted from natural lightning consists of radiation, static, and induction components [1]. As the static component gradually prevails over the radiation component when propagating towards the sensor, the slow-varying field could be employed as a cost-effective and straightforward lightning warning system to notify people about nearby lightning, as it will be detected when close lightning occurs. However, compared to numerous other lightning localization techniques, slow fields operate at low frequencies, offering a minimal cost.

Existing lightning detection systems rely on techniques such as Magnetic Direction Finders (MDF), Time of Arrival (TOA), and Direction of Arrival (DOA). These methods analyse changes in fast atmospheric electric fields, magnetic fields, and Very High Frequency (VHF) signals [2-13] to estimate the distance and location of lightning strikes. While all the mentioned techniques provide accurate lightning strike locations, their development requires a high budget and a complicated setup, consuming significant resources and time.

In contrast, this project takes an innovative approach by combining both fast and slow electric field sensors for even greater precision in distance and radius estimation [9-12]. Fast sensors capture frequency ranging from 10 Hz to 30 MHz, while slow sensors capture frequency between 0.1 Hz and 10 kHz. This comprehensive range coverage provides a more complete picture of the lightning event. LEGOLAND primarily requires short-range detection (up to 30 km) for guest safety during storms, where slow electric fields excel, being cost-effective and well-suited for the resort's needs. Analysing slow electric field waveforms for lightning detection has not been extensively explored, and this project aims to fill this gap, offering valuable insights for future research and applications [1-13].

Therefore, this project prioritizes slow electric fields as a cost-effective and accurate solution for LEGOLAND's short-range lightning detection needs, simultaneously contributing valuable data to the field. In essence, this project pushes the boundaries of lightning detection by combining different sensor types for enhanced accuracy and data validation, while also providing valuable knowledge in the field of slow electric field analysis.

## II. METHODOLOGY

A distinctive combination of slow and fast electric field sensors has been implemented in this project. Slow electric field sensors excel in short-range detection (up to 30 km) and provide accurate distance and radius information, aligning perfectly with needs of the resort. However, to determine the type of lightning, a fast electric field sensor has been incorporated into the system. The fast electric field sensor capture frequency ranging from 10 Hz to 30 MHz, while slow electric field sensor capture frequency ranging between 0.1 Hz to 10 kHz.

Fig. 1 illustrates the process of designing slow and fast electric field sensors using Multisim software, simulated with frequency generators spanning from 1 Hz to 100 MHz. In the simulation, if the circuit's output signal does not align with the input signal, the circuit needs to be reconstructed and simulated iteratively until achieving the desired outcome. Once the desired result is achieved, the subsequent step involves fabricating and constructing the printed circuit boards (PCB) for the slow and fast electric field sensors, requiring the soldering of all necessary components for both sensor circuits.

The subsequent step involves calibrating both sensors, as depicted in Fig. 2. LeCroy Wavesurfer 3054 oscilloscope is utilized to calibrate both sensor circuits. The frequency generator is configured to operate from 1 Hz to 10 MHz and is applied to both sensor circuits. Similar to the simulation process, if the input signal does not match the output signal, it is necessary to reconstruct the sensor circuit by verifying and re-soldering the existing components and reassessing the connections. Once the desired outcome is achieved, both sensors are enclosed in separate boxes, making them ready for use [14-17].

To measure the electromagnetic field from lightning, the decay constant should be taken into consideration. Capacitance value of the antenna and cable circuit are the main parameter values needed to determine the decay time constant of the system. Below is the calculation flow how to determine decay time constant.

$$\begin{aligned} \text{Decay constant of slow field system} \\ \tau = RC \quad (1) \\ \tau = (100M\Omega) (59pF + 60pF + 10nF) \\ = 1.0119 \text{ s} \end{aligned}$$

$$\begin{aligned} \text{Lower frequency of the slow field system} \\ \text{Lower frequency, } FL = \frac{1}{2\pi\tau} \quad (2) \\ \frac{1}{2\pi(1.0119)} = 0.157 \text{ Hz} \end{aligned}$$

$$\begin{aligned} \text{Decay constant of fast field system} \\ \tau = (100M) (59pF + 60pF + 15pF) \\ = 13.4\text{msec} \end{aligned}$$

$$\begin{aligned} \text{Lower frequency of the fast field system} \\ \frac{1}{2\pi(13.4\text{m})} = 11.88 \text{ Hz} \end{aligned}$$

$$\begin{aligned} \text{Upper frequency for both systems} \\ \text{Given rise time of OPA 633k} = 2.5 \text{ ns} \\ \text{Upper frequency, } Fu = \frac{1}{2\pi(2.5n)} = 63.66\text{MHz} \quad (3) \end{aligned}$$

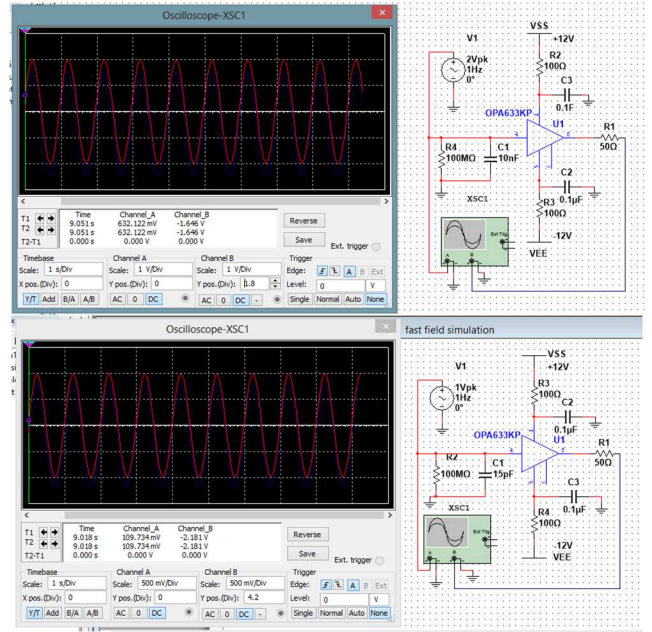


Fig. 1 Multisim circuit simulation for slow and fast electric field sensor.



Fig. 2 Slow and fast electric field sensors, calibrated using LeCroy Wavesurfer 3054 oscilloscope.

## III. DATA TRANSMISSION NETWORK AND DATALINE (DTN) AND LIGHTNING DETECTION SYSTEM (LDS)

Data Transmission Network and Dataline, formerly known as Telvent DTN (<https://www.dtn.com/>), is a private company headquartered in Burnsville, Minnesota. The company specializes in subscription-based services for real-time weather, agricultural, energy, and commodity market information analysis and delivery. As of 2018, DTN boasts approximately 600,000 subscribers, primarily in the United States. Renowned for its accurate meteorological forecasting, extensive network of 6,000 weather stations, market analysis services, and pioneering use of radio and satellite systems for report transmission in the Midwest, DTN combines various data through the National Center for Atmospheric Research's Dynamic Integrated foreCast (DICast) technology, licensed from the University Corporation for Atmospheric Research.

LEGOLAND utilizes the DTN to stay informed about weather and lightning conditions. The estimated monthly subscription fee ranges from 200 to 500 US dollars (equivalent to MYR 943 to 2358). As illustrated in Fig. 4, when lightning is detected, DTN sends an email to the LEGOLAND base, providing information such as the time and radius of the lightning. Consequently, in the event of lightning near the LEGOLAND area, the base promptly instructs on-duty staff to alert visitors in open areas and the water playground, urging them to seek shelter in the nearest building.



Fig. 3. Capacitive antenna with slow and fast electric field sensor attached, PicoScope 4000 series, AC-DC power supply with -12VDC +12VDC and desktop computer with PicoScope 6 software installed.

The Lightning Detection System (LDS) installed on the roof of the chemical store in LEGOLAND, as depicted in Fig. 3, is a straightforward yet effective and economical system for lightning detection. It comprises a capacitive antenna, a buffer circuit with slow and fast electric field sensors, a PicoScope (digitizer), and a desktop computer with PicoScope 6 software. The capacitive antenna receives electromagnetic radiation in analog form from lightning strikes and sends it to the buffer circuit.

The buffer circuit eliminates unwanted noise, amplifies, and filters the signal, delivering a clear signal to digitizer. PicoScope digitizes the lightning data in real-time, and the installed software functions as a real-time analyzer with features such as spectrum analysis, voltage-based triggering, and the ability to save/load waveforms to the hard disk. The fully functional LDS operates as a closed-loop system, triggering and recording lightning data when a lightning strike occurs and storing it on the hard disk, waiting for the next strike. Data collected and stored by the LDS are compared with data from DTN, and the analysis results are presented in Table 1.

#### IV. RESULT AND ANALYSIS

From July 2020 to December 2022, a vast dataset comprising approximately 50,000 lightning strikes was collected. This section undertakes a comparative analysis of two systems, with a specific focus on December 2020 as it was Malaysia's peak season for both rain and lightning. It was the ideal month to assess and compare the performance of the DTN and the LDS. Table 1 shows that DTN, a subscription service, provides LEGOLAND with real-time weather and lightning updates. In contrast, the LDS was installed and operated directly from LEGOLAND's chemical store roof.

As indicated in Table 1, out of a total of 58 lightning flashes detected by LDS, 24 were detected as Within Reversal Distance (WRD  $\leq 7$ km), while the rest were detected as Beyond Reversal Distance (BRD 7 to 30 km). Besides, the data generated by DTN is limited to only one set of information for each lightning event, whereas LDS is not constrained to just one data point for each lightning event. LDS records a series of lightning events in detail for each occurrence, providing a more comprehensive dataset compared to DTN. Information obtained from DTN includes time, date, distance, direction, and a graphical user interface, while information from LDS includes time, date, amplitude, waveform, and the type of lightning.

TABLE I. DATALINE (DTN) AND LIGHTNING DETECTION SYSTEM (LDS)

| Date      | Data | Time        | Type | WRD/BRD | Amp. FF   | Amp. SF (RS) | Amp. SF (Static) |
|-----------|------|-------------|------|---------|-----------|--------------|------------------|
| 3-Dec-20  | DTN  | 3:42 PM     |      |         |           |              |                  |
|           | LDS  | 3:24:21 PM  | IC   | WRD     | 4.55E-01  | 3.33E-01     | -1.76E-01        |
|           | LDS  | 3:09:26 PM  | IC   | WRD     | 3.30E-01  | 2.38E-01     | -5.45E-01        |
| 9-Dec-20  | DTN  | 4:33 PM     |      |         |           |              |                  |
|           | LDS  | 4:32:25 PM  | NBE  | WRD     | -6.54E-01 | 2.68E-02     | -8.41E-01        |
|           | DTN  | 6:06 PM     |      |         |           |              |                  |
|           | LDS  | 6:06:57 PM  | NCG  | WRD     | 5.88E-01  | 1.33E-02     | -4.86E-01        |
|           | LDS  | 6:06:05 PM  | NCG  | WRD     | 3.03E-01  | 3.09E-01     | -5.51E-01        |
|           | DTN  | 6:37 PM     |      |         |           |              |                  |
|           | LDS  | 6:36:23 PM  | NBE  | BRD     | 2.41E-01  | 2.35E-01     | -4.76E-02        |
|           | DTN  | 6:38 PM     |      |         |           |              |                  |
|           | LDS  | 6:37:35 PM  | NCG  | BRD     | 2.55E-01  | 2.50E-01     | -6.09E-02        |
|           | DTN  | 6:46 PM     |      |         |           |              |                  |
|           | LDS  | 6:40:54 PM  | NCG  | BRD     | 2.11E-01  | 2.05E-01     | -3.10E-02        |
|           | DTN  | 7:03 PM     |      |         |           |              |                  |
|           | LDS  | 6:52:15 PM  | NBE  | BRD     | 2.15E-01  | 2.63E-01     | -3.14E-02        |
| 10-Dec-20 | DTN  | 2:31 PM     |      |         |           |              |                  |
|           | LDS  | 2:31:32 PM  | NCG  | BRD     | 1.65E-01  | 2.04E-01     | -4.44E-01        |
|           | DTN  | 3:33 PM     |      |         |           |              |                  |
|           | LDS  | 3:26:32 PM  | NCG  | WRD     | 8.78E-01  | 9.60E-01     | -5.60E-01        |
|           | LDS  | 3:15:16 PM  | NCG  | WRD     | 1.15E-01  | 8.61E-02     | -3.98E-01        |
| 15-Dec-20 | DTN  | 3:42 PM     |      |         |           |              |                  |
|           | LDS  | 3:37:23 PM  | NCG  | BRD     | 6.63E-01  | 2.33E-01     | -3.65E-02        |
|           | LDS  | 3:35:26 PM  | NBE  | BRD     | 7.72E-01  | 2.74E-01     | -6.33E-04        |
|           | LDS  | 3:35:06 PM  | NCG  | BRD     | 7.83E-01  | 2.93E-01     | -6.93E-04        |
|           | LDS  | 3:34:36 PM  | NCG  | BRD     | 7.47E-01  | 2.63E-01     | -5.43E-04        |
|           | LDS  | 3:33:18 PM  | NCG  | BRD     | 7.07E-01  | 2.40E-01     | -2.27E-04        |
|           | LDS  | 3:33:13 PM  | NCG  | BRD     | 7.48E-01  | 2.67E-01     | -1.52E-04        |
|           | LDS  | 3:33:05 PM  | NCG  | WRD     | 7.80E-01  | 2.83E-01     | -4.58E-02        |
|           | DTN  | 3:53 PM     |      |         |           |              |                  |
|           | LDS  | 3:53:58 PM  | NCG  | WRD     | 9.99E-01  | 8.53E-01     | -8.63E-02        |
| 17-Dec-20 | DTN  | 3:56 PM     |      |         |           |              |                  |
|           | LDS  | 3:55:40 PM  | NCG  | BRD     | 3.28E-01  | 3.19E-01     | -3.09E-03        |
|           | LDS  | 3:55:30 PM  | NCG  | BRD     | 2.60E-01  | 2.60E-01     | -4.54E-01        |
|           | LDS  | 3:52:08 PM  | NCG  | BRD     | 4.22E-01  | 4.12E-01     | -3.70E-03        |
|           | LDS  | 3:48:36 PM  | NCG  | BRD     | 2.20E-01  | 2.20E-01     | -1.76E-01        |
|           | LDS  | 3:45:36 PM  | PCG  | WRD     | 2.68E-01  | 2.70E-01     | -1.00E+00        |
|           | LDS  | 3:45:01 PM  | NCG  | BRD     | 2.79E-01  | 2.84E-01     | -4.15E-01        |
|           | LDS  | 3:41:21 PM  | NCG  | BRD     | 1.39E-01  | 1.40E-01     | -4.51E-01        |
|           | LDS  | 3:36:12 PM  | IC   | BRD     | 2.40E-01  | 2.40E-01     | -2.70E-01        |
|           | DTN  | 4:04 PM     |      |         |           |              |                  |
|           | LDS  | 3:59:36 PM  | NBE  | BRD     | 1.61E-02  | 4.98E-03     | -1.95E-01        |
|           | LDS  | 3:59:04 PM  | NCG  | BRD     | 3.11E-01  | 3.03E-01     | -2.83E-03        |
|           | DTN  | 4:19 PM     |      |         |           |              |                  |
|           | LDS  | 4:13:15 PM  | NCG  | BRD     | 3.32E-01  | 3.22E-01     | -2.17E-03        |
| 24-Dec-20 | DTN  | 11:38 AM    |      |         |           |              |                  |
|           | LDS  | 11:30:04 AM | PCG  | BRD     | 2.29E-01  | 2.33E-01     | -1.00E+00        |
|           | LDS  | 11:25:25 AM | NCG  | BRD     | 4.18E-01  | 4.14E-01     | -5.69E-01        |
|           | LDS  | 11:23:43 AM | PCG  | WRD     | 3.20E-01  | 3.20E-01     | -1.00E+00        |
|           | LDS  | 11:22:23 AM | PCG  | WRD     | 4.18E-01  | 4.17E-01     | -2.59E-01        |
| 26-Dec-20 | DTN  | 2:52 PM     |      |         |           |              |                  |
|           | LDS  | 2:52:24 PM  | NCG  | WRD     | 7.48E-01  | 8.34E-01     | -4.56E-01        |
|           | LDS  | 2:48:53 PM  | NCG  | WRD     | 2.95E-01  | 3.59E-01     | -4.95E-01        |
|           | DTN  | 3:07 PM     |      |         |           |              |                  |
|           | LDS  | 3:04:51 PM  | NCG  | BRD     | 2.60E-01  | 2.59E-01     | -2.12E-02        |
|           | DTN  | 3:08 PM     |      |         |           |              |                  |
|           | LDS  | 3:08:56 PM  | NCG  | WRD     | 5.87E-01  | 6.50E-01     | -5.64E-01        |
|           | DTN  | 3:49 PM     |      |         |           |              |                  |
|           | LDS  | 3:33:54 PM  | NCG  | WRD     | 1.00E+00  | 1.00E+00     | -5.36E-01        |
|           | LDS  | 3:30:25 PM  | NCG  | WRD     | 1.00E+00  | 1.00E+00     | -5.39E-01        |
|           | DTN  | 3:56 PM     |      |         |           |              |                  |
|           | LDS  | 3:56:56 PM  | NCG  | WRD     | 1.00E+00  | 1.00E+00     | -5.71E-01        |
|           | LDS  | 3:52:20 PM  | NCG  | BRD     | 2.77E-01  | 2.96E-01     | -4.39E-01        |
|           | LDS  | 3:51:03 PM  | NCG  | BRD     | 7.47E-01  | 7.50E-01     | -1.97E-01        |
|           | DTN  | 4:57 PM     |      |         |           |              |                  |
|           | LDS  | 4:56:04 PM  | NCG  | BRD     | 1.98E-01  | 1.52E-01     | -3.03E-01        |
|           | LDS  | 4:54:15 PM  | NCG  | BRD     | 1.63E-01  | 1.40E-01     | -4.32E-01        |
|           | LDS  | 4:51:07 PM  | NCG  | BRD     | 2.08E-01  | 1.15E-01     | -4.16E-01        |
|           | LDS  | 4:48:37 PM  | NCG  | BRD     | 1.71E-01  | 1.31E-01     | -3.17E-01        |
|           | LDS  | 4:44:39 PM  | NCG  | BRD     | 2.96E-01  | 2.96E-01     | -2.84E-01        |
|           | LDS  | 4:42:03 PM  | NCG  | WRD     | 1.00E+00  | 1.00E+00     | -6.26E-01        |
|           | DTN  | 7:33 PM     |      |         |           |              |                  |
|           | LDS  | 7:33:00 PM  | IC   | WRD     | 2.25E-01  | 2.25E-01     | -3.80E-01        |
| 27-Dec-20 | DTN  | 3:52 PM     |      |         |           |              |                  |
|           | LDS  | 3:52:25 PM  | NCG  | WRD     | 1.74E-01  | 2.66E-01     | -4.26E-01        |
|           | DTN  | 4:15 PM     |      |         |           |              |                  |
|           | LDS  | 4:02:01 PM  | NCG  | WRD     | 6.98E-01  | 7.62E-01     | -4.47E-01        |
|           | LDS  | 4:00:12 PM  | NCG  | WRD     | 1.00E+00  | 1.00E+00     | -4.03E-01        |
|           | DTN  | 6:14 PM     |      |         |           |              |                  |
|           | LDS  | 5:58:49 PM  | NCG  | BRD     | 2.23E-01  | 2.24E-01     | -1.97E-01        |
|           | DTN  | 6:29 PM     |      |         |           |              |                  |
|           | LDS  | 6:28:27 PM  | NBE  | BRD     | 2.04E-01  | 2.29E-01     | -2.99E-02        |
|           | LDS  | 6:25:31 PM  | NCG  | BRD     | 2.16E-01  | 2.16E-01     | -4.57E-02        |
|           | DTN  | 6:44 PM     |      |         |           |              |                  |
|           | LDS  | 6:33:00 PM  | NCG  | WRD     | 3.62E-01  | 3.60E-01     | -3.77E-01        |

Upon closer inspection, it becomes apparent that LDS is capable of detecting lightning events slightly earlier than DTN. As shown in Fig. 4-10, DTN detected lightning at 3:56 pm while LDS detected lightning consecutively starting at 3:51 pm, 3:52 pm, and 3:56 pm. The time difference between the two systems from starting to detect lightning is

about 5 minutes. This could be attributed to the fact that LDS is installed within LEGOLAND and detects lightning occurrences in the immediate area, allowing for direct data capture and viewing. In contrast, the location and distance of DTN's system from LEGOLAND are unknown, and DTN transmits information via email, which may lead to delays in reaching end-users. Fig. 4 below presents the data captured by DTN, while Fig. 5-10 depict the data captured by LDS.

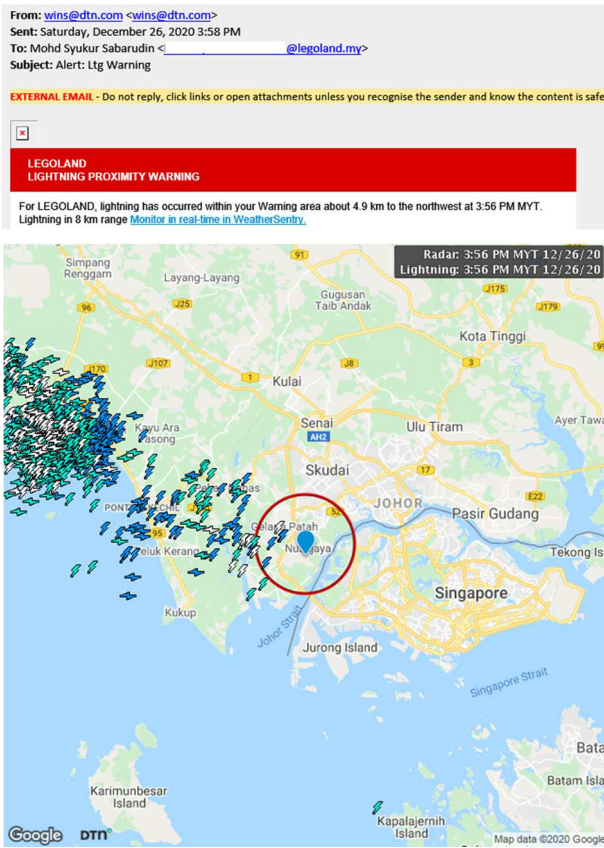


Fig. 4 Lightning has occurred within warning area about 4.9 km to the northwest captured by DTN at 3:56 PM on December 26<sup>th</sup> 2020

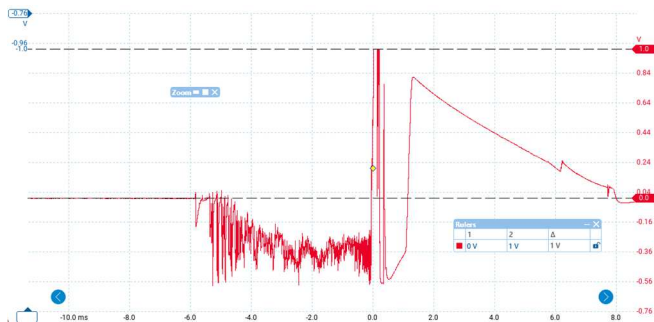


Fig. 5 Slow electric field waveform captured by LDS at 3:56:56 PM on December 26<sup>th</sup> 2020, type of lightning is negative cloud-to-ground (NCG) and it is within reversal distance (WRD) with return stroke amplitude  $1.00E+00$  and static amplitude  $-5.71E-01$ .

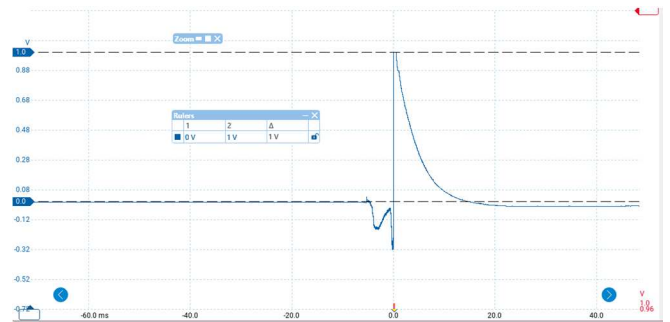


Fig. 6 Fast electric field waveform captured by LDS at 3:56:56 PM on December 26<sup>th</sup> 2020, type of lightning is negative cloud-to-ground (NCG) and it is within reversal distance (WRD) with amplitude  $1.007E+00$

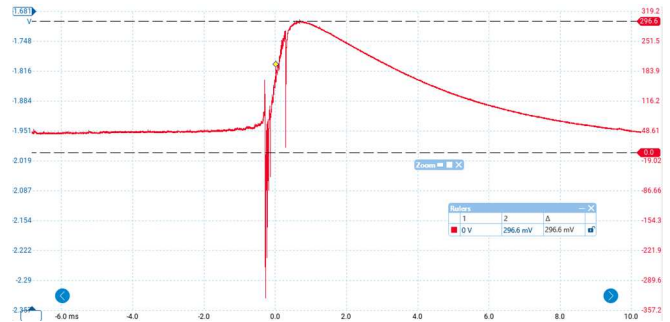


Fig. 7 Slow electric field waveform captured by LDS at 3:52:20 PM on December 26<sup>th</sup> 2020, type of lightning is negative cloud-to-ground (NCG) and it is beyond reversal distance (BRD) with return stroke amplitude  $2.97E-01$  and static amplitude  $-4.39E-01$

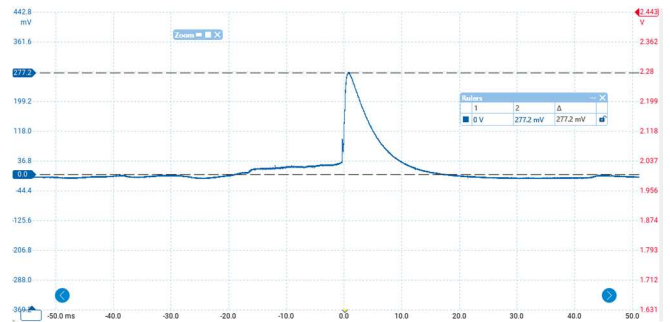


Fig. 8 Fast electric field waveform captured by LDS at 3:52:20 PM on December 26<sup>th</sup> 2020, type of lightning is negative cloud-to-ground (NCG) and it is beyond reversal distance (BRD) with amplitude  $2.77E-01$

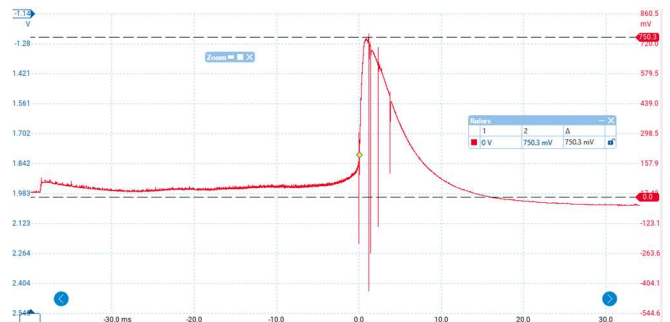


Fig. 9 Slow electric field waveform captured by LDS at 3:51:03 PM on December 26<sup>th</sup> 2020, type of lightning is negative cloud-to-ground (NCG) and it is beyond reversal distance (BRD) with return stroke amplitude  $7.50E-01$  and static amplitude  $-1.97E-01$

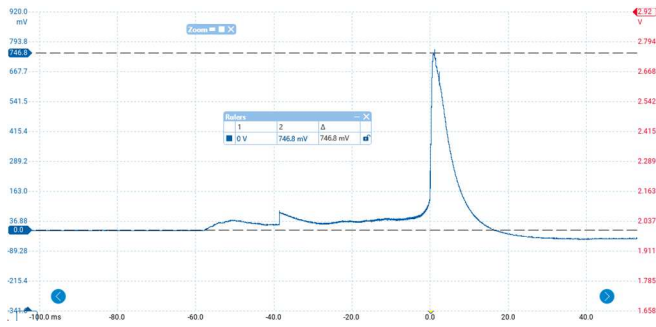


Fig. 10. Fast electric field waveform captured by LDS at 3:51:03 PM on December 26<sup>th</sup> 2020, type of lightning is negative cloud-to-ground (NCG) and it is beyond reversal distance (BRD) with amplitude 7.47E-01

## V. DISCUSSION AND CONCLUSION

The LDS system at LEGOLAND, utilizing both slow and fast electric field sensors, offers unparalleled precision in lightning detection. This unique combination excels by covering complementary frequency ranges, ensuring reliability through data validation, and requiring simultaneous detection by both sensors for accuracy. The system's strategic placement within LEGOLAND allows for faster, real-time lightning detection, proactive measures, and early warnings, outperforming the outsourced DTN. The research delivers a real-time, short-range lightning detection system that enhances guest safety and operational efficiency, with potential applications extending beyond amusement parks to safeguard communities worldwide.

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