Time-to-Thunder Method of Lightning Distance Determination

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***Abstract*—The lightning strike hazards may be properly managed by using a lightning detector system. In this paper, a system to determine the lightning strike distance from the measuring point was developed and tested. The time-to-thunder method was used to determine the strike distance. The technique was implemented using two kinds of sensors, namely, a broadband antenna to detect the electric field, and a microphone to detect the acoustic signal produced when lightning strike to the ground. A simple procedure to find the strike distance (*d*) was explained. A broadband parallel plate antenna was used to detect the electric field signal. The acoustic signal was detected by a microphone. The arrival time-delay between both signals was used to calculate the strike distance. The LabVIEW 8.5 software was used as a data logger to calculate the distance and to save the data. The lightning distance data were recorded for duration from January 2010 until March 2010 using the developed system. The range of the lightning detection is up to 10 km in radius.**

Keywords **— Lightning Distance; Electric Field; Time-to-Thunder, Antenna, Time Delay.**

I. INTRODUCTION

Lightning discharges radiate intense electromagnetic pulses (sferics), which have been used to detect the distance of the lightning source strikes. The quest of lightning distance [1] can be solved by means of multi-station or single-station techniques. Multi-station techniques are the most accurate and several systems have been developed in the past decades. An example is the United States National Lightning Detection Network (NLDN), which in 1996 used 106 sensors located over the continental United States to achieve a typical accuracy of 0.5 km [2]. While, single station techniques use a single VLF receiver and give a more convenient way to locate the sources. The system [3] usually a combine the direction finding with estimation of the distance to the source strikes.

The earliest single-station technique is using the ratio [4] between the electromagnetic signals and electric field signals. The lightning distance also can be determined based on spherics field pattern [5] by analyzing the smooth-type spherics waveform or using wave impedance technique [6].The derivation technique [7] based on delay time between arrival times of ELF and VLF in slow tail atmospherics also has been used.

In this paper, the time-to-thunder method was used to determine the lightning strike distance. The method used the combinations of broadband VHF antenna and microphone to form a single-station lightning distance determination. In the method, the broadband antenna was used to detect the electric field signals and the microphone was used to detect the acoustic signals. Based on the different time delay between both signals, the lightning strike can be calculated.

II. TIME –TO- THUNDER METHOD

A. Theory

The method was implemented by using two kinds of antenna which are wire antenna used to sense the electric field wave and a microphone is used to sense the pressure wave produce by the thunder storm when lightning strike to the ground. The electric field wave is propagating with the speed of light while the pressure wave produces by the thunder storm is propagating with the average speed of around 350 m/s. The delay in time for the microphone to sense the pressure wave compare with the wire antenna to sense electric field wave can be used to calculate the distance of lightning strike by the following formula by assuming the speed of electrostatic wave is very fast compare with the speed of thunder storm:

$$d = V_T * T_D \qquad (1)$$

Where *d* is the distance strike, V_T is the average speed of thunderstorm which is 350 m/s and T_D is time delay between wire antenna and microphone in second.

B. Application

In the experiment, a single-station parallel plate antenna has been used to detect the electric field, while a microphone has been used to detect the acoustic signal. The antenna and microphone was put outside of IVAT's laboratory for data measurement. Both signals were captured by oscilloscopes and the data were save using LabVIEW 8.5. The captured data were analyzed to find the time delay between electric field and the acoustic signal. Then, using the time-to-thunder method distance estimation can be calculated.

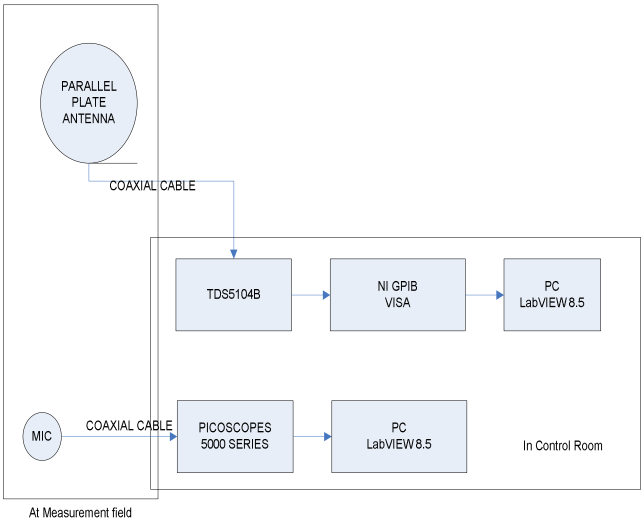

Figure 1. Equipment was used in the experiment to determine the lightning distance

III. Measurement And Experiments Setup

A. Hardware Development

In the hardware development, both of these sensors were combined to form a single-station lightning observation system (Fig 2). A coaxial cable, (Mitti, 3C-2V, 75Ω) was used to connect both sensors. The length of the cable is same (22 meter). In the software development, graphical user interface (GUI) program was developed using LabVIEW 8.5 software (Fig 3). The program was used as a data logger to save both signals. Both developed hardware and software need to be integrated by using a NI-GPIB Visa and a Picospoce 5000 Series (Fig 4).

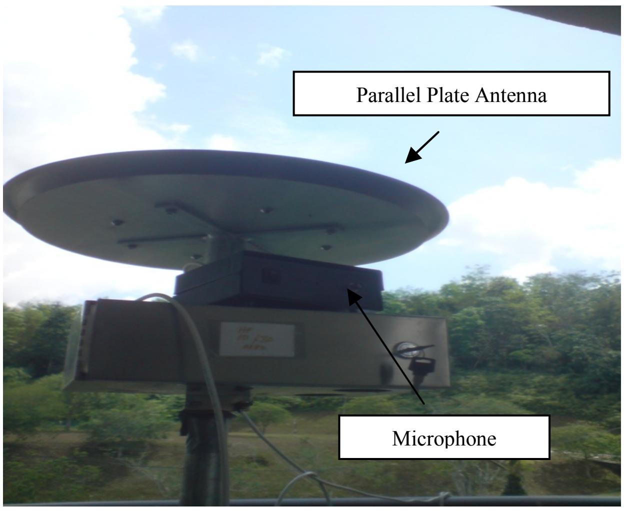

Figure 2. Parallel plate antenna with microphone

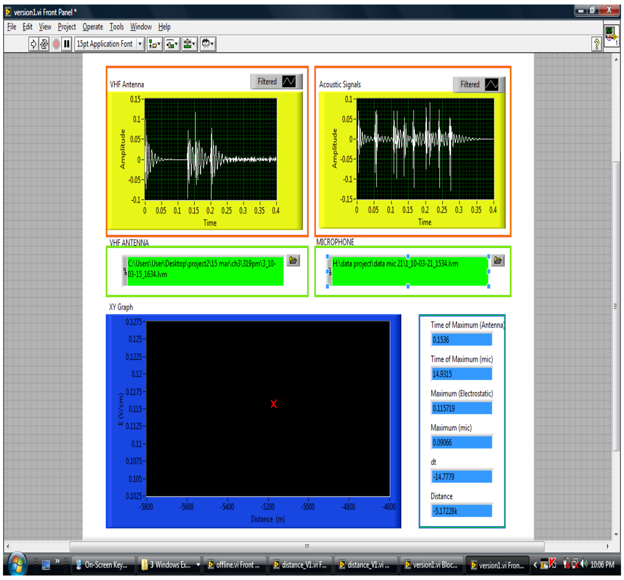

Figure 3. Graphical user interface (GUI) for lightning distance determination

The lightning electric field signal was captured by channel 1 of the TDS5104B oscilloscope (with a setting of 500 samples and 40 ms time scale, 100 mV trigger level). A high trigger level prevented the program from capturing undesirable signals such as noises, unwanted reflections and refractions.

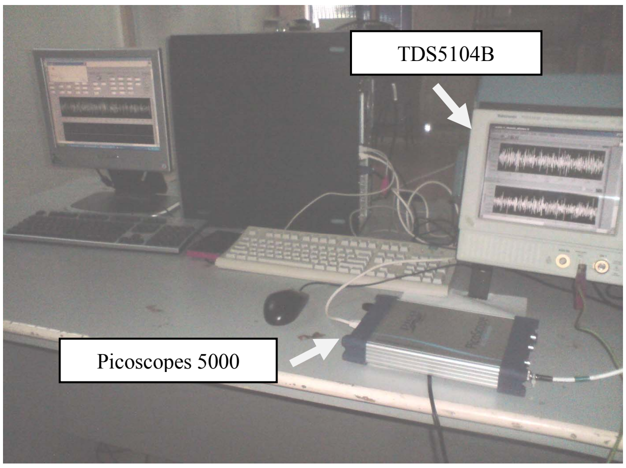

Figure 4. Interfacing equipment in lab

To avoid saving unnecessary data due to the long delay time between different signal sources triggering, the acoustic signal from the microphone was captured by using another independent measuring instrument, namely the PicoScope 5000 series. On the graphical user interface (GUI) front panel, the buffer size was set to 500, and the sample rate was set to 100 ksamples/s. The typical time range on the screen was therefore about 400 ms.

As for the TDS5104B oscilloscope, a USB type NI-GPIB VISA was used as an interface between the oscillocope and the LabView enabled PC. All the measuring equipment was placed in the control room and was put on stand-by.

B. *Software Development*

In the software development, graphical user interface (GUI) program was developed using the LabVIEW 8.5 software. The program was only to capture and to save the data in the data logger. Fig.5 shown the programming structure using LabVIEW.

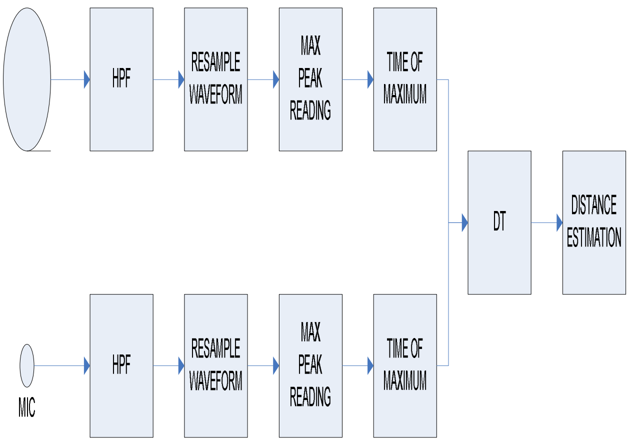

Figure 5. Programming flow structure

A high pass filter (HPF) facility in the LabView was used to eliminate noise in the signals captured. The cut off frequency was set to 2 MHz [8] for the VHF antenna. After filtering, the signal was then resampled again (Fig. 6).

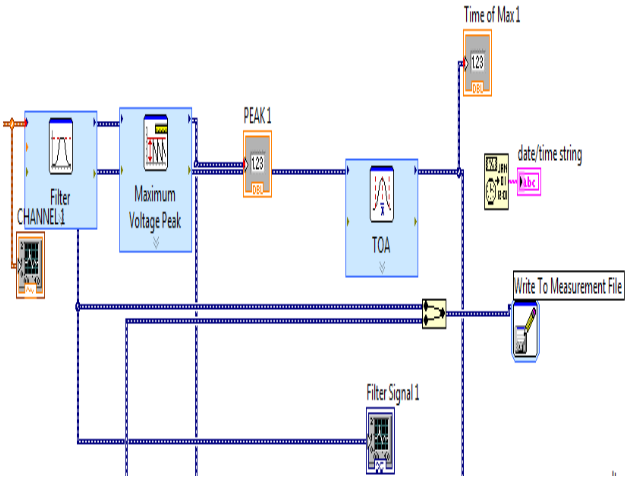

Figure 6. High Pass Filter on LabVIEW block diagram

The maximum peak reading for each signal was shown at the front panel of the GUI. By using the statistic function, the time of maximum for each signal was determined. The program determined the time of maximum for the signals from the VHF antenna and as well as from the microphone. The time delay can then be calculated by calculating the arrival time difference between the two signals (Fig.7).This was done automatically for each lightning strike.

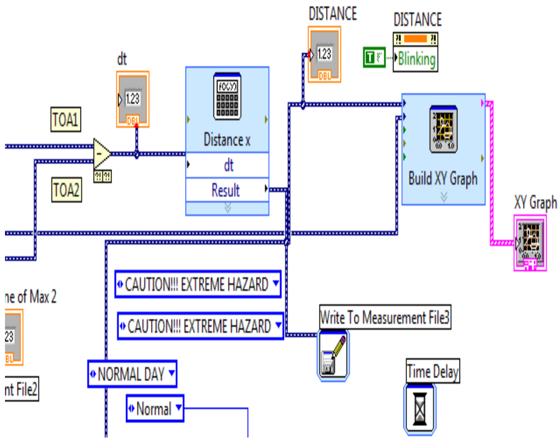

Figure 7. Time delay between two signals (TOA1 & TOA2).

The programming structure (Fig.5) was applied in LabVIEW programming. The block diagram (Fig.8) showed the combination of electric field signal and acoustic signal in order to determine the lightning distance. The front panels of LabVIEW programming was showed in Figure 3.

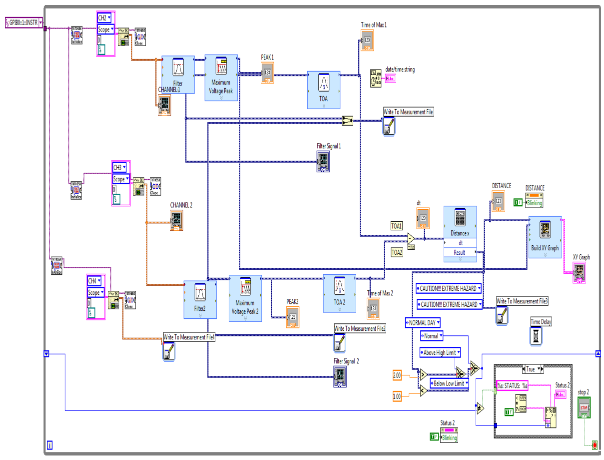

Figure 8. LabVIEW block diagram shown combination of two sensor programming (Acoustic and microphone)

C. *Detection Concept*

On the lightning day, the intensity or rate of electric field was increased in atmosphere. The parallel plate antenna is a very high frequency antenna and it was capable to detect the electric field the lightning distance in short range radius. In the experiment, it was proved to determine the lightning strike in range of 10km (in radius).

Lightning produces an EMF by stripping electron from atom in the air. The process starts with transient collision of ice crystal with riming graupel pellet. Thus transferring charges within the maturing cloud as the heavier (-ve) particles fall, resulting in vertical electric field (–ve) charge from the atmospheres is transfer to earth (cloud to ground).When the stepped leader hit ground , the return stroke is triggered. The radiated field of the lightning stroke will induce current in the cross loop portion of antenna (H-field) and the sense antenna will recognize the generated vertical field (E- field) .The spectrum of lightning strike consist of broad range of frequency with very fast rise time.

The electric field charge during the thunderstorm day will induce the voltage on the antenna plate. So the derivation of the charge Q induces of it is equal to;

$$\int_s D.ds = \int_v pdv \qquad (2)$$

$$D = E\varepsilon_o \varepsilon_r \qquad (3)$$

Therefore equation (2) becomes,

Electric Flux Density X Area of plate= Charge on plate

And it is mathematically expressed as,

$$D.S = Q$$

From equation (3), the normal electric field becomes

$$E_n = \frac{Q}{\varepsilon_o \varepsilon_r S} \qquad (4)$$

Then the voltage between the flat –metallic plate and ground is;

$$V_g = -\int_0^d E_n dx = -\frac{Q}{\varepsilon_o.\varepsilon_r.S}\int_0^d (-1)dx = \frac{Q.d}{\varepsilon_o.\varepsilon_r.S} \qquad (5)$$

If substitute equation (4) into (5), therefore;

$$V_g = E_n.d \qquad (6)$$

Equation (6) indicates that the voltage between the metallic plate and ground is directly proportional to the electric field normal to the plate and it height respect to the ground.

IV. RESULT

The lightning data was captured during January 2010 to March 2010. The shape of the lightning strike signals and acoustic signals was showed in Fig.9 until Fig.12.

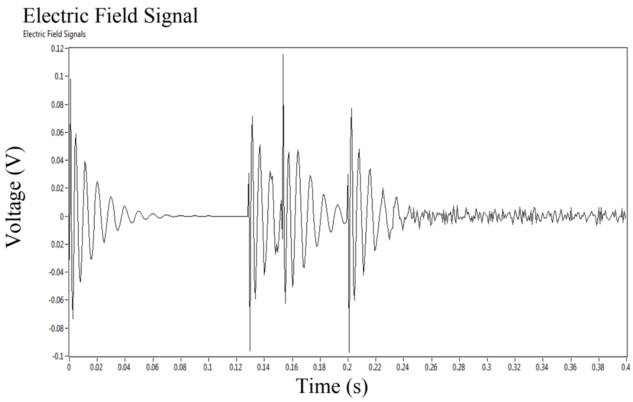

Figure 9. Electric Field Transducer Voltage Signal (15 March 2010, 15:19)

Obviously, the magnitude of the signal is dependent on the lightning strike intensity, and the lightning strike distance from the measuring antenna. On average, most of the captured electric field signals had a peak magnitude of 0.14V or greater.

Most of the lightning signals are quite similar. Single-stroke and multi strokes lightning are common shapes that can be determined from the captured signals. Fig.9. until Fig.12 showed various type of lightning stroke that consist of multiple stroke and single stroke.

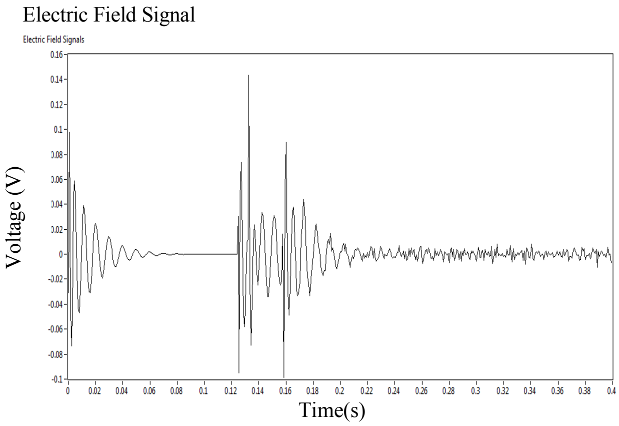

Figure 10. Electric Field Transducer Voltage Signal (15 March 2010, 15:21)

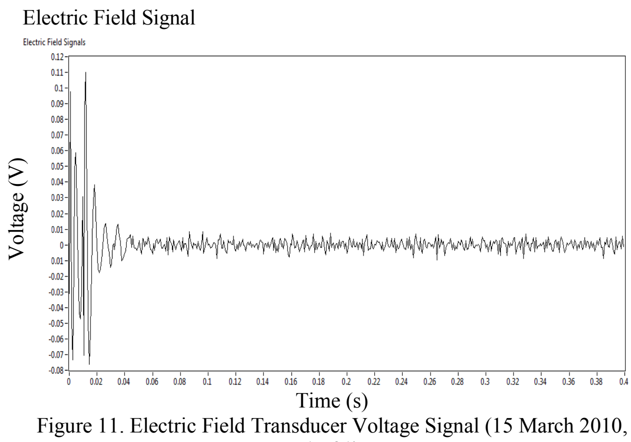

Figure 11. Electric Field Transducer Voltage Signal (15 March 2010, 15:21)

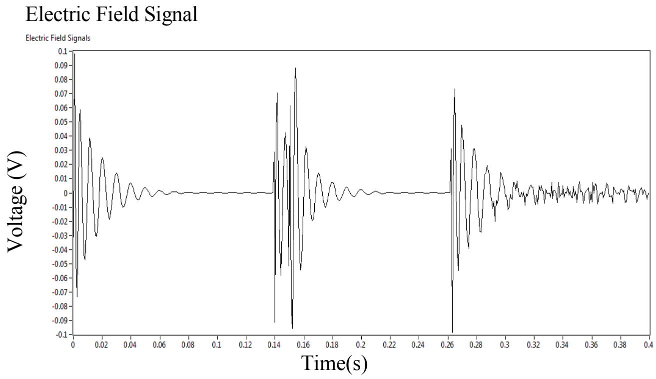

Figure 12. Electric Field Transducer Voltage Signal (21 March 2010,16:01)

From Fig. 13 which shows a typical acoustic signal captured, the peak magnitude is about 0.4 V. On average, a peak magnitude of 1 V can be expected depending on the intensity of the strike. The acoustic signal due to a lightning strike can easily be verified by looking at the shape of the signal.

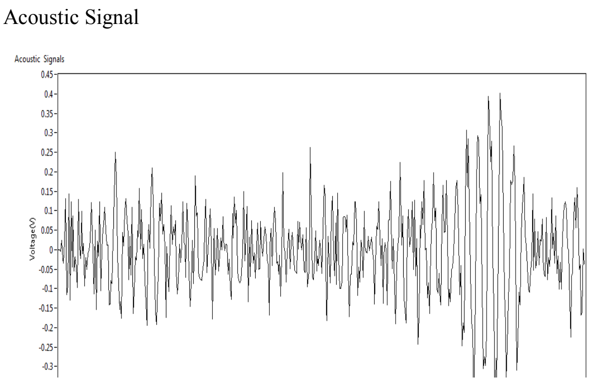

Figure 13. Acoustic signals from microphone (21 March 2010, 16:17)

The objective of the experiments is to find the time delay between both sensors. The time stamp for each sensor can be checked in the saved data file. Table 1 shows a typical captured data on 21 March 2010. Based on the time stamps (TOA-1 and TOA-2), the time delay and hence the lightning distance from the strike source can be determined, using Equation (1).

TABLE 1 DATA OF LIGHTNING DISTANCE ON 21 MARCH 2010

Vant (V)	Vmic (V)	TOA-1 (Antenna)	TOA-2 (microphone)	dt (s)	Distance (km)
0.08	0.27	16:01:22.37	16:01:49.87	27.5	9.6
0.09	0.36	16:02:25.86	16:02:48.55	22.7	7.9
0.09	0.35	16:03:30.25	16:03:49.58	19.3	6.8
0.09	0.35	16:04:58.81	16:05:13.87	15.1	5.3
0.07	0.36	16:08:09.98	16:08:33.23	23.3	8.2
0.1	0.23	16:11:18.55	16:11:45.92	23.4	9.6
0.075	0.3	16:16:20.17	16:16:35.47	15.3	5.4
0.85	0.28	16:39:29.81	16:39:47.76	17.9	6.3
0.08	0.3	16:44:35.59	16:44:58.63	23	8.1
0.09	0.275	16:48:37.95	16:48:57.20	19.3	6.7
0.11	0.3	16:50:44.84	16:51:59.45	14.6	5.1
0.12	0.4	16:51:00.28	16:51:13.05	12.8	4.5

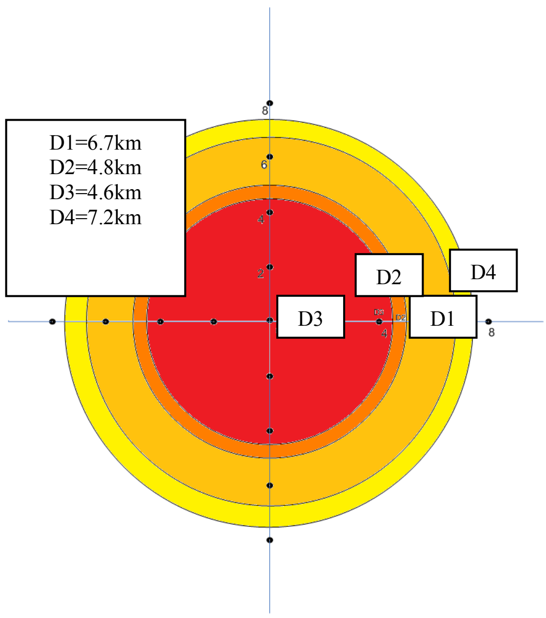

Figure 14. Lightning Distance Determinations on 15 March 2010.

Fig. 14 shows a typical lightning distance calculation done. In this figure, the (0, 0) coordinate refers to the IVAT's building where the sensors were placed. As can be seen, D1, D2 and D3 are getting smaller with time. This is because the thundercloud was then moving towards the sensors. The calculated distance D4 can be said due to a lightning discharge from another thundercloud because the distance of the stroke was suddenly increased.

The expected time of arrival (ETA) for a particular thundercloud can also be determined by calculating the average speed of the thundercloud movement. Based on the lightning data on 21 March 2010 (Fig. 10), the average speed is calculated as 0.35 km.s^{-1}.

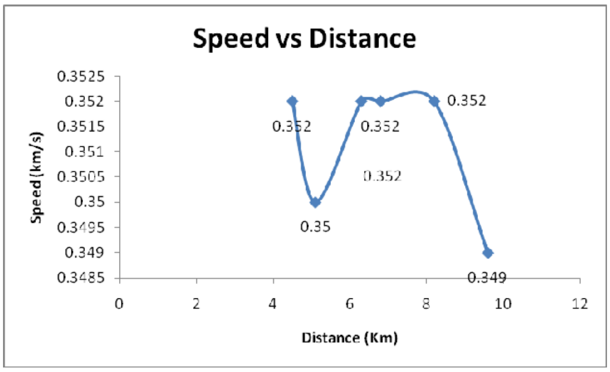

Figure 15. Speed vs distance of lightning

V. CONCLUSION

The detection range of a broadband antenna is up to 10 km (in radius) for lightning detection. From the experiment, the longest distance recorded is 9.6 km (in radius), while the shortest path is 4.22 km (in radius) measured from the sensors' location at IVAT, UTM. Based on the results, it was proven that the detection for the broadband antenna is below 10 km (in radius), and it can be successfully used for this time-to-thunder method of lightning detection.

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REFERENCES

[1] V. Ramachandran, J. N. Prakash, A. Deo, and S. Kumar, "Lightning stroke distance estimation from single station observation and validation with WWLLN data", Ann. Geophys., 25, 1509–1517, 2007.

[2] K. L. Cummins, M. J. Murphy, E. A. Bardo, W. L. Hiscox, R. B. Pyle, and A. E. Pifer, "A combined TOA/MDF technology upgrade of the U. S. national lightning detection network," J. Geophys. Res., vol. 103, no. D8, pp. 9035-9044, Apr. 1998.

[3] V. A. Rafalsky, A. P. Nickolaenko, A. V. Shvets, and M. Hayakawa, "Location of lightning discharges from a single station," J. Geophys. Res., vol. 100, no. D10, pp. 20829-20838, Oct.1995.

[4] Lothar H. Runhke, Boulder, Colo. "Determining Distance to Lightning Strokes from a Single Station. United Stated Patents 3715660, Feb.6, 1963

[5] Hepburn, F., Analysis of smooth type atmospheric waveforms, J. Atmos. Terr. Phys., 19, 37–53, 1960.

[6] M.A Karol` And A.P Nikolaenko, Measurement of distances to nearby Thunderstorm Discharges , Radiophysics and Quantum Electronics, Vol.36, Nov.3-4, 1993

[7] Sao, K., and H. Jindoh, Real time location of atmospherics by single station techniques and preliminary results, J. Atmos. Terr. Phys., 36, 261-266, 1974