Computer based Lightning Detection and Photonic Location

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Abstract - In order to base the protective measures against lightning overvoltages on a regional data collection and to improve the operating performances of power utilities we intend to develop a modern lightning detecting and locating system aimed to detect the cloud and ground flashes and to measure their main characteristics. The lightning location is based on the concept of photonic direction finding. In this paper the operating principles of the lightning detection and location, and some experimental results of lightning activity in Thailand are discussed.

Keywords: lightning counter, return stroke, photodiode, lightning electromagnetic pulse.

1. INTRODUCTION

The transmission and distribution systems are subjected to numerous lightning strikes during each rainy season; therefore it has to be protected in the best possible way not only against direct strikes, but also against lightning generated overvoltages penetrating into the substations. In order to clarify the characteristics of lightning on the regional level, it is necessary to collect not only the data of striking events but also to study lightning physics in the thunderclouds. It is expected that the characteristics of lightning will be clarified in the detail by the simultaneous measurement of electromagnetic irradiation by several kinds of antennas.

Lightning represents a version of the gas discharge at very large length. General length of the lightning channel reaches several kilometers, and the significant part of this channel is situated inside a gas cloud. As a cloud is formed of a little bit isolated from each other charged regions (as usual in the cloud bottom part mainly negative charges are accumulated), lightning is usually repeated, i.e. consists of the several individual strokes, developing on the same way, and each stroke begins by leader. Channel of the leader is finished by the return stroke, as well as any streamer channel, and it is filled by plasma, hence has certain conductivity and radiates in a wide range of a spectrum, including visible light and infrared radiation [1-3].

Considering that the main parameters of a lightning discharge are depending more or less on the geo-climatic conditions prevailing in the region and that without a clear statistical knowledge of expected lightning discharge characteristics, it is difficult to find the optimal solution for protection against lightning overvoltages, a number of lightning counters were developed. Well known modern lightning counter systems process lightning information according to following principles. They receive lightning data from electromagnetic timing and direction finding sensors (antennas) covering the country area, through the processor. All sensors units are connected to the central server via modem and telephone line, in this manner that each time the report about lightning activity may be done. In spite of its powerful information capability such system has a disadvantage because of multisensor direction finding concept (truthful information about real lightning strike position can be found using two or more sensors only). Clearly that autonomous (single sensor based) lightning detecting and locating station, capable in addition to stored and analyze not only electromagnetic field but optical emission from the lightning strike channel becomes more attractive in most applications.

The purpose of this paper is to describe the operating principle of an original lightning detecting and locating system and to discuss some results of lightning activity in Thailand during rainy seasons of 1997-1999.

2. LIGHTNING DETECTING AND LOCATING HARDWARE AND SOFTWARE

The main requirements for such kind of system is well known [4] and could be presented as follow:
1) Collection and analysis of reliable data on lightning strike regional incidence.
2) Detection and warn of their occurrence, location the strike points, and measurement some of their parameters. Modern computer based technology is able to satisfy these requirements.

2.1. Basic operating principles

Original lightning detecting and locating system can be divided by several separate base blocks such as: lightning electromagnetic pulse (LEMP) detection, return stroke waveform storage and analysis, photonic multichannel lightning location, optical signal storage and analysis, calculation of lightning position and peak current. The result of these different operations will be a computer made table containing all kind of possible lightning parameters providing for successful statistical treatment.

2.1.1. LEMP detection and analysis

The plate electromagnetic antenna was used as a sensor for LEMP detection. It was connected to the computer DAQ card by coaxial cable. We used NI DAQ AT-MIO-16E1 card and standard Pentium PC. The output signal of this setup is proportional to the first derivation of the electric field strength *dE/dt* and carried the information about different lightning parameters. Lightning data was storied in the computer memory and analyzed with help of LabView software [5]. The program designed for this purpose contains following base blocks (see Fig.1). Signal waveform capturing and acquisition unit (1) is represented virtual digital storage oscilloscope. Photonic locator (2) compares the amplitudes from different optical channels and gives the azimuth to the flash. Electromagnetic signal virtual harmonic analyzer (3) is necessary for separation of ground flash from cloud one. Its operation is based on the fact that the ground lightning stroke frequency is much less than cloud one. Electromagnetic pulse waveform analyzer (4) returns main lightning pulse parameters (amplitude, rise time and so on). Stroke number counter (5) is represented virtual peak detector with peak counting ability. Lightning peak current and distance calculator (6) analyzes the data delivered by both electromagnetic and photonic antennas and calculates the distance to the lightning and its peak current. Real time clock (7) shows the date and time (second including) of each lightning event. All parameters found during data acquisition are stored into memory with help of the lightning data writer (8). Fig.2 shows the typical waveform of negative ground return stroke detected at the distance about 10 *km*. It is in strong accordance with the data mentioned in [2-3]. Because of sufficiently high sampling rate of AD conversion (0.6 *MS/s*) the detection of multistroke lightning flashes is available so that each separate stroke (positive or negative) can be analyzed independently.

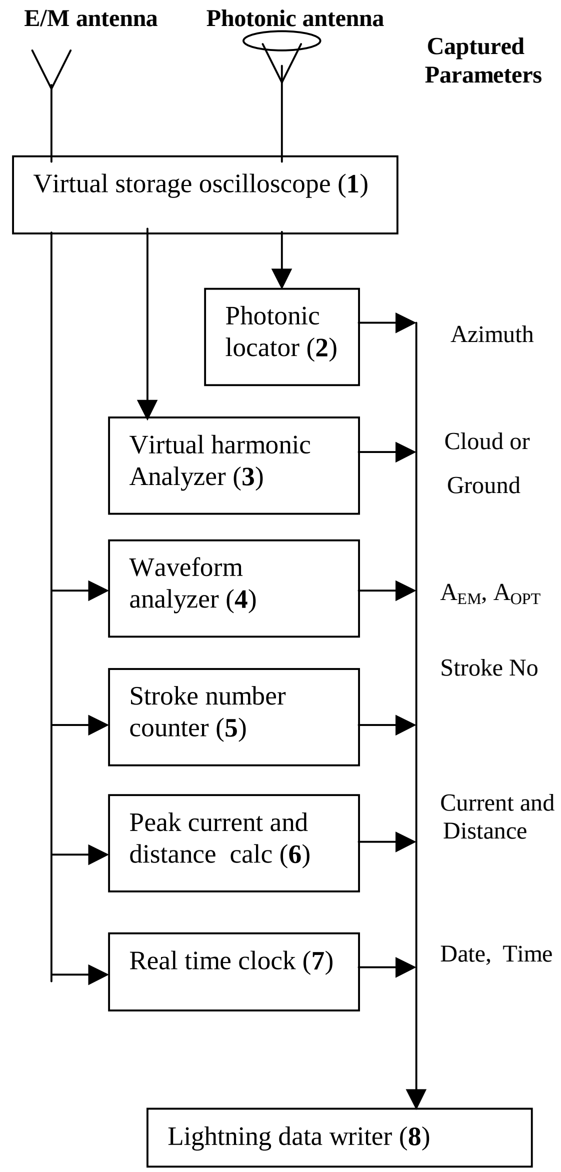


Fig.1.Lightning data acquisition block diagram.

2.1.2.Photonic lightning location

Lightning channel represents a plasma substance with characteristic peak temperature about 20,000 *K*. Under this condition practically all atoms of air become ions, which emit the light of different wavelength (from infrared to ultraviolet). One of the most intensive irradiation is produced by neutral and singly ionized nitrogen atoms (λ = 520-670 *nm*) that corresponds to visible portion of spectrum. This effect can be used for lightning direction finding because of high sensitivity and short response time ($\tau \approx 1$ *ns*) of modern silicon photodiodes. The numerous photodiodes with appropriate azimuth distribution around the ring and limited input aperture are presented so called photonic lightning antenna with direction-finding capabilitie. Another approach to photonic location is optical fiber cable based system. Multicore optical fiber cable coupled to number of optical connectors distributed around the ring (about 50 *cm* diameter) represents

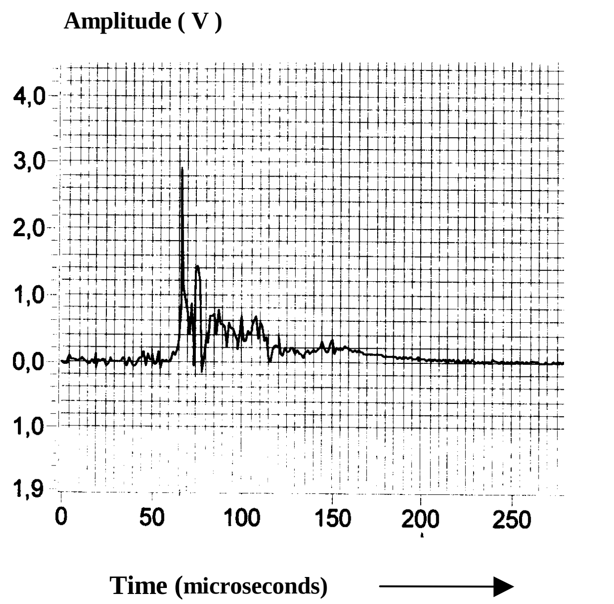


Fig.2. Typical "negative" ground return stroke waveform.

phothonic antenna with connector end as a sensor. The unique requirement for this antenna position is the open place (field, roof of a building) allowed the detection of all possible lightning flashes.

In our experiments we used combined electromagnetic plate antenna and 12-channels photonic antenna containing 12-core outdoor optical fiber cable (40 *m* length). Antenna was coupled to indoor receiver unit containing 12 photodiode preamplifiers on the base of operational amplifier. The output of each preamplifier was connected to the multichannel DAQ computer card mentioned above. Each optical channel and therefore each azimuth have its own number and can be acquire separately. Optical signal is triggered by LEMP, detected by electromagnetic antenna, so that the synchronization between two different signals is available. Waveforms of optical signal corresponded to different channels may be memorized for the successful computer analysis and lightning location with help of special computer program. Another way is to compare and analyze all optical signals for the purpose of lightning location in the same program cycle. As a result - the real azimuth to the lightning flash may be found. This equipment allows the lightning detection and direction finding in the range about 15 *km* around the station. Photonic lightning direction finding is allowed during both night and day time because of low level of solar irradiation in the thunderstorm cloudy conditions.

In Fig.3 the optical signal waveform of the same first stroke detected by electromagnetic antenna (see Fig.2) is presented. It may be observed from Fig.2 and 3, that significant difference between two waveforms is available. Really, the lightning photoresponse has Gaussian form and its peak amplitude is delayed from LEMP maximum about

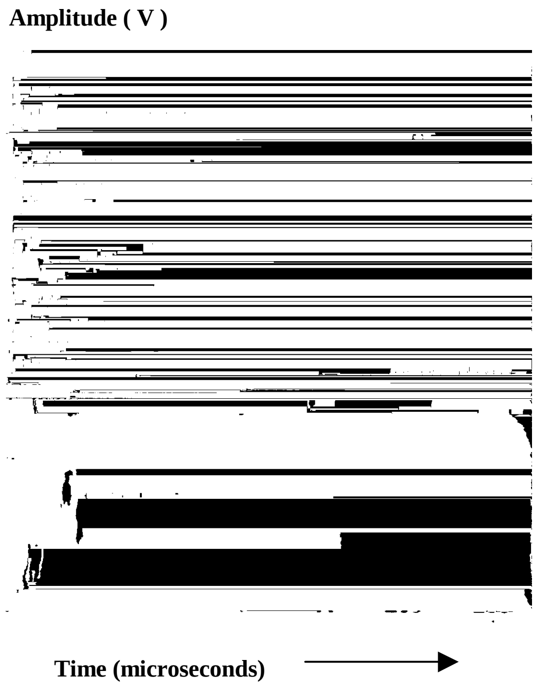


Fig.3. Typical fist stroke optical signal waveform.

on 100 microseconds. This time interval is necessary for complete ionization of the lightning channel and subsequent radiative recombination of exited atoms and ions[3]. Usually the optical pulse duration is much higher than the LEMP one (see Fig.7), that also can be explained by characteristic time of radiative recombination processes into lightning's plasma channel. Amplitude of the photoresponse is dependent as on sensitivity of receiver components, and on specific lightning parameters. In the majority of cases it is impossible to find strong correlation between peak lightning current and distance on the one hand, and amplitudes of two types of signals on the other hand. Often the weak electrical discharge corresponds to powerful optical peak (see for example Fig.8). It is obvious, that different dependence of electromagnetic pulse amplitudes and amplitude of lightning photoresponse on lightning peak current and on its distance is available. The latter enables to estimate both of these important lightning parameters with help of the mathematical analysis of empirical formulas, relating a peak current and distance with amplitudes of two types of signals taking into account the calibration of the receiving equipment. Really, LEMP amplitude as a function of lightning current and distance could be approximate as follow

$$A_{EM} \approx \frac{c \times I}{d}$$

where I is the peak lightning current in *kA*,
d – distance to lightning in *km*, and
c is the calibration parameter.

The most suitable approximation for optical amplitude is following

$$A_{opt} \approx b \times I^2 \times 10^{-ad/10}$$

where b is dimensionless calibration parameter, and
a - light loss in atmosphere in *dB/km*.

Note that both LEMP and optical signal amplitude are functions of peak lightning current and distance to lightning flash. The simultaneous solution of these equations with respect to I and d inside the same computer cycle gives the possibility to find a peak lightning current and distance values for incoming input signal amplitudes (unit **6** in Fig.1). Calibration parameters c and b are defined with help of comparative analysis of the same lightning discharges registered by various counters and they are used for hardware calibration. Parameter a is well known and its value can be fixed as 20 *dB/km* for usual atmospheric conditions. The output information is submitted as a computer report, containing all kind of measured lightning parameters.

3. SOME RESULTS OF LIGHTNING ACTIVITY IN THAILAND

The hardware and software shortly described above made possible the statistical analysis of the thunderstorm activity in Bangkok at the rainy seasons of 1997-1999.

3.1.Ground to cloud and polarity ratio

Despite a ground lightning is the most interesting phenomena for the electrical power utilities, we had try to analyze ground-to-cloud lightning ratio. Ground and cloud discharges were separated thanks to incorporated virtual spectrum analyzer. Really, the central frequency of the ground lightning is vastly less that the cloud one and it is limited by frequency band of 2-50 *kHz*. In Fig.4 the statistics of a ground lightning return stroke frequency is presented.

As we can see the most of ground lightning discharge has the frequencies about 4-5 *kHz* that is in good accordance with [2]. For comparison the central frequency of cloud discharge is much greater (f > 100 *kHz)* and it can be easy separate from ground one (unit **3** in Fig.1). The statistic of ground-to-cloud ratio found using this method shows that only about 14% of total discharges could be named "ground" lightning. However this statistic is changed in the case when we consider not the total lightning number per long period, but lightning activity in the real thunderstorm time. In Fig.5 the dynamics of ground-to-cloud discharges ratio versus 10 minutes time intervals for typical thunderstorm is presented. It may be observed from Fig.5 that in the period of thunderstorm highest activity ground-to-cloud discharges ratio could go up to 57%. This the most dangerous thunderstorm period may have the duration about 50 minutes or more.

Important information about polarity of ground flashes was found after return stroke waveform analysis. There are three types of lightning discharges so called: "negative", "positive" and "bipolar". This definition is made according polarity of cloud charge, which initialize the lightning. Analysis of registered LEMP waveforms gives the possibility to separate different types of lightning strokes. The criterion of this separation is very simple - highest signal amplitude of given polarity. In the case when positive amplitude is comparable to negative one, we talk about bipolar lightning. Fig.6 shows the statistic of polarity ratio for the rainy season of 1997 in Thailand. As we can see the number of positive and bipolar discharges is too small in comparison with negative lightning that is corresponding to the data presented in [2-3]. However inside the separate multistroke lightning all possible stroke polarity are to meet (see Fig.8a) and often weak positive or bipolar second or third return stroke follows high amplitude negative first return stroke.

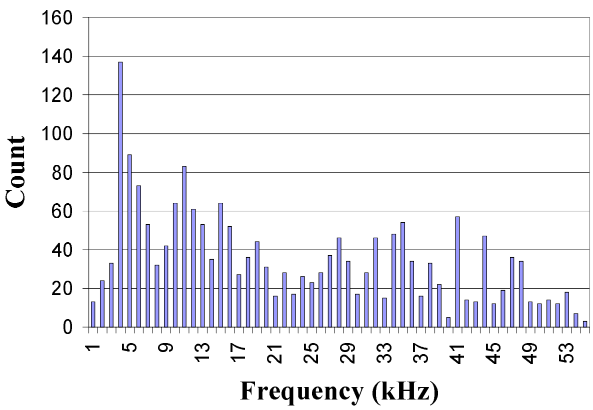


Fig.4. Ground lightning return stroke peak frequency distribution.

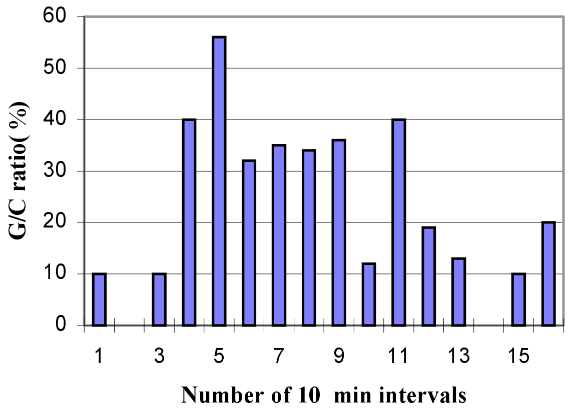


Fig.5. Dynamics of ground-to-cloud ratio for typical thunderstorm.

3.2. LEMP and optical signal waveform timing analysis

As it was shown above there are significant distinctions between LEMP and optical signal waveforms. The statistics demonstrates that LEMP zero crossing time seldom exceeds 50 μs, while half-width of registered optical signals makes as a rule 100-200 μs (see Fig.7). This result is corresponded to time-resolved slitless spectrum of return stroke presented in [3]. Accordingly LEMP rise time can make 5 to 15 μs as

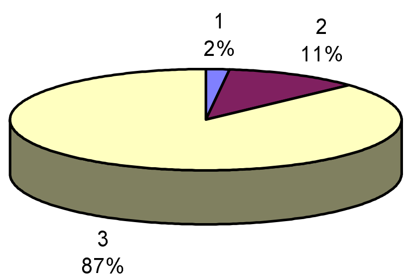


Fig. 6. Ground lightning polarity ratio. (**1**-"positive"; **2**-"bipolar"; **3**-"negative" strokes).

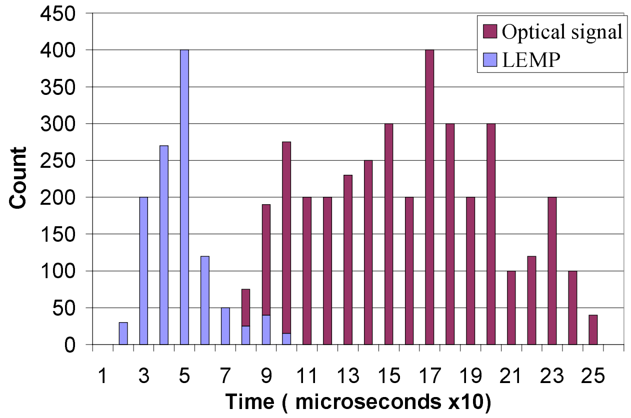
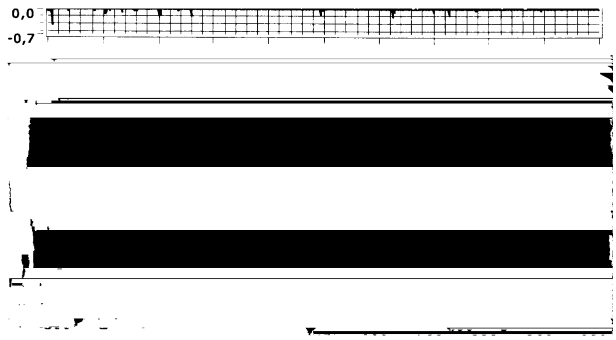


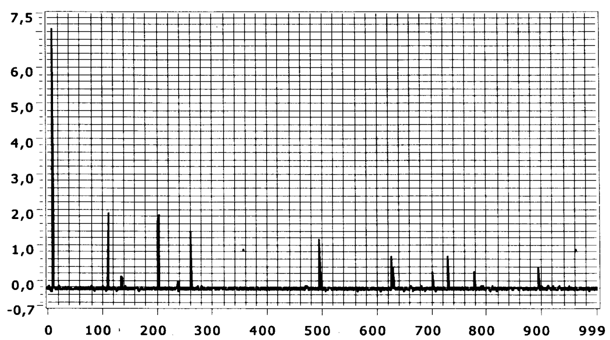
Fig.7. Optical signal half-width in comparison with LEMP zero-crossing time.

opposed to 25-50 μs for an optical pulse. These distinctions are explained by a different nature of these two signals. Clearly that the information about electromagnetic pulse and optical signal amplitude values, as well as their waveform parameters present some "passport" of given lightning, which will allow to distinguish it from any other atmospheric discharge.

Amplitude (V) **(a)**



Time (milliseconds) →



Amplitude (V) **(b)**

Time (milliseconds) →

Fig.8. Multistroke LEMP waveform (**a**) in comparison with photonic lightning detection (**b**).

3.3.Multistroke lightning detection

The data collected in rainy seasons of 1997-1999 during the peak thunderstorm activity in Thailand allows to analyze a multistroke lightning statistics.It was possible because of virtual stroke number counter (unit **5** in Fig.1). Fig.8 is an example of 12-stroke lightning registered with help of both electromagnetic (Fig.8a) and photonic (Fig.8b) antennas. The comparison of two diagrams gives the possibility to find the following specific multistroke lightning particularities:

1) the strong correlation between stroke electromagnetic amplitude and optical signal value dose not exist;

2) the stroke number calculation is more convenient with help of optical registration because of its single polarity;

3) the separate stroke inside multistroke lightning flash can present any polarity (Fig.8a);

4) as usual the separate stroke optical brightness is decreased with increasing of stroke number (Fig.8b);

5) the time interval between stroke can form as several groups of ten milliseconds so and few hundreds milliseconds;

6) the total duration of multistroke lightning can reach one second or more.

Fig.9 shows the multistroke lightning statistics. It can be seen that the most of cloud and ground flashes is single-stroke and the stroke number is decreased exponentially for both cloud and ground lightning. However we had detected few 12-stroke lightnings. Twin-stroke lightning is met very often and the average stroke number could be determined as 2-3. In Fig.10 multistroke lightning dynamics during typical thunderstorm is presented. The thunderstorm is starting by single or low order stroke lightning and in its peak point about half registration is multistroke lightning.

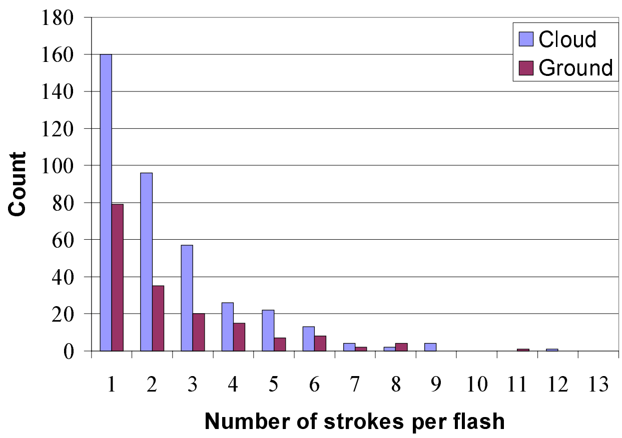


Fig.9. Distribution of flashes by stroke number.

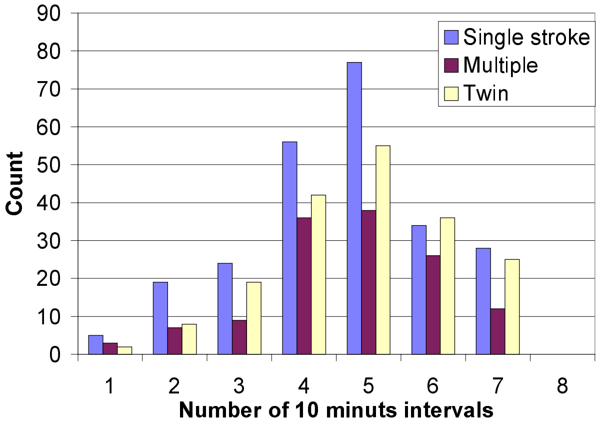


Fig.10. Typical multistroke lightning dynamics.

4. CONCLUSION

There is no doubt that the collection and processing of local and regional lightning data in order to create a real, well-founded base for overvoltage protection is very important. So there is a strong necessity of the creation a new computer based lightning counter system capable not only for lightning electromagnetic pulse detection but having advanced possibility for the lightning physics studying. In this paper we tried to describe the hardware and software developed for the purpose of lightning detection and location. It is consist of two kinds of antenna, conditioning equipment and computer with DAQ card. LabView based computer program was used for lightning data acquisition, storage, and analysis. In addition we discussed the lightning data collected during a few rainy seasons in Thailand. The analysis of lightning data is showing that the implementation of a new lightning locating methods such as photonic direction finding make possible the creation of a complete picture of regional thunderstorm activity, which may present important advantage for electrical power utilities.

5. REFERANCES

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