Grzegorz KARNAS

Rzeszow University of Technology

doi:10.15199/48.2015.11.55

Time synchronization of electric field measurement and high-speed video registration at the lightning observation station in Rzeszow, Poland

Abstract. *Time synchronization is one of the most difficult tasks during the registration of lightning phenomena. Precise synchronization helps to identify particular strokes with data from commercial lightning location systems. This paper is aimed to present and analyze GPS synchronized recordings of the lightning electric field from the lightning observation station installed at the Rzeszow University of Technology, Poland. Synchronization with UTC was achieved by the simultaneous analysis of the electric field waveforms and the signal from the GPS receiver. Several improvements were made regarding synchronization and triggering of the system. For this purpose a set of functions in Matlab has been prepared. In order to explain used algorithms, lightning electric field waveforms and the GPS signal were analyzed simultaneously. Performance of the optical trigger was verified in high voltage laboratory. Results showed a good performance of this technique and suggested to use it during the high-speed camera and DSLR registration.*

Streszczenie*. Synchronizacja czasowa jest jednym z najtrudniejszych zadań podczas rejestracji zjawisk piorunowych. Precyzyjna synchronizacja zapewnia możliwość precyzyjnej identyfikacji poszczególnych wyładowań z danymi komercyjnych systemów lokalizacji wyładowań atmosferycznych. Celem artykułu jest przedstawienie i analiza przebiegów piorunowego pola elektrycznego zarejestrowanych na stacji obserwacji wyładowań atmosferycznych Politechniki Rzeszowskiej. W pracy opisano najnowsze modyfikacje systemu w kontekście synchronizacji czasowej oraz wyzwalania procesu rejestracji. W tym celu przygotowano zestaw funkcji w programie Matlab. Synchronizację z UTC wyjaśniono poprzez jednoczesną analizę przebiegów pola elektrycznego oraz sygnału z odbiornika GPS. Dokonano weryfikacji pracy optycznego wyzwalacza rejestracji. Testy przeprowadzono w laboratorium wysokich napięć. Rezultaty badań uwidoczniły dobre parametry wyzwalacza optycznego i wskazały na możliwość zastosowania tej techniki podczas rejestracji szybką kamerą oraz aparatem fotograficznym.* ***(Synchronizacja czasowa pomiaru pola elektrycznego oraz wideo-rejestracji na stacji obserwacji wyładowań atmosferycznych w Rzeszowie, Polska).***

Keywords: lightning electric field, fast video recording, GPS synchronization, lightning protection
Słowa kluczowe: piorunowe pole elektryczne, szybka rejestracja wideo, synchronizacja GPS, ochrona odgromowa

Introduction

Simultaneous recording of video and electromagnetic field (EMF) from lightning is an important source of data about parameters of this phenomenon [1]. It helps to understand the nature of very complicated processes occurring during developing of the lightning channel and when the return stroke (RS), the most dangerous part of cloud-to-ground (CG) discharge, is propagating through the channel. Many other signatures of lightning, such as continuing current (CC) or M-component, might be identified by direct comparison of the channel luminosity and the corresponding electric field recordings [2]. Unfortunately, in practice there is hard to directly compare video, electromagnetic field or lightning current data because of microsecond scale of these phenomena and time shifts during acquisition process [1]. It is important to synchronize acquiring circuits with a stable reference signal. The best resolution is absolute UTC time from GPS receiver. It enables user to identify its own registrations in databases obtained from commercial or local lightning location systems [3,4,5]. GPS synchronized recordings of video and electric field give important data for verification of lightning location systems performance [6]. When geographic coordinates and altitude of a particular stroke are recognized then the current waveform might be estimated from electric field assuming one of the models of the lightning current propagation [7,8,9].

Similar studies of synchronized recording of lightning were taken by different groups of researchers [10,11,12]. Most of those papers are based on triggered lightning and natural positive cloud-to-ground discharges from tall objects [1]. The reason of this is much easier prediction of strike point in this case. Data based on triggered or tall object events do not give completed information about statistics of both, positive as well as negative lightning. Approximately 90 percent of CG lightning is negative [1]. Increased number of positive CG registrations might disrupt characteristics determined for natural lightning. Observation station in Rzeszow was configured to overcome this problem.

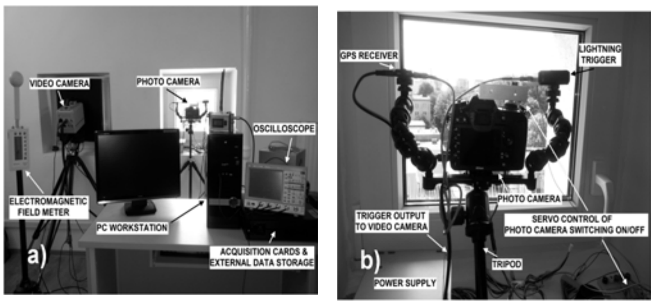

Fig.1. Lightning observation station in Rzeszow. a) Equipment installed under the roof of the Electrical Department of the Rzeszow University of Technology building. b) DSLR with dedicated GPS receiver and lightning trigger

The station was equipped with a set of electric and magnetic field sensors. Currently, there are working a fast electric field (EF) antenna with bandwidth from 0.5 Hz up to 3 MHz, and a slow electric field meter (the mill) for recording electrostatic component of lightning electric field (0 Hz - 10 Hz). Antennae are located at the roof of the Rzeszow University of Technology (RUT). Additionally, Maschek ESM-100, a commercial EMF meter, was installed to measure long term variation of electromagnetic field (5 Hz – 400 kHz) during the entire stage of thunderstorm [Fig.1]. The meter is continuously recording electric and magnetic field in three perpendicular directions.

The second branch of the system is video-imaging of lightning. A high-speed camera Photron SA5 is implemented to record at speed of 7000 fps with HD resolution. Recently, a DSLR camera Nikon D7100 has been installed to complement video-registration by photo-registration. The purpose of the DSLR is to increase a number of registered events and quality of image. Both cameras are triggered from NeroTrigger, a commercial device dedicated to triggering DSLR during thunderstorm conditions.

It is important that the system is powered only when the sufficient EF variation from lightning is detected. This allows to reduce energy consumption and save hardware resources. The switching on/off process is completely automated and enables work without user interaction, even at night. More detailed information about the Lightning Research System of RUT can be found in [13,14].

Synchronization and processing of lightning electric field

Most of commercial lightning location systems have implemented GPS receivers to synchronize recording process. Typical system uses dedicated software program which synchronizes its own PC clock with GPS data card. Time synchronization can be also achieved via the internet by NTP servers. Both methods do not allow for a very precise synchronization of the entire system. It is important when lightning data from several independent devices have to be compared each other. Incidental time delays from application execution should be reduced to minimum. One possible way is to record GPS signal simultaneously with lightning data, and synchronize during postprocessing. This method was implemented in the system working in Rzeszow.

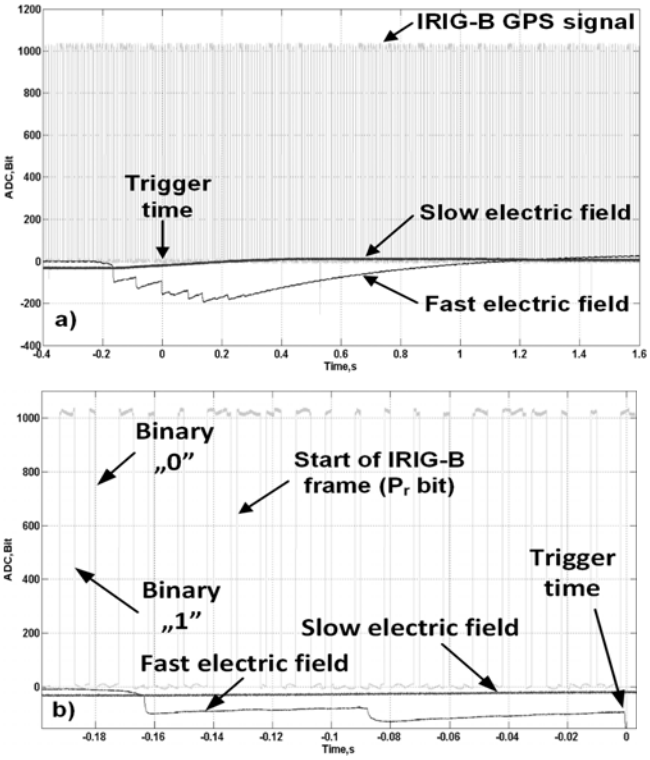

Fig.2. a) Waveforms of slow and fast lightning electric field registered at the Rzeszow University of Technology together with GPS time reference signal. b) The initial part of the IRIG-B signal used to synchronization. Notice the trigger time was indicated in a) and b)

Electric field recording was realized with application of Spectrum M2i.3131 acquisition data card. The resolution is 25 MS for each of four 12-bit channels independently. Currently three channels are used. Waveforms of slow (0 Hz – 10 Hz) and fast (0.5 Hz – 3 MHz) lightning electric field are recorded together with IRIG-B signal generated by the GPS data card. GPS receiver used in the system is Meinberg GPS 170. It gives about 200 ns time precision. A typical raw registration from ADC was showed in Fig.2. Dedicated program was prepared in Matlab to handle registration process. The program was compiled and runs during system start-up. The electric field is recorded with a precision depending only of ADC and GPS card parameters. It is extremely important during comparison with LINET data.

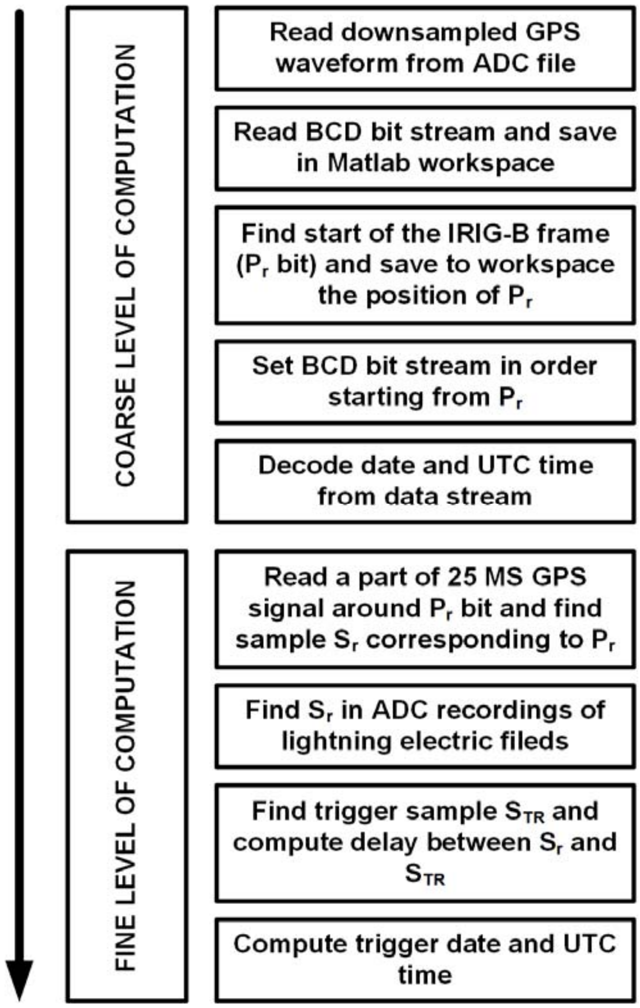

Fig.3. Algorithm of the GPS time decoding implemented to synchronization of electric field measurement at the Lightning Research Station in Rzeszow

Waveforms from Fig.2 were registered on July 12, 2014 at 13:35:58.230573 (UTC). This time is corresponding to the rising edge of the trigger signal generated by the fast electric field antenna. In order to get the UTC time information the one-second IRIG-B frame was used [15]. Each frame consists of 100 bits which differ by width. Binary "0" has 2 ms, and "1" has 5 ms pulse-width. Two subsequent pulses of 8 ms mark the beginning of frame. Decoding algorithm was implemented in Matlab. ADC recording has length of 2 s and 0.4 s pretriggering time. This is sufficient to decode at least one IRIG-B frame. The algorithm was presented in Fig.3.

It works in two main steps. The first – coarse level is aimed to decode BCD information about UTC time. The information is gathered from downsampled signal. This makes the algorithm very fast and efficient because there is no need to read full size data into RAM. Moreover, computational matrices are small. The second – fine level is much more precise. It operates on 25 MS sampled data. The computational matrices are still relatively small because only selected parts of the recorded file need to be read into memory. The fragments are chosen based on markers founded during coarse level of computation. Implementation of this resolution increased speed of the algorithm from several seconds to less than 0.1 s. It reduced the time of postprocessing analysis.

Video-synchronization and camera triggering tests in high voltage laboratory

Comparison of data from acquisition devices which are synchronized in different ways is a difficult task. This becomes important when a fast phenomenon such as lightning should be analyzed. The high-speed camera Photron SA5 working in Rzeszow is one of such devices. It allows for video-recording with speed up to 1 milion frames per second (fps), and up to 7000 fps in HD resolution. Current configuration is 7000 fps with 0.1 s pretriggering time and 0.5 s record length. Absolute time synchronization was implemented by manufacturer of this device. Each raw video-file has an information about UTC time. The entire video-registration process was automated. SDK libraries delivered by Photron were implemented under Matlab and compiled in the same way as for Meinberg ADC card. The software application allows for registration at night, when the probability of thunderstorm is relatively high, and the optical conditions are better than during the day.

In case of high-speed lightning imaging there are a lot of hardware limitations. The size of data is large e.g. for present configuration of 0.5 s record length, the raw file is 5 GB which needs about 30 s to be downloaded from camera to the PC hard drive. The average time between lightning flashes is 5 s. It forces that only the most interesting video-registrations should be saved. Therefore, the algorithm which control registration has a software filter implemented. This filter detects if lightning flash was present within camera view and decides about quality of the registration. Recordings are automatically deleted if only blinks from the lightning channel were recorded. At least a part of the developing lightning channel should be in the camera view to qualify data to save. Tests of the registration filtering algorithm were performed in high voltage laboratory. The 500 kV Marx generator [16] was used during the tests [Fig.4g]. Sparks from the generator were recorded by the camera which was triggered by dedicated optical sensor manufactured by NeroTrigger. It was the new method which replaced the old technique based on triggering signal from fast EF antenna. Tests showed better performance of the optical triggering. Optical sensor was very fast. Video frames were perfectly correlated with the trigger [Fig.4]. The filtering algorithm could faster analyze video frames because there was no need to find where illuminated frames were located. As shown in Fig.4., there were only four frames needed to force trigger circuit. It gives the time delay of the sensor below 1 ms. It is sufficient for triggering by lightning because the overall duration of stepped leader is about 35 ms [1]. Currently, the camera is working at the station in Rzeszow and the only remained thing is adjust setting of optical system to lightning luminosity. It is not an obvious task because lens configuration is very dependent of recording speed and shutter. Results of the research might be implemented by other lightning research groups using Photron high-speed cameras [17,18,19].

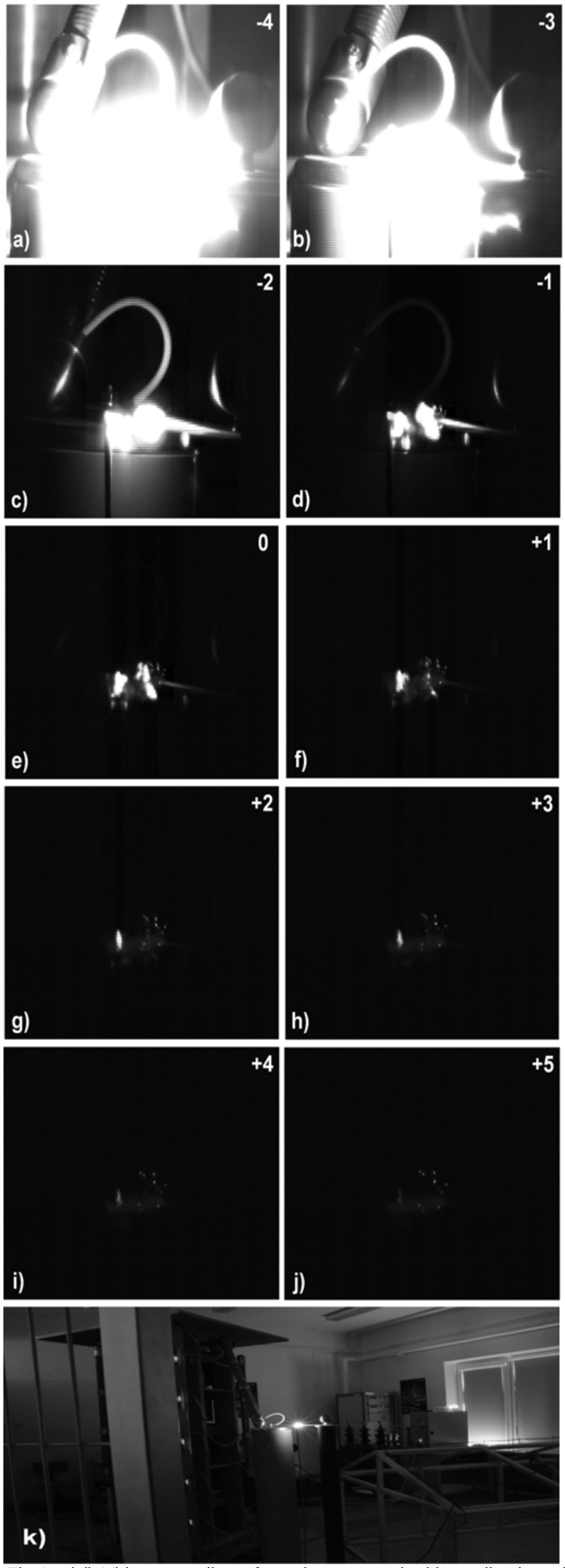

Fig.4. a)-j) Video recording of spark generated with application of high voltage generator. Notice the numbers in the upper-right edge indicate frame numbers in respect to the trigger frame. k) a photo obtained from NIKON camera corresponding to the video registration

The system is also equipped with a photo camera NIKON D7100. The camera is triggered by the same circuit as the Photron SA5. Each photo includes information about GPS coordinates and time with 1 s precision. This allows for identification of the photo registration with the corresponding video recording. The photo camera sensor resolution of 24.1 mpix. is useful for lightning channel geometry analysis. NIKON camera switching on/off process is invoked by servomechanism controlled by ATMEGA8 microprocessor. The photo camera was tested in the high voltage laboratory to work simultaneously with the video camera. The result was presented in Fig.4g. Simultaneous tests showed a good agreement of both registration techniques.

Conclusions and final remarks

Synchronization of video recording and electric fields generated by lightning was presented in this paper. Entire procedure was explained by direct comparison of field waveforms and GPS signal recorded simultaneously by the ADC. Dedicated algorithm was prepared in Matlab. Two-level structure of the algorithm made it relatively fast and accurate in computing UTC time information. Additionally, the proposed solution eliminated time delays associated with processing of operating system. Some unique resolutions including equipment setup were depicted in the text.

Tests of video- and photo registration circuits were done in high-voltage laboratory with application of the Marx generator. The aim was to check performance of a new optical trigger. A sequence of high-speed images from this experiment was included. The new system showed a great potential and better performance characteristics than the old electric field antenna-based trigger. Results of the research might help other lightning observatories to improve their own systems and setup registration parameters for similar equipment. In the future there is a plan to introduce given resolutions into mobile version of the lightning research station in Rzeszow.

REFERENCES

[1] Rakov V.A., Uman M.A., Lightning: Physics and Effects, Cambridge Univ. Press, 2003, New York

[2] Campos L.Z.S., Saba M.M.F., Pinto Jr. O., Ballarotti M.G., Waveshapes of continuing currents and properties of M-components in natural negative cloud-to-ground lightning from high-speed video observations, Atmospheric Research 84, 4, 302-310, 2007, DOI: 10.1016/j.atmosres.2006.09.002

[3] Betz H., Schmidt K., Laroche P., Blanchet P., Oettinger W., Defer E., LINET – A New Ligthning Detection Network in Europe, 13-th International Conference on Atmospheric Electricity, 2007, Beijing, China

[4] Loboda M., Betz H.D., Baranski P., Wiszniowski J., Dziewit Z., New Lightning Detection Networks in Poland – LINET and LLDN, The Open Atmospheric Science Journal 01/2009; 3:29-38. doi:10.2174/1874282300903010029

[5] Cummins K.L., Murphy M.J., An Overview of Lightning Locating Systems: History, Techniques, and Data Uses, With an In-Depth Look at the U.S. NLDN, IEEE Transactions on Electromagnetic Compatibility, vol. 51, pp. 499-518, 2009, doi: 10.1109/TEMC.2009.2023450

[6] Nucci C.A., Rachidi F., Ianoz M.V.,Mazzetti C., Lightning-Induced Overvoltages on Overhead Lines, IEEE Transactions on Electromagnetic Compatibility, vol. 5, no.1,1993

[7] Cooray V., Rakov V.A., Rachidi F., Montano R., Nucci C.A., On the Relationship Between the Signature of Close Electric Field and the Equivalent Corona Current in Lightning Return Stroke Models, IEEE Transactions on Electromagnetic Compatibility, vol. 51, pp. 921-927, 2008, doi: 10.1109/TEMC.2008.926918

[8] Bermudez J.L., Rachidi F., Rubinstein M., Janischewskyj W., Shostak V.O., Pavanello D., Chang J.S., Hussein A.M., Nucci C.A., Paolone M., Far-field-current relationship based on the TL model for lightning return strokes to elevated strike objects, IEEE Transactions on Electromagnetic Compatibility, vol. 47, pp. 146-159, 2005, doi: 10.1109/TEMC.2004.842102

[9] Schulz W., Pichler H., Diendorfer G., Vergeiner C., Pack S., Validation of detection of positive flashes by the austrian lightning location system ALDIS, Lightning Protection (XII SIPDA), 2013, doi: 10.1109/SIPDA.2013.6729206

[10] Xiang N., Gu.S, A Precisely Synchronized Platform for Observing the Lightning Discharge Processes, Power and Energy Engineering Conference (APPEEC), 2011, doi: 10.1109/APPEEC.2011.5748369

[11] Hussein A.M., Milewski M., Janischewskyj W., Correlating the Characteristics of the CN Tower Lightning Return-Stroke Current with Those of Its Generated Electromagnetic Pulse, IEEE Transactions on Electromagnetic Compatibility, vol. 50, pp. 642-650, 2008, doi: 10.1109/TEMC.2008.924398

[12] Berger G., Lafon G., Serrie G., Sigogne C., Recent progress in lightning studies at the Pic du Midi observatory, 7th Asia-Pacific International Conference on Lightning (APL), 2011, doi: 10.1109/APL.2011.6110150

[13] Karnas G., Maslowski G., Baranski P., Berlinski J., Pankanin G., Instrumentation and data analysis process at the new lightning research station in Poland, vol.6, 2013

[14] Karnas G., Maslowski G., Preliminary measurements and analysis of lightning electric field recorded at the observation station in the South-east part of Poland, Przeglad Elektrotechniczny, ISSN 0033-2097, R.90, no.4, 2014

[15] Timing Committee Teleommunications and Timing Group Range Commanders Council, IRIG Serial Time Code Formats. IRIG Standard 200-04,Secretariat Range Commanders Council U.S. Army White Sands Missile Range, New Mexico 88002-5110, 2004

[16] E. Kuffel, W. S. Zaengl, J. Kuffel High voltage engineering: fundamentals,Newnes, 2000 ISBN 0-7506-3634-3, pages 63, 70

[17] Qie X., Jiang R., Sun Z., Liu M. Wang Z., Lu G., Zhang H., High resolution observation on rocket-triggered lightning, 2014 International Conference on Lightning Protection, Shanghai, China, 2014

[18] Sigogne C., Pignolet P., Reess T., De Ferron A.S., Berger G., Lafon G., Serrie G., New Results At The Pic du Midi Lightning Station, 2013 International Symposium on Lightning Protection, Belo Horizonte, Brazil, 2013

[19] Beger G., Lafon G., Serrie G., Sigogne C., Recent progress in lightning studies at the Pic du Midi observatory, 2011 7th Asia-Pacific International Conference on Lightning, November 1-4, Chengdu, China, 2011

***Autorzy**:*
Grzegorz KARNAS, Rzeszow University of Technology, gkarnas@prz.edu.pl