DEVELOPMENT OF A LIGHTNING RECORDING AND LOCATION SYSTEM

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Abstract: A low-cost system for automatic recording of lightning was developed at the High Voltage Laboratory of National Technical University of Athens. The system includes two pair loop antennae for the measurement of the magnetic flux density caused by the lightning current, an electronic integrator of the signal, a data acquisition system and a personal computer with a software package which was developed for the analysis of the measurements.

Key words: lightning, lightning location system.

1. Introduction

Current lightning studies are focused mainly on its physical effects. Electrical engineers, physicists of the atmosphere, meteorologists and other skilled disciplinarians probe the behavioural complexities of various sectors. Lightning is a random and unpredictable event. Lightning effects can be direct and/or indirect. Direct effects are owed to resistive heating, arcing and burning. Indirect effects are more probable. They include capacitive, inductive and magnetic behaviour. The determination of the lightning current characteristics and the accurate location of lightning discharges to ground, is very useful for lightning research and other applications.

One technique for the recording of lightning currents employs the magnetic cathode-ray direction finder. In a typical installation, a pair of orthogonal loop antennae tuned to a VLF frequency, typically 10 kHz, detect the horizontal magnetic field produced by lightning. The azimuth angle to the discharge is obtained by displaying the outputs of both antennae simultaneously on a x-y oscilloscope, so that the resulting vector denotes the direction of the discharge. Two or more systems, at fixed positions, are sufficient to determine the location of a discharge from the intersection of simultaneous azimuth vectors [1-5].

2. Fundamentals

Lightning is a complex and not completely understood phenomenon. A simple model for the description of the magnetic field of a lightning discharge is shown in Fig. 1.

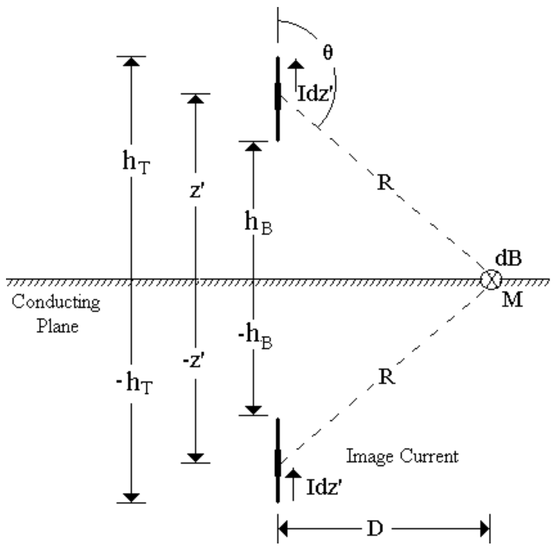

Fig.1: Magnetic field of a lightning discharge.

The magnetic flux density owed to a finite element *dz'* of the arc which is simulated by a vertical channel above perfect ground ($\sigma \to \infty$) is given by the following formula [3] using Maxwell equations:

$$d\vec{B}(r,\phi,z,t) = \frac{\mu_o \cdot dz'}{4 \cdot \pi} \cdot \left[\frac{r}{R^3} \cdot i(z',t-\frac{R}{c}) \right] \cdot \vec{i}_\phi + \frac{\mu_o \cdot dz'}{4 \cdot \pi} \cdot \left[\frac{r}{c \cdot R^2} \cdot \frac{\partial i(z',t-\frac{R}{c})}{\partial t} \right] \cdot \vec{i}_\phi \qquad (1)$$

Finally, the integration of this formula gives the magnetic flux density:

$$B(r,\phi,0,t) = \frac{\mu_o}{2\cdot\pi}\cdot\left[\int_{h_T}^{h_T}\frac{r}{R^3}\cdot i(z',t-\frac{R}{c})dz'\right]\cdot\vec{i}_\varphi$$

$$+\frac{\mu_o}{2\cdot\pi}\cdot\left[\int_{h_B}^{h_T}\frac{r}{c\cdot R^2}\cdot\frac{\partial i(z',t-\frac{R}{c})}{\partial t}dz'\right]\cdot\vec{i}_\phi \quad (2)$$

where:
r, φ, z are cylindrical co-ordinates,
i is the lightning current,
R is the distance,
c is the velocity of light,
z' is the vertical distance and
μ_o is the permeability of free space.

The magnetic flux density $B(t)$ at a given point M depends upon the lightning current $i(t)$, the distance R of the point from the finite element dz' and the angle of view θ from the point M to dz'. Obviously, the lightning current i(t) can be defined if $B(t)$, R and θ are known. The magnetic flux density $B(t)$ is measured by means of a loop antenna from long distances. The angle θ is determined by the well known direction finders and the distance R is calculated using two or more direction finders.

Direction finders measure the direction of lightning electromagnetic pulses, using two vertical magnetic loop antennae mounted orthogonaly to each other. The ratio of the induced voltages to the loops gives the tangent of angle θ (Fig. 2).

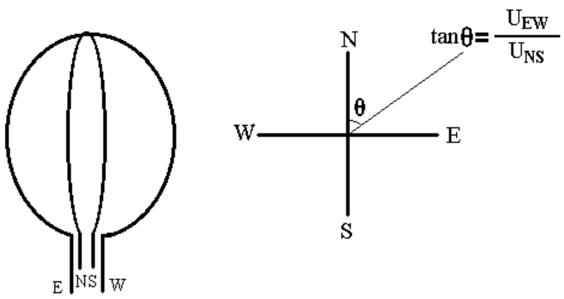

Fig.2: Direction finder with two vertical loops.

If two orthogonal loops are used, it's not possible to determine whether a pulse is generated by a flash to a direction lowering positive charge to ground or by a flash in the opposite direction lowering negative charge to ground, as there is an 180° ambiguity. This ambiguity can be removed by measuring the polarity of the vertical E-field change [2]. The azimuth θ is the direction measured clockwise with the direction towards north as reference.

Using two direction finders geographically separated, the location P of the flash can be defined, by triangulation, as the intersection point of the two bearings (Fig. 3). The accuracy of the location is influenced [2] by the accuracy of the measured bearings, the angle of intersection θ_i and the distance R_i.

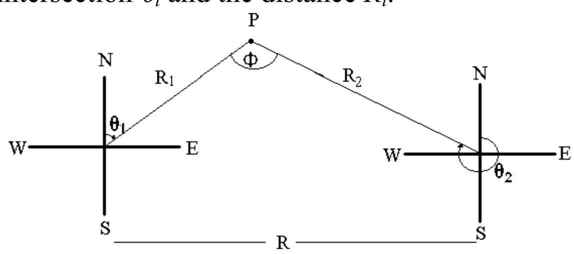

Fig.3: Location by triangulation using bearings, measured by two direction finders.

3. Apparatus

The developed system [1, 6, 7] includes two vertical loop antennae, an electronic circuit, a data acquisition system, a personal computer and the software (Fig. 4).

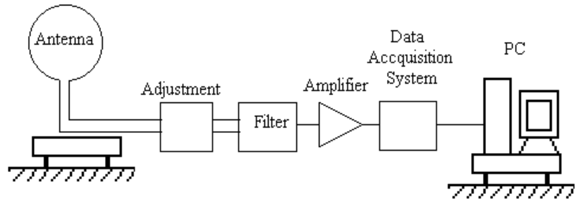

Fig. 4: Diagram of the measurement system.

The antenna is constructed of coaxial cable RG-58A/U. Its diameter is 440 mm and the characteristic impedance is 50 Ù. The antenna is placed vertically on a horizontal base. The base is made of wood and covered with a special plastic material for insulation.

The induced voltage U_a to the loop antenna is proportional [4-6] to the time-derivative dB/dt of the magnetic flux density and to the geometrical factor A which depends upon the loop surface and the angle of the discharge:

$$U_a(t) = A \cdot \frac{dB}{dt} \quad (3)$$

This signal (U_a) is integrated differentially by the electronic circuit of Fig. 5 connected in series to the antenna. The output U_e of this circuit (Fig. 5, J1) is proportional to the magnetic flux density B. A battery-powered (±5V) differential follower LF412, located at the antenna base, behaves as an impedance transformer for transmission of *dB/dt* signals from the antenna to the differential integrator through a coaxial cable. The resistance R1 is used for adjustment. The resistance R2 and the capacitor C1 form a high pass filter.

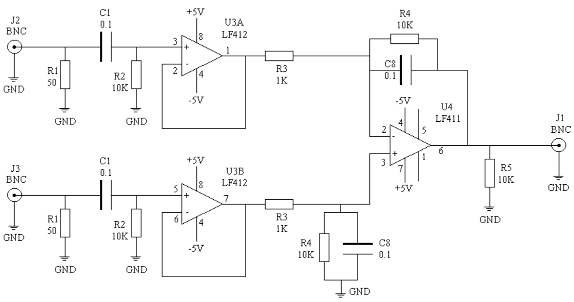

Fig. 5: The electronic circuit.

The output U_e of the differential integrator depends upon the magnetic flux density *B(t),* the azimuth θ to the direction measured clockwise with the direction towards north as reference, and the geometrical factor *A'*:

$$U_e(t) = A' \cdot B(t) \cdot \cos(\theta) \quad (4)$$

The U_e waveform is recorded by a data acquisition system connected to the output J1 of the integrator. The data are transferred to a computer connected to the data acquisition system. The rate of transfer is improved using the RAM as buffer, before data are stored on the hard disk. The measuring bandwidth is 40 MHz.

The waveform is analysed by a software package [1, 7], developed by the authors of this paper, using Pascal and C++. The computer programme calculates the azimuth angle θ of the direction from the integrated output signals of the vertical antennae. On the other hand, the distance R_i is obtained using two or more separate systems as it is described in Fig. 3. Finally, the polar co-ordinates are defined and the lightning stroke is geographically located on the digital map of the covered area (Fig. 6).

Further analysis of the obtained data leads to the analytical definition of the lightning current waveform. Moreover, the developed software calculates the parameters (peak current, charge, front duration, maximum *di/dt*, stroke duration, energy, flash duration, polarity of stroke, time interval between negative strokes) of the lightning current. An analysis of these parameters, based on determined values of the respective parameters from the literature [9], permits the estimation of the probability [1, 7] to be the recorded signal a lightning stroke.

Fig.6: Digitised map for possible applications.

4. Results

The developed system was tested experimentally outdoors by recording impulse lightning currents applied on a vertical rod by an impulse current generator (Fig. 7). A large number of laboratory experiments has been made at the High Voltage Laboratory of NTUA. A typical waveform of an injected lightning current and of the measured one is depicted in Fig. 8.

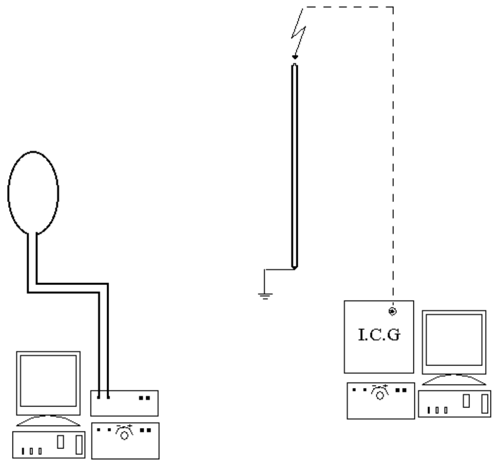

Fig. 7: Experimental layout.

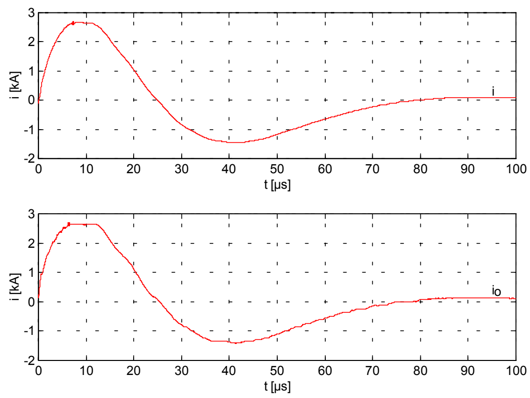

Fig.8: Comparison of the applied lightning stroke i_o with the measured one *i*.

5. Conclusions

The developed system gave reliable results during its experimental application. The potential of the system is not comparable to the one of well known lightning location systems. However, it is believed that its low cost will facilitate projects of lower budget and applications in the area of the research of the effects of lightning strokes. Furthermore, the test of this system for a long period of time and for several positions will give better conclusions about its reliability.

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