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Contribution to the analysis of the electromagnetic field radiated by lightning taking into account the conductivity of the ground

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Abstract—The objective of this work is the analysis of the electromagnetic field radiated by lightning below a homogeneous ground (the conductivity of the finished ground) and in the air, characterized by a finite conductivity. The calculation of the electromagnetic field radiated by the arc phase in return of a descending lightning strike was successfully carried out. The computer implementation of this calculation was carried out by developing a simulation program under MATLAB environment which offers very interesting results.

Index Terms—Electromagnetic field, Modeling, FDTD, Lightning strike, Conductivity of the ground.

I. INTRODUCTION

In recent years, several models of the return arc, with different degrees of complexity, have been developed in order to quantify its electromagnetic radiation. One of the major difficulties in modeling the lightning channel is that the current can only be measured at the base of the channel; however, in order to determine the radiated electric and magnetic fields, it is necessary to know the distribution of the current along the channel, an important property that makes the difference between the models of the proposed return arc on the spatial and temporal distribution of the current. along the lightning channel $i(z', t)$ [1, 2, 3,4]. Most recent researches are conducted for the computation of the electromagnetic field have been conducted towards the Heidler model and the biexponential model. For this our approach in this work is that we adopt the model MTLL (Modified Transmission Line) also named: modified engineers model proposed by Nucci and Rachidi [5] and approved by convincing results by several authors in different works [6]. The passage of the lightning current from the base of the channel to the cloud is the main source of the electromagnetic field. The calculation of the electromagnetic field requires:

- An analytical expression of the shape of the lightning current measured at the base of the channel.
- Spatio-temporal modeling of the current distribution in the Lightning Channel.

Among these EDP algorithms, it is the FDTD method that

has the largest number of application domains at the level of the structures that can be modeled as at the level of the frequency domains explored. This method was proposed by Yee in 1966 [7], then more or less forgotten until 1975. That year, Allen Taflove [8] - [9], who could not solve a problem of penetration of microwaves on the human eye (many cataracts had been observed on radar technicians during the Second World War), decides to use Yee's algorithm. Despite the success of its modeling and the various improvements it brings to the method, it falls back into oblivion, no doubt, for lack of sufficient computer means (only the American defense continues to use it). By the end of the 1980s, the computer revolution made it possible to generalize the use of the FDTD method [10] [11] [12]. This success is mainly due to the simplicity of the basic principle of the method. It is a question of implementing the Maxwell equations and applying them on the whole modeling space for any moment of simulation.

Algorithm for calculations with matlab

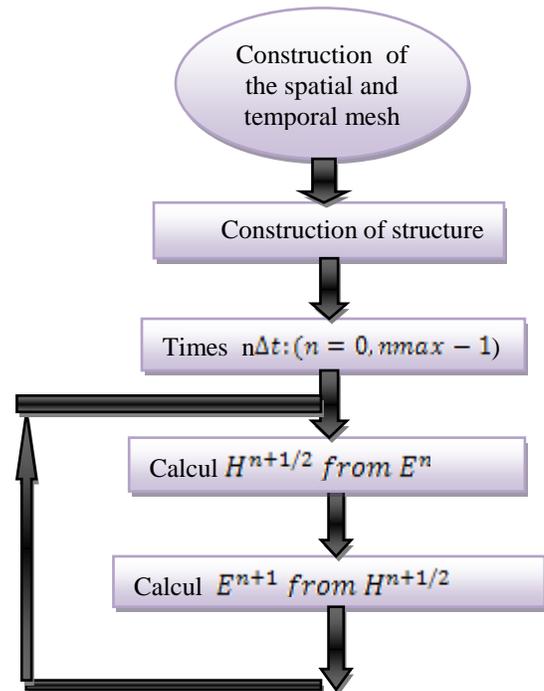


Fig.1 Simplified organizational chart of the FDTD program

II. THE APPLICATION UNDER STUDY

A. Geometric model chosen for the calculation of the Electromagnetic field

The lightning channel is considered a one-dimensional vertical antenna of height H . The return arc propagates vertically from the ground with a velocity v . It is traversed by a current whose spatiotemporal distribution $i(zc; t)$ determines the electromagnetic field at any point in space. Moreover, the cylindrical symmetry of the problem makes the components of the electromagnetic field independent of the azimuthal angle. The field will be defined by:

- the vertical electric field E_z ;
- the radial electric field E_r ;*
- the radial magnetic field H_ϕ .

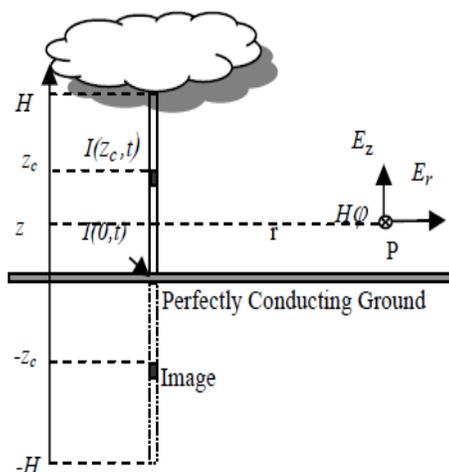


Fig.2 Study domain geometry

B. Analytical representation of the arc current back to the base of the lightning channel

The shape of the discharge current in time. The theory shows, and the experiment verifies, that the discharge current has a temporal evolution of the form :

$$i(t) = I_0 (\exp(-\alpha t) - \exp(-\beta t)) \quad (1)$$

The simulated current is represented by the expression developed by Nucci et al. [47] :

$$I(0, t) = \frac{I_{01}}{\eta} \frac{t/\tau_1}{t/\tau_1 + 1} e^{-t/\tau_2} + I_{02} \left(e^{-t/\tau_2} - e^{-t/\tau_1} \right) \quad (2)$$

III. MODIFIED TRANSMISSION LINE MODELS WITH LINEAR ATTENUATION (MTLL)

In this model the current is attenuated according to the height

$$I(z', t) = I(0, t - z'/c) (1 - z'/(H_{tot})) \quad \forall \quad z' \leq vt \quad (3)$$

$$I(z', t) = 0 \quad \forall \quad z' > vt$$

Where H_{tot} is the total height of the lightning channel.

A. Time Domain

The study of disturbances generated by lightning directly involves us in the field of electromagnetic compatibility, the ultimate goal of which is to make compatible the functioning of a sensitive electrical / electronic system in a disturbed electromagnetic environment while respecting the 03 criteria. following:

- No interference with other systems.
- No susceptibility to emissions from other systems.
- No interference of the system with itself.

Dans un problème de CEM, on trouvera deux éléments: une source de perturbation (la foudre), un moyen de couplage (conduction, rayonnement).

In an EMC problem, we will find two elements: a source of disturbance (lightning), a means of coupling (conduction, radiation). For the general case of a finite conductivity sol, the application of the Maxwell equations to the geometry adopted above makes it possible to obtain the equations of the electromagnetic field. These equations involve the Sommerfeld integrals whose numerical evaluation is a delicate task. Assuming a perfectly conducting ground, simpler expressions of the vertical and horizontal components of the electric field and the azimuthal component of the magnetic field can be developed. These expressions are written in the time domain according to M.A Uman [13] [14]:

$$E_r(r, z, t) = \frac{1}{4\pi\epsilon_0} \left[\int_{-H}^H \frac{3r(z-z')}{R^5} \int_0^t i(z', \tau - R/c) d\tau dz' \right] + \int_{-H}^H \frac{3(z-z')}{cR^4} i(z', t - R/c) dz' + \int_{-H}^H \frac{r^2}{c^2 R^3} \frac{\partial i(z', t - R/c)}{\partial t} dz'$$

$$E_z(r, z, t) = \frac{1}{4\pi\epsilon_0} \left[\int_{-H}^H \frac{3r(z-z')^2 - r^2}{R^5} \int_0^t i(z', \tau - R/c) d\tau dz' \right]$$

$$+ \int_{-H}^H \frac{2r(z-z')^2 - r^2}{cR^4} i(z', -R/c) dz' + \int_{-H}^H \frac{r(z-z')}{c^2 R^3} \frac{\partial i(z', t - R/c)}{\partial t} dz'$$

$$B_\phi(r, z, t) = \frac{1}{4\pi\epsilon_0} \left[\int_{-H}^H \frac{r}{R^3} (z', \tau - R/c) dz' + \int_{-H}^H \frac{r}{cR^2} \frac{\partial i(z', t - R/c)}{\partial t} dz' \right]$$

$$R = \sqrt{(z - z')^2 + r^2} \quad (6)$$

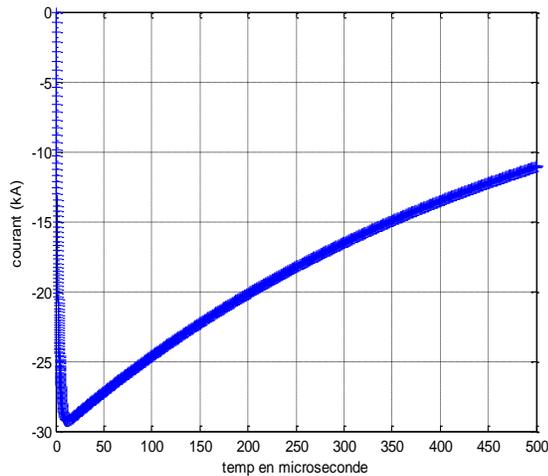
Er, Ez: the Horizontal field and the vertical field; Hφ is the azimuthal magnetic field.

The three terms in Equations (4) and (5) represent the Electrostatic, Induction and Radiation Fields, respectively, while the first term in Equation (6) represents the field of induction and the second is the radiation field. Whereas the vertical electric field and the magnetic field are practically independent of the height z of the observation point (for z varying from 0 to about 30 m), the horizontal electric field, which is zero at ground level, increases almost linearly. with z [15] [16].

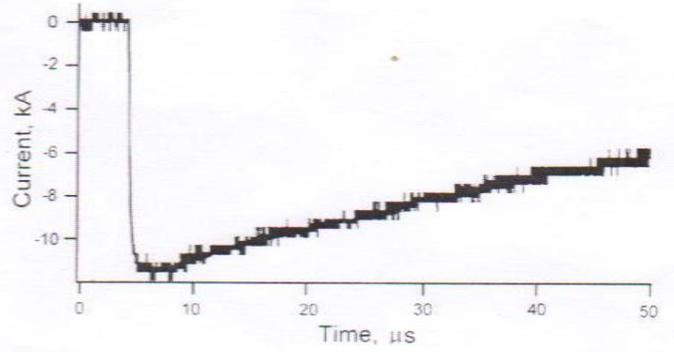
Current parameter at the base of the lightning channel :

$$I_{01} = 3.25 \text{ kA}, \tau_1 = 0.07 \mu\text{s}, \tau_2 = 16.67 \mu\text{s},$$

$$n_1 = 2, I_{02} = 8.95 \text{ kA}, \tau_3 = 100 \mu\text{s}, \tau_4 = 0.5 \mu\text{s}, n_2 = 2$$



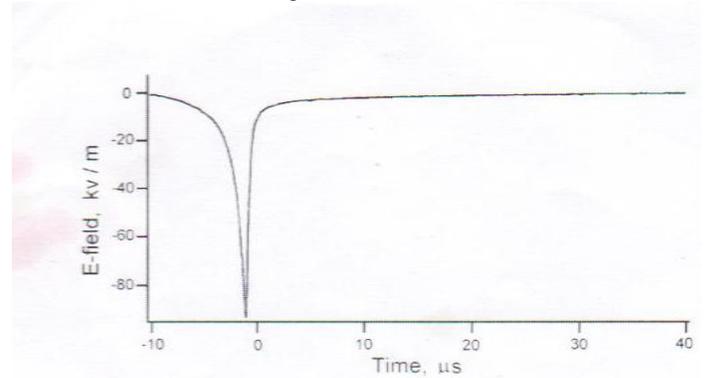
(a)



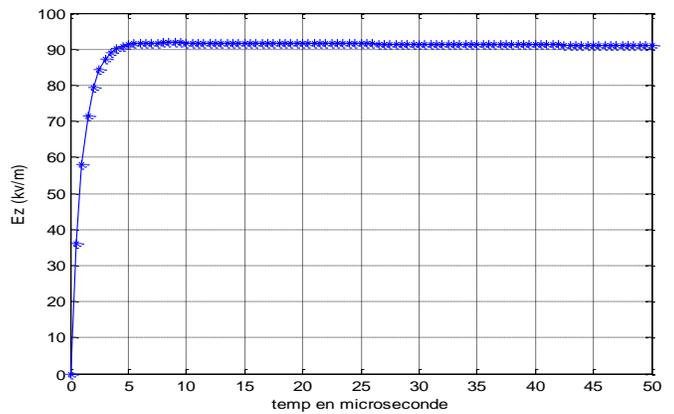
(b)

Fig.3 Current at the base of the lightning channel (a) calculated by the measured FDTD (b) method

At the end of this comparison, we can conclude that the simulation results (Current at the base of the channel) are in agreement with the experimental results (figure above). To calculate the vertical electric field, we adopt the MTLL model to represent the current of the arc back. The speed of the return arc is assumed to be 150 m / μs. The curves of the calculated electric field are shown in Figure 5.



(a)



(b)

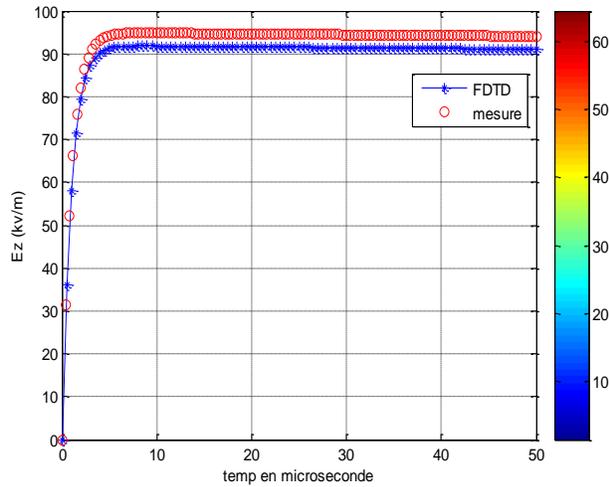


Fig. 5 vertical electric field 15 m of lightning canal (a) Measured adapted the [78] and (b) calcul

We obtain a passage zone between the measured electric field lower than that obtained by the FDTD method FIG. horizontal electric field (a) the FDTD-method, (b) adopted from .

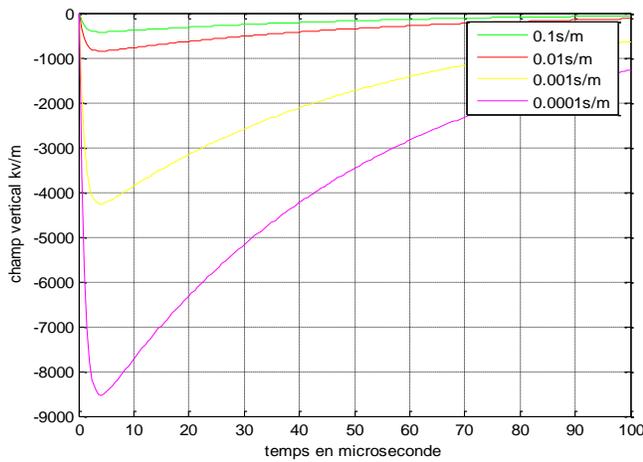


Fig.6 variation the vertical electric field

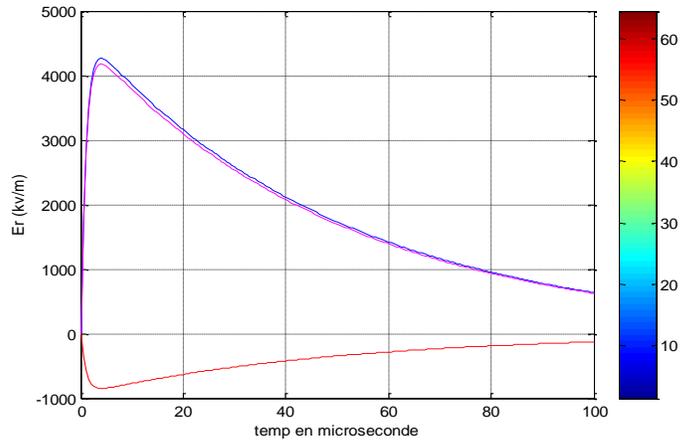
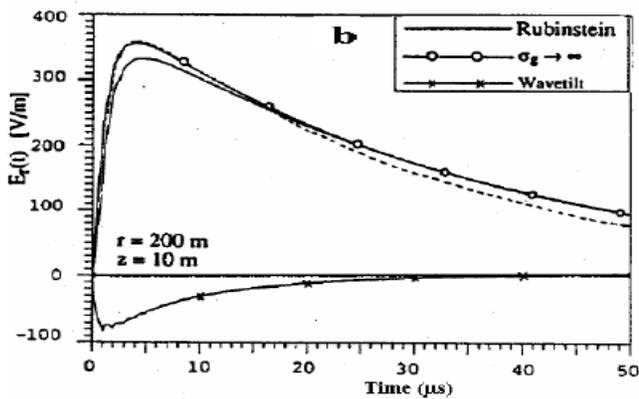


Fig.7 Horizontal electric field (a) the FDTD-method, (b) Adopted from

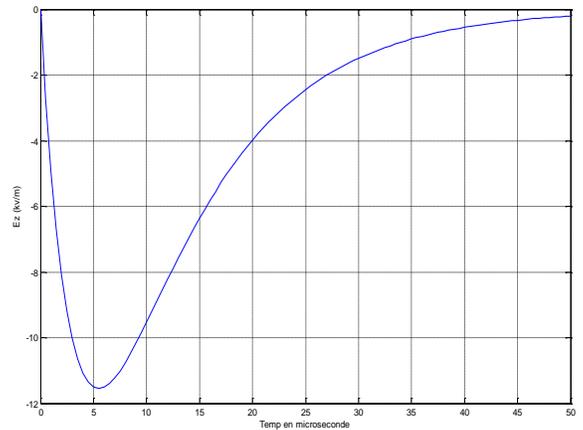
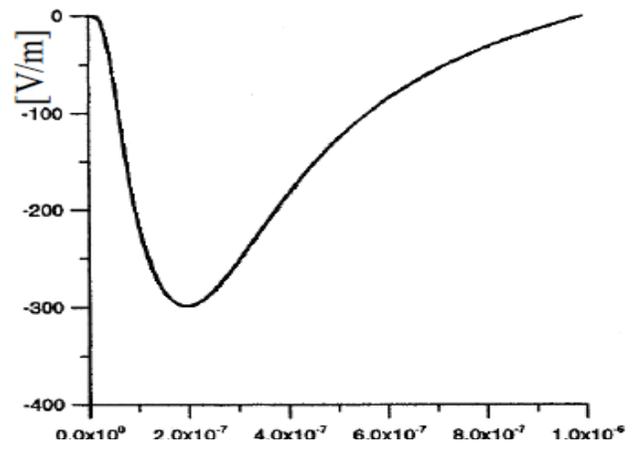


Fig.8 The temporal variation of electric field for distance 200 m ($\sigma = 0.001 \text{ S / m}$) (a) the method FDTD (b) Adopted from

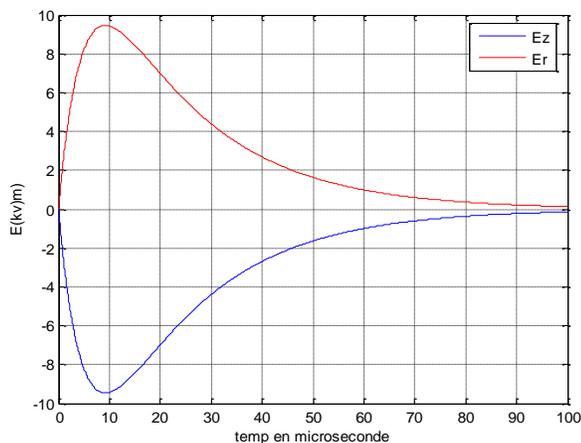
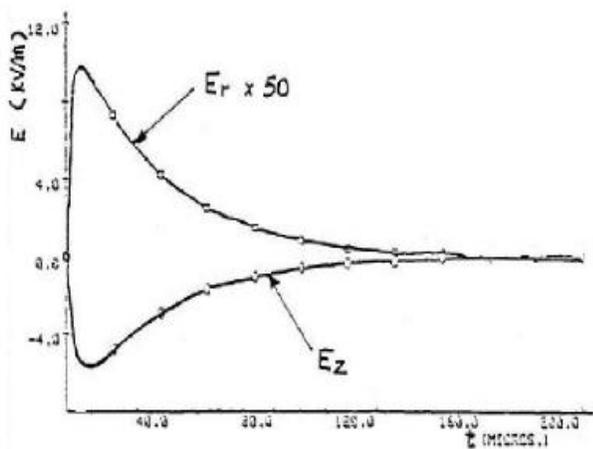


Fig.9 Field radiated by the lightning channel at a distance of 200 m

The figure (Fig. 9) represents the field radiated by the lightning channel at a distance of 200 m and at a height of 6 m. current along the channel takes place with the transmission line model (TL) Field radiated by the lightning channel at a distance of 200 m.

V. CONCLUSION

The purpose of this paper was to develop a computation code of the electromagnetic field radiated by the arc phase in return for a thunderbolt. The determination of the components of the electromagnetic field requires knowledge of the spatiotemporal distribution of the lightning current along the channel. Allowing low temporal 3D problem solving. And for its speed of calculation by avoiding the use of solid numerical methods (FDTD) to improve the calculation efficiency, which often require computation time and important memory space.

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