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Attenuation Effect of Lossy Ground on Peak Electromagnetic Intensities Investigated by Method of Moments

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***Abstract*— Influence of the current waveforms and channel geometry on peak intensities of electromagnetic field waveforms associated with rocket-triggered lightning is investigated through numerical electromagnetic analysis by using an electromagnetic model of lightning channel with the help of NEC-4. Peak intensities of electromagnetic field vary more than several tens of percent depending on the current waveforms, channel geometry and the azimuth to observation points.**

***Keywords*— lightning, LEMP, numerical electromagnetic field analysis, NEC-4**

I. INTRODUCTION

The peak current amplitude of a lightning return stroke is one of the key parameters for lightning protection. However, direct measurement of it is quite difficult. Thus, estimation of it through electromagnetic field observation is quite important. Vaisala's LLS (Lightning Location System) estimates the peak current amplitude by compensating the attenuation effect of finite ground conductivity [Cummins et al., 2006]. Parameters used in the compensation calculation were estimated from data of subsequent return strokes or rocket-triggered lightning at Camp Blanding (CB). However, the attenuation effect varies by the local ground conductivity, terrain, current waveforms [Cooray, 2014] and lightning channel geometry [Saito and Ishii, 2015]. Thus the parameters in the compensation calculation will change depending on the location and current waveforms.

In this paper, the attenuation effect on peak intensities of electromagnetic field waveforms associated with rocket-triggered return strokes is investigated by using an electromagnetic model. Numerical Electromagnetics Code (NEC-4) based on the method of moments is employed for the numerical analysis.

II. CALCURATION OF ELECTRIC FIELD WAVEFORMS

Electromagnetic fields and current waveforms associated with rocket-triggered return strokes are numerically reproduced by using NEC-4. A model of a lightning channel, consisting of a vertical thin wire attached to the ground, is employed for numerical electromagnetic analysis.

The analyzed model is shown in Fig.1. A voltage source (V.S.) is placed between a lightning channel model and ground i.e. at the striking point. It generates a voltage having 10%-90% rise time of 0.5 μs, expressed by Heidler function. Parameters of the electromagnetic model of the lightning channel, namely the channel radius, loaded resistance and inductance per unit length are 0.01 m, 0.3 Ω/m and 6 μH/m, respectively. The apparent propagation velocity of the current on this model channel is about 0.5c.

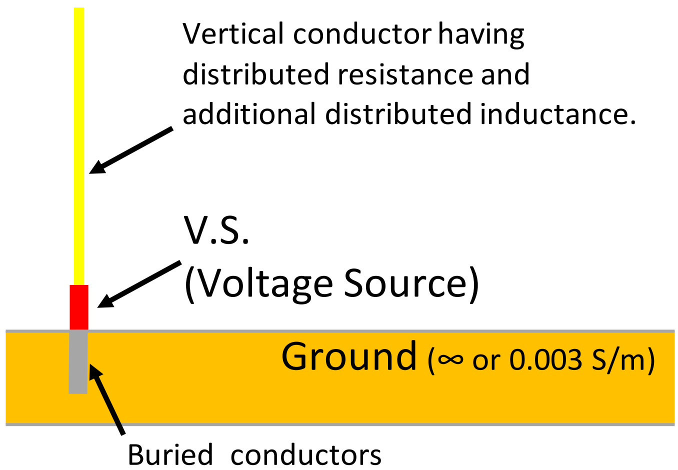


Fig. 1 Electromagnetic model of vertical lightning channel.

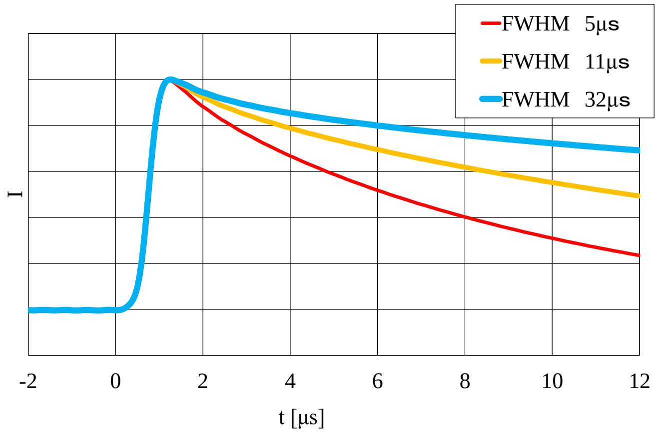
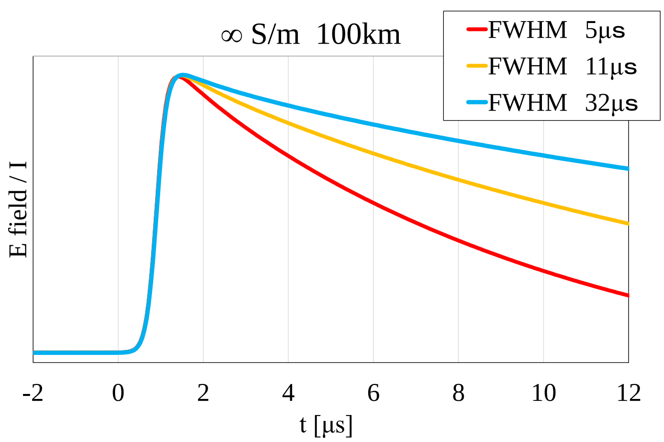


Fig. 2 Calculated current waveforms at the point of V.S. shown in Fig. 1.

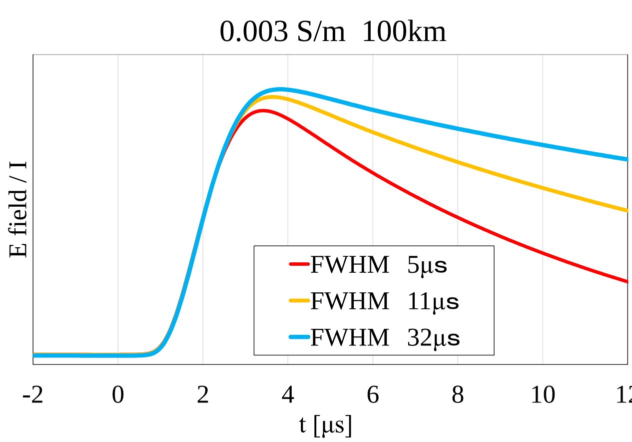
Calculations are performed at 50 ns time step. Ground conductivity is set to infinite or the value around CB, about 0.003 S/m. The effect of ground conductivity is calculated by Sommerfeld ground model of NEC-4. In the case of the ground conductivity of 0.003 S/m, relative permittivity of soil is set to 10, and at the striking point, the thin wire is divided into several thin wires and buried in the soil, so its grounding resistance is less than several tens of ohms. Thus its influence in calculated current waveforms and electric field waveforms is negligible.

III. Effect by the Differences of Current Waveforms

Fig. 2 shows the current waveforms generated by the V.S. shown in Fig. 1 at the striking point. Three voltage waveforms having the same rise time (10%-90% 0.5 μs) and different FWHM (full width at half maximum) (5μs, 11μs, 32μs) are selected for the calculation. The FWHM values of calculated current waveforms are in the range of actually observed values at rocket-triggered lightning [Schoene et al., 2009].

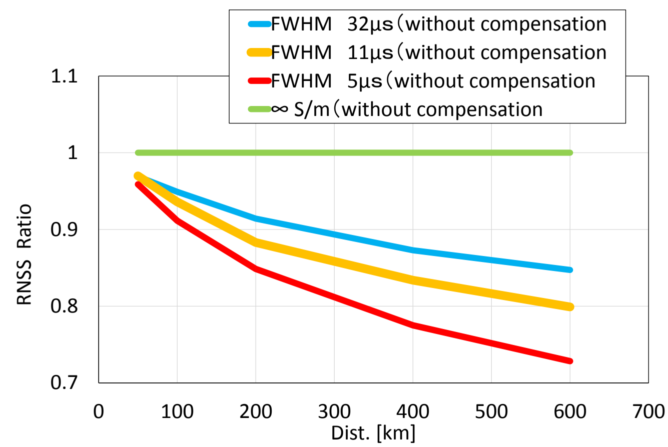


(a) ∞ S/m

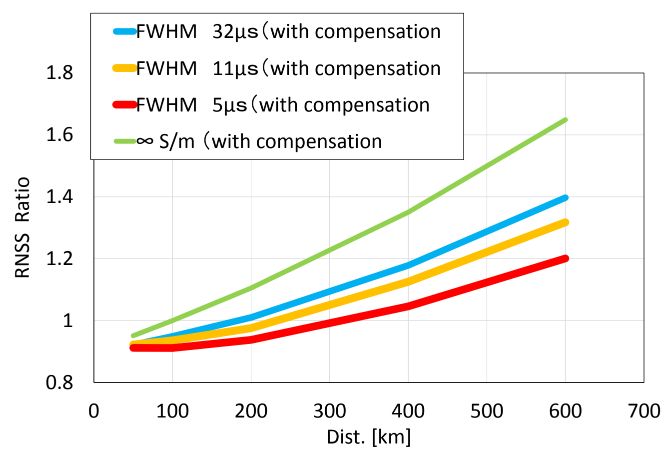


(b) 0.003 S/m

Fig. 3 Calculated electric field waveform at a distance of 100 km at each ground conductivity.



(a) Without compensation



(b) With compensation

Fig. 4 Relation between calculated RNSS for each current waveform and distance to lightning stroke.

Fig. 3 shows the calculated electric field waveforms at a distance of 100 km from the striking point. As shown in Fig. 3 (a), over the perfectly conducting ground, field waveforms are almost the same as the current waveforms shown in Fig. 2. However, at the ground conductivity of 0.003 S/m, the peak values and waveforms vary by FWHM of the current.

Calculated RNSS (Range normalized signal strength) peak intensities with and without compensation employed at NLDN [Cummins et al., 2006] are shown in Fig. 4. 350 kHz 2nd order LPF is applied for the calculation of field waveforms. The difference of calculated RNSS values depending on the current waveform increases with the increase of distance.

IV. Effect of the Geometry of Lightning Channel

At the rocket triggered lightning, the lightning channel is almost vertical from ground level to 200 or 300 m altitude. However, the channels above such nearly vertical channels sometimes had slant or zigzag shapes [Rakov et al., 2005]. Thus, the influence of such tilted lightning channels on electric field waveforms is surveyed by using the electromagnetic model shown in Fig. 5. This model has a part of slant channel with the elevation angle of 30 degrees at the altitude of 200 m or higher.

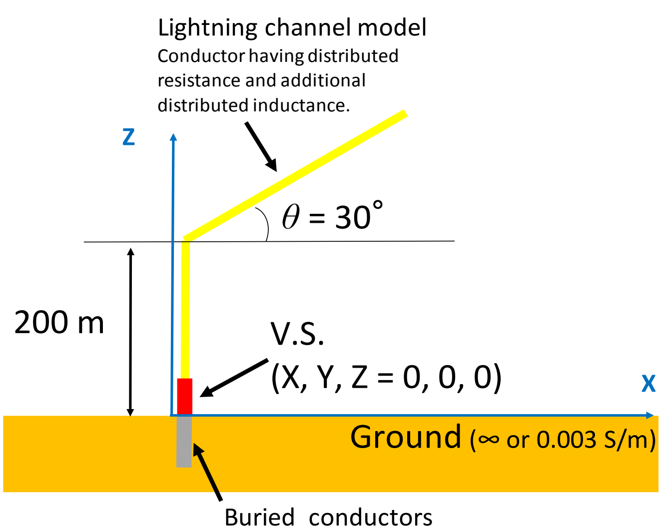


Fig. 5 Electromagnetic model of partially tilted lightning channel.

For the analysis, current waveform having 5 μs of FWHM, shown in Fig. 2, was employed. Remote electromagnetic fields are calculated at points A, B and C shown in Fig. 6. Fig. 7 shows calculated electric field waveforms at a distance of 100 km from the striking point by using the model shown in Fig. 5 for infinite and 0.003 S/m ground conductivities. Over perfectly conducting ground, Fig. 7 (a), the peak field amplitudes are the same, though the wave tails are different depending on the azimuth to the observation points. However, at the ground conductivity of 0.003 S/m, Fig. 7 (b), both of the peak intensity and the electric field waveform vary depending on the azimuth.

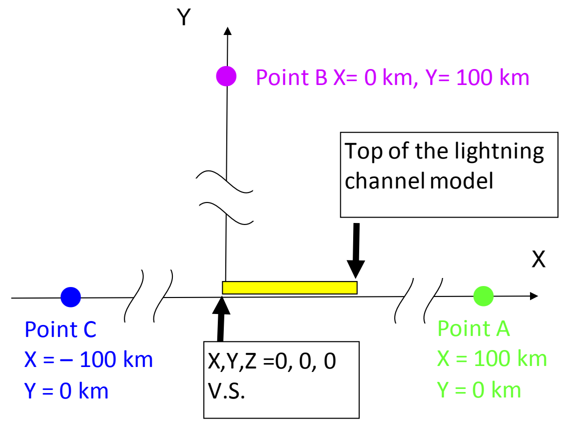


Fig. 6 Plan view of the inclined lightning channel model and location of three observation points.

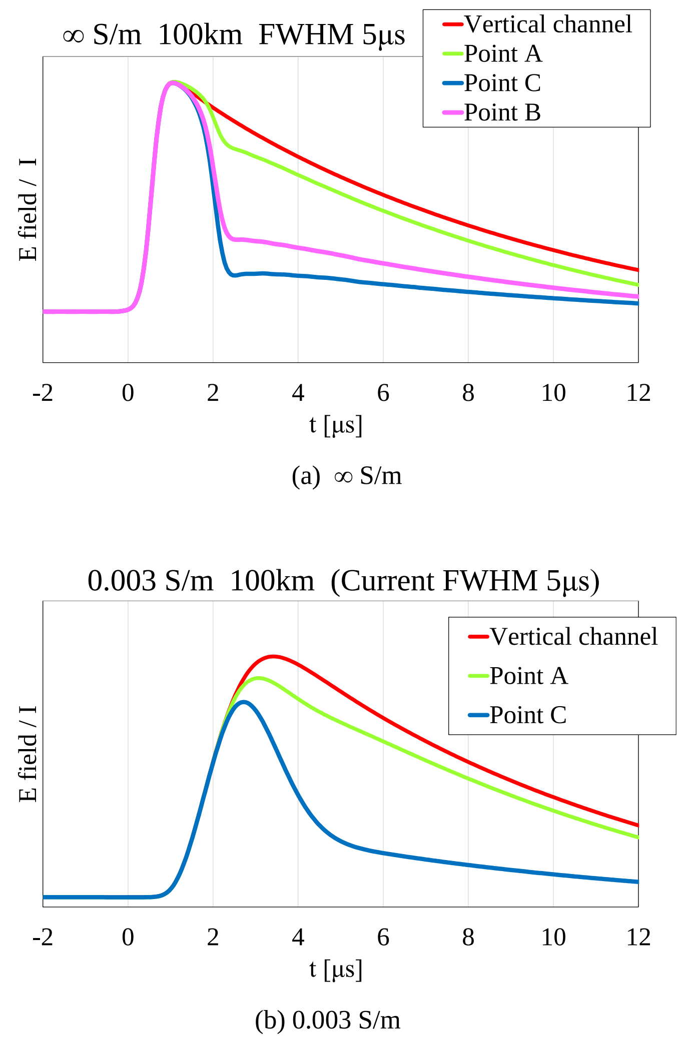
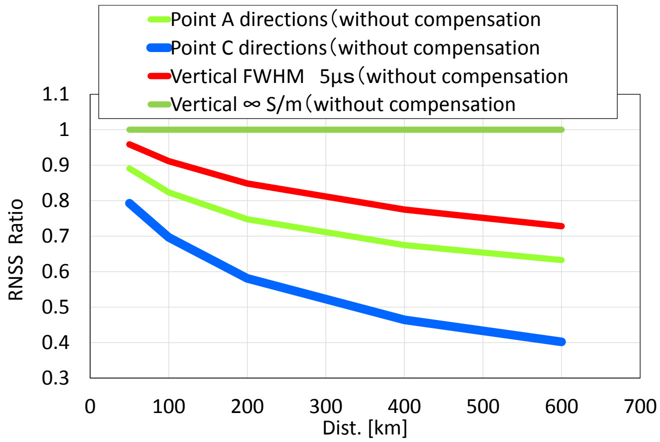
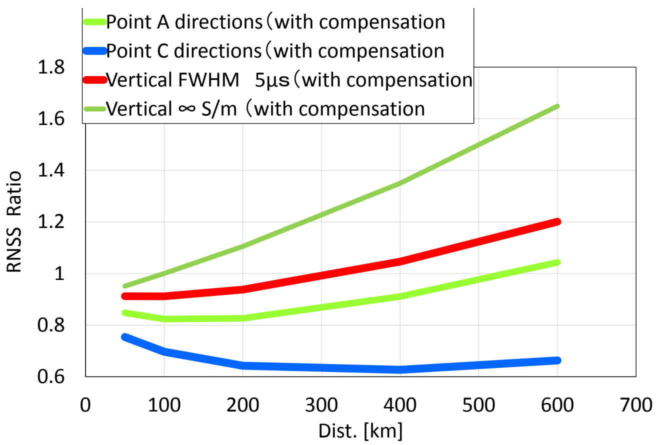


Fig. 7 Calculated electric field waveforms at a distance of 100 km at each ground conductivity by using the model shown in Fig. 5.



(a) Without compensation



(b) With compensation

Fig. 8 Relation between calculated RNSS and distance to lightning strokes with and without compensation employed at NLDN.

Fig. 8 shows the dependence of calculated RNSS on the distance with and without compensation employed at NLDN, produced in a similar way to that of Fig. 4. Dependences of RNSS on the azimuth to observation points also are quite different each other.

V. Discussion

As shown in Fig. 3, the radiated electric field waveforms vary by the shape of the lightning current, and the shape the waveform around the initial peak cannot be expressed simply by FWHM only. A conceptual diagram of this problem is shown in Fig. 9. FWHM of the three waveforms is the same, however, manners of decay after the peak vary like those of Fig. 2. The electric field waveforms around their peaks radiated from the lightning currents shown in Fig. 9 are similar to those shown in Fig. 3, therefore, a parameter to describe the wave shape around the peak of the current is necessary for practical discussion on the influence of the current waveform.

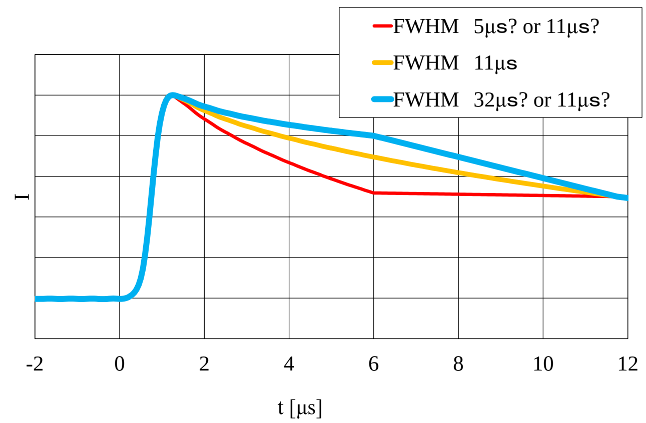


Fig. 9 Conceptual diagram of current waveforms having the same FWHM and different shapes around the peak.

The effect of geometry of lightning channels on radiated electromagnetic field waveforms are also significant. Channels of upward lightning launched from rocket, high structures or structures on the mountain are frequently tilted. Such lightning channels radiate electromagnetic field waveforms having weaker peak intensities than those from a vertical channel with the same peak current, and different waveforms depending on the direction from the lightning channel. Thus, the channel geometry is also an important property for further analysis.

VI. Conclusion

The relationship between the current waveform, the geometry of lightning channel and the peak amplitude of electromagnetic field waveforms associated with rocket-triggered lightning strokes is investigated by using an electromagnetic model on lossy ground with the help of NEC-4.

Peak amplitudes of electromagnetic field waveforms are considerably influenced by the current waveform, the channel geometry and the azimuth toward the observation points. These are significant causes of uncertainty in estimating the peak current amplitude of return strokes by LLS.

References

Cooray, V. (2014), On the various approximations to calculate lightning return stroke-generated electric and magnetic fields over finitely conducting ground, in *The Lightning Flash*, 2nd Edition, IET, London.

Cummins, K. L., J. A. Cramer, C. J. Biagi, E. P. Krider, J. Jerauld, M. A. Uman, and V. A. Rakov (2006), The U.S. National Lightning Detection Network: post-upgrade status, Second Conference on Meteorological Applications of Lightning Data, No. 6.1.

Rakov, V.A., M.A. Uman, K.J. Rambo (2005), A review of ten years of triggered-lightning experiments at Camp Blanding, Florida, Atmospheric Research, Vol. 76, doi:10.1016/j.atmosres.2004.11.028

Saito, M., M. Ishii (2015), Peak intensities of electromagnetic field waveforms of return strokes influenced by tilted lightning channel, 9th Asia-Pacific International Conference on Lightning, 1174, Nagoya, Japan.

Schoene, J., M. A. Uman, V. A. Rakov, K. J. Rambo, J. Jerauld, C. T. Mata, A. G. Mata, D. M. Jordan, G. H. Schnetzer (2009), Characterization of return-stroke currents in rocket-triggered lightning, Journal of Geophysical Research, Vol. 114, D03106, doi:10.1029/2008JD009873.