First International Symposium on LIGHTNING PHYSICS AND EFFECTS
April 3-4, 2006 – Vienna, Austria

Estimation of lightning induced effects in complex systems using engineering return-stroke models

Grzegorz Maslowski
Rzeszow University of Technology, POLAND

© Photo 30.05.2005
Rzeszów, POLAND

OUTLINE OF PRESENTATION

- Introduction
- The engineering return-stroke models in the frequency domain
- Estimation of lightning induced voltages in complex systems
- Conclusion

INTRODUCTION

Lightning return-stroke models:

We usually define four classes of lightning return-stroke models:

1. The gas dynamic (or "physical") models.
2. The distributed-circuit models.
3. **The electromagnetic models.**
4. **The engineering return-stroke models.**

INTRODUCTION

The electromagnetic models - advantages:

1. The electromagnetic models are based on the antenna theory.
2. The induced effects can be calculated in the cylindrical conductors freely situated in space.
3. Influence of lossy ground on lightning effects can be investigated based on the well-known Sommerfeld integrals.
4. The lightning channel with turtuosity and branches can be considered.
5. The electromagnetic models can be easily implemented into the standard software tools (e.g. NEC, AWAS, CDEGS).

INTRODUCTION

The electromagnetic models - disadvantages:

1. A long time of computation is required to determine currents in all segments which create the lightning channel, especially, when the lossy ground is taken into account.

$$\begin{cases} \mathbf{t} \cdot (\mathbf{E}^i + \mathbf{E}^s) = I_l \, Z_s \\ \mathbf{t} \cdot \mathbf{E}^s = \dfrac{\mathrm{j}\omega\mu_1}{4\pi} \int\limits_l I_l(\mathbf{r'}) G(\mathbf{r},\mathbf{r'}) dl \end{cases}$$

$$G(\mathbf{r},\mathbf{r'}) = G(\mathbf{r},\mathbf{r'}) - G_{image}(\mathbf{r},\mathbf{r'}) + G_{Sommerfeld}(\mathbf{r},\mathbf{r'})$$

2. Additional inductive loads distributed along the whole channel are needed in order to reduce the return-stroke velocity.

INTRODUCTION

The engineering return-stroke models

1. The spatial and temporal distribution of the lightning channel current is chosen in the arbitrary manner.

2. Defined variation in time as well as the specific attenuation with height of this current reflect such observed lightning return-stroke characteristic as the current at the channel base, the speed of the upward-propagating front and the channel luminosity profile.

3. The electromagnetic field predicted by these models in wide range of distances (from tens of meters to hundreds of kilometers) is generally in fairly good agreement with observations.

THE ENGINEERING RETURN STROKE MODELS IN THE FREQUENCY DOMAIN

Return-stroke current in the time domain

$$i(z',t) = \begin{cases} P(z')\, i(0,t - z'/v) & z' \le vt \\ 0 & z' > vt \end{cases} \qquad (1)$$

the Fourier transform of (1)

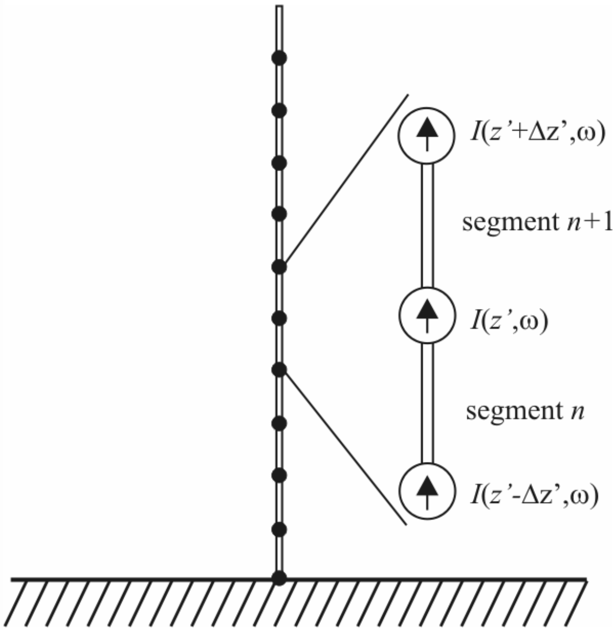
$$I(z',v,\omega) = P(z') \int_{z'/v}^{\infty} i(0,t - z'/v)\exp(-j\omega t)dt \qquad (2)$$

$$I(z',v,\omega) = P(z')\exp(-j\, z'\omega / v) I(0,\omega) \qquad (3)$$

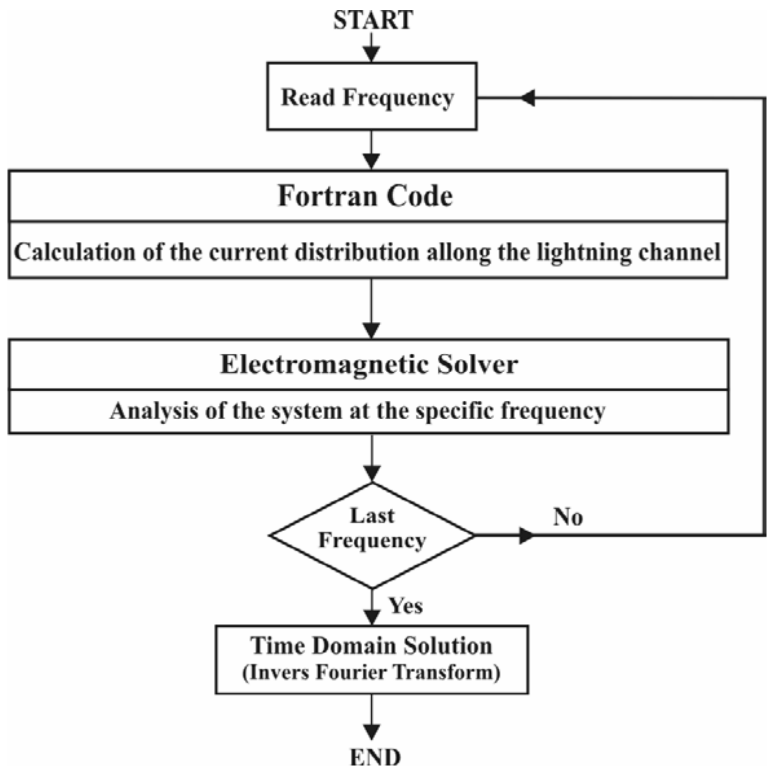
$$I(0,\omega) = \int_{0}^{\infty} i(0,t')\exp(-j\omega t')dt' \qquad (4)$$

THE ENGINEERING RETURN STROKE MODELS IN THE FREQUENCY DOMAIN

Lightning channel with distributed phased-shifted current sources

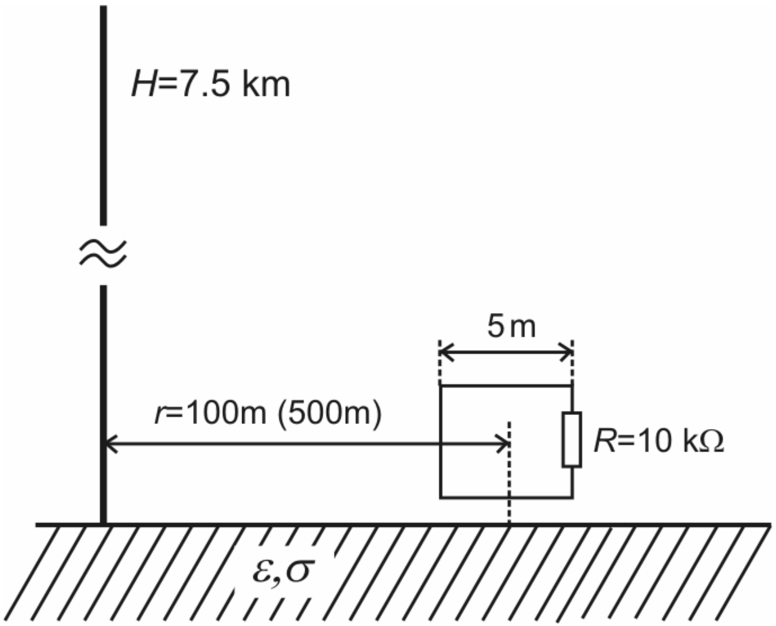


Flowchart describing the computational method



LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

Geometry of system during calculation of lightning induced voltages. The same lossy ground was adopted for all considered cases.



ASSUMPTIONS OF THE PHYSICAL MODEL

- Air and ground are homogeneous media.
- The ground and wires have defined real parameters and are linear and isotropic media.
- A thin-wire approximation is applied in relation to cylindrical wires forming the studied system.
- The enforcing function representing the lightning current is realized in the form of ideal current generators.

MATEMATICAL APPROACH OF THE COMPUTATION METHOD

- Computation method is based on the analysis of the studied system in the frequency domain
- The system can be studied with an individual frequency or with their whole set representing the frequency spectrum of the enforcing input signal.
- System responses for a specific set of harmonics enable determination of the transfer function , as well as the time response of the output signal.

LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

Different frequency regimes are chosen in order to minimize the time computation

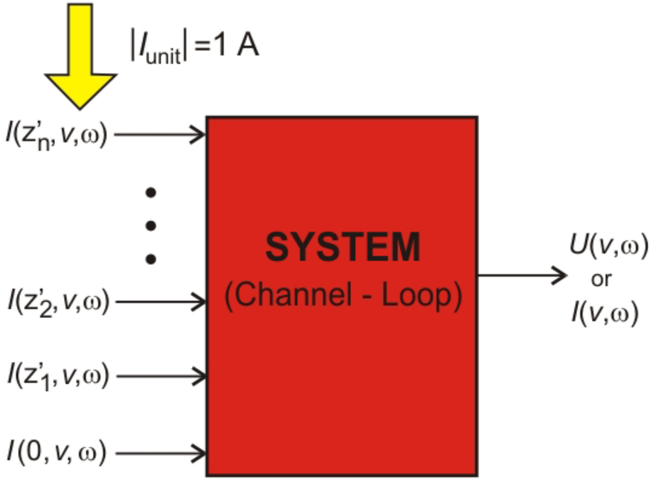
FREQUENCY REGIMES CHOSEN DURING COMPUTER SIMULATIONS

Frequency range		Frequency step
1st regime	**1 kHz – 100 kHz**	$\Delta f = 1\text{kHz}$
2nd regime	**100 kHz – 1 MHz**	$\Delta f = 10\text{kHz}$
3rd regime	**1 MHz – 16 MHz**	$\Delta f = 20\text{kHz}$

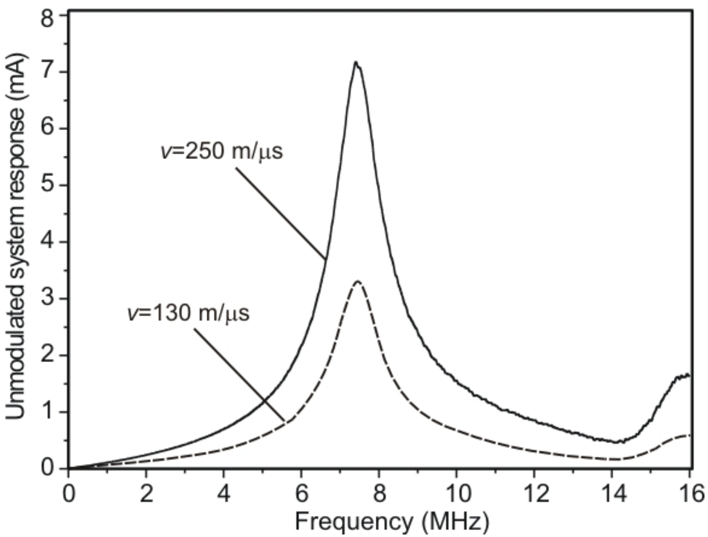
LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

Set of input signals (distributed phased-shifted current sources) and the output signal (induced voltages or currents) and the unmodulated system responses.

$I_{unit}(z', v, \omega) = \exp(-jz'\omega/v)$

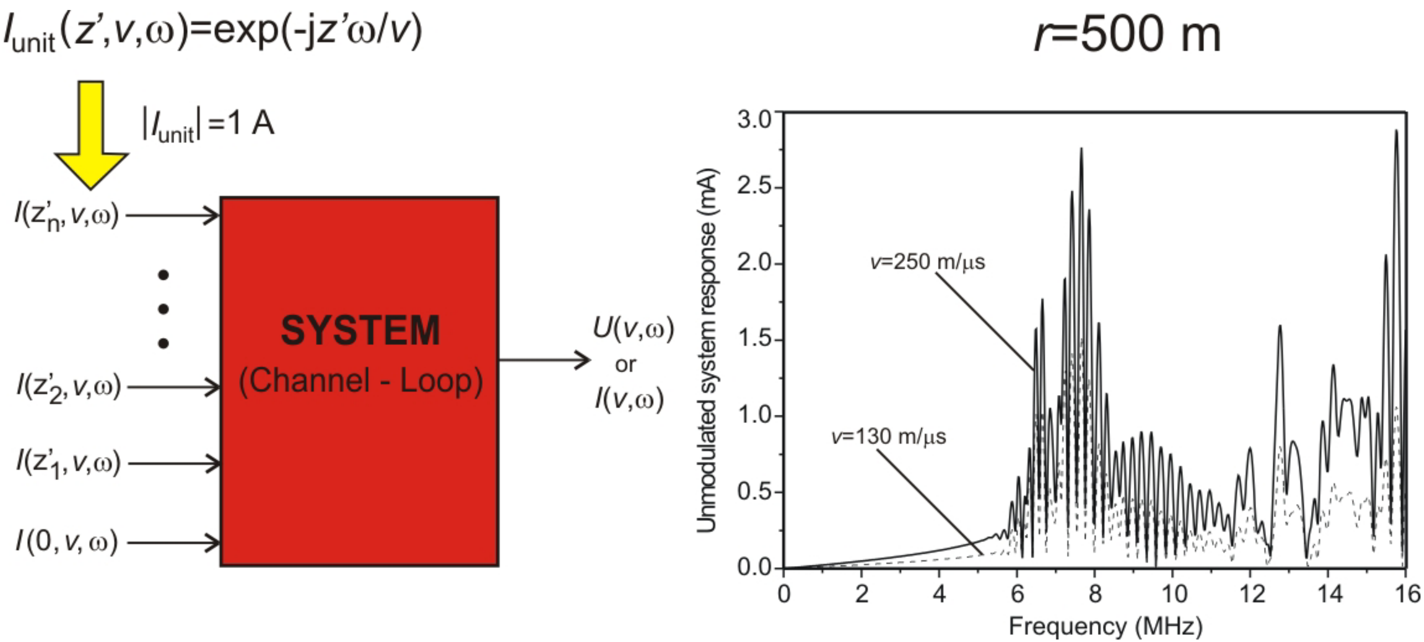


r=100 m



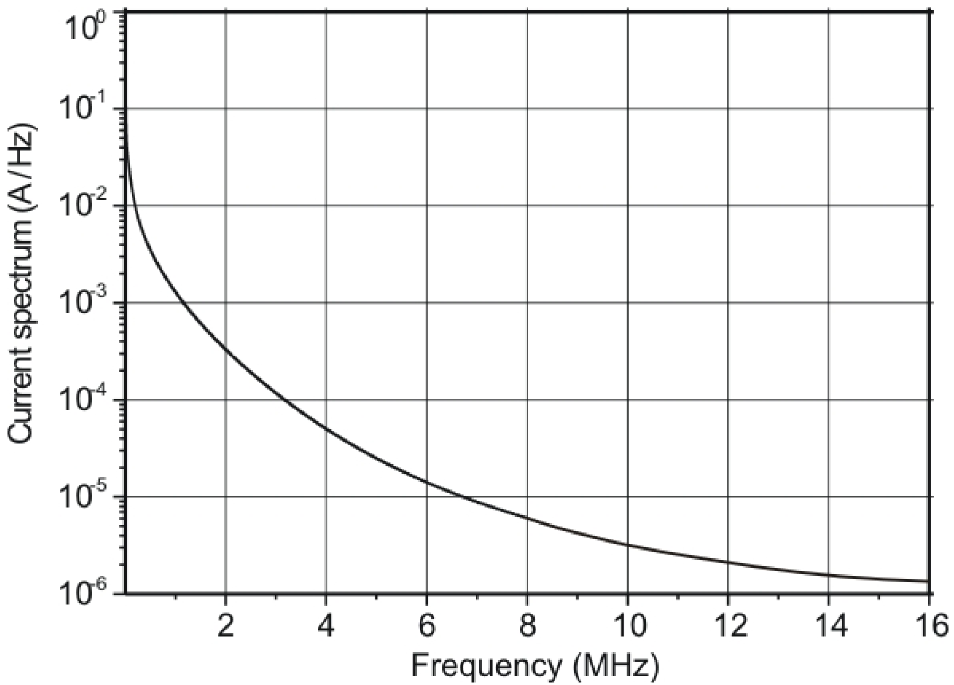
LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

Set of input signals (distributed phased-shifted current sources) and the output signal (induced voltages or currents) and the unmodulated system responses.



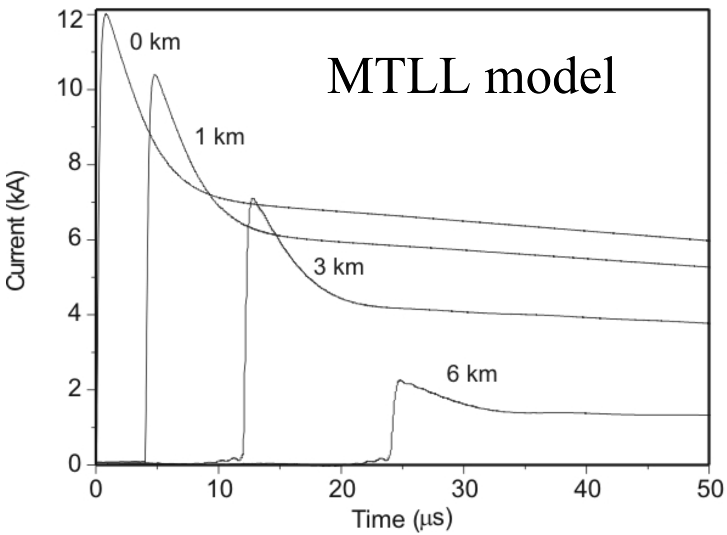
LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

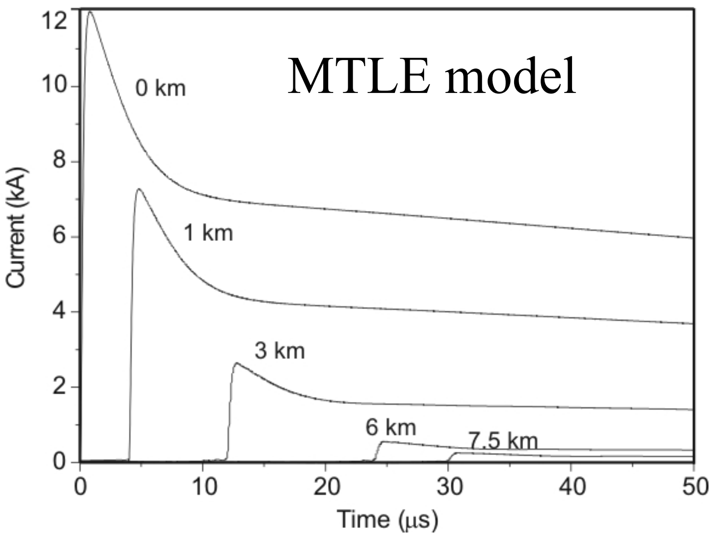
The channel-base current spectrum up to the upper limit of analyzed frequencies



LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

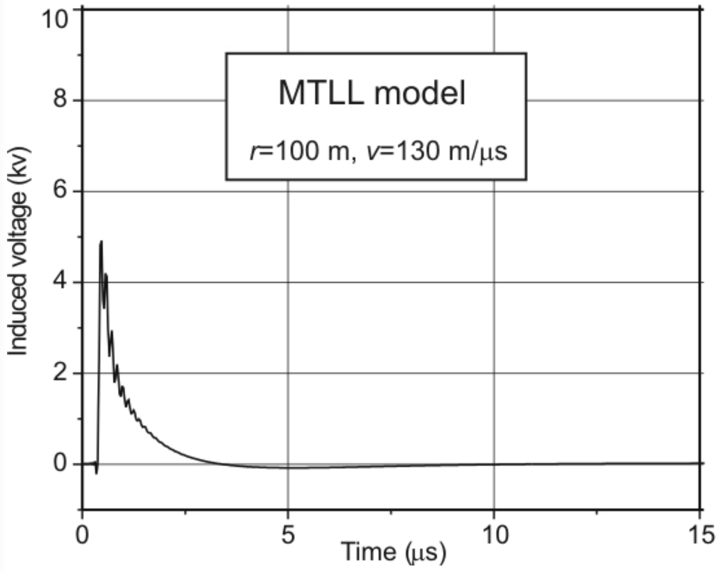
Lightning current calculated based on the transmission-line type models formulated in the frequency domain (*v*=250 m/us)

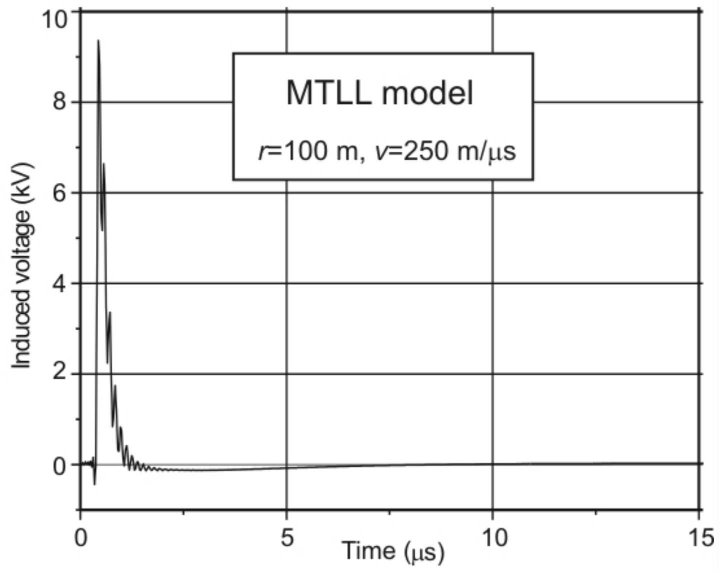




LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

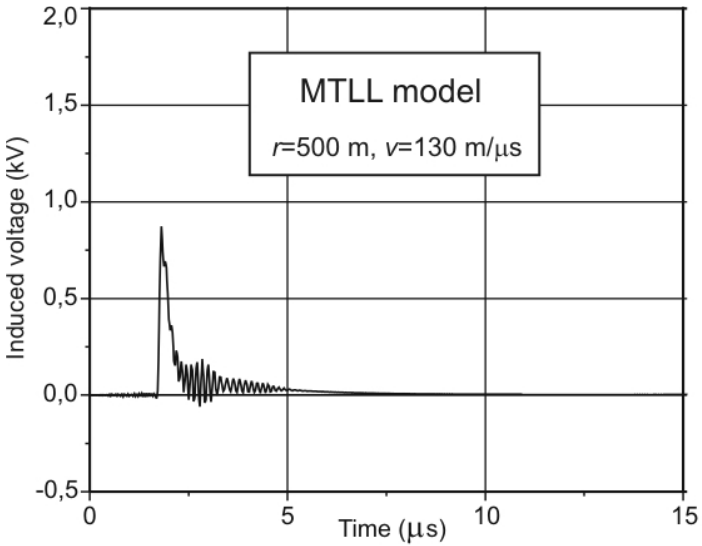
Lightning induced voltages inside the square loop which is situated 100 m far from the lightning return-stroke channel

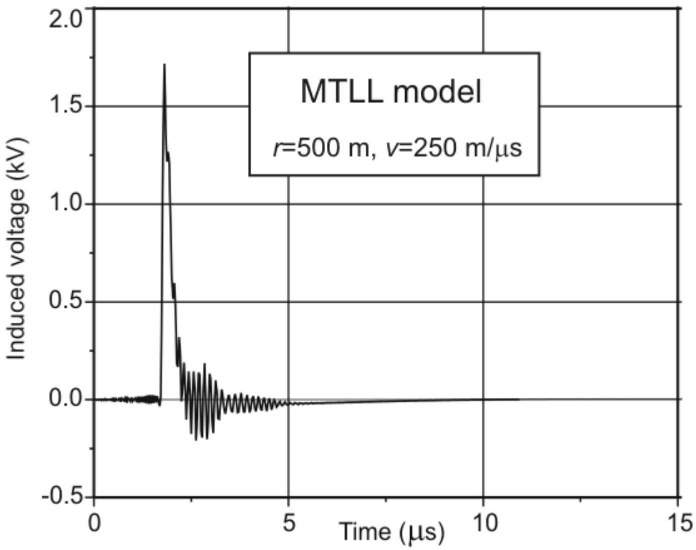




LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

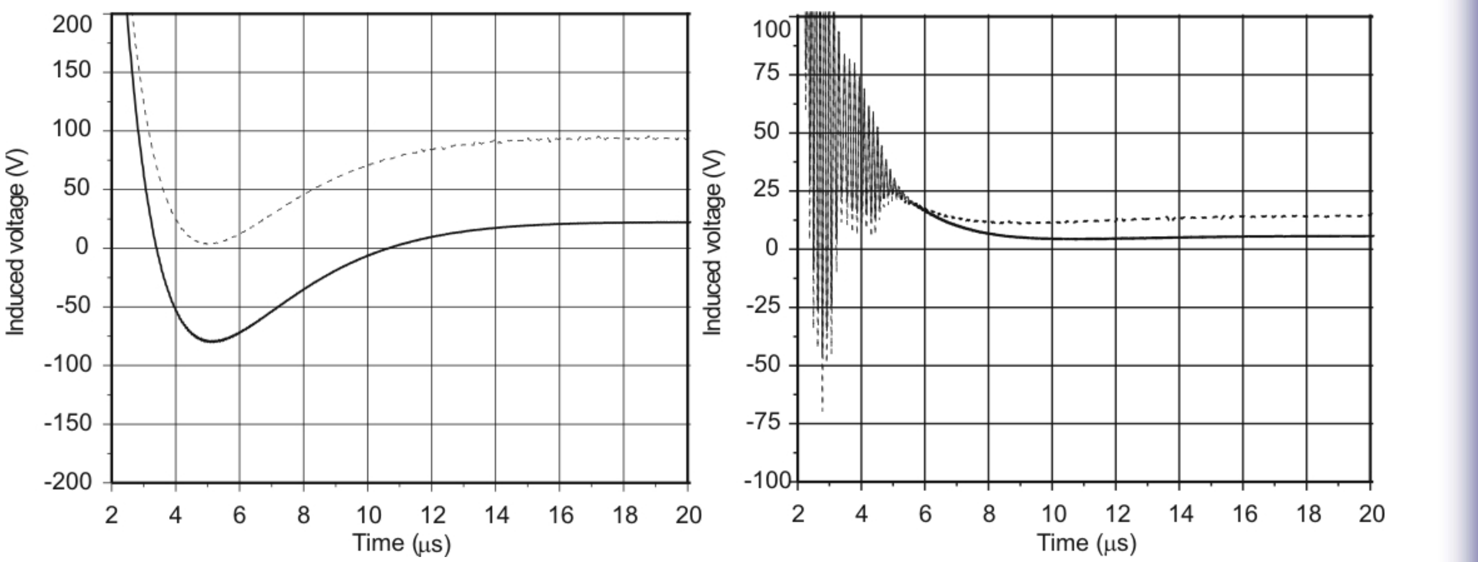
Lightning induced voltages inside the square loop which is situated 500 m far from the lightning return-stroke channel





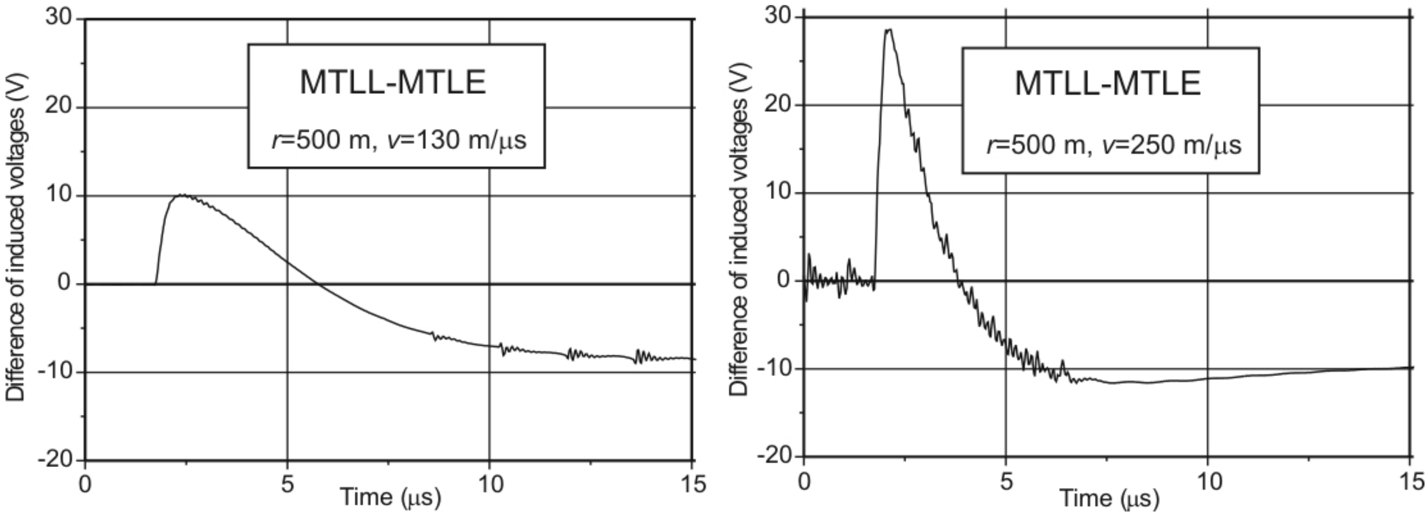
LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

Lightning induced voltages inside the square loop which is situated 100 and 500 m far from the lightning return-stroke channel calculated for the MTLL model (solid line) and the MTLE model (dashed line) for later times (H = 7.5 km, λ = 2 km, v = 130 m/μs).



LIGHTNING INDUCED VOLTAGES INSIDE THE SQUARE LOOP

Differences between the induced voltages calculated based on MTLL and MTLE models at distance 500 m from the lightning channel.



CONCLUSION

- Lightning induced voltages inside a complex system situated above and under the surface of lossy ground can be determined during
full-wave frequency domain calculations and using the frequency domain implementation of the engineering return-stroke models.

- The same approach can be used to determine the lightning induced effects in overhead and buried transmission lines.

- Obtained results show that the lightning voltages induced inside the square loop depend significantly on speed of upward propagating return-stroke front while different attenuation of lightning current predicted by the MTLL and MTLE models gives difference between lightning induced voltages less than 3%.

- Further study of the presented issue will be still continued.