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Measurement of lightning-induced currents in an experimental coaxial buried cable

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Outline

I. Introduction

II. Cable characteristics

III. Experimental set-up

IV. Measurement results

V. Conclusions

Introduction

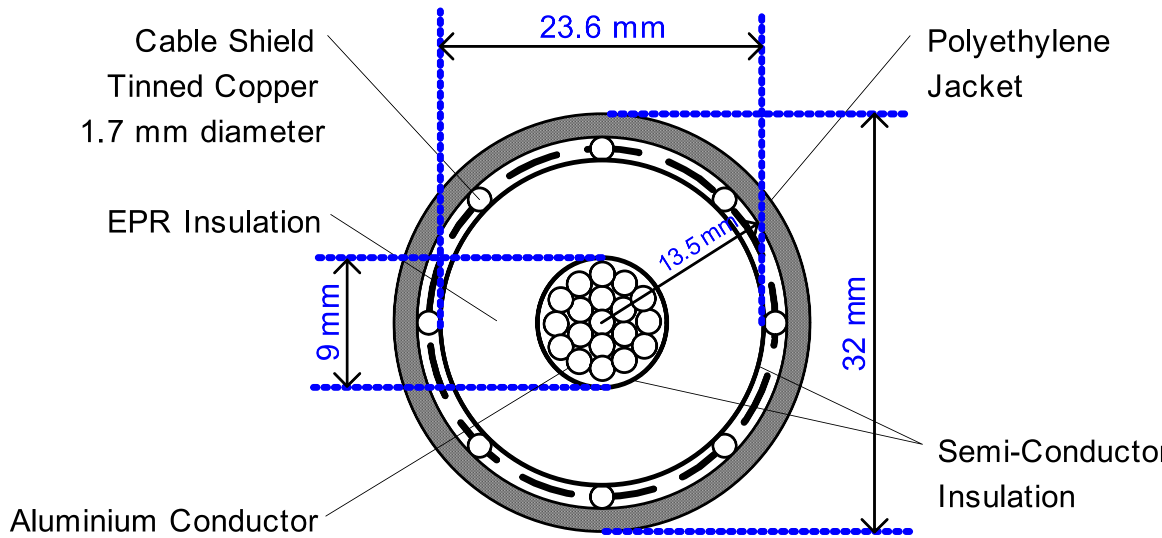
- The paper presents experimental results obtained at the International Center for Lightning Research & Testing (ICLRT), Camp Blanding, Florida. During Summer 2002, current induced by triggered and natural lightning was measured at one end of a distribution network coaxial buried cable, both in the cable shield and in the inner conductor. Simultaneously, the horizontal magnetic field and the lightning return stroke current (for triggered events) were also measured. For the natural events, the recorded induced current waveforms are correlated with the data obtained by the U.S. National Lightning Detection Network (NLDN).
- The paper provides also a discussion of the correlation between the horizontal magnetic field and the induced current, as well as of the effect of lightning stroke position and distance from the buried cable on the induced disturbances.

Cable characteristics

The underground cable:

- 15-kV coaxial power cable
- approximately 140-m long
- contained within a PVC pipe of 11 cm diameter and 0.7 cm thickness
- buried at a depth of 0.9 m.

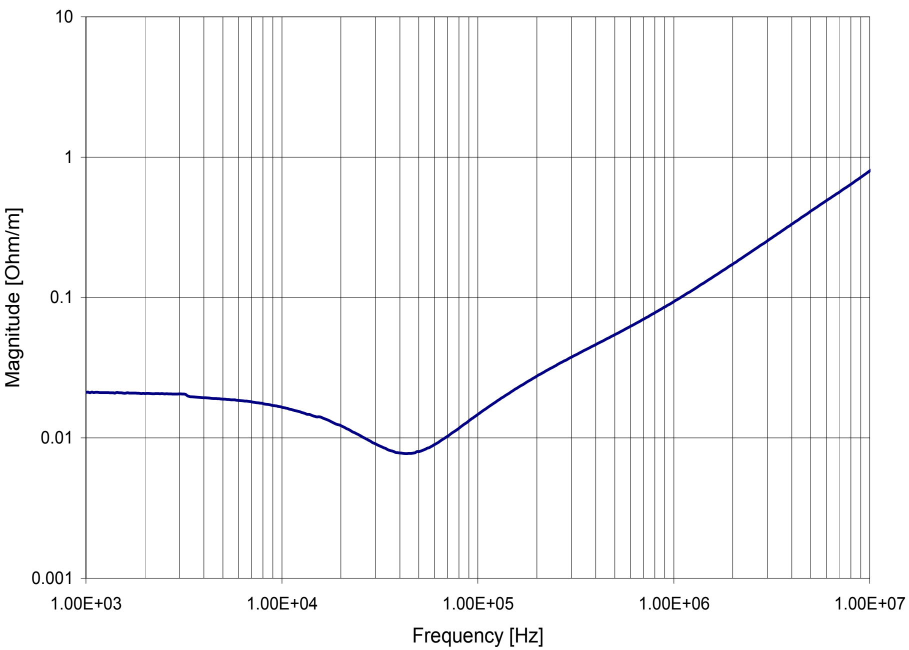
Cable cross-section



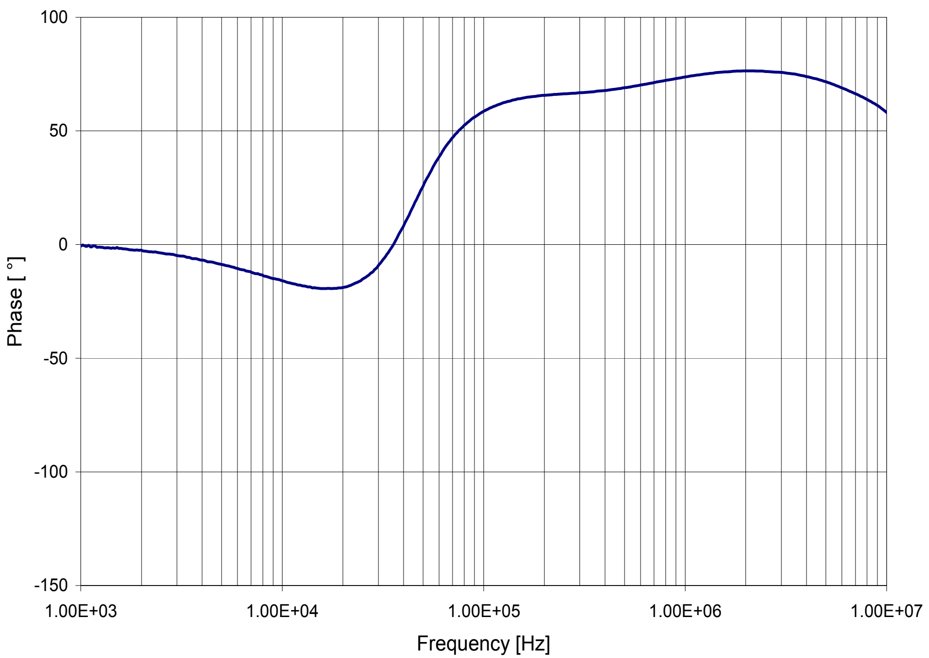
Geometrical parameters of the cable

Cable characteristics – Z_t

Transfer impedance of the shielded cable



Magnitude



Phase

The transfer impedance of the cable has been measured at the EMC laboratory of the Swiss Federal Institute of Technology in Lausanne using a triaxial-adapted measurement set up.

Experimental set-up

The topology of the experimental set-up - *triggered lightning events*

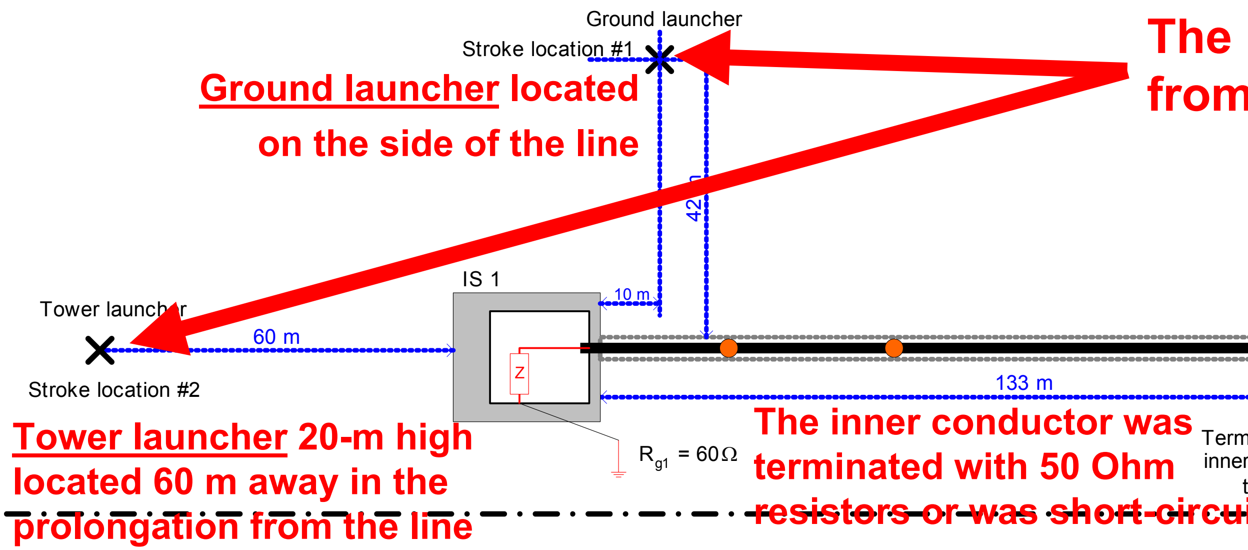
The rockets were launched from

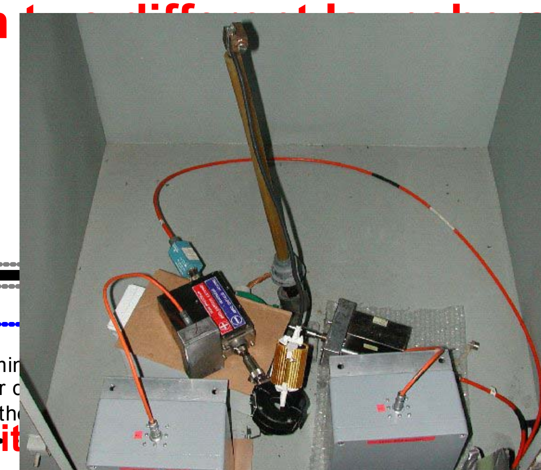
Ground launcher located on the side of the line

Tower launcher 20-m high located 60 m away in the prolongation from the line left-end

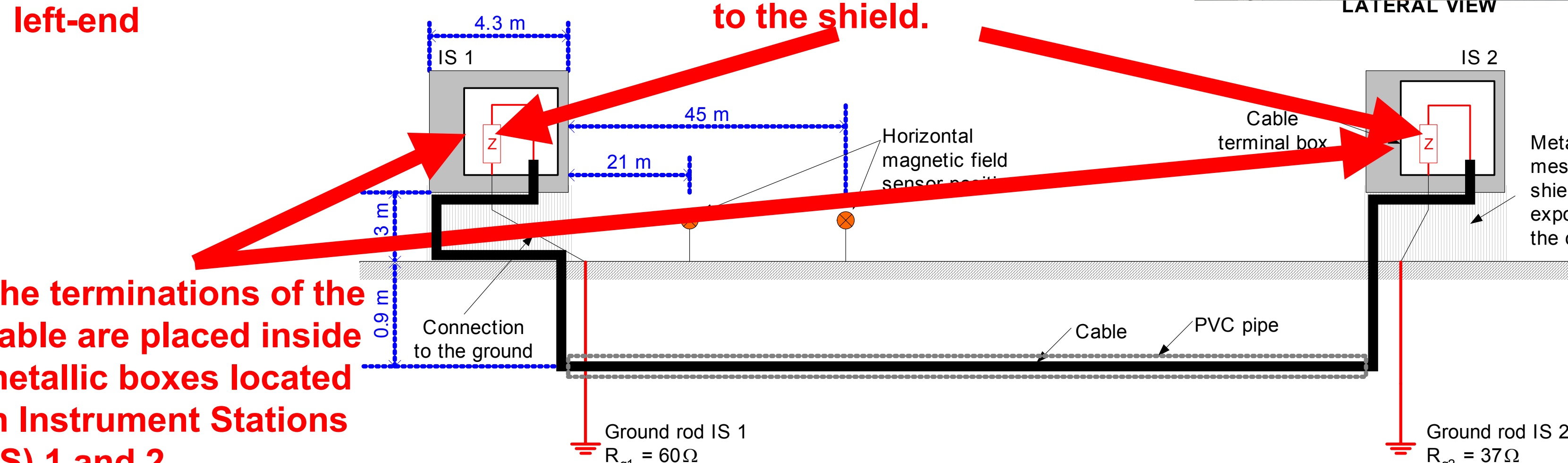
The inner conductor was terminated with 50 Ohm resistors or was short-circuit to the shield.

The terminations of the cable are placed inside metallic boxes located in Instrument Stations (IS) 1 and 2





LATERAL VIEW



Experimental set-up

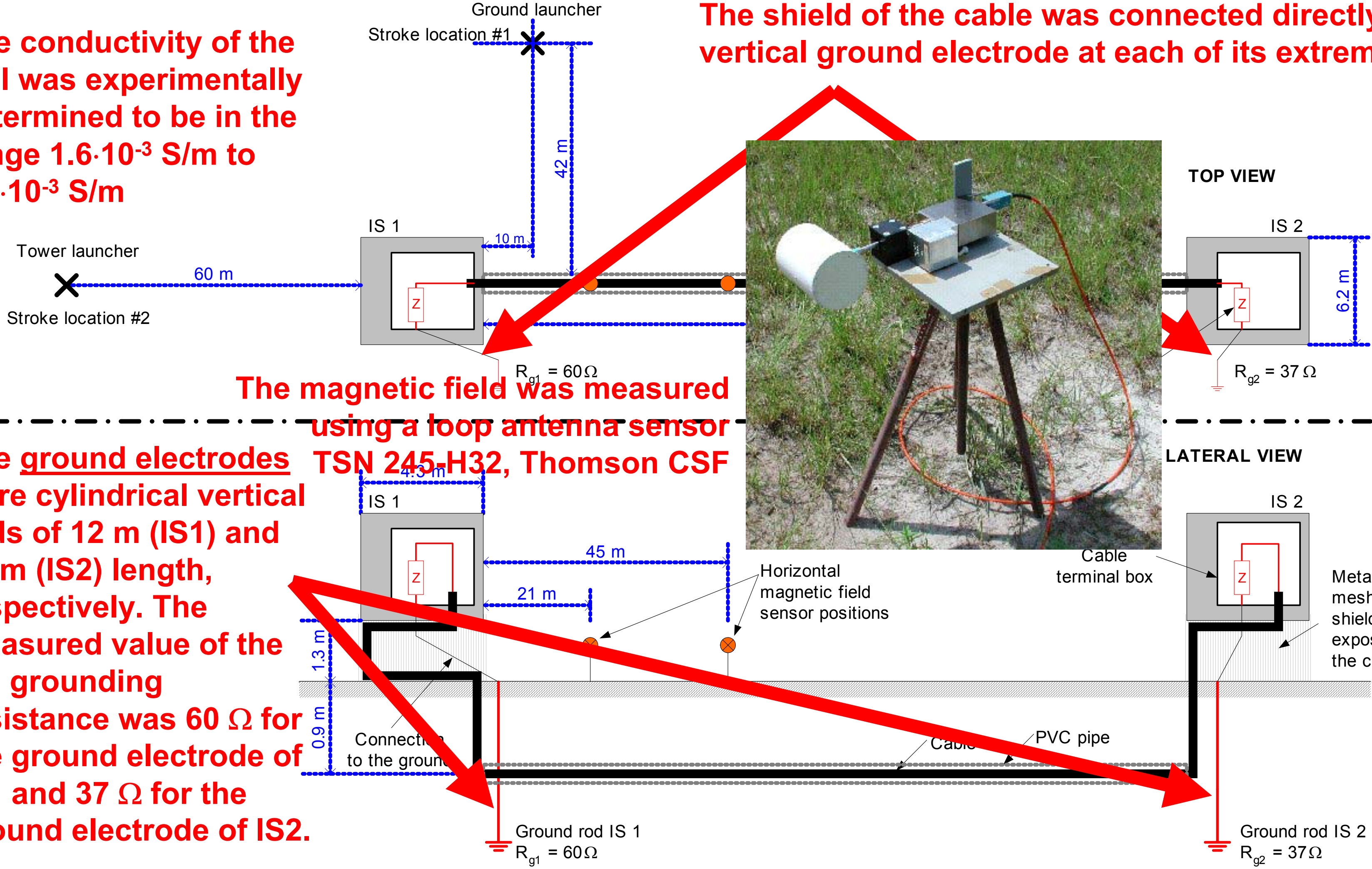
The topology of the experimental set-up

The shield of the cable was connected directly to a vertical ground electrode at each of its extremities.

The conductivity of the soil was experimentally determined to be in the range $1.6 \cdot 10^{-3}$ S/m to $1.8 \cdot 10^{-3}$ S/m

The magnetic field was measured using a loop antenna sensor TSN 245-H32, Thomson CSF

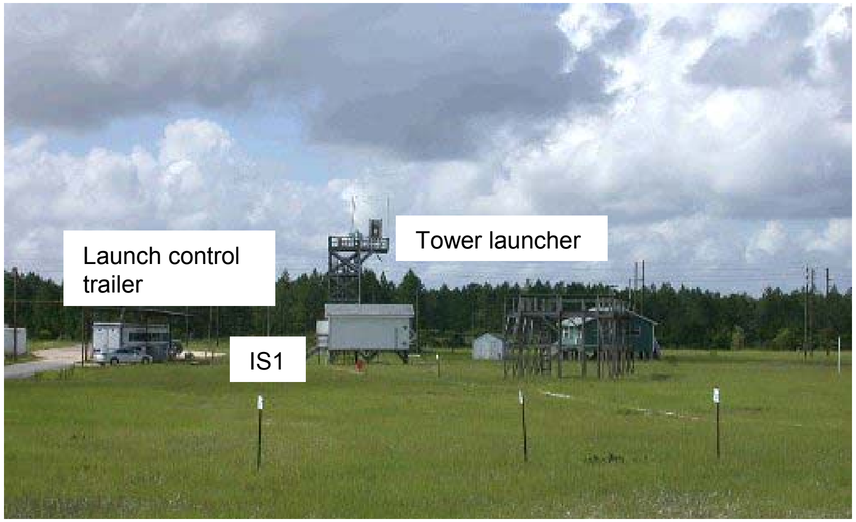
The ground electrodes were cylindrical vertical rods of 12 m (IS1) and 24 m (IS2) length, respectively. The measured value of the DC grounding resistance was 60 Ω for the ground electrode of IS1 and 37 Ω for the ground electrode of IS2.



Experimental set-up

Instrument Stations 1 and 2 and their position with respect to the launchers

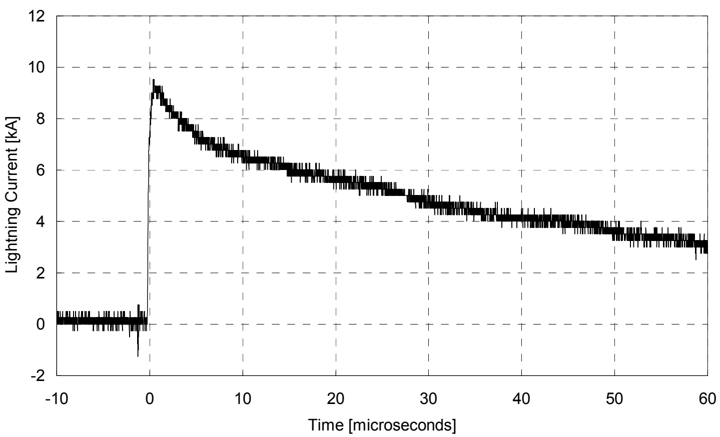
View from the tower launcher



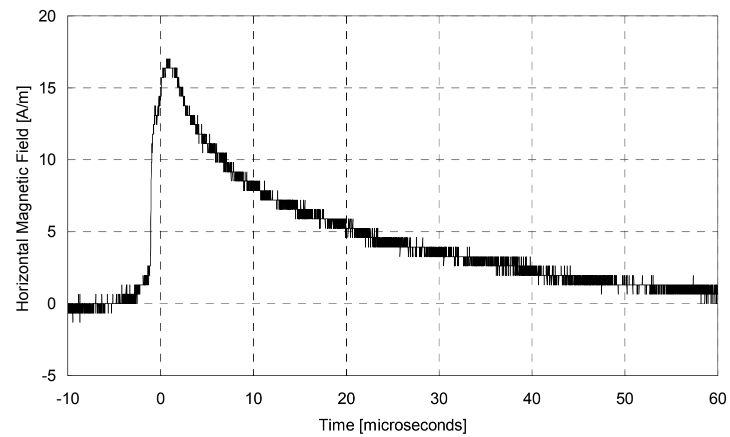
View from IS2

Measurement results - Triggered lightning

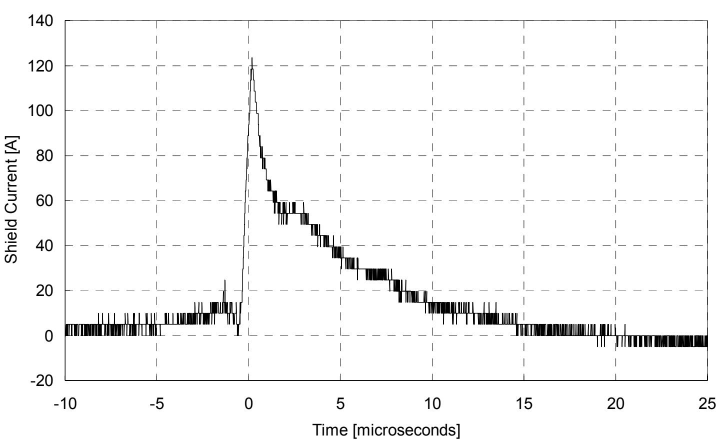
Stroke location 1 (recorded on August 18th, 2002)



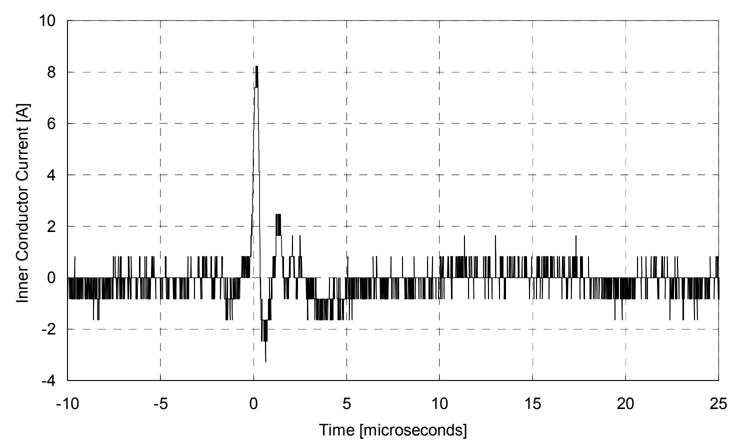
(a) Return stroke current.



(b) Horizontal magnetic field.



(c) Induced current in the cable shield at IS2.



(d) Induced current in the inner conductor at IS2.

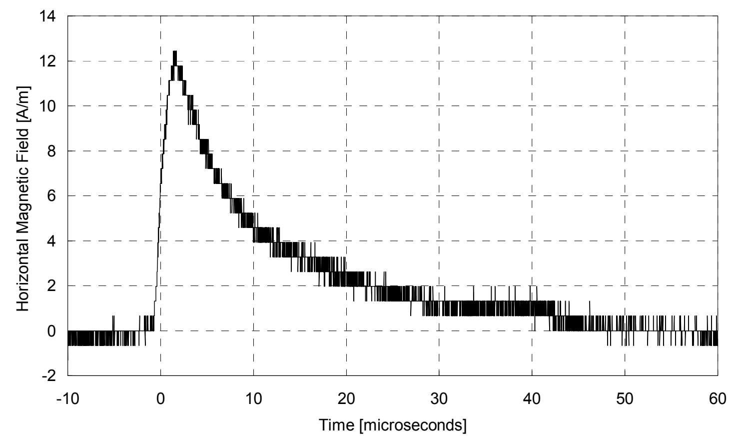
Measurement details:
- the inner conductor was terminated at each ends with a 50 Ω resistor
- the magnetic field sensor was placed 45 meters from IS1 along the path of the buried cable.

Measurement results - Triggered lightning

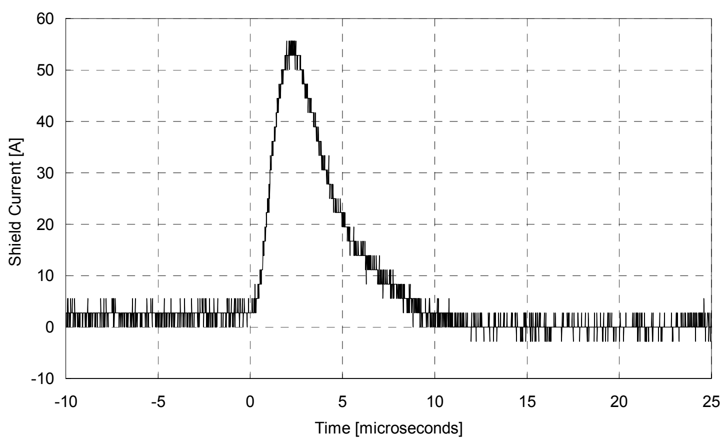
Stroke location 2 (recorded on July 25th, 2002)

Measurement details:

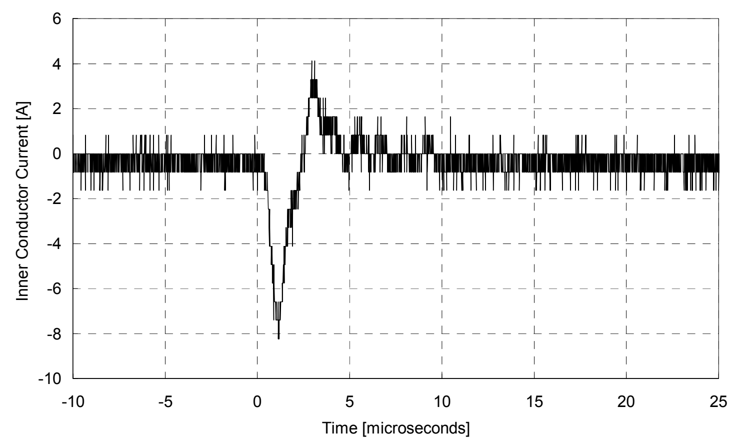
- The lightning current was not measured directly, its peak value can be estimated to be about 11 kA.
- The inner conductor of the buried cable was terminated on a 50 Ω resistor in IS1, and was short circuited in IS2
- The magnetic field sensor was placed 21 meters from IS1 along the path of the buried cable.



(b) Horizontal magnetic field.



(c) Induced current in the cable shield at IS2.



(d) Induced current in the inner conductor at IS2.

Measurement results - Triggered lightning

- In the cases presented above the induced current in the shield of the cable can reach large values about 100 A. The shield current has a unipolar waveshape with a HPW (half-peak width) duration of about 5 μs, shorter than the FWHM of the return stroke current (about 30 μs), as well as that of the magnetic field (about 10 μs).

- Due to the high value of the cable transfer impedance, the current in the inner conductor is a non-negligible fraction of the shield current. As a consequence, the common weak coupling assumption when calculating the response of such a cable might not be adequate.

Measurement results - Natural lightning

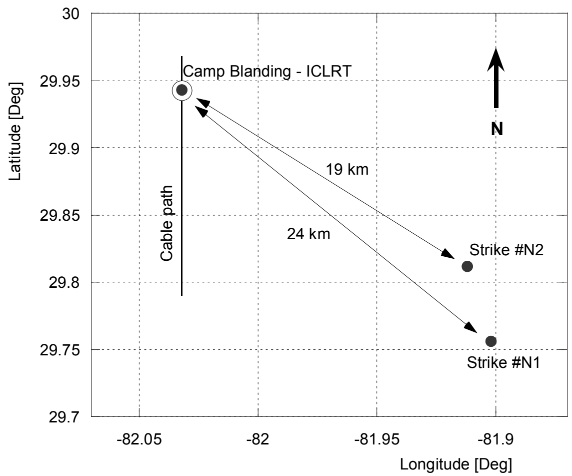
Induced currents from lightning strokes at distant ranges (natural lightning)

During Summer 2002, in addition to the triggered lightning events, we recorded simultaneous waveforms of magnetic field and induced currents in the buried cable due to natural lightning events.

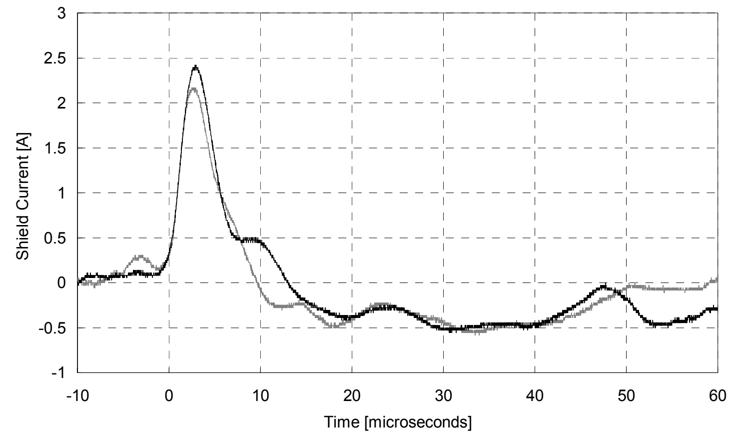
The impact position of the lightning stroke was determined by correlating our records to data obtained from the US National Lightning Detection Network (NLDN).

The inner conductor was terminated at each end in 50 Ω, and the magnetic field sensor was placed 45 m from IS1, oriented to measure primarily the magnetic field component perpendicular to the cable.

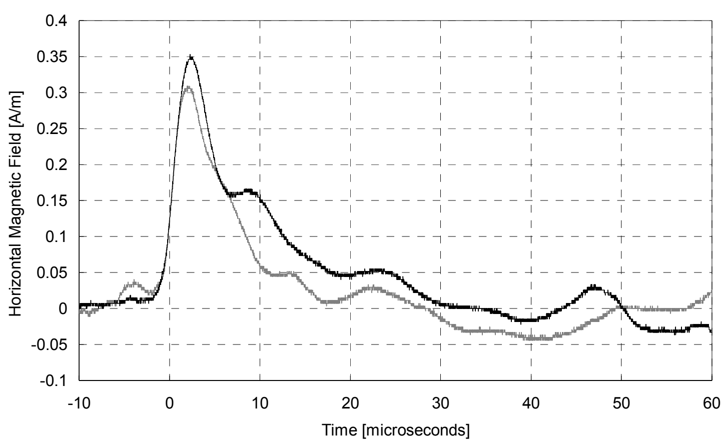
Measurement results - Natural lightning



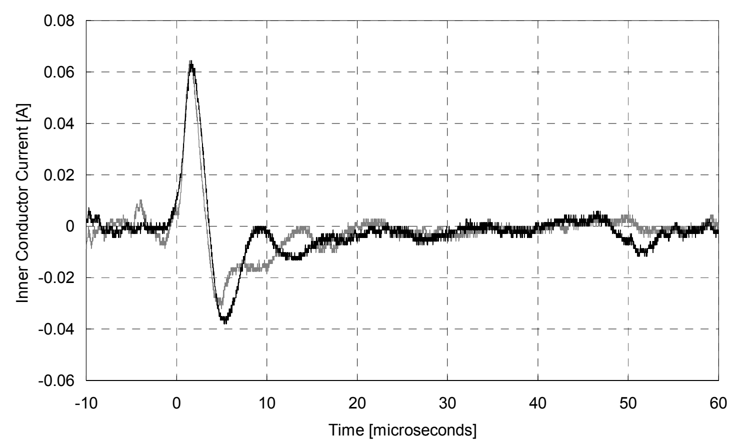
(a) Lightning stroke locations relative to the buried cable.



(c) Induced current in the shield at IS2



(b) Horizontal magnetic field



(d) Induced current in the inner conductor at IS2

Experimental data corresponding to the two natural events occurred on 26 August 2002 at 19:14:51 GMT (Strike #N1) and 19:32:12 GMT (Strike #N2), respectively. Dark line: Stroke location #N1; Grey line: Stroke location #N2.

Measurement results - Natural lightning

- Comparing the triggered lightning event #1 and the natural events #1 and #2 (events in which the cable terminations are the same), where it can be seen that the ratio between the cable induced peak current and the (transverse) magnetic field peak value are similar.
- The waveform of the induced current in the cable shield is very similar to the waveform of the magnetic field. This can be explained by considering that the horizontal electric field along the buried cable that excites the line can be approximately related to the magnetic field through the surface impedance. The resulting horizontal electric field has a waveform similar to the time-derivative of the magnetic field. Since the induced current in the cable shield is obtained by integrating the horizontal electric field along the cable, it will have a similar waveshape to that of the magnetic field.

Conclusions

It is shown that the induced current in the cable shield can reach values of about 100 A for close stroke locations (within 100 m). The induced current in the cable shield is characterized by a pulse width shorter than that of the corresponding magnetic field at close range; while at distant ranges, the induced current waveshape becomes very similar to that of the magnetic field.

Conclusions

Due to the high value of the cable transfer impedance, the current in the inner conductor is a non-negligible fraction of the shield current. As a consequence, the common weak coupling assumption used in calculating the response of such a cable might be inadequate.

The obtained results can be used to validate models of underground cables illuminated by lightning electromagnetic fields.