Experimental results

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The Test Site

LOCATION:

National Institute of Space Research - INPE

Cachoeira Paulista - São Paulo - BRAZIL

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The Test Site

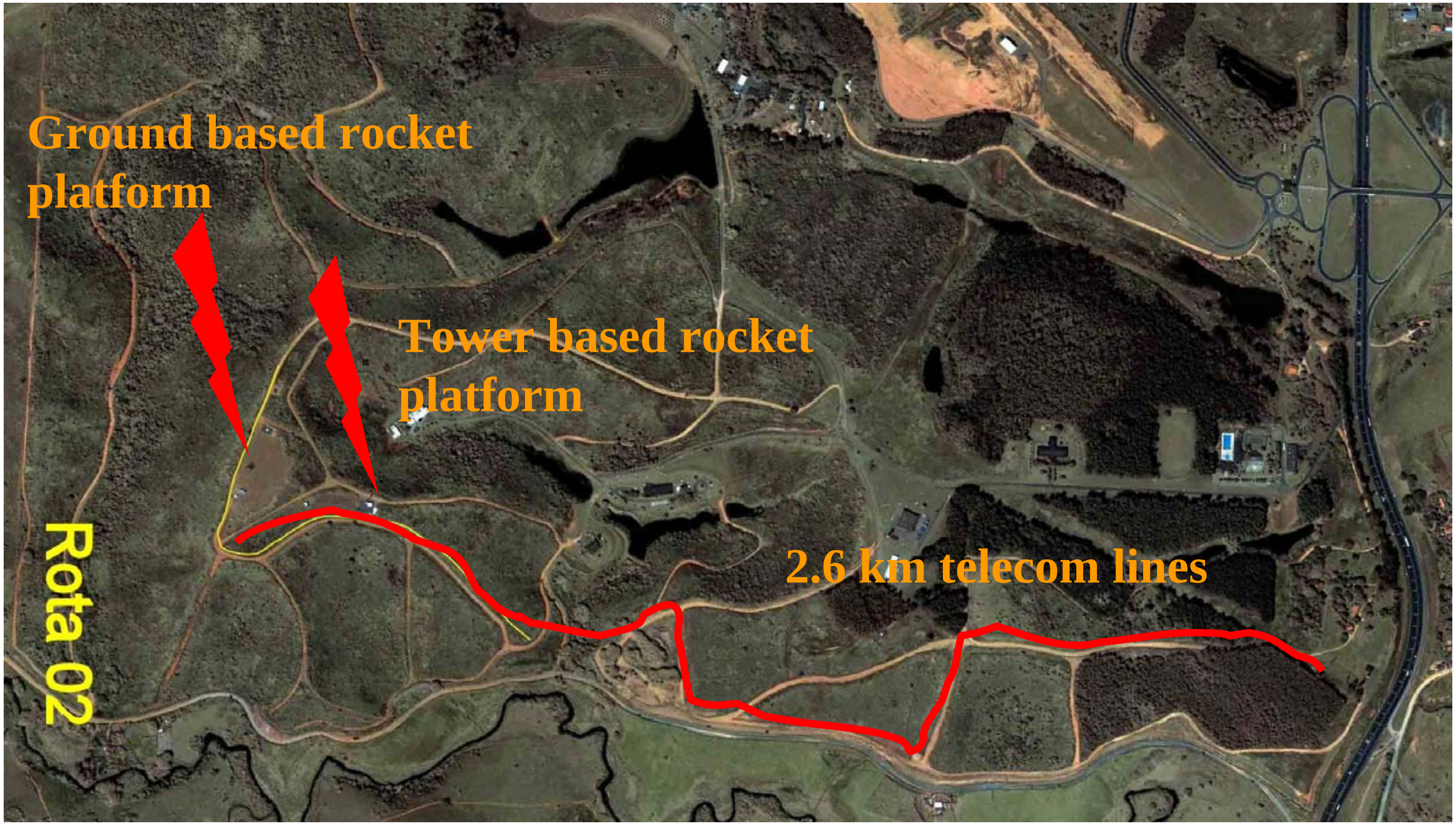
PARTICIPANTS

- **TELECOM EXPERIMENTS**
  - **CPqD Telecom & IT Solutions - Brazil**
  - **France Télécom R&D - France**
  - **Telstra Corp. – Australia**
  - **Federal University of Minas Gerais – Brazil**
  - **State University of Campinas – Brazil**

- **OTHER EXPERIMENTS**
  - **Indelec – France**
  - **National Inst. of Space Research – Brazil**
  - **Hindelet - Brazil**
  - **Hydro-Québec - Canada**
  - **Catholic University of RS - Brazil**

The Test Site

Satellite view



3.0 km

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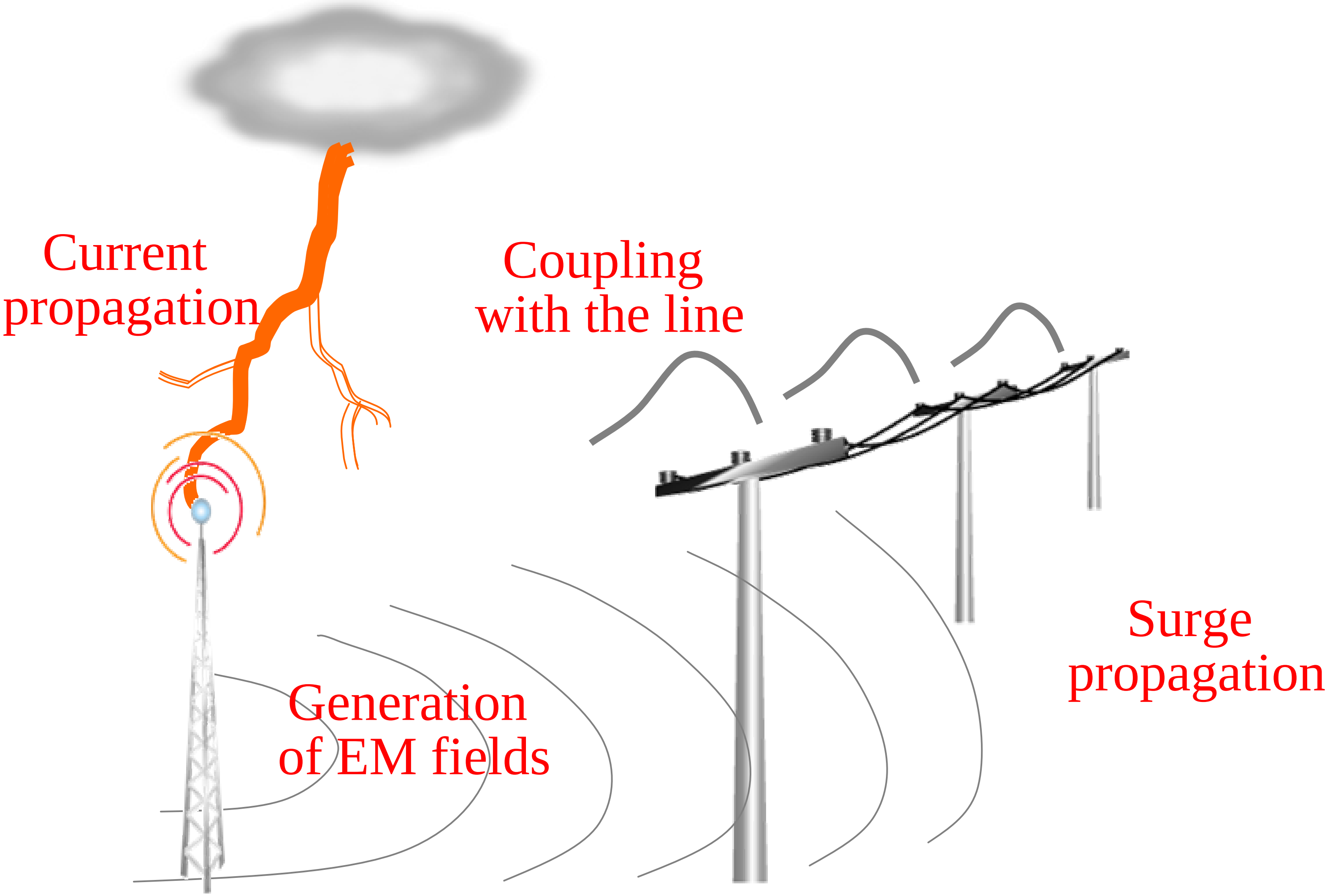
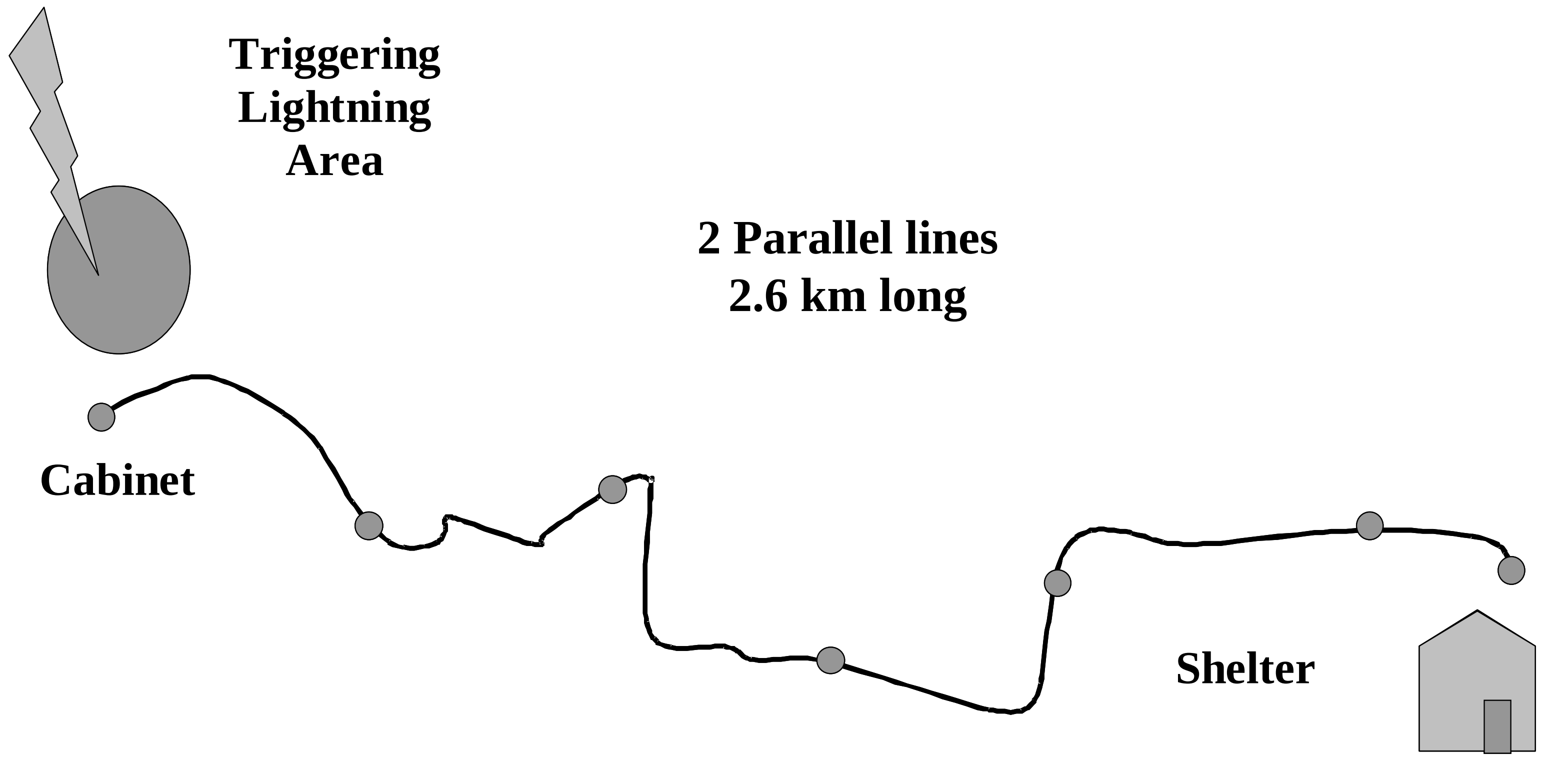
Line Experiments - Rationale



Line Experiments - Rationale

The lines run from near the triggering area up to the Measuring Station (Shelter), which was kept operating 24 hours a day and remotely supervised by wireless modem. Thus, both natural and triggered lightning induced surges could be recorded.

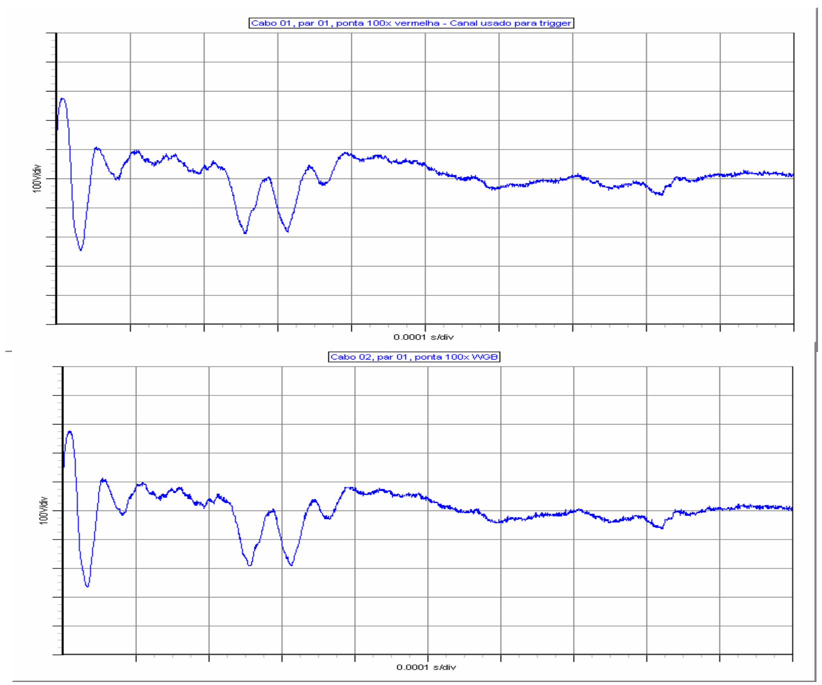


Line Experiments - Rationale

The two lines are identical and have such a separation that:

- **They are close enough to be illuminated by the same electromagnetic fields produced by lightning discharges;**
- **They are far enough so that their electromagnetic coupling can be kept under control.**

Therefore, when the lines have the same configuration, the same lightning surge is induced in both lines.



Line 1
277 V peak

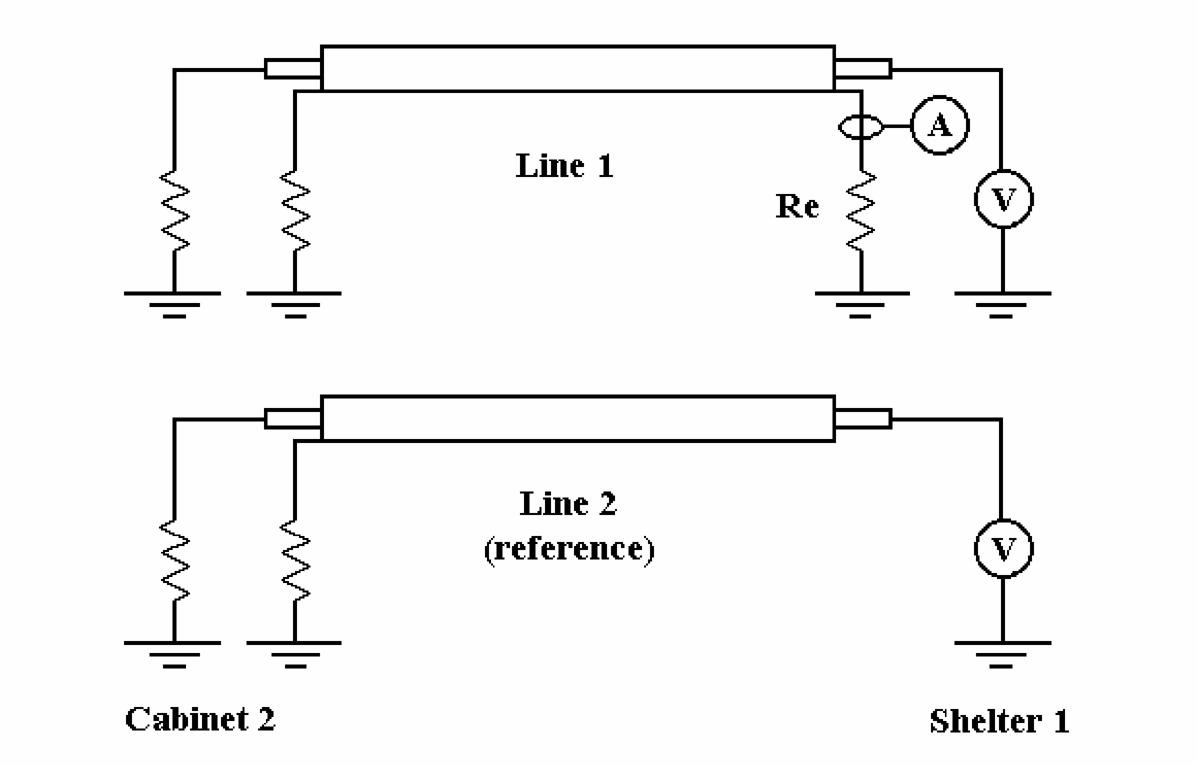
Voltage base
100 V/div

Line 2
277 V peak

Time base
100 μs/div

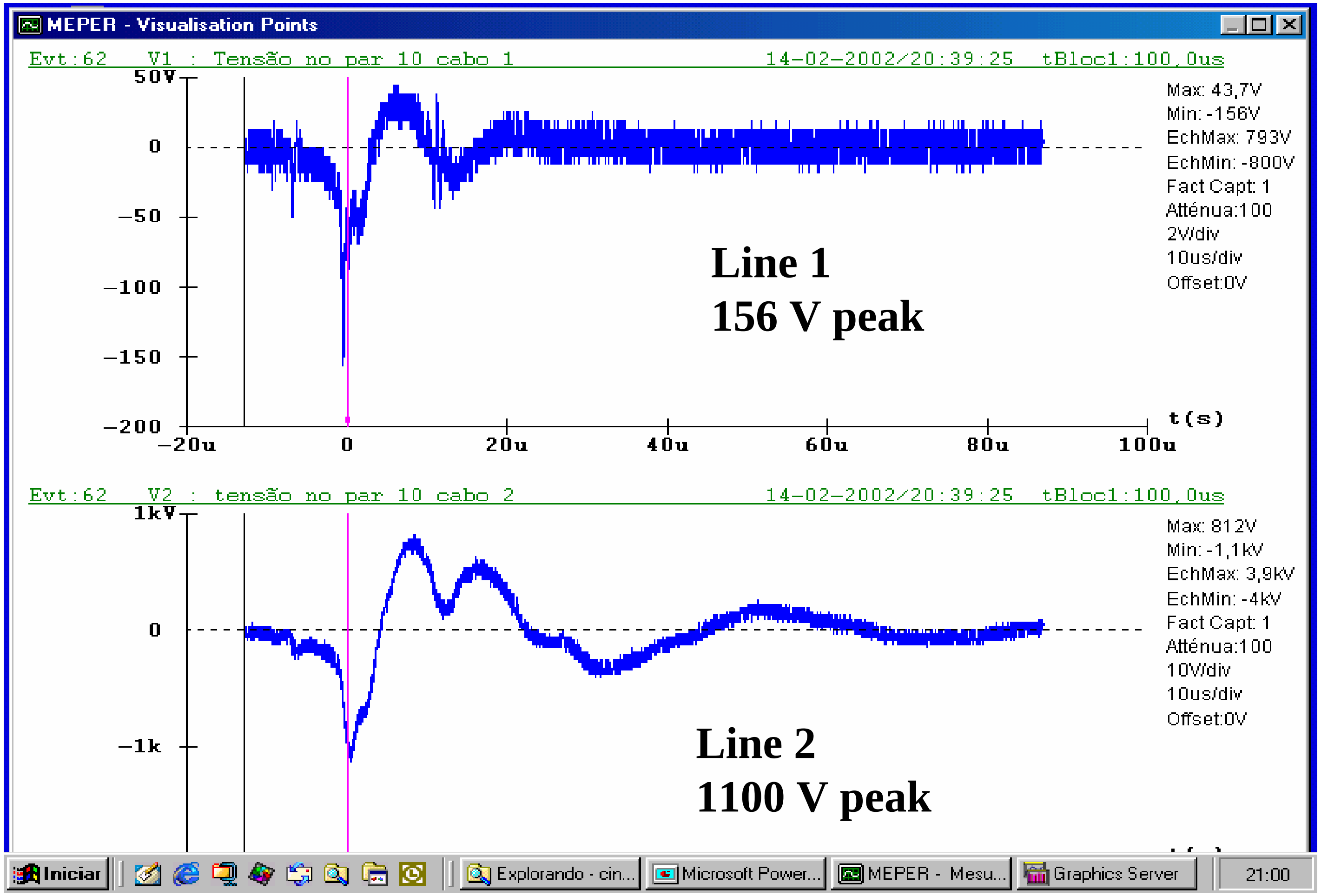
Line Experiments - Rationale

Comparing the lightning induced surges for different earthing configurations of the metallic sheath allows the evaluation of the shielding effect. Also, comparing the surges with and without SPD allows the evaluation of its protective effect.



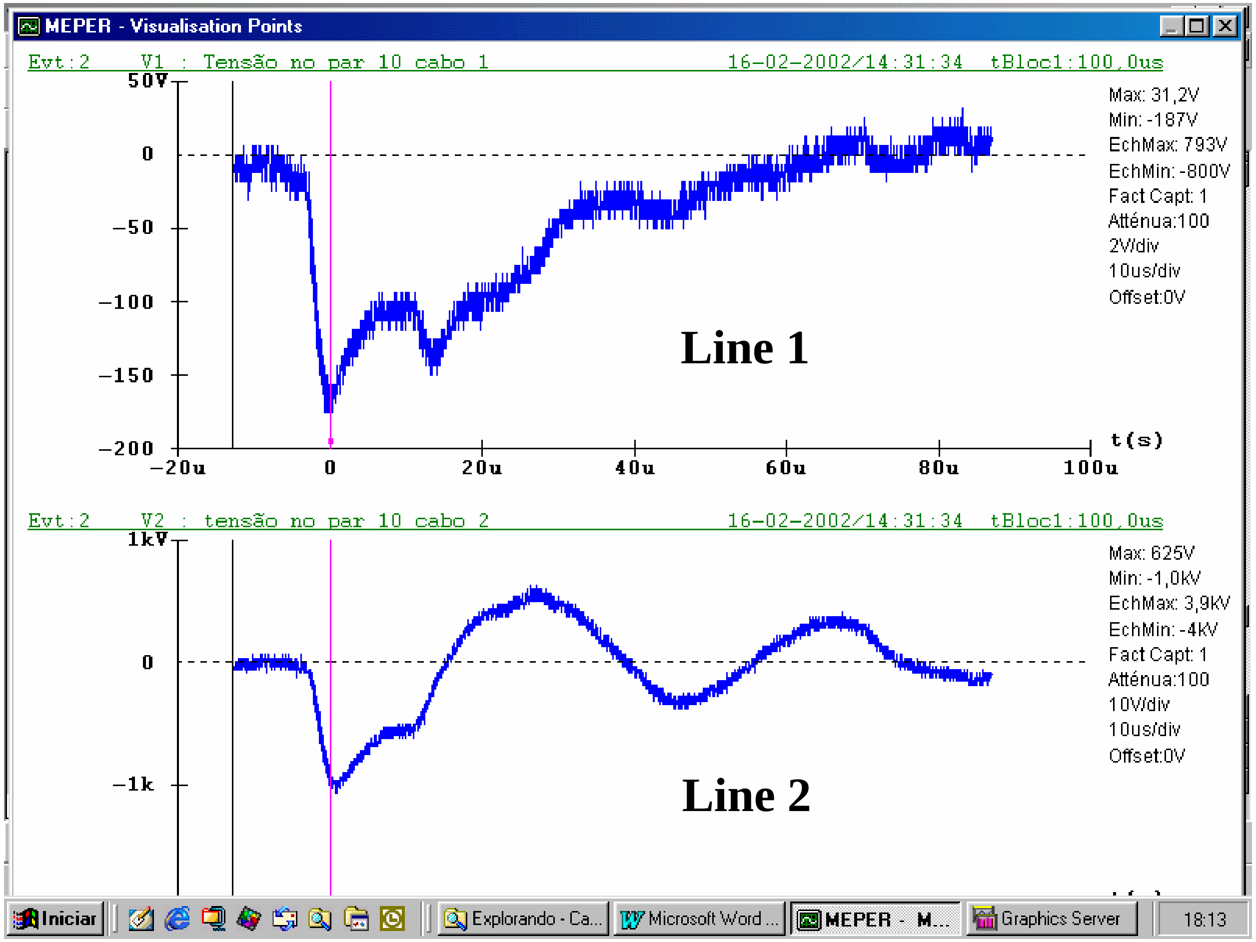
Line Experiments - Results

Line 1 earthed at far end (40 Ω) and near end (40 Ω).
Line 2 earthed at far end (40 Ω) and open at near end.
Shielding effect = 156 / 1100 = 0.14



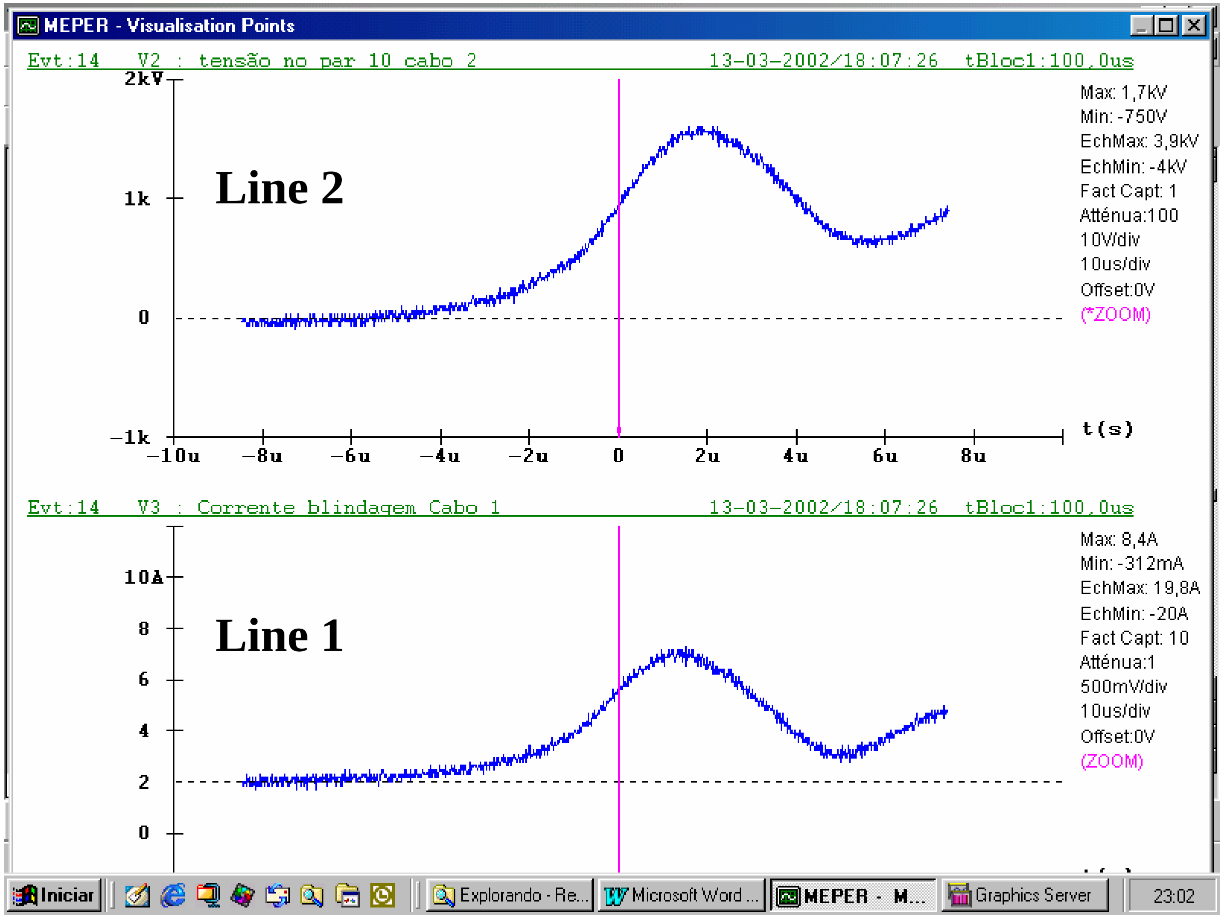
Line Experiments - Results

Peak values are determined by the travelling wave regime, followed by the natural oscillations of the line.



Line Experiments - Results

The ratio between the open circuit voltage in Line 2 to the current to ground in Line 1 is very close to the surge impedance of the line (Z = 440 Ohms).

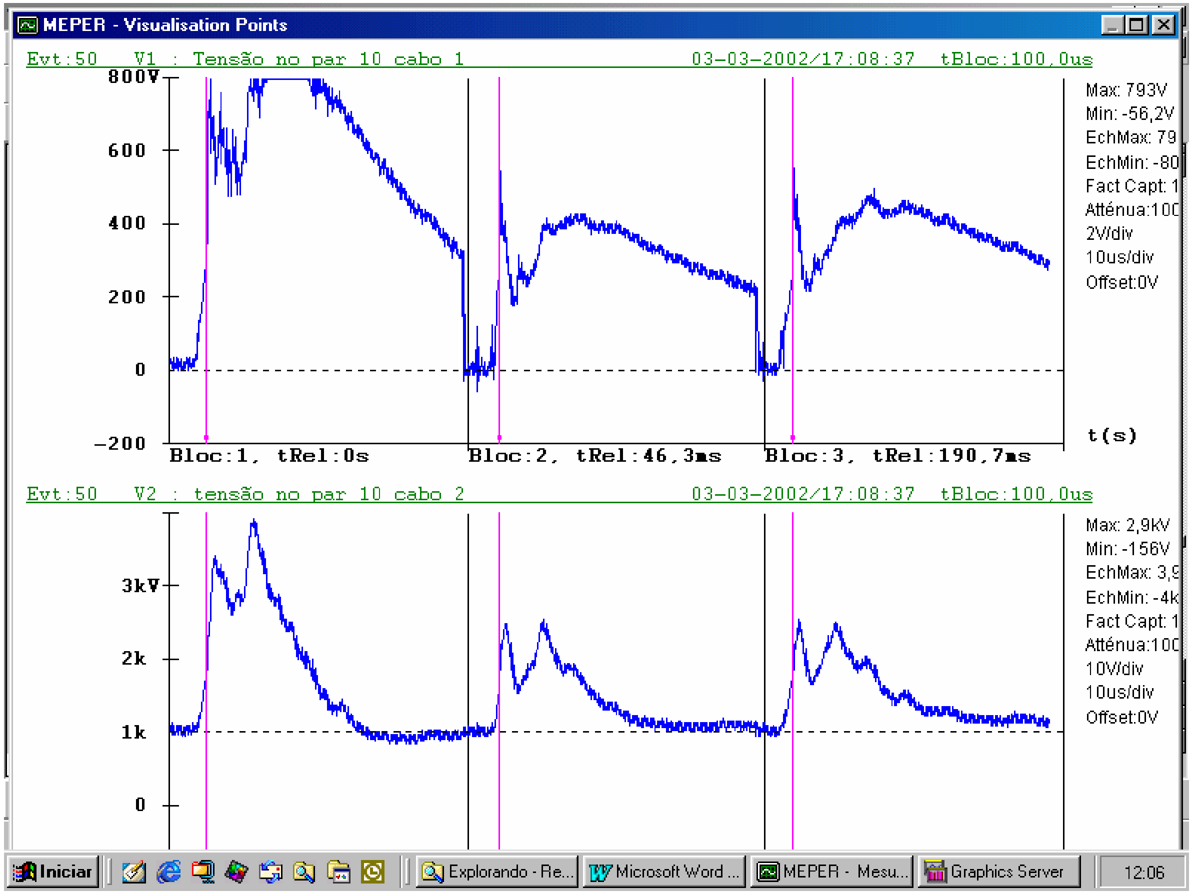


Line Experiments - Results

The wave shape of lightning induced surges due to the return and subsequent strokes are similar, indicating that it's determined by the relative position of the discharge with respect to the line.

Line 1

Line 2



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Line Experiments - Results

Applying travelling wave analysis to the line configuration leads to the following expression for the shielding factor, considering the coupling between the lines:

$$\eta = \frac{(1+\beta)(1+k) + \frac{R}{Z}[(1-\beta)(1-k)]}{2(1+k\beta)}$$

Where:

$\beta = (R_e - Z)/(R_e + Z)$ is the reflection coefficient for Line 1

k is the ratio between the mutual and self line impedances

Z is the line self impedance

R is the sheath resistance (R << Z)

Re is the earthing resistance at the near end

Line Experiments - Results

The comparison between the measured and calculated shielding factor values is shown in table below:

Earthing resistance (Ω)		Shielding factor η_e	
Far end	Near end	Measured	Calculated
40	∞	1,00	1,00
40	40	0,14	0,14
40	80	0,26	0,23
80	40	0,13	0,14

Measured values are based on the average shielding factors taken from 260 pairs of oscillograms.

Line Experiments - Results

- **The shielding effect related to earth provided by the telecommunication cable's metallic sheath can be modelled by the travelling wave theory.**

- **For a stand alone line the shielding factor for a sheath earthing at the line end is given by:**

$$\eta_e = R_e / (R_e + Z)$$

- **If the sheath earthing is made along the line (away from the line ends), it's given by:**

$$\eta_e = 2R_e / (2R_e + Z)$$

- **This result has been incorporated into the Rec.K.46 - "Protection of telecommunication lines with metallic symmetric conductors against lightning induced surges".**

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Line Experiments - Results

Comparison between the shielding effect related to earth calculated by different documents (Z = 400 Ω):

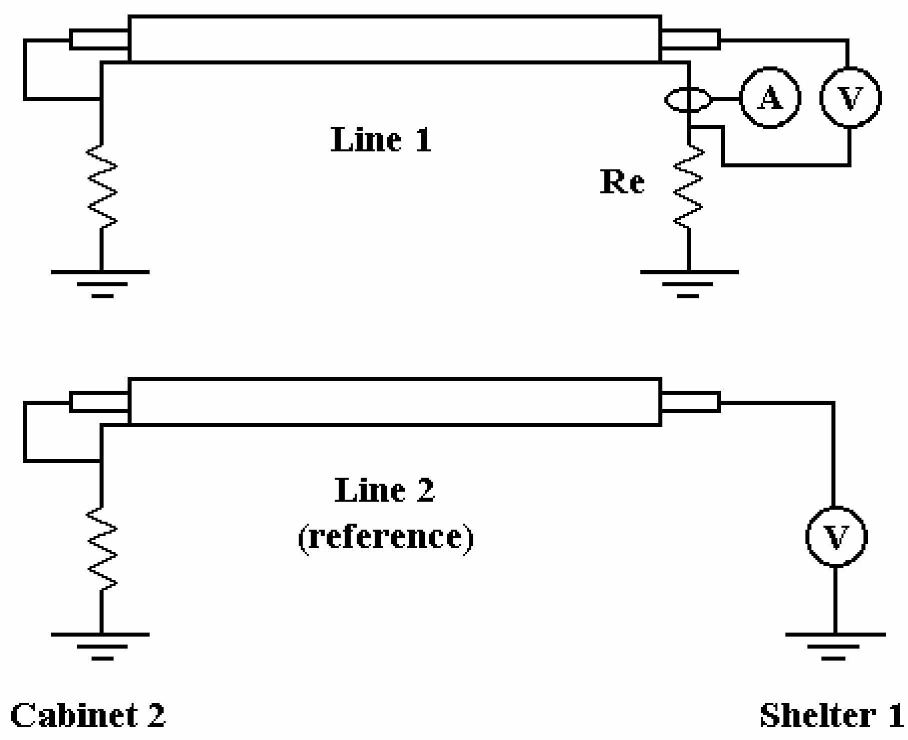
Earthing resistance at the line end (Ω)	Shielding factor related to the earth		
	ITU-T Rec.K.46	Rusck Eq.51	IEC 62305-2
5	0,012	0,012	0,500
10	0,024	0,024	0,500
30	0,070	0,070	0,500
60	0,130	0,130	0,500
100	0,200	0,200	0,500

- **In IEC 62305-2 (Table B7) this shielding factor is called "shield not bonded to equipotential bonding bar to which equipment is connected" and it's assumed as 0,5 independently of the earthing resistance value.**

- **In Rusck's Equation 51 the sheath height was considered equal to the conductor's height and the mutual impedance equal to the self impedance, which is the case for a telecom cable.**

Line Experiments - Results

For the shielding factor related to the shield (η_s) the following experiment has been carried out:



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Line Experiments - Results

For the shielding factor related to the shield (η_s) the following equation gives a conservative value for the experimental results, where Rs is the resistance of the metallic sheath and Z is the line surge impedance:

$$\eta_s = R_s / Z$$

Values of η_s from the test lines
(average from 46 pairs of oscillograms)

Maximum	**0.018**
Minimum	**0.0054**
Average	**0.013**
Median	**0.013**
Theoretical	**0.017**

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Line Experiments - Results

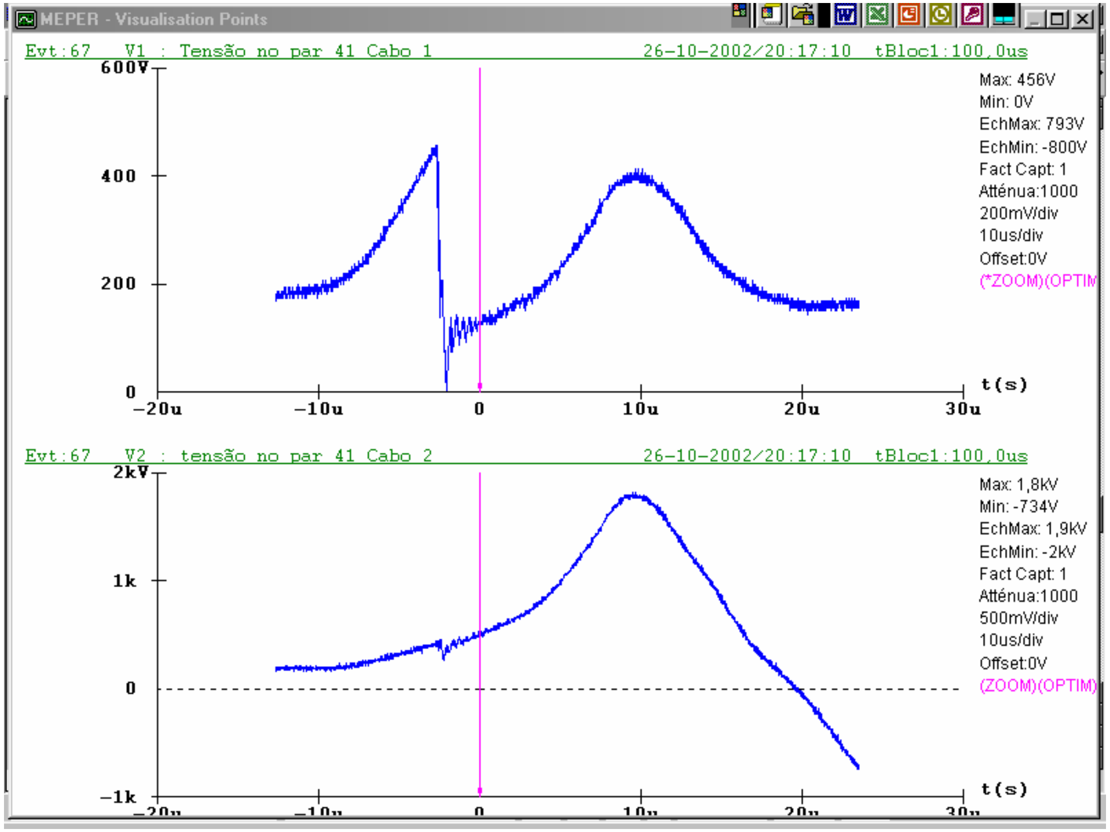
Comparison between the shielding effect related to shield calculated by different documents (Z = 400 Ω):

Resistance of the cable sheath (Ω)	Shielding factor related to the shield		
	ITU-T Rec.K.46	IEC 62305-5	New Equation
2	0,042	0,042	0,005
5	0,098	0,098	0,013
10	0,18	0,18	0,025
30	0,40	0,40	0,075
60	0,57	0,57	0,15

Proposal: to revise η_s in Rec. K.46

Line Experiments - Results

The protective effect of SPD in an unshielded line was also analysed using the same approach as for the shielding factor.



Example of voltages at line termination with and without SPD.

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Line Experiments - Results

- **The protective effect provided by the installation of SPD at an unshielded telecommunication line can be modelled by the travelling wave theory.**

- **The protective effect of a SPD installed at the line end is given by:**

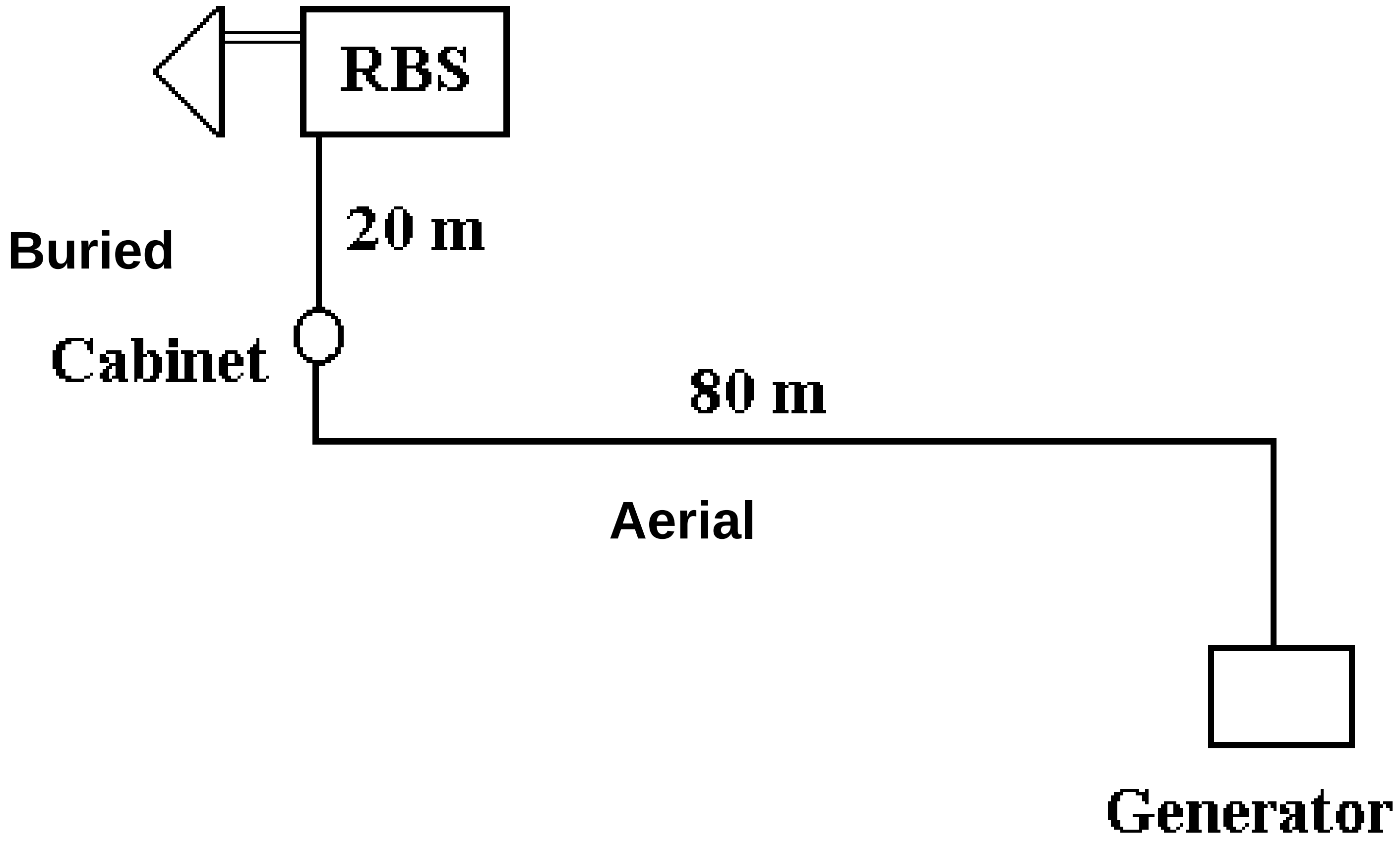
$$K_{SPD} = R_e / (R_e + Z)$$

- **If the sheath earthing is made along the line (away from the line ends), it's given by:**

$$K_{SPD} = 2R_e / (2R_e + Z)$$

- **These equations are also in line with Rusck's Equation 178 and should be incorporated into the Rec.K.46.**

The Test Site – RBS Experiments



The Test Site – RBS Experiments

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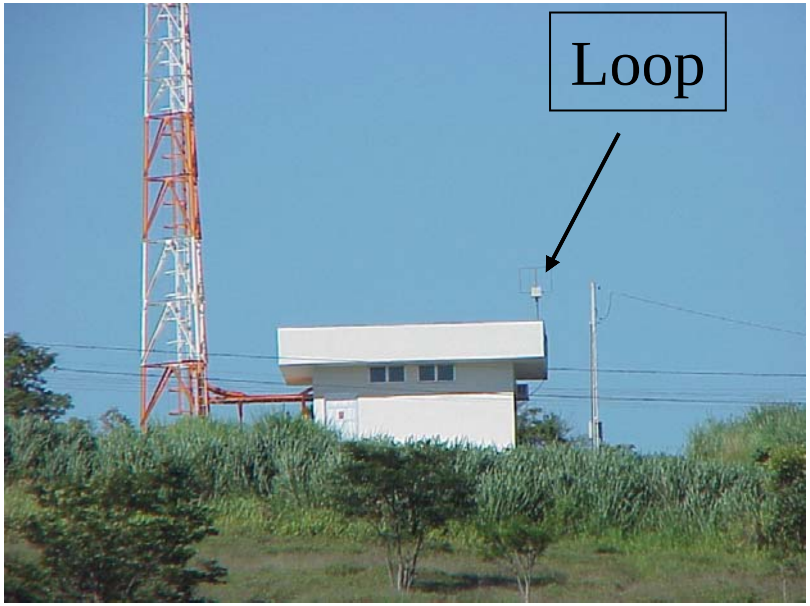
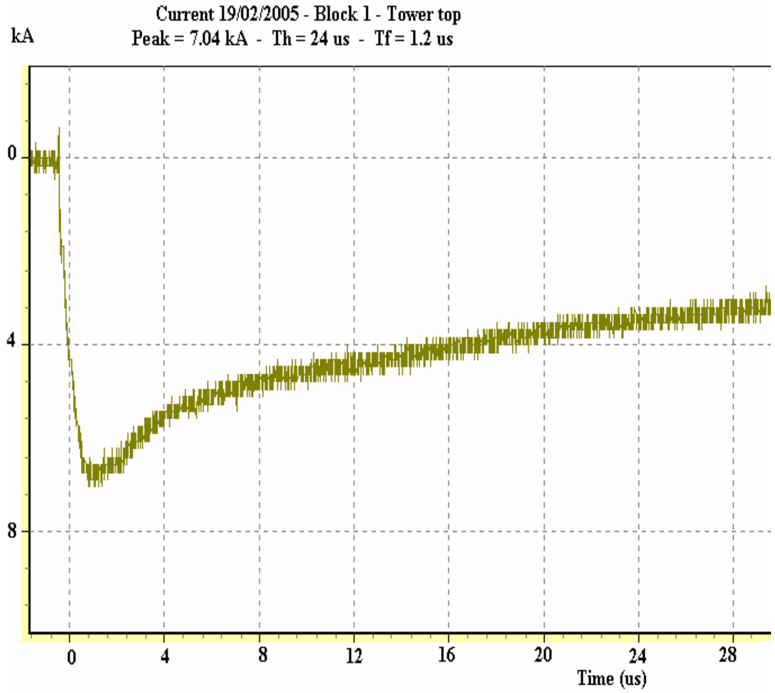
RBS Experiments - Results

Current recorded into a short circuited loop:

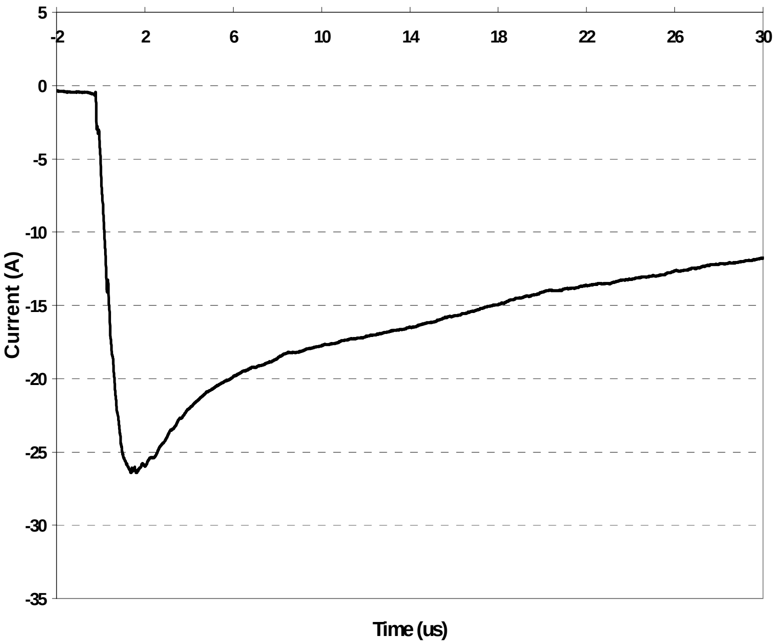


RBS Experiments - Results

Lightning current



Loop current



Same wave shape and peak values corresponding to the ratio between the loop self inductance and the mutual inductance between the lightning channel and the loop. Result incorporated into K.surge.

RBS Experiments - Results

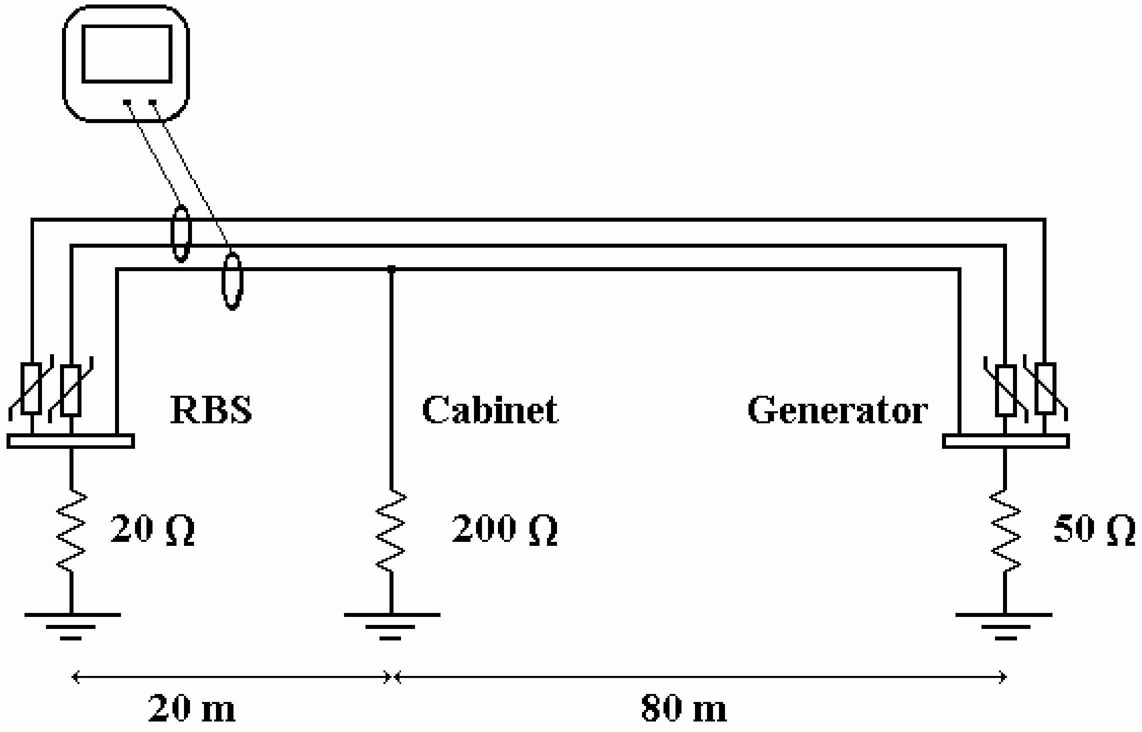
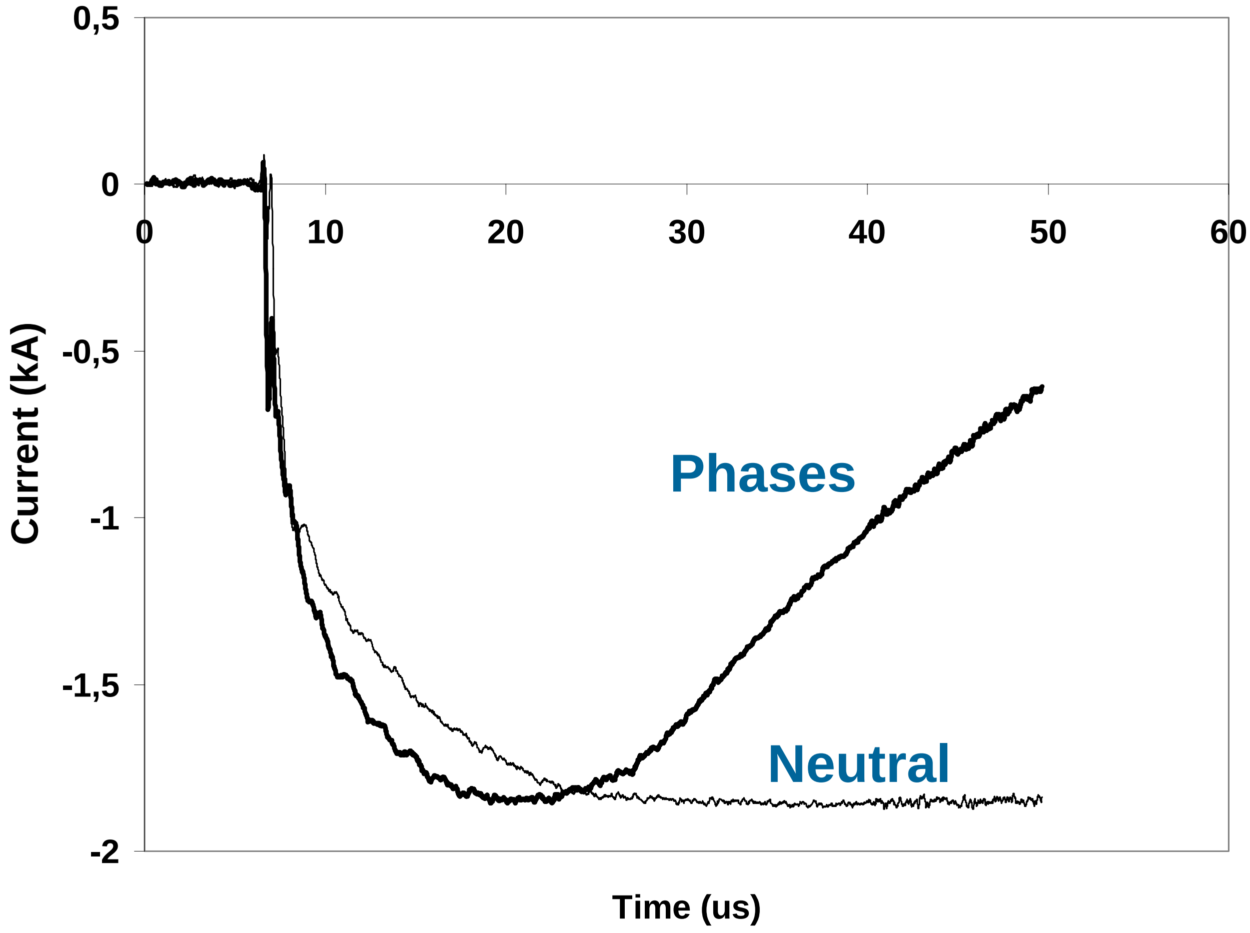


Diagram for the current measurement on the power conductors (2 phases and 1 neutral)

RBS Experiments - Results



Currents measurement on the power conductors

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RBS Experiments - Results

Parameter	Lightning stroke	Phase	Neutral
Front time	0,3 μs	10 μs	20 μs
Time to half value	25 μs	37 μs	>>50 μs
Peak value	11.7 kA	0.95 kA	1.9 kA
Average di/dt	39 kA/ μs	95 A/ μs	95 A/ μs
Maximum di/dt	270 kA/ μs (only at the top)	1.7 kA/ μs	2.8 kA/ μs

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RBS Experiments - Results

The power conductors carried about 1/3 of the total lightning current

The average di/dt on the phase conductor is only 0.24% of the average di/dt of the stroke current

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RBS Experiments - Results

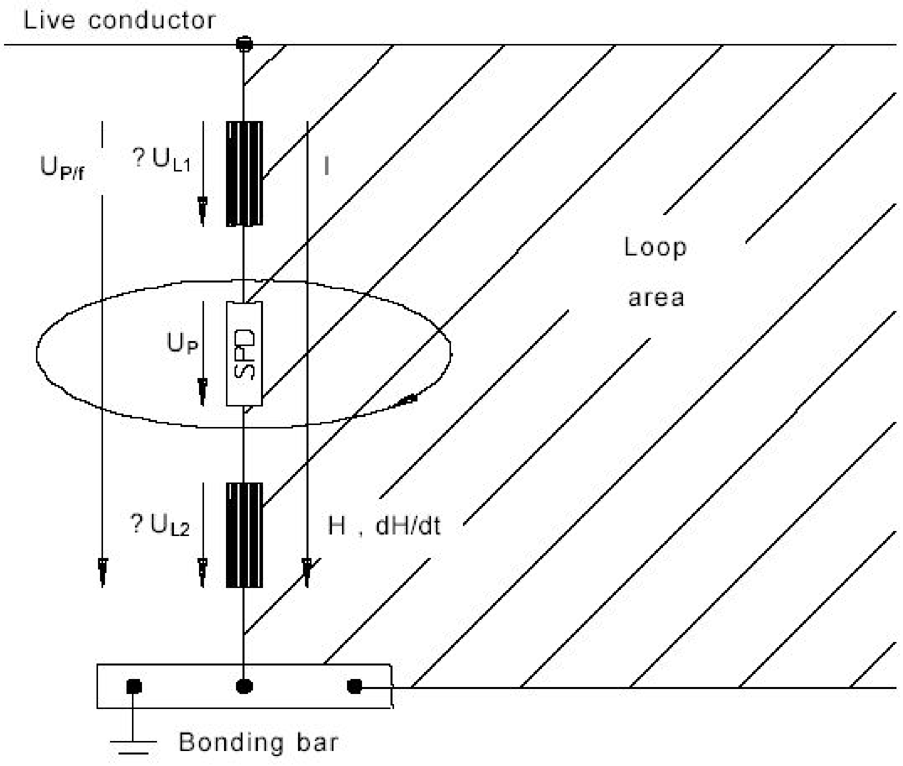
$$V = V_p + L_e . \frac{di}{dt}$$

V = inductive voltage drop on SPD's conductors

di/dt = time derivative of the current

Vp = SPD's residual voltage

Le = inductance of SPD's conductors



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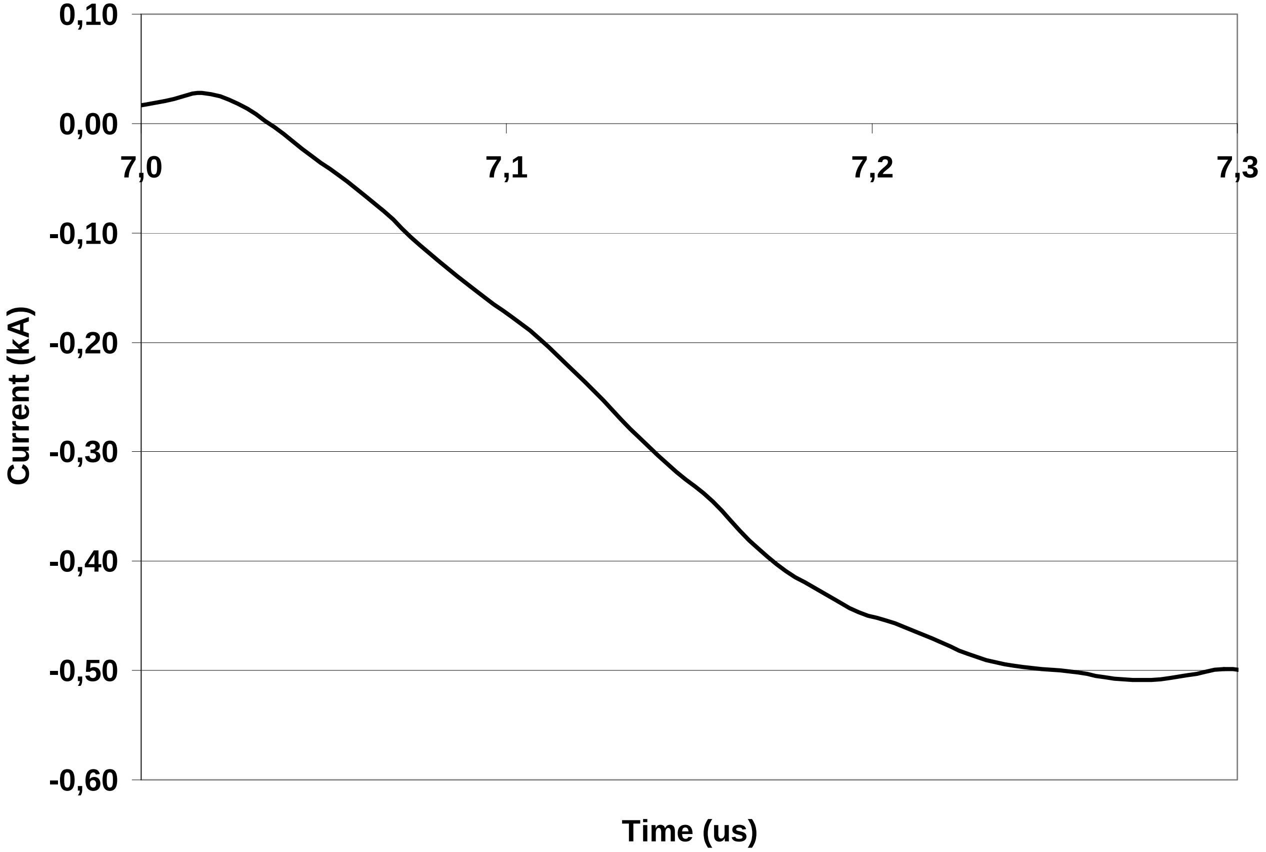
RBS Experiments - Results



Zoom on the beginning of the neutral current where the highest di/dt is observed

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RBS Experiments - Results

$$\left(\frac{di_P}{dt}\right)_{MAX} = \frac{R}{(R+Z)}\left(\frac{di_S}{dt}\right)_{AVE}$$

$(di_P/dt)_{MAX}$	is the maximum di/dt on the power line;
$(di_S/dt)_{AVE}$	is the average di/dt of the lightning stroke = 39 kA/μs;
R	is the earth resistance of the installation = 20 Ω;
Z	is the surge impedance of the power line = 110 Ω;

$(di_P/dt)_{MAX}$ = 6.0 kA/μs calculated by the equation above

$(di_P/dt)_{MAX}$ = 6.2 kA/μs measured at the site

Note: update K.56

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RBS Experiments - Results

Other results are available, such as:

- Surge voltage induced by lightning into an open loop
- Effect of earthing the bending point of feeder cables in a radio base station (RBS)
- Energy dissipated by SPD installed at power lines of an installation struck by lightning
- Voltages at the ports of equipment inside the RBS

New experiments are under development concerning the effect of protective measures against lightning discharges applied to buried telecom cables.

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Conclusions

- The experimental data from the test site is an important source of information for the development of standards on lightning protection.
- The data available shall be considered in order to revise the existing standards and to develop new ones.