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**Expected surges on telecommunication
networks due to lightning**

Recommendation ITU-T K.67



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Expected surges on telecommunication networks due to lightning

Summary

Recommendation ITU-T K.67 allows the assessment of the characteristics (waveshapes and peak values) of the expected lightning surges on metallic telecommunication lines. These characteristics are presented as a function of the lightning current parameters and the location on the telecommunication network. A set of formulas and tables are provided, alongside the relevant instructions.

History

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Table of Contents

	Page
1 Scope.....	1
2 References.....	1
3 Definitions	1
3.1 Terms defined elsewhere	1
3.2 Terms defined in this Recommendation.....	1
4 Abbreviations and acronyms	2
5 Conventions	2
6 Reference configuration.....	2
7 Lightning parameters	3
8 Conducted surges due to direct flashes to a structure.....	4
9 Induced surges due to flashes to or near to a structure	5
10 Direct flashes to telecommunication lines	6
11 Flashes near telecommunication lines	6
Annex A – Formulas for the loop inductances	7
A.1 Mutual inductance between a lightning flash and a loop	7
A.2 Self-inductance of a loop.....	7
Appendix I – Model to compute the lightning current in a telecommunication line due to a direct flash.....	8
I.1 Introduction	8
I.2 Aerial line	8
I.3 Buried line	9
Bibliography.....	12

Recommendation ITU-T K.67

Expected surges on telecommunication networks due to lightning

1 Scope

The scope of this Recommendation is to assess the overvoltages and overcurrents due to lightning at different points of the telecommunication access network, both outside and inside structures, i.e., exchanges, customer premises and remote sites. This Recommendation provides the tools that allow the user to obtain the peak values and waveshapes of the overvoltages and overcurrents.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.98] Recommendation ITU-T K.98 (2014), *Overvoltage protection guide for telecommunication equipment installed in customer premises*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 lightning protection level (LPL): [b-IEC 62305-1] Number related to a set of lightning current parameters values relevant to the probability that the associated maximum and minimum design values will not be exceeded in naturally occurring lightning.

NOTE – Lightning protection level is used to design protection measures according to the relevant set of lightning current parameters.

3.1.2 surge: [b-ITU-T K.46] Temporary excessive voltage or current, or both, coupled on a telecommunication line from an external electrical source.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 front time or rise time (T_1): The front time or rise time of an impulse voltage is defined as 1.67 times the time interval between the instants when the impulse is 30% and 90% of the peak value. The front time of an impulse current is defined as 1.25 times the interval between the instants when the impulse is 10% and 90% of the peak value.

3.2.2 surge protective device (SPD): A device that is intended to mitigate surge overvoltages and overcurrents of limited durations. It may consist of a single component or have a more complex design, where several functions are integrated.

3.2.3 time to half value (T_2): The time to half value of an impulse voltage or current is the time interval between the virtual origin and the first instant at which the voltage or current has decreased to half the peak value.

NOTE – The virtual origin of an impulse voltage or current is the instant preceding that at which the voltage or current is 30% or 10% of the peak value by a time equal to $0.3 T_1$ or $0.1 \cdot T_1$ respectively.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

LPL	Lightning Protection Level
MDF	Main Distribution Frame
MET	Main Earthing Terminal
SPD	Surge Protective Device

5 Conventions

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus this requirement need not be present to claim conformance.

The keywords "is prohibited from" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "can optionally" indicate an optional requirement which is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with this Recommendation.

6 Reference configuration

Figure 1 shows the reference configuration for the telecommunication lines, where the nodes indicated have the following descriptions:

Node L:	Transition between exchange equipment and external cabling.
Node E:	Entrance of the exchange building, e.g., the main distribution frame (MDF).
Node P:	Transition between paper-insulated and plastic-insulated buried cables.
Node C:	Transition between buried and aerial cables.
Node D:	Transition between shielded and unshielded aerial cables.
Node S:	Entrance of the customer's building.
Node A:	Transition between customer equipment and external cabling.
Node M:	Transition between exchange equipment and internal cabling.
Node I:	Transition between customer equipment and internal cabling.

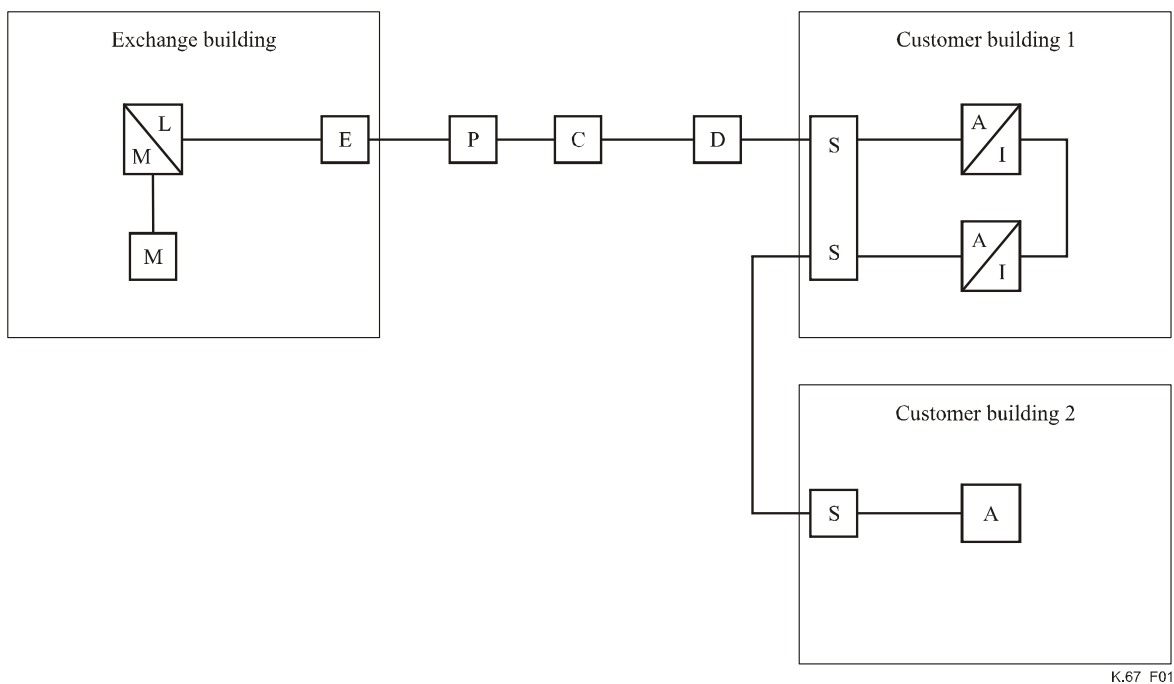


Figure 1 – Reference configuration

7 Lightning parameters

The use of equipment with suitable characteristics is necessary in order to achieve equipment protection and limit its risk of damage. The inherent resistibility requirements of telecommunication equipment used at different points of telecommunication networks have been defined in [b-ITU-T K.20], [b-ITU-T K.45] and [b-ITU-T K.21] for equipment installed in the exchange building, in the access network and in the customer's building, respectively.

The inherent resistibility allows the equipment to withstand the majority of the induced surges caused by lightning. Because these surges are the most frequent, the use of additional protective measures (primary protection) is limited to the "exposed" installations, which are determined according to [b-ITU-T K.46] and [b-ITU-T K.47].

The use of primary protection prevents excessive energy from reaching vulnerable parts of the telecommunication installations. Therefore, the rating of primary protectors shall be determined for a low-probability lightning flash, which is done by the selection of the appropriate lightning protection level (LPL) and its associated probability. These low-probability lightning parameters are given in Table 1 which has been adapted from [b-IEC 62305-1].

The data contained in Table 1 should be used for assessing the rating of primary protectors. For other assessments, the data related to the most common negative flashes should be used. With this aim, the parameters of the common negative first strokes and subsequent strokes according to [b-Electra 69] are given in Table 2. These parameters are based on a comprehensive set of measurements and according to a recent study from Cigré [b-Cigré TB549], they represent the most reliable set of data of lightning parameters.

Table 1 – Parameters of return stroke currents according to [b-IEC 62305-1]

Current parameters		Symbol	Unit	LPL (probability of being exceeded)			
				I (1%)	II (2%)	III (5%)	IV (5%)
Positive first stroke	Peak value	I_p	kA	200	150	100	
	Waveshape	T_1/T_2	$\mu\text{s}/\mu\text{s}$	10/350			
Negative subsequent stroke	Peak value	I_p	kA	50	37.5	25	
	Rate of rise	di/dt	$\text{kA}/\mu\text{s}$	200	150	100	
	Waveshape	T_1/T_2	$\mu\text{s}/\mu\text{s}$	0.25/100			

Table 2 – Parameters of return stroke currents from negative flashes according to [b-Electra 69]

Current parameters		Symbol	Unit	Probability of being exceeded		
				95%	50%	5%
First stroke	Peak value	I_p	kA	14	31	69
	Front time	T_1	μs	1.8	4.5	11
	Time to half value	T_2	μs	30	75	200
Subsequent stroke	Peak value	I_p	kA	5.2	12	29
	Front time	T_1	μs	0.1	0.6	2.8
	Time to half value	T_2	μs	6.5	32	140
	Rate of rise	di/dt	$\text{kA}/\mu\text{s}$	10	40	162

8 Conducted surges due to direct flashes to a structure

The conducted surges due to direct flashes to a structure are relevant in order to assess the currents delivered at the entrance of the structures (Nodes E and S in Figure 1). The rationale for this assessment is described hereafter.

The lightning current of a direct flash to a structure flows into the earthing system of the structure as well as into the services connected to structure. Therefore, part of the lightning current enters the conductors of the telecommunication cable directly or via surge protective devices (SPDs) connected to them. As a first approximation, it is assumed that 50% of the lightning current (I), flows into the earthing system and the remaining 50% is shared between the n services connected to the structure. The waveform of the surge current is assumed to be equal to that of the lightning stroke current.

If the telecommunication line is unscreened and is not routed into a metallic conduit, each of the m conductors of the line carries an equal part (I_f), of the peak lightning current, which may be evaluated by:

$$I_f = \frac{0.5 I}{n m} \quad \text{for an unshielded line} \quad (1)$$

For shielded lines or for those routed into a metallic conduit, it is assumed that the shield or the conduit is bonded to the structure earthing system. Therefore, the peak value (I_f) of the current entering each one of the m conductors is given by:

$$I_f = \frac{0.5 I R_s}{n (m R_s + R_c)} \quad \text{for a shielded line} \quad (2)$$

where:

R_s = resistance for unit length of the shield or the metallic conduit

R_c = resistance for unit length of the conductor

n = number of services connected to the structure

m = number of conductors of the telecommunication line.

The voltage between a conductor and the main earthing terminal (MET) is approximately given by the product of the earthing resistance to half of the lightning current. The magnitude of this voltage is likely to be sufficiently high to operate the primary protection or to cause breakdown of the conductor insulation, if there is no primary protection. Therefore, detailed procedures for calculating the peak voltage are not considered.

9 Induced surges due to flashes to or near to a structure

A lightning flash to or near to a structure induces common mode surges into the loops formed by the telecommunication line inside the structure. These surges would stress the equipment connected to the nodes E, L, M, S, A and I of the reference configuration shown in Figure 1. For a relatively close flash and a short loop, the peak value V_{oc} of the induced open circuit voltage is given by:

$$V_{oc} = L_M \frac{di}{dt} \quad (3)$$

where:

L_M = the mutual inductance between the induced loop and the current path;

di/dt = time-derivative of the stroke current.

The peak value of the short circuit current (I_{sc}), is estimated by:

$$I_{sc} = \frac{L_M}{L_S} I \quad (4)$$

where L_S is the self-inductance of the induced loop.

Annex A provides formulas for calculating the self-inductance of a loop and mutual inductances.

For the open circuit voltage the worst case probability scenario refers to subsequent strokes, whose data are provided in Tables 1 and 2, depending on the desired probability. The waveshape of the induced open circuit voltage is expected to have a time to half value close to the lightning current front time and a front time about one-third of this value.

For the short circuit current the worst case probability scenario refers to first strokes, whose data are provided in Tables 1 and 2, depending on the desired probability. If the loop has negligible resistance, the waveshape of the short circuit current is close to that of the lightning current. However, losses in the loop significantly reduce the induced current duration. [b-IEC 62305-1] proposes the standard 8/20 μ s for the induced current, which may be considered as an acceptable approximation.

10 Direct flashes to telecommunication lines

Direct flashes to telecommunication lines generate surges on the lines, especially on the external nodes E, P, C, D and S shown in the reference configuration of Figure 1.

For a lightning flash striking a telecommunication line far away from the point of interest (e.g., several kilometres), the total peak current in the line that reaches the structure can be assessed as twice the line to earth breakdown voltage divided by the line surge impedance. In this case, the current reaching the structure is independent of the lightning protection level (LPL).

Representative values for surge impedances of aerial and buried telecommunication lines are 400 Ω and 100 Ω , respectively. Considering that the breakdown voltage of the outer cover of a regular telecommunication cable is around 100 kV, it comes out that the expected short circuit currents at the end of the cable would be 500 A and 2 kA for aerial and buried lines, respectively.

For a lightning flash striking the telecommunication line at an arbitrary distance not far from the point of interest, it is necessary to use more sophisticated calculation methods. Appendix I presents a method for such calculation, based on the use of a circuit simulation software. This method was applied in [ITU-T K.98], which presents a large set of representative results that shall be used as reference.

11 Flashes near telecommunication lines

Lightning flashes near telecommunication lines generate surges on the lines, especially on the external nodes E, P, C, D and S shown in the reference configuration of Figure 1.

The surge voltages and currents which can appear in the access network have been measured in several countries and the measurement data are reported in Chapter 10 of [b-ITU-T LH]. These data have been collected in the field on lines composed of a mixture of buried and aerial shielded sections and often a short unshielded section near the customer (the drop wire). The majority of the data were measured at the exchange and at the subscriber ends. These data are summarized in Table 3.

Table 3 – Measured open circuit voltages and short circuit currents per conductor at different nodes of telecommunication lines due to nearby lightning flashes

Probability of being exceeded (%)	Nodes L, E, P, and C (Exchange side)		Nodes D, S, and A (Customer side)	
	Voltage (kV) (10/700 waveshape)	Current (A) (Note) (5/310 waveshape)	Voltage (kV) (10/700 waveshape)	Current (A) (Note) (5/310 waveshape)
1	1	20	3.5	35
2	0.8	15	2.5	25
5	0.6	10	1.5	15

NOTE – This current is approximately produced by the 10/700 generator described in [b-ITU-T K.44] when short-circuited.

Annex A

Formulas for the loop inductances

(This annex forms an integral part of this Recommendation.)

A.1 Mutual inductance between a lightning flash and a loop

Figure A.1 shows the configuration considered, where the vertical bold line represents the path of the lightning stroke current, which may be the lightning channel or a lightning down-conductor. The mutual inductance (in μH) between the lightning current path and the loop is given by:

$$L_M = 0.2 h \times \ln \left(\frac{d+l}{d} \right) \quad (\text{A.1})$$

where (see Figure A.1):

h = height of the loop in meters

l = length of the loop in meters

d = distance from the lightning channel to the loop, in meters.

It is assumed that the lightning path and the loop are contained in the same plane, as shown in Figure A.1. If this is not the case, the loop shall be represented by its projection in a plane that contains the lightning path and the closest vertical loop conductor.

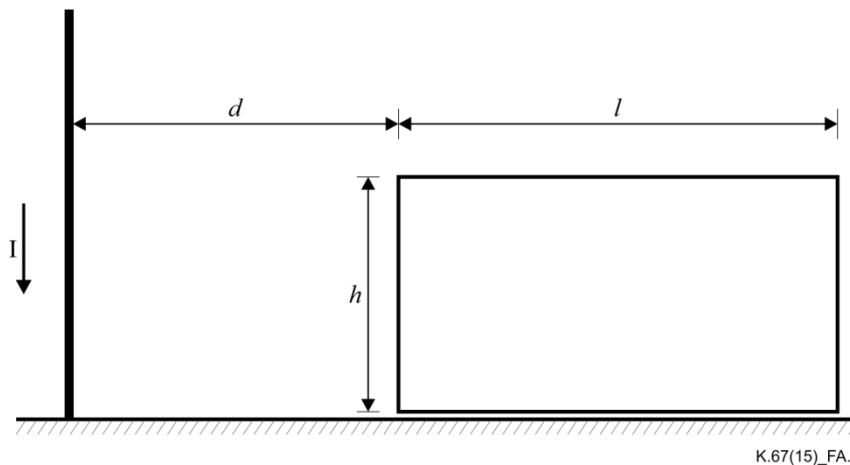


Figure A.1 – Lightning channel and a loop

A.2 Self-inductance of a loop

Considering the loop of Figure A.1, its self-inductance L_S (in μH) is given by:

$$L_S = 0.8 \sqrt{l^2 + h^2} - 0.8 (l+h) + 0.4 l \ln \left[\frac{\frac{2h}{r}}{1 + \sqrt{1 + \left(\frac{h}{l}\right)^2}} \right] + 0.4 h \ln \left[\frac{\frac{2l}{r}}{1 + \sqrt{1 + \left(\frac{l}{h}\right)^2}} \right] \quad (\text{A.2})$$

where r is the radius of the loop conductor, in meters.

Appendix I

Model to compute the lightning current in a telecommunication line due to a direct flash

(This appendix does not form an integral part of this Recommendation.)

I.1 Introduction

Circuit models with lumped parameters have been successfully used to compute the propagation of electromagnetic waves on transmission lines [b-Paulino], so that this technique was applied in [ITU-T K.98] in order to assess the voltages and currents conducted to an installation by a telecommunication cable struck by a lightning flash. Several simulation results are presented in [ITU-T K.98].

The aim of this appendix is to provide a simple model for the computation of currents and voltages in a telecommunication line due to a direct strike to the line. The computation may be carried out with regular computer codes for circuit simulation.

I.2 Aerial line

I.2.1 Circuit model

The circuit model is shown in Figure I.1, where the current source I represents the stroke current, the resistance R_S is the earth resistance at the striking point (including the contribution of upstream cable, if any), R_T is the earthing resistance at the line termination and the section R_1 , L_1 , and C_1 is a lumped representation of the line distributed resistance, inductance and capacitance, respectively. This section shall be replicated n times between the current source and the line termination, where n shall be assessed by:

$$n \gg \frac{l}{vT_1} \quad (\text{I.1})$$

where l is the total line length, v is the propagation velocity ($v = 300 \text{ m}/\mu\text{s}$ for an aerial line) and T_1 is the front time of the stroke current waveform.

The value of R_S shall be selected so that the voltage across this component is close to the line insulation breakdown voltage. For that purpose, a voltage-operated switch may be included in the circuit or the resistor R_S may be replaced by a voltage-dependent resistor.

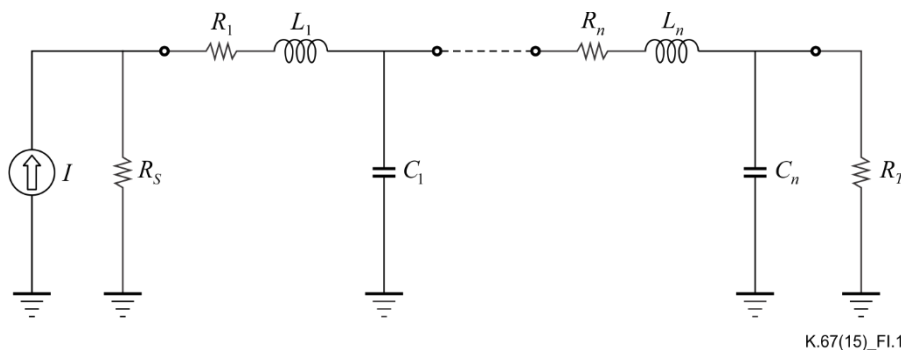


Figure I.1 – Circuit model for an aerial line

I.2.2 Cable parameters

The aerial cable parameters per unit length are R , L and C and they relate to the section values by:

$$R_1 = \frac{Rl}{n}, \quad L_1 = \frac{Ll}{n}, \quad \text{and} \quad C_1 = \frac{Cl}{n} \quad (\text{I.2})$$

For an aerial line and the frequency content associated with lightning first strokes, the soil could be considered as perfectly conducting. Under this assumption, R is the low-frequency resistance of the cable (conductors and shield in parallel) and:

$$L = \frac{\mu_0}{2\pi} \ln\left(\frac{2h}{r}\right) \quad (\text{I.3})$$

$$C = \frac{2\pi\epsilon_0}{\ln(2h/r)} \quad (\text{I.4})$$

where h is the line height (distance above earth), r is the cable radius, $\mu_0 = 4\pi \times 10^{-7}$ H/m is the free-space permeability and $\epsilon_0 = 8.85 \times 10^{-12}$ F/m is the free-space permittivity.

I.3 Buried line

I.3.1 Circuit model

For a buried line, the cable parameters are frequency-dependent, so that a more complex circuit model is required. Figure I.2 presents a linear circuit model that can mimic the frequency-dependency of the series impedance by adding the R_{e1} and L_{e1} components in parallel with the inductor L_1 .

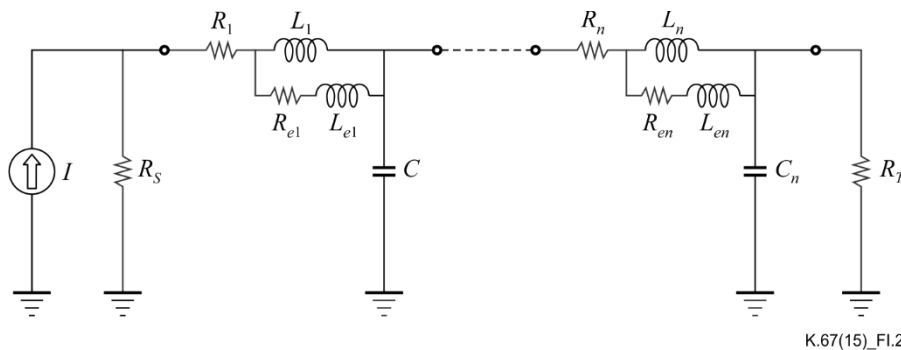


Figure I.2 – Circuit model for a buried line

I.3.2 Cable parameters

The buried cable parameters per unit length are R , R_e , L , L_e , and C and they relate to the section values by:

$$R_1 = \frac{Rl}{n}, \quad R_{e1} = \frac{R_e l}{n}, \quad L_1 = \frac{Ll}{n}, \quad L_{e1} = \frac{L_e l}{n} \quad \text{and} \quad C_1 = \frac{Cl}{n} \quad (\text{I.5})$$

For the frequency content associated with lightning first strokes, the resistance R can be approximated by the low-frequency resistance of the cable (conductors and shield in parallel) and the capacitance C can be assumed as frequency-independent and given by:

$$C = \frac{2\pi\epsilon_{ri}\epsilon_0}{\ln(b/a)} \quad (\text{I.6})$$

where a and b are defined in Figure I.3 and ϵ_{ri} is the relative permittivity of the cable insulating jacket.

NOTE 1 – This is an approximation. Refer to [b-Petrache] if a more precise evaluation is needed.

The values of the circuit parameters L , R_e , and L_e are calculated considering that, for the frequency range of interest, the resultant series impedance shall be close to Z_s which is adapted from [b-Petrache].

$$Z_s = j\mu_0 f \left[\ln\left(\frac{b}{a}\right) + \ln\left(\frac{1+b\gamma_g}{b\gamma_g}\right) \right] \quad (\text{I.7})$$

where f is the frequency and γ_g is the propagation constant in the ground:

$$\gamma_g = \sqrt{j\omega\mu_0(\sigma_g + j\omega\epsilon_0\epsilon_{rg})} \quad (\text{I.8})$$

where $\omega = 2\pi f$ is the angular frequency, σ_g is the ground conductivity, and ϵ_{rg} is the ground relative permittivity.

NOTE 2 – In Equation (I.7), the internal inductance of the conductor has been neglected, as it is usually small when compared with the external inductance. For a more complete calculation, see [b-Petrache].

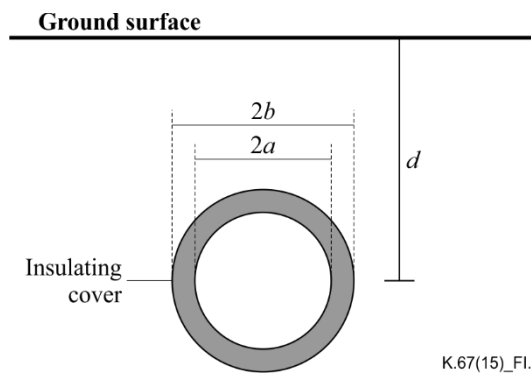


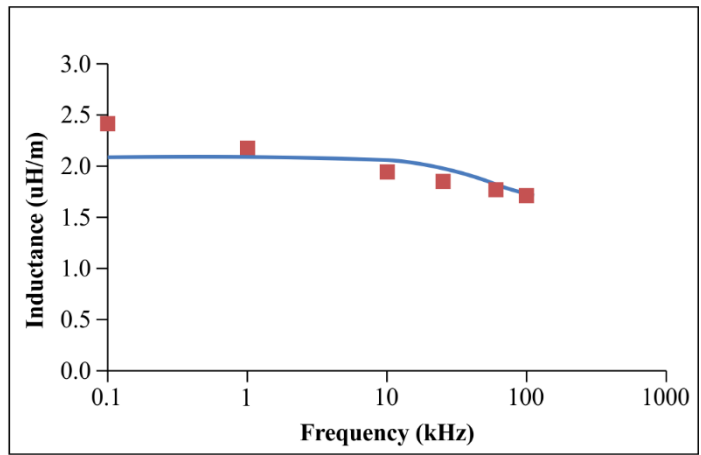
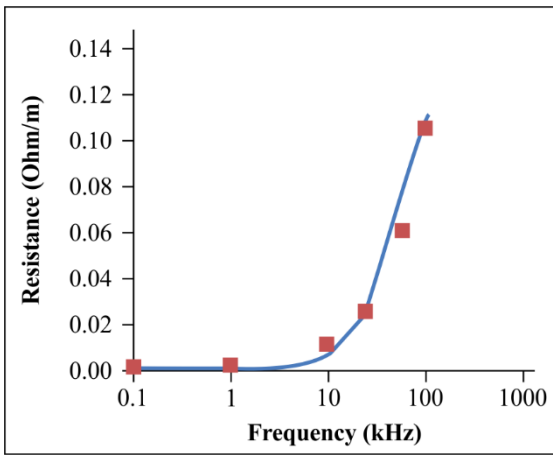
Figure I.3 – Dimensions of the buried cable

I.3.3 Example of representative values

Let us consider a telecommunication cable made of 30 pairs, 0.64 mm conductors covered by a metallic sheath and a plastic protective cover with the following dimensions: $a = 8$ mm and $b = 10$ mm (see Figure I.3). The cable is buried at a depth $d = 0.7$ m and its insulating jacket has a relative permittivity $\epsilon_{ri} = 3$. The ground conductivity is 0.001 S/m and its relative permittivity is $\epsilon_{rg} = 10$. The low-frequency resistance of the cable conductors in parallel (shield and pairs) is 0.72 m Ω /m. Considering also that the frequency range of interest goes up to 100 kHz, the following set of parameters can be calculated:

- $R = 0.72$ m Ω /m (conductor resistance)
- $C = 0.75$ nF/m (conductor capacitance to ground)
- $R_e = 3.0$ Ω /m (equivalent resistance of the ground return)
- $L = 2.1$ μ H/m (first part of the equivalent cable inductance)
- $L_e = 7.9$ μ H/m (second part of equivalent cable inductance)

Figure I.4 shows the resistance and inductance values of the cable series impedance, as a function of the frequency. The continuous lines are calculated from Equation (I.7) and the dots are obtained from the equivalent lumped series circuit shown in Figure I.2. It can be seen that the equivalent circuit can reasonably mimic the frequency-dependent characteristic of the cable impedance, allowing its simulation by a regular circuit simulation software. It is worth mentioning that the small inductance mismatch seen below 1 kHz is not relevant for surge propagation.



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Figure I.4 – Resistance and inductance components of the buried cable considered

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