INTERNATIONAL TELECOMMUNICATION UNION

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THE INTERNATIONAL
TELEGRAPH AND TELEPHONE
CONSULTATIVE COMMITTEE

RED BOOK

VOLUME IX

PROTECTION AGAINST INTERFERENCE

RECOMMENDATIONS OF THE K SERIES

CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

RECOMMENDATIONS OF THE L SERIES

VIII[TH] PLENARY ASSEMBLY
MALAGA-TORREMOLINOS, 8-19 OCTOBER 1984

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ISBN 92-61-02371-1

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APPLICABLE AFTER THE EIGHTH PLENARY ASSEMBLY (1984)

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Part I – Series K Recommendations

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PRELIMINARY NOTES

1 The Questions entrusted to each Study Group for the Study Period 1985-1988 can be found in Contribution No. 1 to that Study Group.

2 In this Volume, the expression "Administration" is used for shortness to indicate both a telecommunication Administration and a recognized private operating agency.

PART I

Series K Recommendations

PROTECTION AGAINST INTERFERENCE

(In this Series of Recommendations the publication *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines* is often cited. It was originally published in loose-leaf form in 1963 and modified in the years 1965, 1974, 1978 and 1982.)

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PROTECTION AGAINST INTERFERENCE[1]

Recommendation K.1 (New Delhi, 1960)

CONNECTION TO EARTH OF AN AUDIO-FREQUENCY TELEPHONE LINE IN CABLE

Introduction

The present state of technique is such that cables can now be so manufactured that the capacitances of the various circuits at audio-frequencies, with respect to the sheath, are very exactly balanced.

This balance of the capacitances is adequate in the case of circuits having no unbalanced connections to earth.

On the other hand, every connection to earth, even with apparent balance, is likely to involve the inductance and resistance unbalances of each of the circuits to which such an earth connection is made.

The dielectric strength between the conductors of a cable is appreciably less than that between the conductors and the sheath and, consequently, the connection to earth of some of these conductors would create a danger of breakdown of the dielectric separating the conductors when the cable is subjected to severe induction.

When a loaded cable is subjected to a high induced electromotive force, the presence of connections to earth would permit a flow of current the value of which could, in some cases, exceed the limit for avoiding deterioration of the magnetic properties of loading coils.

For these reasons, the CCITT makes the following unanimous recommendations:

No earth connection should be made at any point whatsoever on an audio-frequency circuit, unless all the line windings of the transformers are permanently connected to the sheath by low resistance connections at one or both ends of the cable.

As a general rule, it is desirable not to make any earth connection at any point whatsoever on an installation (telephone or telegraph) connected metallically to a long-distance line in cable.

However, if, for special reasons, an earth connection must be made to an installation directly connected to audio-frequency circuits, the following precautions should be taken:

a) The earth connection must be made in such a manner as not to affect the balance of the circuits with respect to earth and with respect to the neighbouring circuits.

b) The breakdown voltage of all the other conductors of the cable, with respect to the conductors of the circuit connected to earth, must be appreciably greater than the highest voltage which, owing to induction from neighbouring electricity lines, could exist between these conductors and those of the circuit connected to earth.

c) When the installation connected to the cable is a telegraph installation, it is also necessary to conform to CCTT Recommendations concerning the conditions for coexistence of telephony and telegraphy (Series H Recommendations).

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1) See also the CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines*, ITU, Geneva, 1963, 1965, 1974, 1978, 1982. In this Series of Recommendations, the foregoing manual is referred to as the *Directives* for short. When a specific passage in the *Directives* is cited, a reference number within brackets is used.

Recommendation K.2 (New Delhi, 1960)

PROTECTION OF REPEATER POWER-FEEDING SYSTEMS AGAINST INTERFERENCE FROM NEIGHBOURING ELECTRICITY LINES

To avoid interference to the power feeding of repeaters, either by magnetic induction from a neighbouring electricity line or as the result of resistance coupling with a neighbouring electricity line, the CCITT recommends that, whenever possible, the repeater power-feeding system should be so arranged that the circuit in which the power-feeding currents circulate (including the units connected to it) remains balanced with respect to the sheath and to earth.

Recommendation K.3 (New Delhi, 1960)

INTERFERENCE CAUSED BY AUDIO-FREQUENCY SIGNALS INJECTED INTO A POWER DISTRIBUTION NETWORK

In the event of the use by electricity authorities of audio-frequency signals injected into the power distribution network for the operation of remote control systems, such signals may cause interference to neighbouring telecommunication lines.

Calculation of such interference may be carried out, using the formulae in the *Directives*, and finding the values of the equivalent disturbing voltages and currents for these audio-frequency signals.

Recommendation K.4 (Geneva, 1964)

DISTURBANCE TO SIGNALLING

In order to reduce interference to direct current signalling or to alternating current signalling at mains frequencies on telecommunication lines on open wires, in aerial or underground cables, or on composite lines, arising from neighbouring alternating or direct current electricity lines, the possibility should be examined of adopting one or more of the following methods in each case where such interference appears liable to be produced or where it has been observed to exist:

- development and use of telecommunication systems:
  - a) in which the balance to earth of the signalling circuit is maintained in all circumstances, even during switching operations (see [1]);
  - b) in which, besides being balanced, interference in such systems due to longitudinal currents arising from direct or indirect earth connections is avoided;
- choice of site for telephone exchange earths so that, as far as possible, they are, in particular, remote from electric traction lines and also from the earth electrodes of power systems;
- adoption of measures for reducing induced currents (use of telephone cables with a low screening factor, use of booster transformers in single-phase traction lines, etc.) to facilitate the use of existing signalling systems;
- use of neutralizing transformers or use of the active reduction system in telecommunication circuits to compensate currents produced by induced voltages;
- use of tuned circuits to provide a high impedance at the frequency of the interfering current.

Note – The *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines* mention a limit of 60 V for the voltage induced into telecommunication lines. This limit of 60 V concerns only the safety of personnel and should not be taken to be a limit for the purpose of ensuring that there is no interference to signalling systems. In the case of unbalanced signalling systems, such interference may be caused by much lower voltages, as is mentioned in [2].

References

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines,* Chapter XVI, ITU, Geneva, 1963, 1965, 1974, 1978, 1982.

[2] *Ibid.*, Chapter V, Section 3.

Recommendation K.5 (Geneva, 1964)

JOINT USE OF POLES FOR ELECTRICITY DISTRIBUTION AND FOR TELECOMMUNICATIONS

Administrations that wish to adopt joint use of the same supports for open-wire or aerial cable telecommunication lines and for electricity lines are recommended, when national laws and regulations permit such an arrangement, to take the following general considerations into account:

1) There are economic and aesthetic advantages to be derived from the joint use of poles by Administrations and electricity authorities.
2) When suitable joint construction methods are used, there is, nevertheless, some increased likelihood of danger by comparison with ordinary construction methods, both to staff working on the telecommunication line and to the telecommunication installation connected thereto. Special training of personnel working on such lines is highly desirable and especially when the electricity line is a high-voltage line.
3) The rules given in the *Directives* in connection with danger, disturbance, and staff safety should be complied with (see [1]).
4) Special formal agreements are desirable between the Administration and the electricity authority in the case of joint use of poles in order to define responsibilities.
5) If joint use is applied on short sections (of the order of 1 km), in most cases a few simple precautions may be enough to ensure that disturbances due to electric and magnetic induction are tolerable.

Reference

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines*, Chapters IV, V and XX, ITU, Geneva, 1963, 1965, 1974, 1978, 1982.

Recommendation K.6 (Geneva, 1964)

PRECAUTIONS AT CROSSINGS

Introduction

Crossings between overhead telecommunication lines and electricity lines present dangers for persons and for equipment.

A number of arrangements have been made by the responsible authorities in various countries, resulting in national regulations. These regulations are sometimes rather inconsistent and the effectiveness of the arrangements made varies somewhat.

Bearing in mind the stage now reached in technique and the experience gained in the various countries, it now seems possible for the CCITT to issue a Recommendation advocating the arrangements which seem to be the most effective, on the basis of which countries might draw up or revise their national regulations.

It is therefore recommended that, when an overhead telecommunication line has to cross an electricity line, either of two methods may be used: namely, to route the overhead telecommunication line in an underground cable at the crossing, or to leave it overhead.

1 Line routed underground

This method is not always to be recommended because if a conductor of the electricity line breaks, the underground cable may be in a region where the ground potential is high. This situation is dangerous if the cable has a bare metallic sheath; the higher the voltage of the power line, the shorter the length of the cable section, and the higher the resistivity of the soil, the greater is the danger. This dangerous situation also arises whenever an earth fault occurs on a pylon near the cable.

If circumstances require the overhead line to be routed in a cable, special precautions will have to be taken at the crossing, for example:

- the use of an insulating covering around the metal sheath of the cable;
- the use of a cable with an all-plastic sheath.

2 Line left overhead

The method whereby the power line is separated from the telecommunication line by a guard-wire or a cradle cannot generally be recommended.

In any case, regardless of the circumstances, a minimum vertical distance has to be kept between telecommunication conductors, in conformity with national regulations.

There are, moreover a number of arrangements that could be introduced to reduce the danger:

2.1 *Use of a common support* at the crossing-point, provided the insulators used for the telecommunication line have, if necessary, a high breakdown voltage.

2.2 *Insulation of the conductors*, preferably the telecommunication conductors, provided that such insulation is properly adapted to the conditions existing.

2.3 *Reinforcement of the construction* of the power line where the crossing takes place, so as to minimize the risk of a break.

3 Circumstances in which the various arrangements in §§ 2.1, 2.2 and 2.3 above are applicable

The application of these methods depends primarily on the voltage of the power line. The voltage ranges to be taken into account are not related to the International Electrotechnical Commission (IEC) standardization, because of the special features of the problem raised.

3.1 *Systems using voltages of 600 V or less*

Arrangements to be as in § 2.1 and/or § 2.2.

3.2 *Systems using voltages of 60 kV or more*

(In particular the "high reliability" system referred to in [1].

Arrangements to be as in § 2.3, if necessary.

3.3 *Intermediate voltage systems*

For the 600-V to 60-kV range, because of the variety of voltages, the mechanical characteristics of lines and the operating methods encountered, it is impossible to issue precise recommendations.

However, one or more of the arrangements described above might be applicable, although certain special cases call for thorough examination in close collaboration with the services concerned.

Reference

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines*, Preliminary Chapter, § 3.2.3, ITU, Geneva, 1963, 1965, 1974, 1978, 1982.

Recommendation K.7 (Geneva, 1964; modified Malaga-Torremolinos, 1984)

PROTECTION AGAINST ACOUSTIC SHOCK

In certain unfavourable circumstances, sudden transient voltages of exceptionally high instantaneous amplitude, of the order of 1 kV for example, may occur across a telephone set which is normally connected to a metal wire line, as a result of electromagnetic disturbances affecting the line.

If such voltages occur during a telephone call, they are liable to cause, through the earphone, such strong sound pressure as to endanger the human ear and the nervous system.

Such bursts are most likely to occur when lightning protectors are inserted in the two conductors of a telephone line and do not function simultaneously, so that a compensating current flows through the telephone. The CCITT therefore recommends the use, particularly on lines equipped with vacuum lightning protectors, of protection devices against acoustic shock arising from inadmissibly high induced voltages (see Chapter I/6 of the *Directives*, page 16).

Such devices consist, for example, of two rectifiers, in parallel and with opposite polarities, or of other semiconductor components connected directly in parallel to the telephone receiver.

For telephone sets of more recent design, sudden voltage bursts liable to occur in the receiver may be eliminated by ensuring that the electrical circuits between the access to the line where dangerous voltages originate and the earphone itself have suitable characteristics.

It is also recommended that the proposed provisions should limit the aural discomfort which might be caused by abnormal electrical signals applied to subscriber systems as a result of erroneous operation or unwanted actuation of the equipments to which subscriber systems are connected.

The provisions adopted to provide protection against acoustic shock should:

- be compatible with the technical requirements applicable to the equipment;
- facilitate performance checks;
- not noticeably impair telephone transmission quality.

For this purpose, it is particularly recommended that:

1) with regard to specific devices, their dimensions should be such that they occupy a small space, so that they can be placed in the case of the subscriber's or operator's telephone receiver;
2) the electrical characteristics should not show significant changes under the temperature and humidity conditions to which the device is subjected in service;
3) effectiveness should be checked in conformity with the provisions of CCITT Recommendation P.36.

Recommendation K.8 (Mar del Plata, 1968)

SEPARATION IN THE SOIL BETWEEN TELECOMMUNICATION AND POWER INSTALLATIONS

The magnitude of possible voltages in the soil in the vicinity of telecommunication cables depends on a number of factors, for example, the power-system voltage, the fault-current level, the soil resistivity, the layout of both the power system and the telecommunication installations, and other local conditions. It is, in consequence, impossible to suggest general rules regarding the minimum separation to be recommended. In principle, the effect of the power system on the telecommunication installation should be established by tests whenever conditions indicate the possibility of excessive voltages. In many cases, however, such tests may require such a large amount of work that they could not be justified. Experience has shown that problems do not arise if the minimum separation admitted between telecommunication plant and pylon footings is 10 m, provided that the earth resistivity is not unduly high (of the order of a few hundred ohm-metres) and that there are no other known or suspected conditions that might make this distance insufficient. Such known or suspected conditions may necessitate an increased separation (a separation of up to 50 m has been used in Sweden under extremely severe soil conditions).

On the other hand, circumstances may exist where a separation of 10 m is not necessary, and a separation of 2 m or even less is found sufficient in some countries under stated circumstances. (See Annex A.)

If local conditions do not permit the adoption of a requisite separation, the sheath of the telecommunication cable could be provided with suitable insulation (for example, by being placed in ducts or provided with an insulating covering) within the area of possible excessive soil voltage.

ANNEX A

(to Recommendation K.8)

Information supplied by CIGRE (1964-1968)

Figure A-1/K.8 shows a practical example in the Paris area where a telecommunication cable has been laid in the same trench as a 225-kV high-tension cable over a length of 4911 m. The three single-phase power cables are in a steel tube which is carefully earthed at its ends and the telecommunication cable (7 quads, lead-covered) is in a lightly reinforced, prefabricated, concrete duct.

Measurements of induction made for several values of short circuit current over the total length of the telecommunication circuit (4911 m) have given the following induced electromotive forces:

Short-circuit current (in amperes)	100	200	400
Induced e.m.f. (in volts per ampere)	0.055	0.046	0.036

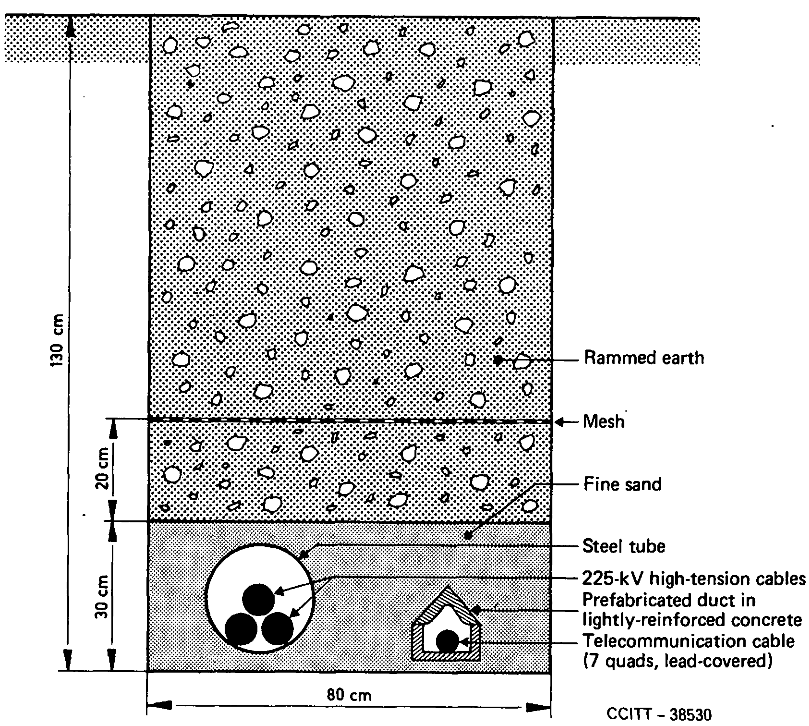


FIGURE A-1/K.8

Common trench for a power cable and a telecommunication cable

Recommendation K.9 (Mar del Plata, 1968)

PROTECTION OF TELECOMMUNICATION STAFF AND PLANT AGAINST A LARGE EARTH POTENTIAL DUE TO A NEIGHBOURING ELECTRIC TRACTION LINE

1 General

From the technical standpoint the precautions taken on electrified railways to protect staff and plant may differ according to a number of factors, the chief of which are:

- ground resistivity;
- electrical line equipment (track circuits) which, though necessary for railway safety installations, may prevent the systematic connection to rail of metal structures near the railway;
- the characteristics of the protective devices required which, with a.c. electric traction systems, may be to some extent affected by the presence (or absence) of booster-transformers;
- the degree of insulation of the contact system, which may also affect the nature of the protective devices, particularly in the case of relatively low-voltage electric systems such as 1500 V d.c. lines;
- the means to be recommended for linking a metal structure to the rail in case of overvoltage without making a permanent connection (one method is to make the connection via a spark gap).

2 A.c. electric traction lines

It is recommended that neighbouring metal structures, for example all those within a certain distance from the line, be connected to rail, provided that there are no safety installations which make this impossible.

If the structures cannot be connected to rail, it is recommended that they be earthed to an earth electrode having a sufficiently low resistance.

3 D.c. electric traction lines

Protective measures should also take account of the need to avoid any risk of electrolytic corrosion. Such measures may amount to connecting to rail only such metal structures as are sufficiently insulated from the ground or linking them via a spark gap or, in the case of metal structures carrying an adequately insulated contact system or lines with a sufficiently low service voltage, connecting neither to rail nor to earth.

4 Telecommunication cables

In new installations, it is recommended that cables near rails, at the entry to substations or over metal bridges should have an outer plastic covering, possibly of high dielectric strength, where it is necessary to prevent contact between the cables and such structures.

If, on the other hand, cables with metal sheaths already exist, a good solution, at least in the case of large railway stations, may be to connect the sheaths to rail.

5 Conditions to be fulfilled by PTT installations in the neighbourhood of electric traction lines

The following are the main precautions taken to protect such installations:

- placing them outside the danger zone;
- screening;
- substituting insulating components for metal components, in particular the sheaths or covering of cables or in the construction of repeater cabinets or boxes.

Note – The above recommendations are inspired solely by technical considerations which are to be carefully weighed up in each case. It goes without saying that every Administration must comply with the laws and regulations in force in its country.

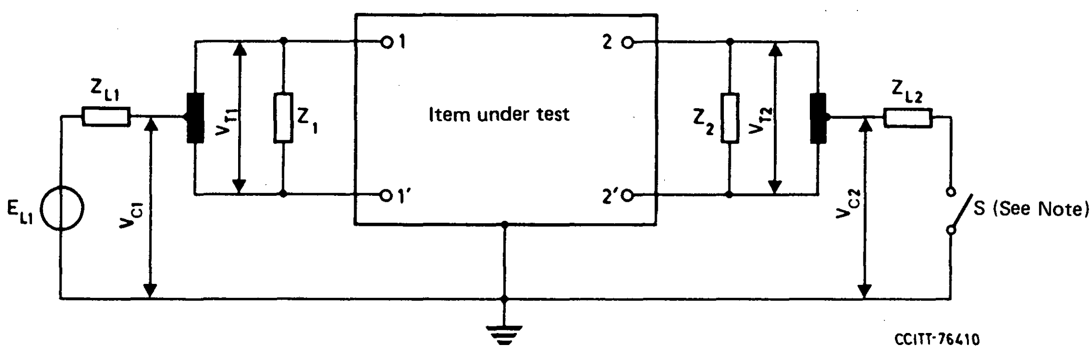
Recommendation K.10 (Mar del Plata, 1968; modified Malaga-Torremolinos, 1984)

UNBALANCE ABOUT EARTH OF TELECOMMUNICATION INSTALLATIONS

1 Unbalance about earth of telecommunication equipments

In the interests of maintaining an adequate balance of telecommunication equipments and of the lines connected to them, it is recommended that the minimum permissible value for the unbalance of telecommunication installations longitudinal conversion loss (LCL) should be 40 dB (from 300 to 600 Hz) and 46 dB (from 600 to 3400 Hz). This is a general minimum value and does not exclude the possibility of higher minimum values being quoted for particular requirements in other Recommendations of the CCITT[1)].

The test arrangement in Figure 1/K.10 should be used to measure the unbalance of telecommunications equipment.



Note – Measurements are normally made, and limits specified, with switch S closed. However, for certain equipments, e.g. those described in Recommendation Q.45, it may be necessary to specify limits for longitudinal conversion transfer loss (LCTL) with switch S closed and with switch S open.

FIGURE 1/K.10

Test arrangement

Nomenclature, definition and measurement of unbalance are based on Recommendations G.117 and O.121.

The specification $Z_{L1} = Z_1/4$, $Z_{L2} = Z_2/4$ should apply in the audiofrequency range. (See Recommendation Q.45 and Recommendation O.121, § 3.2.)

The following terms are specified:

– longitudinal conversion loss (LCL) (applicable for one- and two-port networks):

$$20 \log_{10} \left| \frac{E_{L1}}{V_{T1}} \right| \text{ dB}$$

– longitudinal conversion transfer loss (LCTL) (applicable for two-port networks only):

$$20 \log_{10} \left| \frac{E_{L1}}{V_{T2}} \right| \text{ dB}$$

2 Unbalance about earth of telecommunication lines

If a long line is tested, essentially the same test circuit and nomenclature should be used as given in Figure 1/K.10. However, both the longitudinal induction and unbalances are distributed along the line. Consequently, the longitudinal conversion losses and longitudinal conversion transfer losses are not only determined by the inherent parameters but also by the distribution of the wire to earth/sheath voltages. To obtain

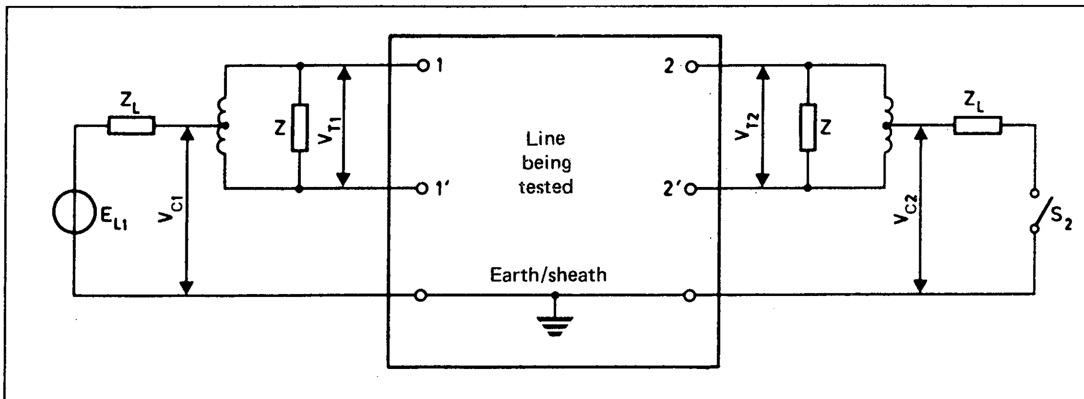
1) See, in particular, Recommendation Q.45, and also the outcome of further studies under Question 13/V. [1]

the effect of unbalance in practical cases, it is recommended that measurements be made both with the wire to sheath voltage of constant polarity (i.e. supply at end, see Table 1/K.10) and with the wire to sheath voltage changing in polarity at the midpoint (i.e. supply at the middle, see Table 2/K.10).

In Table 3/K.10, conclusions derived from those measurements are listed.

TABLE 1/K.10

Unbalance test results for a line when the longitudinal path is energized at one of the terminations



Port 1		Port 2	
Termination	Terms used	Terms used	Termination
E_{L1}	Longitudinal conversion losses $20 \log_{10} \left\lvert \frac{E_{L1}}{V^{o}_{T1}} \right\rvert$	Longitudinal conversion transfer losses $20 \log_{10} \left\lvert \frac{E_{L1}}{V^{o}_{T2}} \right\rvert$	S_2 Open
	$20 \log_{10} \left\lvert \frac{E_{L1}}{V^{c}_{T1}} \right\rvert$	$20 \log_{10} \left\lvert \frac{E_{L1}}{V^{c}_{T2}} \right\rvert$	S_2 Closed
Open S_1	Longitudinal conversion transfer losses $20 \log_{10} \left\lvert \frac{E_{L2}}{V^{c}_{T1}} \right\rvert$	Longitudinal conversion losses $20 \log_{10} \left\lvert \frac{E_{L2}}{V^{o}_{T2}} \right\rvert$	E_{L2}
Closed S_1	$20 \log_{10} \left\lvert \frac{E_{L2}}{V^{o}_{T1}} \right\rvert$	$20 \log_{10} \left\lvert \frac{E_{L2}}{V^{c}_{T2}} \right\rvert$	

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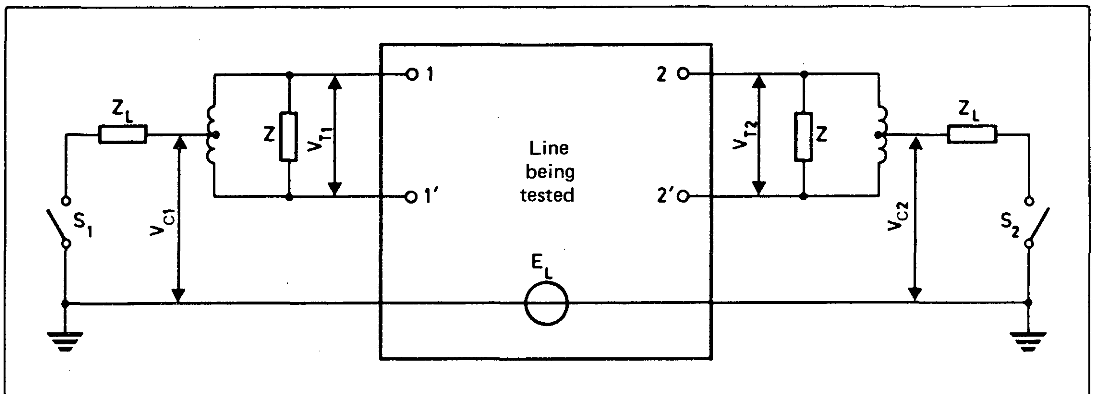
Note 1 – The superscripts of o and c indicate the open and closed state of switch S respectively.

Note 2 – The values of V_{C1} and V_{C2} give some indication to the distribution of wire to earth/sheath voltage.

TABLE 2/K.10

Unbalance test results for a line when the longitudinal path is energized at an intermediate section



Test No.	Port 1 Termination	Port 1 Longitudinal conversion losses	Port 2 Longitudinal conversion losses	Port 2 Termination
1	Open S_1	$20 \log_{10} \left\| \frac{E_L}{V_{T1}^{oo}} \right\|$	$20 \log_{10} \left\| \frac{E_L}{V_{T2}^{oo}} \right\|$	S_2 Open
2	Closed S_1	$20 \log_{10} \left\| \frac{E_L}{V_{T1}^{cc}} \right\|$	$20 \log_{10} \left\| \frac{E_L}{V_{T2}^{cc}} \right\|$	S_2 Closed
3	Open S_1	$20 \log_{10} \left\| \frac{E_L}{V_{T1}^{oc}} \right\|$	$20 \log_{10} \left\| \frac{E_L}{V_{T2}^{oc}} \right\|$	S_2 Closed
4	Closed S_1	$20 \log_{10} \left\| \frac{E_L}{V_{T1}^{co}} \right\|$	$20 \log_{10} \left\| \frac{E_L}{V_{T2}^{co}} \right\|$	S_2 Open

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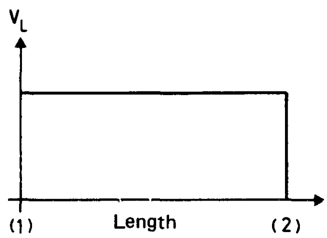
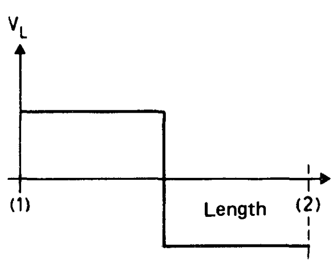
Note 1 – The superscripts of o and c indicate the open and closed state of the switches respectively.

Note 2 – The values of V_{C1} and V_{C2} give some indication to the distribution of wire to earth/sheath voltage.

TABLE 3/K.10

Measurement procedures for the determination of unbalance about earth for lines

Measurement situation	Characteristics under examination
E.m.f. applied to terminals (see Table 1/K.10)  Wire to sheath voltage of some polarity	Degree of unbalance inherent to a line itself : – highest transverse voltage normally measured on a line – distribution of unbalance along a line (by interchanging transmitter and receiver) – determination of line sections with abnormal high unbalance
E.m.f. applied at the midpoint of line (see Table 2/K.10)  Wire to sheath voltage changes polarity at the midpoint	Influence of distribution of line to sheath voltage along a line : – transverse voltages more in accordance with practical situations – compensation effects due to changing polarity of line to sheath voltage – indications for polarity of unbalance by comparison with results of other line to sheath voltage distributions

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Note – If the longitudinal path is closed by switches, the effect of a terminal equipment connected to line with low impedance with respect to earth is simulated.

(to Recommendation K.10)

Example for calculating transverse voltages of a telecommunications line

A.1 *General*

The Contribution mentioned in reference [2] contains many calculated values regarding the relationship between the longitudinal voltage and its conversion into the transverse one. This annex is an extract of that Contribution. It gives background information about the application of measurement proposals for lines which are contained in Recommendation K.10.

The most important results are summarized in Table A-1/K.10. They relate to a symmetric pair composed of paper-insulated copper wires of 0.9 mm in diameter and stranded in star quads with an equivalent mutual capacitance of 34 nF/km. In the course of the calculation, only the capacitance unbalance has been simulated.

A.2 *Wire to sheath voltages*

The distribution of the wire to sheath (earth) voltages are basically determined by (see column 2 of Table A-1/K.10 where, for the sake of simplicity, it is assumed that the total voltage source in the longitudinal path is 100 V):

- the location of the longitudinal source (see column 1 in Table A-1/K.10), and
- the termination of the longitudinal path (see column 3 of Table A-1/K.10).

On the basis of schemes indicated in column 2 of Table A-1/K.10, the following tendencies are worth mentioning:

a) When the e.m.f. is applied at one of the terminals of the longitudinal path, the wire to sheath voltages tend to be uniform with the same polarity along the line. When switch S is closed, the voltages decrease (compare the solid line with broken ones in the 1st row and 2nd column).

b) When the e.m.f. is applied at an intermediate section of the line, e.g. concentrated in the middle or distributed uniformly, then the wire to earth voltages have the same magnitudes but opposite polarity on each half of the line (see the curves of broken line in the 2nd and 3rd rows). The symmetry of the distribution is disturbed if only one switch at the terminals is closed (see the solid lines in the 2nd and 3rd rows). The differences between voltage distributions arising from terminations of open/closed and closed/closed switch positions tend to decrease with the increase of both the length of line and frequency.

A.3 *Longitudinal conversion losses*

The longitudinal conversion losses and the longitudinal transfer losses (defined in Tables 1/K.10 and 2/K.10) are basically determined by:

- the distribution of wire to sheath voltages, see § A.2, and
- the magnitude and distribution of capacitance unbalance.

Regarding the second aspect, three cases have been studied. These are indicated in Table A-1/K.10 as one-sided, perfectly equalized and equalized with additional unbalance. The one-sided uniform $\Delta C = 600$ pF/km tends to simulate the worst case which in practice does not exist. The perfectly equalized line (with crossing at each 0.5 km) can also never be reached.

The magnitudes of longitudinal conversion losses can be explained by a consideration of the fact that high transverse voltages are generated as a result of capacitance unbalance if the location of an unbalance coincides with high wire to earth voltages. The unbalance of a subsequent section tends to amplify the transverse voltage if both the direction of the unbalance and polarity of the wire to earth voltage are the same as those of the previous section. However, if one of them is reversed, the resultant transverse voltages become lower.

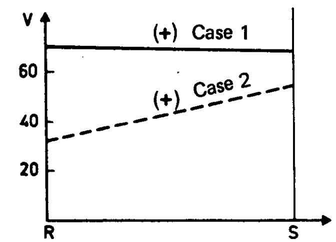
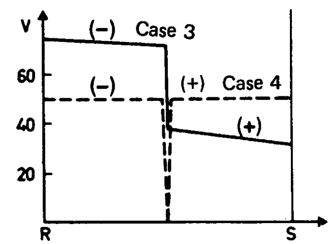
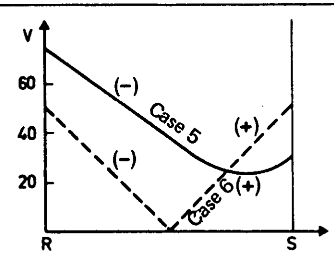
In the case of a well equalized line, the magnitude of the longitudinal conversion losses is high and is largely independent of both the location of the e.m.f. and the position of the switches at the terminals (see column 5 in Table A-1/K.10).

If the conversion losses increase significantly in magnitude with the opening of switch S and depend on the direction of supply, then the presence of local unbalance may be expected (see column 6 of Table A-1/K.10).

The low values of longitudinal conversion losses (i.e. less than 60 dB) might be caused by a one-sided nature of the capacitance unbalance (see column 4 of Table A-1/K.10). This is the case for Recommendation K.10 where the testing method specified in § 2 may produce significantly higher values for longitudinal conversion losses than the actual values in real conditions of power induction. In this case, more realistic values can be obtained by the method given in Table 2/K.10.

TABLE A-1/K.10

Demonstration of wire to earth voltages and longitudinal conversion losses
(length of cable: 10 km; frequency: 800 Hz; capacitance unbalance: ΔC = 600 pF/km)

	Location of e.m.f.	Distribution of wire, to earth voltage	Termination of longitudinal path (switch position) at terminal		Longitudinal conversion losses dB					
					Character of ΔC distribution					
					One-sided		Perfectly equalized		Equalized with additional unbalance	
			R (1)	R (2)	R (1)	S (2)	R (1)	S (2)	R (1)	S (2)
1	At terminal S (1)		Case 1 open S	150 Ω	49	49	101	101	77	84
			Case 2 closed 150 Ω S	150 Ω	53	53	112	102	83	90
2	At the middle		Case 3 open S_2	150 Ω S_1 closed	57	58	96	100	78	84
			Case 4 closed 150 Ω S_2	150 Ω S_1 closed	70	70	100	99	83	88
3	Uniform		Case 5 open S_2	150 Ω S_1 closed	57	58	95	102	78	84
			Case 6 closed 150 Ω S_2	150 Ω S_1 closed	74	74	99	101	83	88
	Col. 1	Col. 2	Col. 3		Col. 4		Col. 5		Col. 6	

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The main unbalance on lines is the capacitance unbalance. However, occasionally, the resistive unbalance (series resistance, R) is important as well. As has been pointed out before, when switch S_2 is open, the effect of shunt unbalance (in case of line *C*) is emphasized. If the switch S_2 (or S_1 and S_2 indicated in Table 2/K.10) is opened and the conversion loss remains unchanged (or even decreases), it indicates that series unbalance may not be the primary cause of the line unbalance. On the other hand, if there is an increase, the series unbalances are dominant. It should be noted, that while the reason for having Z_L and S_2 is to allow the tester to distinguish between series and shunt unbalances of the line, the effectiveness of this feature depends on the shunt impedance of the line provided by the resultant earth capacitance of the line (e.g. length of line [3]).

References

[1] CCITT Question 13/V *Unbalance of telephone installations.*

[2] CCITT Contribution COM V-38, *Study of relation between unbalance and induced transverse voltages,* 1981-1984 (Hungarian Administration).

[3] IEEE Std 455 – 1976 *IEEE Standard test procedure for measuring longitudinal balance of telephone equipment operating in the voice band.* Published by IEEE, Inc., September 30, 1976.

Recommendation K.11 (Geneva, 1972; modified Malaga-Torremolinos, 1984)

PRINCIPLES OF PROTECTION AGAINST OVERVOLTAGES AND OVERCURRENTS

Introduction

Current CCITT documents recognize lightning and faults on nearby electrical installations as sources of dangerous disturbances in telecommunications lines, which may cause damage leading to interruptions in service and the need for repairs or even hazards to personnel.

The object of the present Recommendation is to set out principles which enable the frequency and seriousness of such disturbances to be limited to levels which take account of quality of service, operating costs and safety of personnel. These principles are applicable to all parts of a telecommunications system. More details on certain methods of protection and for certain parts of the system are given in the References and in the following Recommendations: K.5, K.6, K.9, K.12, K.15, K.16, K.17. Information about disturbing phenomena and protection techniques are given in [1] and [2].

This Recommendation deals principally with the local exchange, local loop plant and subscribers equipment, but its contents may have wider application.

Note – The disturbing phenomena, when they appear, are relatively rare or of very brief duration (usually of the order of a fraction of a second) and in framing the present Recommendation, consideration has not been given to methods of avoiding interruption of the functioning of equipment during an actual disturbance. The CCITT is pursuing the study of such methods.

1 General considerations

1.1 *Origin of dangerous overvoltages and overcurrents*

1.1.1 *Direct lightning strikes*

Such strikes may cause currents of some thousands of amperes to flow along wires or cables for some microseconds. Physical damage may occur and overvoltage surges of many kilovolts may apply stress to the dielectrics of line plant and terminal equipment.

1.1.2 *Lightning strikes nearby*

Lightning currents flowing from cloud to earth or cloud to cloud cause overvoltages in overhead or underground lines near to the strike. The area affected may be large in districts of high earth resistivity.

1.1.3 *Induction from fault currents in power lines including electric traction systems*

Earth faults in power systems cause large unbalanced currents to flow along the power line inducing overvoltages into adjacent telecommunications lines which follow a parallel course. The overvoltages may rise to several kilovolts and have durations of 200 to 1000 ms (occasionally even longer) according to the fault clearing system used on the power line.

1.1.4 *Contacts with power lines*

Contacts may occur between power and telecommunication lines when local disasters, e.g. storms, fires, cause damage to both types of plant or when the normal safeguards of separation and insulation are not followed. Overvoltages rarely exceed 240 V a.c., r.m.s. above earth in countries where this is the normal distribution voltage but may continue for an indefinite period until observed. Where higher distribution voltages, e.g. 2 kV, are used the power line protection arrangements usually ensure that the voltage is removed in a short time if a fault occurs. The overvoltage may cause excessive currents to flow along the line to the exchange earth causing damage to equipment and danger to staff.

1.1.5 *Rise of earth potential*

Earth faults in power systems cause currents in the soil which raise the potential in the neighbourhood of the fault and of the power supply earth electrode. (See also Recommendation K.9.) These earth potentials may affect telecommunication plant in two ways:

a) Telecommunication signalling systems may malfunction if the signalling earth electrode is in soil whose potential rises by as little as 5 V with respect to true earth. Such voltages may be caused by minor faults on the power system which may remain undetected for long periods.

b) Higher rises of earth potential can cause danger to staff working in the affected area or, in extreme cases, may be sufficient to break down the insulation of the telecommunications cable causing extensive damage.

1.2 *Methods of protection*

1.2.1 Some of the protective measures for lines which are described in § 2 have the effect of reducing overvoltages and overcurrents at their source and so reduce the risk of damage to all parts of the system.

1.2.2 Other protective measures which may be applied to specific parts of the system as indicated in §§ 2, 3 and 4 fall broadly into 2 classes:

- the use of protective devices which prevent excessive energy from reaching vulnerable parts either by diverting it (for example, spark gaps) or by disconnecting the line (for example, fuses);
- the use of equipment with suitable dielectric strength, current carrying capacity and impedance so that it can withstand the conditions applied to it.

1.3 *Types of protective devices*

1.3.1 *Air-gap protectors with carbon or metallic electrodes*

Usually connected between each wire of a line and earth, they limit the voltage which can appear between their electrodes. They are inexpensive but their insulation resistance can fall appreciably after repeated operation and they may require frequent replacement.

1.3.2 *Gas discharge tubes*

Usually connected between each wire of a line and earth or as 3-electrode units between a pair and earth. Their performance may be specified to precise limits to meet system requirements. The protectors are compact and will operate frequently without attention.

Detailed requirements for gas discharge tubes appear in Recommendation K.12.

1.3.3 *Semi-conductor protective devices*

Used in a similar way to carbon electrode protectors or gas-discharge tubes, these will protect equipment from values of overvoltage as low as 1 V. They are precise and fast-acting, but may be damaged by excessive currents.

1.3.4 *Fuses*

These are connected in series with each wire of a line to disconnect when excessive current flows. Simple fuses have a uniform wire which melts. Slow-acting fuses have a uniform wire which melts quickly when a large current flows, and a spring-loaded fusible element which melts gradually and disconnects when lower currents flow for a prolonged time. High level currents of 2 A and prolonged currents of 250 mA are typical operating levels. Fuses should not sustain an arc after operation. Fuses do not give protection against lightning surges and in districts where such surges are common, fuses of a high rating (up to 20 A) may be necessary to avoid trouble from fuse failures. Such fuses may not give adequate protection against power line contacts. Fuses can also be a source of noise and disconnection faults.

1.3.5 *Heat coils*

Fitted in series with each wire of a line, heat coils either disconnect the line, earth it, or do both, with the earth extended to line. Heat coils have some fusible component and operate when currents of, typically, 500 mA flow for some 200 s.

1.3.6 *Self-restoring current-limiting devices*

Fuses and heat coils have the disadvantage that they permanently interrupt a circuit when operated and it is then necessary to replace them manually. Certain variable impedance devices are available which, when heated by overload currents, increase their electrical resistance to a very high value. The device will return to a normal low electrical resistance when the overload current is removed. Attention is drawn to the response time and voltage handling capabilities of these items.

1.4 *Residual effects*

The essential purpose of protective measures is to ensure that the major part of the electrical energy arising from a disturbance is not dissipated in a vulnerable part of the installation and does not reach personnel. However, no device exists which has characteristics for suppressing ideally all voltages or currents connected with disturbances, for the following reasons:

1.4.1 *Residual overvoltages*

Account should be taken of:

a) voltages which are unaffected by the protective device because they are below its operating level;

b) transients which pass before the device operates;

c) residuals which are sustained after the device operates;

d) transients produced by the operation of the device.

1.4.2 *Transverse voltages*

Protective devices on the two wires of a pair may not operate simultaneously and so a transverse pulse may be produced. Under certain conditions, particularly if the equipment to be protected has a low impedance, operation of one protective device may prevent the operation of the other one and a transverse voltage may remain as long as the longitudinal voltages are on the line.

1.4.3 *Effect on normal circuit operation – coordinated design*

Sufficient separation should be allowed between the operating voltage of the protective devices and the highest voltage occurring on the line during normal operation.

Likewise the normal characteristics (internal impedances) of the protective elements must be compatible with the normal functioning of the installations, which must take account of their possible presence.

1.4.4 *Modifying effects*

A protective device may safeguard one part of a line at the expense of another, e.g. if a main distribution frame (MDF) fuse operates due to a power line contact, the voltage on the line may rise to full power line voltage when the fuse disconnects the telecommunication's earth.

Likewise the operation of a protector may greatly reduce the equivalent internal impedance of a circuit relative to equipment connected to it, thus permitting the circulation of currents which may cause damage.

1.4.5 *Coordination of primary and secondary protection*

For the protection of sensitive equipment it is sometimes necessary to use more than one protective device, e.g. a fast-operating, low-current device such as a semiconductor and a slower-operating, high-current device such as a gas-discharge tube. In such cases steps must be taken to ensure that in the event of a sustained overvoltage, the low-current device does not prevent the operation of the high-current device since, if this happens, the smaller device may be damaged, or the interconnecting wiring may conduct excessive current.

1.4.6 *Temperature rise*

Protective components should be designed and positioned in such a way that the rise in temperature which occurs when they operate is unlikely to cause damage to property or danger to people.

1.4.7 *Circuit availability*

The circuit being protected may be temporarily or permanently put out of service when a protective device operates.

1.4.8 *Fault liability*

The use of protective devices may cause maintenance problems due to unreliability. They may also prevent some line and equipment testing procedures.

1.5 *Assessment of risk*

1.5.1 The performance of a telecommunications system with respect to overvoltages depends on:

- the environment, i.e. the magnitude and probability of overvoltages occurring in the line network associated with the system;
- the construction methods used in the line network, see § 2;
- the resistibility of equipment in the system to overvoltages;
- the provision of protective devices;
- the quality of the earth system provided for operation of the protective devices.

1.5.2 *The environment*

In assessing the environment, consideration should be given to the factors mentioned in § 1.1.

The severity of overvoltages due to lightning varies widely in different localities. A high keraunic level and a high soil resistivity increase the risk of direct and nearby lightning strokes and, since lightning is the cause of a large proportion of power system faults, induction and rise of earth potential effects are also increased. On the other hand buried metal plant such as water pipes, armoured cables, etc., screens telephone cables and greatly reduces overvoltages due to lightning or induction.

- In city centres and in regions of low keraunic activity experience shows that overvoltages rarely exceed the residual voltages of protective devices and such environments may be classified as "unexposed". Recommendation K.20 and [3] specify the tests to be applied to equipment for use in unexposed environments without protection and these tests give an indication of the most severe environment which can be regarded as unexposed.

– All other environments are classified as "exposed" but this, of course, covers a wide range of conditions including exceptionally exposed situations where a satisfactory service can only be achieved by the use of all available protective measures.

In the case of induced voltages and rise of earth potential the overvoltages can be calculated as indicted in [2] which also recommends the maximum values which may be permitted under various conditions.

1.5.3 *Fault records*

The risk of overvoltages and overcurrents can only be properly assessed in the light of experience. It is recommended that fault statistics be kept in a form which is convenient for that purpose. Faults due to overvoltages or overcurrents and faults due to failures of protective components should be separated from each other and from other component faults.

1.6 *Decision on protection*

1.6.1 In considering the degree to which a telecommunications network should withstand overvoltages, two classes of failure may be recognized:

– minor failures affecting only small parts of the system. These may be allowed to occur at a level acceptable to the Administration;

– major breakdowns, fires, exchange failures, etc., which must, so far as possible, be avoided completely.

Examples of conditions which may be permitted to cause minor failures but not major breakdowns are given in Recommendation K.20. It is desirable also that failure of a single protective device should not cause a major breakdown.

1.6.2 Particular attention should be given to overvoltage and overcurrent protection for new types of exchange or subscribers' equipment to ensure that the benefits of its improved facilities are not lost due to unacceptable failures arising from exposure to overvoltages or overcurrents. Such equipment may be inherently sensitive to these conditions and damage or malfunction may affect large parts of a system.

1.6.3 It should be noted that over-protection, by the provision of unnecessary protective devices, is not only uneconomic but may actually worsen system performance since the devices themselves may have some liability to cause failures.

1.6.4 In the light of the above considerations and the assessment of risks in accordance with § 1.5, a decision should be made on the protection to be provided in all parts of the system. Account should be taken of commercial considerations such as the cost of protective measures, the cost of repairs, relations with customers and the probable frequency of faults due to overvoltage and overcurrent relative to the fault rate due to other causes.

The responsibility for making this decision and for ensuring the provision of any protective devices needed to coordinate lines and equipment should be clearly laid down.

It is necessary for manufacturers of equipment to know from the operating Administration the conditions the equipment will need to resist and for line engineers to know the resistibility of the equipment which will be connected to the lines. The line engineer should also define the constraints which equipment connected to the line will encounter, depending on the standards of line protection provided. Where parts of the network, such as subscribers' apparatus, lines and switching centres may be under different ownership, this coordination may require formal procedures such as the production of local standards. Recommendation K.20 and [3] give guidance for the preparation of these standards.

2 Protection of lines

2.1 *Protective measures external to the conductors themselves*

2.1.1 Telecommunication lines may be shielded from lightning to some extent by adjacent earthed metal structures, e.g. power lines or electric railway systems. Efficient metallic screens either in the form of cable sheaths, cable ducts or lightning guard wires, reduce the effects of lightning surges and power line induction. In areas with a high risk of lightning strikes special cables with multiple screens and high strength insulation are often used. Bonding all metal work gives useful protection.

2.1.2 Induction from power lines may be minimized by coordinating the construction practices for the power and telecommunication lines. The level of induction may be reduced at its source by the installation of earth wires and current limiters in the power system.

2.1.3 The likelihood of contacts occurring between power and telecommunications lines is reduced if agreed standards of construction, separation and insulation are followed. Economic considerations arise but it is often possible to benefit from jointly using trenches, poles and ducts, providing suitable safe practices are adopted. (See Recommendations K.5 and K.6.) It is particularly important to avoid contacts with high voltage power lines by a high standard of construction since, if such contacts occur, it may be very difficult to avoid serious consequences.

2.2 *Special cables*

Special cables of high dielectric strength may be used where high overvoltages are likely to occur.

Standard plastic insulated and sheathed cables have a higher dielectric strength than paper insulated, lead-sheathed cables and are suitable for most situations where cables with extra thick insulation were formerly used. The use of cables with strengthened insulation may be justified in situations where there is exceptional proximity or length of parallelism to power lines, high rise of earth potential in the immediate neighbourhood of power stations or extreme exposure to lightning due to high keraunic level and low soil conductivity.

Other examples of the use of special cables are:

- cables with metal sheaths which provide a good reduction factor to screen circuits within the cable;
- cables which carry circuits to exposed radio towers and which must be able to carry lightning discharge currents without damage;
- all-dielectric (i.e. non-metallic) optical fibre cables to effect isolation between conductive lengths of cable.

2.3 *Use of protective devices*

The use of protective devices may be desirable in the following circumstances:

2.3.1 They may be more economical than the special construction described in §§ 2.1 and 2.2. In this connection the cost of maintenance should not be overlooked since protective devices inevitably incur some maintenance expenditure whereas special cables, screening, etc., though initially expensive, usually incur no continuing costs.

2.3.2 Cables with extra thick insulation may themselves be undamaged by overvoltages or overcurrents but they can nevertheless conduct such conditions to other more vulnerable parts of the network. Extra protection is then required for the more vulnerable cables and is particularly important if these are large underground cables which are expensive to repair and affect service to many customers.

2.3.3 Induced overvoltages from power or traction line faults may still exceed levels permitted by the *Directives* even after all practicable avoidance measures have been followed.

2.4 *Installation of protective devices*

2.4.1 To protect conductor insulation it is beneficial to bond all metal sheaths, screens, etc., together, and to connect overvoltage protectors between the conductors and this bonded metal which should be connected to earth. This technique is particularly useful in districts of high soil resistivity as it avoids the need for expensive electrode systems for the protector earth connection.

2.4.2 Where protectors are used to reduce high voltages appearing in telecommunication lines due to induction from power line fault currents, they should be fitted to all wires at suitable intervals and at both ends of the affected length of line, or as near to this as practicable.

2.4.3 To protect underground cables against lightning surges protective devices may be placed at the points of connection to overhead lines. The protective devices fitted at the MDF and at subscribers' terminals reduce the risk of damage to lines but their main function is to protect components having lower dielectric strength than the cables. See Recommendation K.20 and [3].

2.4.4 Connections for lines and earth to overvoltage protectors used against lightning should be as short as possible to minimize surge voltage levels between lines and the equipotential bond point.

2.5 *Planning of works*

The general considerations of §§ 1.5 and 1.6 apply to the protection of lines. To the greatest extent possible it is recommended that the protective measures applied to the line should be decided at the outset of a project and should depend on the environment. It may be difficult and expensive to achieve a satisfactory standard of reliability from a line provided initially with insufficient protection.

3 **Protection of exchange and transmission equipment**

3.1 *Need for protection external to the equipment*

Operating organizations should take account of the possible need to fit protection external to the equipment, bearing in mind the following considerations:

3.1.1 A telecommunication line will give some protection to equipment under certain conditions, e.g.:

- a conductor may melt and disconnect an excessive current;
- conductor insulation may break down and reduce an overvoltage;
- air-gaps in connection devices may break down and reduce overvoltages.

3.1.2 The increased robustness of plastic insulated cables has the effect of increasing the levels of overvoltages and overcurrents which can circulate in the lines and be applied to equipment. By contrast the use of miniature electronic components in exchange and transmission equipment tends to increase its vulnerability to electrical disturbances.

For these reasons, in districts exposed to frequent and serious disturbances (lightning, power lines, soil of low conductivity), it is usually necessary to interpose protective devices of the types described in § 1.3 between the cable conductors and the equipment to which they are connected, preferably on the MDF. This will prevent cables from the MDF to equipment from having to carry heavy overcurrents.

The protective devices are fitted to the line side of the MDF to avoid the need to carry discharge currents in the MDF jumper field and to expose as little of the MDF wiring and terminal strips as possible to mains voltage in the event that a mains voltage line contact causes a series protective device to disconnect the line.

3.1.3 In less exposed locations it may be that disturbances (voltages and currents) have statistical characteristics of level and frequency so low that in practice the risks do not exceed those resulting from the residual effects indicated in § 1.4 for exposed regions. Protective devices then serve no purpose and are an unnecessary expense.

3.2 *Need for equipment to have a minimum level of electrical robustness*

In locations where lines are exposed and protective devices are provided, the residual effects considered in § 1 can cause overvoltages and overcurrents to appear in the equipment. In less exposed environments the disturbances described in § 3.1.3 can cause similar effects. It is necessary for equipment to be designed to withstand these conditions and detailed recommendations on the resistibility which equipment should possess are given in Recommendation K.20.

3.3 *Effect of switching conditions*

Since the configuration and interconnection of equipment connected to a given line is required to vary during the successive stages of connecting a call, it is important not to limit the study of protection solely to individual line equipments. Much equipment is common to all lines and can be exposed to disturbances when connected to a particular line.

The effectiveness of the protection provided can be influenced by the reduction in the probability of exposure if the effective duration of the connection to lines is short. On the other hand common equipment should be better protected since its failure risks more serious degradation in the performance of the exchange or the district.

4 Protection of subscribers' terminal equipment

The protection methods already set out for exchange equipment can often be usefully applied to subscribers' equipment. Detailed tests to determine the resistibility of subscriber equipment are given in [3]. It is also appropriate to consider the specific aspects described below.

4.1 *Degree of exposure*

Lines to installations near exchanges in urban or industrial zones are usually little exposed to surges on account of the screening effect of numerous nearby metallic structures as described in § 2.1.

On the other hand, lines to installations remote from built-up areas can be very exposed on account of their length, the absence of a protective environment, overhead construction at the subscriber's end and the high resistivity of the soil. The mechanical robustness of the overhead cables at the subscriber's end makes the effect of surges all the more serious since the line itself can carry higher voltages and currents.

4.2 *Dielectric strength*

It is desirable to have a high dielectric strength for the insulation between the conducting parts connected to the lines and all parts accessible to the user.

4.3 *Use of protectors*

Where telephone lines are exposed to frequent and severe disturbances from power line faults or lightning, the voltage of the lines relative to local earth potential may be limited by connecting protective devices of the types described in § 1.3 between the line conductors and the earth terminal.

The terminal equipment dielectric strength should be chosen taking account of the breakdown voltage of the protective device and the impedance of the protector-line to earth connection.

4.4 *Common bonding*

At installations of subscriber terminal equipment a low resistance earth for overvoltage protectors may be unavailable, or the costs of procuring a suitable low-resistance earth may be excessive compared to other installation costs. Furthermore, the terminal equipment may be located adjacent to earthed systems, such as water pipes, or may receive power from an electricity system.

To minimize both equipment damage and exposure of the subscriber to high voltages, even if the earth resistance is not sufficiently low, all earthed systems, signalling earths and the power neutral should be bonded together either directly or by means of a spark gap. Although this bonding may be expensive it allows the difficulty of providing a low resistance earth to be resolved and is a technique widely used. In some countries connection to the electricity system neutral is governed by national regulations, so that agreement with the electrical Authority should be obtained.

4.5 *National regulations*

Many countries have national standards covering the protection of users of telecommunications equipment not only from the risks associated with connection to the electricity mains but also from conditions which may appear on the telephone line.

4.6 *High cost of maintenance of subscribers' installations*

The cost of repairs at exposed terminal installations may be high by reason of the distance from the maintenance centre, transport delays and, possibly, the seriousness of the damage. Moreover, insufficient protection is the cause of repeated interruptions of service which are particularly damaging to the quality of service and the satisfaction of the customer. This justifies the granting of special attention to protection measures.

References

[1] CCITT Manual *The protection of telecommunication lines and equipment against lightning discharges*, ITU, Geneva 1974, 1978.

[2] CCITT *Directives concerning the protection of telecommunications lines against harmful effects from electricity lines*, ITU Geneva. (The Directives are under revision and will in future be divided into a number of Volumes. This reference will then be expanded to indicate the appropriate Volumes).

[3] Draft CCITT Recommendation *Resistibility of subscribers telecommunications equipment to overvoltages and overcurrents*, Annex 3 to Contribution COM V-R 9.

[4] CCITT Manual Earthing of telecommunication installations, ITU, Geneva, 1976.

Recommendation K.12 (Geneva, 1972, modified Malaga-Torremolinos, 1984)

CHARACTERISTICS OF GAS DISCHARGE TUBES FOR THE PROTECTION OF TELECOMMUNICATIONS INSTALLATIONS

Introduction

This Recommendation gives the basic requirements to be met by gas discharge tubes for the protection of exchange equipment, subscribers' lines and subscribers' equipment from over-voltages. It is intended to be used for the harmonization of existing or future specifications issued by gas discharge tube manufacturers, telecommunication equipment manufacturers, or Administrations.

Only the minimum requirements are specified for essential characteristics. As some users may be exposed to different environments or have different operating conditions, service objectives or economic constraints, these requirements may be modified or further requirements may be added to adapt them to local conditions.

This Recommendation gives guidance on the use of gas discharge tubes to limit over-voltages on telecommunications lines.

1 Scope

This Recommendation:

a) gives the characteristics of gas discharge tubes used in accordance with CCITT Recommendation K.11 for protection of exchange equipment, subscribers' lines and subscribers' equipment against over-voltages,

b) deals with gas discharge tubes having 2 or 3 electrodes,

c) does not deal with mountings and their effect on tube characteristics. Characteristics given apply to gas discharge tubes by themselves mounted only in the ways described for the tests,

d) does not deal with mechanical dimensions,

e) does not deal with quality assurance requirements,

f) does not deal with gas discharge tubes which are connected in series with voltage-dependent resistors in order to limit follow-on currents in electrical power systems,

g) may not be sufficient for gas discharge tubes used on high frequency or multi-channel systems.

2 Definitions

Appendix I gives definitions of a number of terms used in connection with gas discharge tubes. It includes some terms not used in this Recommendation.

3 Environmental conditions

Gas discharge tubes shall be capable of withstanding during storage the following conditions without damage:

– Temperature: -40 to $+90$ °C;

– Relative humidity: up to 95%.

See also §§ 7.5 and 7.7.

4 Electrical characteristics

Gas discharge tubes should have the following characteristics when tested in accordance with § 5.

§§ 4.1 to 4.5 apply to new gas discharge tubes and also, where quoted in § 4.6, to tubes subjected to life tests.

4.1 *Spark-over voltages* (see §§ 5.1, 5.2 and Figures 1/K.12, 2/K.12 and 3/K.12)

4.1.1 Spark-over voltages between the electrodes of a 2-electrode tube or between either line electrode and the earth electrode of a 3-electrode tube shall be within the limits in Table 1/K.12.

TABLE 1/K.12

d.c. spark-over voltage			Maximum impulse spark-over voltage	
Nominal (V)	Minimum (V)	Maximum (V)	at 100 V/μs	at 1000 V/μs
230	180	300	700	900
250/1	200	450	700	900
250/2	200	300	700	900
300	255	345	700	900
350/1	265	600	1000	1100
350/2	290	600	900	1000

4.1.2 For 3-electrode tubes, the spark-over voltage between the line electrodes shall not be less than the minimum d.c. spark-over voltage in Table 1/K.12.

4.2 *Holdover voltages* (see § 5.5 and Figures 4/K.12 and 5/K.12)

All types of tube shall have a current turn-off time less than 150 ms when subjected to one or more of the following tests according to the projected use:

4.2.1 2-electrode tubes tested in a circuit equivalent to Figure 4/K.12 where the test circuit components have the values in Table 2/K.12.

TABLE 2/K.12

Component	Test 1	Test 2	Test 3
PS1	52 V	80 V	135 V
R3	260 Ω	330 Ω	1300 Ω
R2	Note	150 Ω	150 Ω
C1	Note	100 nF	100 nF

Note – Components omitted in this test.

4.2.2 3-electrode tubes tested in a circuit equivalent to Figure 5/K.12 where components have the values in Table 3/K.12.

TABLE 3/K.12

Component	Test 1	Test 2	Test 3
PS1	52 V	80 V	135 V
PS2	0 V	0 V	52 V
R3	260 Ω	330 Ω	1300 Ω
R2	Note	150 Ω	150 Ω
C1	Note	100 nF	100 nF

Note – Components omitted in this test.

4.3 *Insulation resistance* (see § 5.3)

Not less than 1000 Mohms initially.

4.4 *Capacitance*

Not greater than 20 pF.

4.5 *Impulse transverse voltage – 3-electrode tubes* (see § 5.9 and Figure 6/K.12)

The difference in time not to exceed 200 ns.

4.6 *Life tests* (§§ 5.6, 5.7 and 5.8)

The currents specified in § 4.6.1 for the appropriate nominal current rating of the tube shall be applied. After each current application, the gas discharge tube shall be capable of meeting the requirements of § 4.6.2. On completion of the number of current applications specified, the tube shall be capable of meeting the requirements of § 4.6.3.

4.6.1 *Test currents*

Gas discharge tubes intended for use only on main distribution frames or similar situations where connection to lines is via cable pairs, shall be subjected to the currents of Columns 2 and 3 of Table 4/K.12. Gas discharge tubes intended for applications where they are directly connected to open wire lines will be designated EXT by the purchaser and shall be subjected to the currents of Columns 2, 3 and 4 of Table 4/K.12.

TABLE 4/K.12

Nominal current	a.c. 15-62 Hz for 1 s		Impulse current 10/700, 500 applications, or 10/1000, 300 applications	Impulse 8/20, 10 applications (EXT tubes only)
A (1)	A rms (2)	No. of applications (3)	A peak (4)	kA peak (5)
2.5	2.5	5	50	2.5
5	5	5	100	5
10	10	5	100	10
20	20	10	200	20

4.6.2 *Requirements during life test*

Insulation resistance: not less than 10 Mohms.

d.c. and impulse spark-over voltage: not more than the relevant value in § 4.1.

4.6.3 *Requirements after completion of life test*

Insulation resistance: not less than 100 Mohms (10 Mohms if particularly specified by the purchaser).

d.c. and impulse spark-over voltage: as in § 4.1.

Holdover voltage: as in § 4.2.

5 Test methods

5.1 *d.c. spark-over voltage* (see § 4.1 and Figures 1/K.12 and 2/K.12)

The gas discharge tube shall be placed in darkness for at least 24 hours immediately prior to testing and tested in darkness with a voltage which increases so slowly that the spark-over voltage is independent of the rate of rise of the applied voltage. Typically, a rate of rise of 100 V/s is used, but higher rates may be used if it can be shown that the spark-over voltage is not significantly changed thereby. The tolerances on the wave-shape of the rising test voltage are indicated in Figure 1/K.12. The voltage is measured across the open-circuited terminals of the generator. U_{max} of Figure 1/K.12 is any voltage greater than the maximum permitted d.c. spark-over voltage of the gas discharge tube and less than three times the minimum permitted d.c. spark-over voltage of the gas discharge tube.

The test shall employ a suitable circuit such as that shown in Figure 2/K.12. A minimum of 15 minutes shall elapse between repetitions of the test, with either polarity, on the same gas discharge tube.

Each pair of terminals of a 3-electrode gas discharge tube shall be tested separately with the other terminal unterminated.

Note – The use of Figure 1/K.12 may be explained as follows:

A single mask will do for all values of U_{max} and the nominal rate of rise, provided that it is a suitable size for the display of the waveform and that the scales of U and T of the waveform can be adjusted. This follows because the Y-axis has arbitrary points marked 0 and U_{max} with 0.2 U_{max} at the appropriate point between them while the X-axis has arbitrary points marked 0 and T_2 with T_1 (= 0.2 T_2), 0.9 T_1, 1.1 T_1, 0.9 T_2, 1.1 T_2 marked at the appropriate points. The X and Y zeros need not coincide and, in fact, need not be shown at all.

To compare a waveform trace with the mask, it is necessary to know the values of U_{max} and the nominal rate of rise for the waveform in question. As an example, consider a waveform with U_{max} = 750 V and nominal rate of rise = 100 V/sec.

Then 0.2 U_{max} = 150 V, T_2 = 7.5 s, T_1 = 1.5 s.

Hold the mask against the trace and adjust the vertical scale so that the 150 V calibration is against 0.2 U_{max} and the 750 V point against U_{max}. Adjust the horizontal scale similarly for 1.5 s = T_1 and 7.5 s = T_2. Slide the mask so that the 150 V point on the trace is within the bottom boundary of the test window; the remainder of the trace up to 750 V must be within the test window.

5.2 *Impulse spark-over voltage* (§ 4.1 and Figures 1/K.12 and 3/K.12)

The gas discharge tube shall be placed in darkness for at least 15 minutes immediately prior to testing and tested in darkness. The voltage waveform measured across the open circuit test terminals shall have a nominal rate of rise selected from § 4.1 and shall be within the enclosed limits indicated in Figure 1/K.12. Figure 3/K.12 shows a suggested arrangement for testing with a voltage impulse having a nominal rate of rise of 1.0 kV/µs.

A minimum of 15 minutes shall elapse between repetitions of the test, with either polarity, on the same gas discharge tube.

Each pair of terminals of a 3-electrode gas discharge tube shall be tested separately with the other terminal unterminated.

5.3 *Insulation resistance* (§ 4.3)

The insulation resistance shall be measured from each terminal to every other terminal of the gas discharge tube. The measurement shall be made at an applied potential of at least 100 V and not more than 90% of the minimum permitted d.c. spark-over voltage. The measuring source shall be limited to a short circuit current of less than 10 mA. Terminals of three-electrode gas discharge tubes not involved in the measurement shall be left unterminated.

5.4 *Capacitance* (§ 4.4)

The capacitance shall be measured between each terminal and every other terminal of the gas discharge tube. In measurements involving 3-electrode gas discharge tubes, the terminal not being tested shall be connected to a ground plane in the measuring instrument.

5.5 *Holdover test (§ 4.2)*

5.5.1 *2-electrode gas discharge tube* (Figure 4/K.12)

Tests shall be conducted using the circuit of Figure 4/K.12. Values of PS1, R2, R3 and C1 shall be selected for each test condition from Table 2/K.12. The current from the surge generator shall have an impulse waveform of 100 A, 10/1000 or 10/700 measured through a short circuit replacing the gas discharge tube under test. The polarity of the impulse current through the gas discharge tube shall be the same as the current from PS1. The time for current turn-off shall be measured for each direction of current passage through the gas discharge tube. Three impulses shall be applied at not greater than 1-minute intervals and the current turn-off time measured for each impulse.

5.5.2 *3-electrode gas discharge tube* (Figure 5/K.12)

Tests shall be conducted using the circuit of Figure 5/K.12. Values of circuit components shall be selected from Table 3/K.12. The simultaneous currents that are applied to the gaps of the gas discharge tube shall have impulse waveforms of 100 A, 10/1000 or 10/700 measured through a short circuit replacing the gas discharge tube under test. The polarity of the impulse current through the gas discharge tube shall be the same as the current from PS1 and PS2.

For each test condition, measurement of the time to current turn-off shall be made for both polarities of the impulse current. Three impulses in each direction shall be applied at intervals not greater than 1 minute and the time to current turn-off measured for each impulse.

5.6 *Impulse life – all types of gas discharge tube* (§ 4.6)

Fresh gas discharge tubes shall be used and impulse currents shall be applied as specified in Table 4/K.12, Column 3, for the relevant nominal current of the tube. Half the specified number of tests shall be carried out with one polarity followed by half with the opposite polarity. Alternatively, half the tubes in a sample may be tested with one polarity and the other half with the opposite polarity. The pulse repetition rate should be such as to prevent thermal accumulation in the gas discharge tube.

The voltage of the source shall exceed the maximum impulse spark-over voltage of the gas discharge tube by not less than 50 per cent. The specified impulse discharge current and waveform shall be measured with the gas discharge tube replaced with a short circuit. For 3-electrode gas discharge tubes, independent impulse currents each having the value specified in Table 4/K.12, Column 3, shall be discharged simultaneously from each electrode to the common electrode.

The gas discharge tube shall be tested after each passage of impulse discharge current or at less frequent intervals if agreed between the supplier and the purchaser to determine its ability to satisfy the requirements of § 4.6.2.

On completion of the specified number of impulse currents the tube shall be allowed to cool to ambient temperature and tested for compliance with § 4.6.3.

5.7 *Impulse life – additional tests for tubes designated EXT* (§ 4.6)

As in § 5.6, but applying the conditions of Table 4/K.12, Column 4.

5.8 *AC life – all types of tube* (§ 4.6)

Fresh tubes shall be used and alternating currents applied as specified in Table 4/K.12, Column 2, for the relevant nominal current of the tube.

The time between applications should be such as to prevent thermal accumulation in the tube. The rms a.c. voltage of the current source shall exceed the maximum d.c. spark-over voltage of the gas discharge tube by not less than 50 per cent.

The specified a.c. discharge current and duration shall be measured with the gas discharge tube replaced with a short circuit. For 3-electrode gas discharge tubes, a.c. discharge currents each having the value specified in Table 4/K.12 shall be discharged simultaneously from each electrode to the common electrode.

The gas discharge tube shall be tested after each passage of a.c. discharge current to determine its ability to satisfy the requirements of § 4.6.2.

On completion of the specified number of current applications, the tube shall be allowed to cool to ambient temperature and tested for compliance with § 4.6.3.

5.9 *Impulse transverse voltage* (§ 4.5 and Figure 6/K.12)

The duration of the transverse voltage shall be measured while an impulse voltage having a virtual steepness of impulse wavefront of 1 kV/μs is applied simultaneously to both discharge gaps. Measurement may be made with an arrangement as indicated in Figure 6/K.12. The difference in time between the spark-over of the first gap and that of the second is specified in § 4.5.

6 Radiation

The emerging radiation from any radioactive matter used to pre-ionize the discharge gaps must be within the limits specified as admissible in the regulations concerning the protection from radiation which are issued by the country of the manufacturer as well as of the user. This provision applies both to individual and to a batch of gas discharge tubes (for example, when packed in a cardboard box for dispatch, storage, etc.).

The supplier of gas discharge tubes containing radioactive materials shall provide recommendations, complying with the International Atomic Energy Agency (IAEA) "Regulations for the safe transport of radioactive materials" and with all other relevant international requirements, on the following matters:

a) maximum number of items per package,

b) maximum quantity per shipment,

c) maximum quantity which may be stored together,

d) any other storage requirements,

e) handling precautions and requirements,

f) disposal arrangements.

7 Environmental tests

7.1 *Robustness of terminations*

The user shall specify a suitable test from International Electrotechnical Commission (IEC) standard 68-2-21 (1975) if applicable.

7.2 *Solderability*

Soldering terminations shall meet the requirements of IEC standard 68-2-20 (1979) Test Ta Method 1.

7.3 *Resistance to soldering heat*

Gas discharge tubes with soldering terminations shall be capable of withstanding IEC standard 68-2-20 (1979) Test Tb Method 1B. After recovery, the gas discharge tube shall be visually checked and show no signs of damage and its d.c. spark-over shall be within the limits for that tube.

7.4 *Vibration*

A gas discharge tube shall be capable of withstanding IEC standard 68-2-6 (1970) 10-500 Hz, 0.15 mm displacement for 90 minutes without damage. The user may select a more severe test from the document. At the end of the test, the tube shall show no signs of damage and shall meet the d.c. spark-over and insulation resistance requirements specified in §§ 4.1 and 4.3.

7.5 *Damp heat cyclic*

A gas discharge tube shall be capable of withstanding IEC standard 68-2-4 Test D Severity IV. At the end of the test, the tube shall meet the insulation resistance requirement specified in § 4.3.

7.6 *Sealing*

A gas discharge tube shall be capable of passing IEC standard 68-2-17 (1978) Test Qk, severity 600 hours, for fine leaks. Helium shall be used as the test gas. The fine leak rate shall be less than 10^{-7} bar.cm.^{3} s.$^{-1}$.

The tube shall then be capable of passing the coarse leak test Qc Method 1.

7.7 *Low temperature*

A gas discharge tube shall be capable of withstanding IEC standard 68-2-1 Test Aa. $-40\,°C$, duration 2 hours, without damage. While at $-40\,°C$ the tube must meet the d.c. and impulse spark-over requirements of § 4.1.

8 Identification

8.1 *Marking*

Legible and permanent marking shall be applied to the tube as necessary to ensure that the purchaser can determine the following information by inspection:

a) manufacturer,

b) year of manufacture,

c) type.

The purchaser may specify the codes to be used for this marking.

8.2 *Documentation*

Documents shall be provided to the purchaser so that from the information in § 8.1 he can determine the following further information:

a) full characteristics as set out in this Recommendation,

b) name of radioactive material used in the tube or statement that such material has not been used.

9 Ordering information

The following information should be supplied by the purchaser:

a) drawing giving all dimensions, finishes and termination details (including numbers of electrodes and identifying the earth electrode),

b) nominal d.c. spark-over voltage, chosen from § 4.1.1,

c) nominal current rating chosen from § 4.6.1,

d) the designation EXT if the tests of Table 4/K.12, Column 4, are required,

e) holdover voltage tests required in § 4.2,

f) marking codes required for § 8.1,

g) robustness of terminations – test required for § 7.1,

h) destruction characteristic, if required, including failure mode (see Note),

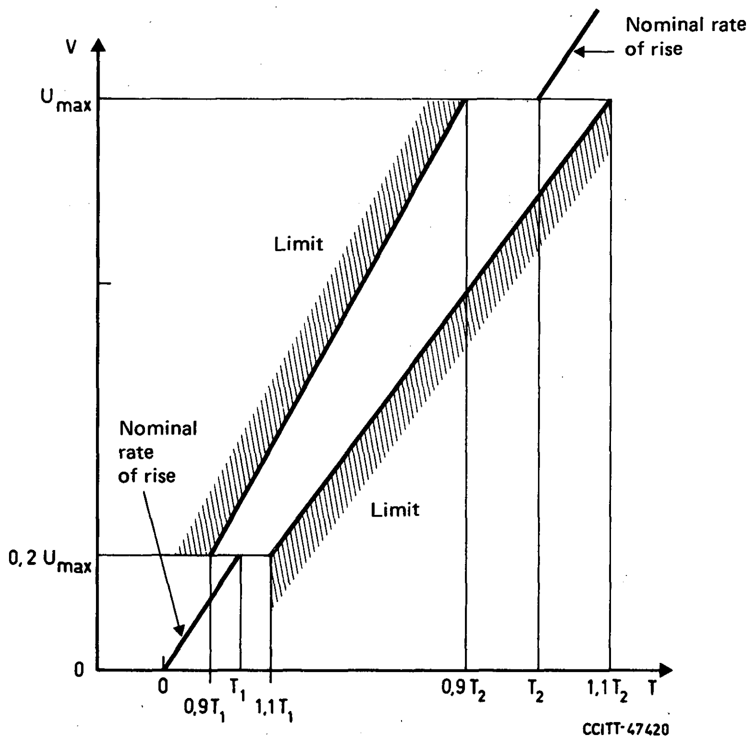
i) quality assurance requirements.

Note – After passage of an alternating or impulse current of value much higher than that shown in § 4.6.1, the gas discharge tube may be destroyed, i.e. its electrical characteristics may be greatly modified. Two situations may occur:

1) The gas discharge tube becomes in effect an insulator and presents a higher dielectric strength than it had initially – that is to say, it becomes open circuit.

2) The gas discharge tube becomes of limited resistance – generally a low value which does not allow normal operation of the line – that is to say it becomes a short circuit. (This situation may be preferable from the point of view of protection and maintenance.)

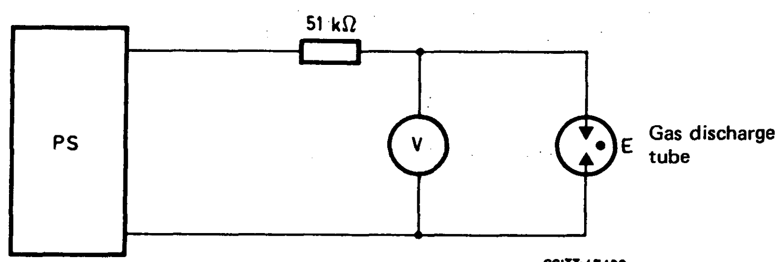
Test methods and the relations between the value and duration of the destructive current are not detailed in this Recommendation nor is the state of the element after destruction. Administrations should cover their requirements in these respects in their own documentation.



Note – Spark-over test waveform (nonconducting) must be within enclosed limits.

FIGURE 1/K.12

Spark-over test waveform
(§§ 4.1, 5.1 and 5.2)



PS : Variable voltage power supply

Note – Means shall be included to ensure that the gas discharge tube sparks over once only.

FIGURE 2/K.12

Circuit for d.c. spark-over voltage test
(§§ 4.1 and 5.1)

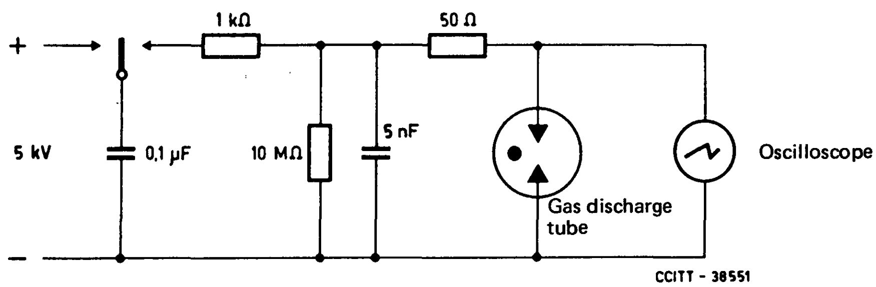
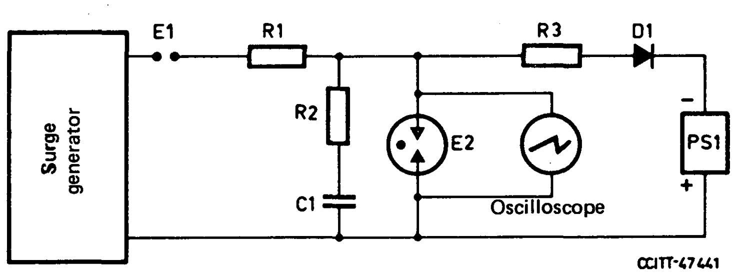


FIGURE 3/K.12

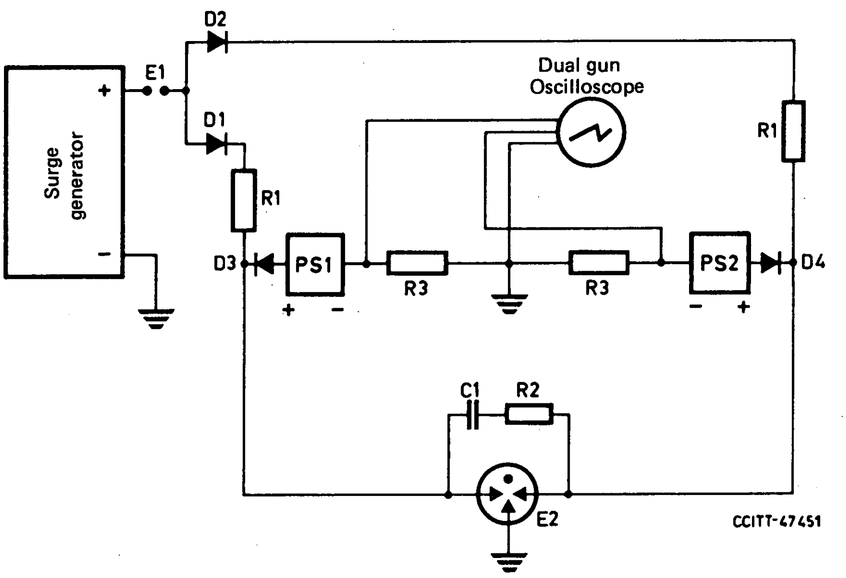
Testing arrangement producing a voltage impulse having a wavefront with a virtual steepness of 1 kV/μs (§§ 4.1 and 5.3)



PS1 : Constant voltage d.c. supply or battery
E1 : Isolation gap or equivalent device
E2 : Gas discharge tube
D1 : Isolation diode or other isolation device
R1 : Impulse current limiting resistor or wave-shaping network

FIGURE 4/K.12

Circuit for hold-over test of 2-electrode gas discharge tube (§§ 4.2.1 and 5.5.1)

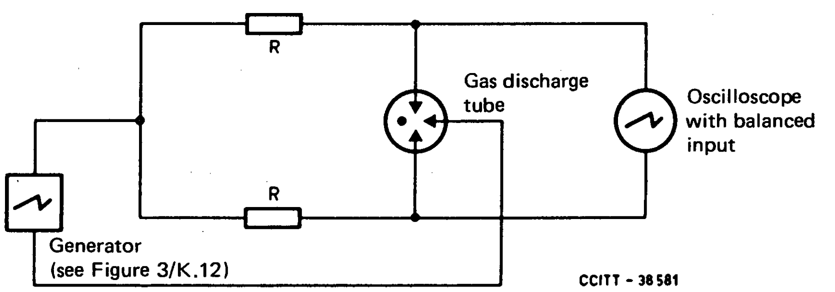


E1 : Isolation gap or equivalent device
E2 : Gas discharge tube
PS1, PS2 : Batteries or d.c. power supplies
R1 : Impulse current limiting resistors or wave-shaping networks

Note – The polarity of diodes D1 to D4 shall be reversed when the polarity of the d.c. power supplies and surge generators are reversed.

FIGURE 5/K.12

Circuit for hold-over test of 3-electrode gas discharge tube
(§§ 4.2.2 and 5.5.2)



R = line impedance

FIGURE 6/K.12

Circuit for impulse transverse voltage test
(§§ 4.5 and 5.9)

APPENDIX I

Definitions of terms associated with gas discharge tubes

I.1 **arc current**:

The current which flows after spark-over when the circuit impedance allows a current that exceeds the glow-to-arc transition current.

I.2 **arc voltage**:

The voltage appearing across the terminals of the gas discharge tube during the passage of the arc current.

I.3 **breakdown**:

See "spark-over".

I.4 **current turnoff time**:

The time required for the gas discharge tube to return itself to a nonconducting state following a period of conduction.

I.5 **destruction characteristic**:

The relationship between the value of the discharge current and the time of flow until the gas discharge tube is mechanically destroyed (break, electrode short circuit). For periods of time between 1 μs and some ms, it is based on impulse discharge currents, and for periods of time of 0.1 s and greater, it is based on alternating discharge currents.

I.6 **discharge current**:

The current that passes through a gas discharge tube when spark-over occurs.

I.7 **discharge current, alternating**:

The r.m.s. value of an approximately sinusoidal alternating current passing through the gas discharge tube.

I.8 **discharge current, impulse**:

The peak value of the impulse current passing through the gas discharge tube.

I.9 **discharge voltage**:

The voltage that appears across the terminals of a gas discharge tube during the passage of discharge current. Also referred to as "residual voltage".

I.10 **discharge voltage/current characteristic**:

The variation of crest values of discharge voltage with respect to discharge current.

I.11 **follow current**

The current from the connected power source that passes through a gas discharge tube during and following the passage of discharge current.

I.12 **gas discharge tube**:

A gap, or several gaps, in an enclosed discharge medium, other than air at atmospheric pressure, designed to protect apparatus or personnel, or both, from high transient voltages. Also referred to as "gas tube surge arrester".

I.13 **glow current**:

The current which flows after spark-over when circuit impedance limits the discharge current to a value less than the glow-to-arc transition current.

I.14 **glow-to-arc transition current**:

The current required for the gas discharge tube to pass from the glow mode into the arc mode.

I.15 **glow voltage**:

The voltage drop across the terminals of the gas discharge tube during the passage of glow current.

I.16 **holdover voltage**:

The maximum d.c. voltage across the terminals of a gas discharge tube under which it may be expected to clear and to return to the high impedance state after the passage of a surge, under specified circuit conditions.

I.17 **impulse spark-over voltage/time curve**:

The curve which relates the impulse spark-over voltage to the time to spark over.

I.18 **impulse waveform**:

An impulse waveform designated as x/y has a rise time of x μs and a decay time to half value of y μs as standardized in IEC Publication 60.

I.19 **nominal alternating discharge current**:

For currents with a frequency of 15 Hz to 62 Hz, the alternating discharge current which the gas discharge tube is designed to carry for a defined time.

I.20 **nominal d.c. spark-over voltage**:

The voltage specified by the manufacturer to designate the gas discharge tube (type designation) and to indicate its application with respect to the service conditions of the installation to be protected. Tolerance limits of the d.c. spark-over voltage are also referred to the nominal d.c. spark-over voltage.

I.21 **nominal impulse discharge current**:

The peak value of the impulse current with a defined wave shape with respect to time for which the gas discharge tube is rated.

I.22 **residual voltage**:

See "discharge voltage".

I.23 **spark-over**:

An electrical breakdown of a discharge gap of a gas discharge tube. Also referred to as "breakdown".

I.24 **spark-over voltage**:

The voltage which causes spark-over when applied across the terminals of a gas discharge tube.

I.25 **spark-over voltage, a.c.**:

The minimum r.m.s. value of sinusoidal voltage at frequencies between 15 Hz and 62 Hz that results in spark-over.

I.26 **spark-over voltage, d.c.**:

The voltage at which the gas discharge tube sparks over with slowly increasing d.c. voltage.

I.27 **spark-over voltage, impulse**:

The highest voltage which appears across the terminals of a gas discharge tube in the period between the application of an impulse of given waveshape and the time when current begins to flow.

I.28 **transverse voltage**:

For a gas discharge tube with several gaps, the difference of the discharge voltages of the gaps assigned to the two conductors of a telecommunications circuit during the passage of discharge current.

INDUCED VOLTAGES IN CABLES WITH PLASTIC-INSULATED CONDUCTORS

According to [1], when a fault occurs on a power line near a telecommunication cable having all its circuits terminated by transformers, the permissible induced longitudinal voltage in the cable conductors should not exceed 60% of the voltage used to check the dielectric strength of the cable, as required by individual specifications for checks of the breakdown strength between the cable conductors and the sheath. This induced voltage is generally 1200 V r.m.s. value for paper-insulated conductors (60% of 2000 V). The *Directives* give no indication of the frequency of occurrence of such a voltage or of its permissible duration. In order that such voltages do not endanger line maintenance staff, the safety precautions for staff given in [2] must be observed.

Plastic-insulated cables can have a much higher dielectric strength than paper-insulated cables. Moreover, this dielectric strength is retained following the mechanical stresses that occur during the laying of the cable. There should thus be no danger of breakdown of the insulation between the conductors and the metal sheath when it is subjected to induced logitudinal e.m.f. sufficiently below the breakdown voltage of the cable. A sufficient safety margin is ensured if induced voltages are kept below 60% of the voltage used for checking the dielectric strength of the cable as given in the individual specifications; this voltage is, of course, related to the breakdown voltage.

At very little extra expense, sleeves and joints can be made to have the same dielectric strength as the insulation between the conductors and the metallic sheath, although transformers and terminal equipments must be suitably protected when their dielectric strength is not up to the conditions concerned.

If the source of the induced longitudinal e.m.f. is a high-reliability power line, as defined in the *Directives*, there is only a very small probability that staff will be in contact with a line at the precise moment when such a voltage of short duration occurs in the telecommunication cable. Any danger to staff is very slight given due observation of the safety precautions for maintenance staff working on telephone lines in which high voltages may be induced by neighbouring electricity lines.

For a cable not having its circuits terminated by transformers the above conditions also apply provided that surge voltages are prevented from reaching the telecommunication equipment by the striking of the lightning protectors installed at the ends of the circuits.

For these reasons, the CCITT is unanimously of the opinion that:

1 It is possible to make telecommunication cables with conductors that are insulated from each other and from the metallic sheath by high breakdown strength plastics. For such cables, when there is a fault on a neighbouring electricity line, the value of induced longitudinal e.m.f. that can be allowed is that which does not exceed 60% of the test voltage applied between the conductors and the metallic sheath for checking the dielectric strength (this test voltage, which is given in the individual cable specifications, is related to the breakdown voltage) provided the following conditions are observed:

a) circuits in such cables are terminated at their ends and at branching points on transformers or are provided with lightning protectors;

b) equipment, joints and cableheads associated with such cables must have a dielectric strength at least equal to that of the insulation between the conductors and the metallic cable sheath of the cable, given that the transformers mentioned in a) above must be provided with lightning protectors when their dielectric strength does not meet the required conditions;

c) the power line causing the induction must meet the conditions for high-reliability power lines given in [3];

d) staff working on telecommunication cables must take the safety precautions specified in [2].

2 When the circuits of such a cable are connected direct to the telecommunication equipment, that is, when no transformers or lightning protectors are inserted, and when the condition laid down in § 1.c) above is fulfilled, the maximum permissible induced longitudinal e.m.f. should be 650 V.

References

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines*, Chapter IV, Section 2, ITU, Geneva, 1963, 1965, 1974, 1978, 1982.

[2] *Ibid.*, Chapter XX.

[3] *Ibid.*, Preliminary Chapter, § 3.2.3.

Recommendation K.14 (Geneva, 1972; modified Malaga-Torremolinos, 1984)

PROVISION OF A METALLIC SCREEN IN PLASTIC-SHEATHED CABLES

A metal sheath provides a cable with electrostatic screening and a degree of magnetic screening. A plastic sheath has no intrinsic screening properties. Some plastic-sheathed cables, for example those with paper-insulated cores, incorporate a metal screen as a water barrier. Such a metal screen, which is usually in the form of a longitudinally applied aluminium tape, provides the same screening properties as a nonferrous metal sheath of the same longitudinal conductivity. The tape must, however, be connected to the telephone exchange earth electrode systems at its ends and/or to conveniently located earthing points, such as metal cable sheaths, along its length. It is also important that at jointing points the tape be extended through by connections of very low resistance. Although the degree of screening provided by the tape may be small at 50 Hz, it can be considerable at frequencies which give rise to noise interference. The presence of a screen on a cable also reduces the induction arising from the high-frequency components of transients caused by power-line switching and also induced transients from lightning strokes; such transient induced voltages are of increasing importance with the increasing use of miniaturized telecommunication equipment with very small thermal capacity.

On the basis of the above considerations and experience with the use of plastic-sheathed cables,

the CCITT recommends that the following provisions be observed:

1 Since plastic-sheathed subscriber distribution cables without a screen give satisfaction for distribution from the exchange to subscribers, they may be used in localities where there are no alternating current electrified railways. However, account must always be taken of the risk of noise interference that may arise in the vicinity of electric railways, especially those with thyristor controlled equipment in the locomotives. Consideration should also be given to possible interference by radio transmitters which operate in the same frequency range as the circuits in the plastic-sheathed cable.

2 Trunk and junction cables should contain a screen which can have the form of an aluminium-tape water barrier. Cables provided with a screen having a conductance of the order of half that of a cable having the same core diameter, but with a lead sheath, have given complete satisfaction where there are no risks of severe magnetic induction.

3 If a plastic-sheathed cable is provided with a screen of a conductance equivalent to that of a conventional lead-sheathed cable, then in the presence of induction the plastic-sheathed cable can be used in entirely the same circumstances as the lead-sheathed cable.

4 If the effect of the screen according to §§ 2 and 3 above is not sufficient to limit the magnetic induction at mains frequencies, or to these harmonics arising from neighbouring power lines or electric railways, to permissible values the screening factor can be improved by increasing:

4.1 the inductance of the metal sheath, if necessary, by a lapping of steel tapes;

4.2 the conductance of the existing screen by additional metal tapes or wires which are arranged below the screen.

An improved screening effect may also become necessary if there is the risk of noise interference in the vicinity of electric railways equipped with thyristor controlled devices.

5 The screen must be connected to the earth electrode systems of the telecommunication centres. In the case of subscribers' cables the remote end should be connected to a suitable earth. It is also important for the screen of the cable to be extended through at cable joints by means of connections of very low resistance.

6 In view of the increase in the number of electrical installations and the level of harmonics resulting from new techniques, it is to be expected that the effects of interference will become worse. This being so, it may be extremely useful to improve the screening effect of plastic-covered cables as indicated above.

7 If cables have to be laid in areas where there is a danger of atmospheric discharges, attention is drawn to the importance of the metallic screen and of its construction in the protection of cables against lightning and also to the importance of the interconnections between the screen and other structures. (See the manual cited in [1].)

8 Screening factor

The following considerations enable the screening factor at the mains frequency to be determined fairly accurately for all types of cable regardless of the outer plastic covering used. In particular, they show how the screening factor to be used in practice may vary depending on the conditions in which the cable is used.

8.1 *General*

The screening effect produced by the metal screen of a cable mainly depends on:

- the frequency of the induced e.m.f. The limitation of this e.m.f. mains frequency (16 2/3 Hz, 50 Hz, 60 Hz) is therefore a determining factor in the choice of a cable from the standpoint of safety of staff and installations. On the other hand, the screening factor at higher frequencies should also be taken into account in seeking to protect equipment against interference. A substantial reduction of the induced e.m.f. at the mains frequency may suffice for complete protection;
- the level of induced e.m.f. per unit length in the case of screens made by ferromagnetic material. The screening effect of such a cable is optimum for a given value of induced e.m.f. per unit length, so that a cable designed for the reduction of high induced e.m.f. per unit length may be of no practical use for protection against low induced e.m.f. per unit length. The composition of the screen must be adapted to the level of the induced e.m.f. per unit length;
- the quality of its earthing. The screening effect is determined by the value of the current circulating in the metal screen. The resistance of the parts ensuring current flow between screen and earth is therefore decisive. For cables with an insulating plastic outer covering, if earth connections are provided only at the ends, they must be of very low resistance: the sheath should preferably be earthed at intervals along the line. When the plastic outer covering is conductive, the sheath is in practice continuously earthed;
- the length of the induced section of the link to be protected. It is easier to improve the screening effect when this section is long. The concept of length in this case relates to the quality of earthing required.

8.1.1 *The screening factor* (for explanation of symbols, see Appendix I)

The following most frequently used screening factors are defined in the *Directives:*

- Nominal screening factor, k_n (see Figure 1/K.14). This factor can easily be measured in a laboratory and is used to qualify the efficiency of the screening effect.

$$k_n = \left| \frac{U_{FM}}{E} \right| = \left| \frac{Z_i^E}{Z_e^E + Z_S} \right|$$

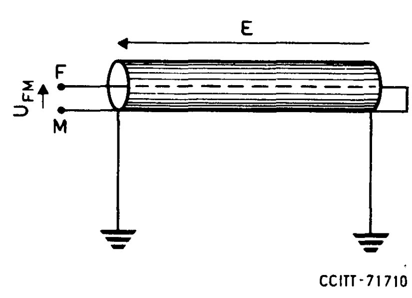


FIGURE 1/K.14

– Screening factor related to distant earth, $k_{ff'}$ (see Figure 2/K.14). This factor must be taken into account in ensuring protection against danger and interference, the conductors of the subscriber pairs being connected at their terminals to a neutral earth through certain parts of the equipments, without transformers.

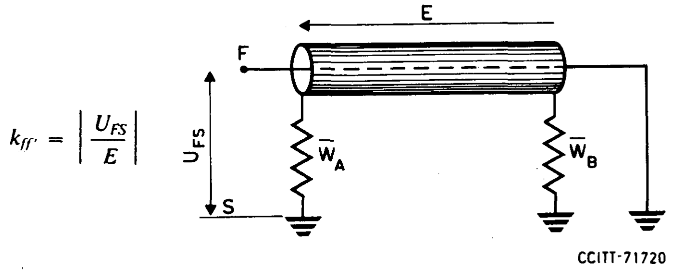


FIGURE 2/K.14

– Screening factor related to the sheath k_{fm} (see Figure 3/K.14). This factor must be taken into consideration in cases where the only accessible earths are those used for earthing the screen. This relates to cables connecting telecommunication centres to one another, their screens being connected to the earths of the centres.

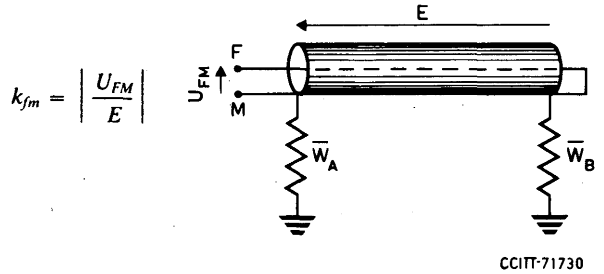


FIGURE 3/K.14

The *Directives* contain very detailed explanations and formulas for the accurate calculation of these factors in a wide variety of situations. On the other hand, these screening factors can be evaluated on the basis of simple expressions which often provide an adequate degree of accuracy. These expressions differ according to whether the outer cable covering is insulative or conductive and use the constants and variables listed in Appendix I.

8.2 *Cables with insulating outer covering*

The outer covering of the metallic cable sheath is made of an insulating plastic material. To obtain a screening effect, this sheath must be earthed at both ends and possibly at points in between.

8.2.1 *Calculation of the screening factor*

The screening factor can then be calculated by means of the expressions (see also the *Directives*, Chapter XII, § 3.3.3):

$$k_{ff'} = \left| \frac{Z_i^E L + \overline{W_A} + \overline{W_B}}{Z_e^E L + Z_s L + \overline{W_A} + \overline{W_B}} \right| \tag{8-1}$$

$$k_{fm} = \left| \frac{Z_i^E L}{Z_e^E L + Z_s L + \overline{W_A} + \overline{W_B}} \right| \tag{8-2}$$

Strictly speaking, the use of these expressions presupposes that the sheath is earthed only at the ends. It may be assumed, however, that in fairly comparable situations only the earths near the ends have any influence on the screening effect. The expression thus gives a good approximation of the screening effect in the case of intermediate earths.

As a general consequence, earthing connections at intermediate points tend to improve $k_{ff'}$, but, on the other hand, make k_{fm} worse.

8.2.2 *Influence of length*

When the earths of a sheath required to obtain a screening factor $k_{ff'}$ close to nominal value k_n have a resistance value which makes earthing very difficult, the link may be considered to be "short". In the contrary case, it is regarded as "long". (*Note* – "Link" is held to mean the cable length actually subjected to induction.)

8.2.2.1 *"Long" links*

Scrutiny of Equations (8-1) and (8-2) shows that for very long links, screening factors $k_{ff'}$ and k_{fm} are close to k_n. This is true of lengths in excess of about

$$10 \frac{\overline{W_A} + \overline{W_B}}{Z_i^E}$$

In this case, a non-armoured cable (Z_e^E close to Z_i^E) may be used. Moreover, the longer the link, the higher the resistance value of the sheath earthing may be.

This need not be taken into account in the choice of a cable, which can be based on the curve of values of nominal screening factor k_n for different values of induced e.m.f., since the efficiency obtained will be very similar.

8.2.2.2 *"Short" links*

In this case, the value of $Z_i^E L$ is approximately the same order of magnitude as the sum of the extreme terminal earth values $\overline{W_A} + \overline{W_B}$. Screening factors $k_{ff'}$ and k_{fm} may be calculated by means of Equations (8-1) and (8-2).

Armoured cables must be used to protect such links, and the screening effect is then provided through the increase in the value of impedance Z_e^E obtained by using material with high magnetic permeability for the outer part of the sheath.

To evaluate $k_{ff'}$ and k_{fm} by means of Equations (8-1) and (8-2), it is necessary to know the curve of variations of Z_e^E as a function of the current flowing through the sheath (Figure 4/K.14).

The calculation then calls for some simple successive approximations for evaluating Z_e^E after choosing a value of $\overline{W_A}$ and $\overline{W_B}$ corresponding to earths which may be expected to be feasible in view of the ground resistivity at the ends of the link.

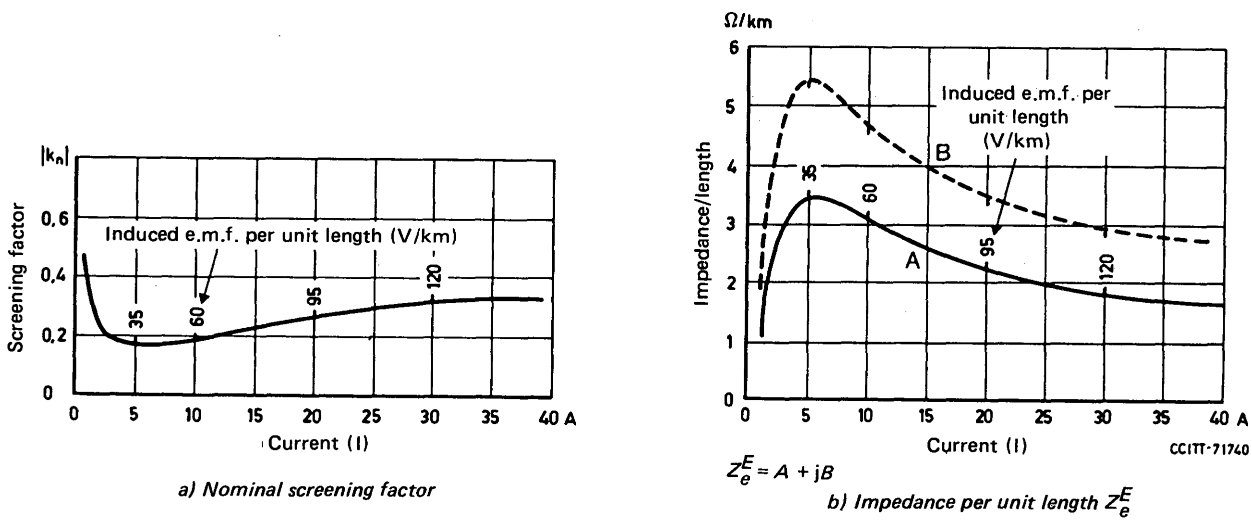


FIGURE 4/K.14

Cable parameters – example of cable protecting links against low induced e.m.f. per unit length generally produced by electric traction lines

8.3 *Cables with conductive outer covering*

The outer covering of the metallic cable sheath is made of a conductive plastic material providing electrical contact between the sheath and the earth surrounding the cable.

Intermediate connections of the sheath to the earth other than at the ends will be unnecessary if the resistivity of the conductive material is close to or better than that of the surrounding earth (values of about 50 Ω · m are easily obtained).

The current flowing through the sheath varies along the link, particularly near the terminals, and in the middle part remains at a value very close to $I_M = e/(Z_e^E + Z_s)$, corresponding to the current which would circulate in the sheath if it were completely earthed (earths with zero resistance value).

To calculate screening factor $k_{ff'}$, we can thus use an equivalence consisting in replacing this cable by one with a sheath connected to the earth at each end by zero resistance earths and of a length equal to that of the link L, shortened at each end by a length l such that $|P|\,l = 1$.

This means that the cable has a nominal screening factor on a shorter length equal to $L - 2l$.

$k_{ff'}$ can then be evaluated approximately by means of the following expression:

$$k_{ff'} = k_n\left(1 - \frac{2l}{L}\right) + \frac{2l}{L} \tag{8-3}$$

In the same way, k_{fm} can be expressed by:

$$k_{fm} = k_n\left(1 - \frac{2l}{L}\right)$$

Equation (8-3) is not applicable in cases where the earthing of the metallic sheath is really excellent. The link is then considered to be "long" and $k_{ff'} = k_{fm} = k_n$.

The parameters required for the calculation are those of the cable (Z_e^E, Z_i^E), the induced e.m.f. per unit length and the admittance per unit length Y of the sheath in relation to the earth, which may be chosen according to ground resistivities between 1 S and 10 S (1 S should be chosen if nothing is known about earthing quality).

8.3.1 *Influence of length*

The remarks relating to cables with insulating covering are also applicable in this case.

8.3.2 *"Long" links*

The screening factor is close to k_n. The cable may or may not be armoured, according to the results required.

8.3.3 *"Short" links*

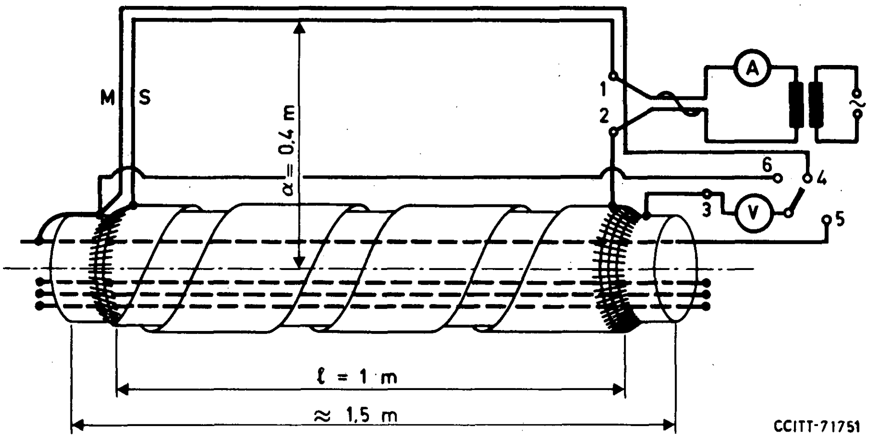
Screening factor $k_{ff'}$ may be estimated by means of Equation (8-3). The cable should be armoured in most cases.

8.4 *Determination of cable parameters*

If the nominal screening factor and impedance per unit length Z_i^E can be measured by means of the arrangement described in the *Directives* (Chapter XII, § 3.3.3.4), determination of impedance per unit length Z_i^E can be based:

- either on a calculation based on the phaser diagram, plotted from the measured parameters I, U_{oi} and U_{oe};
- or on the measurement of the voltage U_{oe} appearing between the end of a conducting wire laid on the outside of the sheath and reference point 3, the other end of the wire being connected to the sheath (Figure 5/K.14).

For certain cables with screens consisting of several non-ferromagnetic, highly-conductive layers, these parameters can be measured more approximately by a coaxial-type measuring device.



$$k_n = \frac{U_{oi}}{U_{oe}} = \frac{U_{53}}{U_{43}}$$

$$Z_i^E = \frac{U_{oi}}{I \cdot l} = \frac{U_{53}}{I \cdot l}$$

$$Z_e^E = \frac{U_{oe}}{I \cdot l} = \frac{U_{63}}{I \cdot l}$$

FIGURE 5/K.14

Measurement of cable parameters

APPENDIX I

(to Recommendation K.14)

Letter symbols used in Recommendation K.14

Z_i^E: Internal impedance per unit length with external return. For power frequencies, this value is close to resistance per unit length for direct current.

Z_e^E: External impedance with external return per unit length.

Z_s: Ground return impedance per unit length.

Y: Admittance per unit length of the sheath-earth circuit.

P: Propagation constant of the sheath-earth circuit.

K: Characteristic impedance of the sheath-earth circuit.

$\overline{W}_A$, $\overline{W}_B$: Impedance value of earths at the ends of the sheath.

L: Length of link subject to induction.

e: Induced e.m.f. per unit length.

E: Total induced e.m.f.

I: Current flowing through the sheath.

Reference

[1] CCITT manual *The protection of telecommunication lines and equipment against lightning discharges*, Chapter 4, § 2.1, ITU, Geneva, 1974, 1978.

PROTECTION OF REMOTE-FEEDING SYSTEMS AND LINE REPEATERS AGAINST LIGHTNING AND INTERFERENCE FROM NEIGHBOURING ELECTRICITY LINES

Preliminary recommendation

To minimize interference to the power feeding of repeaters from external sources, the CCITT recommends that, whenever possible, the repeater power-feeding system should be so arranged that the circuit in which the power-feeding currents circulate (including the units connected to it) remains balanced with respect to the sheath and to earth, and that the circuit in which the power-feeding currents circulate does not provide low impedance paths for longitudinal currents.

Introduction

The presence of components capable of withstanding only moderate excess voltage stress, in particular semiconductor components (transistors, etc.) in telecommunication equipment, necessitates protective measures against overvoltages which may occur at the terminals. This is so even if the overvoltages only slightly exceed the service voltages, as they are still capable of disturbing the functioning of these components and even of destroying them.

In addition, the functioning of circuits provided with repeaters may be disturbed by electromotive forces induced by power lines, depending on how the lines are operated; disturbance may be caused even when there is no fault on the lines.

Components, in particular the semiconductor components of apparatus which is directly connected to the conductors of telecommunication lines, may be damaged since these conductors, whether in cable or in open-wire lines, are exposed to overvoltages due to external sources such as the magnetic induction caused by power lines or atmospheric discharges.

The repeaters inserted at intervals on telecommunication lines belong to this category of equipment. As the remote feeding is by the cable or open-wire conductors which are used for transmission, the overvoltages may reach the terminals of the semiconductor components and damage them. This can be avoided if protective devices or appropriate circuit designs are provided in order to limit the overvoltages at sensitive points to permissible values or to preclude them altogether.

The protective measures required depend partly on the following:

- the value of the e.m.f. which may occur;
- the composition of the line, particularly when cable pairs are used;
- the arrangements made with regard to the outer conductor of coaxial pairs in relation to the metallic sheath of the cable (floating potential or earth);
- the type of power supply (d.c. or a.c.).

If the overvoltages occurring on conductors used for the power supply are due to magnetic induction caused by neighbouring power lines, one can start by assessing their values by the calculation methods indicated in the *Directives.* Additional calculations are necessary to find what protective measures are required.

When the overvoltages are due to atmospheric discharges, their values can only be reckoned approximately. The protection provided must therefore be tested in the apparatus concerned under the most realistic possible conditions.

The above requirements are met by the measures recommended below. These do not pretend to be complete as the technique is still changing; they will, however, ensure for the manufacturer and the user of such systems a high degree of protection.

1 Methods of calculation

1.1 The *Directives* [1] explain, in principle, how to calculate the longitudinal e.m.f. induced in the remote-feeding circuit. The calculation method is applicable both under normal operating conditions and when there is a fault on the electricity line.

1.2 The additional calculation of voltages and currents induced in a coaxial pair is based on the longitudinal e.m.f. reckoned from the information referred to in § 1.1 above. For this calculation it is advisable to refer to Recommendation K.16. (See also reference [2].)

1.3 For the evaluation of voltages and currents (peak value of short impulses) that may occur in remote-feeding circuits following atmospheric discharges, reference should be made to the manual cited in [3]. (See also reference [4].)

2 Limit values of overvoltages

2.1 *Longitudinal voltages caused by magnetic induction*

In principle, the limit values of induced longitudinal voltages indicated in [5] must not be exceeded when the ability of the material (cables, conductors, equipment) to withstand higher voltages is in doubt. A higher limit may be permitted, however, if a previous examination of the dielectric strength of the insulation of the conductors and the equipment connected to them show that there is no danger of breakdown (see [6]).

If the remote-feeding equipment raises the conductors permanently to a high potential with respect to the metallic sheath of the cable or to earth, it must be borne in mind that the induced voltage is superimposed on the power supply voltage (see [7]).

2.2 *Overvoltages caused by atmospheric discharges*

The permissible limit values of impulse voltages depend mainly on the dielectric strength of the insulation of the conductors and the equipment connected to them unless additional provision is made (e.g. in the systems) to limit the overvoltages to values below the breakdown voltages. The permissible limits at the terminals of equipment including semiconductor components depend on the characteristics of those components.

3 Protective measures

3.1 *Protection against overvoltages*

The protective measures should be designed to function whatever the source of the overvoltages (magnetic induction, atmospheric discharges, etc.).

3.1.1 *Protection of conductors in cables*

If the limit values indicated in §§ 2.1 and 2.2 above are exceeded, adequate protective measures should be applied. For example, the dielectric strength of the insulation may be increased when new equipments are installed. It is also possible to use cables with an improved screening factor. Furthermore, voltages may be limited by lightning protectors or other voltage limiting devices. In the latter case, care must be taken to ensure that the lightning protector ceases to function once the overvoltage has disappeared and that the power feeding conductor resumes normal operation. Other protective measures are not excluded.

In composite cables in which some pairs are used for power feeding, it is advisable to coordinate the protective measures for all the conductors so as to preclude harmful effects on the cable as a whole.

3.1.2 *Protection of repeaters*

Protection must be provided both at the input and output of the repeater and on the remote-feeding circuit.

It is recommended that protection be incorporated in repeaters using solid-state devices at the time of manufacture so as to prevent damaging magnitudes of overvoltages from reaching the terminals of sensitive elements, e.g. the semiconductor components.

When lightning protectors are employed to limit overvoltages, it must be borne in mind that certain overvoltages whose amplitude is less than the striking voltage are still high enough to damage some components, e.g. the semiconductor junctions of components, transistors, etc. present in the equipment. It is therefore advisable to provide protection internally by associating with the lightning protectors other protective components, such as Zener diodes and filtering, (this may already be provided in the equipment). The combination of these elements inside the equipment gives protection that is an integral part of the equipment. This is done in such a way that the overvoltages, whatever their source or value, are reduced by stages to a sufficiently low level as not to cause any harm.

It may happen that the protection of repeaters from voltages induced permanently by power or traction lines requires fewer components and is less expensive when the outer conductor of the coaxial pairs is at a floating potential than when it is earthed. On the other hand, when the outer conductor is earthed, staff working on coaxial pair lines are better protected against accidental contact with the inner conductor which, as it is used for power feeding, is raised to a certain potential. As each system has its advantages and disadvantages, the choice will depend on operating requirements.

3.2 *Measures to ensure the satisfactory functioning of equipment in the presence of a disturbing voltage permanently induced in the cable*

Steps must be taken to ensure that the repeater functions properly in the presence of disturbing voltages and current permanently induced in the cable conductors by power or traction lines. This refers to power lines that cause interference, but which are fault-free. The values of the induced voltages and currents may be assessed by the calculation methods referred to in § 1.1 above.

4 Testing of power-fed repeaters using solid-state devices

4.1 *General*

It is advisable that the test conditions simulate real conditions as closely as possible. They must reproduce not only normal working conditions but accidental circumstances, for example when a conductor which is normally insulated comes into contact with the metallic sheath of the cable or with the earth.

4.2 *Testing by impulse voltages*

It is recommended that the information in Recommendation K.17 should be referred to when tests are carried out by means of impulse voltages and currents. With regard to the amplitude of the waveforms, it is not enough to allow it to increase to the maximum; it is also necessary to make the test with an amplitude which is less than any threshold voltage of the protection (e.g. striking voltage of lightning protectors). The effectiveness of the protective devices (diodes, for example) can thus be ascertained in respect of overvoltages whose amplitude is low but whose energy may be high.

When lightning protectors are employed, it is necessary to ensure that their striking voltages are less than the dielectric strength between the conductors and the equipment chassis in order to prevent any breakdown.

4.3 *Testing by alternating voltages*

When repeaters are power fed by symmetric or coaxial pairs whose outer conductors are insulated from earth or from the metallic cable sheath, it is advisable to carry out a test with an alternating voltage to ensure that the strength of the insulation with respect to earth is higher than the values permitted in the *Directives* for voltages due to magnetic induction.

In order to check the behaviour of the repeaters and their power supply path when the lightning protectors strike, an alternating current in accordance with the information given in Recommendation K.17 should be applied to the terminals of the path.

In systems where a permanently induced voltage may be expected due, for example, to the alternating current in railway lines, it is necessary to superimpose on the feed current an alternating current of the same frequency (50 Hz, 60 Hz, 16 2/3 Hz) and strength as that produced in the power-feeding section when the induced voltage has the value specified in [8]. During the flow of the induced current the hum modulation must be so small that the values for route sections suggested by Study Group XV in Question 11 are obtained.

References

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines*, Part 3, ITU, Geneva, 1963, 1965, 1974, 1978, 1982.

[2] KEMP, (J.), SILCOOK, (H. W.), STEWARD, (C. J.): Power frequency induction on coaxial cables with application to transistorized systems, *Electrical Communication*, Vol. 40, No. 2, pp. 255-266, 1965.

[3] CCITT manual *The protection of telecommunication lines and equipment against lightning discharges*, ITU, Geneva, 1974, 1978.

[4] KEMP, (J.): Estimating voltage surges on buried coaxial cables struck by lightning, *Electrical Communication*, Vol. 40, No. 3, pp. 381-385, 1965.

[5] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines*, Chapter IV, ITU, Geneva, 1963, 1965, 1974, 1978, 1982.

[6] *Ibid.*, Chapter IV, § 48.

[7] *Ibid.*, Chapter IV, § 53.

[8] *Ibid.*, Chapter IV, §§ 6, 7 and 35.

Recommendation K.16 (Geneva, 1972)

SIMPLIFIED CALCULATION METHOD FOR ESTIMATING THE EFFECT OF MAGNETIC INDUCTION FROM POWER LINES ON REMOTE-FED REPEATERS IN COAXIAL PAIR TELECOMMUNICATION SYSTEMS

1 Summary

The article mentioned in reference [1] contains a general treatise covering all possible cases of magnetic induction and permitting calculation of the location-dependent variation of the induced voltages and currents for full or partial exposure to induction of a route. This Recommendation gives general information on how to find an equivalent circuit which permits rapid estimation of the maxima of the voltages and currents in cable conductors for any length and location of exposure. The lumped capacitances and the transfer impedance of the equivalent circuit must be appropriately chosen. Only two groups of parameters are required here, depending upon whether the length of the exposed section is shorter than, or equal to, or greater than half the length of the power-feeding section. The manner of switching from the complex formulae given in [1] to the simplified calculation is explained in Annex A.

To check the usefulness of this universally applicable equivalent circuit, the maxima of the voltages and currents induced on the conductors of a cable when the outer conductors are at floating potential are calculated in Annex B for some of the exposure values evaluated numerically in the article mentioned above. They are also entered in the diagrams. It will be seen that the calculation procedure shown in this Annex B gives sufficiently accurate results for practical purposes.

Annex C shows how the equivalent circuit must be modified in cases where the outer conductors of the coaxial pairs are earthed at the terminals and at the repeater points.

A similar calculation method for the effects of magnetic induction of power lines on telecommunication systems installed on coaxial pair cables whose outer conductor is insulated is described in the article mentioned in reference [2].

2 Advantages of the equivalent circuit

One of the reference quantities in the exact formulae given in the two articles cited above is the longitudinal voltage induced in the cable. This can be calculated by the usual methods (see the CCITT *Directives*).

Once it is known, the induced voltages and currents can be numerically evaluated very precisely from the exact formulae, but the results approximate the actual values only in so far as this is permitted by the limited accuracy of the basic parameters used. Experience shows, however, that this accuracy is low since certain factors which cannot be accurately determined – such as the effective conductivity of the soil – play a considerable part.

In view of the unavoidable inaccuracy in calculating the induced longitudinal voltage used as reference quantity, a further error of up to about 20% is tolerated in the remainder of the calculation. The exact formulae can then be considerably simplified for all applications (since in practice $\Gamma \cdot l \leqslant 2$ and $\overline{\Gamma} \cdot l \leqslant 2$ nearly always holds) and corresponding equivalent circuits can be devised for each case. (The quantities Γ and $\overline{\Gamma}$ are the propagation constants of the circuits *cable sheath – outer conductor* and *outer conductor – inner conductor*, respectively.)

3 Statement of the problem

Equivalent circuits may be considered for the following cases of induction:

1) outer conductor earthed, uniform induction;
2) outer conductor at a floating potential, uniform induction (see Figure A-1/K.16);
3) outer conductor earthed, partial exposure on a short length at midroute;
4) outer conductor at a floating potential, partial exposure on a short length at midroute (see Figure A-2/K.16).

In practice it is much easier to deal with a single equivalent circuit instead of four. Moreover, it would be advantageous if, on the basis of the article mentioned in reference [1], a universally applicable uniform equivalent circuit could be devised which furnished sufficiently accurate information on the maxima of the voltages and currents induced on the cable even with an arbitrarily chosen partial exposure to induction of a power-feeding section.

As is shown in Annex A, such an equivalent circuit can be derived with the aid of the circuit diagrams shown in Figures A-1/K.16 and A-2/K.16. This circuit is shown in Figure 2/K.16.

4 Parameters and symbols employed

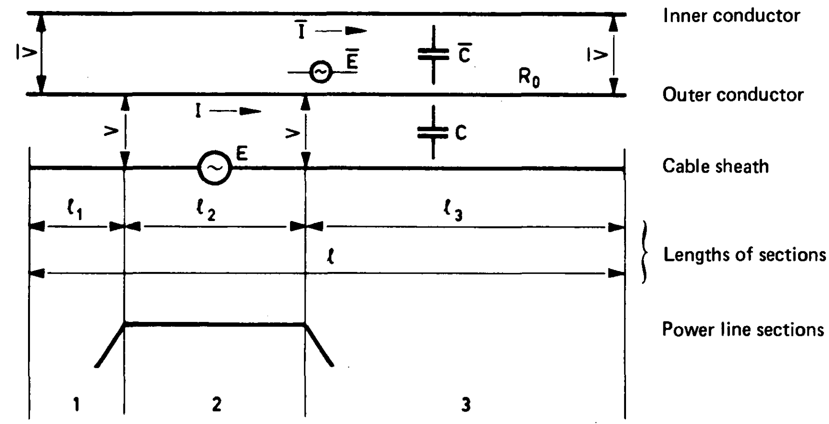
On the basis of the general assumption that a power-feeding section with the outer conductors at floating potential (not bonded to the cable sheath or to a grounding system) is exposed to induction along an arbitrarily located section, we can draw Figure 1/K.16 below, which shows the conventions and symbols employed.

The symbols denoting the quantities (E, C, V, I) associated with the circuit *cable sheath – outer conductor* will be written without a bar and all those ($\overline{E}$, $\overline{C}$, $\overline{V}$, $\overline{I}$) associated with the circuit *outer conductor – inner conductor* with a bar.

5 Universally applicable equivalent circuit

The arguments in Annex A make it possible to define a universal equivalent circuit (Figure 2/K.16).

For all long-distance communication systems with power-feeding sections that are either uniformly exposed to magnetic induction or partially exposed along a short central section this equivalent circuit furnishes the maxima of the voltages and currents induced in the two circuits in Figure 1/K.16, with an accuracy of about 10%. When this circuit is applied to other cases of exposure, deviations of up to about 20% from the theoretical values must be expected but this error rate may be tolerated in practice in view of the uncertainty in determining the induced longitudinal voltage E and because conditions can then be rapidly estimated.



E	=	longitudinal voltage induced in the cable (volts)
$\bar{E}$	=	longitudinal voltage in the coaxial tube (volts)
l_2	=	length of the exposed section (km)
l_1, l_3	=	lengths of the unexposed sections (km)
l	=	length of the power-feeding section (km) $= l_1 + l_2 + l_3$
$V, \bar{V}, I, \bar{I}$	=	maxima of the voltages and currents to be determined
$C, \bar{C}$	=	capacitances (F/km) effective per unit length

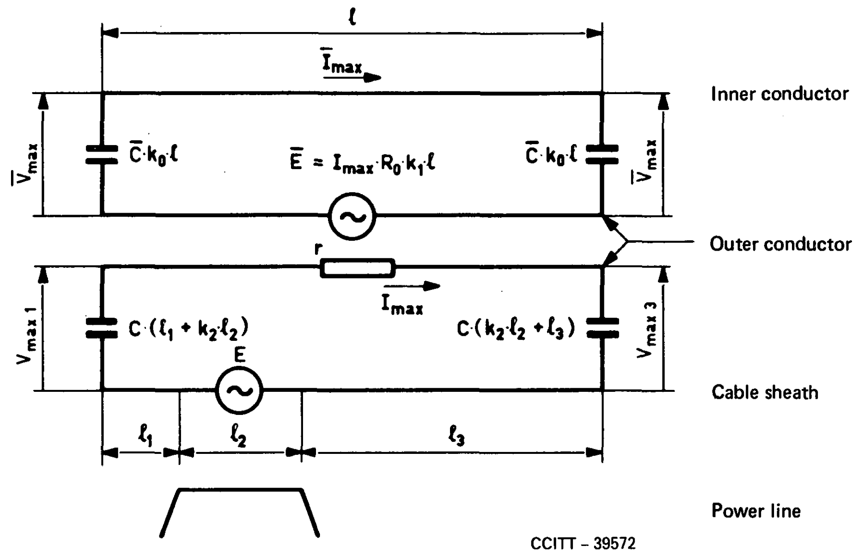
where

$$C = \frac{C_{0s} \cdot l_s + C'_{0s}}{l_s} \text{ and } \bar{C} = \frac{C_{io} \cdot l_s + C_f}{l_s}$$

C_{0s}	=	capacitance per unit length between outer conductor and cable sheath (F/km)
C'_{0s}	=	capacitance between the outer-conductor and the cable sheath located at the repeater (if any) (F)
C_{io}	=	capacitance per unit length between the inner and the outer conductor (F/km)
C_f	=	sum of all capacitances between the power-feeding path and the outer conductor in the power separating filters of a repeater (F)
l_s	=	length of repeater section (km)
Z_t	=	effective transfer impedance per unit length (Ω/km) between the circuit *cable sheath – outer conductor* and the circuit *outer conductor – inner conductor*
R_0	=	resistance per unit length (Ω/km) of the outer conductor alone
R_i	=	resistance per unit length (Ω/km) of the inner conductor, to which a corrective term is added, which corresponds to the value, per km, of the resistance of the directional filters

FIGURE 1/K.16

Schematic representation of circuits



Value of parameters k			
	k_0	k_1	k_2
for $l_2 \leq \frac{l}{2}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$
for $l_2 > \frac{l}{2}$	$\frac{5}{16}$	$\frac{2}{3}$	$\frac{1}{4}$

Note – The resistance r is to be considered only for earthed outer conductors (see Annex C).

FIGURE 2/K.16
Equivalent circuit

The following comments will help to explain the simplified diagram:

1) All the components of the real transmission lines are assumed to be concentrated, which is acceptable for a short line open at both ends, for a wavelength corresponding to 50 Hz.

2) The conductor resistance is not taken into account in the circuits, except for constituting the inter-circuit transfer impedance; it is introduced weighted by a coefficient k_1 which depends on the length of the section exposed and is such that $k_1 < 1$.

This implies that the circuits shown in Figure 2/K.16 are in fact open (for induced currents at 50 Hz) at the ends of the remote-feeding section. This may not be the case, particularly if the power supply equipments include filters and balancing devices to fix the inner conductor potentials in relation to the earth. The circuit *inner conductor – outer conductor* is then terminated across high-value capacitors which must be added in parallel at $C k_0 l$ at the two ends of Figure 2/K.16. In this case, the inner conductor series resistance cannot now be disregarded. A practical example is given in Annex C.

3) The capacitances $C l_1$ and $C l_3$ correspond to the precise terminal beyond the exposed section; the capacitance of the exposed section is introduced weighted by a coefficient k_2 which depends on the length of the exposed section and is such that $2\ k_2 < 1$.

4) The simplified diagram gives rise to dissymmetrical voltages in the circuit *sheath – outer conductor.* It can be used to determine the maximum values at the ends. Figure 3/K.16 gives an idea, adequate for practical purposes, of the voltage and current throughout the remote-feeding section. The voltage varies little outside the exposed section and is zero near the middle. The maximum current occurs near the middle of the exposed section; the current is obviously zero at the ends, since the circuit is open when the outer conductor is at floating potential.

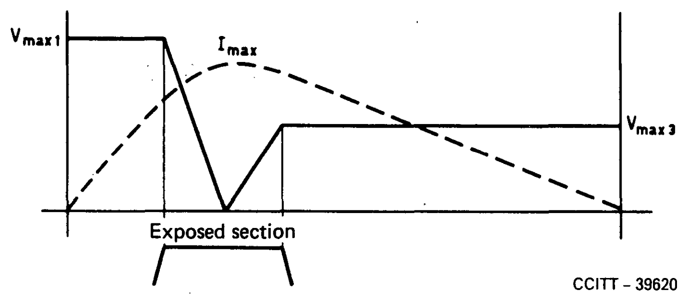


FIGURE 3/K.16

Voltage and current throughout the remote-feeding section in the circuit *sheath – outer conductor*

5) On the other hand, in the circuit *inner conductor – outer conductor* the voltage and current are much more symmetrical. The capacitance is weighted by a coefficient k_0 which depends on the length of the exposed section and is such that $2\ k_0 < 1$.

6) The simplified diagram makes it possible to calculate, in the same way as in 4) above, the maximum voltage and current in the circuit *inner conductor – outer conductor.* Depending on the nature of the circuit, these values may be much lower than in the circuit *sheath – outer conductor.* Figure 4/K.16 gives an idea, adequate for practical purposes, of the voltage and current throughout the remote-feeding section. The extreme voltages are symmetrical, while the zero voltage and maximum current are always very near the middle of the remote-feeding section, irrespective of the position of the exposed section.

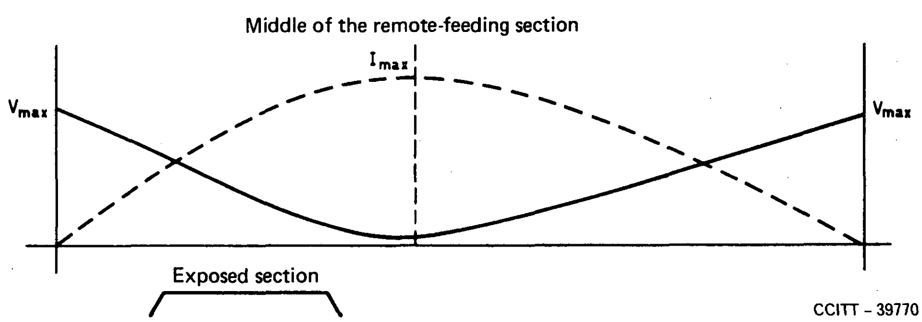


FIGURE 4/K.16

Voltage and current throughout the remote-feeding section in the circuit *inner conductor – outer conductor*

ANNEX A

(to Recommendation K.16)

Justification of the parameters included in the universally applicable equivalent circuit

A.1 *General case*

The article mentioned in reference [1] gives equation systems containing the complex transmission parameters of the two circuits in question.

These equations can be used to arrive at a complete solution of the problem of circuits open at both ends. These formulae develop a large number of terms into hyperbolic functions of complex parameters which make them inconvenient to apply in practice. Several approximation stages are required to arrive at a very simple diagram which can be used for an elementary calculation.

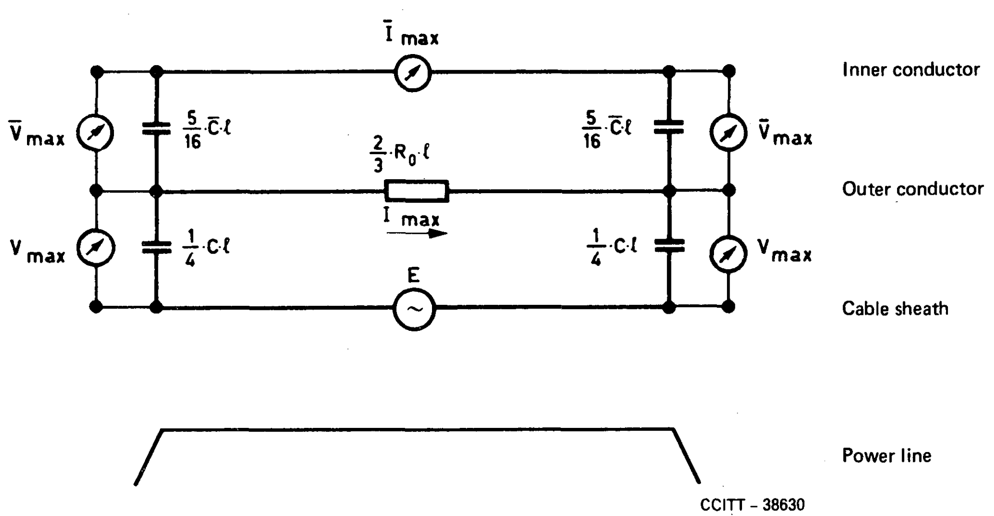
A.2 *First stage – Symmetrical exposure – Full calculation*

The general formulae are applied to two cases of symmetrical exposure, shown in Figures A-1/K.16 and A-2/K.16; in the first case, the exposure covers the entire remote-feeding section, while in the second case it is confined to a short length in the middle of the section. The curves plotted from the calculations are contained in reference [1] and are also shown in Figure B-1/K.16.

A.3 *Second stage – Symmetrical exposure – Simplified diagram*

Account is taken of the short electrical length of the lines and of the phase angle near ± 45° of the secondary propagation parameters. This makes it possible to replace the distributed elements by capacitors and lumped resistances, shown in Figures A-1/K.16 and A-2/K.16. Coefficients such as 5/16, 1/4, 1/2, 1/3 derive from the series development of the complex hyperbolic terms.

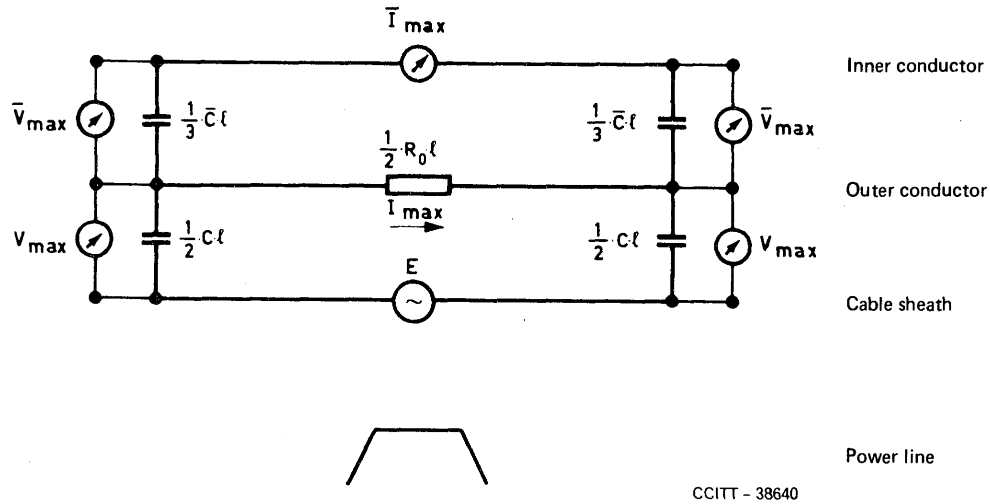
The equivalent circuits in Figures A-1/K.16 and A-2/K.16 can be used to calculate the maximum voltages and currents in two cases of symmetrical exposure; since these cases are both extremely exceptional, we should, at the same time, consider the general case of a dissymmetrical exposure of any length. This is the subject of the following stage.



E = longitudinal voltage induced in the cable (volts)
R_0 = resistance of the outer conductor (Ω/km)
l = length of the power-feeding section

FIGURE A-1/K.16

Uniform exposure to induction of the power-feeding section



E = longitudinal voltage induced in the cable (volts)
R_0 = resistance of the outer conductor (Ω/km)
l = length of the power-feeding section

FIGURE A-2/K.16

Partial exposure of short length in the middle of the section

A.4 *Third Stage – General case – Simplified diagram*

A.4.1 *Circuit cable sheath – outer conductor*

In the exposed section 2, of length l_2, the circuit *cable sheath/outer conductor* can be treated as a 2-wire line exposed to uniform induction whose ends are terminated by the line capacitances of the adjacent unexposed sections 1 and 3.

If section 2 is far longer than the sections 1 and 3 ($l_2 \gg l/2$), the current and voltage distributions are mainly determined by the exposed section itself and they will therefore be almost or fully symmetrical with reference to the middle of the section. The effective capacitance values shown in Figure A-1/K.16 for the uniformly induced 2-wire line can then be inserted for section 2. The arrangement in Figure A-3/K.16 is then obtained for $l_2 \gg l/2$.

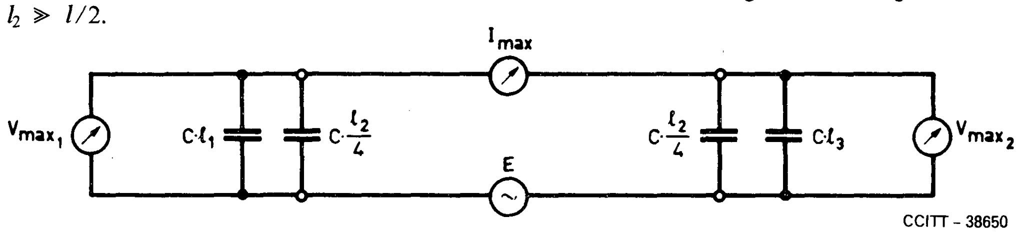


FIGURE A-3/K.16

Circuit *cable sheath – outer conductor* – long exposed section

When, however, the exposed section is far shorter than the unexposed sections ($l_2 \ll l/2$) the current and voltage distribution will be mainly determined by the admittances at the section ends. The induced current maximum moves then towards that end of section 2 which is adjacent to the longer of the two unexposed sections. The largest displacement of the current maximum occurs when section 2 is located directly at the beginning or at the end of the power-feeding section ($l_1 = 0$ or $l_3 = 0$, respectively). In this limit case, the condition of l_2 approaches that of a uniformly induced 2-wire line with a short circuit at one end.

The following equivalent circuit (Figure A-4/K.16) will therefore be used to determine the maximum induced current.

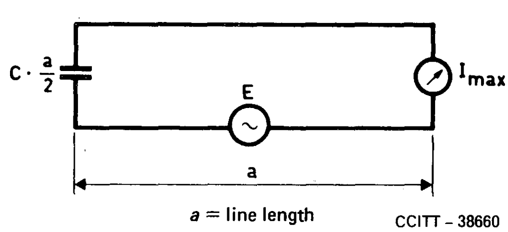


FIGURE A-4/K.16

Line with a short-circuit at one end

This circuit diagram is obtained from one half of the configuration in Figure A.1/K.16, showing a line of length $l = 2\ a$, with uniform induction and with both ends open, when a connection is established at midroute; this connection does not change the conditions.

Since, however, the end of section 2 is not short-circuited in the limit case under consideration, but is terminated by finite admittance ($\omega\ C \cdot l_3$ and $\omega\ C \cdot l_1$, respectively), the effective lumped capacitance $C \cdot l_2/x$ associated with section 2 in the partial equivalent circuit must range between the limits:

$$C \cdot \frac{l_2}{4} < C \cdot \frac{l_2}{x} < C \cdot \frac{l_2}{2} \quad \text{at the end with the shorter extension, and}$$

$$C \cdot \frac{l_2}{4} > C \cdot \frac{l_2}{x} > 0 \quad \text{at the other end.}$$

As will be shown subsequently, the assumption of $x = 3$ at each end is a compromise which gives satisfactory results for all locations of the short exposed section. The following configuration (Figure A.5/K.16) is then obtained for $l_2 \ll l/2$.

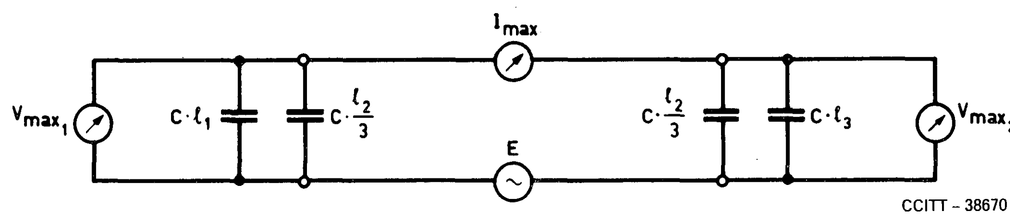


FIGURE A-5/K.16

Circuit ***cable sheath – outer conductor*** **– short exposed section**

A.4.2 *Effective transfer impedance* [1)]

The current I flowing in the circuit *cable sheath – outer conductor* produces a longitudinal voltage $\bar{E}$ across the resistance of the outer conductor in the coaxial system. This current I has a maximum in the exposed section and decreases to zero at the ends of the route. An effective resistance to be used with the maximum of I appears in the equivalent circuits derived from the simplified formulae. In the equivalent circuit method an effective resistance is introduced. Once this and the current I are known, it is possible to calculate $\bar{E}$. This effective resistance, designated by $Z_t \cdot l$, is called the effective transfer impedance. It replaces the resistance $R_0 \cdot l$. The value of $\bar{E}$ is given by the equation: $\bar{E} = I_{max} \cdot Z_t \cdot l$.

With unform induction over the power-feeding section, as in Figure A-1/K.16, the value to be used for the transfer impedance is given by:

$$Z_t \cdot l = \frac{2}{3} \cdot R_0 \cdot l.$$

This value can also be inserted where the variation of the current I along the route is largely similar to that occurring with uniform induction ($l_2 \gg l/2$).

With a short partial exposure at the middle of the power-feeding section (see Figure A-2/K.16):

$$Z_t \cdot l = \frac{1}{2} \cdot R_0 \cdot l$$

must be used for the transfer impedance.

When the short partial exposure is located at the beginning or end of the power-feeding section, the same value is obtained (as can be proved from the equivalent circuit for a partial exposure at midsection, by inserting $2 \cdot l$ instead of l).

[1)] The transfer impedance is often also called the coupling impedance of the metallic cable sheath.

It can therefore be assumed that, as a first approximation, this value will not vary to any great extent even with an arbitrary location of the short exposed section.

The following values result accordingly for the transfer impedance of the equivalent circuit:

$$Z_t \cdot l = \frac{2}{3} R_0 \cdot l \text{ for } l_2 \gg \frac{l}{2} \text{ and}$$

$$Z_t \cdot l = \frac{1}{2} R_0 \cdot l \text{ for } l_2 \ll \frac{l}{2}$$

A.4.3 *Circuit outer conductor-inner conductor*

In the circuit *outer conductor – inner conductor* the longitudinal voltage $\bar{E}$ extends over the full length of the power-feeding section even in the case of partial exposure. As can be gathered from the Figures in Annex B, the minimum of the voltage $\bar{V}$ between the inner and the outer conductor appears exactly at midroute in the case of a symmetrical exposure and nearly at midroute in all cases of unsymmetrical exposures (even with extremely short induced sections at the beginning or end of the power-feeding section). The values calculated for current and voltage in the coaxial pair will therefore not change to any great extent, if it is assumed that the longitudinal-voltage field strength $\bar{E}/l$ is symmetrically distributed irrespective of the length or location of the exposed section.

With this assumption the circuit diagrams in Figure A-6/K.16 derived from Figures A-1/K.16 and A-2/K.16 for symmetrical exposure can also be used, as a general rule, for any configuration.

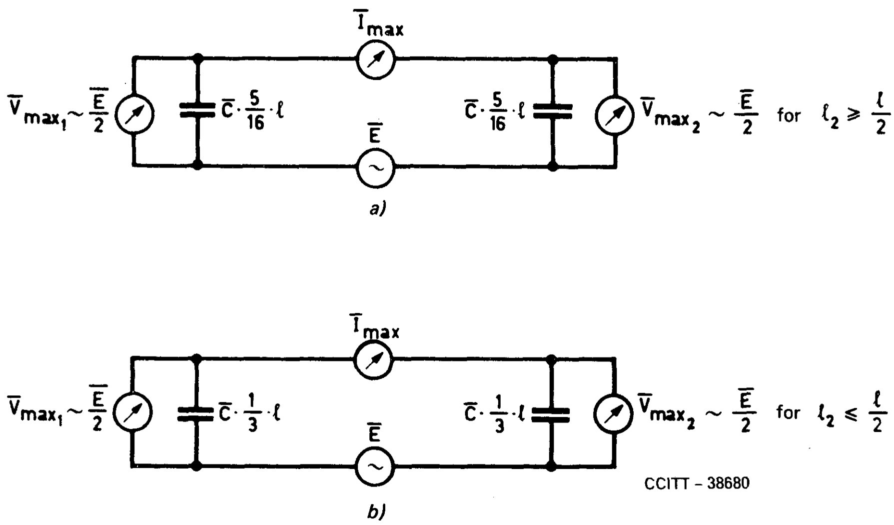


FIGURE A-6/K.16

Circuit *outer conductor – inner conductor*;
***a)* long exposed section, *b)* short exposed section**

A.5 *Conclusion of Annex A*

From the diagrams in Figures A-3/K.16 to A-6/K.16, a generally applicable equivalent circuit can be set up where the numerical values associated with the capacitances and the transfer impedance will vary according to the length of the exposed section:

$$l_2 \gg \frac{l}{2} \text{ and } l_2 \ll \frac{l}{2} \text{ respectively.}$$

As can be proven with numerical examples, satisfactory results are obtained by keeping the parameters associated with the case $l_2 \ll l/2$ even for $l_2 = l/2$. If then we replace:

$$l_2 \gg \frac{l}{2} \text{ by } l_2 > \frac{l}{2} \text{ and}$$

$$l_2 \ll \frac{l}{2} \text{ by } l_2 \leqslant \frac{l}{2}$$

the full range of all cases of exposure can be covered with two groups of parameters, leaving the error in the transition zone within tolerable limits.

The resulting generally applicable equivalent circuit is shown in Figure 2/K.16.

ANNEX B

(to Recommendation K.16)

Practical examples of complete calculations and of the simplified calculation. Case in which the outer conductors are at floating potential

To check the usefulness of this equivalent circuit for arbitrarily chosen partial exposures, the maxima of the voltages and currents were calculated by means of the equivalent circuit for some cases of exposures completely calculated in [1] and the values determined were entered in the corresponding diagrams reproduced from this reference.

The following values for a 300-channel system on small-diameter coaxial pairs were inserted for the comparative calculation:

$C = 0.12\ \mu\text{F/km}$; $R_0 = 6.2\ \Omega\text{/km}$ $\overline{C} = 0.2\ \mu\text{F/km}$; $l = 64$ km

The curves of Figures 1 to 5 of this Annex, accurately plotted, show the voltages and currents induced in a 300-channel telecommunication system. These figures correspond to Figure 4/K.16 and Figures A-1/K.16 to A-3/K.16 of Annex A as reproduced from reference [1] except that a longitudinal voltage of $E = 1000$ V, instead of 2000 V, was chosen as reference quantity. The approximate values of the maxima calculated with the equivalent circuit are indicated by black dots. The agreement with the values furnished by the exact analysis is satisfactory in all cases.

Example of calculation for Figure B-4/K.16 below

A 64-km power-feeding section of a 300-channel system on small-diameter coaxial pairs, whose outer conductor is at a floating potential, is assumed to be exposed to a power line between the 12th and the 28th kilometre. The longitudinal voltage in the cable is assumed to be 1000 V, 50 Hz. The maxima of the voltages and currents appearing in the cable have to be assessed.

There is thus $l_1 = 12$ km, $l_2 = 16$ km, $l_3 = 36$ km, $l/2 = 32$ km. Since $l_2 < l/2$, the following parameters for the equivalent circuit (see Figure 2/K.16) have to be applied: $k_0 = 1/3$, $k_1 = 1/2$, $k_2 = 1/3$. Other given parameters are: $\overline{C} = 0.2\ \mu\text{F/km}$, $R_0 = 6.2\ \Omega\text{/km}$, $C = 0.12\ \mu\text{F/km}$.

Calculation scheme:

$$Cl_1 = 0.12 \times 12 = 1.44\ \mu\text{F} \qquad Ck_2\, l_2 = 0.12 \times \frac{1}{3} \times 16 = 0.64\ \mu\text{F} \qquad Cl_3 = 0.12 \times 36 = 4.32\ \mu\text{F}$$

$$\underbrace{1.44\ \mu\text{F} + 0.64\ \mu\text{F}}_{2.08\ \mu\text{F}} \qquad \underbrace{0.64\ \mu\text{F} + 4.32\ \mu\text{F}}_{4.96\ \mu\text{F}}$$

$$\frac{1}{\omega C} \text{ at 50 Hz:} \quad 1530\ \Omega \quad + \quad 640\ \Omega \quad = \quad 2170\ \Omega$$

$$I_{max} = \frac{1000\ \text{V}}{2170\ \Omega} = 0.461\ \text{A}$$

$$\times\ 1530\ \Omega = V_{max_1} = 705\ \text{V}$$

$$\times\ 640\ \Omega = V_{max_2} = 295\ \text{V}$$

$$\times\ 198.5\ \Omega = \overline{E} = 91.6\ \text{V}$$

$$\frac{1}{2} R_0\, l = \frac{1}{2} \times 6.2 \times 64 = 198.5\ \Omega$$

$$\frac{1}{2}\overline{E} \approx \overline{V}_{max_1} \approx \overline{V}_{max_2} = 45.8\ \text{V}$$

$$\frac{1}{3}\,\omega\,\overline{C}l = \frac{1}{3} \times 314 \times 0.2 \times 10^{-6} \times 64 = 1.34 \times 10^{-3}\ \text{mhos}$$

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$$\overline{I}_{max} = 1.34 \times 10^{-3} \times 45.8 = 61.5\ \text{mA}$$

TABLE B-1/K.16

Comparison of the equivalent circuit determination with the accurately calculated maxima

(Values from Figure B-4/K.16)

Maxima	Exact calculation	Equivalent-circuit determination	Deviation from the exact calculation
V_{max_1}	685 V	705 V	+2.9 %
V_{max_2}	315 V	295 V	−6.3 %
I_{max}	0.455 A	0.461 A	+1.3 %
$\bar{V}_{max_1}$	48 V	45.8 V	−4.6 %
$\bar{V}_{max_2}$	37.5 V	45.8 V	+22 %
$\bar{I}_{max}$	55 mA	61.5 mA	+11.8 %

This comparison shows that, with the exception of the value of $\bar{V}_{max2}$, all deviations from the exact calculation remain below 12% and the equivalent circuit values are mostly greater than the exact values. The deviation of 22% in the case of $\bar{V}_{max2}$ is of no practical importance since this involves the smaller of the two maxima of $\bar{V}$.

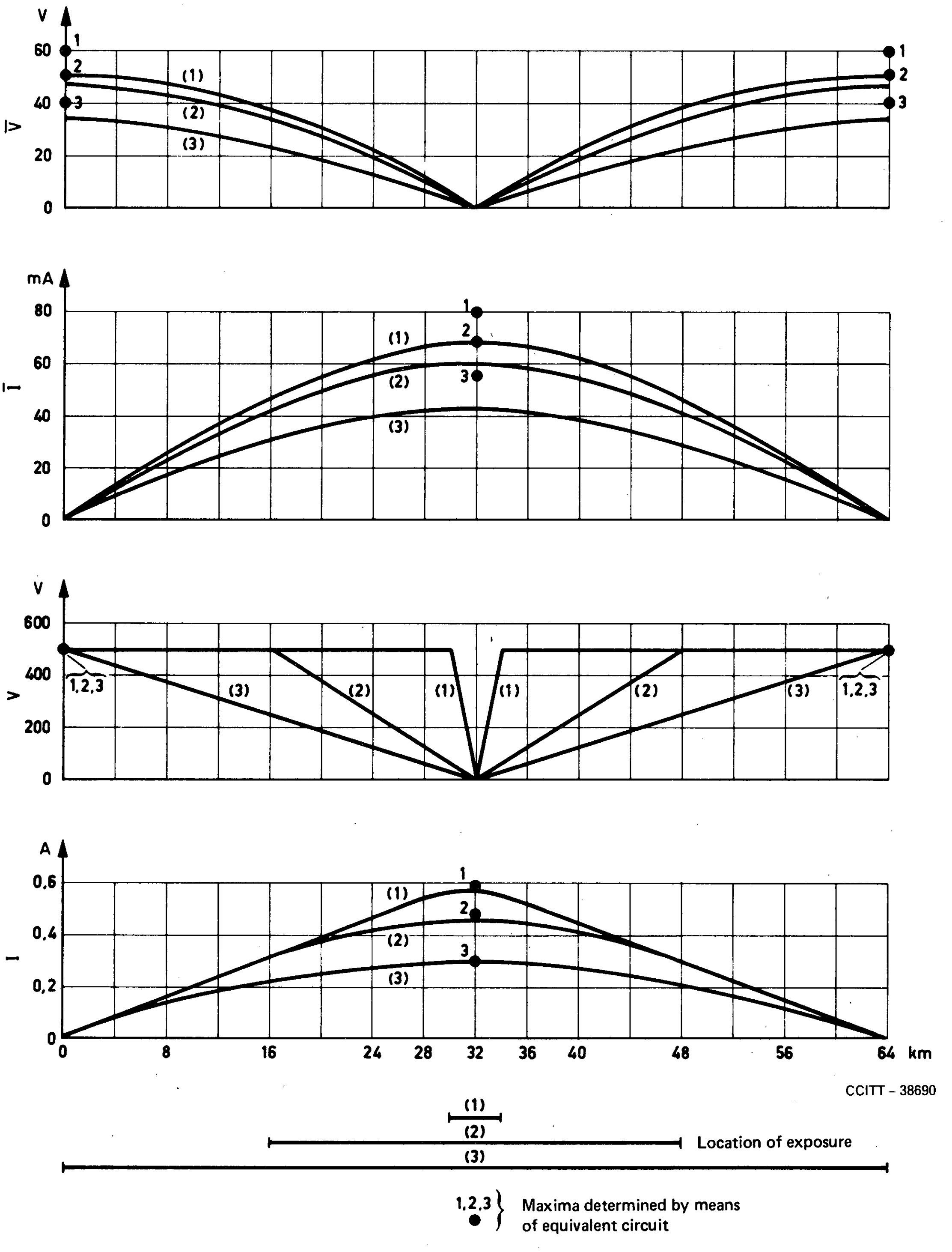


FIGURE B-1/K.16

Voltages and currents for a 300-channel route with symmetrical exposures. Voltage induced along the exposed section: 1000 volts (outer conductors of coaxial pairs at floating potential)

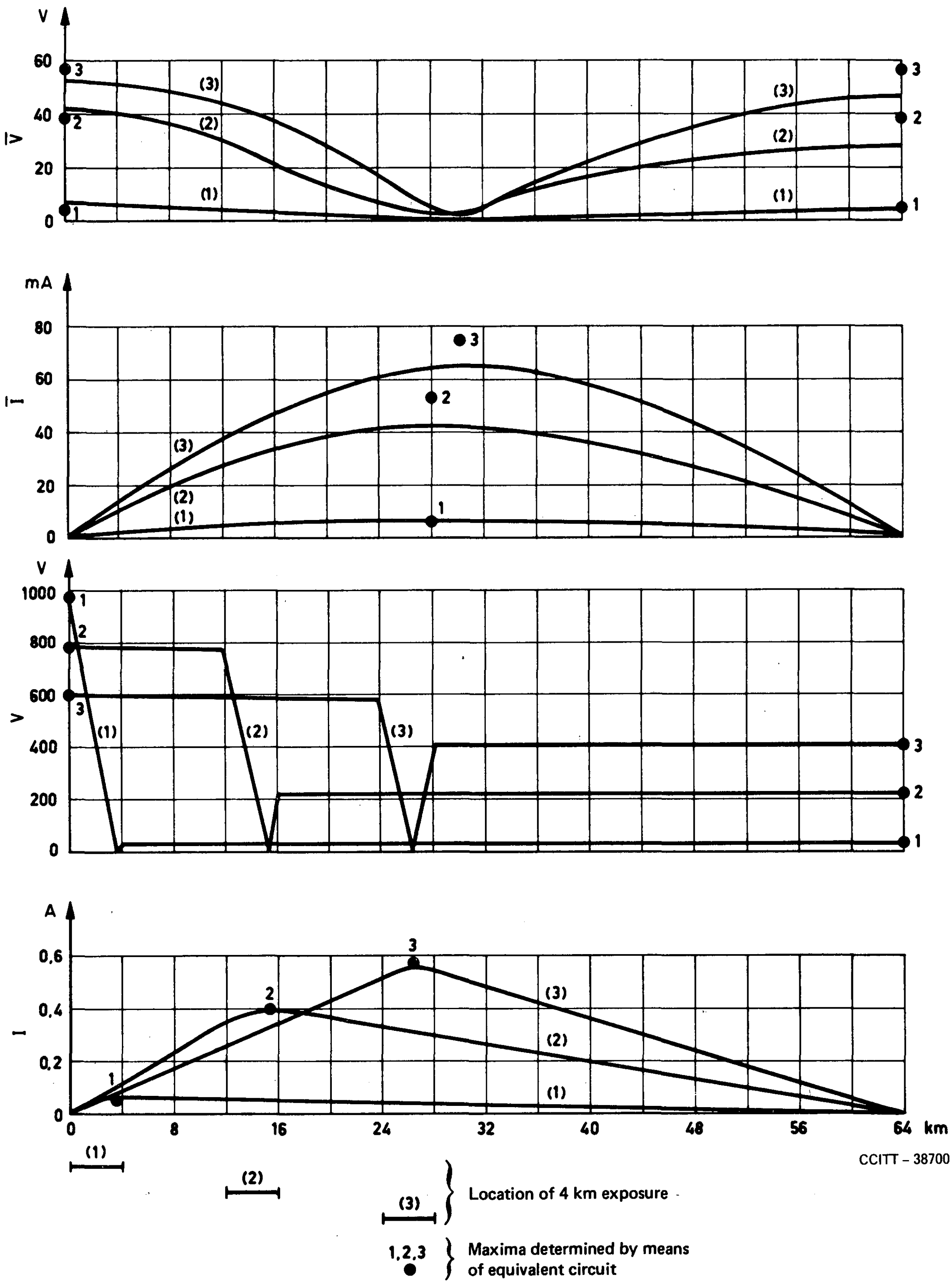


FIGURE B-2/K.16

Voltages and currents for a 300-channel route with asymmetrical exposures. Length of exposure 4 km. Voltage induced along the exposed section: 1000 volts (outer conductors of coaxial pairs at floating potential)

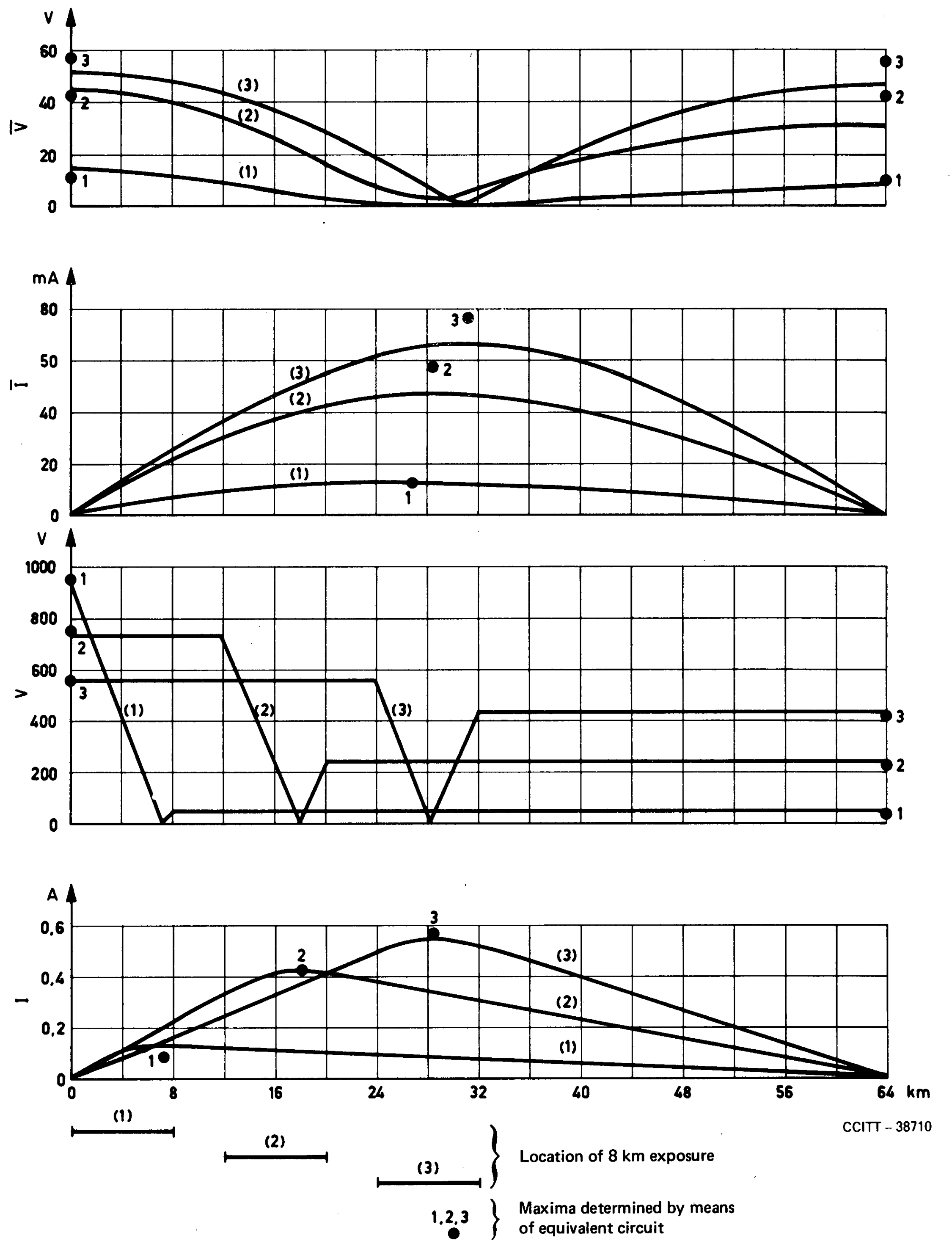


FIGURE B-3/K.16

Voltages and currents for a 300-channel route with asymmetrical exposures. Length of exposure 8 km. Voltage induced along the exposed section: 1000 volts (outer conductors of coaxial pairs at floating potential)

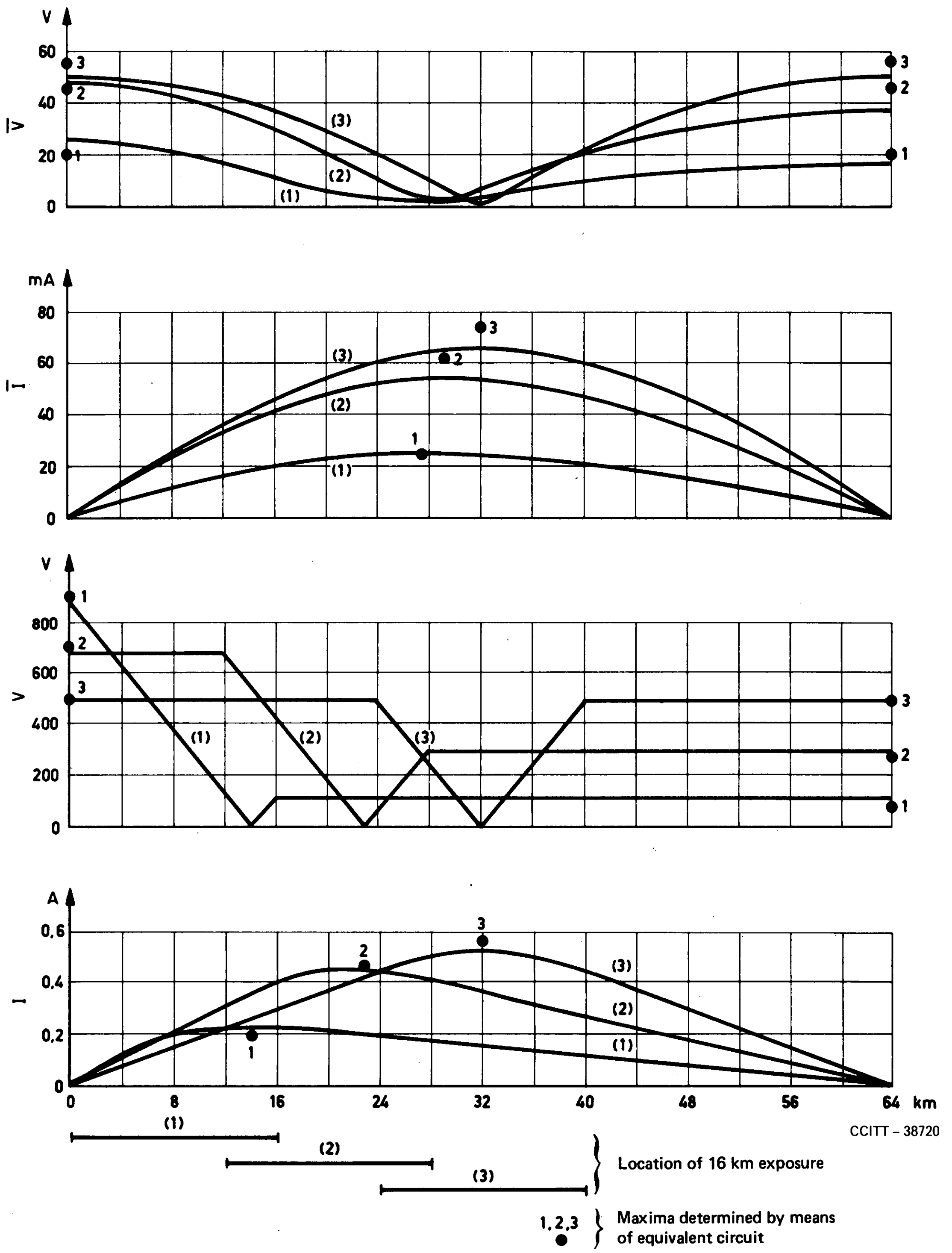


FIGURE B-4/K.16

Voltages and currents for a 300-channel route with asymmetrical exposures. Length of exposure 16 km. Voltage induced along the exposed section: 1000 volts (outer conductors of coaxial pairs at floating potential)

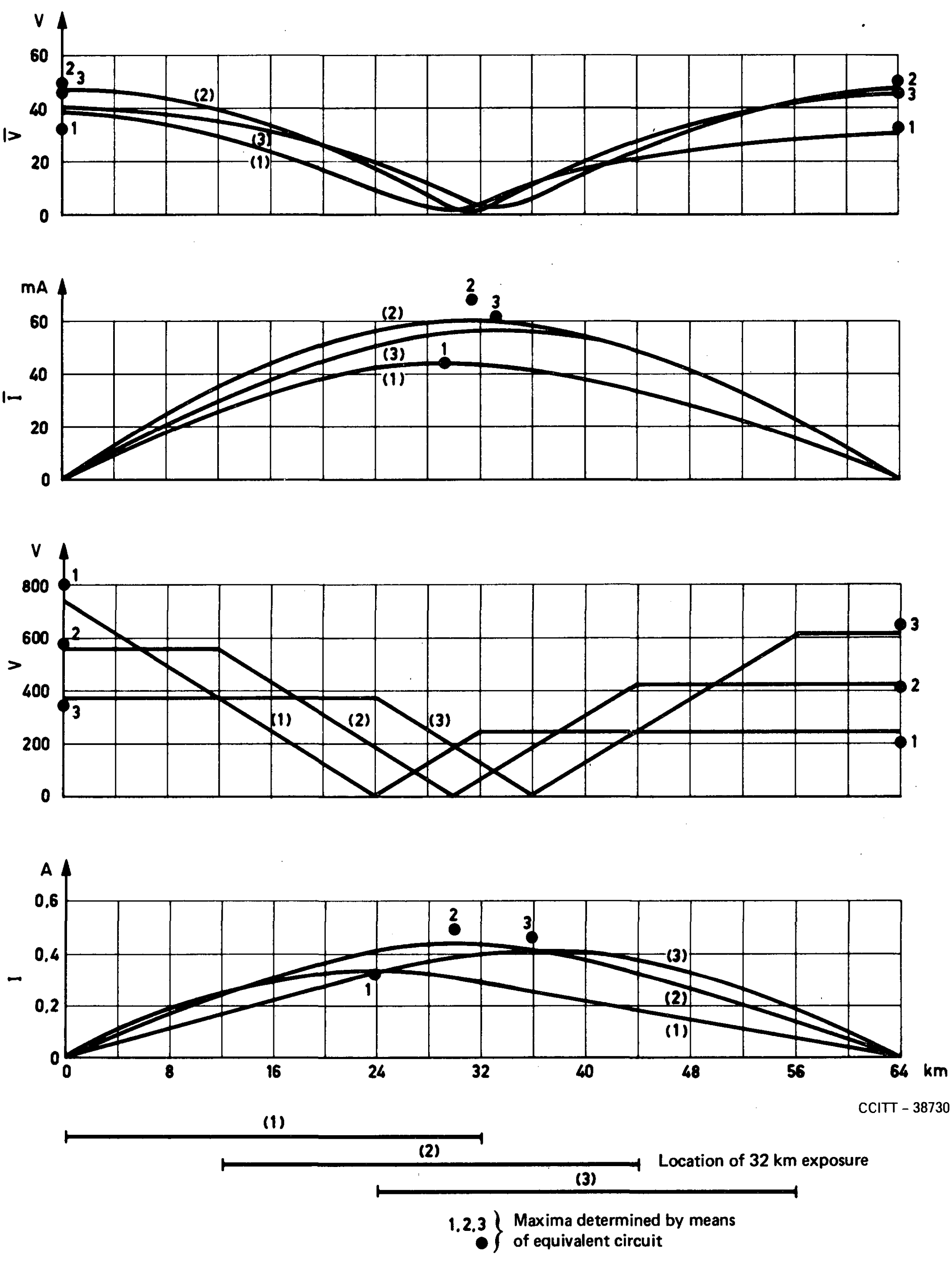


FIGURE B-5/K.16

Voltages and currents for a 300-channel route with asymmetrical exposures. Length of exposure 32 km. Voltage induced along the exposed section: 1000 volts (outer conductors of coaxial pairs at floating potential)

ANNEX C

(to Recommendation K.16)

Practical examples of complete calculations and of the simplified calculation case in which the outer conductors are earthed

C.1 *Where the inner conductors are at a regulated potential, slightly decoupled*

For the case of earthed outer conductors and inner conductors at a regulated potential with low-value earth decoupling capacitors, only the part of the diagram simulating the circuit *outer conductor – inner conductor* must be considered in the equivalent circuit, inserting logically the capacitance $\overline{C}$ instead of C. The resistance $k_1 R_0 l$ representing the transfer impedance is also omitted. The universal diagram is reduced in this case to the diagram shown in Figure C-1/K.16.

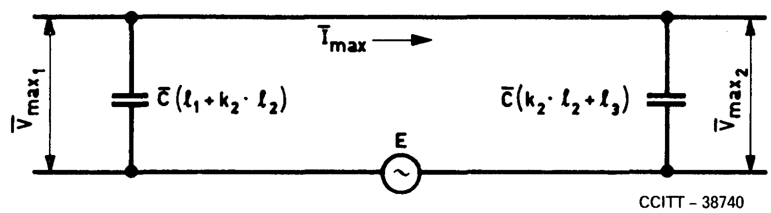


FIGURE C-1/K.16

Circuit *cable sheath – outer conductor* **(long exposed section)**

C.2 *Where the inner conductors are earthed through a low impedance in the power-feeding station*

The universal diagram is reduced in this case to the diagram shown in Figure C-2/K.16.

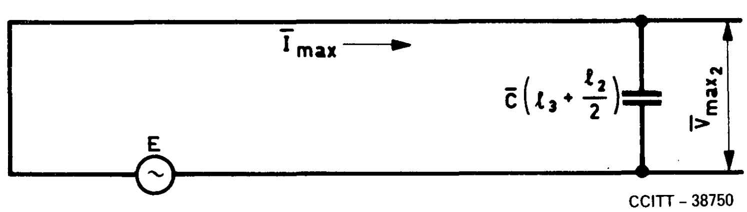


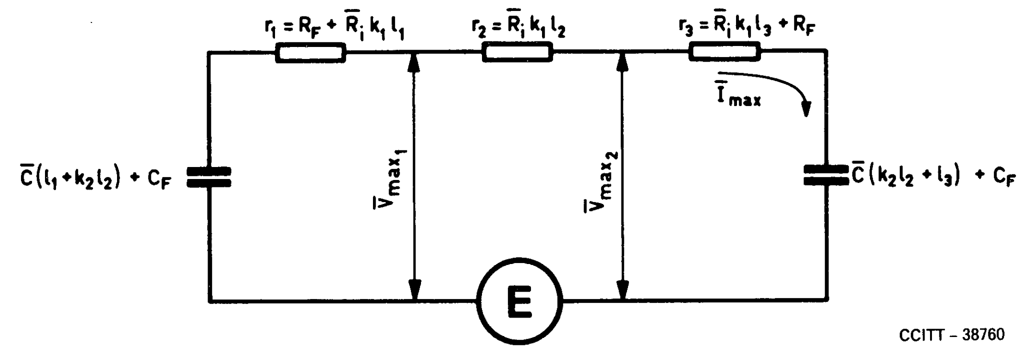
FIGURE C-2/K.16

Line with a short circuit at one end

C.3 *Where the inner conductors are at a regulated potential, strongly decoupled*

When the outer conductors are earthed and the inner conductors are connected to a regulated potential with powerful earth decoupling capacitors (several μF), the simplified diagram (Figure C-1/K.16) is insufficient. Account must also be taken of the resistance of the centre conductors of the coaxial pairs (possible resistances in series in repeater power feeds).

To ensure the validity of the equivalent circuit thus modified, a calculation was made using a definite example representing actual service conditions. The systems involved are still 300-channel small-diameter coaxial pair systems, this time involving a circuit 66 km long, with $\overline{C}$ = 0.11 μF/km, R_i = 17 Ω/km, the decoupling impedance of the regulated supply systems being equivalent to a resistance R_F of 50 ohms in series with a capacitance C_F of 15 μF. The diagram is shown in Figure C-3/K.16.

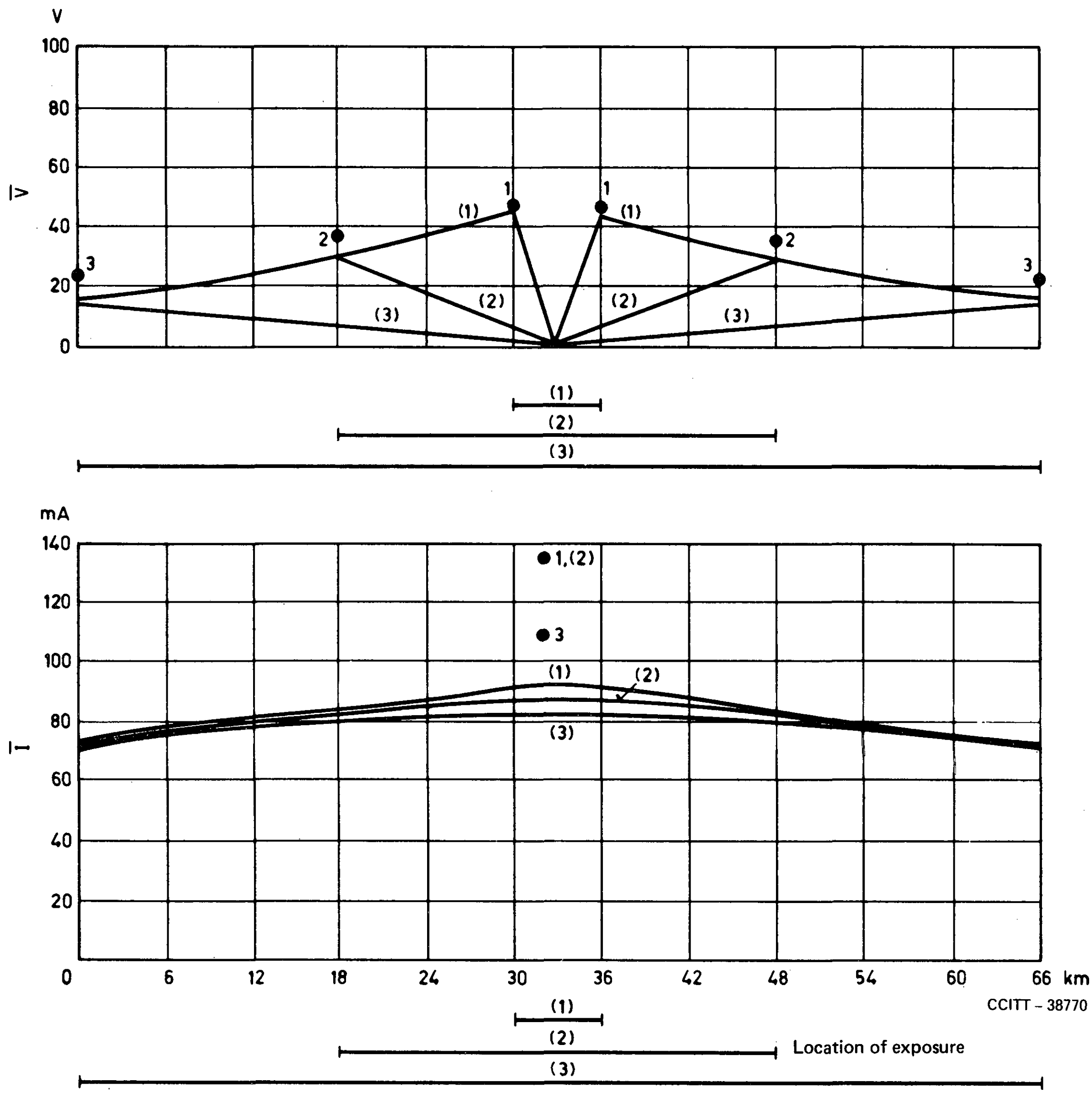


Note – $\bar{R}_i$ is the resistance per kilometre of the inner conductor plus the total resistance of all the repeater directional filters, expressed as a resistance value per kilometre.

FIGURE C-3/K.16

Equivalent circuit where the outer conductors of the coaxial pairs are earthed and the inner conductors have a strongly decoupled regulated feed

The induced voltage is assumed to be such that, taking account of the screening factor of the cable, the interference voltage to be considered is 100 V (if the voltage could not be restricted to such a value, another solution would be applied, reversion to the floating potential for example). For an induced voltage *E* of 100 V, after taking the combined screening factor of the cable sheath and the earthed outer conductors into account, Figures C-4/K.16 to C-7/K.16 below show the values of the voltages and currents obtained in the complete circuit; the points corresponding to the use of the equivalent circuit in Figure C-3/K.16 are plotted on these figures. Agreement between the two series of results is entirely satisfactory.

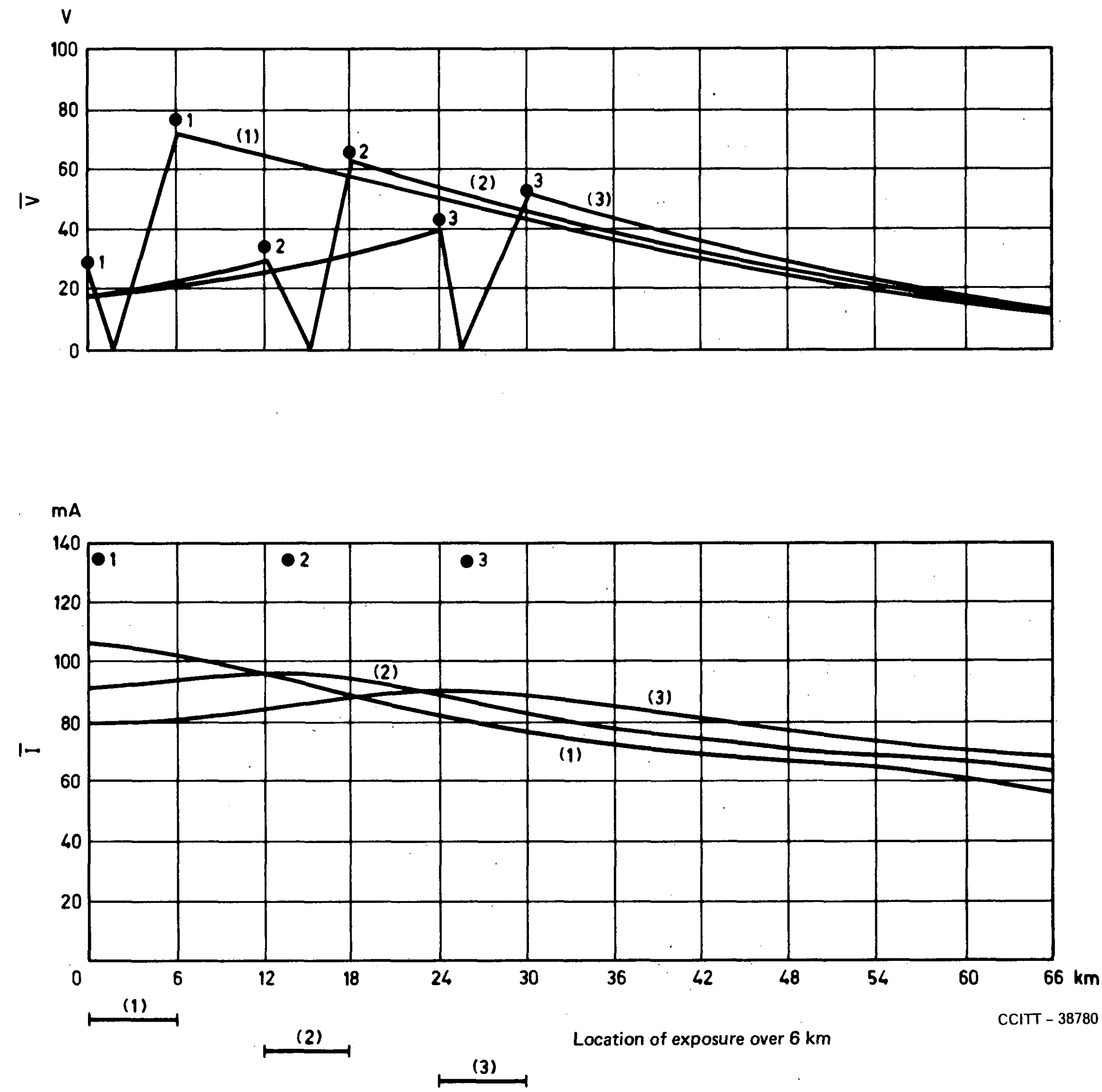


1, 2, 3 } Maxima determined by means
● } of equivalent circuit

Length of exposure: 6 km, 30 km or 66 km
Inducing voltage : 100 V

FIGURE C-4/K.16

Voltages and currents for a 300-channel route with symmetrical exposures (outer conductor of coaxial pairs earthed)

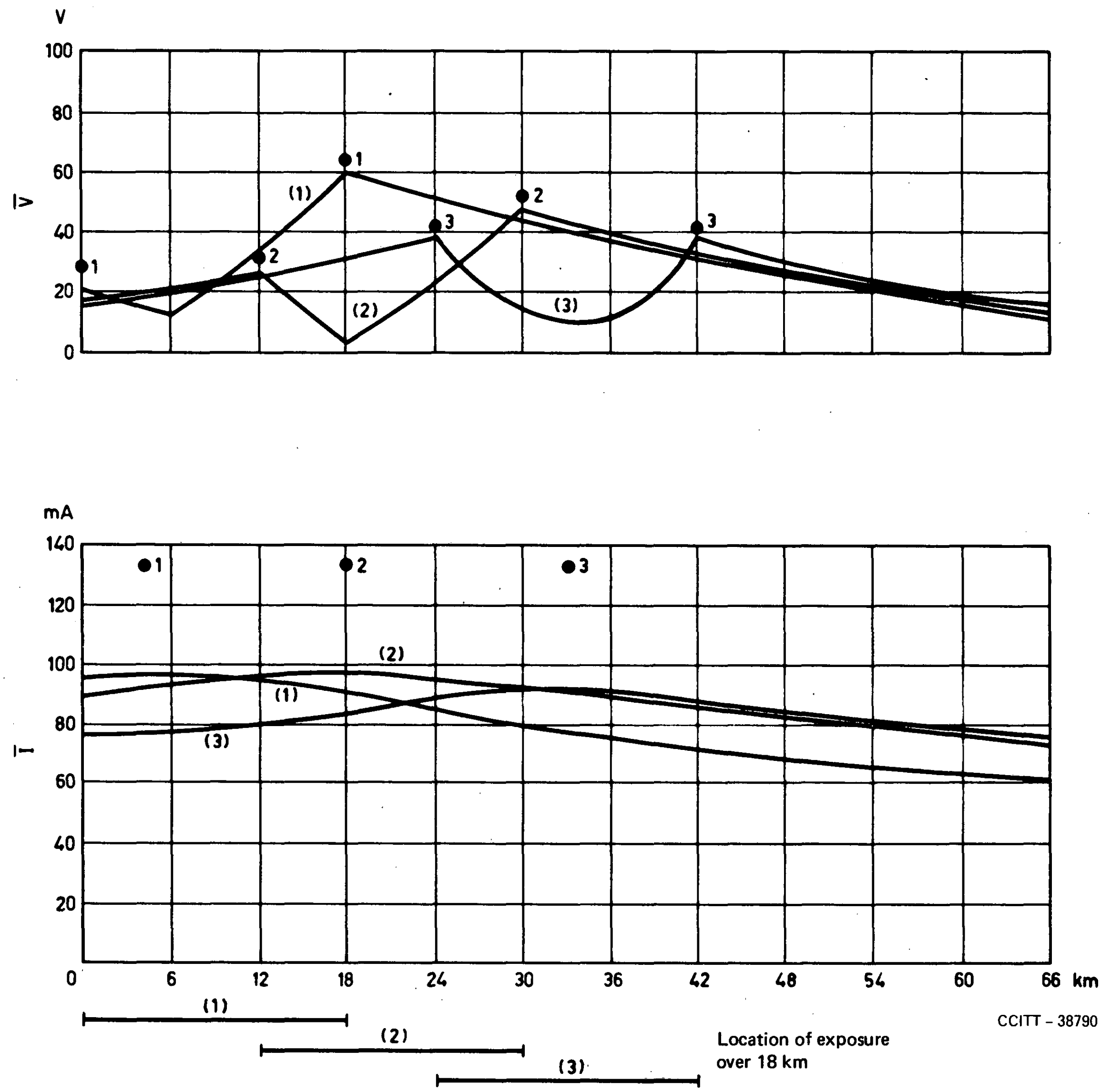


1, 2, 3 } Maxima determined by means of equivalent circuit

Length of exposure: 6 km
Inducing voltage : 100 V

FIGURE C-5/K.16

Voltages and currents for a 300-channel route with asymmetrical exposures (outer conductor of coaxial pairs earthed)

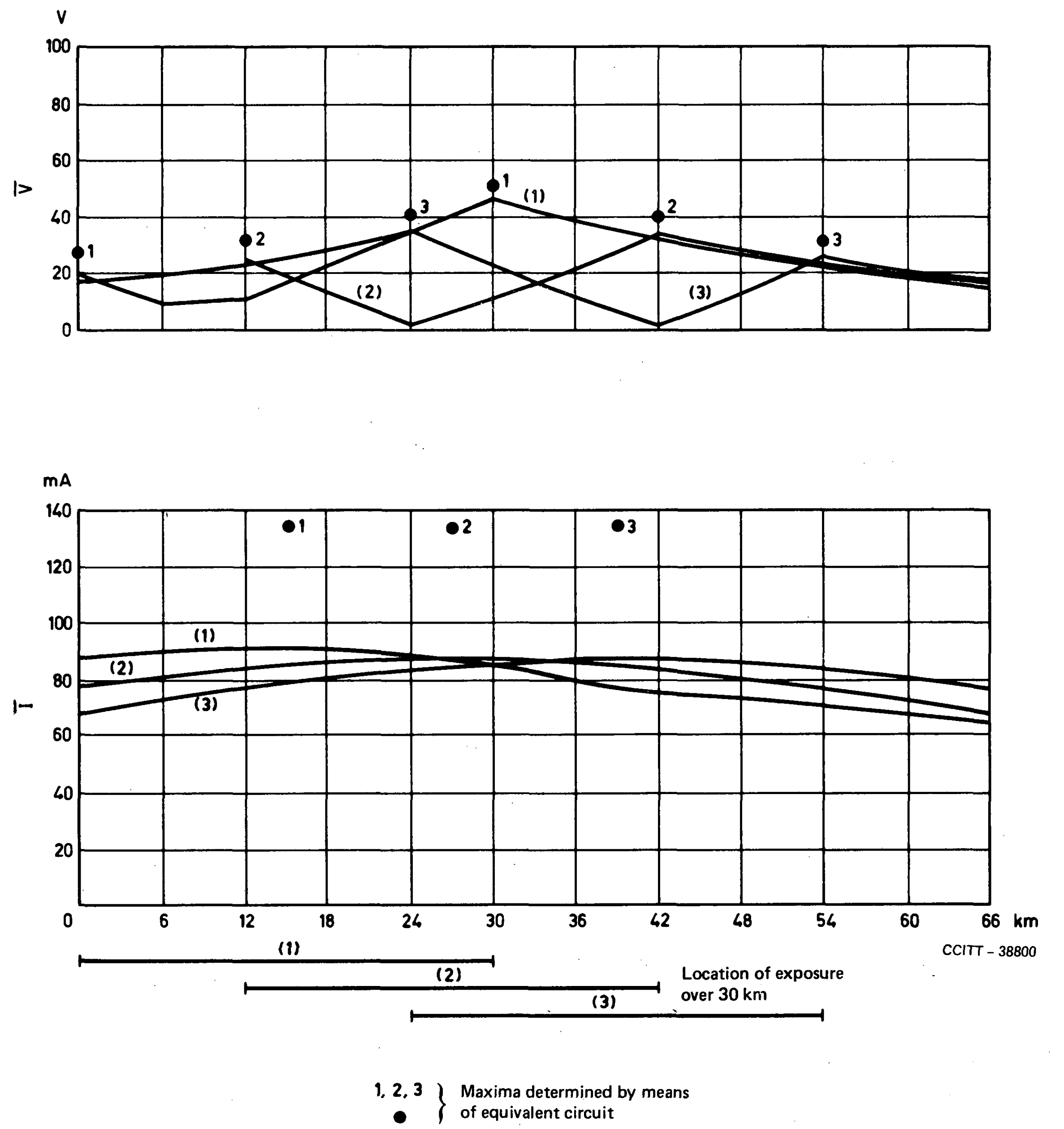


1, 2, 3 ● } Maxima determined by means of equivalent circuit

Length of exposure : 18 km
Inducing voltage : 100 V

FIGURE C-6/K.16

Voltages and currents for a 300-channel route with asymmetrical exposures (outer conductor of coaxial pairs earthed)



Length of exposure: 30 km
Inducing voltage : 100 V

FIGURE C-7/K.16

Voltages and currents for a 300-channel route with asymmetrical exposures (outer conductor of coaxial pairs earthed)

References

[1] KEMP (J.), SILCOOK (H.W.), STEWARD (C.J.): Power frequency induction on coaxial cables with application to transistorized systems, *Electrical Communication*, Vol. 40, No. 2, pp. 255-266, 1965.

[2] SALZMANN (W.), VOGEL (W.): Berechnung der Starkstrombeeinflüssung von Nachrichtenkabeln mit Koaxialpaaren und isolierten Aussenleitern (Calculation of power current interference in telecommunication cables with coaxial pairs and insulated outer conductors), *Signal und Draht 57*, No. 12, pp. 205-211, 1965.

Bibliography

KEMP (J.): Estimating voltage surges on buried coaxial cables struck by lightning, *Electrical Communication*, Vol. 40, No. 3, pp. 381-385, 1965.

POPP (E.): Lightning protection of line repeaters, *Conference Proceedings, ICC 68 of the IEEE*, pp. 169-174.

Recommendation K.17 [1), 2)] (Geneva, 1976, modified Malaga-Torremolinos, 1984)

TESTS ON POWER-FED REPEATERS USING SOLID-STATE DEVICES IN ORDER TO CHECK THE ARRANGEMENTS FOR PROTECTION FROM EXTERNAL INTERFERENCE

1 Introduction

1.1 As pointed out in Recommendation K.15, § 4.1, it is advisable that the test conditions simulate real conditions as closely as possible. As certain Administrations may be exposed to different environments, or have different service objectives or economic constraints, these tests may be modified to adapt them to local conditions.

If the environment is not known, the text given in this Recommendation should be applied.

1.2 None of the tests given in this Recommendation should cause any significant change in the characteristics concerning the repeaters under test.

In particular, this applies for:

a) current and voltage in the feeding circuit,

b) gain-frequency characteristic,

c) total noise,

d) bit error rate.

The tests consist of:

– prototype tests,

– acceptance tests.

Tests are intended to check the effectiveness of all the various arrangements made to protect repeaters using solid-state devices. These arrangements include protective devices incorporated as an integral part of the repeater or installed externally at the repeater location.

1.3 *Prototype tests*

Prototype tests are carried out to check the effectiveness of the repeater design and protective elements in a severe environment.

In deciding what protective measures should be adopted, allowance should be made for the most dangerous e.m.f.s that may be produced at the inputs and outputs of repeaters using solid-state devices, even where the occurrence of such e.m.f.s is very rare.

1) See also Recommendations K.15 and K.16.

2) The tests specified in Recommendation K.17 can also be applied in a similar manner to terminal equipment, e.g. locally-fed repeaters, power separating filters, power feeding equipment, which are all affected in the same way as intermediate repeaters.

When a repeater using solid-state devices with lightning protectors at its input (or output) terminals is subjected to an impulse voltage, the (residual) energy capable of reaching components within the time-interval from zero to the striking-time of the lightning protectors depends, among other things, on the steepness of the impulse wave-front.

During the prototype test this residual energy should be as large as in the worst case that may be expected in practice.

This is ensured by choosing an impulse wave of suitable steepness and amplitude. It is, however, additional to the test described previously, which recommends that the repeater be subjected to an impulse having an amplitude less than the striking voltage of the lightning protectors, in order to find out how it responds over the whole of the impulse wave.

1.4 *Acceptance tests*

These tests are carried out on equipment after assembly, to check that the protection is working properly. The test is in general less severe than the prototype test in order to avoid exposing certain components to a degradation that might remain undetected by any measuring process. However, users are at liberty to stipulate more stringent tests (adapted to special, real conditions).

The user may decide whether the tests are to be carried out on each equipment or by sampling.

Note – In certain circumstances, users may consider it worthwhile to carry out additional tests adapted to their own special requirements. Such tests are not given below.

2 Testing methods

2.1 *Testing methods concerning the protection of repeaters against overvoltages resulting from lightning (impulse tests)*

Tests will be carried out with a device of the type described in Figure 1/K.17. The values for components C_2 and R_3 are given in Table 1/K.17. Capacitor C_1 will have to withstand a charging voltage equal to the peak voltage value given in Table 1/K.17.

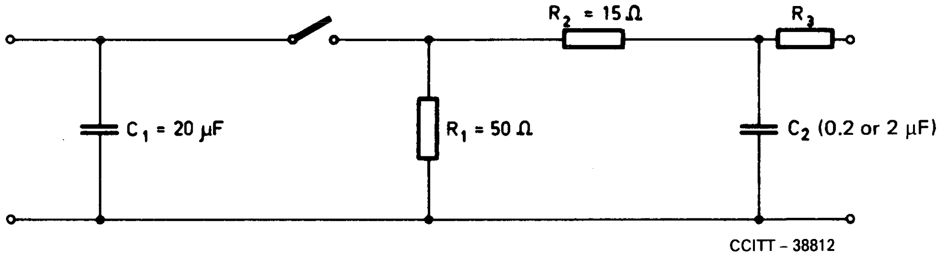


FIGURE 1/K.17

Diagram of an impulse generator

Note – When symmetric-pair (balanced) or μ coaxial-pair amplifiers are to be tested the short-circuit current of the testing equipment should be limited to adequate values by R_3, considering the higher conductor resistances of symmetric-pair and μ coaxial-pair lines in comparison to lines in coaxial-pair cables.

The waveforms given in the table are in accordance with the definitions in [1] (the voltages and waveforms refer to a generator without load).

TABLE 1/K.17

Characteristics of waveforms to be used for the tests

	Coaxial-pair repeaters ($\geq$ 1.2/4.4 mm)				Symmetric-pair repeaters				μ coaxial-pair repeaters (0.7/2.9 mm)			
	Prototype tests		Acceptance tests		Prototype tests		Acceptance tests		Prototype tests		Acceptance tests	
	Test 1 Test 2	Test 3 a)	Test 1 Test 2	Test 3 a)	Test 1 Test 2	Test 3	Test 1 Test 2	Test 3	Test 1 Test 2	Test 3 a)	Test 1 Test 2	Test 3 a)
Column No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Waveform b)	10/700	10/700	100/700	100/700	10/700	10/700	100/700	100/700	10/700	10/700	100/700	100/700
Load	0.1 coulomb	max. 0.1 coulomb	0.06 coulomb	max. 0.06 coulomb	0.03 coulomb	0.03 coulomb	0.03 coulomb	0.03 coulomb	0.1 coulomb	max. 0.1 coulomb	0.06 coulomb	max. 0.06 coulomb
Peak voltages	5 kV	5 kV	3 kV	3 kV	1.5 kV	1.5 kV	1.5 kV	1.5 kV	5 kV	5 kV	3 kV	3 kV
Short-circuit current	333 A		200 A		37.5 A		37.5 A		125 A		75 A	
Peak current in the power-feeding circuit		50 A		50 A		37.5 A		37.5 A		50 A		50 A
C_2	0.2 μF	0.2 μF	2 μF	2 μF	0.2 μF	0.2 μF	2 μF	2 μF	0.2 μF	0.2 μF	2 μF	2 μF
R_3	c)	c)	c)	c)	25 Ω	25 Ω	25 Ω	25 Ω	25 Ω	25 Ω	25 Ω	25 Ω
Number of pulses	10	10	2	2	10	10	2	2	10	10	2	2

a) For Test 3 on coaxial-pair repeaters, the peak voltage may be reduced to such a value as to cause not more than 50 A to flow.

b) Approximate values (see also the *Note* under § 2.1 in the text).

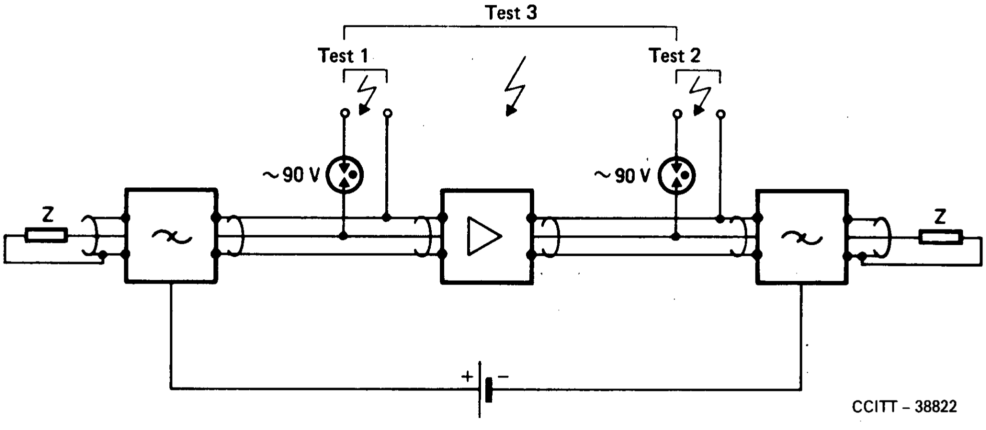
c) Resistor R_3 (0-2.5 ohms) may be introduced to prevent oscillatory discharge. It may be greater than 2.5 ohms if C_2 and R_2 are adjusted to maintain the waveform under load.

The tests are carried out with the polarity reversed at consecutive pulses, with a time interval of one minute between pulses; the number of pulses applied to each test point in the different cases is given in the bottom line of Table 1/K.17. Impulse waves should be applied at the following points:

- *Test 1:* at the input of the repeater, with the output terminated by its characteristic impedance;
- *Test 2:* at the output of the repeater, with the input terminated by its characteristic impedance;
- *Test 3:* (longitudinal) between the input-side inner conductor and the output-side inner conductor of the repeater in the case of coaxial-pair repeaters (at the terminals of the feeding circuit, in the case of symmetric-pair repeaters).

Power should be supplied to the repeater during Tests 1 and 2, but not for Test 3.

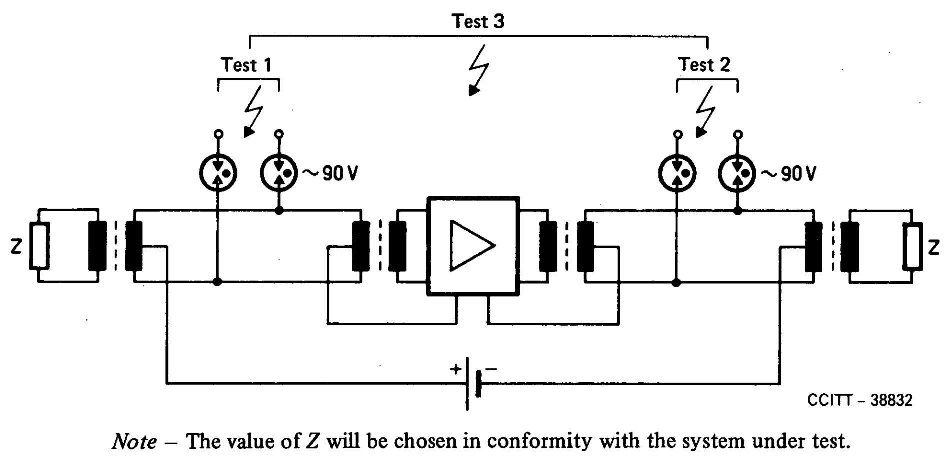
For these tests the circuit arrangement given in Figure 2/K.17 for coaxial pairs and in Figure 3/K.17 for symmetric pairs may be found helpful. To couple the impulse generator to the repeater, lightning protectors with a striking voltage of approximately 90 V may be used, as illustrated in Figures 2/K.17 or 3/K.17, respectively.



Note – The value of *Z* will be chosen in conformity with the system under test.

FIGURE 2/K.17

Example of an impulse voltage test circuit for power-fed repeaters used on coaxial-pair cables



Note – The value of *Z* will be chosen in conformity with the system under test.

FIGURE 3/K.17

Example of circuit arrangement for impulse voltage test for power-fed repeaters used on symmetric-pair cables

2.2 *Testing methods concerning the protection of repeaters against a.c. induction caused by a fault in a power line*

2.2.1 *A.c. tests on the input and output terminals of a repeater*

An alternating e.m.f. (source frequency 16 2/3, 25, 50 or 60 Hz) is applied:

- across the repeater input, the output being terminated with an impedance twice the characteristic impedance;
- across the repeater output, the input being terminated with an impedance twice the characteristic impedance.

The value, the duration and the internal impedance of the e.m.f. source must be representative of local conditions. (This test is only specified for coaxial-pair repeaters.)

2.2.2 *A.c. tests on the terminals of the power-feeding path of the repeater*

An alternating current of the appropriate frequency and value is fed into the terminals of the power feeding path.

If the additional stress from the application of power feeding is negligible, power feeding should not be applied during tests specified under § 2.2. However, if this stress is not negligible, the highest level of power feeding stress should be simulated during the a.c. tests.

2.3 *Testing methods concerning the protection for repeaters against disturbances resulting from the presence of alternating longitudinal e.m.f.s permanently induced by electricity lines*

For satisfactory operation in the presence of steady-state induced voltages (see Recommendation K.15, § 3.2) the hum modulation characteristics of the repeaters should, as specified in Recommendation K.15, § 4.3, meet the recommendations for route sections prepared by Study Group XV and the repeater should operate without significant change to its transmission performance (for example, see the Recommendation cited in [2]) when connected to a typical power-feeding circuit in the presence of:

a) an alternating voltage of the appropriate frequency (50 Hz, 16 2/3 Hz, etc.) applied to:

   i) the signal input terminals, or

   ii) the signal output terminals.

   The source of this alternating voltage shall have, at the points of connection to the test circuit, such an impedance as not significantly to disturb the transmission-frequency characteristics of the circuit.

b) an alternating current of the appropriate frequency superimposed on the power-feeding current of the repeater.

The test specified in a) must be performed with 60 V or 150 V according to the limits of permanently induced e.m.f. (see [3]). The test specified in b) must be performed with a current value corresponding to an e.m.f. of 60 V or 150 V calculated according to Recommendation K.16 and assuming the *most adverse situation.*

3 Tests to be carried out for the different cases

3.1 *Test conditions for repeaters used on coaxial pairs*

The following tests were formulated for the case where the outer conductor is connected to the metallic cable sheath. This covers the case where the outer conductor (normally at a floating potential) comes accidentally into contact with the metallic sheath.

3.1.1 *Prototype tests*

3.1.1.1 *Tests at the input and output terminals of the repeater*

3.1.1.1.1 *Impulse tests*

These tests will be carried out under conditions listed in Column 1 of Table 1/K.17.

If protection is ensured by *operating threshold* type devices (e.g., lightning protectors) at the input and output of the repeater and they do not strike under the above test conditions, the charging voltage of the capacitor, C_1, should be gradually increased (though not beyond 7 kV [1)]) until they do so.

[1)] If repeaters used for μ coaxial-pairs are tested, the maximum peak voltage need not exceed 5 kV.

If the protectors do not strike at 7 kV[1], or if the repeaters subjected to prototype tests are not provided with lightning protectors, the waveform suggested above may not be suitable. A pulse shape which simulates a breakdown in the cable can be produced by the test generator already mentioned above when a spark gap of the proper striking voltage is connected across the circuit. Where lightning protectors are provided, and if they strike under the above test conditions, the charging voltage of the capacitor, C_1, should be gradually decreased until they do not strike.

3.1.1.1.2 *A.c. tests* [2]

A voltage having an r.m.s. value which will produce 1200 V across a resistor of 150 ohms shall be applied for 0.5 seconds at:

- the input of the repeater, with the output terminated by a resistor of 150 ohms,
- the output of the repeater, with the input terminated by a resistor of 150 ohms.

The impedance of the source of voltage shall be such that any current which flows, lies between 8 A and 10 A.

The e.m.f. of the source of the voltage should be such that when it is loaded with a resistor having a value of 150 ohms, a voltage of at least 1200 V r.m.s. appears across the load resistor. An example of a test circuit suitable for a frequency of 50 Hz is shown in Figure 4/K.17.

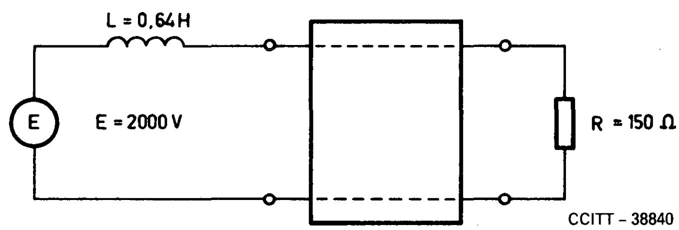


FIGURE 4/K.17

Example of test circuit for a.c. tests at 50 Hz

3.1.1.1.3 *Steady-rate a.c.-induced voltage tests*

These tests should be carried out in accordance with § 2.3 above.

3.1.1.2 *Tests at the terminals of the repeater power-feeding circuit*

3.1.1.2.1 *Impulse tests*

These tests will be carried out under conditions listed in Column 2 of Table 1/K.17.

In this test the capacitor, C_1, may be charged either at 5 kV or at a lower voltage provided the peak current in the power-feeding circuit reaches 50 A.

3.1.1.2.2 *A.c. tests*

These tests consist in passing an alternating current, comparable in intensity and frequency to the alternating currents that are likely to be met with in practice, through the power-feeding circuit. The current should be applied for 0.5 sec., but should not exceed 10 A r.m.s.

3.1.1.2.3 *Steady-state a.c.-induced voltage tests*

These tests should be carried out in accordance with § 2.3 above.

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1) If repeaters used for µ coaxial-pairs are tested, the maximum peak voltage need not exceed 5 kV.

2) This part of the Recommendation may be modified following future studies and tests. If an Administration considers that these values are too high for its requirements in view of the local conditions concerned, a lower value may be specified.

3.1.2 *Acceptance tests*

3.1.2.1 *Tests at the input and output terminals of the repeater*

These tests will be carried out under conditions listed in Column 3 of Table 1/K.17.

3.1.2.2 *Tests at the terminals of the power-feeding circuit of the repeater*

These tests will be carried out under conditions listed in Column 4 of Table 1/K.17. In this test, the capacitor, C_1, may be charged either at 3 kV, or at a lower voltage, provided the peak current in the power-feeding circuit reaches 50 A.

3.2 *Test conditions for repeaters used on symmetric pairs*

3.2.1 *Prototype tests*

3.2.1.1 *Tests at repeater input and output terminals*

3.2.1.1.1 *Impulse tests*

These tests will be carried out with a waveform having the characteristics listed in Column 5 of Table 1/K.17.

Where the dielectric strength of the symmetric pairs is greater than that of paper-insulated pairs, it would be advisable to use a higher peak voltage than that shown in Table 1/K.17.

Where lightning protectors are provided and if they strike under the above test conditions, the charging voltage of the capacitor, C_1, should be gradually decreased until they do not strike.

Note – When lightning protectors are placed between the input and output terminals of the repeater and its chassis, one of the terminals should be connected to the chassis before making the transverse-voltage test to simulate striking of a lightning protector.

3.2.1.1.2 *A.c. tests*

A.c. tests are not specified.

3.2.1.2 *Tests at the terminals of the repeater power-feeding circuit*

3.2.1.2.1 *Impulse tests*

These tests will be carried out under conditions listed in Column 6 of Table 1/K.17.

3.2.1.2.2 *A.c. tests*

These tests consist in passing an alternating current, comparable in intensity and frequency to the alternating currents that are likely to be met with in practice, through the power-feeding circuit. The current should be applied for 0.5 second.

These tests may be omitted if the repeaters, in their environment, are not likely to experience longitudinal e.m.f.s induced by electricity lines which will produce the flow of longitudinal currents.

3.2.1.2.3 *Steady-state a.c.-induced voltage tests*

These tests should be carried out in accordance with § 2.3 above.

3.2.2 *Acceptance tests*

3.2.2.1 *Tests at the input and output terminals of repeaters*

These tests will be carried out under conditions listed in Column 7 of Table 1/K.17.

3.2.2.2 *Tests at the terminals of the repeater power-feeding circuit*

These tests will be carried out under conditions listed in Column 8 of Table 1/K.17.

References

[1] IEC publication No. 60-2/1973.

[2] CCITT Recommendation *Unwanted modulation and phase jitter*, Rec. G.229, § 1.3.

[3] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines*, Chapter IV, 6, 7 and 35, ITU, Geneva, 1963, 1965, 1974, 1978.

Recommendation K.18 (Geneva, 1980, modified Malaga-Torremolinos, 1984)

CALCULATION OF VOLTAGE INDUCED INTO TELECOMMUNICATION LINES FROM RADIO STATION BROADCASTS AND METHODS OF REDUCING INTERFERENCE

1 Introduction

Although inductive interference from radio waves is seldom observed on circuits in underground cables, many examples of such interference have been reported in circuits carried by open wires, aerial cables or cables inside buildings.

Interference on voice-frequency circuits occurs because the induced radio wave is detected and demodulated by the nonlinear components in a telephone set or by metal oxide layers formed at conductor joints. This interference is mostly intelligible noise and may occur up to 5 km from a radio station whose radiating power is more than several tens of kilowatts.

On carrier or video transmission circuits, the induced radio wave impairs circuit performance when the radio-wave frequency is within the operating frequency of the transmission system. The interference usually consists of a single frequency tone within a telephone channel and is unintelligible. It reduces the signal-to-noise ratio (SNR) for the transmission system. This interference may occur within a wide area around a radio station. Interference on video transmission circuits has been reported in only a few cases, but it is expected to cause serious problems when video transmission services increase in number in the future.

An unusual example of interference may arise in which outside plant maintenance personnel receive burns due to radio frequency currents. Such problems have been reported only in the immediate vicinity of a radio station antenna.

2 Analysis of interference

In the theoretical analysis of the voltage induced from a radio wave, the following conditions are assumed:

- Earth resistivity is homogeneous and uniform.
- A cable or a wire is supported in a straight line at a constant height above the earth's surface.
- The metallic screen of a cable is earthed at both ends.
- The radio-wave electric field has a constant intensity and a constant incidence angle, and phase change along the cable is uniform.
- The radio wave is originally polarized vertically. However, while it propagates along the surface of the earth, a horizontal component is generated due to the finite conductivity of the earth.

Constants and variables used for theoretical analysis are shown in Annex A.

2.1 For telecommunication lines without a metallic screen, the horizontal component of the radio-wave electric field acts directly as an electromotive force on the telecommunication line. This causes induced noise at terminals when the circuit has an impedance unbalance with respect to earth. Induced longitudinal voltages at the ends of a telecommunication line without a metallic screen are given by Equations (B-1) and (B-2).

2.2 For telecommunication cables with a metallic screen, the horizontal component of the radio-wave electric field acts as an electromotive force, causing induced current to flow in the earth return circuit composed of the metallic screen of the cable and the earth. Due to the current in the screen, an electromotive force is induced in the conductors through the transfer impedance between the conductors and the metallic screen. This electromotive force may cause disturbance to metallic circuits in the cable, according to the degree of their unbalance with respect to the metallic screen (or the earth).

Induced longitudinal voltages at the ends of a telecommunication cable with a metallic screen are given by Equations (B-3) and (B-4). In reference [1] the values obtained by using these equations are shown to agree with measured values.

2.3 The equations in Annex B are very complicated and involve many parameters. It is therefore useful to estimate the approximate value of the maximum induced longitudinal voltage by the following simplified equation:

$$V_2(0)\ \text{dB}\ [\approx V_2(l)] = 20 \log_{10} V_2(0)$$

$$= 20 \log_{10} \frac{PE_v (\cos \theta)\, Z_K}{4Z_{01}} - 30 \log_{10} f - 20 \log_{10} \alpha_{20} + 300 \qquad (2\text{-}1)$$

where

$$l \geqslant \frac{1.5\, \beta_0}{f \cdot \beta_2} \times 10^8 \qquad (2\text{-}2)$$

$$20\ \Omega < |Z_{1R}|, |Z_{1L}| \leqslant |Z_{01}| \qquad (2\text{-}3)$$

$$\gamma_2 = \alpha_2 + j\beta_2$$

$$\alpha_2 = \alpha_{20}\sqrt{f} \times 10^{-3}\ (\text{dB/km})$$

α_{20} is the attenuation coefficient at 1 MHz (dB/km)

f is the radio-wave frequency expressed in Hz.

Other constants and variables are shown in Annex A.

Equation (2-1), which gives the maximum induced longitudinal voltage in dB (0 dB = 0.775 V), is obtained on the basis of the following:

The induced longitudinal voltage calculated by the equations in Annex B reaches an initial peak value when cable length

$$l = \frac{1.5\, \beta_0}{f \cdot \beta_2} \times 10^8$$

and subsequently describes a series of peak values. Its maximum value occurs at one of the earliest peak values along the cable length.

$$l \geqslant \frac{1.5\, \beta_0}{f \cdot \beta_2} \times 10^8.$$

The induced longitudinal voltage reaches its maximum at one of the earliest peak values due to the attenuation of the induced radio wave along the cable (Figure 3/K.18).

The errors involved in using Equation (2-1) instead of the full equations of Annex B are described in detail in Annex C.

2.4 If the line configuration is very complicated, it is necessary to divide the line into several segments and to estimate the induced longitudinal voltage for each segment by Equations (B-1) to (B-4). Estimated induced voltages for each segment are then combined to obtain the overall induced voltage, taking into account the transmission characteristics and the boundary conditions of the line involved.

When the simplified equation (2-1) is applied to a complicated line, a straight line model may be used to estimate the maximum induced longitudinal voltage. Calculations should commence at the point nearest to the radio station and the smallest value of radio wave incidence angle should be used.

2.5 When field measurement of the radio-wave electric field strength is carried out, the measured value may be used for E_v in Equation (2-1).

When the measured value is not available, the radio-wave electric field strength E_v can be calculated by Equation (2-4), taking into account the distance from the radio station and the power of the radio station transmitter (see [2]).

$$E_v = \frac{1}{r}\sqrt{\frac{1.5\,P\,Z_0}{2\pi}} \tag{2-4}$$

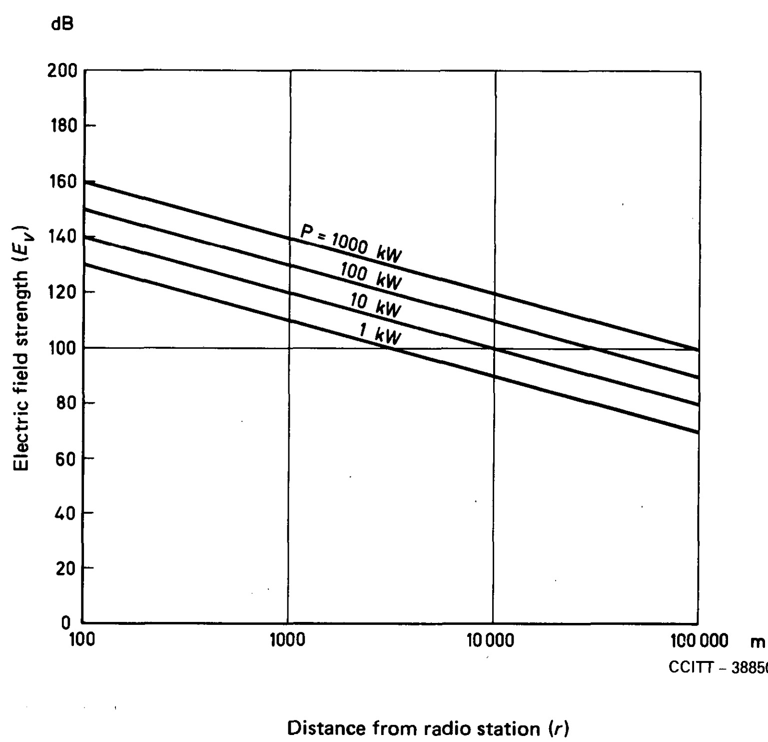
where

P is the radio station transmitting power (W)

r is the distance from radio station (m)

Z_0 is the intrinsic impedance of free space ($\approx 377\ \Omega$)

Figure 1/K.18 shows values of E_v obtained from Equation (2-4) using various values of P.



Note – E_v is expressed in dB (0dB = 1 μV/m).

FIGURE 1/K.18

Radio-wave electric field strength related to the distance from the radio station

2.6 The angle of incidence made by the radio wave onto the telecommunication line may vary according to circumstances.

When the telecommunication line is installed in open country, either a measured value of the incidence angle or a value calculated from the relative location of the radio station and the telecommunication line may be used.

When the telecommunication line is installed near structures which obstruct radio wave propagation, the incidence angle may be taken as zero and the severest condition assumed.

2.7 The induced longitudinal voltage at the ends of the telecommunication cable shown in Figure 2/K.18 may be estimated using the simplified method which follows.

Inserting the values for parameters P, f, α_{20}, β_2 and θ given in Figure 2/K.18 together with calculated values for E_v and Z_K into Equations (2-1) and (2-2), the following results are obtained:

$$V_2(0) \approx V_2(l) = -35.0 \text{ dB}$$

$$l \geqslant 210 \text{ m}$$

Moreover, using $\theta = 0°$ as the most severe value, the following is obtained:

$$V_2(0) \approx V_2(l) = -32.0 \text{ dB}$$

$$l \geqslant 210 \text{ m}$$

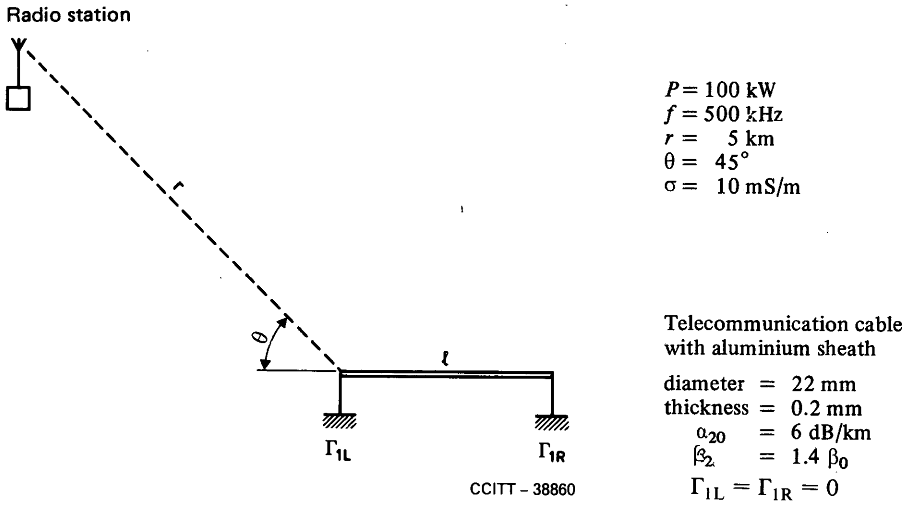


FIGURE 2/K.18

Relative position of radio station and telecommunication line

In Figure 3/K.18 the results obtained by using the simplified calculations are compared with others derived from using the more rigorous methods described in Annex B, in which values of V_2 related to cable length are expressed. It is apparent that the simplified method is adequate for estimating the most severe interference likely to be experienced.

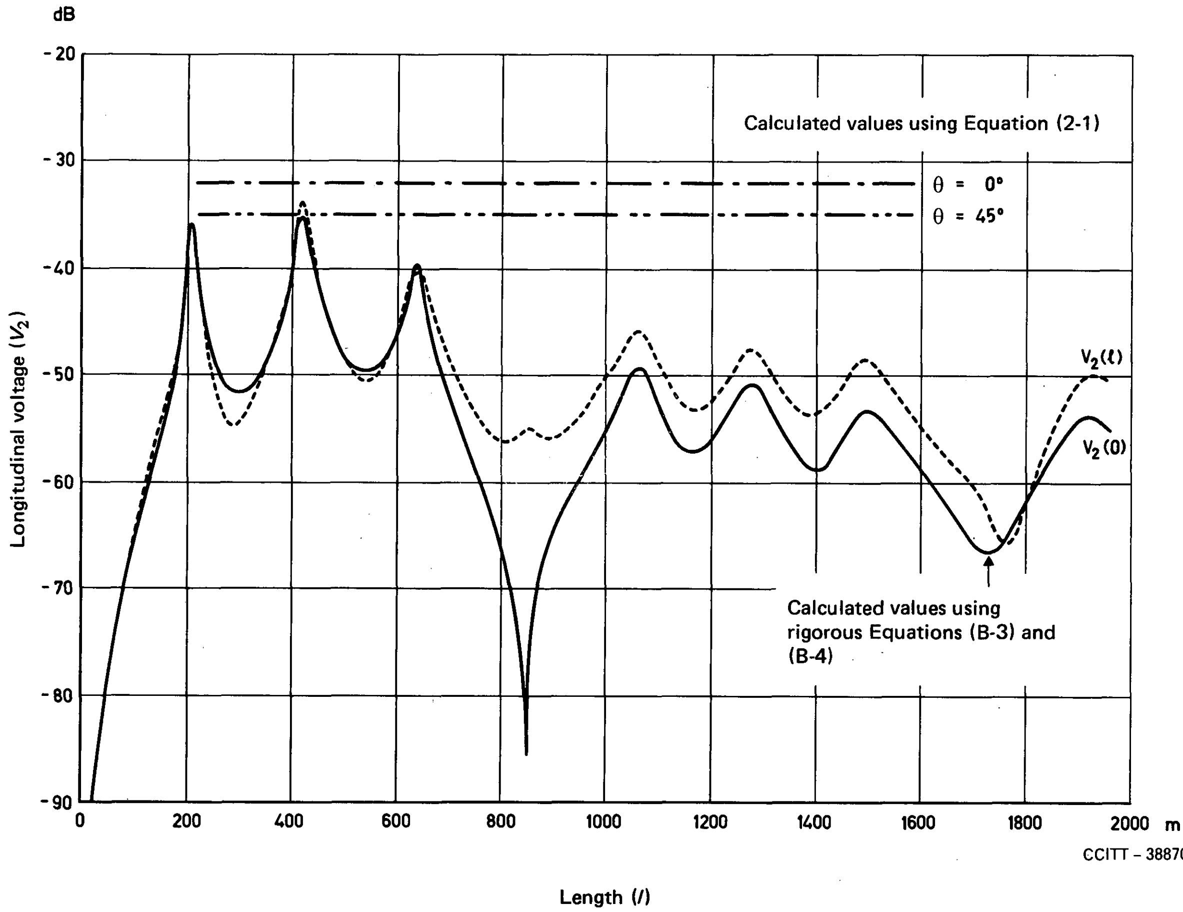


FIGURE 3/K.18

Calculated induced longitudinal voltage at ends of cable shown in Figure 2/K.18

2.8 Transverse voltages which cause noise arise due to the imperfect balance of the circuit with respect to the metallic screen (or earth). If a ratio, λ is used to related longitudinal and transverse voltages, noise levels may be obtained from calculated or measured values of the induced longitudinal voltage:

$$V = \lambda \cdot V_2$$

where

$V_2[V_2(0)$ or $V_2(l)]$ is the longitudinal voltage at the ends of the longitudinal circuit under open circuit conditions,

$V[V(0)$ or $V(l)]$ is the transverse voltage at the ends of the circuit when terminated with its characteristic impedance at both ends.

For example, in the case shown in Figure 2/K.18 and λ equal to −40 dB, the noise level, V is obtained as follows:

(in this case, $V_2 = -35$ dB [0 dB = 0.775 V])

$V = -35 - 40$ dB $= -75$ dB

3 Reduction of interference

The following measures may be taken to minimize interference:

3.1 Interference to a voice-frequency circuit can be reduced by inserting a 0.01 ~ 0.05 μF capacitor between conductors and the earth at the input terminal or at the telephone set, to bypass induced radio-wave currents.

3.2 Interference to carrier and video transmission systems can be reduced by the following measures:

3.2.1 An adequate screen should be incorporated in the cable, e.g. a 0.2-mm thick aluminium screen around a cable provides a reduction of interference of about 70 dB. The aluminium screen should be earthed at both ends with resistance less than $|Z_{01}|$ Ω, when earth conductivity is less than 0.1 S/m. If the screen thickness is increased to 1.0 mm the reduction is improved by a further 50-60 dB.

3.2.2 Conductors should be completly shielded by a metallic screen around cable joints and at cable terminals.

Note – If the metallic screen is removed for a length of about 30 cm, induced voltages increase by about 30 dB, even if the metallic screen is connected electrically. Even if only 5 cm of the metallic screen is removed from a cable end, induced voltages increase by about 10 dB.

3.2.3 In sections susceptible to radio-wave interference, underground cable should be installed or different cable routings should be used.

3.2.4 Distances between repeaters should be reduced to provide an acceptable signal-to-noise ratio (SNR) for the system.

3.2.5 The admittance unbalance of the terminal equipment and repeaters at the radio-wave frequency should be improved with respect to earth.

3.2.6 Pre-emphasized level setting of the transmission system should be used.

3.3 To reduce the induced dangerous voltage to maintenance personnel, a capacitor may be inserted between the conductors and the earth at suitable intervals within the induced section to bypass the induced current.

In this case, care must be taken, in selecting an appropriate capacitor, to combine minimum attenuation of the transmission frequencies with effective earthing at the radio-wave frequency. Care should be taken to prevent the capacitor from being damaged by overvoltages appearing on the conductors.

ANNEX A

(to Recommendation K.18)

Constants and variables used in Recommendation K.18

A.1 The ratio of horizontal component to vertical component, P for a radio-wave electric field propagating along the ground surface is:

$$P = \frac{E_h}{E_v} = \left| \frac{1}{\sqrt{\varepsilon_r - j \dfrac{\sigma}{\omega \varepsilon_0}}} \right| \approx \sqrt{\frac{\omega \varepsilon_0}{\sigma}} \tag{A-1}$$

where

E_h is the horizontal component in radio wave electric field strength (V/m)

E_v is the vertical component in radio wave electric field strength (V/m)

ε_r is the specific dielectric constant of earth

ε_0 is the dielectric constant of free space (F/m)

Z_0 is the intrinsic impedance of free space (Ω)

β_0 is the phase constant of free space (rad/m)

σ is the earth conductivity (S/m)

ω is the angular frequency of radio wave (rad/s)

f is the frequency of radio wave (Hz)

A.2 The transfer impedance of the metallic screen of a cable sheath, Z_K is:

$$Z_K = \frac{Kt}{\sinh Kt} \cdot R_{dc} \qquad \Omega/\text{m} \tag{A-2}$$

where

R_{dc} is the direct-current resistance per unit length of metallic screen (Ω/m)

$K = \sqrt{j\omega\mu g}$

μ is the permeability of metallic screen (H/m)

g is the conductivity of metallic screen (S/m)

t is the thickness of metallic screen (m).

A.3 In connection with the following symbols, see Figure A-1/K.18.

θ is the incidence angle of radio wave to telecommunication line (rad)

l is the cable length (m)

x is the distance along the cable from the cable end near to the radio station (meters)

Z_{01} is the earth return circuit characteristic impedance (Ω)

γ_1 is the earth return circuit propagation constant

Z_{02} is the longitudinal circuit characteristic impedance (Ω)

γ_2 is the longitudinal circuit propagation constant

Z_{1L}, Z_{1R} earth return circuit terminal impedance (Ω)

Z_{2L}, Z_{2R} longitudinal circuit terminal impedance (Ω)

$\Gamma_{1L} = \dfrac{Z_{01} - Z_{1L}}{Z_{01} + Z_{1L}}$ is the earth return circuit current reflection coefficient at $x = 0$

$\Gamma_{1R} = \dfrac{Z_{01} - Z_{1R}}{Z_{01} + Z_{1R}}$ is the earth return circuit current reflection coefficient at $x = l$

$\Gamma_{2L} = \dfrac{Z_{02} - Z_{2L}}{Z_{02} + Z_{2L}}$ is the longitudinal circuit current reflection at $x = 0$

$\Gamma_{2R} = \dfrac{Z_{02} - Z_{2R}}{Z_{02} + Z_{2R}}$ is the longitudinal circuit current reflection at $x = l$

$V_{1m}(x)$ (for $m = 0$) is the voltage in earth return circuit with matching at both ends

$V_{1m}(x)$ (for $m = \text{L}$) is the voltage in earth return circuit with mismatching at $x = 0$

$V_{1m}(x)$ (for $m = \text{R}$) is the voltage in earth return circuit with mismatching at $x = l$

$V_{2m}(x)$ (for $m = 0$) is the voltage in longitudinal circuit with matching at both ends

$V_{2m}(x)$ (for $m = \text{L}$) is the voltage in longitudinal circuit with mismatching at $x = 0$

$V_{2m}(x)$ (for $m = \text{R}$) is the voltage in longitudinal circuit with mismatching at $x = l$

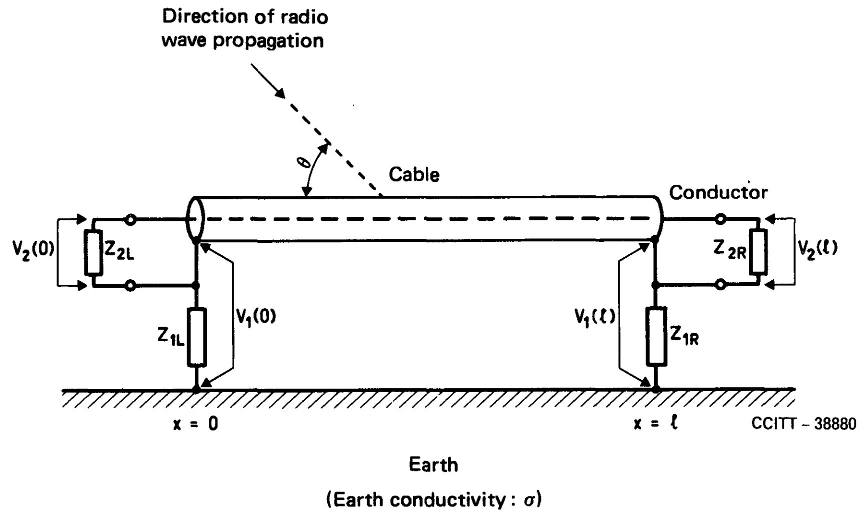


FIGURE A-1/K.18

Termination of earth return circuit (Z_{1L}, Z_{1R}) and longitudinal circuit (Z_{2L}, Z_{2R})

ANNEX B

(to Recommendation K.18)

Induced longitudinal voltage calculation

B.1 *Telecommunication lines without metallic screen*

Induced longitudinal voltages at the ends of a telecommunication line without a metallic screen are given by Equations (B-1) and (B-2).

Induced longitudinal voltage at the end nearest the radio station:

$$\left.\begin{aligned}
V_1(0) &= V_{10}(0) + V_{1L}(0) + V_{1R}(0) \\
V_{10}(0) &= -\frac{PE_V \cos\theta}{2}\,\frac{1 - e^{-(\gamma_1 + j\beta_0 \cos\theta)\, l}}{\gamma_1 + j\beta_0 \cos\theta} \\
V_{1L}(0) &= \frac{-\Gamma_{1L}\left[1 - \Gamma_{1R}\, e^{-2\gamma_1 l}\right]}{1 - \Gamma_{1L}\Gamma_{1R}\, e^{-2\gamma_1 l}}\, V_{10}(0) \\
V_{1R}(0) &= \frac{-\Gamma_{1R}\, e^{-\gamma_1 l}\left[1 - \Gamma_{1L}\right]}{1 - \Gamma_{1L}\Gamma_{1R}\, e^{-2\gamma_1 l}}\, V_{10}(l)
\end{aligned}\right\} \qquad \text{(B-1)}$$

Induced longitudinal voltage at the end farthest from the radio station:

$$\left.\begin{aligned}
V_1(l) &= V_{10}(l) + V_{1L}(l) + V_{1R}(l) \\
V_{10}(l) &= \frac{PE_V \cos\theta}{2}\, e^{-j\beta_0 \cos\theta l}\, \frac{1 - e^{-(\gamma_1 - j\beta_0\cos\theta) l}}{\gamma_1 - j\beta_0\cos\theta} \\
V_{1L}(l) &= \frac{-\Gamma_{1L}\, e^{-\gamma_1 l}\left[1 - \Gamma_{1R}\right]}{1 - \Gamma_{1L}\Gamma_{1R}\, e^{-2\gamma_1 l}}\, V_{10}(0) \\
V_{1R}(l) &= \frac{-\Gamma_{1R}\left[1 - \Gamma_{1L}\, e^{-2\gamma_1 l}\right]}{1 - \Gamma_{1L}\Gamma_{1R}\, e^{-2\gamma_1 l}}\, V_{10}(l)
\end{aligned}\right\} \quad \text{(B-2)}$$

where the constants and variables are as shown in Annex A.

B.2 *Telecommunication cables with metallic screen*

Induced longitudinal voltages at the ends of a telecommunication cable with a metallic screen are given by Equations (B-3) and (B-4)

Induced longitudinal voltage at the end nearest to the radio station:

$$\left.\begin{aligned}
V_2(0) &= V_{20}(0) + V_{2L}(0) + V_{2R}(0) \\
V_{20}(0) &= -\frac{PE_V(\cos\theta)\, Z_K}{4\, Z_{01}} \left[\left\{\frac{1}{\gamma_1 - j\beta_0\cos\theta} + \frac{1}{\gamma_1 + j\beta_0\cos\theta}\right\}\cdot\right. \\
&\quad \cdot \frac{1 - e^{-(\gamma_2 + j\beta_0\cos\theta) l}}{\gamma_2 + j\beta_0\cos\theta} + \left\{-\frac{1}{\gamma_1 - j\beta_0\cos\theta} + \frac{1}{1 - \Gamma_{1L}\Gamma_{1R}\, e^{-2\gamma_1 l}}\cdot\right. \\
&\quad \cdot \left(\Gamma_{1L}\, \frac{1 - e^{-(\gamma_1 + j\beta_0\cos\theta) l}}{\gamma_1 + j\beta_0\cos\theta} + \Gamma_{1L}\Gamma_{1R}\, e^{-j\beta_0\cos\theta l}\, e^{-\gamma_1 l}\,\cdot\right. \\
&\quad \left.\left.\cdot \frac{1 - e^{-(\gamma_1 - j\beta_0\cos\theta) l}}{\gamma_1 - j\beta_0\cos\theta}\right)\right\} \frac{1 - e^{-(\gamma_2 + \gamma_1) l}}{\gamma_2 + \gamma_1} + \left\{-\frac{e^{-(\gamma_1 + j\beta_0\cos\theta) l}}{\gamma_1 + j\beta_0\cos\theta} + \right. \\
&\quad + \frac{1}{1 - \Gamma_{1L}\Gamma_{1R}\, e^{-2\gamma_1 l}} \left(\Gamma_{1L}\Gamma_{1R}\, e^{-2\gamma_1 l}\, \frac{1 - e^{-(\gamma_1 + j\beta_0\cos\theta) l}}{\gamma_1 + j\beta_0\cos\theta} + \right. \\
&\quad \left.\left.\left. + \Gamma_{1R}\, e^{-j\beta_0(\cos\theta) l}\, e^{-\gamma_1 l}\, \frac{1 - e^{-(\gamma_1 - j\beta_0\cos\theta) l}}{\gamma_1 - j\beta_0\cos\theta}\right)\right\} \frac{1 - e^{-(\gamma_2 - \gamma_1) l}}{\gamma_2 - \gamma_1}\right] \\
V_{2L}(0) &= \frac{-\Gamma_{2L}\left[1 - \Gamma_{2R}\, e^{-2\gamma_2 l}\right]}{1 - \Gamma_{2L}\Gamma_{2R}\, e^{-2\gamma_2 l}}\, V_{20}(0) \\
V_{2R}(0) &= \frac{-\Gamma_{2R}\, e^{-\gamma_2 l}\left[1 - \Gamma_{2L}\right]}{1 - \Gamma_{2L}\Gamma_{2R}\, e^{-2\gamma_2 l}}\, V_{20}(l)
\end{aligned}\right\} \quad \text{(B-3)}$$

Induced longitudinal voltage at the end farthest from the radio station:

$$V_2(l) = V_{20}(l) + V_{2L}(l) + V_{2R}(l)$$

$$\begin{aligned}
V_{20}(l) = {} & \frac{PE_V \cos\theta\, Z_K}{4\, Z_{01}} \Bigg[\left\{ \frac{1}{\gamma_1 - j\beta_0 \cos\theta} + \frac{1}{\gamma_1 + j\beta_0 \cos\theta} \right\} \cdot \\
& \cdot \frac{1 - e^{-(\gamma_2 - j\beta_0 \cos\theta)\, l}}{\gamma_2 - j\beta_0 \cos\theta} e^{-j\beta_0 \cos\theta l} + \Bigg\{ - \frac{1}{\gamma_1 - j\beta_0 \cos\theta} + \\
& + \frac{1}{1 - \Gamma_{1L}\Gamma_{1R} e^{-2\gamma_1 l}} \left(\Gamma_{1L} \frac{1 - e^{-(\gamma_1 + j\beta_0 \cos\theta)\, l}}{\gamma_1 + j\beta_0 \cos\theta} + \Gamma_{1L}\Gamma_{1R} e^{-j\beta_0 \cos\theta l} \cdot \right. \\
& \left. \cdot\, e^{-\gamma_1 l} \frac{1 - e^{-(\gamma_1 - j\beta_0 \cos\theta)\, l}}{\gamma_1 - j\beta_0 \cos\theta} \right) \Bigg\} \frac{1 - e^{-(\gamma_2 - \gamma_1)\, l}}{\gamma_2 - \gamma_1} e^{-\gamma_1 l} + \\
& + \Bigg\{ - \frac{e^{-(\gamma_1 + j\beta_0 \cos\theta)\, l}}{\gamma_1 + j\beta_0 \cos\theta} + \frac{1}{1 - \Gamma_{1L}\Gamma_{1R} e^{-2\gamma_1 l}} \left(\Gamma_{1L}\Gamma_{1R}{}^{-2\gamma_1 l} \cdot \right. \\
& \left. \cdot \frac{1 - e^{-(\gamma_1 + j\beta_0 \cos\theta)\, l}}{\gamma_1 + j\beta_0 \cos\theta} + \Gamma_{1R} e^{-j\beta_0 \cos\theta l} e^{-\gamma_1 l} \frac{1 - e^{-(\gamma_1 - j\beta_0 \cos\theta)\, l}}{\gamma_1 - j\beta_0 \cos\theta} \right) \Bigg\} \cdot \\
& \cdot \frac{1 - e^{-(\gamma_2 + \gamma_1)\, l}}{\gamma_2 + \gamma_1} e^{\gamma_1 l} \Bigg]
\end{aligned}$$

$$V_{2L}(l) = \frac{-\Gamma_{2L} e^{-\gamma_2 l} \left[1 - \Gamma_{2R}\right]}{1 - \Gamma_{2L}\Gamma_{2R} e^{-2\gamma_2 l}} V_{20}(0)$$

$$V_{2R}(l) = \frac{-\Gamma_{2R} \left[1 - \Gamma_{2L} e^{-2\gamma_2 l}\right]}{1 - \Gamma_{2L}\Gamma_{2R} e^{-2\gamma_2 l}} V_{20}(l) \qquad \text{(B-4)}$$

where the constants and variables are as shown in Annex A.

ANNEX C

(to Recommendation K.18)

Errors involved in using simplified equation (2-1)

Simplified Equation (2-1) can be used when 3 dB/km $\leqslant \alpha_{20} \leqslant$ 30 dB/km, 1.2 $\beta_0 \leqslant \beta_2 \leqslant 3\,\beta_0$, 500 kHz $\leqslant f \leqslant$ 1.6 MHz, 10 mm $\leqslant d \leqslant$ 50 mm, 0° $\leqslant \theta \leqslant$ 90°, 0.1 mS/m $\leqslant \sigma \leqslant$ 500 mS/m and $-1 \leqslant \Gamma \leqslant 1$. Those conditions are likely to apply for overhead cables.

The error which arises from using Equation (2-1) instead of the more rigorous method described in Annex B depends on the values of σ and Γ, rather than other parameters. An example of this is shown in Figure C-1/K.18. The error is shown in Table C-1/K.18, corresponding to the (σ, Γ) range in Figure C-2/K.18. Here only the range of $\Gamma_1 \geqslant 0$ is considered, because $|Z_1| \leqslant Z_{01}$ can be realized easily. Range (I) in Figure C-2/K.18 is the usual case, while ranges (II) and (IV) are rare cases and range (III) is difficult to realize. In a range having a large error (for example, ranges II, III and IV), or when the cable length is too short to satisfy Equation (2-2), it is better to calculate by using the rigorous method of Annex B.

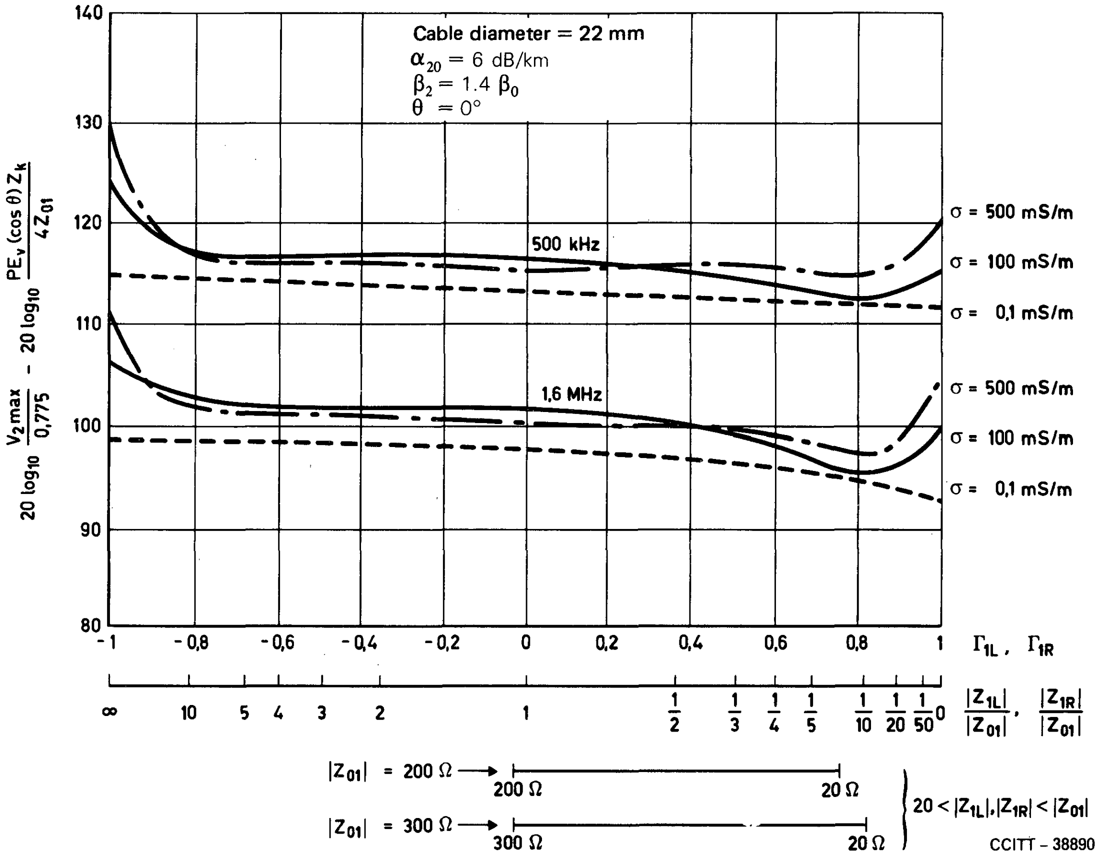


FIGURE C-1/K.18

Example of the relation between the induced longitudinal voltage and (σ, Γ)

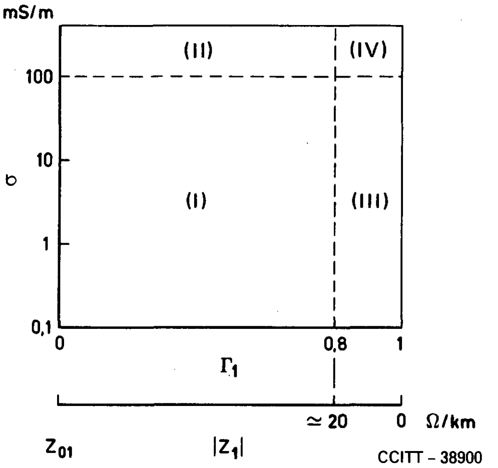


FIGURE C-2/K.18

Ranges of (σ, Γ)

TABLE C-1/K.18

The error in Equation (2-1) compared with results using the rigorous method of Annex B

Range	Error
(I) (usual case)	±5 dB
(II) (rare case)	±8 dB
(III) (rare case)	−5 + 15 dB
(IV) (rare case)	−5 +23 dB

ANNEX D

(to Recommendation K.18)

Effect of the environment of the telecommunication line on the measured radio-wave electric field

(Report from NTT)

The radio-wave electric field strength is not affected by the environment of the telecommunication line and may be taken to be the theoretically calculated value (see Figure D-1/K.18).

On the other hand, the radio-wave incidence angle to the telecommunication line may be influenced by a number of factors and it may be difficult to estimate a precise value. However, in open country, the measured incidence angle between the radio wave and the telecommunication line is in good agreement with the value calculated from the relative locations of the radio station and the telecommunication line (Figure D-2/K.18).

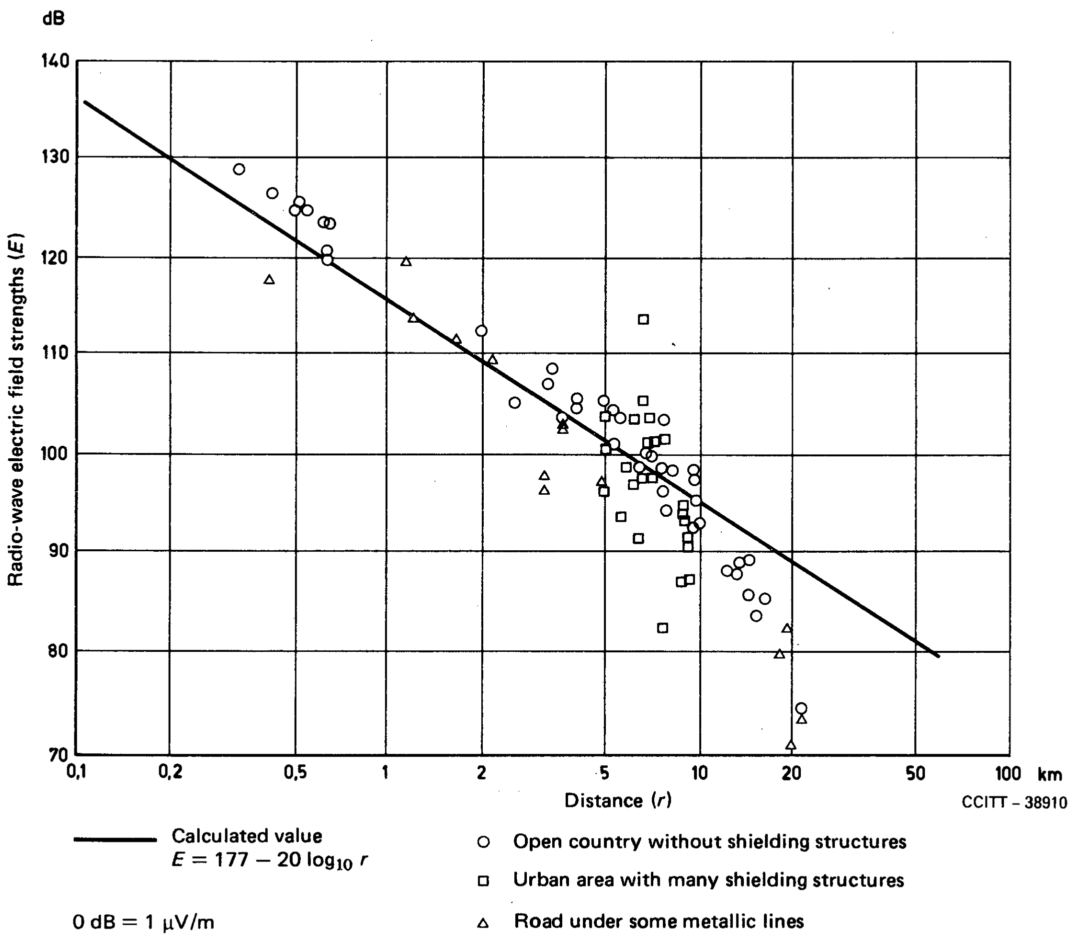


FIGURE D-1/K.18

Radio-wave electric field strength as a function of distance from radio station

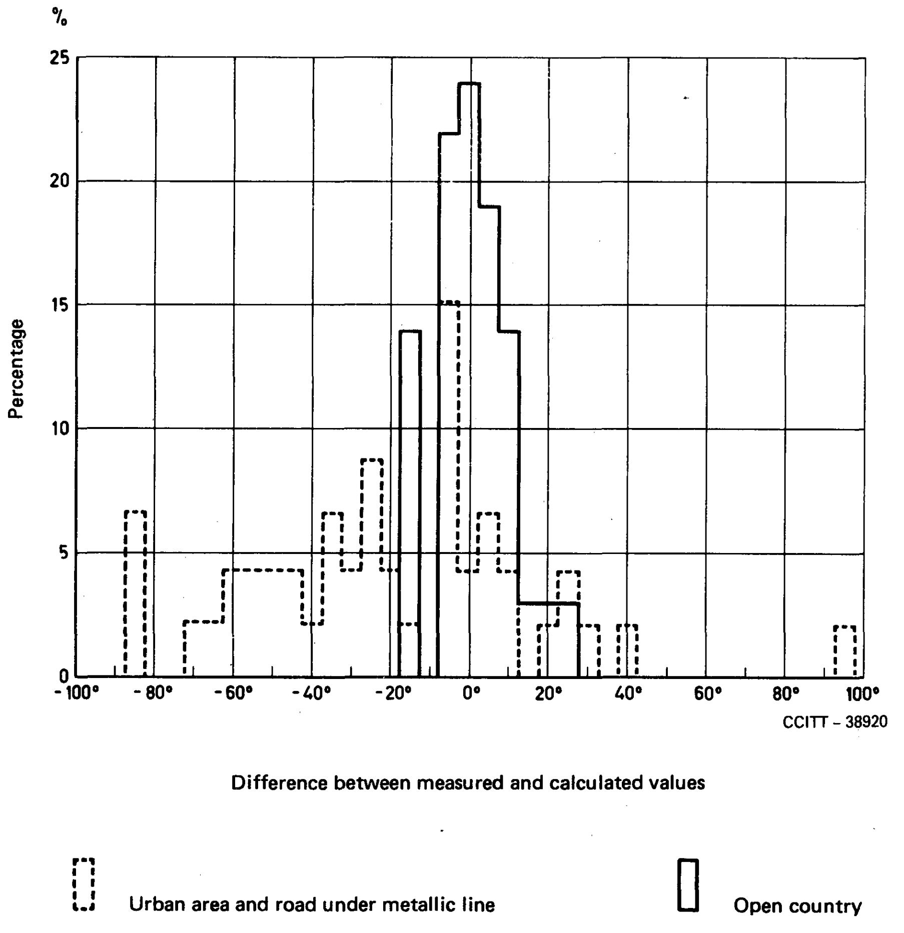


FIGURE D-2/K.18

Histogram of difference between measured and calculated radio-wave incidence angle to the telecommunication line

ANNEX E

(to Recommendation K.18)

Examples of ratio λ between induced longitudinal and transverse voltages

(Report from NTT)

Longitudinal and transverse (noise) voltages induced by radio wave on overhead cables were measured in fields.

Figure E-1/K.18 shows examples of λ obtained from measured longitudinal voltage V_2 and transverse voltage V ($\lambda = V - V_2$ dB).

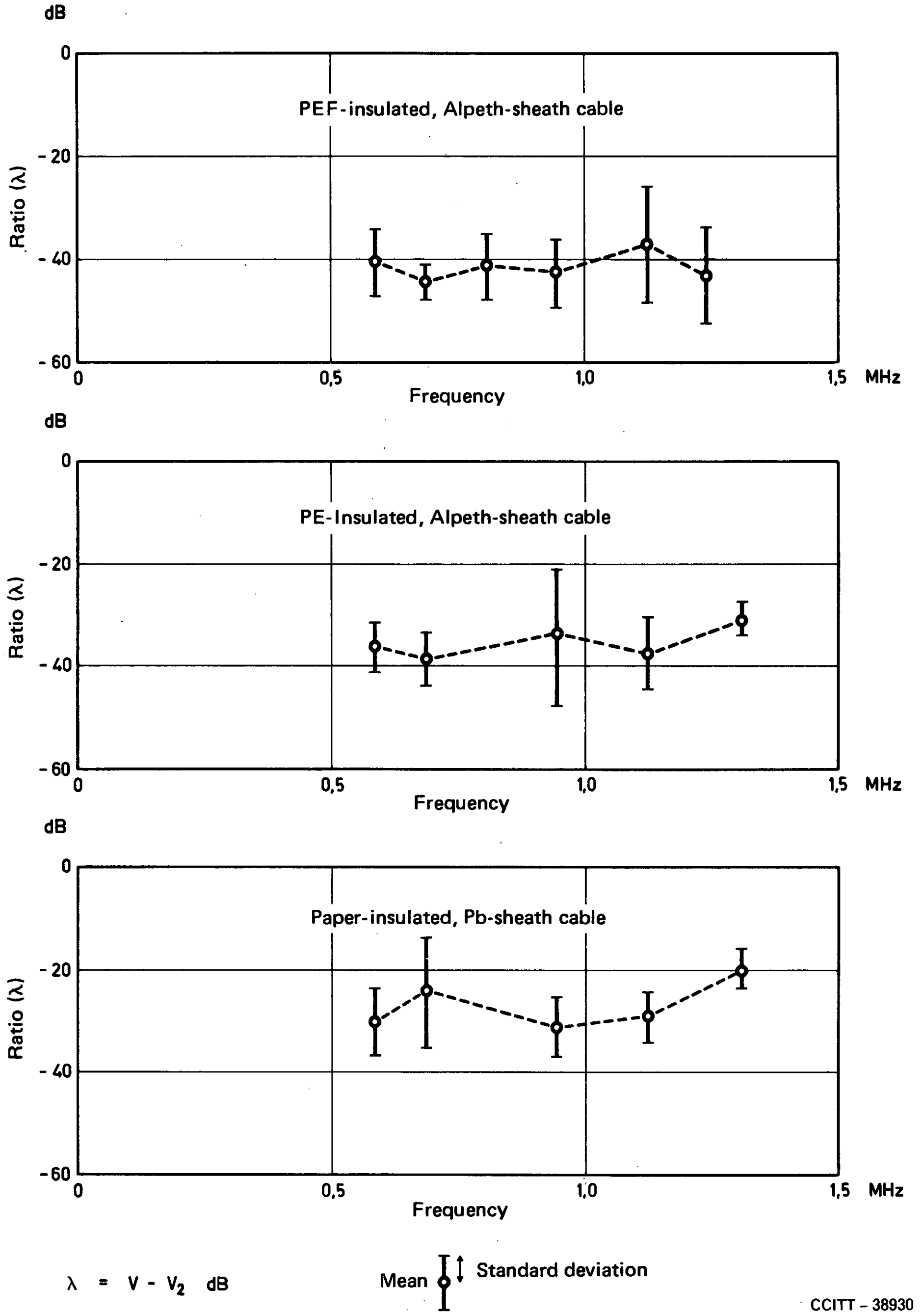


FIGURE E-1/K.18

Examples of the ratio, λ

ANNEX F

(to Recommendation K.18)

Examples of radio wave interference and countermeasures in various countries

(Based on the report by the Special Rapporteur, submitted to the 1978 Study Group V meeting)

Examples of radio-wave induction interference to telecommunication systems and some countermeasures have been collected and are summarized in Table F-1/K.18.

Radio-wave induction interference to circuits in buried or underground cables were found to be rare.

TABLE F-1/K.18

Radio-wave induction interference and countermeasures

Kind of circuits	Inducing radio wave		Affected area electric field intensity	Circuit condition related to interference	Interference	Countermeasure
	Frequency	Power				
Voice-frequency circuit	LF MF (mainly broad-casting)	Several tens of kW	Up to 5 km from radio station (several V/m)	– Overhead cable (plastic sheathed with and without metallic screen, lead sheathed) – Open wire	Demodulated intelligible noise from radio programme, at times unintelligi-ble	– Insertion of capacitors (at input terminals of telephone set) – Replacement by cable with metallic screen – Screening drop wire – Insertion of choke coil in circuit
High-frequency circuit e.g. carrier transmis-sion	LF MF Mainly MF	Several kW	– Up to several tens of km – In the case of subscriber carrier system interference up to nearly 1000 km has been reported. (0.03 to 1.8V/m)	– Mainly over-head cable with metallic screen (balanced pair, coaxial pair) – Cabling in building (between multiplex and antenna, between demodulation stages) – Open wire	Single tone or un-intelligible noise in demodulated telephone channel (degra-dation of SNR in transmission system)	– Improvement in shielding efficiency for cable, cabling, etc. – Improvement on earthing of cable sheath, repeater, ter-minal equipment, etc. – Adopt buried or underground cable – Adopt different cable route – Increase signal level, shortening repeater spacing – Compensation for pair conductor admittance unbalance with respect to earth
Radio frequency heating	MF (broad-casting)	–	Immediate vicinity of radio station antenna	– Open wire – Drop wire	Radio frequency burns	Capacitor insertion between conductors and earth

ANNEX G

(to Recommendation K.18)

Radio wave interference to repeater station coaxial cabling and countermeasures

G.1 *Affected transmission systems and interference*

Interference has been experienced in carrier transmission systems in repeater stations due to radio-emissions.

When the induced radio wave frequency falls within the transmission frequency band, it causes single tone or unintelligible noise in the demodulated telephone channel. The interference is caused by induced currents in the outer conductors or screens of the coaxial cables in the repeater station.

Interfering frequencies of radio waves are mainly medium frequency (MF) and high frequency (HF) (of the order of 1-15 MHz).

G.2 *Electric field strength*

Radio wave interference occurs when the electric field strength exceeds 100 dBμV/m outside the station building or 80 dBμV/m inside the station building.

The degree of attenuation provided by the building depends on the form of construction used. In the case of a concrete building, for example, the attenuation may be 20-30 dB, at 1-15 MHz.

The electric field in the building is not homogeneous, and large variations, of about 20-30 dB, have been observed.

G.3 *Countermeasures*

One of the most efficient protective measures is the improvement of screening for coaxial cables. The screening efficiency for a coaxial cable depends on its transfer impedance (Z_T), and adopting a coaxial cable with lower transfer impedance is useful. For example, μ-metal screened coaxial cable (e.g. $Z_T \approx 0.01$ mΩ/m at 1 MHz) and triple-braided (screened) coaxial cable (e.g. $Z_T \approx 0.1$ mΩ/m at 1 MHz) have been used. For example, a 15-20 dB reduction can be obtained by replacing a double-braided coaxial cable with a triple-braided one.

The use of a low transfer impedance connection between the station cable and the equipment and the provision of good earthing arrangements in the repeater station also give benefits.

References

[1] SATO (T.), NAKAHIRA (M.), KOJIMA (N.): Radio wave interference in overhead communication cables, *Proceedings of the 22nd IWCS*, 1973.

[2] SCHULZ (E.), VOGEL (W.): Beeinflussung von Trägerfrequenz-Nachrichtensystemen durch hochfrequente Beeinflussungsquellen, *ETZ-A*, Bd. 85, H. 20, 1964.

JOINT USE OF TRENCHES AND TUNNELS FOR TELECOMMUNICATION AND POWER CABLES

1 General

The joint use of trenches and tunnels for telecommunication and power cables may, under favourable conditions, offer the following advantages:

- the overall costs are reduced;
- available space for underground services is used more efficiently;
- there is a reduced amount of roadway surfacing work and consequently less delay to traffic;
- the separation of power and telecommunication cables is more precisely assured.

2 Electrical safety

If power and telecommunication cables are not easily distinguished from each other they should be clearly marked.

Power cables should generally be buried deeper than telecommunication cables.

Power and telecommunication cables should be separated by a suitable distance according to:

a) the voltage of the power cable;

b) the type of the power cable;

c) the type of the telecommunication cable;

d) the nature of the separating material.

The minimum distance is often stipulated in national standards.

Under the following circumstances national standards may allow reduced distances:

- the power cable having a concentric neutral operates at low voltage and the telecommunication cable has an earthed armouring, or
- the cables are separated by concrete fillings or similar material

If there is danger to staff doing manual excavation, high voltage power cables should be protected by covers of suitable material (brick, concrete, etc.).

3 Electromagnetic induction

In order to avoid inadmissibly high danger and interference to telecommunication cables from power cables the *Directives* must be observed. Such effects are especially to be expected when:

a) the power cable belongs to a network with a directly earthed neutral;

b) the individual phase conductors of the power line are run in separate cables (e.g. three-phase single-core cables); or

c) the currents in the power lines have a high harmonic content.

Danger and interference are not to be expected when:

- the power cable works under normal operational conditions, and in case of three-phase single-core cable the individual phase cables are properly arranged and transposed; or
- the length of the parallel running is relatively small (e.g. some hundred metres).

Proper arrangement and transposition of phase conductors of the power cable system are effective for reducing electromagnetic induction.

Other metallic conductors in the tunnel (e.g. pipe-lines, concrete reinforcements) have normally a reducing effect on the induced longitudinal voltages. The magnitude of this screening factor depends to a great extent on the arrangement of the various installations in the tunnel and on the construction of the tunnel and can, therefore, only be determined for each individual case.

4 Other dangers

The joint use of trenches and tunnels may increase the exposure of telecommunications staff to other dangers such as:

- striking power cables during excavation;
- access difficulties and isolation problems while working inside tunnels;
- explosions due to leakage from gas pipes if these are also present in jointly-used tunnels;
- foul air accumulations in tunnels.

Suitable safe working methods to overcome such dangers should be incorporated in the joint working agreement.

5 Practical limitations

The successful use of joint trenches and tunnels requires a disciplined cooperation by all parties concerned. The duties and responsibilities of each party should be precisely defined. Special measures may be necessary to overcome limitations of space underground and to facilitate subsequent maintenance of the cables, and such special measures need to be agreed before the joint construction work commences.

Recommendation K.20 (Malaga-Torremolinos, 1984)

RESISTIBILITY OF TELECOMMUNICATION SWITCHING EQUIPMENT TO OVERVOLTAGES AND OVERCURRENTS

1 General

This Recommendation seeks to establish fundamental testing methods and criteria for the resistibility of telecommunication switching equipment to overvoltages and overcurrents. It should be read in conjunction with the CCITT manual, *Protection of telecommunication lines and equipment against lightning discharges* and Recommendation K.11 which deals with the general economic and technical aspects of protection. The methods may be varied in the light of particular local circumstances and technical developments.

2 Scope

The Recommendation relates to telephone exchanges and similar telecommunication switching centres and is concerned mainly with test conditions to be applied to points intended for the connection of 2-wire subscriber lines. Ports carrying more complex circuits or more concentrated traffic (such as junctions or multi-channel circuits) may be tested either in accordance with this Recommendation or in accordance with other Recommendations such as K.15 and K.17, as considered appropriate.

The tests are type tests and, although they are applicable to a complete switching centre, it is recognized that they may be applied to individual items of equipment during development and design work. In making the tests, it is necessary to take account of any switching conditions, either in the unit under test or elsewhere, which may affect the results.

3 Overvoltages and overcurrent conditions

Aspects of overvoltage or overcurrent covered by this Recommendation are:

- surges due to lightning strokes on or near to the line plant; (equipment complying with this Recommendation may not necessarily resist severe direct lightning strokes);
- short-term induction of alternating voltages from adjacent power lines or railway systems, usually when these lines or systems develop faults;
- direct contacts between telecommunication lines and power lines, usually of a low voltage nature.

It is recognized that under some circumstances, problems may arise if overvoltages or overcurrents occur simultaneously on a number of lines and produce large currents in common wiring or components. Such conditions are not covered by this Recommendation. The aspects of rise of earth potential is not covered but is being studied in CCITT.

4 Levels of resistibility

4.1 Only two levels of resistibility are covered: a lower level suitable for unexposed environments where overvoltages and overcurrents are low, and a higher level for more exposed environments. Account is taken of the fact that in the more exposed environments, protection may be fitted on the main distribution frame (MDF) or elsewhere outside the equipment.

4.2 Extreme conditions are not covered. In very sheltered environments, it may be possible for equipment of lower resistibility than specified herein to operate satisfactorily. On the other hand, equipment with even higher resistibility than specified may be needed for exceptionally exposed environments. Equally, other combinations of equipment resistibility and external protection are possible. For example, certain equipment may require protection even in unexposed environments and other equipment may operate satisfactorily in exposed environments without external protection. Although only two categories of resistibility are described in this Recommendation, these cover a large proportion of present-day needs.

4.3 It is for Administrations to classify the environment of a particular switching centre, taking into account business policy, economic and technical considerations. Recommendation K.11 gives information to help in making this decision.

4.4 The test conditions and voltages of Table 1/K.20 reflect the conditions which are expected to occur on lines in unexposed environments.

4.5 The test conditions and voltages of Table 2/K.20 simulate the effects of an exposed environment on equipment protected by main distribution frame protectors and constitute additional requirements to ensure compatibility with external protection and proper functioning in the more severe environment. Higher voltages may well occur on the lines, but because the MDF protection operates, the effects on the equipment may not be more severe.

4.6 Equipment satisfying the requirements for an exposed environment may be used in either environment, but equipment satisfying only the requirements for an unexposed environment should be used only in an unexposed environment.

5 Exchange equipment boundary

The variations of different types of equipment make it necessary for each exchange to be seen as a "black-box" having three terminals, A, B and Earth. It is likely that some protective devices have already been provided in the equipment, either distributed on its line-cards, etc., or connected to its terminals. For the purpose of these tests, manufacturers are expected to define the boundaries of the "black-box" and any protective device which is included must be considered an immutable part of that exchange.

6 Test conditions

The following conditions apply to all the tests specified in § 8.

6.1 All tests are type tests.

6.2 The input terminals at which tests on the equipment are to be applied should be identified by the manufacturer and labelled A, B and Earth.

6.3 The equipment should be tested in any operating state of significant duration.

6.4 The equipment should be able to pass the tests in § 8 throughout the ranges of temperature and humidity of its intended use.

6.5 For tests in the "exposed" situation, it is current practice to protect subscribers' lines at the MDF with some surge protectors such as gas-discharge tubes. Recognizing that such a device is likely to be needed in most cases to handle high surge currents, and that the operation of these protectors exposes exchange switching equipment to other modified conditions, the characteristics of the external protectors to be used should be agreed between the equipment supplier and the Administration. Protectors having characteristics within the agreed range should be used where specified in Table 2/K.20. A new set of protectors may be used after the completion of each test sequence. Alternatively, some Administrations may choose to omit the external protectors but to modify the applied voltages and durations so that the conditions applied to the equipment are the same as could reasonably be expected to occur under the conditions of Table 2/K.20.

6.6 In all cases where a maximum voltage is specified, tests should also be made at lower voltages if this is necessary to confirm that the equipment will resist any voltage up to the maximum value specified.

6.7 Each test should be applied the number of times indicated in the relevant table. The time interval between applications should be 1 minute and, in the case of pulse tests, the polarity should be reversed between consecutive pulses.

6.8 Power induction and power contact tests should be made at the frequencies of the a.c. mains or electric railways used in the country of application.

7 Permitted malfunction or damage

Two levels of malfunction or damage are recognized:

Criterion A – Equipment shall withstand the test without damage or other disturbance (such as corruption of software or misoperation of fault-protection facilities) and shall operate properly within the specified limits after the test. (It is not required to operate correctly while the test condition is present.) If specifically permitted by the Administration, the test may cause the operation of fuses or other devices which have to be replaced or reset before normal operation is restored.

Criterion B – A fire hazard should not arise in the equipment as a result of the tests. Any damage or permanent malfunction occurring should be confined to a small number of external line interface circuits.

The conditions likely to give rise to Criterion B are considered to be so rare that complete protection against them is not economical.

8 Tests

8.1 *General*

The test circuits used for the three overvoltage or overcurrent situations are as follows:

- Figure 1/K.20: lightning surges;
- Figure 2/K.20: power induction;
- Figure 3/K.20: power contacts.

Note – Certain considerations which justify the test proposals are stated in Annex A to this Recommendation. The response of equipment to lightning surges may be modified by the input impedance of the equipment. To explain this effect, Annex A includes an example in which, for clarity, values are assigned to the input impedance so that instantaneous levels of voltage at different points in the circuit may be compared. These values are included for illustration only and do not form any part of this Recommendation.

8.2 *Unexposed environment*

Equipment for use without external protection in unexposed environments should be tested according to Table 1/K.20.

8.3 *Exposed environment*

Equipment for use in exposed environments should pass the tests described in Table 1/K.20 and also those in Table 2/K.20.

TABLE 1/K.20

Test conditions and voltages for unexposed environments

No.	Test	Between	Test circuit	Maximum Test voltage and duration	Number of tests	Acceptance criteria
1	Lightning surge simulation	A and E with B earthed	Figure 1a)/K.20	$U_{c\ (max)} = 1$ kV See Note 1	10	§ 7, Criterion A
		B and E with A earthed	Figure 1a)/K.20	$U_{c\ (max)} = 1$ kV See Note 1	10	
		A + B and E	Figure 1b)/K.20	$U_{c\ (max)} = 1$ kV See Note 1	10	
2	Power induction	A + B and E	Figure 2/K.20 $R_1 = R_2 = 600\ \Omega$ S_2 unoperated Tests made with and without S_1 operated	$U_{ac\ (max)} = 300\ V_{rms}$ 200 ms See Note 2	5 for each position of S_1	§ 7, Criterion A
3	Power contact	A + B and E	Figure 3/K.20 Tests are made with switch S in each position. See Note 3	$U_{ac\ (max)} = 220\ V_{rms}$ 15 min See Note 2	1 for each position of S	§ 7, Criterion B

Note 1 – Administrations may specify a lower value of $U_{c\ (max)}$.

Note 2 – Administrations may specify lower values of $U_{ac\ (max)}$ and may vary the duration of the test to meet their local requirements (e.g. local mains voltage).

Note 3 – Heat coils, fuses, fuse cables, etc. may be left in circuit during these tests.

TABLE 2/K.20

Test conditions and voltages for exposed environments

No.	Test	Between	Test circuit	Maximum test voltage and duration	Number of tests	Added protection (see § 6.5)	Acceptance criteria
1	Lightning surge simulation	A and E with B earthed	Figure 1a)/K.20	$U_{c\,(max)} = 1$ kV Se Note 1	10	None	§ 7, Criterion A
		B and E with A earthed	Figure 1a)/K.20	$U_{c\,(max)} = 1$ kV See Note 1	10	None	
		A + B and E	Figure 1b)/K.20	$U_{c\,(max)} = 1$ kV See Note 1	10	None	
2	Lightning surge simulation	A and E with B earthed	Figure 1b)/K.20	$U_{c\,(max)} = 4$ kV See Note 2	10	Agreed primary protection	§ 7, Criterion A
		B and E with A earthed	Figure 1a)/K.20	$U_{c\,(max)} = 4$ kV See Note 2	10	Agreed primary protection	
		A + B and E	Figure 1b)/K.20	$U_{c\,(max)} = 4$ kV See Note 2	10	Agreed primary protection	
3 (a)	Power induction	A + B and E	Figure 2/K.20 $R_1 = R_2 = 600\ \Omega$ S_2 operated	$U_{ac\,(max)} = 300\ V_{rms}$ 200 ms See Note 3	5	Agreed primary protection	§ 7, Criterion A
3 (b)	Power induction	A + B and E	Figure 2/K.20 $R_1 = R_2 = 200\ \Omega$ S_2 operated	See Note 4	1	Agreed primary protection	§ 7, Criterion B

Note 1 – Where the maximum impulse spark-over voltage of the agreed primary protection is less than 1 kV then Administrations may choose to reduce $U_{c\,(max)}$.

Note 2 – Administrations may vary $U_{c\,(max)}$ to meet their local requirements.

Note 3 – Administrations may lower values of U_{ac} and vary the period of application.

Note 4 – Voltages and durations should be in accordance with CCITT Directives or such other limits as Administrations may set.

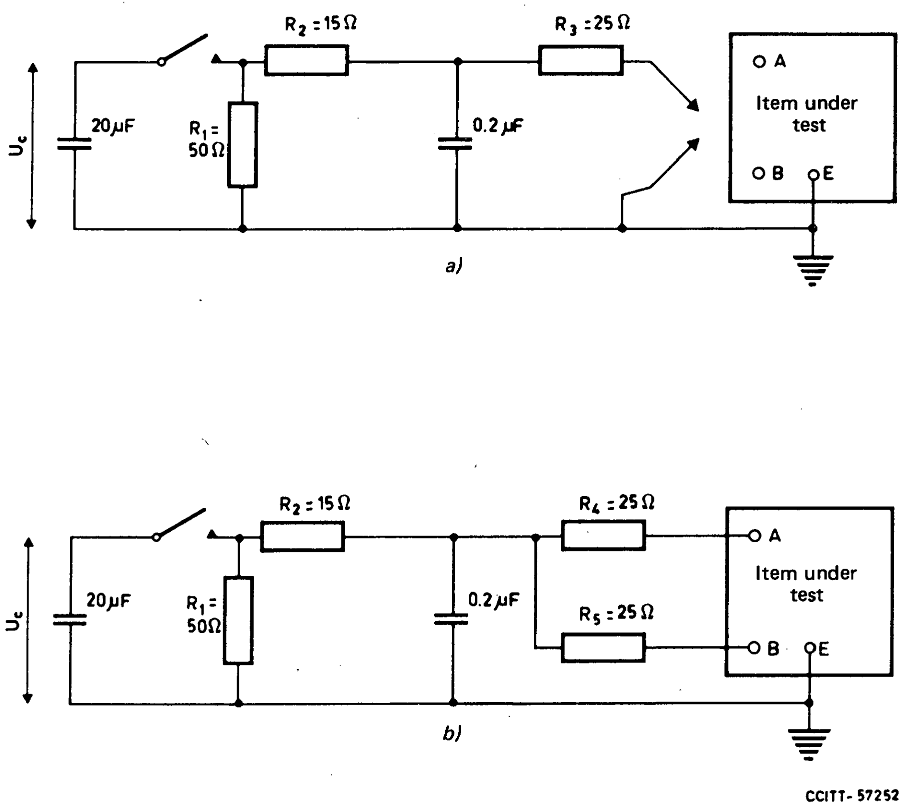


FIGURE 1/K.20

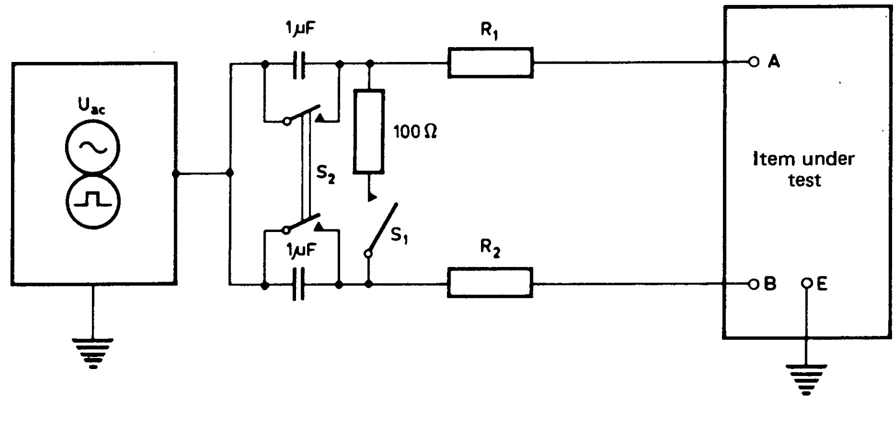


FIGURE 2/K.20

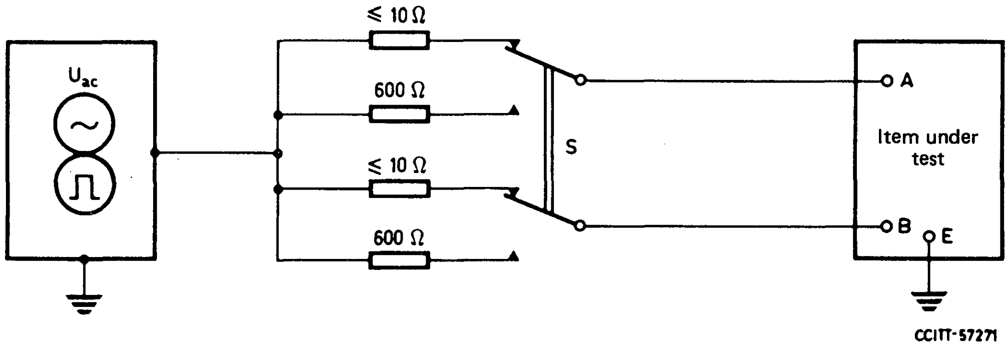


FIGURE 3/K.20

ANNEX A

(to Recommendation K.20)

Explanations which illustrate test conditions

A.1 *Lightning surges*

A.1.1 *Operation of simulation circuit*

Figure A-1/K.20 shows the test generator of Figure 1/K.20 connected to an example of an exchange circuit with primary protection provided at the MDF and secondary protection in the exchange equipment itself. Apart from the test generator of Figure 1/K.20, all the circuit layout and component values have been chosen purely for explanatory purposes and are not put forward as some recommended practice.

When the charging voltage, U_c, is progressively raised, the voltages and currents which occur at various points in the circuit of Figure A-1/K.20 are shown on the graph in Figure A-2/K.20.

For U_c = 0-300 V, the current flows only through the 100 Ω resistor in the equipment.

At U_c = 300 V, the secondary protection operates and the current I_T rises more rapidly.

At U_c = 2385 V, the voltage U across the primary protection reaches U_s=700 V in the case illustrated, and I_E reaches its maximum value of 3 A.

The primary protection operates when U_c = 2385 V and the total current thereafter rises still more rapidly, reaching 100 A when U_c = 4 kV. The voltage U however drops to a low value and the current I_E flowing into the equipment falls to a very low value and becomes practically independent of U_c.

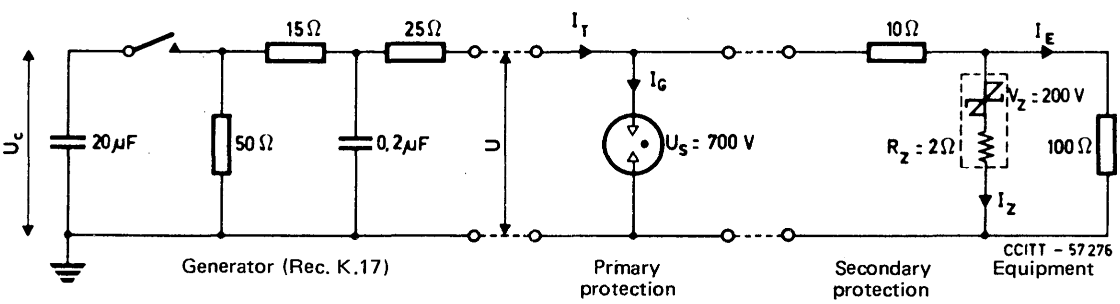
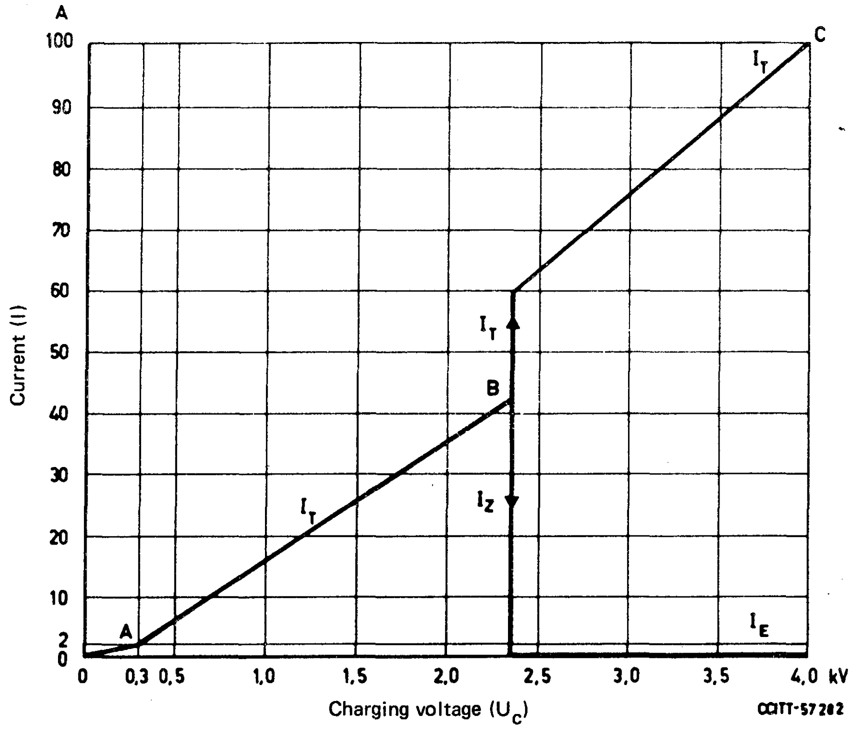


FIGURE A-1/K.20



The voltage and current values along the graph are as follows:

Point on graph	U_C (V)	U (V)	I_T (A)	I_G (A)	I_Z (A)	I_E (A)
A : Secondary protection operates	300	200	2	0	0	2
B : Before GDT strikes	2385	700	42	0	39	3
B : After GDT strikes	2385	30	59	59	0	0.3
C : Maximum U_C	4000	30	100	100	0	0.3

FIGURE A-2/K.20

A.1.2 *Effect of protective devices*

Operation of the primary protection when $U = U_s$ therefore has two effects:

- it limits the maximum voltage applied to the equipment and hence, depending on the internal impedance of the equipment, the maximum current which the equipment must withstand;
- it produces a very rapid change in U and I which, by inductive or capacitive effects can reach sensitive parts of the exchange switching equipment not apparently exposed to line voltages.

For these reasons it is important that the Administration and equipment suppliers should agree on the primary protection which should be used and for the equipment user to provide or simulate this protection when tests are made. The tolerances allowed for such protection components should be taken into account when tests are made.

A.2 *Power induction*

Induced voltages are likely to occur more on long lines, and in the general case where subscribers' lines do not provide a low resistance earth, induced voltages may be considered to have a high source impedance consisting of a 600 Ω wire resistance in series with 1 µF line to earth capacitance as shown in Figure A-3/K.20. Tests 3(a) and 3(b) of Table 2/K.20 represent typical requirements for long and short lines respectively but they do not necessarily provide for limiting conditions. The gas discharge tube shown in Figure A-3/K.20 only exists on exposed lines. Such tubes are represented by S_2 in Figure 2/K.20 and the telephone is represented by S_1.

CCITT Directives admit induced voltages up to 430 V from normal power lines and 650 V from high-security lines, but most Administrations expect voltages to be below 300 V except on the lines in exposed environments.

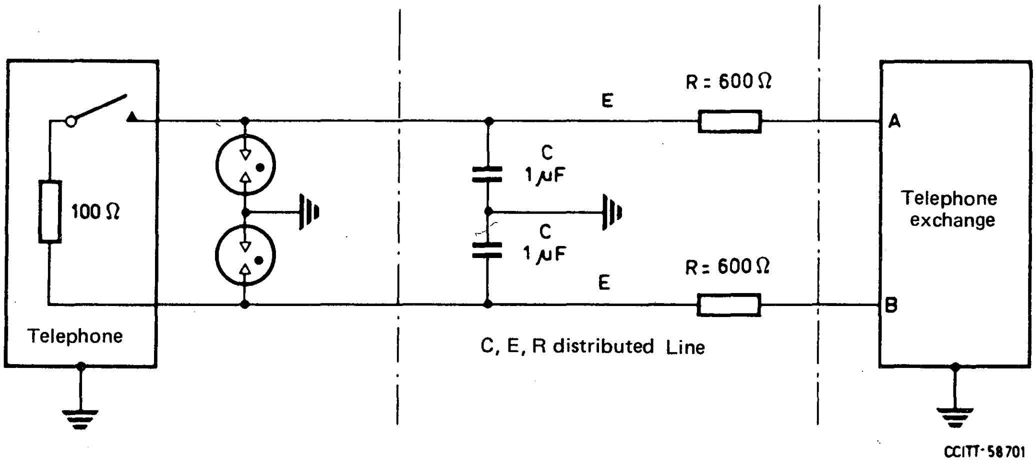


FIGURE A-3/K.20

A.3 *Power contacts*

Direct contact with electrical mains power can occur through network line or cable faults, faulty or unapproved subscriber equipment or other causes. The contact may not cause the operation of a power system circuit-breaker. A.c. currents resulting from a direct contact may make effective protection both difficult and expensive. As such events are rare, equipment is not required to withstand overvoltages or overcurrents arising from direct contacts but may fail in an acceptable manner.

Two particular dangers to equipment may arise:

– a contact near to an exchange where the combined impedance of the cable circuit and exchange termination is low and a high current flow occurs. This condition is simulated by the test in Figure A-4/K.20 by applying 220 V through an impedance of 10 Ω;

– a contact at the maximum distance from an exchange where the combined impedance of the cable circuit and exchange termination is high and a small but harmful current flows continuously. This condition is simulated by the test in Figure A-4/K.20 by applying 220 V through an impedance of 600 Ω.

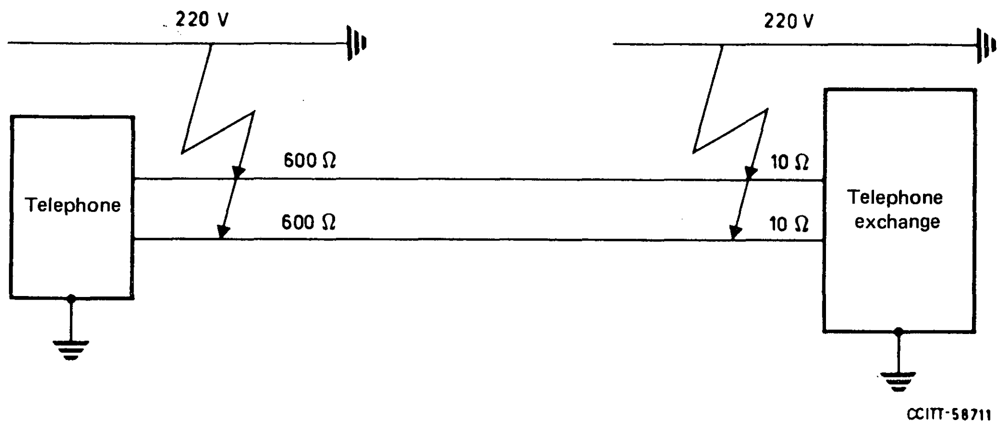


FIGURE A-4/K.20

PART II

Series L Recommendations

CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Recommendation L.1

PROTECTION AGAINST CORROSION

The CCITT,

considering

(a) that the location of faults on underground cables and the repair of these faults can entail great expense,

(b) that the interruptions to service likely to be caused by the occurrence of these faults must be avoided with the greatest care,

(c) that even after a repair has been made as expertly as possible, the quality of the cable may be lessened and its normal life reduced,

unanimously recommends

that, when cables are laid, Administrations will find it in their interest to comply with the CCITT *Recommendations concerning the construction, installation and protection of telecommunication cables in public networks*, ITU, Geneva, revision 1974, amendments and additions, 1977.

Recommendation L.2

IMPREGNATION OF WOODEN POLES

The CCITT draws attention to the economic importance of impregnating the wooden poles carrying overhead telecommunication lines.

The CCITT has issued a manual entitled *The preservation of wooden poles carrying overhead telecommunication lines*, ITU, Geneva, 1974, with a view to providing Administrations, particularly those whose networks are not yet fully developed, with some information on impregnation processes.

This manual is based on a first draft drawn up in 1968-1972 by the Argentine Administration amended and completed on the basis of information supplied by the Administrations of Australia, Austria, Chile, France, Italy, Federal Republic of Germany, United Kingdom and Switzerland.

Recommendation L.3 (Mar del Plata, 1968)

ARMOURING OF CABLES

1 Type of armouring

1.1 The most common forms of armouring are:

a) *Tape armouring* – This consists of overlapping steel tape or tapes, applied in helical form with a short lay, over the cable sheath.

b) *Wire armouring* – This is formed from round, flat or trapezoidal steel wires applied helically around the cable sheath with a relatively long lay.

1.2 These two types of armouring are used in combination with other protective layers (jute, plastic) for constructional or mechanical reasons, or for protection against corrosion.

2 Choice of armouring

In deciding whether or not to use armouring and in choosing between the various types of construction, very careful consideration should be given to the local conditions of installation, such as:

a) whether the cables are laid in duct or direct in the soil;

b) whether the cables are laid in a trench alongside a road or on private land;

c) what material is used for the cable sheath;

d) whether other cables are or may be laid along the same run;

e) the nature of the soil: rocky, sandy, corrosive or not; presence of micro-organisms;

f) the depth of the trench, which in any case should not be less than 50 cm, and for large cables 80 cm;

g) the risk of induction;

h) the risk of attack by rodents or insects;

i) the degree of exposure to lightning;

j) whether the size and importance of the link justifies special precautions, in which case steel-wire armouring provides additional protection, particularly in manholes;

k) whether a long draw-in is required, e.g. crossings under rivers (as cases of this are infrequent, no need is envisaged for a new design of land cable incorporating a central strain wire).

3 Protection provided

With cables laid directly in the soil, armouring contributes to safe installation and reliability of operation by ensuring protection of the cables against:

a) mechanical damage caused by stones and excavation equipment or tools;

b) rodents and insects;

c) chemical or electrolytic corrosion;

d) effects of atmospheric discharges;

e) induction phenomena due to the proximity of power lines.

4 Tape armouring

Tape armouring is to be preferred for protection against damage by pointed digging tools, sharp stones, etc. It is also useful for providing magnetic screening for circuits within the cable, for which wire armouring is much less effective, because the air gaps between the individual steel wires, which are arranged circumferentially around the cable, greatly reduce the magnetic coupling between the armoured sheath and the conductors within the cable.

5 Wire armouring

Wire armouring gives considerable additional tensile strength to a cable and is useful where pulling-in stresses are high (long draw-in) or where high stresses arise from conditions of use, for example where there is ground subsidence in mining districts and where cables are run in water and bogs or in shafts leading to deep level locations.

6 General type of armouring

For cables with a metallic sheath of lead or aluminium, the type of armouring in most common use consists of two helical windings of steel tape between layers of impregnated paper and jute with an external protection of jute yarn or other fibre. This type of armouring ensures good protection in all five cases listed in § 3 above.

For plastic-sheathed cables, a light armouring may be used, formed of metallic tapes (steel, aluminium or copper) between two coverings of plastic material (polyethylene or PVC). Cables of this design are protected chiefly against the hazards mentioned in 3b) and 3c) above and to a certain extent against hazards 3a) and 3d) above.

7 Armouring for main cables

The major cables in a long-distance network are certainly best protected by a watertight metallic sheath and the conventional armouring described above but the price of such protection is relatively high.

The cost of cables can be reduced by using a thin welded-steel sheath protected against corrosion by a bituminous compound and a plastic covering. This protects the cable, though to a lesser degree, against hazards 3a), b), c), d) above; some protection against induction may be obtained by inserting conductor elements or copper or aluminium bonds under the steel sheath.

8 Cables in ducts

Experience shows that symmetric pair, coaxial pair or composite cables without armouring of any kind can be drawn into ducts in lengths of up to 300 metres, provided that the tensile stress is spread between the conductors and the components of the sheath. Thus, the steel-wire armouring formerly used may be dispensed with, except in certain special cases (important links, long draw-in, for example river crossings).

9 Corrosion considerations – cables with metal sheaths

Both tape and wire armouring are useful in mitigating corrosion attack; largely because they tend to keep the impregnated coverings lying beneath them in good order and so safeguard the metal sheath from the effects of differential aeration, etc.

10 Rodents and insects

Damage from rodents tends to be rather high in some areas; either tape or wire armouring will provide a safeguard, but this is an expensive method and the CCITT is studying the possibilities of some form of cheaper sandwich construction, say polyethylene – thin aluminium – coated steel – polyethylene. Insects might penetrate the outer layer, but would then come up against the metal. Assuming this stopped them, the metal would probably later fail by corrosion, but this would be of little importance if the metal were bonded to the inner and outer polyethylene tubes. Besides providing protection against most rodents and insects, such a type of construction might provide some measure of extra strength relatively cheaply.

11 Tropical countries

In tropical countries special attention must be paid to §§ 6 and 7 above and to the danger from micro-organisms.

In general, it is safe to dispense with armouring only when:

- cable is laid in duct;
- no magnetic screening is required, or where this is provided by some other metallic layer included for the purpose;
- when there is no risk of corrosion or where corrosion protection is provided by some other layer included for this purpose;
- in the case of directly buried cables, where the soil is homogeneous and contains no flints or rocks likely to damage the cable, and where there is no danger of damage by rodents and insects.

However, special local conditions may still make armouring necessary, even in the above cases.

Recommendation L.4 (Geneva, 1972, modified Geneva, 1976, and Malaga-Torremolinos, 1984)

ALUMINIUM CABLE SHEATHS

1 General

Because of the technological progress made in the use of aluminium, aluminium cable sheaths are being used on an increasing scale and their favourable characteristics can now be fully exploited.

These characteristics include:

- low density (almost a quarter that of lead);
- much higher mechanical strength than lead, so that the sheath is lighter not only because aluminium is lighter than lead, but because the thickness may be less than for lead;
- very high resistance to vibration;
- high conductivity, so that a better screening factor and more effective protection from overvoltages of atmospheric origin can be obtained.

It is now found that the stiffness of an aluminium sheath does not give rise to any additional serious problems during laying.

However, because aluminium is more vulnerable than lead to electrochemical and electrolytic corrosive action, aluminium cable sheaths and the joints between individual factory lengths (jointing sleeves and adjacent sections of cable) require a Class II (see [1]) outer protective covering of plastic material.

As can be seen from the foregoing, an aluminium sheath has many advantages over a lead sheath. The generalized use of aluminium for sheathing cables is therefore desirable, at least whenever cable costs would not be increased compared with the use of lead, and also whenever aluminium sheaths satisfy the technical requirements to a greater extent. The use of cables with aluminium sheaths is particularly interesting in the case of trunk cables.

2 Types of aluminium sheath

2.1 *Extruded sheaths*

This type of sheath is obtained by extruding the aluminium directly around the cable core. The press may be of the *continuous* type or not. If it is not continuous, care must be taken to ensure that no problems are caused in the zones affected by the intermittent nature of the process.

2.2 *Welded sheaths*

This type of sheath is made by applying around the cable core an aluminium strip which is longitudinally welded.

2.3 *Quality of sheath material*

In order to make the means of protection against corrosion effective, great care has to be taken concerning the quality of the sheath. In case pure aluminium is used, the purity of aluminium for the sheath should not be lower than 99.5% grade, for both the extruded sheath or the welded sheath.

2.4 *Choice of sheath shape and thickness*

After the sheath has been extruded or welded it may either be shrunk on to the cable core (noncorrugated sheath) or corrugated by a variety of methods (corrugated sheath).

The sheath may be corrugated or noncorrugated, depending on the diameter of the cable core, the minimum radius of curvature during laying and on the mechanical characteristics of the aluminium used (see [2]). As a rough guide it can be stated that the sheath should be corrugated in the case of cables of more than 40-mm core diameter.

As stated in § 1 above the thickness of the metal used for aluminium sheaths is usually less than for lead sheaths.

The thicknesses given in Table 1/L.4 are suggested although the values given in this table apply to both extruded and welded sheaths; however, extruded sheaths may not be less than 0.9 mm and welded sheaths may not be more than 1.4 mm, that being the maximum thickness which can be welded by existing methods.

The use of lesser thicknesses than those indicated in Table 1/L.4 is not excluded and, conversely, in the case of coaxial cables without armouring, the thickness of metal for all sheaths may have to be increased to improve mechanical protection. The increase in the thickness may be as much as approximately 0.3 mm.

Values different from those given in Table 1/L.4 may, of course, be adopted in certain cases (for example, if extremely favourable screening factors are required).

TABLE 1/L.4

Suggested thickness

Core diameter (mm)		Metal thickness (mm)	
Minimum	Maximum	Noncorrugated sheaths	Corrugated sheaths [a)]
–	10	0.7 to 1.0	0.5 to 0.9
10	15	0.7 to 1.0	0.6 to 0.9
15	20	0.9 to 1.0	0.7 to 0.9
20	25	1.1	0.8 to 0.9
25	30	1.1 to 1.2	0.9
30	35	1.1 to 1.3	0.9 to 1.0
35	40	1.1 to 1.4	1.1
40	45	1.5	1.1 to 1.2
45	50	1.6	1.1 to 1.2
50	60		1.1 to 1.3
60	70		1.1 to 1.4
70	80		1.3 to 1.5

a) If it is intended to obtain approximately the same screening factor with a corrugated sheath as with a noncorrugated one, the thickness should be the same as with a noncorrugated sheath.

3 Protective coverings

As stated above, since aluminium used in an underground environment is more liable to corrosion than lead, an impermeable (Class II) covering should be provided in accordance with reference [1] to ensure the protection of the cable sheath and the jointing sections of individual factory lengths of cable (jointing sleeves and adjacent sections of cable).

Two types of plastic material can be used at present for protective coverings:

a) polyvinylchloride (PVC);

b) polyethylene.

Polyethylene is preferable since its general characteristics and its low permeability for water vapour give better protection to the aluminium.

To ensure that moisture which may have penetrated the protective covering (for example, because of a defect in the covering) does not spread along the surface of the sheath, extending the areas of corrosion, it is essential to apply a leakproof layer consisting of an adhesive tape or a suitable mixture.

The leakproof layer must adhere well to the aluminium, especially when PVC is used for the covering, since this material, unlike polyethylene, does not cling tightly to the sheath after extrusion.

The protective covering on the aluminium sheath should be sound. One form of test with the cable on the drum is to measure the insulation resistance of the covering.

In the case of corrugated sheaths, the bituminous mixture must fill the corrugations sufficiently to allow complete contact with the outer covering.

Special tests should be made of the efficiency of the leakproof layer. A common test consists in removing a part of the protective covering from a sample of the aluminium sheath and submitting it to electrolytic attack using an outside source of e.m.f. After some time, a check must be made to see whether the corrosion is confined to the place from which the protective covering was removed. The effectiveness of the protective covering can be assessed by means of a test to check the adhesion of the bituminous compound to both the aluminium sheath and the plastic covering.

To ensure the permanent effectiveness of the protective covering when cables are laid in areas exposed to lightning discharges (in particular as concerns avoiding perforations due to lightning discharges) the indications given in the manual cited in [3] should be taken into account.

4 Jointing of aluminium sheaths

Jointing is undoubtedly a more difficult operation for aluminium than for lead sheaths, although these difficulties have been minimized by improved techniques.

There are several methods of jointing aluminium sheaths:

- jointing by means of lead sleeves;
- jointing by means of lead rings or cones which are plumbed using a normal method or fixed with special glue to the aluminium sheath to permit subsequent soldering to lead sleeves;
- jointing by means of aluminium sleeves joined to the aluminium sheath by pressure welding (explosion, pressure or cold welding);
- other methods including the use of adhesive tapes and epoxy pastes.

The methods used for the jointing of aluminium sheaths must meet the conditions recommended in the booklet cited in [4].

For an aluminium-sheathed cable subjected to significant temperature variations, tensions due to cable contraction should not be borne by the joints as this can lead to joint failure, particularly with noncorrugated sheaths.

5 Cathodic protection

The corrosion protection should primarily depend on the anti-corrosive protective coverings. In order to take care of possible defects or faults of these coverings, cathodic protection may also be used as a supplementary measure.

References

[1] CCITT *Recommendations concerning the construction, installation and protection of telecommunication cables in public networks*, § 6.3, ITU, Geneva, revision 1974, amendments and additions, 1977.

[2] *Ibid.*, § 5.4.4.

[3] CCITT manual *The protection of telecommunication lines and equipment against lightning discharges*, ITU, Geneva, 1974, 1978.

[4] CCITT manual *Jointing of plastic-sheathed cables*, ITU, Geneva, 1978.

Recommendation L.5 (Geneva, 1972)

CABLE SHEATHS MADE OF METALS OTHER THAN LEAD OR ALUMINIUM

1 Types of metallic-sheathed cables

1.1 The most common form of metallic sheath used as an alternative to a lead or aluminium sheath is one of corrugated steel. This consists of a long steel strip, shaped into a tube round the cable core, welded by a suitable process (inert-gas arc, mains frequency or high frequency heating) along the longitudinal seam and then corrugated. Outer protection for the steel sheath is provided by means of a special viscous, anti-corrosion compound enclosing one or more plastic tapes and laid so that the troughs of the corrugations are completely filled. An external plastic covering is then extruded over the compound-protected steel to form a smooth outer covering.

1.2 For protection against induced currents the cable described in § 1.1 above may be used with aluminium or copper tapes laid longitudinally or helically beneath the corrugated steel sheath. Alternatively, a corrugated-copper sheath can be used in place of the corrugated-steel sheath.

2 Construction

2.1 The metallic strip is shaped into a long tube round the cable core, welded along the longitudinal seam and then corrugated.

2.2 Unprotected steel is particularly vulnerable to corrosion attack and the protection provided usually consists of a layer of compound in which may be embedded plastic tapes so that the corrugations are completely filled. An outer sheath of polyethylene or similar Class II covering (see reference [1]) is then extruded over the compound.

2.3 Armouring of the cable is not normally necessary, but may be provided in special cases.

3 Uses

Corrugated steel- or copper-sheathed cables may be used for all types of telecommunication cable and the following are the main considerations influencing their use:

a) taking all factors into consideration (laying costs, duct space, cable cost, for example), and although the total diameter of the cable is greater than in the case of plastic, lead or noncorrugated-aluminium sheathed cables, telecommunication cables with steel sheaths may be more economical than lead-covered cables;

b) a steel sheath is not vulnerable to vibration caused by road or rail traffic;

c) a corrugated metal sheath has good flexibility;

d) a corrugated metal sheath with a smooth outer covering is easy to handle during installation;

e) the same type of cable can be laid direct in the ground or pulled into ducts;

f) such a sheath resists moderate crushing stresses and provides protection against most of the damage caused by stones or digging tools;

g) if the plastic covering of steel-sheathed cables is damaged, rapid corrosion may be expected.

Reference

[1] CCITT *Recommendations concerning the construction, installation and protection of telecommunication cables in public networks*, § 6.3, ITU, Geneva, revision 1974, amendments and additions, 1977.

Recommendation L.6 (Geneva, 1972)

METHODS OF KEEPING CABLES UNDER GAS PRESSURE

The CCITT draws attention to the improvements in service made possible by protecting telecommunication cables against the ingress of moisture when the sheath is perforated or damaged. To ensure that the circuits remain free of interruption until repairs can be completed, the CCITT recommends that Administrations recognize the utility of following the advice given in the manual *Protection of telecommunication cables by pressurization*, ITU, Geneva, 1970.

Recommendation L.7 (Geneva, 1976)

APPLICATION OF JOINT CATHODIC PROTECTION

1 General

By joint cathodic protection of several underground metallic structures is meant corrosion protection of these structures by means of common protective devices.

A joint protection system for several underground metallic structures is composed of electrical bonds between the structures and of common protective devices complying with cathodic protection and electrical drainage requirements.

Joint protection techniques enhance the reliability of buried structures, improve efficiency of cathodic protection devices and also reduce total investment and maintenance costs of the protective system.

2 Conditions for application of joint cathodic protection

It is practicable to apply joint cathodic protection of underground metallic plant when several different structures approach or cross each other and when it is necessary to avoid the harmful effects of the protected structure on neighbouring unprotected structures, provided that it is economical and there is no better means to avoid this influence. The harmful influence of cathodic polarization or protected plant on the neighbouring metallic structures occurs when:

a) measured potentials are lower or higher than the values recommended;

b) the danger of corrosion on neighbouring underground metallic structures is increased.

Joint protection of telecommunication cables with other structures can be reasonably applied in the cases when:

a) nearby underground structures are at a distance generally not exceeding 50 metres;

b) the buried plants cross each other;

c) the ground beds or reactive anodes of a cathodic protection system have a harmful influence on nearby unprotected plants.

Joint protection of telecommunications and power cables in accordance with reference [1] may be considered when the potential to earth of the telecommunications cable does not exceed the safe voltage required by local or national safety rules in the event of an earth fault or short circuit on the power supply system.

Joint cathodic protection should provide on the protected plants potentials which are within the values indicated in reference [1].

In the case of joint protection it may be possible to use devices which automatically control the current output of the cathodic protection equipment.

3 Conditions for electrical bonds

Special bonds are used to provide electric contact between jointly protected plants. Bonds may be direct, or provided with a resistor (to limit the current) or polarized.

Direct bonds may be used in the following cases:

a) when underground metallic structures of the same type are crossing or approaching each other;

b) when the provision of bonds between structures of different types does not reduce the efficiency of the primary cathodic protection system.

Resistor bonds which control the current applied to different types of plant should be used when potentials on these structures should be controlled.

Polarized bonds should be used:

a) for joint drainage and cathodic protection systems;

b) to prevent current flowing from a pipeline to telecommunication plant;

c) to protect against failure of the cathodic protection equipment.

Bonds should not be installed between buried structures and power supply cables and equipment unless it is safe to do so in the event of a fault on the power supply system and it is in accordance with local and national safety rules.

4 Monitoring the performance of joint cathodic protection devices

The performance of joint cathodic protection devices should be monitored by means of:

a) routine examination of protective devices and equipment;

b) routine measurements of interaction potential differences with the protection equipment switched on and switched off at all the plants incorporated in the joint protection system, in compliance with local accepted procedures.

When tests or changes are made on the joint cathodic protection system, the presence or agreement of the representatives of operating agencies whose underground structures are incorporated in the joint protection system is recommended.

Reference

[1] CCITT *Recommendations concerning the construction, installation and protection of telecommunication cables in public networks,* ITU, Geneva, revision 1974, amendments and additions, 1977.

Recommendation L.8 (Geneva, 1976)

CORROSION CAUSED BY ALTERNATING CURRENT

Laboratory experiments and the results of examinations of industrial installations show that stray alternating currents can cause corrosion.

However, other experiments on lead to compare the effects of direct current and alternating current by weight loss show that the corrosion effect due to a.c. is very slight compared with corrosion by d.c. A.c. corrosion appears in the form of pitting.

The following points should nevertheless be noted:

- the corrosion, although rare, occurs more readily with frequencies below the usual mains frequency of 50 Hz or 60 Hz;
- rectification may occur due to the nature of the soil or to the presence at the surface of the metals of oxides or polluting substances.

There is no practical way of finding out the current densities and the voltages at which corrosion occurs. The individual pitting that is usual, the fact that anodic and cathodic reactions occur on the same surface of the metals, and variations in the chemical characteristics of the environment make it impossible for any accurate concept or definition of critical current density to be worked out at present.

It seems reasonable to suggest that a.c. at low voltage is not usually harmful to steel or lead but may corrode aluminium in some cases.

Printed in Switzerland — ISBN 92-61-02371-1