INTERNATIONAL TELECOMMUNICATION UNION

CCITT

THE INTERNATIONAL
TELEGRAPH AND TELEPHONE
CONSULTATIVE COMMITTEE

BLUE BOOK

VOLUME IX

PROTECTION AGAINST INTERFERENCE

SERIES K RECOMMENDATIONS

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

SERIES L RECOMMENDATIONS

IXTH PLENARY ASSEMBLY
MELBOURNE, 14-25 NOVEMBER 1988 1984

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PRELIMINARY NOTES

1 The Questions entrusted to each Study Group for the Study Period 1989-1992 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

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PROTECTION AGAINST INTERFERENCE[1)]

Recommendation K.1

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

(New Delhi, 1960)

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 the CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines*, ITU, Geneva, 1988 (see also Recommendation K.26).

Recommendation K.2

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

(New Delhi, 1960)

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

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

(New Delhi, 1960)

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

DISTURBANCE TO SIGNALLING

(Geneva, 1964)

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 electric power and electrified railway 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 electric power and electrified railway lines*, Vol. IX, ITU, Geneva, 1988.

[2] *Ibid.*, Vol. VI.

Recommendation K.5

JOINT USE OF POLES FOR ELECTRICITY DISTRIBUTION AND FOR TELECOMMUNICATIONS

(Geneva, 1964)

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 electric power and electrified railway lines*, Vol. II, ITU, Geneva, 1988.

Recommendation K.6

PRECAUTIONS AT CROSSINGS

(Geneva, 1964)

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 electric power and electrified railway lines*, Vol. VI, ITU, Geneva, 1988.

Recommendation K.7

PROTECTION AGAINST ACOUSTIC SHOCK

(Geneva, 1964; modified at Malaga-Torremolinos, 1984)

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

SEPARATION IN THE SOIL BETWEEN TELECOMMUNICATION CABLES AND EARTHING SYSTEM OF POWER FACILITIES

(Mar del Plata, 1968; modified at Melbourne, 1988)

Introduction

If a buried telecommunication cable without an insulating layer around the metal sheath is located in the vicinity of a high voltage earthing system, part of the earth potential rise (EPR) in the event of an earth fault in the high voltage system can transfer to the telecommunication system through resistive coupling.

According to CCITT and CIGRE[1] documents [1-3], EPR from high voltage power installations is recognized as a source of dangerous disturbance to telecommunication systems and a hazard to service personnel.

It is possible to calculate EPR near power installations following the methods given in the *Directives* [1] (see Volumes II and III), and this is especially recommended for dealing with switchyard earthing systems.

The object of the present Recommendation is to give practical guidelines in determining safe distances between buried telecommunication cables and earthing systems of power facilities in the absence of local measurements or calculated values of EPR.

1 Scope

Earth fault in a power system causes earth currents which raise the earth potential where the fault current leaves and enters the earth. The magnitude and extension of the EPR depends on the fault current level, the earthing resistance, the soil resistivity and the layout of the earthing arrangement. The duration of an earth fault depends on the type of power network.

This Recommendation gives information about:

a) locations where EPR may occur;

b) duration of EPR in different types of power networks;

c) "safe distance" between telecommunication cables and power installations;

d) measures to be taken if the safe distance is not achieved.

2 General considerations

The minimum separation in soil to be recommended between an earthing system of a power installation and telecommunication cables depends on a number of factors:

- type of power network;
- fault current level;
- power earthing system;
- soil resistivity;
- local conditions.

3 Type of power network

Power networks are classified according to how the neutral point is connected to earth. The earthing system affects both the level and duration of the fault current, and hence the EPR.

3.1 *Networks with the neutral point earthed directly or through a low impedance*

The level of an earth-fault current is high. A relay system will clear the fault in a short time.

3.2 *Networks with the neutral point earthed through an arc suppression coil*

The level of an earth-fault current is small, usually not exceeding 100 amperes for each coil. The duration of an earth fault is relatively short.

Such networks may be equipped with delayed tripping to clear permanent earth faults.

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[1] CIGRE International Conference on Large High-Tension Electric Systems.

3.3 *Networks with the neutral point isolated from earth*

The level of an earth-fault current is normally low, but the fault duration might be very long. Networks of large extent may give rise to large capacitive fault currents.

If such networks are equipped with devices for automatic fault clearing, the fault duration is short to medium.

4 Locations where earth potential rise may occur

4.1 *Power stations and sub-stations*

Power stations and sub-stations are most likely to experience EPR. The size of the station, the number and construction of power lines attached to the station, and the earthing arrangement are factors influencing the level and station, and the earthing arrangement are factors influencing the level and zone of EPR. As given in reference [4] the layout and structure of the earthing arrangement depends on regulations, size, age, purpose and location. If the power lines entering the station are provided with earth wires, they will be connected to the earthing system in the station.

4.2 *Power line towers*

Power line towers with footing electrodes are subjected to EPR due to earth-fault current in the power system, and currents from lightning strikes. If the power line is equipped with earth wires, these will normally be connected to the tower electrodes. The probability of high EPR decreases when a power line is equipped with earth wires.

5 Magnitude of earth potential rise

The magnitude of the EPR depends on the power system voltage, the power line construction, the fault current level and the earthing resistance.

6 Zone of earth potential rise

EPR is measured as the earth potential referred to a distant neutral earth. The zone of EPR, near an earthing system, varies from some tens to some thousands of metres, depending on soil resistivity, the layout of the earth electrode, and other local conditions. Further information is found in reference [5]. The zones of EPR in urban areas are small compared to what can be expected in rural areas. Only EPR zones having a potential higher than values given in reference [1] are considered as dangerous. Measurements and calculation of the EPR zones are made by the power distribution authorities.

7 Duration of earth potential rise

The duration of an earth fault and hence the EPR, depends on the type of power network.

7.1 *Networks with the neutral point earthed directly or through a low impedance*

The duration of an earth fault is generally less than 0.2-0.5 s.

7.2 *Networks with the neutral point earthed through an arc suppression coil*

The duration of an earth fault is normally less than 0.8 s, but may in some cases last for several seconds. Such networks may be equipped with delayed (a few seconds) tripping to clear permanent earth faults.

7.3 *Networks with an isolated neutral point*

The duration of an earth fault can be very long, and may last until another earth fault occurs.

If such networks are equipped with automatic fault-clearing devices, the fault duration may be as short as in § 7.1.

8 Minimum separation in soil between buried telecommunication cables and power earthing systems

The EPR near a high voltage earthing system can be estimated from calculations based on idealized earth electrodes and a homogeneous soil resistivity in the EPR zone. In practice it is not possible to make an exact calculation of the potential transferred from a high voltage earthing system to an adjacent telecommunication cable. However, by feeding a current into the high voltage earthing system from a sufficiently great distance, the voltage between the cable sheath and an auxiliary electrode in the area of neutral potential can be measured. The result must be corrected proportionately to the actual earth-fault current. (On armoured cables the correction factor is not linear, but depends on the magnetic characteristic of the ferromagnetic cable screen.) In the absence of other experiments, local measurements or calculated values of EPR, the values in Table 1/K.8 for the minimum separation in soil between "ordinary" telecommunication cable with a metal sheath in direct contact with the soil and a high voltage power earthing system should be observed.

TABLE 1/K.8

Separation in soil (in metres) between telecommunication cables and high voltage earthing systems beyond which no calculation nor measurement is necessary

Earth resistivity	Power network system with		Location
	isolated neutral or arc suppression coil	directly earthed neutral	
Less than 50 ohm · m	2	5	Urban
	5	10	Rural
50-500 ohm · m	5	10	Urban
	10	20	Rural
500-5000 ohm · m	10	50	Urban
	20	100	Rural
Greater than 5000 ohm · m	10	50	Urban
	20	100-200 [a)]	Rural

[a)] 200 metres in areas with extremely severe soil conditions, i.e. greater than 10 000 ohm · m.

Note 1 – The values in the table normally refer to lines and installations which have a nominal voltage equal to or greater than 132 kV.

Note 2 – The hazards due to lightning strokes on electric plants are not covered and may require taking into considerating the methods of § 9 for high keraunic level areas.

Note 3 – In the case of tower earthing, much shorter distances can be used if the power lines include earth wires.

Note 4 – Hazards for people working on telecommunication lines inside the zone of EPR is not taken into consideration by these values; such hazards require additional measures or precautions.

9 Measures to be taken to avoid hazards from EPR

The primary method to avoid dangerous influence from EPR is to increase the distance between telecommunication cables and power earthing systems. If local conditions do not permit sufficient separation to avoid dangerous EPR, the telecommunication cables should be provided with insulation, for example by placing the cables in insulating plastic tubes.

When the magnitude of EPR is extremely high, or the zone of EPR is of very great extension, optical fibre cables or radio-relay systems may be used instead of metallic cables.

References

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electrified power and electrified railway lines*, Vols. II and III, ITU, Geneva, 1988.

[2] CCITT Study Group V – Contribution No. 61/1979.

[3] CIGRE No. 36-04/1970 – Ground potential rise and telecommunication lines.

[4] ELECTRA No. 71/1980 Station grounding – Safety and interference aspects.

[5] ELECTRA No. 60/1978 – Zone of influence of ground potential rise.

Recommendation K.9

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

(Mar del Plata, 1968)

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

UNBALANCE ABOUT EARTH OF TELECOMMUNICATION INSTALLATIONS

(Mar del Plata, 1968; modified at Malaga-Torremolinos, 1984)

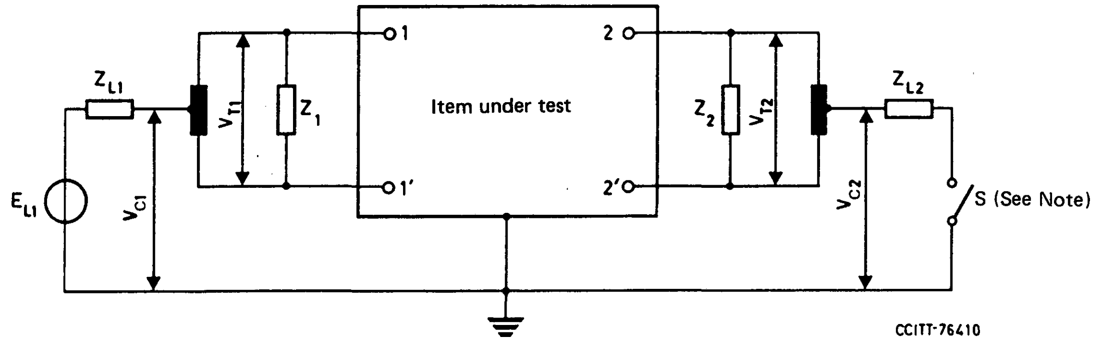
1 Unbalance about earth of telecommunication equipments

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.

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

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



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

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):

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

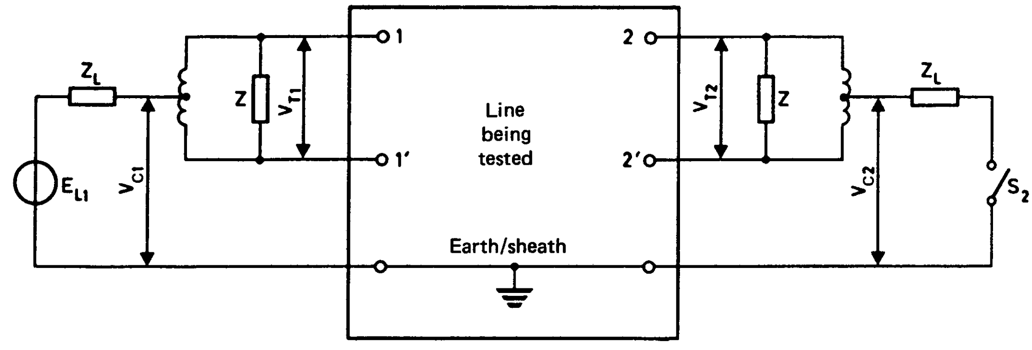
2 Unbalance about earth of telecommunication lines

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 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 $20 \log_{10} \left\| \frac{E_{L1}}{V^{o}_{T1}} \right\|$	Longitudinal conversion transfer losses $20 \log_{10} \left\| \frac{E_{L1}}{V^{o}_{T2}} \right\|$	S_2 Open
	$20 \log_{10} \left\| \frac{E_{L1}}{V^{c}_{T1}} \right\|$	$20 \log_{10} \left\| \frac{E_{L1}}{V^{c}_{T2}} \right\|$	S_2 Closed
Open S_1	Longitudinal conversion transfer losses $20 \log_{10} \left\| \frac{E_{L2}}{V^{o}_{T1}} \right\|$	Longitudinal conversion losses $20 \log_{10} \left\| \frac{E_{L2}}{V^{o}_{T2}} \right\|$	E_{L2}
Closed S_1	$20 \log_{10} \left\| \frac{E_{L2}}{V^{c}_{T1}} \right\|$	$20 \log_{10} \left\| \frac{E_{L2}}{V^{c}_{T2}} \right\|$	

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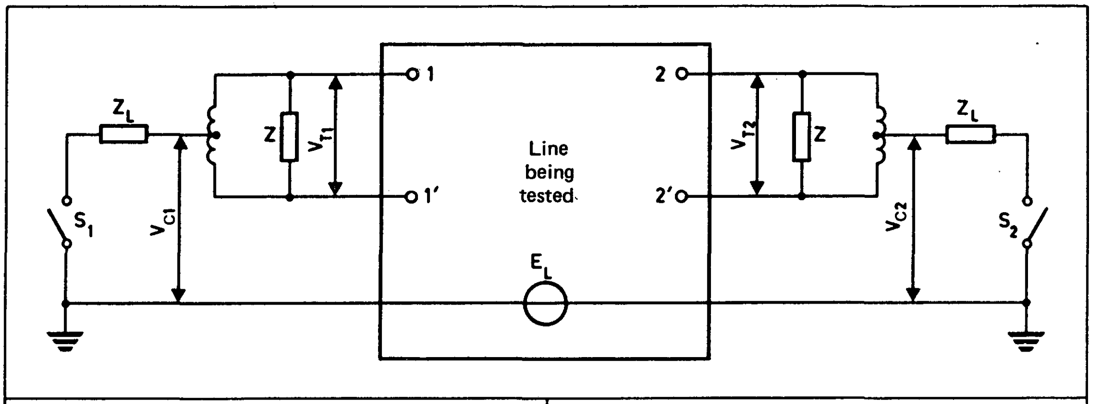
Note 1 – The superscripts of o and c indicate the open and closed state of switch S, respectively.

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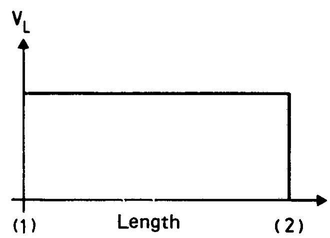
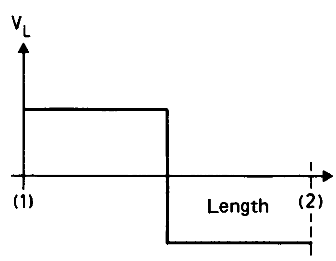
Note 1 – The superscripts of o and c indicate the open and closed state of the switches, respectively.

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.

ANNEX A

(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 ΔC = 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.

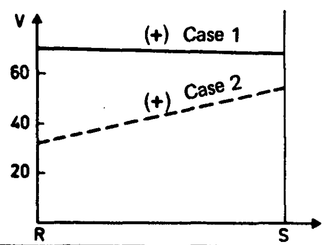
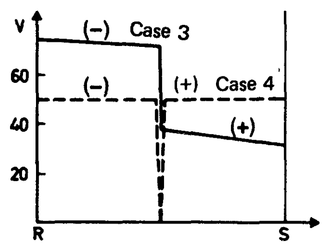
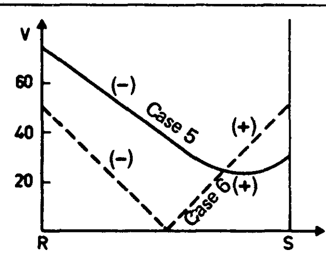
In the case of a well equalized line, the magnitude of the longitudinal conversion losses is high and is largely independent of both the location of the e.m.f. and the position of the switches at the terminals (see column 5 in Table A-1/K.10).

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: $\Delta C = 600$ 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

PRINCIPLES OF PROTECTION AGAINST OVERVOLTAGES AND OVERCURRENTS

(Geneva, 1972; modified at Malaga-Torremolinos, 1984 and at Melbourne, 1988)

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] (see also Recommendation K.26).

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". Recommendations K.20 and K.21 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.

To avoid disturbances in telecommunication circuits caused by activated protective devices, the striking voltage values and the numbers of arrestors should be considered.

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. Recommendations K.20 and K.21 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 Recommendations K.20 and K.21.

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 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.

2.6 *Recommended policy*

Where lines in a telecommunications network are exposed to frequent or severe disturbances from power line faults or lightning, the voltage of these lines relative to local earth potential should be limited either by connecting protective devices between the line conductors and earth or by using appropriate construction methods for the line.

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 Recommendation K.21. 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 should 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 electric power and electrified railway lines*, ITU, Geneva, 1988.

Recommendation K.12

CHARACTERISTICS OF GAS DISCHARGE TUBES FOR THE PROTECTION OF TELECOMMUNICATIONS INSTALLATIONS

(Geneva, 1972, modified at Malaga-Torremolinos, 1984 and at Melbourne, 1988)

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.

Paragraphs 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

<table>
<tr><td>Component</td><td>Test 1</td><td colspan="2">Test 2</td><td colspan="2">Test 3</td></tr>
<tr><td>PS1</td><td>52 V</td><td colspan="2">80 V</td><td colspan="2">135 V</td></tr>
<tr><td>PS2</td><td>0 V</td><td colspan="2">0 V</td><td colspan="2">52 V</td></tr>
<tr><td>R3</td><td>260 Ω</td><td colspan="2">330 Ω</td><td colspan="2">1300 Ω</td></tr>
<tr><td>R2</td><td>[a]</td><td>150 Ω</td><td>272 Ω [b]</td><td>150 Ω</td><td>272 Ω [b]</td></tr>
<tr><td>C1</td><td>[a]</td><td>100 nF</td><td>43 nF [b]</td><td>100 nF</td><td>43 nF [b]</td></tr>
<tr><td>R4 [c]</td><td>136 Ω</td><td colspan="2">136 Ω</td><td colspan="2">136 Ω</td></tr>
<tr><td>C2 [c]</td><td>83 nF</td><td colspan="2">83 nF</td><td colspan="2">83 nF</td></tr>
</table>

[a] Components omitted in this test.
[b] Optional alternative.
[c] Optional.

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 *A.c. 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 $\cdot$ cm^3 $\cdot$ 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),

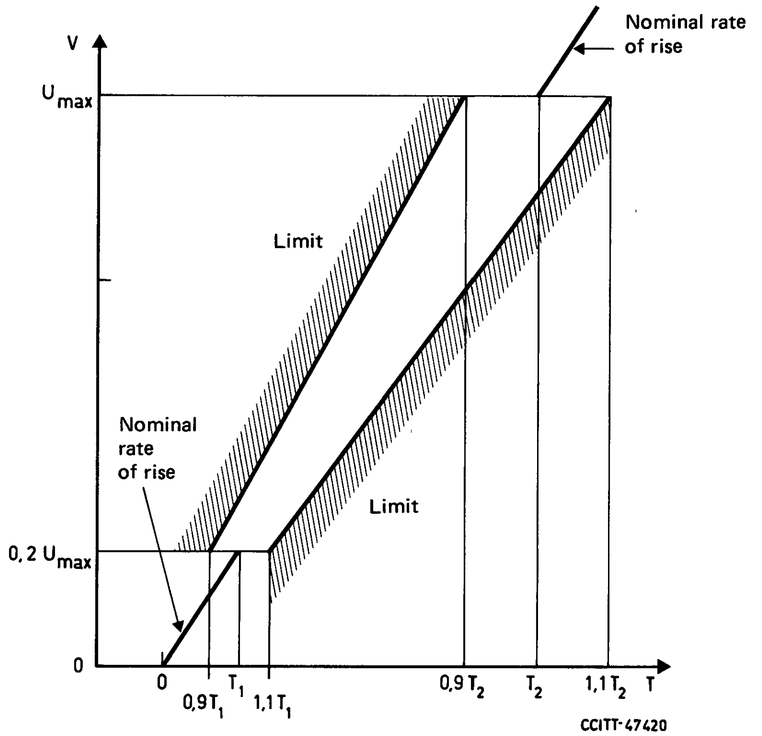
i) quality assurance requirements.

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.)

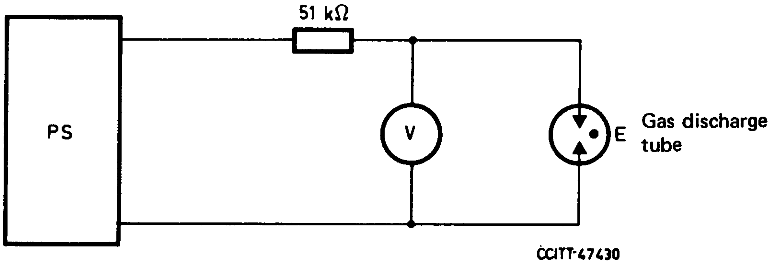
Test methods and the relations between the value and duration of the destructive current are not detailed in this Recommendation nor is the state of the element after destruction. Administrations should cover their requirements in these respects in their own documentation.



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)

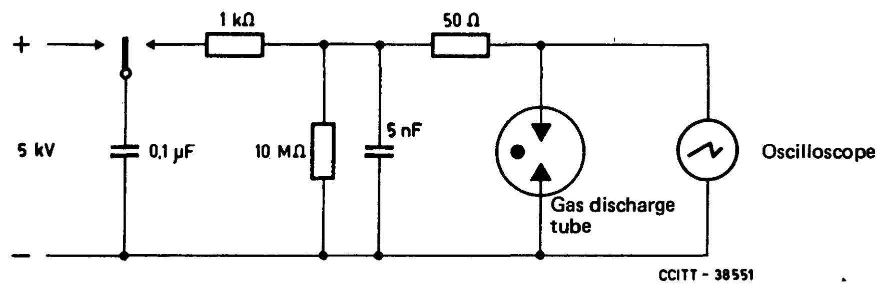
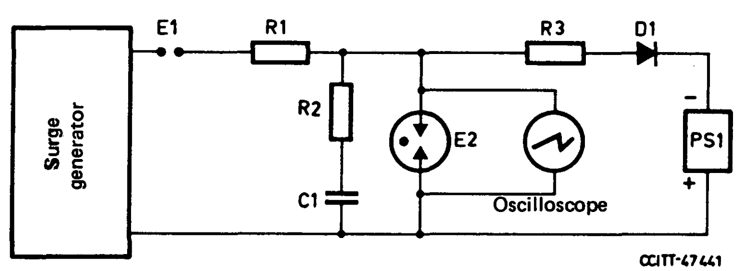


FIGURE 3/K.12

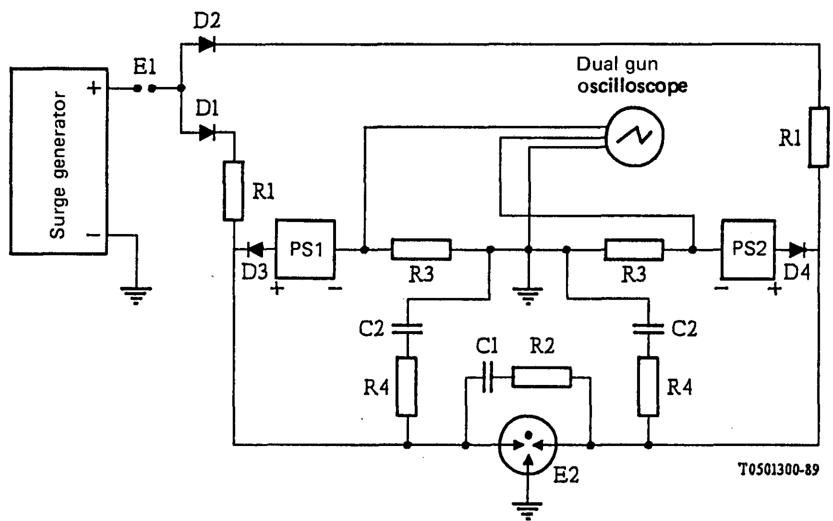
Testing arrangement producing a voltage impulse having a wavefront with a virtual steepness of 1 kV/μs (§§ 4.1 and 5.3)



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)



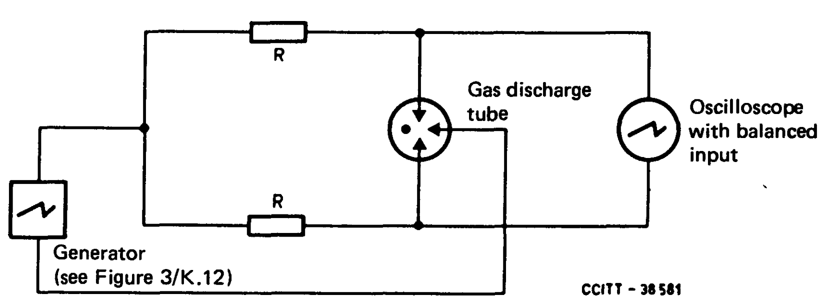
E1 Isolation gap or equivalent device
E2 Gas discharge tube
PS1, PS2 Batteries or d.c. power supplies
R1 Impulse current limiting resistors or wave-shaping networks

Note 1 – C2 and R4 optional.

Note 2 – 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

(to Recommendation K.12)

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

(Geneva, 1972)

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 [1];

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 § 1c) 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 electric power and electrified railway lines*, Vol. VI, ITU, Geneva, 1988.

[2] *Ibid.*, Vol. VII.

Recommendation K.14

PROVISION OF A METALLIC SCREEN IN PLASTIC-SHEATHED CABLES

(Geneva, 1972; modified at Malaga-Torremolinos, 1984)

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.

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

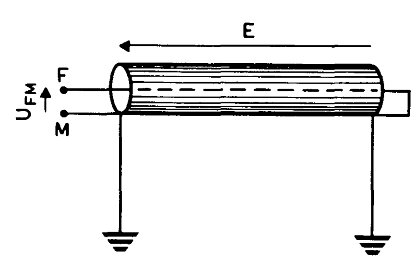


FIGURE 1/K.14

– 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.

$$k_{ff'} = \left| \frac{U_{FS}}{E} \right|$$

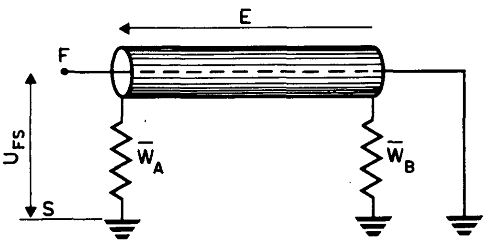


FIGURE 2/K.14

– 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.

$$k_{fm} = \left| \frac{U_{FM}}{E} \right|$$

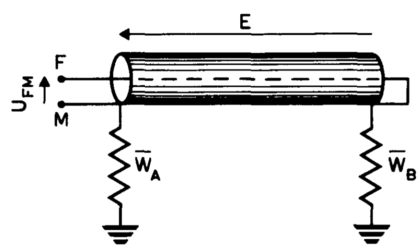


FIGURE 3/K.14

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*, Vol. II):

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

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

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.

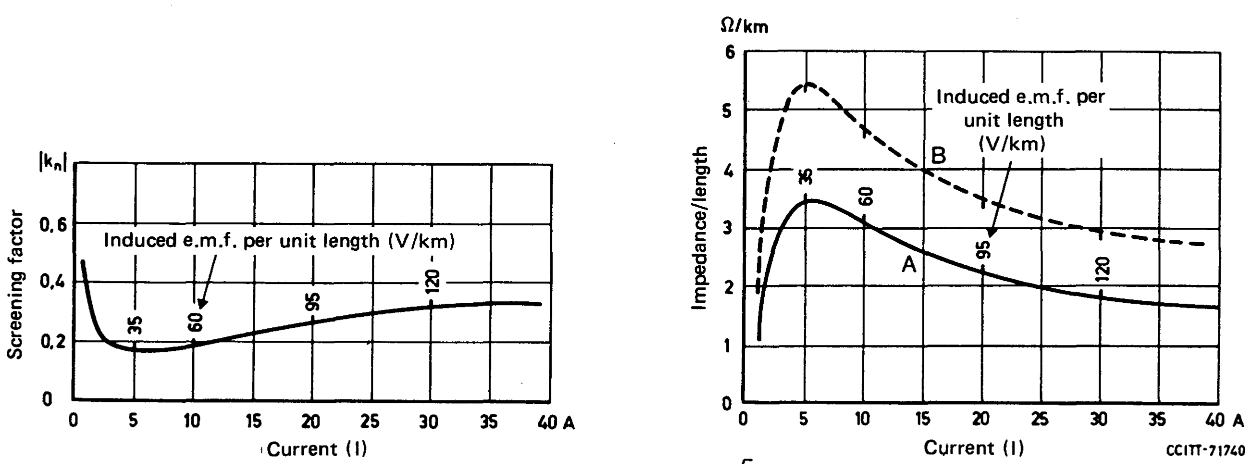
8.2.2.2 *"Short" links*

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.



$Z_e^E = A + jB$

a) Nominal screening factor

b) Impedance per unit length Z_e^E

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:

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

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*

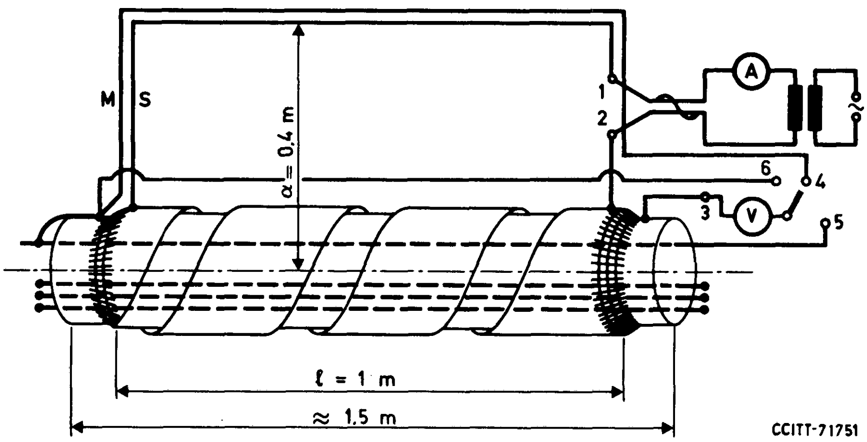
Screening factor $k_{ff'}$ may be estimated by means of Equation (8-3). The cable should be armoured in most cases.

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* (Vol. IX), determination of impedance per unit length Z_e^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

(Geneva, 1972)

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 [5]).

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 [5]).

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 [5]. 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 electric power and electrified railway lines*, Vol. II, ITU, Geneva, 1988.

[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 electric power and electrified railway lines*, Vol. VI, ITU, Geneva, 1988.

Recommendation K.16

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

(Geneva, 1972)

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

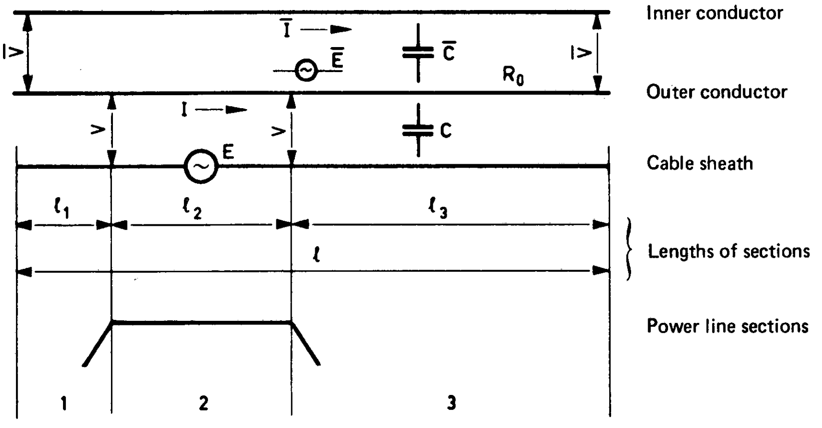
On the basis of the general assumption that a power-feeding section with the outer conductors at floating potential (not bonded to the cable sheath or to a grounding system) is exposed to induction along an arbitrarily located section, we can draw Figure 1/K.16 below, which shows the conventions and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



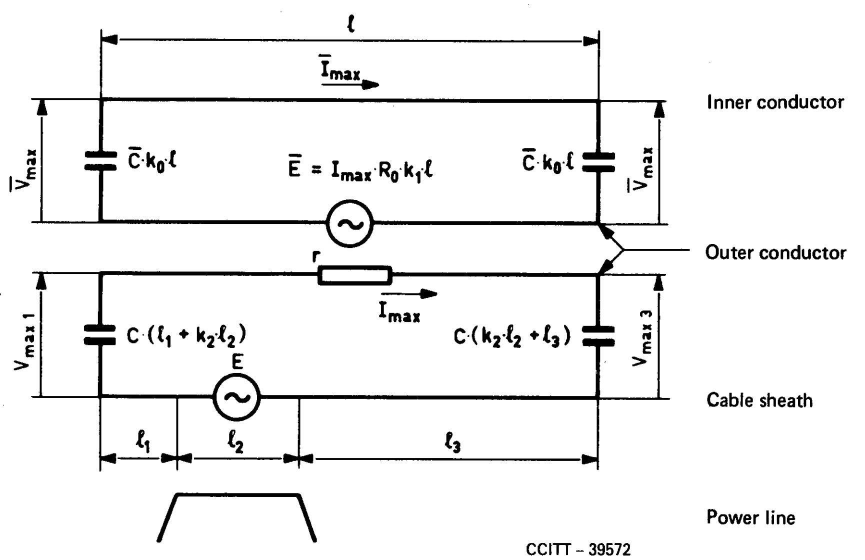
E = longitudinal voltage induced in the cable (volts)
$\bar{E}$ = longitudinal voltage in the coaxial tube (volts)
l_2 = length of the exposed section (km)
l_1, l_3 = lengths of the unexposed sections (km)
l = length of the power-feeding section (km) = $l_1 + l_2 + l_3$
$V, \bar{V}, I, \bar{I}$ = maxima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

$$C = \frac{C_{0s} \cdot l_s + C'_{0s}}{l_s} \text{ and } \bar{C} = \frac{C_{i0} \cdot l_s + C_f}{l_s}$$

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_{i0} = 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 $\ell_2 \leq \frac{\ell}{2}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$
for $\ell_2 > \frac{\ell}{2}$	$\frac{5}{16}$	$\frac{2}{3}$	$\frac{1}{4}$

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.

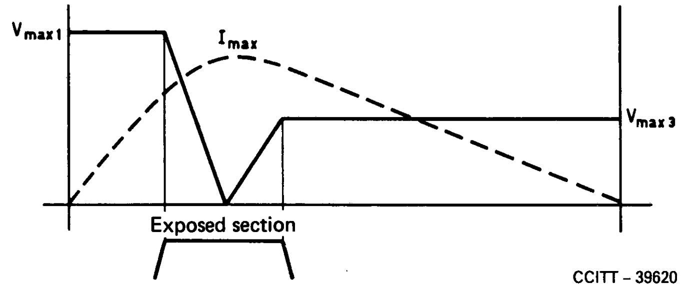


FIGURE 3/K.16

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.

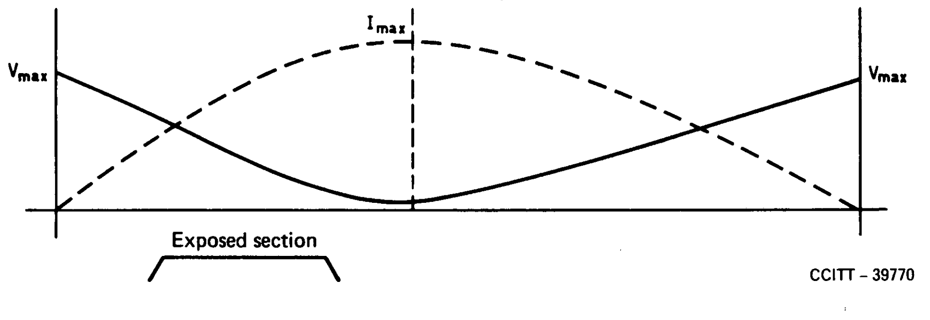


FIGURE 4/K.16

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.

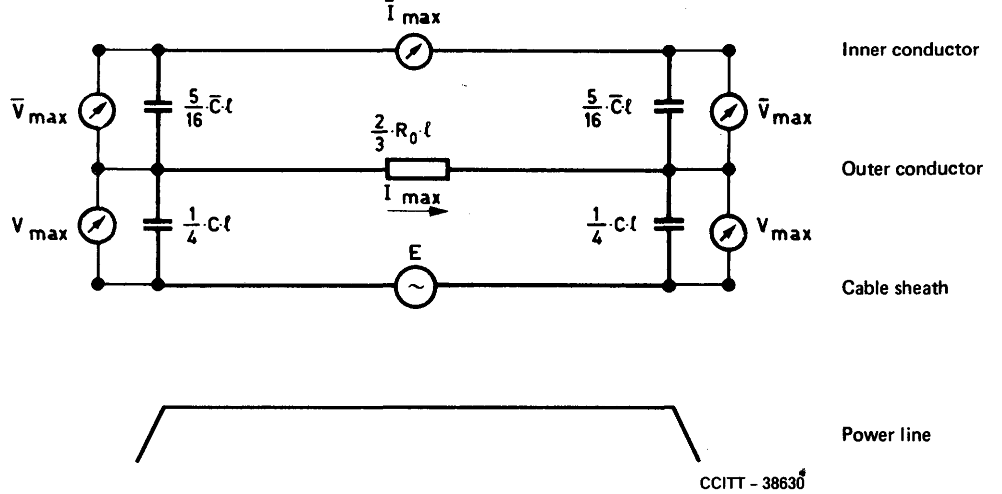
A.2 *First stage – Symmetrical exposure – Full calculation*

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.

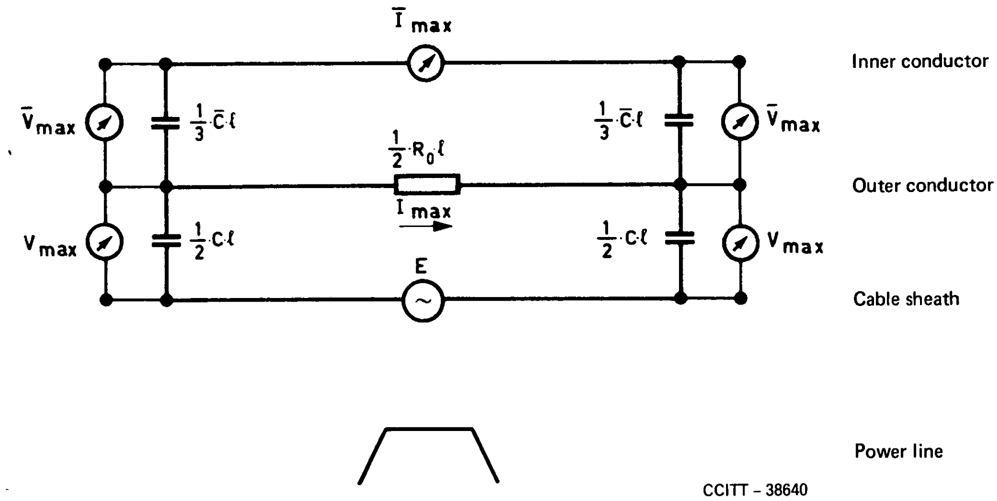
The equivalent circuits in Figures A-1/K.16 and A-2/K.16 can be used to calculate the maximum voltages and currents in two cases of symmetrical exposure; since these cases are both extremely exceptional, we should, at the same time, consider the general case of a dissymmetrical exposure of any length. 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 $l_2 \gg l/2$.

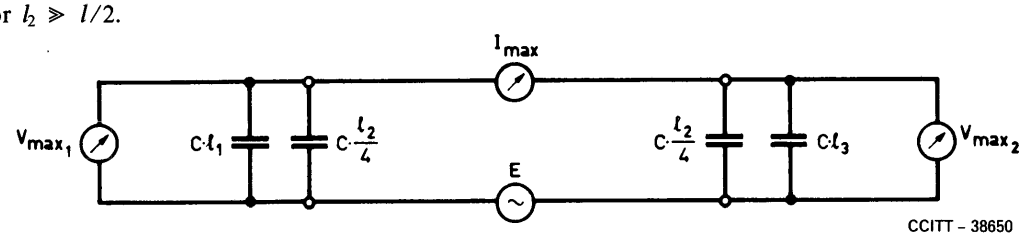


FIGURE A-3/K.16

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.

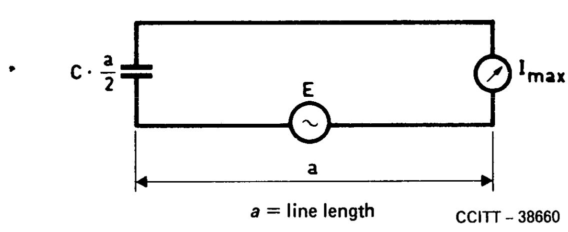


FIGURE A-4/K.16

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 $l_2 \ll l/2$.

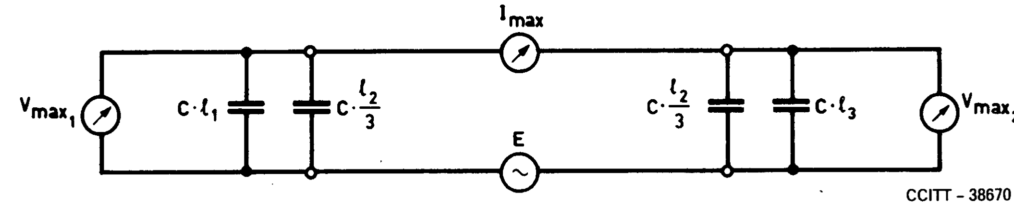


FIGURE A-5/K.16

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.

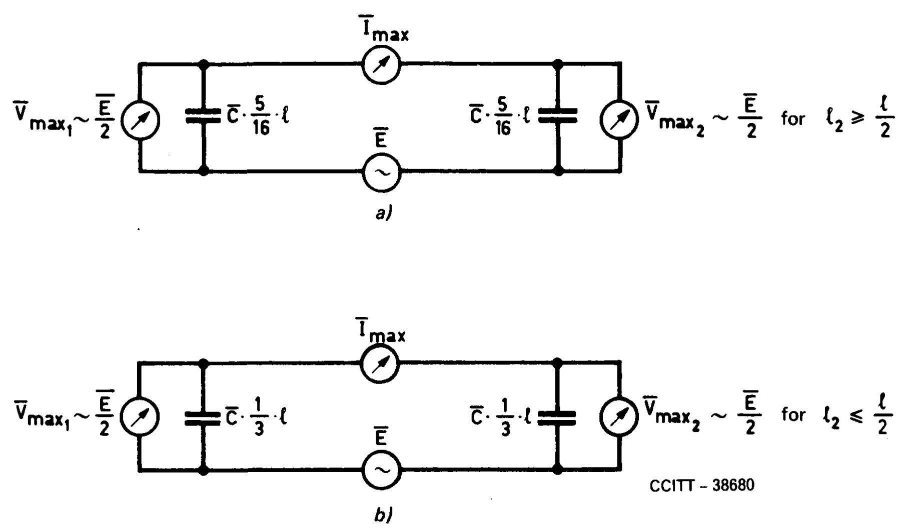


FIGURE A-6/K.16

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:

$C = 0.12$ μF/km; $R_0 = 6.2$ Ω/km $\overline{C} = 0.2$ μF/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: $\overline{C} = 0.2$ μF/km, $R_0 = 6.2$ Ω/km, $C = 0.12$ μF/km.

Calculation scheme:

$C l_1 = 0.12 \times 12 = 1.44\ \mu F$ + $C k_2 l_2 = 0.12 \times \frac{1}{3} \times 16 = 0.64\ \mu F$ → $2.08\ \mu F$

$2.08\ \mu F$ (i.e. $C l_1 + C k_2 l_2$) + $C l_3 = 0.12 \times 36 = 4.32\ \mu F$ → $4.96\ \mu F$ (i.e. $C k_2 l_2 + C l_3$)

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

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

→ × 1530 Ω $= V_{max_1} = 705$ V

→ × 640 Ω $= V_{max_2} = 295$ V

→ × 198.5 Ω $= \overline{E} = 91.6$ V

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

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

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

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$\overline{I}_{max} = 1.34 \times 10^{-3} \times 45.8 = 61.5$ 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_{max1}	685 V	705 V	+2.9 %
V_{max2}	315 V	295 V	−6.3 %
I_{max}	0.455 A	0.461 A	+1.3 %
$\overline{V}_{max1}$	48 V	45.8 V	−4.6 %
$\overline{V}_{max2}$	37.5 V	45.8 V	+22 %
$\overline{I}_{max}$	55 mA	61.5 mA	+11.8 %

This comparison shows that, with the exception of the value of $\overline{V}_{max2}$, 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 $\overline{V}_{max2}$ is of no practical importance since this involves the smaller of the two maxima of $\overline{V}$.

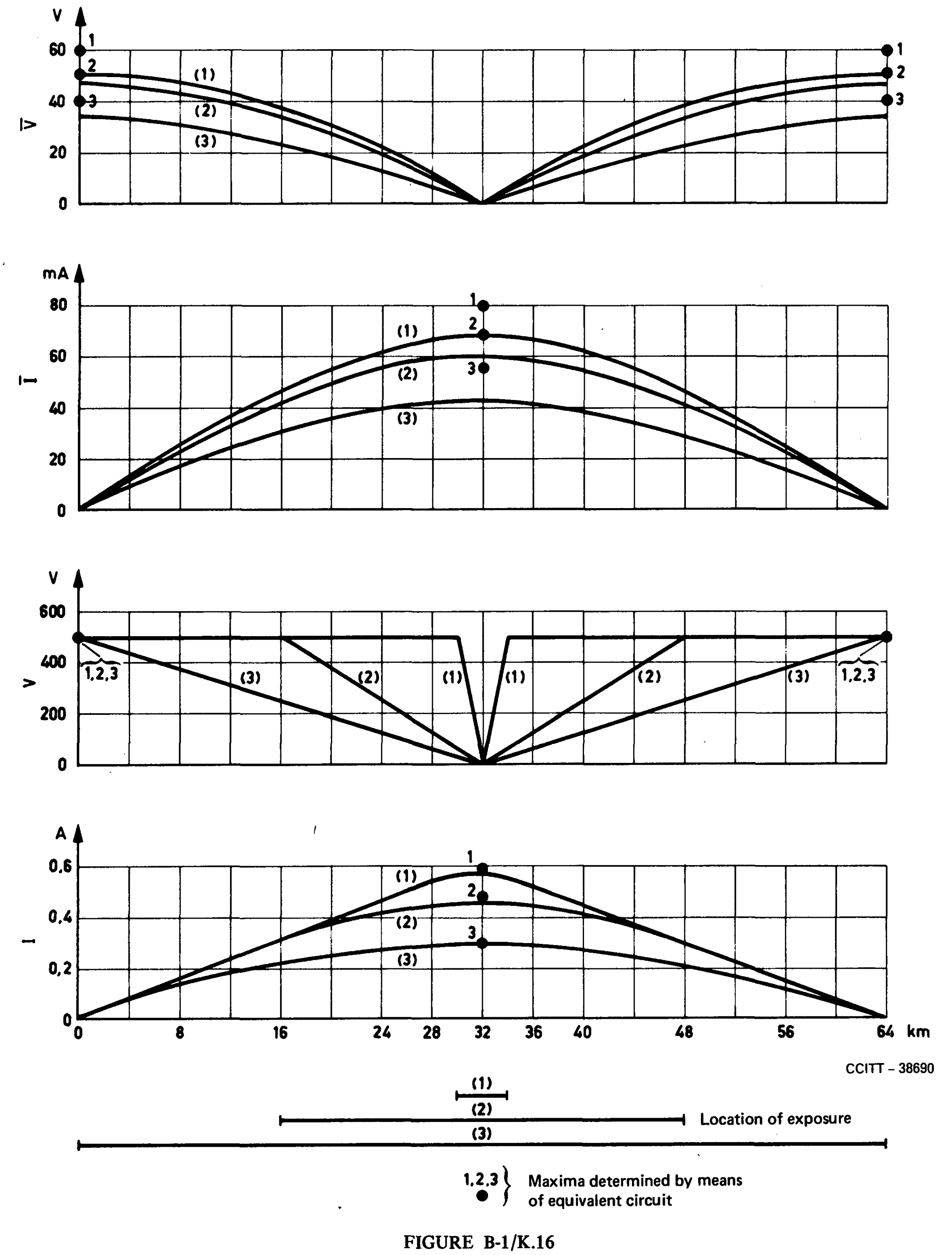


FIGURE B-1/K.16

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)

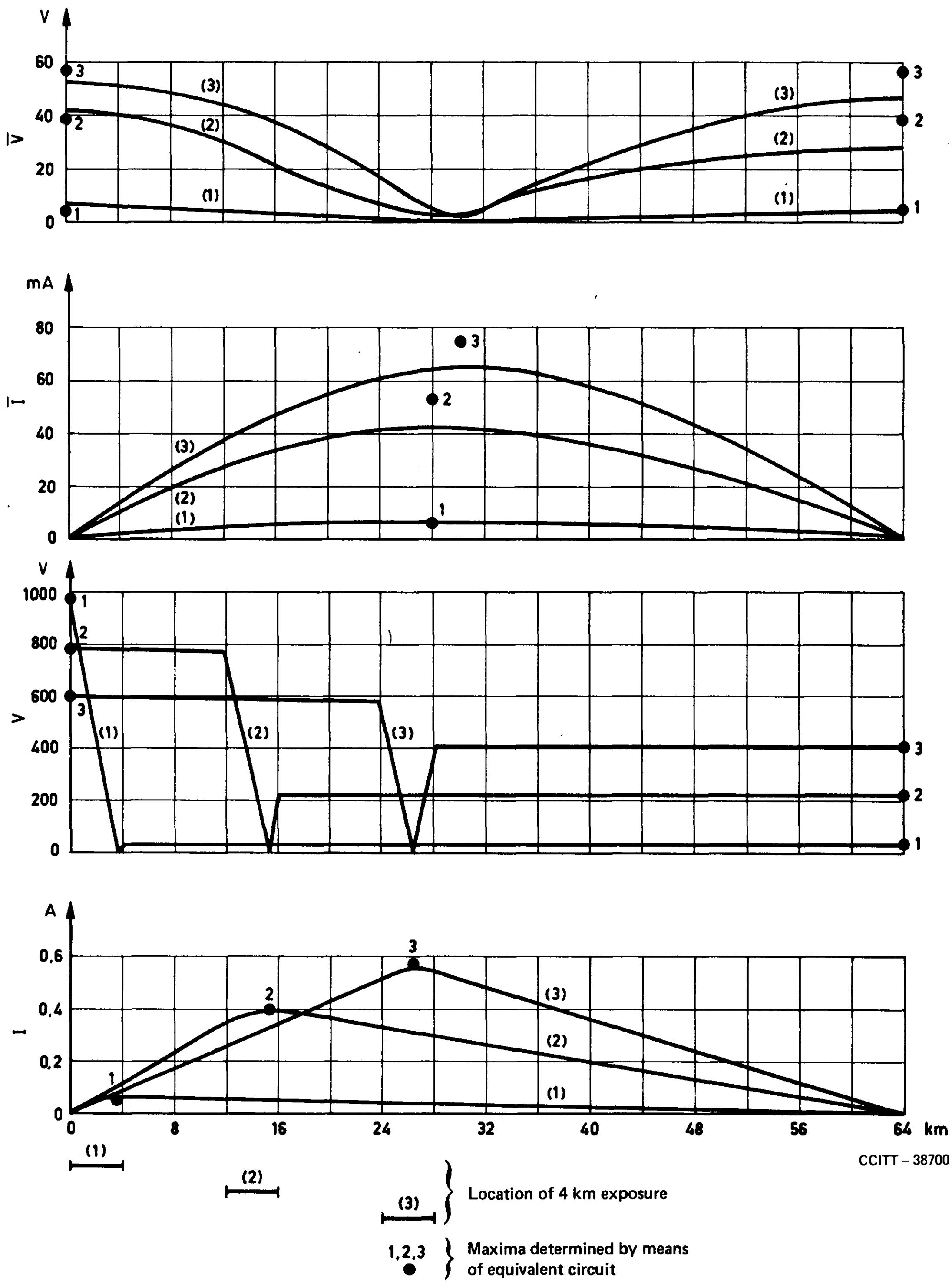


FIGURE B-2/K.16

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)

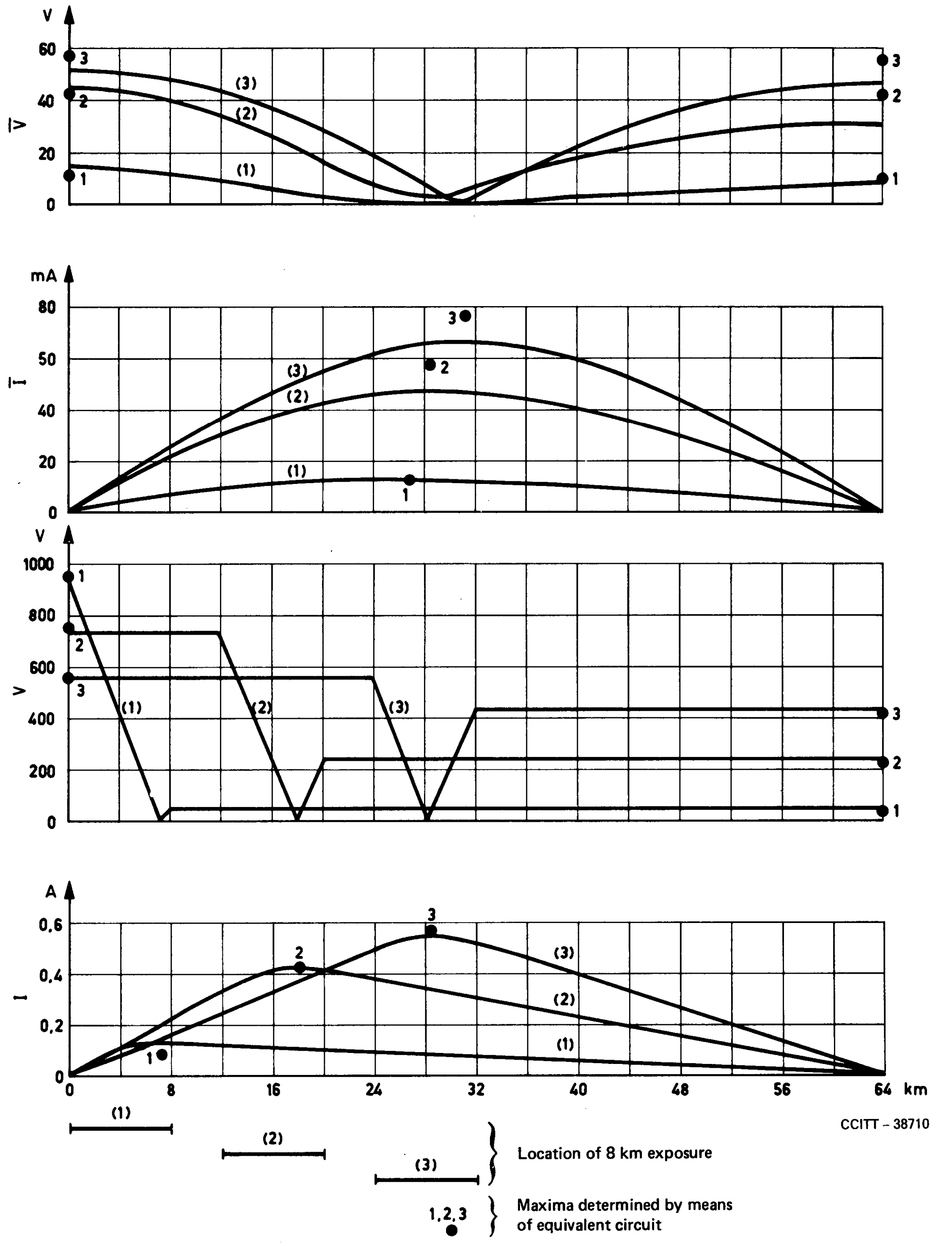


FIGURE B-3/K.16

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)

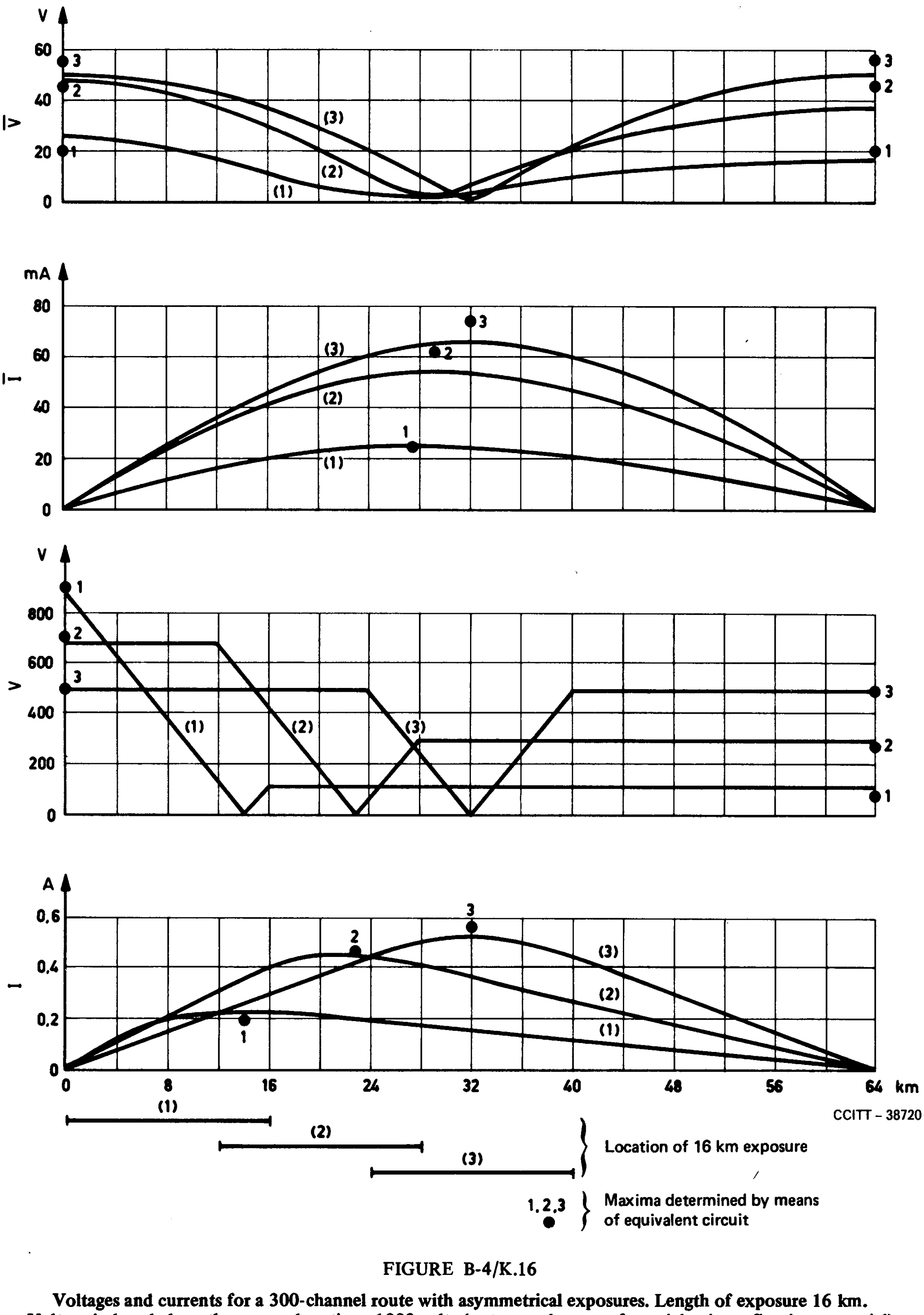


FIGURE B-4/K.16

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)

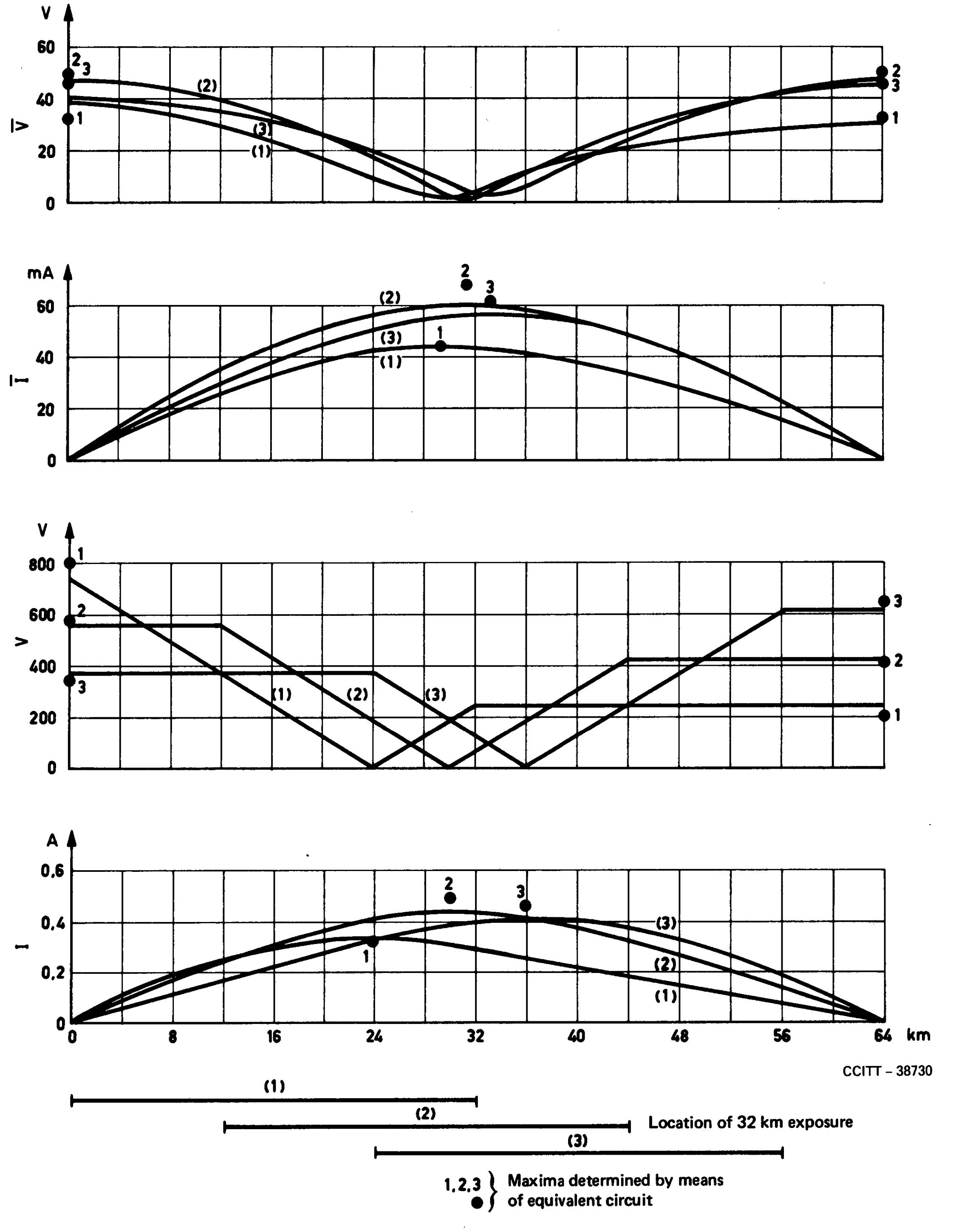


FIGURE B-5/K.16

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.

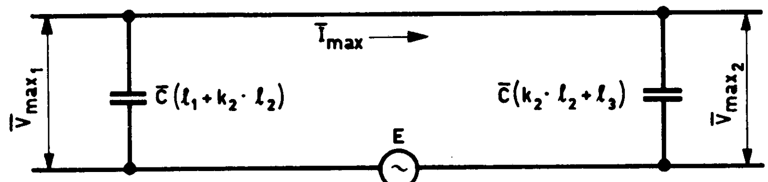


FIGURE C-1/K.16

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.

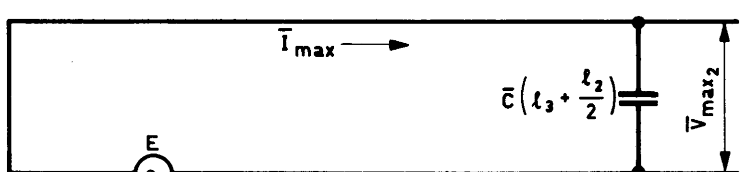


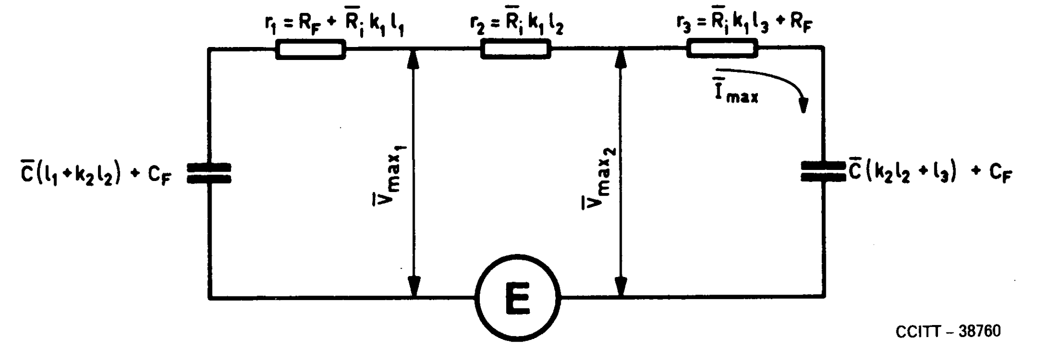
FIGURE C-2/K.16

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.

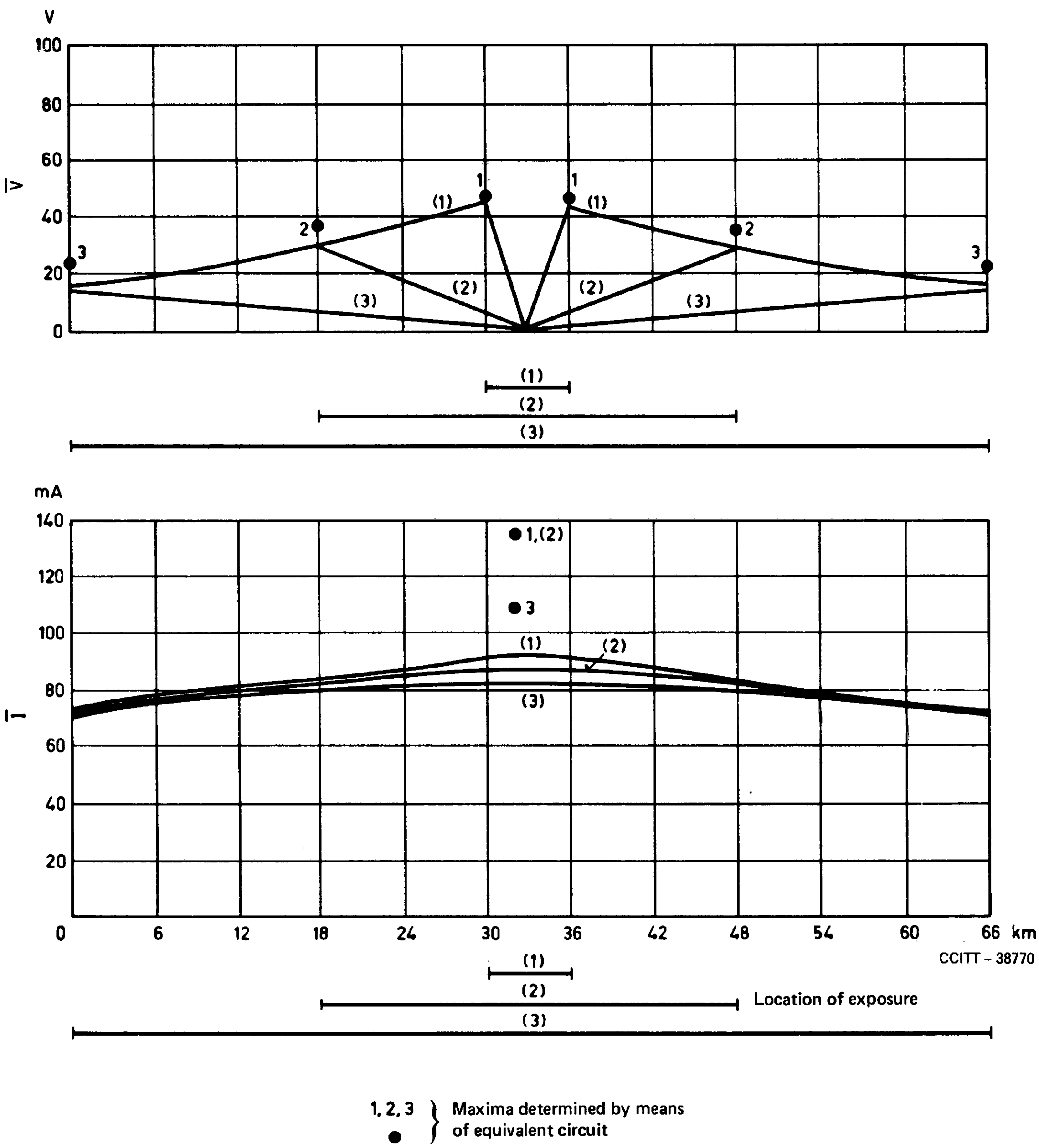


Note – $\bar{R}_i$ is the resistance per kilometre of the inner conductor plus the total resistance of all the repeater directional filters, expressed as a resistance value per kilometre.

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

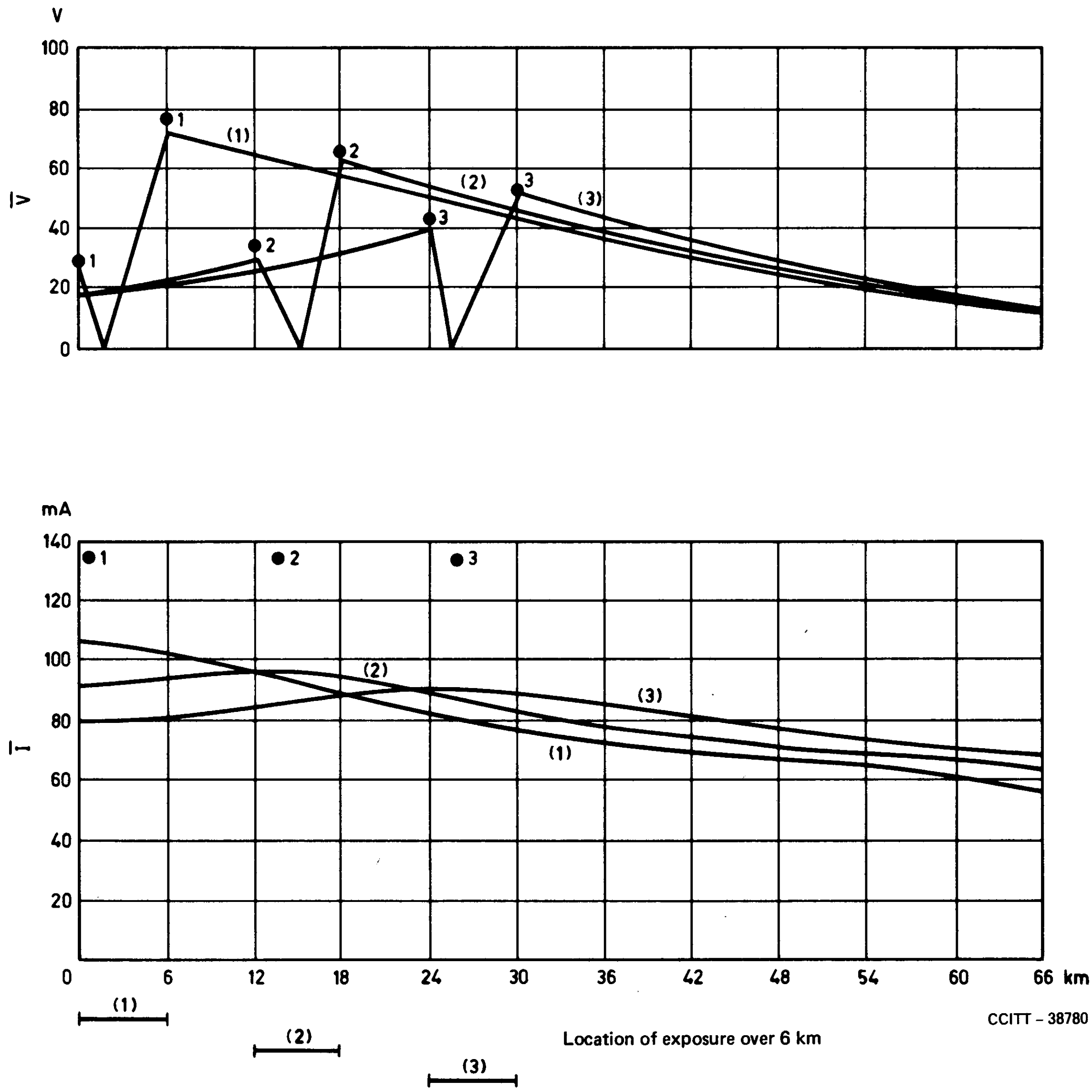
The induced voltage is assumed to be such that, taking account of the screening factor of the cable, the interference voltage to be considered is 100 V (if the voltage could not be restricted to such a value, another solution would be applied, reversion to the floating potential for example). For an 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.



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)

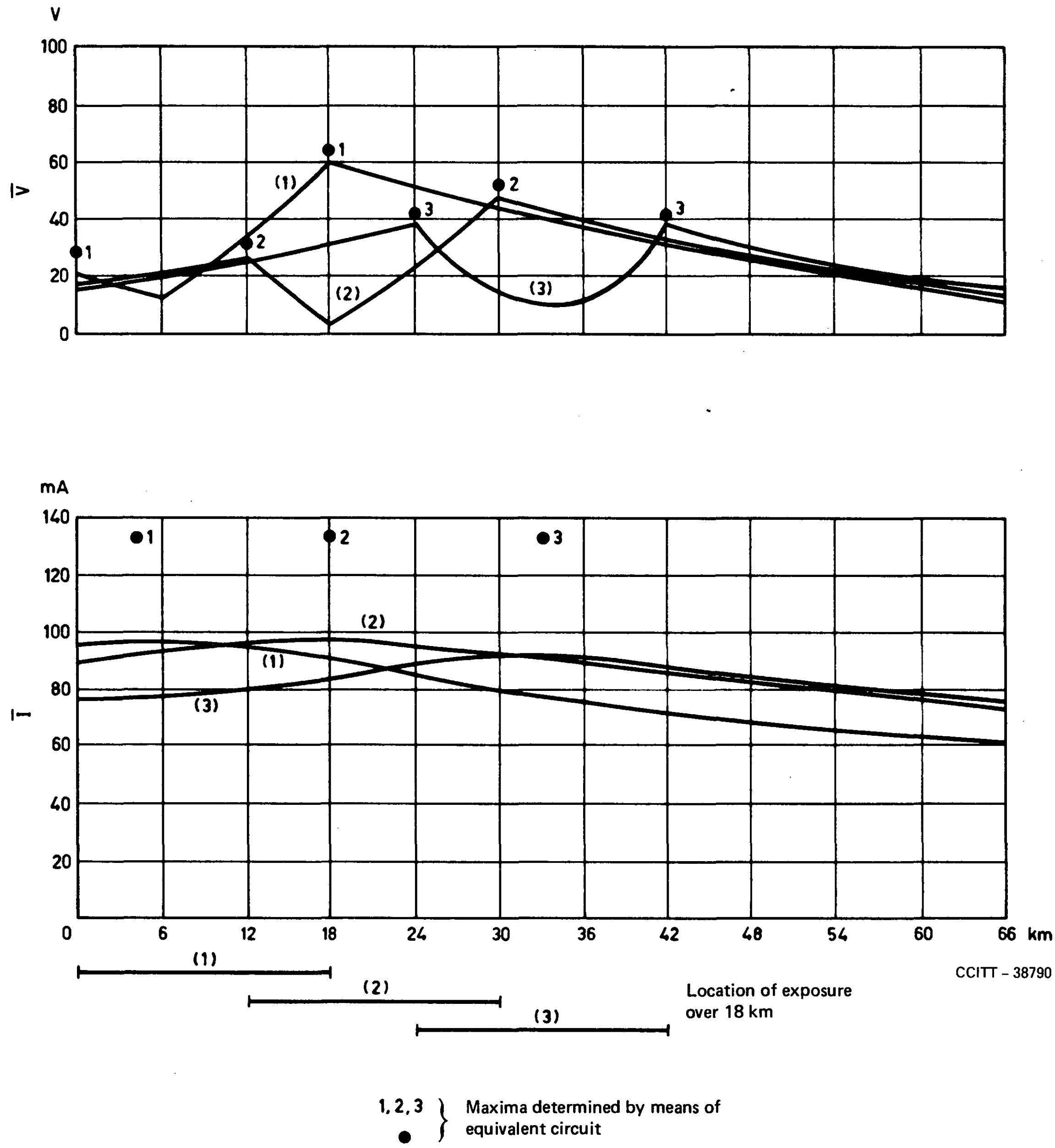


1, 2, 3 ● } Maxima determined by means of equivalent circuit

Length of exposure: 6 km
Inducing voltage : 100 V

FIGURE C-5/K.16

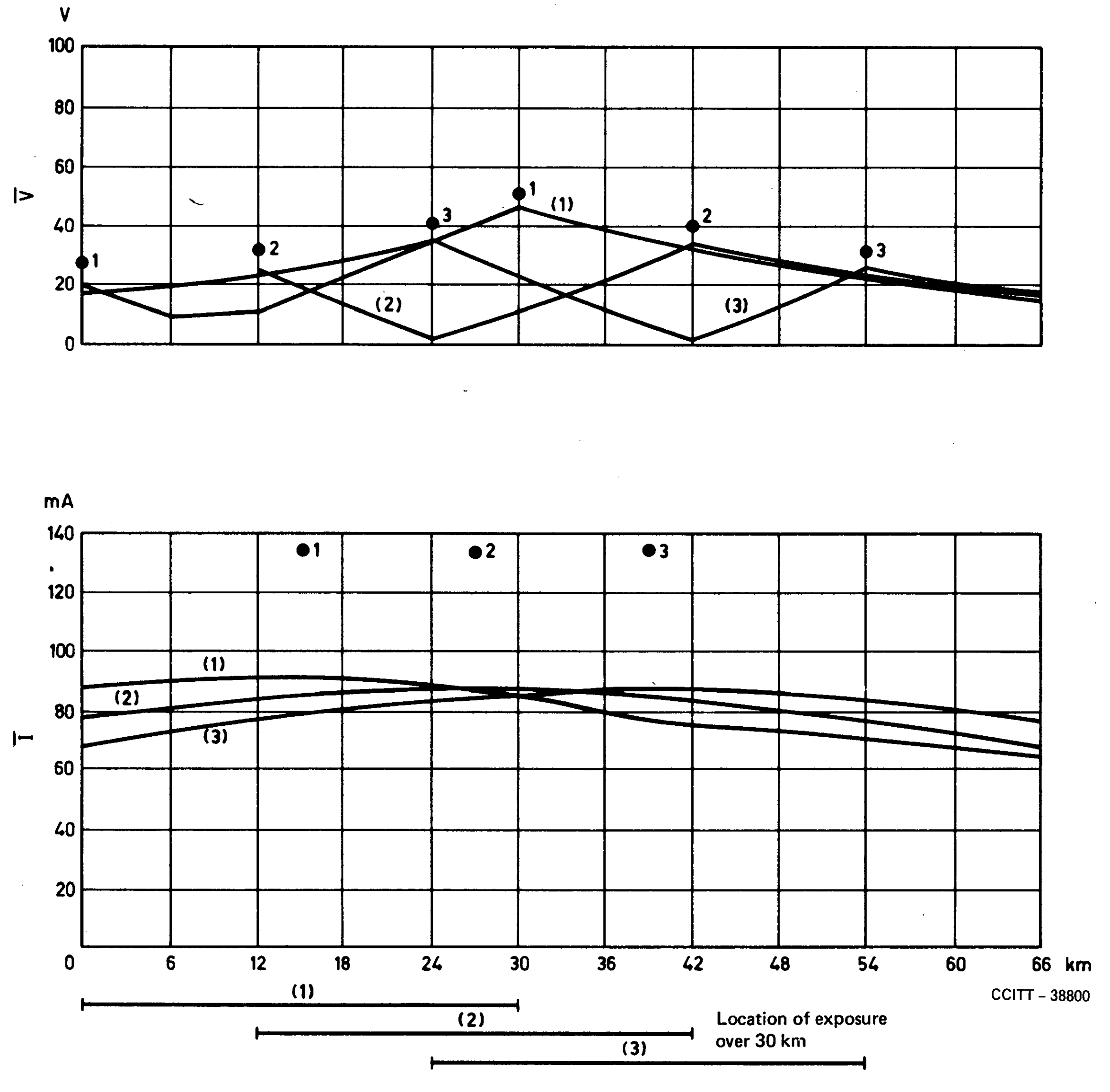
Voltages and currents for a 300-channel route with asymmetrical exposures (outer conductor of coaxial pairs earthed)



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)



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

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)]

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

Geneva, 1976, modified at Malaga-Torremolinos, 1984 and Melbourne, 1988)

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.

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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.

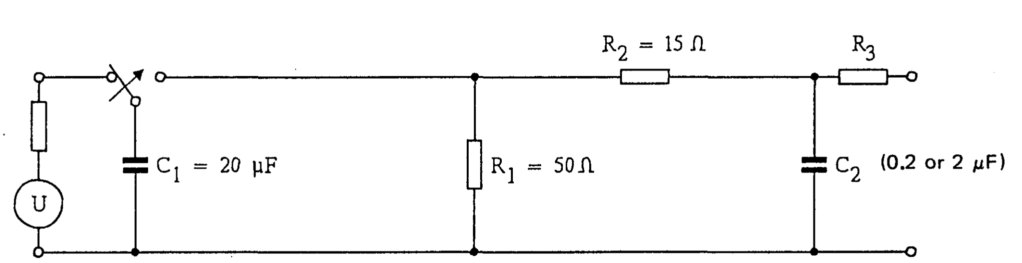


FIGURE 1/K.17

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 (⩾ 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 1a Test 2 Test 2a	Test 3	Test 1 Test 1a Test 2 Test 2a	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.

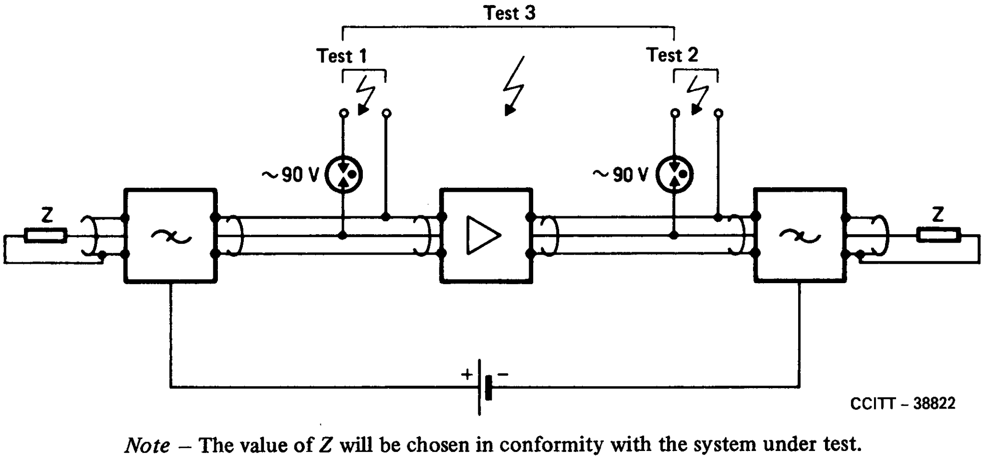
The tests are carried out with the polarity reversed at consecutive pulses, with a time interval of one minute between pulses; the number of pulses applied to each test point in the different cases is given in the bottom line of Table 1/K.17. Impulse waves should be applied at the following points:

- *Test 1:* at the input of the repeater, with the output terminated by its characteristic impedance;
- *Test 1a:* between input terminals of the repeater and conductive housing normally connected to earth in the case of symmetric pair repeaters;
- *Test 2:* at the output of the repeater, with the input terminated by its characteristic impedance;
- *Test 2a:* between output terminals of the repeater and conductive housing normally connected to earth in the case of symmetric pair repeaters.
- *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).

Equipments protected with arresters and installed on symmetrical pair cables, which are induced by a.c. power or traction lines, can be tested with an alternating current, applied for 0.5 second. Current intensity and frequency are comparable to the alternating currents that are likely to be encountered in practice, but should not exceed 10 A r.m.s.

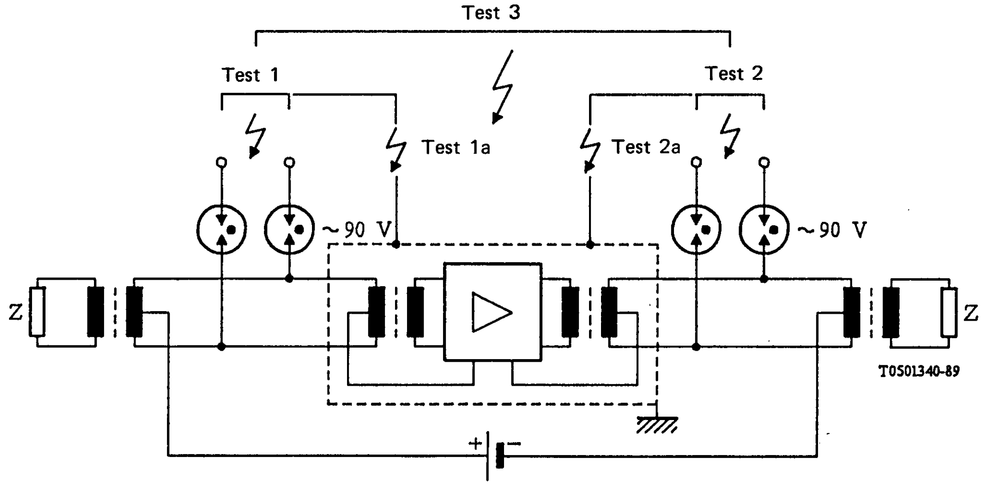
Power should be supplied to the repeater during Tests 1, 1a, 2 and 2a, but not for Test 3.

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



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 [3])) until they do so.

[3]) 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, 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* [4)]

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.

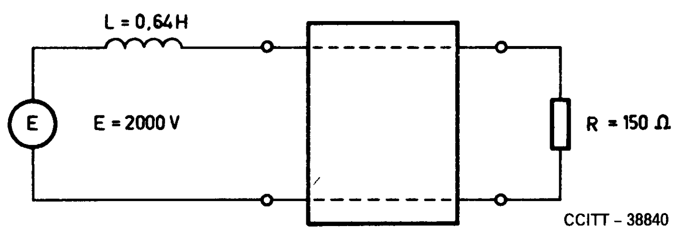


FIGURE 4/K.17

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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4) 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.

3.3 *Test conditions for regenerators and power feeding sources used on optical fibre transmission systems*

The following tests are applicable for all types of regenerators.

In principle two types of regenerators exist: Regenerators with housings on floating potential and regenerators with housings connected to local earth. The regenerators may also be power-fed via separate d.c.-converters. These stand-alone units may be also considered as one "regenerator" for the purposes of this Recommendation.

3.3.1 *Prototype tests*

3.3.1.1 *Impulse tests*

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

Tests should be applied to equipment as indicated in Figure 5/K.17.

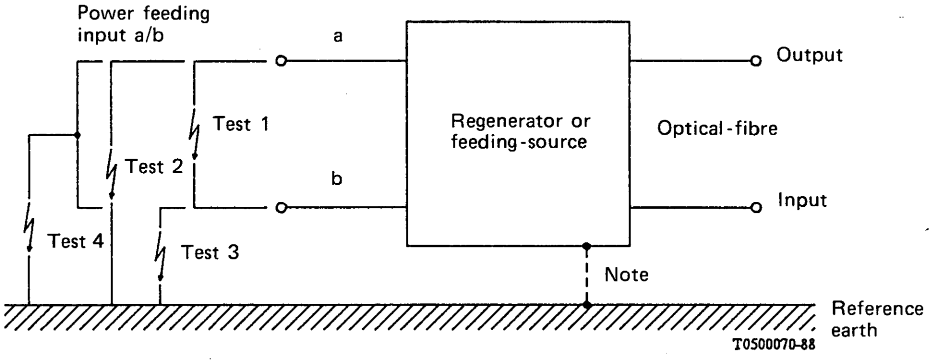
- *Test 1:* between terminals *a* and *b* of the power feeding path;
- *Test 2:* between terminal *a* of power feeding path and reference earth.
- *Test 3:* between terminal *b* of power feeding path and reference earth.
- *Test 4:* between both terminals *a* and *b* of power feeding path and reference earth.

Earth connections of housings to reference earth should be the same as used in practice.

TABLE 2/K.17

Characteristic of waveforms to be used for impulse test of optical fibre systems

	Impulse tests	
	Prototype tests	Acceptance tests
	Test 1 Test 2 Test 3 Test 4	Test 1 Test 4
Column No.	(1)	(2)
Waveform	10/700	100/700
Load	0.1 coulomb	0.06 coulomb
Peak voltages	5 kV	3 kV
Short circuit current	333 A	200 A
C_2	0.2 µF	2 µF
R_3	2.5 Ω	2.5 Ω
Number of pulses	10	2



Note – Earth connection if existing in practice.

FIGURE 5/K.17

Circuit arrangements for impulse tests

3.3.1.2 *A.C. tests*

3.3.1.2.1 *Short-term a.c. induction*

These tests are carried out under conditions listed in Table 3/K.17.

Tests 1, 2, 3 and 4 should be applied to equipment as indicated in Figure 5/K.17 and explained in § 3.3.1.1.

TABLE 3/K.17

Currents and voltages for a.c. tests of optical fibre systems

	A.C. tests	
	Test 1	Test 2 Test 3 Test 4
Voltage		1200 $V_{r.m.s.}$
Current	10 $A_{r.m.s.}$	max. 10 $A_{r.m.s.}$
Duration	0.5 s	0.5 s
Number of tests	1	1

3.3.1.2.2 *Steady state a.c. induction*

These tests should be carried out in accordance with § 2.3b) and equipment should operate during tests without significant increase of bit error rate.

3.3.1.3 *Immunity test against fast transients induced in the power feeding path*

These tests may be carried out to ensure that the regenerator is sufficiently protected against transients occurring in the power feeding path.

These tests should be applied to equipment as indicated in Figure 6/K.17.

For testing, a generator according to IEC publication 801-4 should be used. At test voltages up to 1 kV the simulated signal transmission should not be disturbed severely. It is recommended to carry out this test if the power feeding path is not sufficiently shielded and interferences due to switching in electic power systems may be expected.

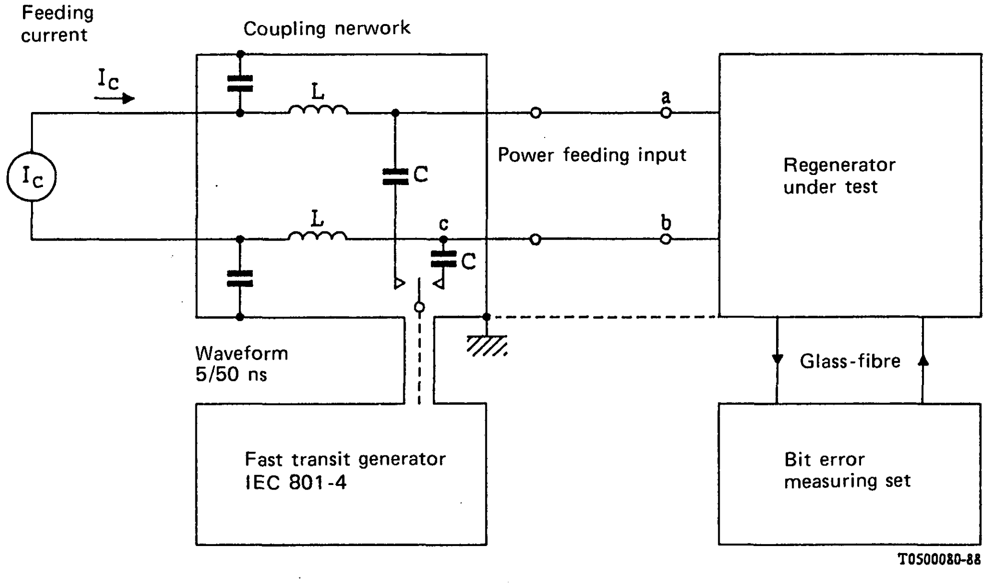


FIGURE 6/K.17

Immunity test for regenerators for glass-fibre systems

3.3.2 *Acceptance tests*

Only impulse tests will be carried out under conditions listed in column 2 of Table 2/K.17.

Tests 1 and 4 have to be performed taking into account the remarks given in § 1.4.

References

[1] IEC publication No. 60-2 *High-voltage test techniques, Part 2: Test procedures*, Geneva, 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 electric power and electrified railway lines*, Vol. VI, ITU, Geneva, 1988.

Recommendation K.18

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

Geneva, 1980, modified at Malaga-Torremolinos, 1984 and at Melbourne, 1988)

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:

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

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

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]).

$$E_v = \frac{1}{r} \sqrt{\frac{1.5 \, P Z_0}{2\pi}} \qquad (2\text{-}4)$$

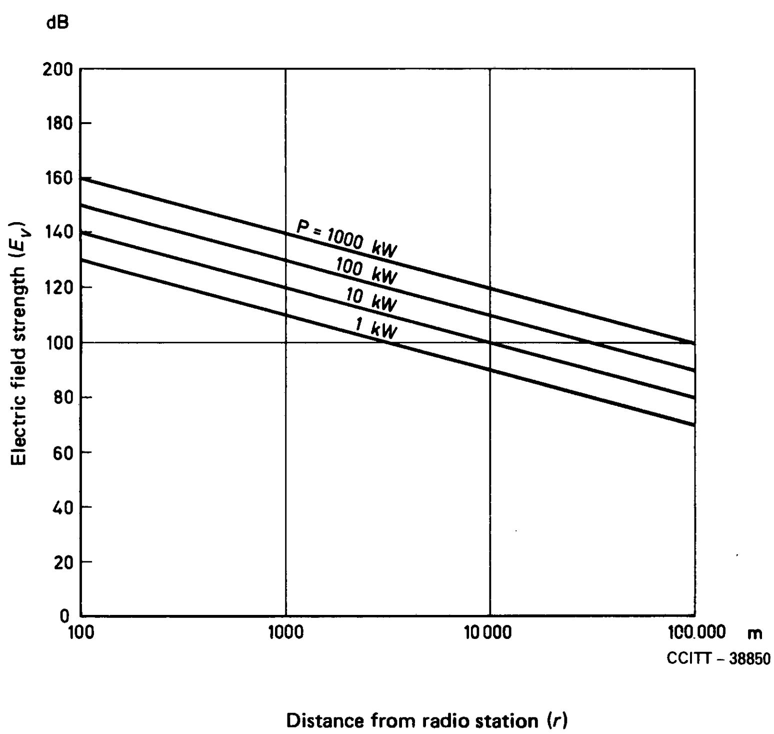
where

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:

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

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

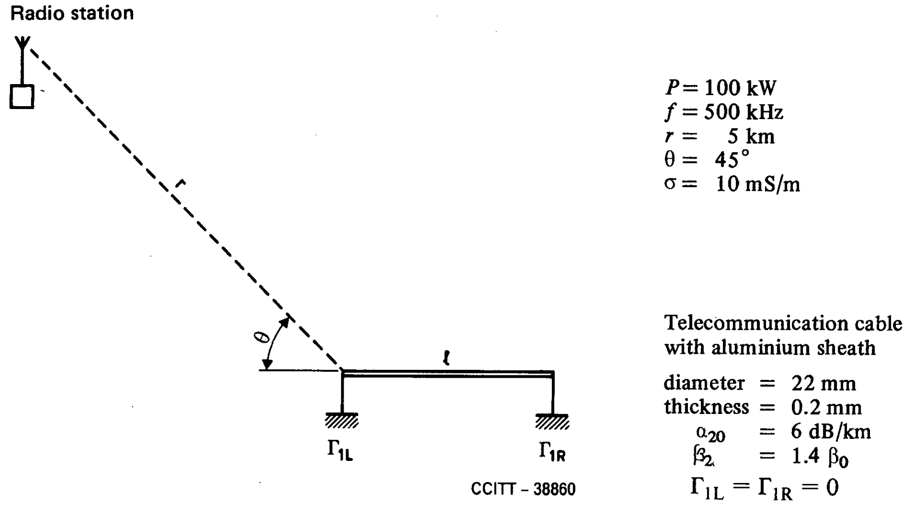


FIGURE 2/K.18

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.

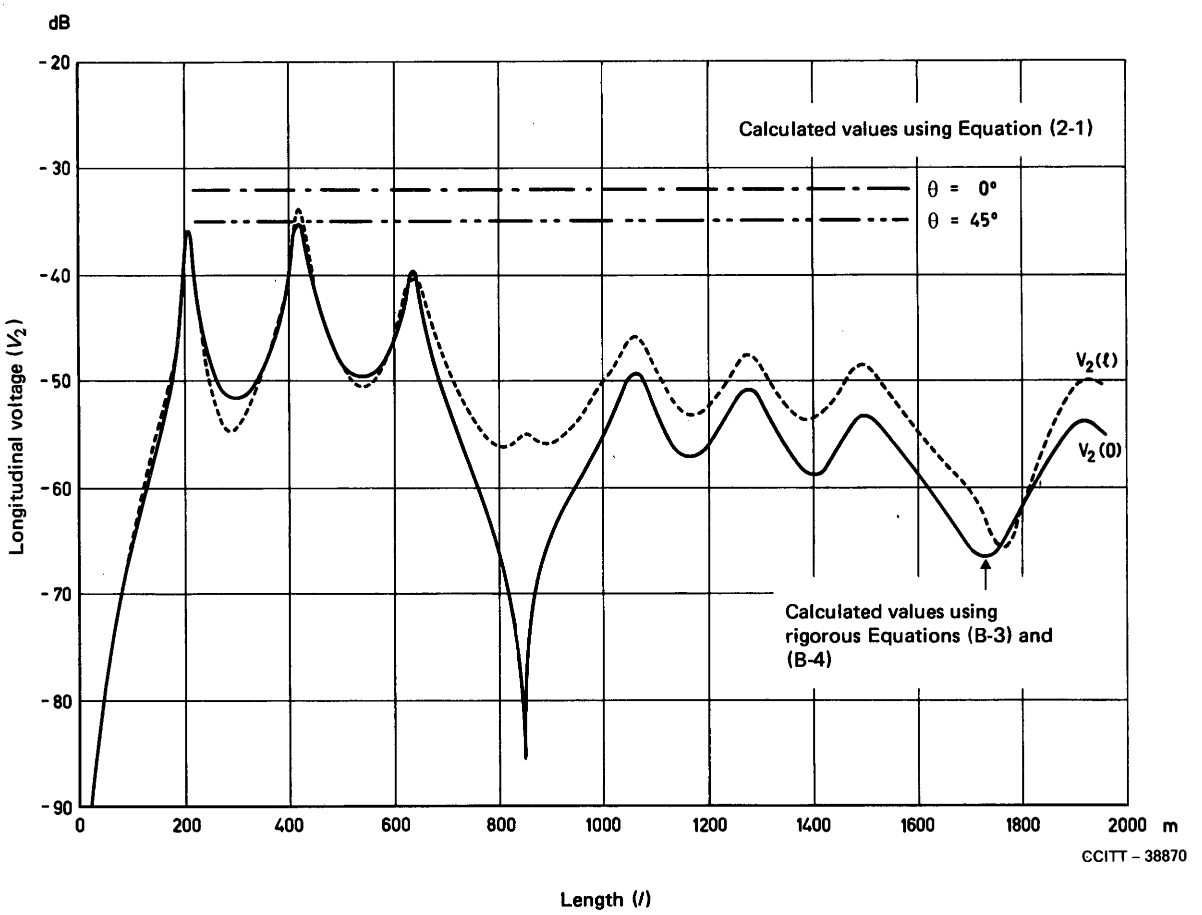


FIGURE 3/K.18

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:

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

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 = L) is the voltage in earth return circuit with mismatching at $x = 0$

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

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

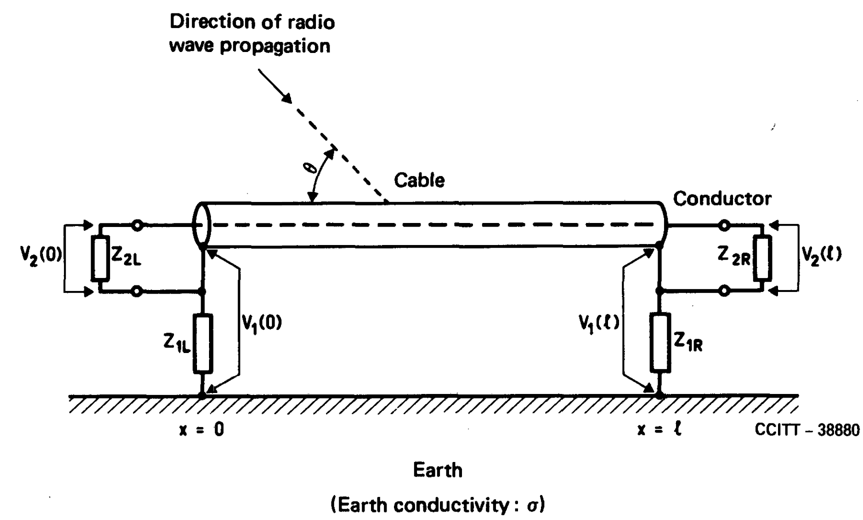


FIGURE A-1/K.18

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:

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

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

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

$$V_{20}(l) = \frac{P E_V \cos\theta \, Z_K}{4 Z_{01}} \Bigg[\Bigg\{ \frac{1}{\gamma_1 - j\beta_0 \cos\theta} + \frac{1}{\gamma_1 + j\beta_0 \cos\theta} \Bigg\} \cdot$$

$$\cdot \frac{1 - e^{-(\gamma_2 - j\beta_0 \cos\theta) l}}{\gamma_2 - j\beta_0 \cos\theta} e^{-j\beta_0 \cos\theta l} + \Bigg\{ - \frac{1}{\gamma_1 - j\beta_0 \cos\theta} +$$

$$+ \frac{1}{1 - \Gamma_{1L} \Gamma_{1R} e^{-2\gamma_1 l}} \Bigg(\Gamma_{1L} \frac{1 - e^{-(\gamma_1 + j\beta_0 \cos\theta) l}}{\gamma_1 + j\beta_0 \cos\theta} + \Gamma_{1L} \Gamma_{1R} e^{-j\beta_0 \cos\theta l} \cdot$$

$$\cdot e^{-\gamma_1 l} \frac{1 - e^{-(\gamma_1 - j\beta_0 \cos\theta) l}}{\gamma_1 - j\beta_0 \cos\theta} \Bigg) \Bigg\} \frac{1 - e^{-(\gamma_2 - \gamma_1) l}}{\gamma_2 - \gamma_1} e^{-\gamma_1 l} +$$

$$+ \Bigg\{ - \frac{e^{-(\gamma_1 + j\beta_0 \cos\theta) l}}{\gamma_1 + j\beta_0 \cos\theta} + \frac{1}{1 - \Gamma_{1L} \Gamma_{1R} e^{-2\gamma_1 l}} \Bigg(\Gamma_{1L} \Gamma_{1R}^{-2\gamma_1 l} \cdot$$

$$\cdot \frac{1 - e^{-(\gamma_1 + j\beta_0 \cos\theta) l}}{\gamma_1 + j\beta_0 \cos\theta} + \Gamma_{1R} e^{-j\beta_0 \cos\theta l} e^{-\gamma_1 l} \frac{1 - e^{-(\gamma_1 - j\beta_0 \cos\theta) l}}{\gamma_1 - j\beta_0 \cos\theta} \Bigg) \Bigg\} \cdot$$

$$\cdot \frac{1 - e^{-(\gamma_2 + \gamma_1) l}}{\gamma_2 + \gamma_1} e^{\gamma_1 l} \Bigg]$$

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

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

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.

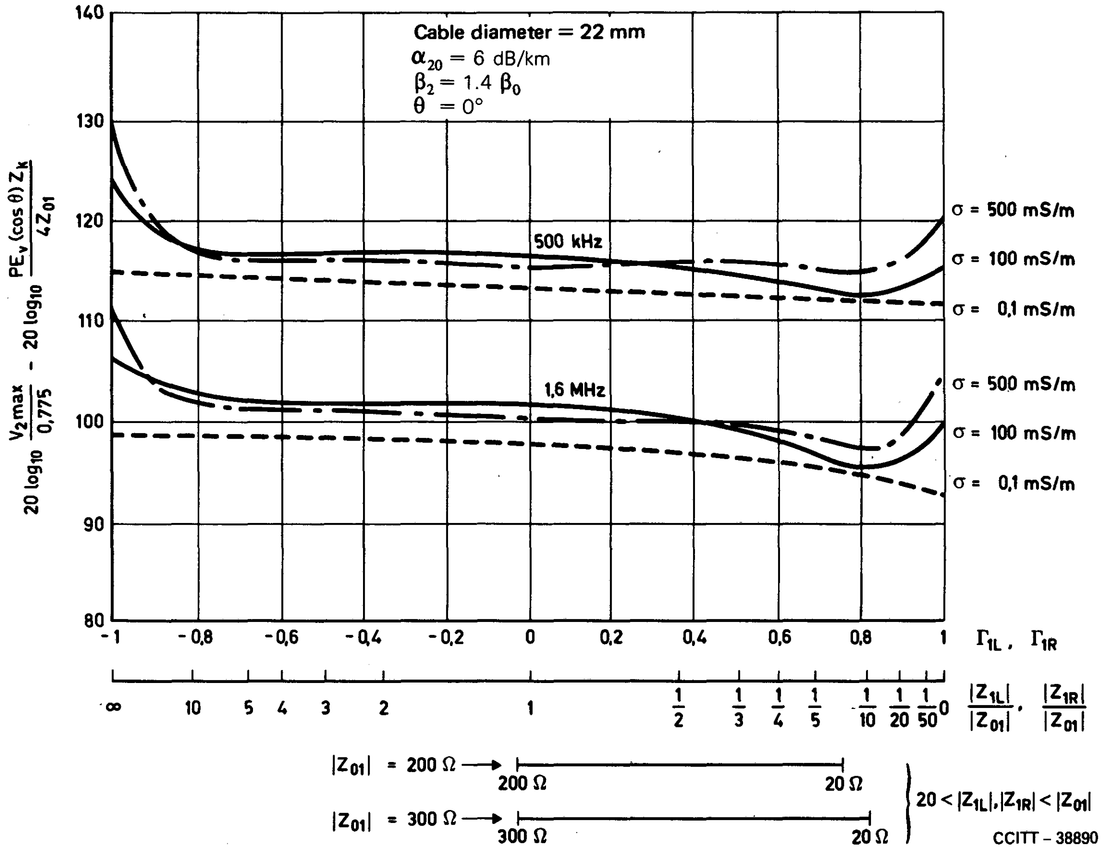


FIGURE C-1/K.18

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

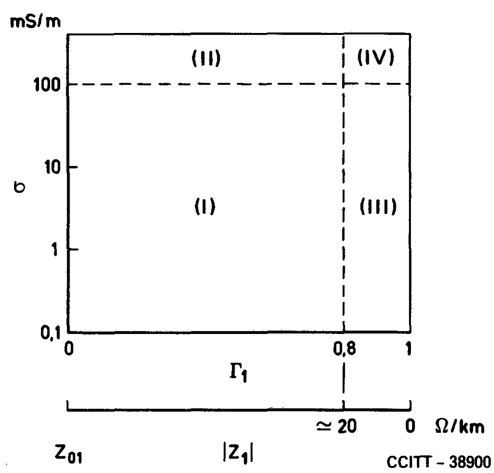


FIGURE C-2/K.18

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).

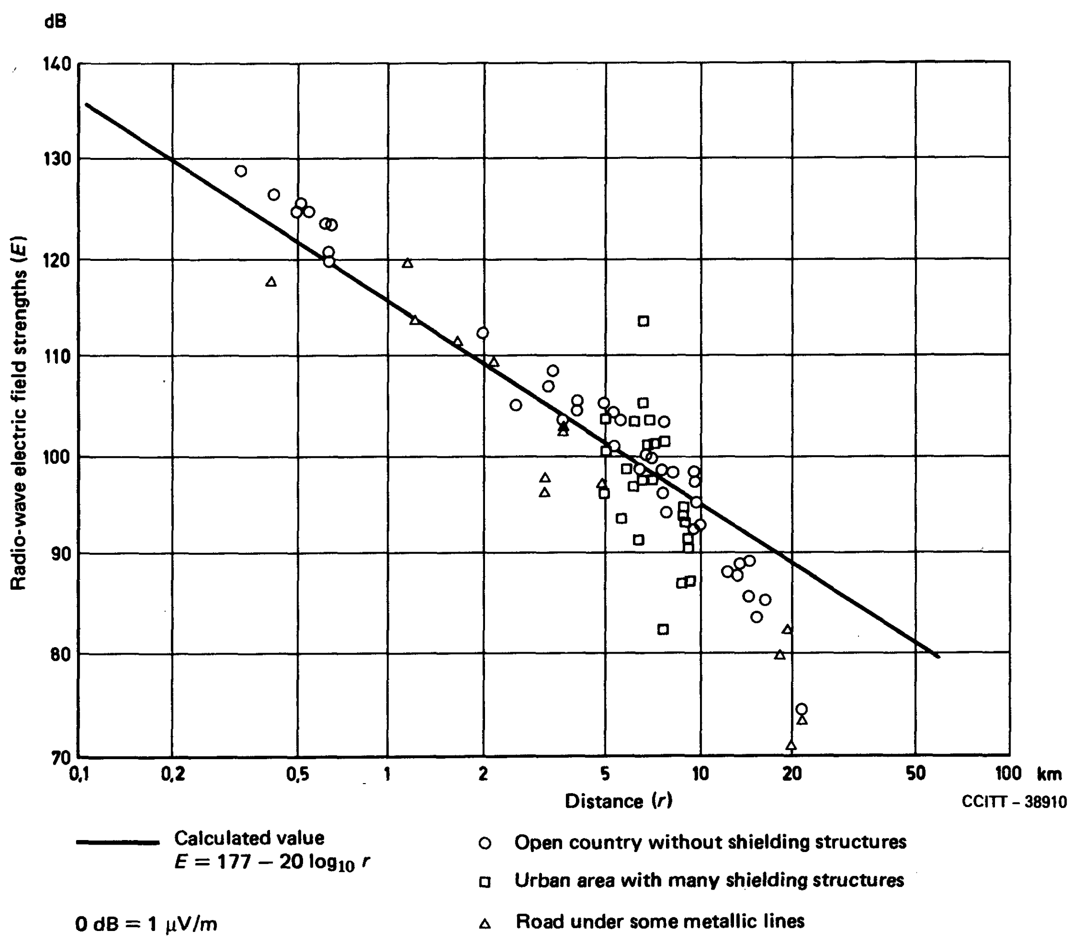


FIGURE D-1/K.18

Radio-wave electric field strength as a function of distance from radio station

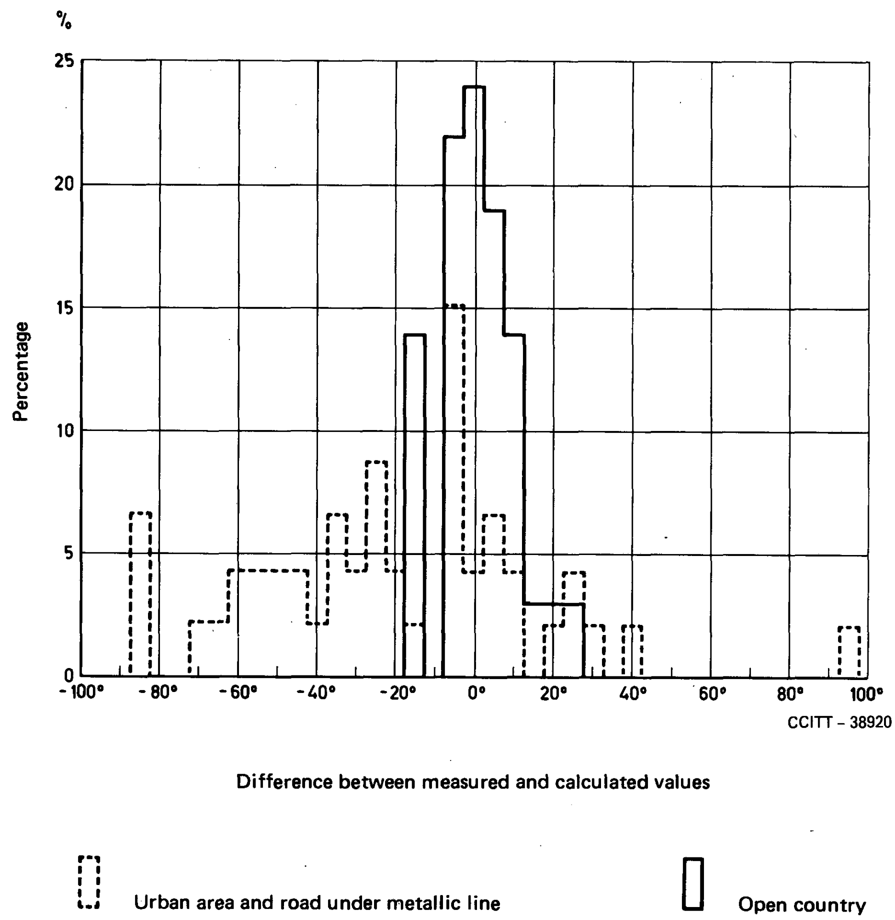


FIGURE D-2/K.18

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).

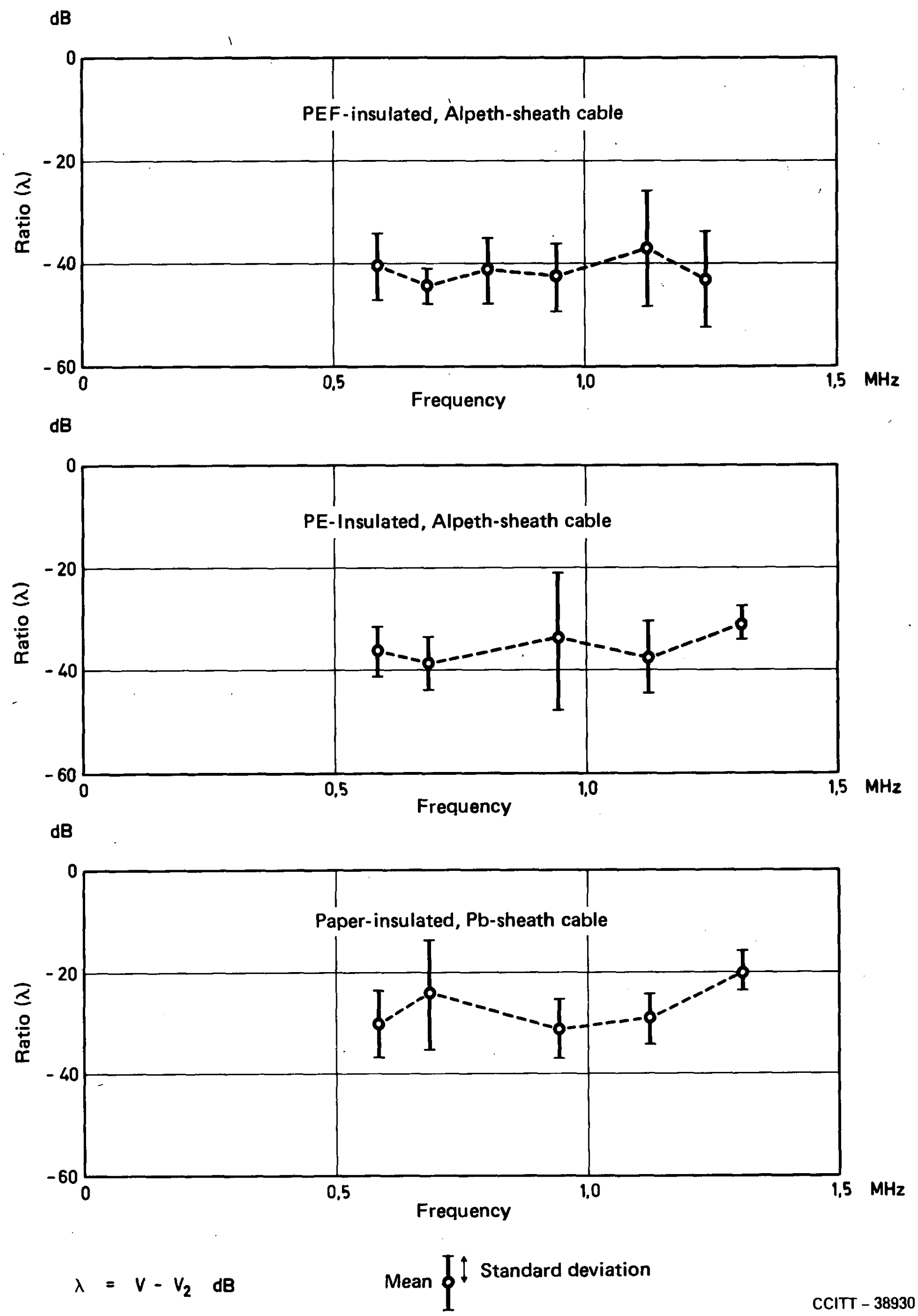


FIGURE E-1/K.18
Examples of the ratio, λ

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 unintelligible	– 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 trans-mission	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 1.8 V/m)	– Mainly overhead cable with metallic screen (balanced pair, coaxial pair) – Cabling in building (between multiplex and antenna, between demodulation stages) – Open wire	Single tone or unintelligible noise in demodulated telephone channel (degradation of SNR in transmission system)	– Improvement in shielding efficiency for cable, cabling, etc. – Improvement on earthing of cable sheath, repeater, terminal 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 – Addition of a compandor to the terminal end of the open-wire carrier circuit – Installation of a sufficiently balanced longitudinal choke coil to the carrier circuits
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

(Geneva, 1980)

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

RESISTIBILITY OF TELECOMMUNICATION SWITCHING EQUIPMENT TO OVERVOLTAGES AND OVERCURRENTS

(Malaga-Torremolinos, 1984)

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 See 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.

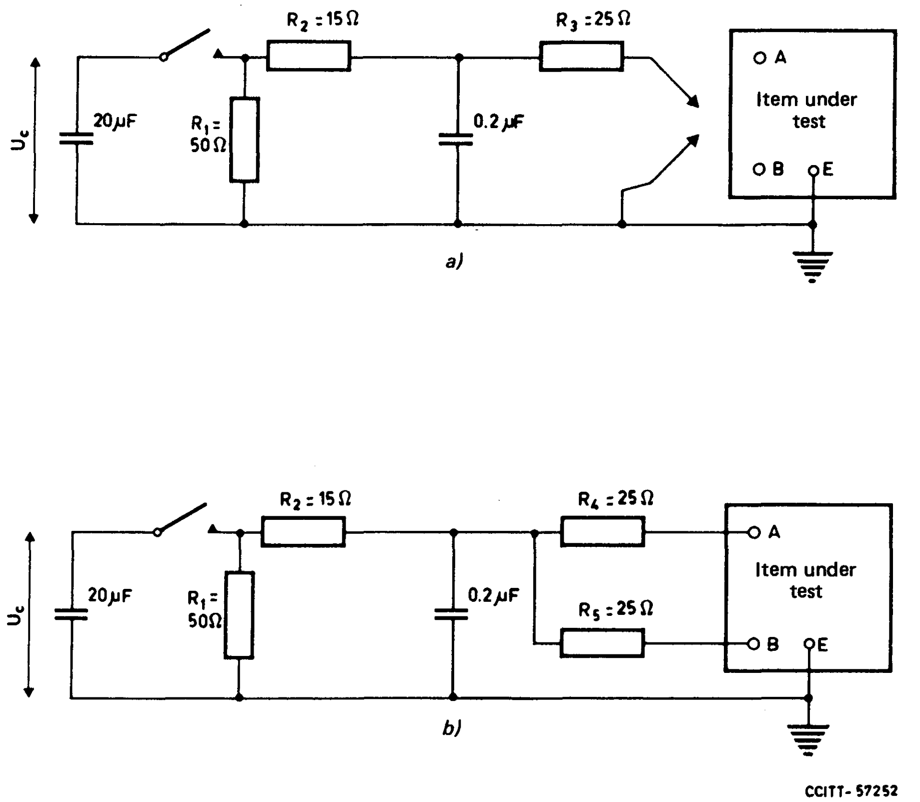


FIGURE 1/K.20

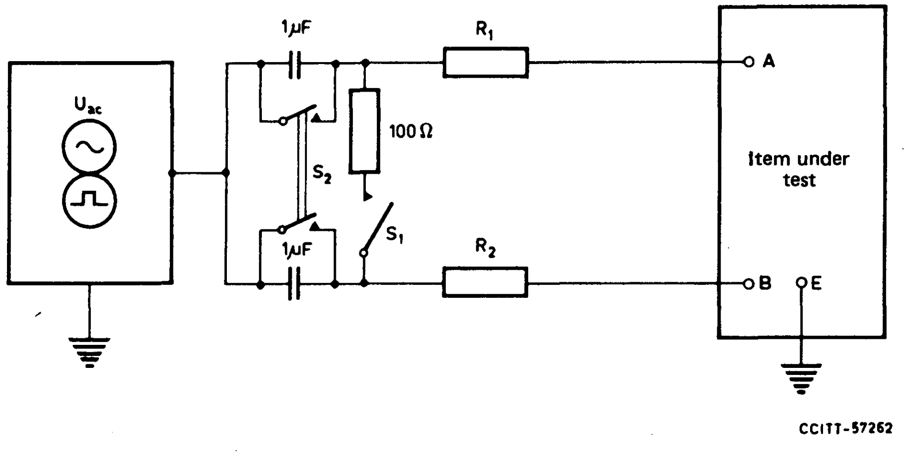


FIGURE 2/K.20

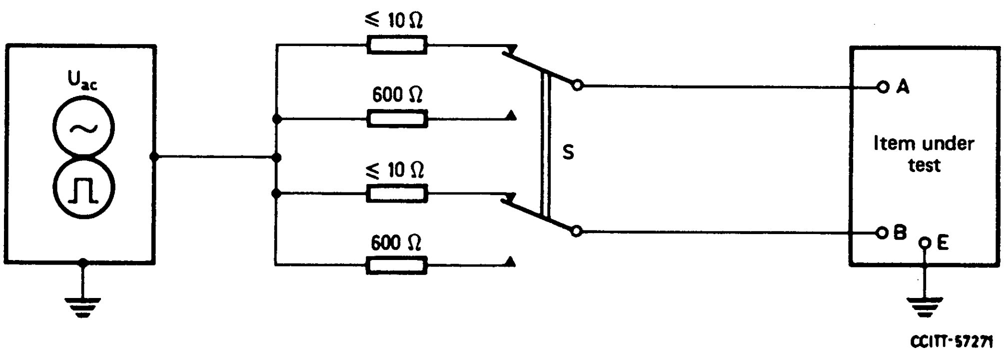


FIGURE 3/K.20

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.

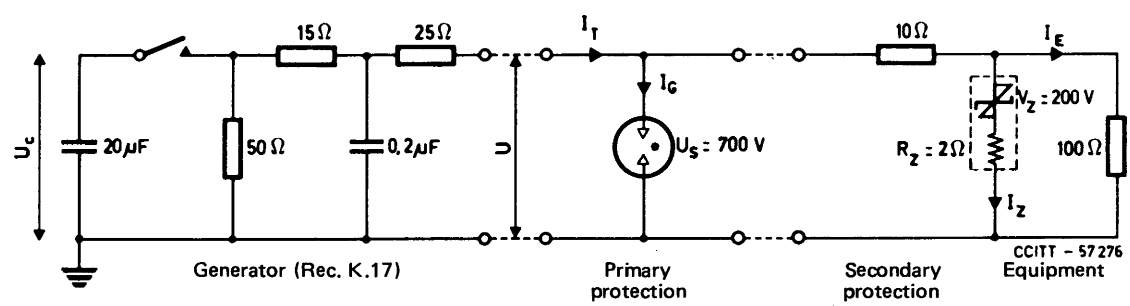
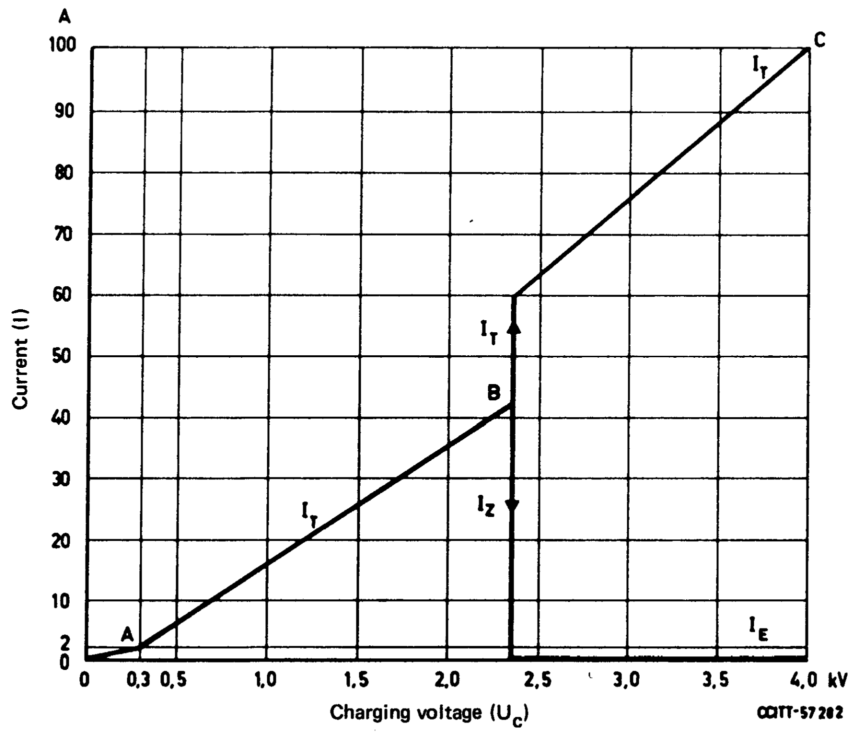


FIGURE A-1/K.20



The voltage and current values along the graph are as follows:

Point on graph		U_C	U	I_T	I_G	I_Z	I_E
		(V)		(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.

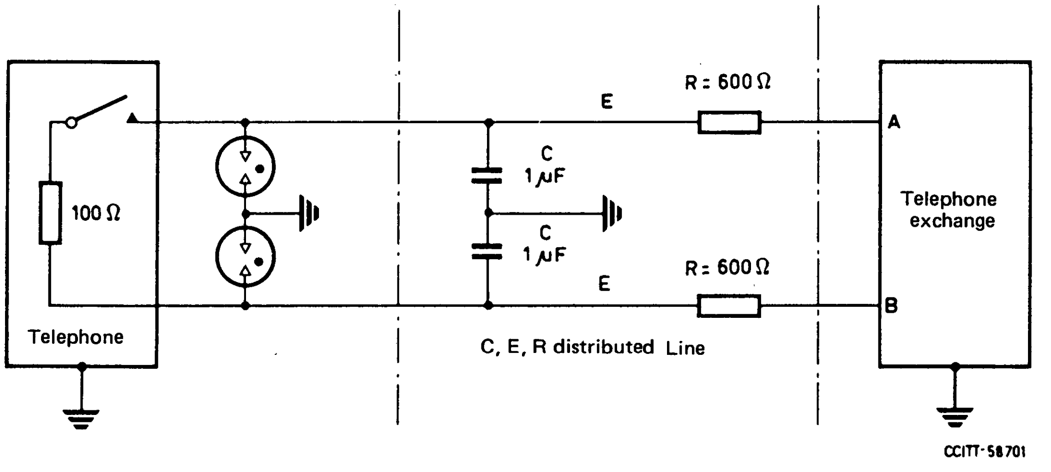


FIGURE A-3/K.20

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.

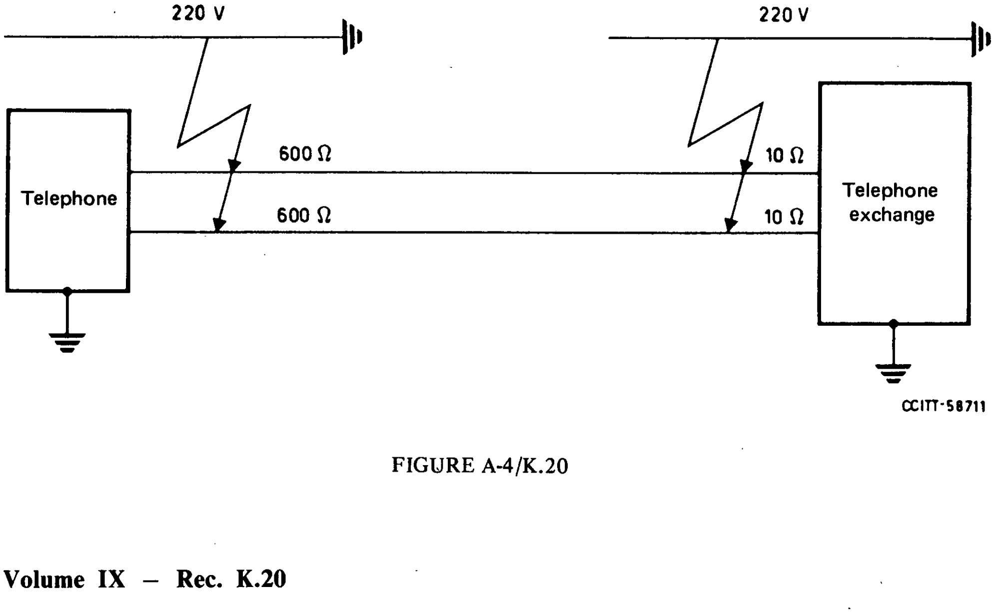


FIGURE A-4/K.20

RESISTIBILITY OF SUBSCRIBERS' TERMINALS TO OVERVOLTAGES AND OVERCURRENTS

(Melbourne, 1988)

Introduction

This Recommendation has been produced by Study Group V to meet the urgent requirements of Administrations and manufacturers who are using or designing subscriber's equipment. The attention of the reader is drawn to the following subjects which CCITT is studying further:

- rise of earth potential;
- electrical fast transients;
- operational tests for barriers between mains ports and telecommunication ports;
- high frequency mains-voltage surges;
- short duration interruptions of mains voltages.

When these studies have been completed, this Recommendation may be expanded.

1 Purpose of the Recommendation

When modern telecommunications equipment is connected to local subscribers' lines, the equipment may be damaged as a result of overvoltages or overcurrents which occur on these lines under occasional conditions. The probability and magnitude of these conditions vary due to many factors, e.g. geography, climate, construction methods, shielding effects. Overvoltage or overcurrent surges arising from electrostatic discharges or transient surges which occur on mains-voltage power supplies may also damage equipment or cause its misoperation. This Recommendation seeks to establish fundamental testing methods which may be varied in detail to suit particular local circumstances and which help to predict the likelihood of survival when the equipment is exposed to these overvoltages or overcurrents.

In its present form, the Recommendation describes tests that should be applied to equipment which is metallically connected directly to balanced pairs. Further studies relating to equipment connected to coaxial and optical fibre cables are being made.

The Recommendation assumes that line protectors are fitted externally to the equipment in exposed areas. Administrations individually will decide their policies for protection. The guidance of Recommendation K.11 should be followed when making this judgement and should take account of the routing of lines to the equipment, in addition to its location.

2 Scope

This Recommendation deals principally with desk-borne equipment. Recommendation K.20 deals with switching equipment powered by central-battery. For the more complex subscriber equipment, Administrations should use either Recommendation K.20 or K.21 as appropriate.

The Recommendation relates to type tests only. Recognizing the difficulty in testing a complex item of subscribers' equipment, the Recommendation concentrates on a series of tests made principally at the telecommunication line and mains input terminals. The tests should be applied at any chosen stage during the normal use of the equipment.

As the equipment may be used in either an exposed or unexposed environment, tests are made with and without line protectors fitted.

The tests for lightning surges assume that an electrical connection between the power system earth terminal and the telecommunications equipment earth can be effected. A study of special test requirements for situations where this is not possible is being made.

The tests for power induction apply only to longitudinal effects and a further study is being made of test requirements for transverse surges.

Some aspects of rise of earth potential, such as may arise from a power line system fault, are not at present covered but are being studied.

Electrical fast transient requirements are not yet included and a study is being made of test requirements for both the telecommunication and mains power lines.

The Recommendation deals primarily with reliability of equipment and although it may provide some level of safety, it is not sufficient by itself to fully protect the user. National standards for electrical safety should be followed in each country where the equipment is used. Furthermore, this Recommendation is not intended to establish whether equipment could produce harmful effects to the network when connected. Interference from low frequency induced voltages or radio frequency interference to the operation of the equipment is not included.

3 Overvoltage and overcurrent conditions

Aspects of overvoltage or overcurrent covered by this Recommendation are:

- surges due to direct or indirect lightning strokes on or near the line plant;
- short-term induction of 50/60 Hz voltages from adjacent power lines or railway systems, usually when these lines or systems develop faults;
- direct contacts between telecommunications lines and power lines, usually of a low voltage nature;
- electrostatic discharges generated by users touching the equipment or adjacent plant;
- transient surges on mains-voltage power supplies to the equipment.

4 Equipment boundary

Variations in equipment make it necessary for each unit to be seen as a "black box" having three or more terminals, A, B, etc. and E (earth). Some protective devices may have already been provided within the equipment, e.g. distributed on cards, or connected to internal terminals. For the purposes of these tests, manufacturers are expected to define the boundaries of the "black box" and any protective device which is thereby included must be considered as an immutable part of the equipment. Where any auxillary telecommunications lead is provided, e.g. to an extension, or as a signalling earth, these wires should be seen to extend the number of terminals to be tested, e.g. A, B, C, D, etc. and E (earth).

5 Test conditions

The following general conditions apply to all the tests specified in §§ 7, 8 and 9 except where otherwise stated.

1) All tests are type tests.
2) The input terminals at which tests on the equipment are to be applied should be identified by the manufacturer and labelled A, B, C, D, etc. and Earth.
3) For the tests specified in §§ 7 and 9 only, the equipment should be enclosed in a foil shroud over those parts likely to have a human contact during use, and the foil connected to the E terminal.
4) The equipment should be tested in each operating mode of significant duration.
5) The equipment should pass the tests listed in §§ 7 and 9 throughout the ranges of temperature and humidity of its intended use.
6) Some of the tests in Table 1/K.21 require the addition of agreed primary protection. It is current practice to protect exposed subscribers' lines with some surge protectors such as gas-discharge tubes. Recognizing that some such device is likely to be needed in most cases to handle high surge currents, and that the operation of these protectors exposes subscribers' equipment to other modified conditions, the characteristics of the external protectors to be used should be agreed between the equipment supplier and the Administration. Administrations applying the tests included in this Recommendation are free to select such protectors with any characteristics within the range acceptable for these nominated devices, when carrying out tests with external protection fitted.

   Protectors having characteristics within the agreed range should be used where specified in Table 1/K.21. 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 and 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 1/K.21.

7) 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.

8) Each test should be applied the number of times indicated in Table 1/K.21. The time interval between applications should be one minute and, in the case of pulse tests, the polarity should be reversed between consecutive pulses.

9) Power induction and power contact tests should be made at the frequency of the a.c. mains or electric railway used in the country of application.

6 Permitted malfunction or damage

Two levels of malfunction or damage are recognized:

- *Criterion A* – Equipment shall withstand the test without damage or other disturbance, e.g. 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 occuring 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.

7 Tests related to lightning surges, power induction and contacts

The test circuits used for the three overvoltage or overcurrent conditions are as follows:

- Figure 1/K.21: lightning surges;
- Figure 2/K.21: power induction;
- Figure 3/K.21: power contacts.

The equipment should be tested according to Table 1/K.21.

8 Tests related to electrostatic discharges

The requirements of IEC publication 801-2 [1] should be followed. The equipment should meet criterion A of this Recommendation when tested to both severity levels 2 and 4 of IEC 801-2. These two severity levels have been chosen because at severity level 2, the rise time is much faster than that at severity level 4. This fast rise time may cause coupling into sensitive circuits to take place and will require an assessment for misoperation due to software corruption, rather than just for energy dissipation.

However, when deemed appropriate by an Administration, alternative severity levels of testing may be used. In addition, an Administration may choose to relax the conditions of criterion A to a limited extent.

9 Tests related to mains-powered equipment

The following tests are made on mains-powered equipment to ensure that the equipment can adequately resist high voltage surges which may arise on power conductors from lightning or other causes, such as load switching.

The equipment under test should be tested with normal operating power applied and with the telecommunication line access at the equipment terminated in such a manner as to simulate the conditions in each state of operation of significant duration.

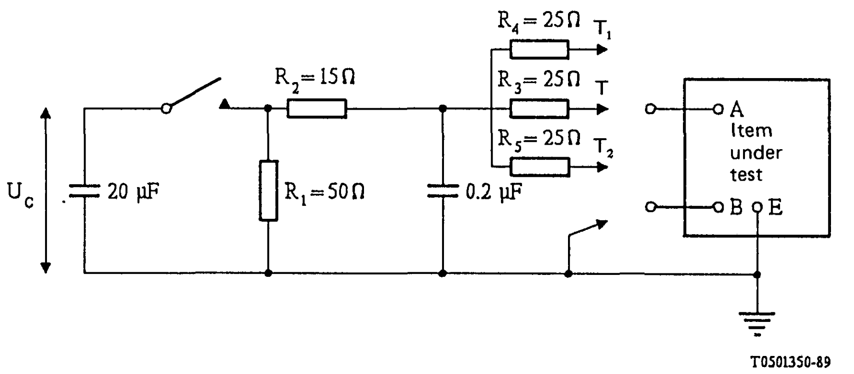


FIGURE 1/K.21

Test circuit for lightning surges

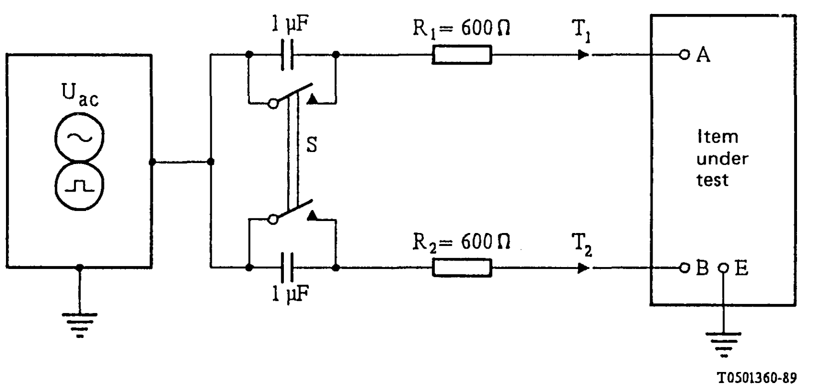


FIGURE 2/K.21

Test circuit for power induction

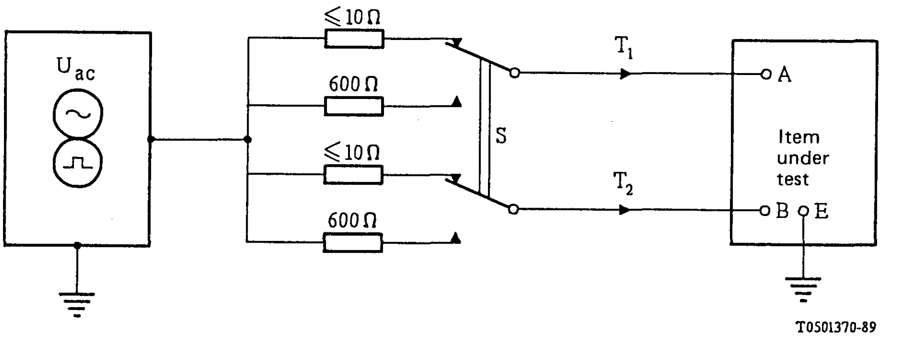


FIGURE 3/K.21

Test circuit for power contacts

TABLE 1/K.21

No.	Test	Terminal connections	Test circuit	Maximum test voltage and duration	Number of tests	Added protection [see 6) of § 5]	Acceptance criteria (see § 6)
1	Lightning surge simulation	T and A, B, etc. in turn with all other equipment terminals earthed (Note 1)	Figure 1/K.21	U_c = 1.0 kV (Note 2)	10	None	Criterion A
				U_c = 4 kV (Note 3)	10	Agreed primary protection	Criterion A
		T_1 and A T_2 and B	Figure 1/K.21	U_c = 1.5 kV (Note 2)	10	None	Criterion A
				U_c = 4 kV (Note 3)	10	Agreed primary protection	Criterion A
2	Power induction	T_1 and A T_2 and B	Figure 2/K.21 S unoperated	$U_{ac\,(\max)}$ = 300 V_{rms} for 200 ms (Note 4)	5	None	Criterion A
			Figure 2/K.21 S operated	(Note 5)	1	Agreed primary protection	Criterion B
3	Power contact	T_1 and A T_2 and B	Figure 3/K.21 Tests made with S in each position (Note 6)	$U_{ac\,(\max)}$ = 230 V_{rms} for 15 min (See Note 4)	1 For each position of S	None	Criterion B

Note 1 – An earthed connection may prevent the establishment of normal operation conditions when the test is made. In these cases, alternative testing procedures should be followed to meet the requirements of this test (e.g. a low voltage spark-gap or other variation in the earth connection should be used).

Note 2 – Administrations may choose other values of $U_{c\,(\max)}$ to suit local circumstances, e.g. to avoid the use of protectors or to align with the impulse spark-over voltage of protectors that are normally used.

Note 3 – Administrations may vary $U_{c\,(\max)}$ to meet their local requirements.

Note 4 – 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 voltages).

Note 5 – Voltages and durations should be in accordance with CCITT directives or such other limits as Administrations.

Note 6 – Fuses, fuse cables, etc., may be left in circuit during these tests. The current conducted by wiring shall not constitute a fire hazard within the premises where the equipment is located.

Equipment not complying with a) below should meet criterion A of this Recommendation when tested with surge tests applied between phase, neutral and protective earth terminals of the equipment in accordance with b) below.

a) *Insulation coordination*

IEC publication 664 [2] describes overvoltage categories for mains-powered equipment, including telecommunication equipment, in respect of overvoltages arising in the supply network. Most subscribers' equipment is expected to be installed in overvoltage category 11 in which the maximum surge voltage arriving at its mains terminals is 2.5 kV peak. Given this and certain other assumptions about atmospheric pollution (e.g. dust) and the quality of insulation, IEC 664 gives guidance to IEC standards committees on coordinated creepage distances and clearances that can be expected to give adequate performance during the lifetime of the equipment.

The guidance in IEC 664 has been adopted in IEC publication 950 [3]. Subject to cases mentioned in c) below, telecommunication equipment that employs insulation spacings that are dimensioned and tested in accordance with IEC 950 need not to be subjected to further tests under this Recommendation.

b) *No insulation coordination*

Where reliance is not placed on insulation coordination, the equipment shall be subjected to tests along the lines indicated in references [3] to [5].

c) *Exceptional overvoltages*

In cases where electrical disturbances may be of exceptional amplitude or simply greater than the values adopted for the tests, it is recommended that additional protective measures external to the terminal equipment be used, e.g.:

- power transformers with high dielectric strength (or the order of 10 kV) in relation to the mains leads;
- overvoltage limiting devices such as lightning arrestors, air gaps, non-linear resistances, etc.;
- combinations of the above.

Note 1 – For situation a), the experience of one country has shown that a Rec. K.17 generator may be substituted, i.e. with a waveshape 10/700 μs and an internal impedance of 40 ohms. A test voltage of $V_{c(\max)} = 2.5$ kV assured a satisfactory performance of equipment operated at a load level interface of low-voltage distribution systems with a nominal voltage of 230/400 V.

Note 2 – Attention is drawn to matters of safety which relate to electrical barriers between the mains power and telecommunication line terminals. These are normally subject to national regulations which have to be followed in each country.

References

[1] IEC publication 801-2, *Electromagnetic compatibility for industrial-process measurement and control equipment, Part 2: Electrostatic discharge requirements*, Geneva, 1984.

[2] IEC publication 664 *Insulation co-ordination within low-voltage systems including clearances and creepage distances for equipment*, Geneva, 1980.

[3] IEC publication 950 *Safety of information technology equipment including electrical business equipment*, Geneva, 1986.

[4] ANSI/IEEE Standard C 62.41, *IEEE guide for surge voltages in low-voltage AC power circuits*, New York, 1980.

[5] CENELEC ENV 41003 *Particular requirements for information technology equipment when connected to a telecommunication network*, Brussels, 1988.

OVERVOLTAGE RESISTIBILITY OF EQUIPMENT CONNECTED TO AN ISDN T/S BUS

(Melbourne, 1988)

1 General

This Recommendation seeks to establish fundamental testing methods and criteria for the resistibility of telecommunication equipment connected to an internal ISDN T/S bus.

Recommendation K.21 should be followed when assessing the resistibility of equipment to be connected directly to a telecommunication network.

2 Scope

The Recommendation relates to any terminal equipment which is intended to be connected to the 4-wire T/S bus of an ISDN installation. It presumes that suitable isolation is provided between the telecommunication network and the T/S bus at the network termination. It is also assumed that the S-bus has no connection to earth, e.g. no earth-connected voltage-limiting devices with non-linear characteristics can be used. In cases where these assumptions cannot be made, Recommendation K.21 should be followed.

3 Overvoltage and overcurrent conditions

Aspects of overvoltage or overcurrent covered by this Recommendation are:

- surges due to lightning strokes on telecommunication lines or to the building housing the equipment;
- electrostatic discharges generated by users touching the equipment or adjacent plant;
- lightning transient surges on mains-voltage power supplies to the equipment.

4 Equipment boundary

Variations in equipment make it necessary for each unit to be seen as a "black box" having three or more terminals, A, B, . . ., etc. Some protective devices may have already been provided within the equipment, e.g. distributed on cards, or connected to internal terminals. For the purposes of these tests, manufacturers are expected to define the boundaries of the "black box" and any protective device which is thereby included must be considered as an immutable part of the equipment.

5 Test conditions

The following general conditions apply:

1) All tests are type tests.
2) The input terminals at which tests on the equipment are to be applied should be identified by the manufacturer and labelled A, B, etc.
3) For the tests specified in §§ 7 and 9 only, the equipment should be enclosed in a foil shroud over those parts likely to have a human contact during use, and the foil connected to the earth terminal (if it is provided).
4) The equipment should be tested in each operating mode of significant duration.
5) The equipment should pass tests under §§ 7 and 9 through the ranges of temperature and humidity of its intended use.
6) In all cases where a maximum voltage is specified, tests shall also be made at lower voltages if it is necessary to confirm that the equipment will resist any voltage up to the maximum specified.

6 Test compliance

Equipment shall withstand all tests without damage or other disturbance, e.g. corruption of software, misoperation of fault-protection facilities, and shall operate properly within specified limits after the tests. It is not required to operate correctly while the test condition is present.

If specifically permitted by the Administration, the tests may cause the operation of fuses or other devices which have to be replaced or reset before normal operation is restored.

7 Surge tests

7.1 *Test circuits*

Three alternative test circuits may be used:

- a surge generator of 1.2/50 μs open-circuit voltage waveshape and 8/20 μs short-circuit current waveshape;
- a surge generator of 2/10 μs open-circuit voltage waveshape and the same short-circuit current waveshape;
- a surge generator of 1.2/50 μs open-circuit voltage waveshape and a corresponding short-circuit current waveshape. Figure 1/K.22 illustrates a typical test circuit.

The short-circuit current provided by the surge generator shall be approximately 100 A.

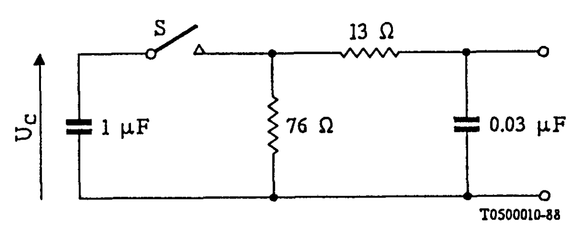


FIGURE 1/K.22

Typical surge generator circuit (see § 7.1)

7.2 *Tests*

The open-circuit voltage of the surge generator should be 1 kV. The surge generator should be connected to the equipment under test through the circuit of Figure 2/K.22. Ten tests should be made with alternating positive and negative polarities.

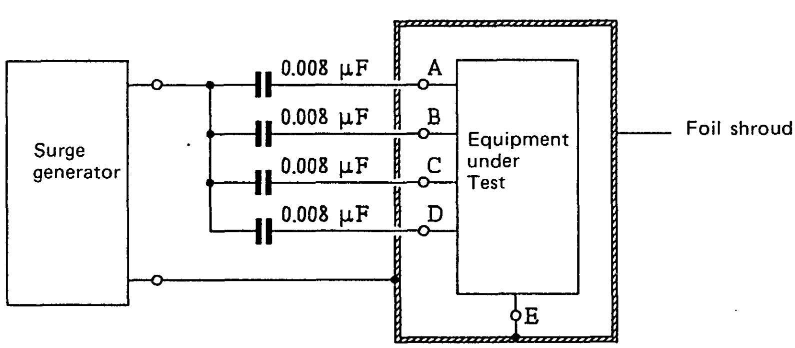


FIGURE 2/K.22

Connection of surge generator to equipment under test (see § 7.2)

8 Tests for electrostatic discharges

The equipment should meet the requirements of IEC publication 801-2 [1] when tested to both severity levels 2 and 4. The two severity levels have been chosen to ensure the equipment is tested with both fast rise times and high test voltages.

9 Tests related to mains-powered equipment

The following tests are made on mains-powered equipment to ensure that the equipment can adequately resist high voltage surges which may arise on power conductors from lightning or other causes, such as load switching.

The equipment under test should be tested with normal operating power applied and with the telecommunication line access at the equipment terminated in such a manner as to simulate the conditions in each state of operation of significant duration.

Equipment not complying with a) below should meet the requirements of § 6 of this Recommendation when tested with surge tests applied between phase, neutral and protective earth terminals of the equipment in accordance with b) below.

a) *Insulation coordination*

IEC publication 664 [2] describes overvoltage categories for mains-powered equipment, including telecommunication equipment, in respect of overvoltages arising in the supply network. Most subscribers' equipment is expected to be installed in overvoltage category 11 in which the maximum surge voltage arriving at its mains terminals is 2.5 kV peak. Given this and certain other assumptions about atmospheric pollution (e.g. dust) and the quality of insulation, IEC 664 gives guidance to IEC standards committees on coordinated creepage distances and clearances that can be expected to give adequate performance during the lifetime of the equipment.

The guidance in IEC 664 has been adopted in IEC publication 950 [3]. Subject to cases mentioned in c) below, telecommunication equipment that employs insulation spacings that are dimensioned and tested in accordance with IEC 950 need not be subjected to further tests under this Recommendation.

b) *No insulation coordination*

Where reliance is not placed on insulation coordination, the equipment shall be subjected to tests along the lines indicated in [3] to [5].

c) *Exceptional voltages*

In cases where electrical disturbances may be of exceptional amplitude or simply greater than the values adopted for the tests, it is recommended that additional protective measures external to the terminal equipment be used, e.g.:

- power transformers with a high dielectric strength (of the order of 10 kV) in relation to the mains leads;
- overvoltage limiting devices such as lightning arrestors, air gaps, nonlinear resistances, etc.;
- combinations of the above.

Note 1 – For situation a), the experience of one country has shown that a Rec. K.17 generator may be substituted, i.e. with a waveshape 10/700 μs and an internal impedance of 40 ohms. A test voltage of $V_{c(\max)}$ = 2.5 kV assured a satisfactory performance of equipment operated at a load level interface of low-voltage distribution systems with a nominal voltage of 230/400 V.

Note 2 – Attention is drawn to matters of safety which relate to electrical barriers between the mains power and telecommunication line terminals. These are normally subject to national regulations which have to be followed in each country.

Note 3 – The attention of the reader is drawn to the following subjects which CCITT is studying further:

- rise of earth potential;
- electrical fast transients;
- operational tests for barriers between mains ports and telecommunication ports;
- high frequency mains-voltage surges;
- short duration interruptions of mains voltages.

When these studies have been completed, this Recommendation may be expanded.

References

[1] IEC publication 801-2 *Electromagnetic compatibility for industrial-process measurement and control equipment, Part 2 : Electric discharge requirements*, Geneva, 1984.

[2] IEC publication 664 *Insulation coordination within low-voltage systems including clearances and creepage distances for equipment*, Geneva, 1980.

[3] IEC publication 950 *Safety of information technology equipment including electrical business equipment*, Geneva, 1986.

[4] ANSI/IEEE Standard C 62.41 *IEEE guide for surge voltages in low-voltage AC power circuits*, New York, 1980.

[5] CENELEC ENV 41003 *Particular requirements for information technology equipment when connected to a telecommunications network*, Brussels, 1988.

Recommendation K.23

TYPES OF INDUCED NOISE AND DESCRIPTION OF NOISE VOLTAGE PARAMETERS FOR ISDN BASIC USER NETWORKS

(Melbourne, 1988)

1 Purpose of this Recommendation

This Recommendation has been produced by Study Group V to meet the urgent requirements of Administrations, manufacturers, and users who should evaluate equipment for its immunity to induced noise in order to design and use the ISDN.

The Recommendation identifies the types of induced noise that can cause degradation of transmission quality and malfunction of the equipment, and the noise voltage parameters that should be evaluated.

2 Scope

This Recommendation covers the degradation of equipment performance due to induced noise voltage on metallic pair cables (including residential inside wire), which is caused by an inducing source external to the cable or by another telecommunication system. However, this Recommendation does not cover interference caused by transmission characteristics of cables (for example, cross talk characteristics).

The Recommendation considers the characteristics of induced noise voltages at metallic-pair ISDN interfaces at subscriber's premises. Interface locations covered by this Recommendation are the S and T interfaces (see Recommendation I.430) as well as the 2-wire interface of the NT1.

The communication line constituting the S/T bus may be confined to a building or connect two separate buildings. The connecting telecommunications line may be either aerial or below-ground.

3 Types of induced noise affecting the ISDN

3.1 *Mode of voltage*

Two voltage modes should be considered: longitudinal voltage and transverse voltage. Figure 1/K.23 illustrates the definition of longitudinal voltage induced in telecommunication lines and the transverse voltage.

When longitudinal voltage is present at equipment interfaces, it may cause malfunction of the equipment. The transverse voltage is induced by conversion from the longitudinal voltage because of transmission line and input terminal equipment impedance unbalance, and by direct coupling with the inducing source. It may cause a degradation of transmission quality. Therefore, both the longitudinal voltage and the transverse voltage should be considered (Figure 2/K.23).

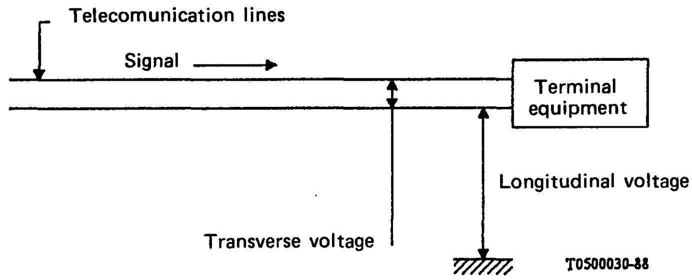


FIGURE 1/K.23

Mode of induced voltage

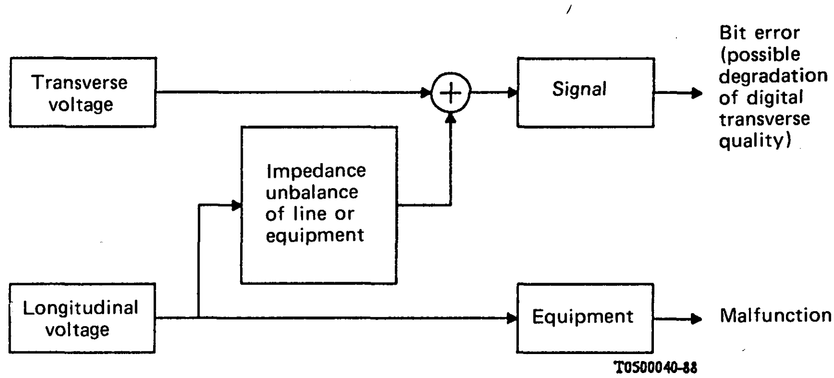


FIGURE 2/K.23

Influence of longitudinal voltage and transverse voltage on a digital transmission line

3.2 *Waveshape of induced noise voltage*

From a waveshape viewpoint, induced noise voltage can be categorized into continuous noise voltage (such as a broadcast wave) and transient noise voltage (such as a switching noise voltage).

The continuous noise waveshape can be reproduced from the components of the frequency spectrum. Continuous noise causes a degradation of the signal-to-noise ratio, which may cause an increase in the error rate.

On the other hand, the transient noise waveshape is composed of spark type waves. As the pulse width of one transient wave is much less than the duration time between two transient waves, each transient wave can be treated as an independent wave. Therefore, a knowledge of the total time of transient noise exceeding the decision voltage is important to the evaluation of digital transmission quality. To evaluate equipment malfunction, the above features of the noise waveshape should be considered.

3.3 *Equipment performance categories*

The induced noise described above may have a number of different functional effects on the performance of equipment and transmission quality. These fall into the following categories:

1) no loss of performance or function;
2) temporary loss of function or performance which is self-recoverable;
3) temporary loss of function or performance which requires operation intervention or system reset;
4) loss of function which is not recoverable due to damage of equipment (components), or due to the continuous nature of the interference.

Table 1/K.23 lists various noise sources that cause induced voltage on transmission lines. It also lists the categories 1) to 4) above of degradation of equipment performance and transmission quality, and the interfaces to be considered for each noise source.

TABLE 1/K.23

Categorization of induced noise source, waveshape to be evaluated, interference to be evaluated and line interfaces involved

Induced noise source (Note 1)			Wave shape to be evaluated		Category of equipment performance (See § 3.3)				Interface to be considered	
			Continuous noise	Transient noise	1	2	3	4	2-wire NT	S and T
External induced noise	Coupling into telecommunication lines from radiating source	① Radio broadcast	X		X			X	X	X
		② Mobil transceiver	X		X	X	X		X	X
		③ Power line (outdoors)	X	X	X	X	X	X	X	
		④ Electric railway	X	X	X	X	X	X	X	
		⑤ Lightning		X	X	X	X	X	X	X
		⑥ Automotive engine ignition		X	X	X	X		X	X
		⑦ Electrostatic discharge		X	X	X	X	X	(Note 2)	(Note 2)
	Coupling into telecommunication lines from a.c. power mains within building	⑧ Continuous operation of electrical apparatus	X		X			X	X (Note 3)	X (Note 3)
		⑨ Switching		X	X	X	X		X (Note 3)	X (Note 3)
Induced noise source in telecommunication system	⑩ Impulsive noise from analog telecommunication circuit			X	X	X	X		X	X
	⑪ Contact noise (e.g. at splices)			X	X	X	X		X	X

Note 1 – Some of these noise sources are being studied under other questions in Study Group V.

Note 2 – Equipment test, not interface.

Note 3 – Test mains input to NT and TE.

4 Induced noise voltage parameters that should be evaluated

Evaluation of transmission quality and malfunction of the equipment using raw data from various induced noise voltage waves is too inefficient. Therefore, it is useful to describe waveshapes using several parameters, which are found by analyzing waveshape features, and to establish a standardized measurement method and a standardized test procedure. This will enable an efficient evaluation of the effect which induced noise voltage has on the digital transmission quality and the malfunction of equipment.

Continuous noise voltage should be evaluated using the amplitudes of the frequency spectrum as a basic parameter since from these amplitudes the waveshapes can be reproduced. Transient noise voltage should be evaluated using amplitude probability distributions, and frequency spectrum as well as waveshape parameters in the time domain (for example, peak value, periodic time, decay time, duration time of burst, etc.). These basic parameters can be used to design a transient noise simulator.

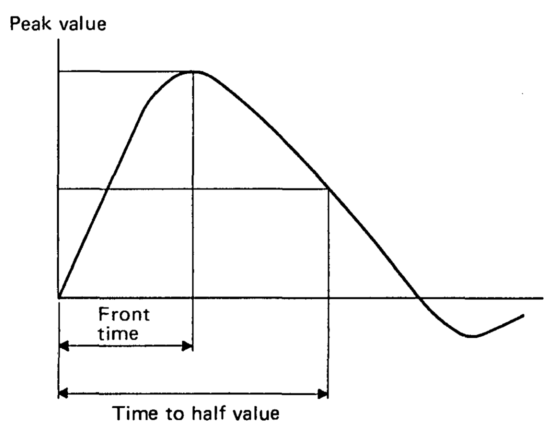
Table 2/K.23 lists some induced noise voltage parameters that should be evaluated.

TABLE 2/K.23

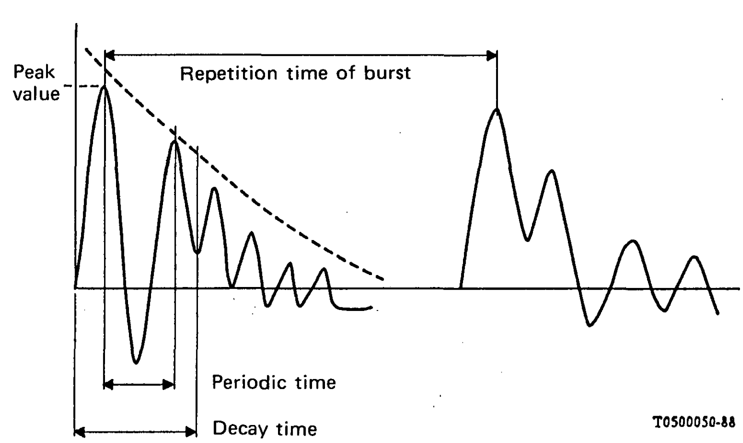
Induced noise voltage parameters that should be evaluated

Type of induced noise waveform (Note)		Frequency domain		Time domain						
		Amplitude	Frequency	Peack value	Front time	Time to half value	Periodic time	Decay time	Duration time of burst	Amplitude probability distribution
Continuous noise voltage	Narrow band ①,②	×	×							
	Broad band ③,④	×	×							
Impulsive noise voltage	Type I ⑤,⑦	×	×	×	×	×				×
	Type II ⑤,⑥,⑧ ⑨,⑩,⑪	×	×	×	×	×	×	×	×	×

Note – The encircled numbers give the induced noise source from Table 1/K.23.



Type I – High energy transient noise



Type II – Repetitive fast transient noise

METHOD FOR MEASURING RADIO-FREQUENCY INDUCED NOISE ON TELECOMMUNICATIONS PAIRS

(Melbourne, 1988)

1 Purpose of this Recommendation

This Recommendation is intended to standardize the method for measuring radio-frequency induced noise that may cause degradation of equipment performance and transmission quality. Standardization of the method for measuring induced noise makes possible the international standardization of the quality of the telecommunication system.

2 Scope

This Recommendation considers measurement methods for radio-frequency induced noise at any telecommunication pair. Locations for measurement are both the cable cntry into a building and the interface point of a terminal equipment.

The frequency range to be considered is 10 kHz to 30 MHz.

Note – Above 30 MHz, the technical problems of making measurements have not been solved and are therefore still under study.

3 Circuits for measuring radio-frequency induced noise voltage

1) *Measured mode of induced noise voltage*

   Both transverse and longitudinal voltages should be measured.

2) *Measured condition of telecommunication line*

   Measurements should be made with all telecommunications equipment disconnected at measuring end and with a measurement termination network.

   i) *Termination network for measurements*

      Measurements should be made at both the cable entry point into the subscribers premises and at the terminal equipment point. In the measurement, a T network shown in Figure 1/K.24 should be used. The longitudinal conversion loss of the T network should be at least 10 dB higher than the value of the LCL for the cable type to be measured (e.g. 60 dB cable requires 70 dB measurement termination network).

      Note – Values of R_x and R_y are under consideration. Administrations and RPOAs are requested to make measurements at both sets of values indicated in Figure 1/K.24.

   ii) *Reference earthing point*

      Either of two reference earthing points may be used. In order of preference they are: 1) the screen of the cable, or 2) the primary protection ground terminal, protective earth, or nearby grounded metal work. Since it affects the result, the reference earthing point used for a measurement should be stated.

      Note – For transverse measurements, a connection to a reference point may not be required, but care must be taken with the capacitance of the measurement equipment to ground. This may be done by using battery powered measuring equipment. An isolating transformer for mains-powered equipment, or a balun termination network, must be used when measuring metallic transverse voltage.

   iii) *Termination network to use at the central office*

      On inside house wire (such as the S/T interface line of ISDN) it is important to terminate the far end of the cable. However, when measuring at the entry point of the local network into the customer's premises (such as the 2-wire interface to NT1 of ISDN), it is not important to have a termination at the far end if the cable length exceeds 1 km. Less than 1 km, it may still be possible to make measurements without terminating the far end, depending on the frequency of the interfering signal and the make-up of the local network.

3) *Detector type*

The detector shall have fundamental characteristics as defined in Section 1 of CISPR specification for radio interference measuring apparatus and measurement method, CISPR publication No. 16, 1987.

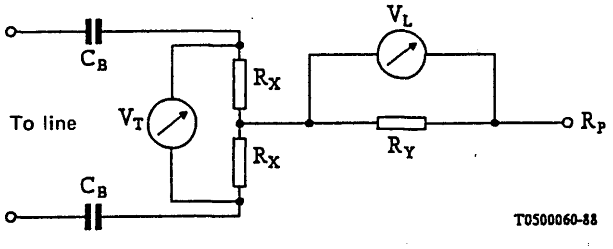
4) *Bandwidth of measurement*

The bandwidth of measurement shall have fundamental characteristics as defined in Section 1 of CISPR specification for radio interference measuring apparatus and measurement method, CISPR publication No. 16, 1987.

Improvements in narrowing the bandwidth and the standardization of appropriate measuring equipment needs further study in cooperation with CISPR (International Special Committee on Radio Interference.).

5) *Electric field immunity of measurement equipment*

The test equipment should have an overall immunity to electromagnetic fields in accordance with CISPR publication 16. Adequate accuracy should be provided for extending the use of the equipment to locations with field strengths above 3 V/m to 10 V/m.



$C_B > 5\ \mu F$

R_M (=2R_X) (ohm)	R_L (=[R_X/2] + R_Y) (ohm)
135	90
400	150

Rp Reference earthing point

FIGURE 1/K.24

Measurement termination network for radio-frequency induced noise voltage

Recommendation K.25

LIGHTNING PROTECTION OF OPTICAL FIBRE CABLES

(Mlebourne, 1988)

1 Introduction

Communications using optical fibres are commonly considered to be immune from damage through surge currents, e.g. lightning. Not all optical fibre cables are, however, completely non-metallic. Components which provide tensile strength during installation, a moisture barrier, rodent protection or communication facilities during repairs may have metal parts. Lightning may strike these components and damage may be caused to the cable.

This damage may be minimized if adequate insulation exists to separate metallic components and if the cable is designed to withstand thermal and mechanical effects at the location of the strike. Adequate dielectric strength between metallic components may prevent repeated arcing taking place between components.

General information regarding the protection of telecommunication lines against lightning given in the manual *The protection of telecommunication lines and equipment against lightning discharges* [1] can be used for both aerial and buried plants with optical fibre cables containing metallic components.

This Recommendation gives interim advice as follows:

- guidance in the use of the manual [1] to evaluate the need to protect optical fibre cables (§ 2) and in selecting the protective measures to minimize damage due to lightning (§ 3);
- to give test methods to evaluate the resistibility of optical fibre cables (§ 3.4).

Future work on this Recommendation is described in § 5.

2 Need for protection

The need for lightning protection of an optical fibre cable depends on the annual frequency of fibre damage N_d and on its tolerable number N_t.

The annual damage rate can be estimated by using the manual [1], Chapter 7 *Frequency of breakdowns in telecommunication systems as a result of lightning discharges.* See also § 5 below.

The maximum lightning current which does not cause faults in the cable is the admissible current indicated in the formulae of this chapter and it refers to secondary damage, i.e. dielectric breakdown in the cable.

The admissible current related to the primary damage, i.e. loss of transmission or lowered resistance to moisture penetration of the cable, can be evaluated by means of the test methods described in § 3.4 below.

If the annual damage rate N_d is higher than the tolerable number of faults N_t, protection measures are necessary to reduce N_d and to minimize the risk of such damage.

Each Administration can define its tolerable number of faults.

3 Protective measures

Protective devices and practices for telecommunications networks are indicated in Chapters 5 and 6 of the manual [1].

For optical fibre cables, the following protective measures are usually considered:

3.1 *Correct connection of metallic moisture barriers*

The moisture barrier of an optical fibre cable should be continuous, i.e. it should be connected across all splices, regenerators etc., along the length of the cable. The moisture barrier should be connected to earth, either directly or through lightning arrestors, at the termination at each end of the cable length.

3.2 *Use of shield wires above the cable*

It may be important to protect the plastic sheath of the moisture barrier against perforation due to lightning discharges. Such a perforation may occur if the potential of the soil relative to remote earth as a result of a lightning strike exceeds the breakdown voltage of the polyethylene sheath of the moisture barrier.

The installation of a shield wire above the optical fibre cable will reduce the likelihood of the polyethylene sheath of the moisture barrier being perforated.

The efficiency of shield wires can be very considerable and can be derived from Chapter 7 of the manual [1].

3.3 *Use of metal-free cables*

This type of cable may be suitable for use in areas exposed to lightning or where severe power induction is experienced. While damage due to these causes may be minimized or prevented, for buried cables the lowered resistance of the cables to moisture penetration and the difficulty of locating them during subsequent maintenance activities should be considered.

3.4 *Use of cables which have metal components but have adequate resistibility to a level of lightning surge currents*

Cables of this type may carry lightning currents during storms, but the passage of these currents is not expected to cause dielectric breakdown or transmission impairment. Two tests have been devised for these cables: one test to establish that adequate dielectric strength exists for general cases and the other to determine threshold values of surge current resistivity for cable selection. The two tests are as follows:

– *Test for dielectric strength*

  The metallic components which are electrically insulated from each other should be considered in pairs. Any pair should be tested where a discharge across the pair might intercept either an optical fibre or a non-metallic moisture barrier. If a cable has a metallic moisture barrier, tests should be made additionally between this barrier and each metallic component insulated from it. Either a.c. or d.c. may be used to carry out these dielectric strength tests. For a.c. tests, 10 kV r.m.s. at a frequency of 50 or 60 Hz shall be applied to the pair of metallic components for five seconds. For d.c. tests, 20 kV shall be applied to the pair of metallic components for five seconds. At the end of these tests, no evidence of dielectric breakdown or transmission impairment should be evident.

– *Test for surge current resistibility*

  A cable sample 1 metre in length shall be immersed in wet sand contained in a non-conducting rigid box having a length of approximately 0.75 metres. The sand shall be 20-40 mesh silica sand, and shall be fully saturated and drained. The cable sample shall be placed in the test box and the wet sand tamped around it. A discharge electrode shall be located near the centre of the test box, between 2.5 and 5.0 cm from the sample. All conducting components in the cable shall be electrically connected together to form one terminal and a test current shall be placed between this terminal and the discharge electrode. It is important for the test current to flow through the sample and to encourage this to occur, any insulating covering over an outer metallic shield or moisture barrier shall be opened with a small slit or hole facing the discharge electrode. The test current waveform may be either unidirectional or damped oscillatory. The time-to-peak value shall be 15 µs. The frequency of the damped oscillatory current waveform shall be between 16 and 30 kHz, and the time to half-value shall be between 50 and 80 µs. A unidirectional current waveform shall have a time to half-value between 40 and 60 µs. Following the applications of dishcharge currents in ascending amplitudes the sample is tested for loss of its transmission or lowered resistance to moisture penetration. The test identifies a threshold value of surge current which causes cable or transmission deterioration, and assists Administrations to select cables which will be adequately reliable in the light of their experience of damage due to lightning.

4 Protection of remote power-feeding circuits in optical fibre equipment

It is advisable to protect remote-power feeding circuits, e.g. supplied over cables, against overvoltages if disturbance from power lines or lightning is possible. Although the power-feeding circuits are usually symmetrical pairs, the test levels for the associated power-feeding equipment are approximately the same as those for coaxial systems (see Recommendation K.17).

5 Future work

This Recommendation describes the protective measures and calculation methods which can be confirmed at the present time.

Further studies of the problems of protecting optical fibre cables will be made. Work in the following areas, typically, is involved:

- coordinating the protection of cables and working staff against overvoltages due to induction from faults in nearby power lines with that for lightning protection. Limits and precautions for staff and cable protection as given in the *Directives* [2] are applicable also for optical fibre cables with metal parts as far as power induction is concerned. See also Question 6/V in Study Group V for Study Period 1988-1992;
- prediction of trouble rates expected on optical fibre cables. See also Question 22 in Study Group V for Study Period 1988-1992 and the Contribution COM V-58, 1987, which will be considered.

References

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

[2] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines*, ITU, Geneva, 1988.

Recommendation K.26

PROTECTION OF TELECOMMUNICATION LINES AGAINST HARMFUL EFFECTS FROM ELECTRIC POWER AND ELECTRIFIED RAILWAY LINES

(Melbourne, 1988)

The CCITT draws attention to the need for adequate and reliable protection to be given to telecommunication facilities to guard them against danger and disturbance arising from nearby electric power or electrified railway lines. The danger and disturbance can arise due to conductive, capacitive or inductive coupling between the systems, and the safety of people using or working on telecommunication installations needs to be assured.

To meet this need, the CCITT has issued the *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines*, Geneva, 1988, which provide guidance in estimating possible overvoltages or overcurrents and recommending limiting values for these conditions. The *Directives* also give advice on methods used to measure overvoltages, overcurrents and relevant parameters, on protective devices and on protection methods and safety precautions.

The *Directives* (1988 edition) consist of nine volumes listed below:

Volume I – Design, construction and operational principles of telecommunication, power and electrified railway facilities

Volume II – Calculating induced voltages and currents in practical cases

Volume III – Capacitive, inductive and conductive coupling: physical theory and calculation methods

Volume IV – Inducing currents and voltages in power transmission and distribution systems

Volume V – Inducing currents and voltages in power transmission and distribution systems.

Volume VI – Danger and disturbance

Volume VII – Protective measures and safety precautions

Volume VIII – Protective devices

Volume IX – Test and measuring apparatus and methods.

These volumes have been established by the CCITT in close cooperation with the International Conference on Large High Voltage Electric Systems (CIGRE) and the International Union of Railways (UIC).

The CCITT recommends that, when telecommunication installations are expected to be affected by nearby power or electrified railway lines, Administrations will find it in their own interest to observe the methods given in the *Directives* (1988 edition).

The *Directives* (1988 edition) replace the *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines*, (Geneva, 1963, amended and supplemented in 1965, 1974, 1978 and 1982).

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

CONSTRUCTION, INSTALLATION AND PROTECTION OF TELECOMMUNICATION CABLES IN PUBLIC NETWORKS

(Melbourne, 1988)

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 the occurence of these faults, other than by outside factors, is mainly determined by the construction, installation and protective measures applied,

unanimously recommends

that, when selecting and installing cables, Administrations will find it in their interest to comply with the CCITT manual *Outside plant technologies for public networks.*

This manual replaces the CCITT *Recommendations concerning the construction, installation and protection of telecommunication cables in public networks,* ITU, Geneva, revision 1974, amendments and additions 1977 and 1986. The manual consists of the following five parts:

Part I: Basic information about the construction of telecommunication cables

Part II: Installations and assemblage of telecommunication cables and their supporting structure

Part III: Pressurization of telecommunication cables

Part IV-A: Protection of telecommunication cables and associated hardware against corrosion

Part IV-B: Protection of telecommunication cables supports and underground structure against other hazards

Part V: Fault location and repair of telecommunication cables.

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.

ARMOURING OF CABLES

(Mar del Plata, 1968; modified at Melbourne, 1988)

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 Through-connection of armouring

In case long-distance cables or similar cables are provided with metal armouring, this should be through-connected electrically at the splicing points. This should be done to obtain maximum protection against the effects of atmospheric discharges and protection against induction.

Metal armouring on cables forming part of the distribution network should also be through-connected in case such protection is needed.

In case metal-armoured cables are also provided with a metal sheath, it may be desirable to through-connect the sheath and the armouring electrically at the splicing and/or repeater points. This should be done to neutralize any differences in potential between the armouring and metal sheath, and to obtain maximum protection against magnetic interference. Through-connection may create corrosion problems, which will usually reduce the lifetime of the metal armouring.

9 Omission of armouring

On directly buried cables, metal armouring can be dispensed with in case the cable is provided with a strong plastic sheath, for example of polyethylene. A further prerequisite is that the soil and laying conditions should be favourable.

Additional protection, for example of optical fibre cables, may be obtained by providing the cable sheath with an external layer of polyamide (thickness 0.4 - 0.5 mm). This has a favourable effect as a wearing surface when drawing the cable over long distances. Moreover, the layer gives a certain degree of protection against light mechanical attacks.

10 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.

11 Rodents and insects

Damage from rodents and insects to direct buried cables may be high in some areas. In those locations, it may be advisable to consider the application of some type of armouring. For detailed information regarding armour protection against rodent and/or insect attack, the reader is directed to Part IV-B, Chapter II of the CCITT manual *Outside plant technologies for public networks*, mentioned in Recommendation L.1.

12 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

ALUMINIUM CABLE SHEATHS

(Geneva, 1972; modified at Geneva, 1976, Malaga-Torremolinos, 1984 and Melbourne, 1988)

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).

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.

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.

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.

If a test of the protective covering is necessary in the manufacturing process, an electric spark detect method or a voltage resistance test method with the cable submerged in water is effective. In the process of installation and operation, if the factors that might cause damage to the protective covering or decrease the protective covering's insulation resistance are to be found, the test should be carried out and the faults should be eliminated.

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 of aluminium sheaths depends mainly on a high quality anti-corrosion protective cover. However, if there is serious risk of damage to the protective cover, and particularly if it is not possible to re-establish the protective cover to its original specifications after repair, the cover should be protected with special measures such as sacrifice anode electrical chemical protection. Aluminium alloy sacrifice anode, which has the advantage of a higher current capacity per unit weight, an appropriate protective potential, an abundant raw material resource base, and ease of manufacture, is an effective measure to protect aluminium sheathed cables. Tests show that good results can be obtained if the protected aluminium sheath potential value with respect to ground is limited within the range of -0.85 to 1.20 V (relative to a $Cu/CuSO_4$ electrode).

6 If there are no special requirements in using aluminium sheaths for optical fibre cables, the same sheath material and manufacturing process may be used as for metallic conductor cables.

References

[1] CCITT manual *Outside plant technologies for public networks*, Part IV-A, Chapter III, § 1.2.2, ITU, Geneva 1988.

[2] *Ibid.*, Part I, Chapter III, § 6.2.2.

[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

CABLE SHEATHS MADE OF METALS OTHER THAN LEAD OR ALUMINIUM

(Geneva, 1972)

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 manual *Outside plant technologies for public networks*, ITU, Geneva, 1988, Part IV-A, Chapter III, § 1.2.2.

Recommendation L.6

METHODS OF KEEPING CABLES UNDER GAS PRESSURE

(Geneva, 1972)

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.

APPLICATION OF JOINT CATHODIC PROTECTION

(Geneva, 1976)

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 manual *Outside plant technologies for public networks*, ITU, Geneva, 1988.

Recommendation L.8

CORROSION CAUSED BY ALTERNATING CURRENT

(Geneva, 1976)

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.

METHODS OF TERMINATING METALLIC CABLE CONDUCTORS

(Melbourne, 1988)

1 General

Metallic cable conductor terminations are installed at various locations within the cable network. The type of terminal and termination device utilized at these locations is dependent on various factors relating to the specific installation:

- type of cable and conductor being terminated;
- location and purpose of the termination;
- number or quantity of terminations required;
- type of service or transmission link involved;
- flexibility and protection requirements.

Basically, all exchange, repeater (amplifier or regenerator), and major cross-connection point terminations are of the "fixed" type utilizing wrapping, soldering of insulation displacement connection (IDC) techniques.

Local distribution and customer terminations utilize a mixture of "fix" and "temporary" (screw terminal) type terminations depending on individual conditions. Where required, over-voltage protection may be provided as an integral component of the terminating device or a separate "add-on" facility.

Within a cable network, two methods of terminating cables are available. These may generally be referred to as the direct and indirect methods.

Direct termination implies that the conductors associated with a particular cable connected directly to the terminal forming the "end" of the cable circuit, e.g. the cable conductor and terminal are directly coupled.

Indirect termination implies that the cable conductor is connected to the end terminal via a device that incorporates a preformed or manufactured termination.

Direct terminations are usually utilized in end terminals such as at the exchange main distribution frame (MDF) and customer premises, although some direct terminations are used in the customer distribution cable area. In most other mid-point terminations (distribution cabinets and pillars, repeater housings and termination points for trunk carrier and coaxial cables), indirect terminations utilizing devices with pre-terminating tail cables are spliced into the basic bearer cables.

The electric conducting parts of terminating devices will be of metal such as copper, brass or other similar alloys suitably plated to resist corrosion and other environmental effects and provide good electrical connection, either by contact, pressure, soldering or wrapping.

Various insulating materials (plastic extrusions and resin moulding) provide the mechanical mounting and electrical insulation of the metallic components.

2 Termination types

2.1 *Termination types for symmetric pair conductors*

2.1.1 *Wire-wrapping type*

In this type the conductor is wire-stripped and cut, inserted in a wire-wrap tool and wire-wrapped around the terminal point.

2.1.2 *Solder-on-type*

In this type the conductor is wire-stripped and cut, then inserted in the terminal slot and soldered.

2.1.3 *Wrap-and-solder type*

In this type, after wrapping, the conductor is soldered to the cut end of a terminal.

2.1.4 *Binder-post type*

There are different forms of this type:

a) Termination by means of screws. The conductor is wire-stripped, cut and fastened with screws by means of a screwdriver.

b) Termination by means of nuts. The termination consists of a fixed threaded brass post containing washers and a threaded hex nut. The conductors are terminated between the washers.

2.1.5 *Insulation displacement contact (IDC) type*

In this type, generally the conductor is installed and pressed into a U-element contact by means of a special tool.

The U-element contact has different forms and is the most frequently used terminating type.

2.1.6 *Termination for unused conductors*

This termination is made by means of plastic connectors without U-element contacts and is used for the protection of unused conductors in a pedestal or splice closure.

2.2 *Termination types for coaxial conductors*

2.2.1 *Connectors types*

Coaxial pairs are terminated in connectors mounted on a metallic diaphragm for accessing the repeater housing of the terminal equipment.

The connector joins the stiff coaxial tube to the flexible one leading into the housing or exchange, and is provided with a device for pneumatic insulation.

2.2.2 *Direct-joint type*

A joint between the air core tube and the flexible coaxial cable is made at times.

3 Termination use

The types of termination mentioned above are used in different devices and locations for terminating cables in all their applications: main distribution frame, regenerating equipments, cabinets, terminal boxes and subscriber's premises.

These devices present some physical characteristics which may vary greatly from country to country, although their technical features (i.e. electrical and environmental requirements) are very similar.

4 Requirements for MDF terminating devices

The basic requirements of the exchange MDF terminating device include the provision for:

- fixed termination of external cable conductors, in multi-pair units (usually 100), and associated jumper cross-connection leads;
- ease of termination, and retermination where necessary, of cable and jumper cross-connection conductors;
- overvoltage protection by add-on or plug-in triode gas protectors;
- circuit isolation by insertion or removal of an appropriate device;
- independent circuit accessing and testing, on equipment and line sides;
- circuit paralleling;
- earthing points or buses;
- ratio of O/G (outgoing) to I/C (incoming) circuit terminating capability of at least two;
- multi-point pair access connection (plugs and leads);

- colour coding of special circuits;
- fanning strips and jumper guides;
- permanent circuit indentification numbering;
- good visibility.

4.1 *Technical requirements*

The design, construction and materials utilized in the terminating device must provide for an expected service life of up to 40 years. Devices must be compatible with the existing MDF construction and utilization practices, interchangeable with the existing termination devices, and maintain or increase current circuit density per unit area.

The line side terminals shall be required to terminate the existing range of copper external cable conductors extending from 0.32 mm to 0.90 mm diameter, plastic insulated with solid or cellular forms of insulation. The terminals on the equipment side shall be required to terminate the existing range of copper internal cable conductors.

Reliable retermination of conductors in the order of 100 to 200 times over the life of the system shall be possible. Prior termination of larger conductors shall not affect the subsequent termination of a second thinner wire.

The line side terminating device on which line cables terminate should allow for the installation and acceptance testing of external cables (automatic simultaneous access, via the MDF termination, to all pairs of a 100-pair, or other, terminating unit.).

Terminating equipment shall be able to withstand the effects of normal concentrations of moisture, sodium chloride, hydrogen sulphide, sulphur dioxide, ammonium chloride and formic acid which may penetrate or originiate in buildings.

Terminating equipment shall be expected to operate satisfactorily in temperatures ranging from −10 °C to 50 °C with daily ambient fluctuations of up to 15 °C. Upper temperature limits shall be assumed to prevail for 25% of total time. Yearly average relative humidity of 75% is to be assumed with maximum values not exceeding 95%.

In addition to the above, terminating equipment will be required to satisfy the following test requirements:

- cold;
- dry heat;
- damp heat;
- accelerated damp heat;
- vibration;
- storage;
- mould growth;
- corrosion test;
- robustness of terminals.

4.2 *Safety requirements*

Terminating systems will need to be designed with safety and security in mind. To this end, designs should:

- minimize the likelihood of unintended electrical contact and/or accidental dislocation of wires;
- use plastic materials with an oxygen index of at least 28, determined in accordance with international standards;
- use plastic materials which do not emit hazardous fumes or smoke when heated;
- avoid sharp corners and edges.

4.3 *Electrical requirements*

All the terminating blocks should have proper electrical characteristics in order to minimize the risk of personal injury to staff, customers and public from electrical causes, arising from the installation, operation, and maintenance of the devices.

If necessary, proper values should be recommended for:

- insulation resistance;
- voltage-proof test;
- capacitance between pairs of terminals.

5 Requirements for cable termination devices

5.1 *Electrical characteristics of terminations*

The main electrical characteristics for termination devices specified by most Administrations are:

- dielectric strength;
- insulation resistance;
- reflection index (coaxial only);
- contact resistance.

These characteristics are different for coaxial-pair terminations, long-distance symmetric-pair cables and local symmetric-pair cables.

5.2 *Environmental requirements of terminations*

The requirements should be specified for at least 20 years of field operation in stationary use at partially weather-protected locations. The IEC Standards should be followed in the areas of:

- temperature cycling, lower and upper limits;
- change of temperature;
- damp heat, steady state;
- standard climatic sequence;
  1) dry heat,
  2) damp heat, cyclic,
  3) cold,
  4) damp heat, cyclic,
- gas-tightness;
- shock or vibration.

Recommendation L.10

OPTICAL FIBRE CABLES FOR DUCT, TUNNEL, AERIAL AND BURIED APPLICATION

(Melbourne, 1988)

Introduction

With the recent progress in optical fibre cable technology, optical fibres for telecommunication use have been applied to trunk and subscriber networks, indoor wiring and submarine sections. There are various kinds of installation, such as aerial, duct, cable tunnel, buried, on-premises and underwater. Thus, optical fibre cables are exposed to natural and man-made external factors.

There is a need to establish the mechanical and environmental characteristics of optical fibres which will satisfy operational requirements and to advise on suitable testing methods.

This Recommendation advises on optical cables to be used in certain installation conditions. Cables for underwater and in-building applications require further study.

1 Scope

This Recommendation:

- refers to multi-mode graded index and single-mode optical fibre cables to be used for telecommunications networks in duct, tunnel, buried and aerial installations;
- deals with mechanical and environmental characteristics of the optical fibre cables concerned. The optical fibre dimensional and transmission characteristics, together with their test methods, should comply with Recommendations G.651 and G.652, which deal with multi-mode graded index and single-mode optical fibres respectively;
- deals with fundamental considerations related to optical fibre cable from the mechanical and environmental points of view;
- acknowledges that some optical fibre cables may contain metallic elements, for which reference should be made to the manual, *Outside plant technologies for public networks* (see Recommendation L.1), and other L-Series Recommendations;
- recommends that an optical fibre cable should be provided with cable end-sealing and protection during cable delivery and storage, as is common for metallic cables. If splicing components have been factory installed they should be adequately protected;
- recommends that pulling devices can be fitted to the end of the cable if required.

2 Characteristics of the optical fibres and cables

2.1 *Mechanical characteristics*

2.1.1 *Fibre microbending*

Severe bending of an optical fibre involving local axial displacement of a few micrometers over short distances caused by localized lateral forces along its length is called microbending. This may be caused by manufacturing and installation strains and also dimensional variations of cable materials due to temperature changes during operation.

Microbending can cause an increase in optical loss. In order to reduce microbending loss, stress randomly applied to a fibre along its axis should be eliminated during the fiber's incorporation into the cable, as well as during and after cable installation.

2.1.1 *Fibre macrobending*

Macrobending is the resulting curvature of an optical fibre after cable manufacture and installation.

Macrobending can cause an increase in optical loss. The optical loss increases if the bending radius is too small.

2.1.3 *Cable bending*

Under the dynamic conditions encountered during installation, the fibre is subjected to strain from both cable tension and bending. The strength elements in the cable and the installation bend radius must be selected to limit this combined dynamic strain. Any fibre bend radius remaining after cable installation shall be large enough to limit the macrobending loss or long-term strain limiting the lifetime of the fibre.

2.1.4 *Tensile strength*

Optical fibre cable is subjected to short-term loading during manufacture and installation, and may be affected by continuous static loading and/or cyclic loading during operation (e.g. temperature variation). Especially in the case of aerial application, continuous loading during the full lifetime of the cable may be present. Fibre strain may be caused by tension, torsion and bending occurring in connection with cable installation and/or type of installation (e.g. aerial) and/or environmental conditions (e.g. wind, ice).

Excessive cable tensile loading increases the optical loss and may cause increased residual strain in the fibre if the cable cannot relax. To avoid this, the maximum tensile strength determined by the cable construction, especially the design of the strength member, should not be exceeded.

Note 1 – Where a cable is subjected to permanent loading during its operational life, the fibre should preferably not experience additional strain.

Note 2 – Aerial cable may be attached to a suspension wire. In this case, the strength member of the cable need only be designed to support the load during manufacture and installation.

2.1.5 *Crush and impact*

The cable may be subjected to crush and impact both during installation and operational life.

The crush and impact may increase the optical loss (permanently or for the time of application of the stress) and excessive stress may lead to fibre fracture.

In the case of self-supporting cylindrical aerial cables, the cable structure should be able to withstand the compression effects to prevent additional optical loss.

2.1.6 *Cable torsion*

Under dynamic conditions encountered during installation and operation, the cable may be subjected to torsion, resulting in residual strain of the fibres and/or damage of the sheath. If this is the case, the design of cable should allow a specified number of cable twists per unit length without an increase in fibre loss and/or damage to the sheath.

2.2 *Environmental conditions*

2.2.1 *Hydrogen gas*

In the presence of moisture and metallic elements, hydrogen gas may be generated. Hydrogen gas may diffuse into silica glass and increase optical loss. It is recommended that the hydrogen concentration in the cable, as a result of its component parts, should be low enough to ensure that the long-term effects on the increase of optical loss are acceptable.

By the use of dynamic gas pressurization, hydrogen absorbing materials, careful selection and construction (moisture barrier sheath) or elimination of metallic components, the increase in optical loss can be maintained within acceptable limits.

2.2.2 *Moisture permeation*

When moisture permeates the cable sheath and is present in the cable core, deterioration of the tensile strength of the fibre occurs and the time-to-static failure will be reduced. To ensure a satisfactory lifetime of the cable, the long term strain level of the fibre must be limited.

Various materials can be used as barriers to reduce the rate of moisture permeation. Alternatively, filled, metal-free cable constructions can be used.

Note – If required, minimum permeation is achieved by a longitudinal overlapped metallic foil. A continuous metallic barrier is effective to prevent moisture permeation.

2.2.3 *Water penetration*

In the event of damage to the cable sheath or to a splice closure, longitudinal penetration of water in a cable core or between sheaths can occur. The penetration of water causes an effect similar to that of moisture. The longitudinal penetration of water should be minimized or, if possible, prevented. Techniques such as filling the cable core with a compound, providing discrete water blocks or water swellable tapes, or providing unfilled cable with dry-air pressurization, may be applied to prevent water penetration.

Water in the cable may be freezed and, under some conditions, can cause fibre crushing with a resultant increase in optical loss and possible fibre breakage.

2.2.4 *Lightning*

Fibre cables containing metallic elements such as conventional copper pairs or a metal sheath are susceptible to lightning strikes.

To prevent or minimize lightning damage, consideration should be given to Recommendation K.21.

When a non-metallic cable is used, the cable should be filled and it should be protected against mechanical and thermal damage.

2.2.5 *Biotic damage*

The small size of an optical fibre cable makes it more vulnerable to rodent attack. Where rodents cannot be excluded, metallic protection should be provided. For further information reference should be made to Part IV-B, Chapter II of the manual *Outside plant technologies for public networks.*

2.2.6 *Vibration*

When optical fibre cables are installed on bridges they will be subject to relatively high amplitude vibrations of various low frequencies, depending on bridge construction and on the type of traffic density. Cables should withstand these vibrations without failure or signal degradation. Care should be exercised, however, in the choice of installation method.

Underground optical fibre cable may be subject to vibrations from traffic, railways, pile-driving and blasting operations. Here again, cables should withstand vibrations generated by these activities without degration.

A well established surveillance routine will identify the activity in order to make a careful choice of route to minimize this type of problem.

2.2.7 *Temperature variations*

During their operational lifetime cables may be subjected to severe temperature variations. In these conditions the increase of attenuation of the fibres shall not exceed the specified limits.

2.2.8 *Wind*

For optical fibre aerial cable, fibre strain may be caused by tension, torsion and vibration occurring in connection with wind pressure. Induced dynamic and residual strain in the fibre may cause fibre breakage if the specified long-term strain limit of the fibre is exceeded.

To suppress any fibre strain induced by wind pressure, the strength member should be selected to limit this strain to safe levels, and the cable construction may mechanically decouple the fibre from the sheath to minimize the strain. Alternatively, to suppress fibre strain the cable may be lashed to a high strength support strand.

In aerial installations winds will cause vibrations and, in figure-of-eight and suspension wire installations, severe oscillations of the entire span of the cable may occur. Cables should be designed and/or installed to provide stability of the transmission characteristics in these situations.

2.2.9 *Snow and ice*

For optical fibre aerial cable, fibre strain may be caused by tension occurring in connection with snow loading and/or ice formation around the cable. Induced fibre strain may cause excess optical loss and may cause fibre breakage if the specified long-term strain limit of the fibre is exceeded.

Dynamic strain in the fibre may be induced by vibration caused by the action of snow and/or ice falling from the cable. This may cause fibre breakage.

Under the load of snow and/or ice, excessive fibre strain may easily be induced by wind pressure.

To suppress the fibre strain by snow loading and/or ice formation, the strength member should be selected to limit this strain to safe levels, and the cable profile may be selected to minimize snow loading. Alternatively, to suppress fibre strain the cable may be lashed to a high strength support strand.

2.2.10 *Strong electric fields*

Metal-free aerial cables installed on high voltage power lines are susceptible to the influence of the electric field of these power lines which may lead to phenomena such as corona, arcing and tracking of the cable sheath.

To prevent damage, special cable sheath materials may have to be used depending on the level of electric field.

3 Cable construction

3.1 *Fibre coatings*

3.1.1 *Primary coating*

Silica fibre itself has an intrinsically high strength, but its strength is reduced by surface flaws. A primary coating must therefore be applied immediately after drawing the fibre to size.

The optical fibre should be proof-tested. In order to guarantee long-term reliability under service conditions, the proof-test strain may be specified, taking into account the permissible strain and required lifetime.

In order to prepare for splicing, it should be possible to remove the primary coating without damage to the fibre, and without the use of materials or methods considered to be hazardous or dangerous.

The composition of the primary coating, coloured if required, should be considered in relation to any requirements of local light-injection and detection equipment used in conjunction with fibre jointing methods.

Note 1 – The coating should have a nominal diameter of 250 μm.

Note 2 – The primary coated fibres should be proof tested with a strain equivalent to at least 0.5% for a duration of one second. The test method should be in accordance with IEC publication 793-1 [1]. For aerial cable applications, taking into account large thermal changes and strong winds, a larger proof-test strain may be necessary.

Note 3 – Further study is required to advise on suitable testing methods for local light-injection and detection.

3.1.2 *Secondary protection*

Secondary protection of the fibre within the cable should be provided.

Note 1 – Methods of secondary protection are described in the manual on the construction, installation, jointing and protection of optical fibre cables [2].

Note 2 – When a tight secondary coating is used it may be difficult to use local light-injection and detection equipment associated with fibre jointing methods.

Note 3 – To limit axial fibre stress, the mechanical coupling between fibre and cable should be minimized.

3.1.3 *Fibre identification*

Fibre should be easily identifided by colour or position within the cable core. If a colouring method is used, the colours should be clearly distinguishable and have good colour-fast properties also in the presence of other materials, during the lifetime of the cable.

3.1.4 *Splicing properties*

Further study is required to advise on suitable testing methods for local light-injection and detection.

3.2 *Cable core*

The make-up of the cable core, in particular the number of fibres, their method of protection and identification, the location of strength members and metallic wires or pairs, if required, should be clearly defined.

3.3 *Strength member*

The cable should be designed with sufficient strength members to meet installation and service conditions so that the fibres are not subjected to excessive strain.

The strength member may be either metallic or non-metallic and may be located either in the cable core and/or in the sheath.

For example, in the metal-free self-supporting aerial cable the strength member may consist of a layer of aramid yarns located between the inner sheath and the outer sheath, or of a single glass-fibre reinforced strand in a figure-of-eight construction. A knowledge of span, sag, wind and ice-loading is necessary to design such a cable.

3.4 *Water-blocking materials*

Filling a cable with water-blocking material is one means of protecting the fibres from water ingress. Any materials used should not be harmful to personnel. The materials in the cable should be compatible, one with the other, and in particular should not adversely affect the fibre performance, or any identification colours of the fibres.

In addition, the material should be non-nutritive to fungus, and be electrically non-conductive, homogeneous and free from contamination.

3.5 *Pneumatic resistance*

If the cable requires dry air pressurization during operation, the pneumatic resistance should be specified.

Note – It is intended that a cable can be pressurized only if it allows a flux of air which is in accordance with the criteria defined in Part III of the manual *Outside plant technologies for public network* (see Recommendation L.1).

3.6 *Sheath*

The cable core should be covered with a sheath suitable for the relevant environmental and mechanical conditions associated with storage, installantion and operation. The sheath may be of a composite construction and may include strength members.

Sheath considerations for optical fibre cables are generally the same as for metallic conductor cables. Consideration should also be given to the amount of hydrogen generated from a metallic moisture barrier. The minimum acceptable thickness of the sheath should be stated, together with any maximum and minimum allowable overall diameter of the cable.

Note 1 – One of the most sheath materials is polyethylene. There may be however, some environmental conditions where it is necessary to minimize the flammability of a cable and limit the emission of fumes, smoke and corrosive products. Special materials should be used for the cable sheath in these situations.

Note 2 – For directly buried cables installed in areas with chemically contaminated soils (acids, hydrocarbons, etc.), specially designed cable sheath combinations may be used.

Note 3 – In the case of aerial cables, the outer sheath should be resistant to the degradation due to ultraviolet radiation.

3.7 *Armour*

Where additional tensile strength or protection from external damage is required, armouring should be provided over the cable sheath.

Armouring considerations for optical fibre cables are generally the same as for metallic conductor cables. However, hydrogen generation due to corrosion must be considered. It should be remembered that the advantages of optical fibre cables, such as lightness and flexibility, will be reduced when armour is provided.

Armouring for metal-free cables may consist of aramid yarns, glass fibre reinforced strands or strapping tape, etc.

3.8 *Identification of cable*

If a visual indentification is required to distinguish an optical fibre cable from a metallic cable, this can be done by visibly marking the sheath of the optical fibre cable.

4 Test methods

4.1 *Test methods for mechanical characteristics*

This section recommends appropriate tests and test methods for verifying the mechanical characteristics of optical fibre cables.

4.1.1 *Tensile strength*

This test method applies to optical fibre cables installed under all environmental conditions.

Measurements are made to examine the behaviour of the fibre attenuation as a function of the load on a cable during installation.

The test should be carried out in accordance with method IEC 794-1-E1 [3].

The amount of mechanical decoupling of the fibre and cable can be determined by measuring the fibre elongation, with optical phase shift test equipment, together with the cable elongation.

This method may be non-destructive if the tension applied is within the operational values.

4.1.2 *Bending*

This test method applies to optical fibre cables installed under all environmental conditions.

The purpose of this test is to determine the ability of optical fibre cables to withstand bending around a pulley, simulated by a test mandrel.

This test should be carried out in accordance with method IEC 794-1-E11 [3].

4.1.3 *Bending under tension (flexing)*

This test method applies to optical fibre cables installed under all environmental conditions.

This subject needs further study.

4.1.4 *Crush*

This test method applies to optical fibre cables installed under all environmental conditions.

This test should be carried out in accordance with method IEC 794-1-E3 [3].

4.1.5 *Squeezing (abrasion)*

This test method applies to optical fibre cables installed under all environmental conditions.

This subject needs further study, and is currently under consideration in the method IEC 794-1-E2 [3].

4.1.6 *Torsion*

This test method applies to optical fibre cables installed under all environmental conditions.

This test should be carried out in accordance with method IEC 794-1-E7 [3].

4.1.7 *Impact*

This test method applies to optical fibre cables installed under all environmental conditions.

This test should be carried out in accordance with method IEC 794-1-E4 [3].

4.2 *Test methods for environmental characteristics*

This section recommends the appropriate tests and test methods for verifying the environmental characteristics of optical fibre cables.

4.2.1 *Temperature cycling*

This test method applies to optical fibre cables installed under all environmental conditions.

Testing is by temperature cycling to determine the stability of the attenuation of a cable due to ambient temperature changes which may occur during storage, transportation and operation.

This test should be carried out in accordance with method IEC 794-1-F1 [3].

Note – For aerial self-supporting cables, the stability of the attenuation may be measured with a specified tension applied to the cable sample.

4.2.2 *Longitudinal water penetration*

This test method applies to completely filled outdoor cables installed under all environmental conditions. The intention is to check that all the interstices of a cable are continuously filled with a compound to prevent water penetration within the cable.

This test should be carried out in accordance with method IEC 794-1-F5 [3].

4.2.3 *Moisture barrier*

This test method applies to optical fibre cables installed under all environmental conditions.

This test applies to cables supplied with a longitudinal overlapped metallic foil. The moisture penetration can be tested according to the test method as described in Part I, Chapter III of the manual *Outside plant technologies in public networks* (see Recommendation L.1).

4.2.4 *Freezing*

This test method applies to optical fibre cables installed under all environmental conditions.

This subject needs further study and is currently under consideration in the method IEC 794-1-F6 [3].

4.2.5 *Hydrogen*

This test method applies to optical fibre cables installed under all environmental conditions.

A suitable short-duration test procedure needs to be determined for the factory complete cable, so that the results of factory tests enable the long-term increase in fibre loss to be predicted.

4.2.6 *Nuclear radiation*

This test method assesses the suitability of optical fibre cables to be exposed to nuclear radiation.

This subject needs further study and is currently under consideration in the method IEC 794-1-F7 [3].

4.2.7 *Vibration (bridge and underground cables)*

This test method assesses the suitability of optical fibre cables for bridge and underground application.

This subject needs further study.

4.2.8 *Vibration (aerial cables)*

This test method assesses the suitability of optical fibre cables for aerial application.

The subject needs further study.

4.2.9 *Ultraviolet resistance*

This test method applies to aerial optical fibre cable and assess the suitability of the cable sheath to withstand ultraviolet radiation.

This subject needs further study.

4.2.10 *Sheath tracking*

This test applies to aerial optical fibre cables used on high voltage power lines.

This subject needs further study.

References

[1] IEC publication 783-1 *Optical fibres, Part 1: Generic specifications*, Geneva, 1987.

[2] CCITT manual *Construction, installation, jointing and protection of optical fibre cables*, ITU, Geneva, 1985.

[3] IEC publication 794-1 *Optical fibre cables, Part 1: Generic specifications*, Geneva, 1987.

Recommendation L.11

JOINT USE OF TUNNELS BY PIPELINES AND TELECOMMUNICATION CABLES, AND THE STANDARDIZATION OF UNDERGROUND DUCT PLANS

(Melbourne, 1988)

The CCITT,

considering

(a) that many countries are interested in the joint use of tunnels and are aware of the advantages, disadvantages and specific dangers they hold;

(b) that the rules governing this type of ducting vary significantly from country to country;

(c) that the importance of the joint use of tunnels increases with increasing density of population and shrinking open spaces, i.e. in large towns;

recommends

that Administrations, who in the future will be interested in this type of installation, follow the rules described in this Recommendation.

1 General considerations

Duct tunnels and trenches are constructions containing one or generally more ducts belonging to different networks. Tunnels which can be inspected (inspectable tunnels) include one or more gangways for initial assembly work and for subsequent control, maintenance and repair operations. A tunnel without standing room, but designed for crawling should have a clear internal height of at least 0.8 m. Duct gangways may not be entered.

The above principles apply to inspectable tunnels, and apply by analogy to tunnels with crawling room only.

Tunnels may contain ducts belonging to the following types of networks:

- collective antennas;
- telecommunications;
- electricity;
- gas;
- water;
- district heating;
- ducted transport (e.g. pneumatic tubes);
- drainage water.

2 Establishment of a routing plan

2.1 *Structure*

Tunnel routing must take into account the structure of networks and their levels of priority.

The transport ducts of different networks do not generally follow the same itinerary, since neither the production units (e.g., power plants, pumping stations or telephone exchanges) nor the transit points from transport to primary distribution coincide. On the other hand, in densely populated areas, primary and secondary distribution ducts often do follow the same itineraries, so that it is advisable to run tunnels under arteries containing primary and secondary distribution ducts.

2.2 *Decision criteria*

The following factors should be taken into account when opting between trenches and tunnels:

2.2.1 *Distribution security*

A high level of distribution security will depen on the following factors:

- durability of material and joints;
- rapid location of damage when if occurs, easy access and minimum repair times;
- low exposure to outside effects (e.g. damage caused by third parties or by earthquakes).

Ducts laid in tunnels generally offer high durability and a low risk of deterioration. They may be repaired rapidly.

2.2.2 *Third party risk, disturbances due to installation and repair work*

Account should be taken of disturbances caused by installation and repair work (rerouting of traffic, noise) and of the possible consequences of damaged ducts (water and fire damage).

2.2.3 *Economic considerations*

Economic considerations should include not only the cost of constructing and maintaining tunnels, but also the savings which will arise in the future from avoiding the secondary effects of buried ducts. By secondary effects are meant the effects produced on local inhabitants, local activities, vehicle traffic and the environment in general by the installation, malfunction, repair and maintenance of ducts.

2.2.4 *Technical considerations*

Before either of the laying methods is chosen, the following factors should be considered:

- ducts, network, dimension (cross-section), power (capacity), material, protection against corrosion, number, distribution priority, duct routing, compatibility with other ducts, state of ducts, repairs, overhaul, replacement, reserves, extensions, emergency ducts, provisional installations, connections to buildings;
- roadway, road width, pavement width, greenery strip, traffic density, surface water drainage, superstructure;
- subsoil, type of ground, groudwater level, existing ducts, existing undergroung constructions;
- schedules, beginning of works, duration of works (stages), start-up.

When a tunnel is planned, special attention should be paid to branch connections with buildings, which may be derived directly from the tunnel if the necessary openings have been provided. An alternative method is to bury secondary distribution ducts alongside the tunnel.

3 Recommendations applicable to tunnels

3.1 *Phases*

The following sequence of phases should be considered:

- construction phase;
- operational phase.

3.2 *General recommendations*

In both the construction and the operational phases, the following requirements should be observed:

- *Introduction of duct components in the tunnel*

  It should be possible to introduce any components either through normal access points or through special openings.

- *Cable pulling*

  Cables in tunnels should be placed in appropriate technical containers, in order to facilitate their installation, repositioning or removal.

- *Construction aids*

  For construction work, especially in the case of heavy tubing, securing devices should be provided at appropriate locations.

- *Movement of duct components in tunnel*

  The necessary facilities should be provided for the transport of duct components inside a tunnel.

- *Reserve facility for network extension*

  Since networks are likely to be extended in the future, appropriate reserve space should be set aside in the tunnel cross-section plan.

- *Clear space around ducts*

  Enough clear space should be allowed between a tunnel wall and ducts, as well as beween ducts in proportion to their diameter (to facilite maintenance, repair and branching).

- *Ambient temeperature*

  High temperatures may occur in tunnels containing heat-emitting ducts. Care should be taken to maintain physiologically acceptable environmental conditions in order to avoid any impairment to health during work or inspections. For telecommunication cables, see § 3.3.2.

- *Corrosion of ducts, fixtures and equipment accessories*

  The working life of fixtures and equipment accessories should be as long as that of the ducts. High levels of humidity may produce condensation and cause non-rustproof metals to corrode. The appearance of corrosion should be considered in the light of Recommendation L.1. Metal components (pillars, racks or supports) should preferably be made of hot galvanized steel. In some cases, cathodic protection may be applied.

- *Vibrations*

  Some ducts may be sensitive to vibrations. In some cases, vehicle traffic may produce vibrations which are propagated inside the tunnels.

3.3 *Comments on distribution networks*

3.3.1 *Collective antennas*

Extra space has to be provided in places to house amplifying equipment. Apart from that, collective antenna cables have no special requirements.

3.3.2 *Telecommunication cables*

The following requirements should be taken into account:

– *Distances from power lines*

  Minimum distances from main ducts should be applied (see § 5).

– *Protection against thermal load*

  Since telecommunications cables are vulnerable to thermal load, thermal conditions in tunnels must be taken into account. This applies especially for optical cables.

– *Protection against corrosion and lightning*

  Telecommunication cables should generally be protected by metal sheaths or shields. This protection may be applied, but the use of joint earth electrodes is either not required or not permissible.

– *Protection against electrical interference*

  Normally no special measures need be taken, although cable constructions with a high screening factor or overvoltage relays may be used in some cases.

– *Protection against mechanical forces*

  Metal shields may be used to protect cables against mechanical effects such as vibrations or impacts. In the case of lead sheaths, vibration-resistent alloys should be used.

– *Protection against outside effects*

  Plastic-covered cables may be protected against rodents with fibreglass or aramid-fibre shielding.

  Contractable cable joints may provide protection against earthquakes.

– *Bends*

  Since cable curvature is limited, layout plans must take account of permitted curvature radii.

– *Specialized work*

  Since work has to be done relatively frequently on telecommunication installations, particularly on sleeves, sufficient working space should be provided (e.g. alcoves or chambers).

3.3.3 *Power cables*

The following requirements should be taken into account:

– *Bends*

  The same rules apply, by analogy, as for telecommunication cables.

– *Ambient temperature*

  The load capacity of electrical cables depends, among other parameters, on ambient temperature, which should be determined in each case to achieve the ideal balance between tunnel cooling and cable load capacity.

3.3.4 *Gas*

Tunnels containing gas ducts should be ventilated (naturally or artificially). Dilation sleeves should be leakproof and located in separate chambers.

3.3.5 *Water*

The choice of tunnel layout or cross-section should take account of the dimensions of special water duct components. Water ducts may require special precautions against climatic effects to avoid overheating or freezing. Ducts with a nominal diameter of 150 mm may give rise to special problems, in which case the following factors should be taken into account:

– *Temperature rise*

  A rise of temperature in a tunnel will have only a negligible effect on the quality of drinking water.

– *Freezing in ducts*

The temperature in inspectable tunnels rarely falls below freezing. Should there be a risk of freezing, appropriate measures should be taken to protect the duct.

– *Bleeding and draining*

Bleeding and draining facilities should generally be located outside tunnels.

3.3.6 *District heating*

The following requirements should be taken into account:

– *Position of ducts*

For assembly purposes, the distance between district heating ducts (not including insulation) and the tunnel wall should not be less than 0.3 m.

– *Heatproofing*

Continuous thermal insulation will diminish heat losses and help prevent the occurrence of thermal shock in the event of a burst water duct.

– *Junctions and intersections*

Permitted radii of curvature for ducts should be observed at junctions and intersections.

– *Dilation devices*

Plans should allow sufficient space for dilation devices.

3.3.7 *Water drainage*

The following aspects should be considered:

– *General*

In most cases pipes will be naturally drained. The means that their level and slope can be adapted to tunnel layouts only within certain limits.

– *Link between drain and tunnel*

In view of the risk of backflow, there should be no open link between the drain and the tunnel.

4 **Safety plan**

4.1 *Safety objectives*

Various aspects of safety should be considered:

– safety of persons working in the tunnel;

– safety of persons and property outside the tunnel;

– security of distribution.

For the first two items, safety objectives concern the risk of personal injury.

Security of distribution is independent of personal safety. The importance of distribution ducts should not be overlooked, however, not only because of the convenience they provide to the public in general, but also because they may constitute in certain circumstances a vital factor of survival.

4.2 *Safety plan*

4.2.1 *Safety during the construction and installation phase*

The safety plan should comply with existing rules governing safety at work. Special attention should be paid to rules concerning construction work in enclosed spaces. In all cases, the maximum permissible levels of harmful substances or vapours, as defined by insurance companies, should not be exceeded.

4.2.2 *Safety during the operational phase*

The company owning an installation should be responsible for issuing instructions to be observed from the start of operations.

In the event of maintenance or extension work, the safety measures laid down for the construction phase should be observed.

Fire risk and fire-fighting facilities should be established in consultation with the fire brigade.

Tables A-1/L.11 and A-2/L.11 show a model of a safety plan in the operational phase, with an indication of possible preventive measures.

The rules applicable to the construction of a tunnel, as described in § 5, should be established in the light of the safety plan.

4.3 *Special problems to be considered*

A special study of safety aspects should be made, where necessary, with regard to the following points:

- interference between telecommunication lines and high voltage or d.c. railway lines;
- tunnel design;
- ventilation;
- thermal protection;
- water drainage;
- electrical installations;
- gas or fire detection systems.

5 **Construction**

5.1 *Transversal cross-section*

5.1.1 *General*

The transversal cross-section of a tunnel comprises the following elements:

- ducts and related facilities, including free spaces for repairs and maintenance;
- reserve spaces;
- duct intersections and junctions;
- service gangways.

5.1.2 *Positioning of ducts*

Over and above assembly requirements, the following rules should be applied:

- *Telecommunications and antenna cables*

  The following spaces should be observed in relation to power lines:

  - low voltage, up to 1000 V: 0.3 m
  - high voltage with low induction: 0.3 m
  - high voltage with high induction: to be determined (rigid earthing systems)

- *Power line ducts*

  Where cables are supported by brackets or racks, thermal and electromagnetic interaction should be taken into account.

- *Natural gas ducts*

  These should be placed as high as possible in the tunnel. This will protect them against mechanical damage and in the event of a leak, gas will accumulate under the ceiling.

- *Water ducts*

  These should be placed as low as possible in the cross-section, for which facilitates installation and anchoring. A further factor is that ambient temperature tends to be lower on the tunnel floor.

5.1.3 *Service gangway*

In order to facilitate free and safe transit through the tunnel, no steps should be placed across the service gangway.

Gangway dimensions should be subject to the following rules:

- minimum width: 0.7 m
- minimum height: 1.9 m
- dimension of the largest element to be introduced in the gangway, plus at least 0.2 m.
- dimensions to be increased according to circumstances, particularly at bends, intersections and working alcoves.

5.1.4 *Transversal slope*

A transveral slope should be provided for water drainage.

5.1.5 *Examples of tunnel profiles*

Figures B-1/L.11 and B-2/L.11 represent circular and rectangular tunnel cross-sections respectively. They show how the available space can be divided among the different networks.

5.2 *Openings, access and partitions*

5.2.1 *Openings for equipment*

Openings large enough should be provided to introduce the largest pieces of equipment during assembly and maintenance work in the tunnel. The openings should be located directly above the service gangway. Further openings may be provided during construction, but these should be sealed off before operations begin. Access should be provided for delivery vehicles.

5.2.2 *Access doors for staff*

Staff access points should be located in accordance with escapeways and alarms. Generally speaking, the distance between two access points should not exceed 500 m. The possibility of introducing emergency exits between access doors should be considered.

Access doors should be arranged so that they cannot be obstructed nor allow water or fumes to enter.

Equipment openings and staff access doors should be lockable and as leakproof as possible.

5.2.3 *Partitions*

Careful consideration should be given to the arrangement of transversal partitions. These should all be compatible with escapeways and exits.

5.2.4 *Facilities for the transport of equipment and assembly accessories*

The operational layout should make provision along the service gangway for transport facilities (e.g. ceiling-mounted rails), and for construction accessories (e.g. hooks for pullies and lifting gear or anchor ties for fixtures).

5.3 *Supports and fixtures*

5.3.1 *Loads to be considered*

The following requirements should be taken into account:

- *Permanent loads*

  Permanent loads should be indicated in the operating plan.

- *Lifting*

  All ducts should, generally speaking, be secured against lifting forces.

- *Seismic effects*

  All ducts brackets, supports and cable racks should be able to resist the effects of seismic forces, in accordance with national standards.

– *Explosions*

The ducts and other contents of a tunnel may be strongly shaken by explosions. If the safety plan shows that essential ducts may be exposed to such overloading, it should be ensured that:

– the operation of such ducts is not affected by breakage or deformation;

– no movement may occur which might wrench essential supply ducts off their supports or allow them to collide against tunnel walls or other part of the construction.

Such risks may be avoided with the introduction of shockproof ties and an appropriate arrangement of ducts. Expert advice should be sought in such matters.

5.3.2 *Protection against corrosion*

It is important to protect supports and ties against corrosion in view of the long life of installations (see § 3.2).

5.4 *Transit points between tunnels and open ground*

At points where ducts transit between tunnels and open ground, due account should be taken to relative movements which may occur between the two types of environment.

Tunnel exit points should be as leakproof as possible, so as to avoid the penetration of gas or water in the tunnel.

5.5 *Shut-off devices*

Suitable care should be taken to position shut-off devices of gas, water, district heating and drainage water ducts, on either side of the tunnel wall. It should be possibe to operate all such devices from outside.

5.6 *Ventilation*

5.6.1 *Objectives and rules*

Ventilation should comply with the following objectives:

– *Environment*

Power lines and district heating ducts give off heat. Insofar as such heat is not transferred to the surrounding ground through tunnel walls, cooling must be provided by ventilation.

Controlled ventilation also provides a means of lowering air humidity and contributes to active protection against corrosion.

– *Safety*

As part of the safety plan, the aim of ventilation is to reduce the danger of explosion, to prevent the entry of vehicle exhaust gases and to maintain noxious fumes given off by welding or brazing at permitted working levels.

5.6.2 *Ventilation systems*

The systems of ventilation are:

– *Natural ventilation*

Natural ventilation causes a draft which arises as a result of differences of temperature and pressure. In many cases natural ventilation will produce sufficient movement of air.

– *Mechanical ventilation*

With pressured mechanical ventilation, air from the outside is blown down the tunnel with a fan. Apart from the movement of air, this leads to an increase in pressure, which prevents dangerous gases from entering the tunnel.

5.6.3 *Choice between natural and mechanical ventilation*

The criteria for the choice between ventilation systems are:

- *Technical and safety criteria*

  Mechanical ventilation is generally needed in the following cases:

  - when old gas ducts, which may not be leakproof, run alongside the tunnel;
  - if there is risk that toxic or inflammable materials may enter the tunnel.

  As far as operating safety is concerned, one advantage of natural ventilation is that since it relies on no mechanical or electrical component there is not risk of air circulation being stopped as a result of a breakdown.

- *Technical environmental criteria*

  In shallow underground constructions, where the walls are in contact with the surrounding ground, internal temperature changes in the tunnel are offset by the thermal inertia of its surroundings. This is why natural ventilation is generally sufficient to provide the required environmetal conditions.

- *Protection against corrosion*

  A high level of humidity and especially condensation will speed up the corrosion of ducts and fixtures. A high level of humidity in a tunnel may be caused by:

  - the infiltration of water through the tunnel walls;
  - bleeding or cleaning water;
  - the cooling of warm humid air introduced from outside by ventilation.

  High relative humidity should be avoided by the evacuation of any outside water by the shortest route. Mechanical ventilation should be switched off if the starts introducing warm humid outside air into a cool tunnel, as long as this does not lead to any undue increase in other risks.

5.6.4 *Dimensioning of mechanical ventilation*

The distribution of internal partitions should take account of ventilation sectors.

- *Dimensions according to temperature limits*

  Temperature limits are generally determined according to physiological acceptable working conditions or according to the capacity of electricity ducts. Owing to the considerable effect of the surrounding terrain on heat transfer as well as thermal effects caused by the construction, relatively little cooling effect is produced by ventilation. Also, little effect is derived from the above-ground outside temperature.

- *Dimensioning allowing for the possibility of gas leaks*

  The dimensioning of mechanical ventilation should allow in normal service for the possibility of slight leaks from the gas duct, provided that the concentration of gas is always maintained below the minimum explosive limit, with a sufficient margin of safety.

5.6.5 *Indications concerning the installation of a ventilation system*

In the case of natural ventilation, the cross-section of air inlets will be determined mainly by the quantity of air required.

Consideration should be given to providing suitable outlets on which mobile air extractors (such as those used by the fire brigade) may be attached to the event of a fault or special work.

5.7 *Water drainage*

5.7.1 *Objective and rules*

The objective is to extract the following types of water:

- groundwater and seepage water entering the tunnel owing to the permeability of the tunnel walls;
- tunnel cleaning water;
- water from the bleeding of water pipes;

- water from district heating ducts;
- water leaking from water pipes;
- condensation water.

The drainage of water from a burst duct should be provided under the safety plan.

The water drainage system should meet the following requirements:

- there should be no passage of gas from the tunnel to the drainage pipe;
- no odours should pass from the ducts to the tunnel (traps should be provided).

5.7.2 *Internal network in the case of small quantities of excess water*

The water drainage system will be similar to that of a building. If only small quantities of water are involved, a drainage channel may be provided if a tunnel is suitable inclined.

5.7.3 *Water drainage in the event of a burst duct*

In the case of a burst duct, the normal drainage channel will usually be insufficient to drain off excess water, possibly on account of insuffient capacity in the drainage pipe to which the tunnel is connected. The safety plan should determine what sort of quantity of escaping water needs to be taken into consideration for removal by the tunnel drainage system, in conjunction with appropriate damming and diversion facilities.

5.7.4 *Water drainage through piping situated below the tunnel*

This system allows water to be drained by the effect of gravity. Special care should be taken to prevent any backflow.

5.7.5 *Water drainage into piping situated above the invert level*

In this case, water has to be pumped from a drainage well. The safety plan should indicate whether one or more pumps are needed. The same considerations apply to the provision of separate emergency drainage. An electric pump should be supplemented with a second pump, driven by a different power source. Some sort of signalling system should generally be provided.

5.8 *Signalling systems*

5.8.1 *General*

Signalling and alarm systems should be installed only if all active safety measures have been considered and are deemed to be inadequate. Signalling and alarm systems should be covered by the special safety plan, but it should be borne in mind that the effectiveness of such equipment is only limited and that it is costly to maintain.

5.8.2 *Gas alarm systems*

These systems activate an alarm (signalled at access points) as soon as they detect a dangerous mixture of gas and air. In tunnels equipped with a ventilation system, the latter may be activated to dilute the mixture. Signalling systems, should be set so that the alarm is given at the latest when the gas concentration reaches 50 percent of the minimum detonation threshold. A system should be provided to ensure continuity of operation in the event of a power cut. All leaks should be detected. Detectors should be placed at regular intervals and if necessary above joints, valves, etc.

Gas detectors are indispensable in the case of tunnels connected directly to buildings. Service entraces in buildings should be leakproof. If fixed gas detection systems are not provided or should fail to operate, the absence of explosive or toxic gases should be ckecked with portable instruments before entry to a tunnel.

5.8.3 *Flood alarm systems*

Flood alarm systems should include floater switches placed at low points and in drainage wells, with additional floaters on different levels, thus setting off successive alarms.

5.8.4 *Fire alarm systems*

The need for a fire alarm system should be considered on a case-by-case basis.

5.9 *Other service installations*

5.9.1 *Telecommunication systems*

Internal service communications should be provided for inspections and repairs. The choice will depend on the length of the tunnel, the frequency of inspections and the maintenance plans of different users.

5.9.2 *Electrical power supply*

It may be necessary to use flameproof service equipment in the tunnel.

5.9.3 *Lighting*

Tunnels should generally be equipped with a permanent electrical lighting system. An independent emergency lighting system should also be provided.

5.9.4 *Tunnel cleaning*

The possibility of using clearing machinery should be considered at the outset (passage width, water taps).

5.9.5 *Marking and signalling*

All obstacles and safety devices should be clearly marked (steps, emergency exists, direction of exit). Ducts should be identified with specific, clearly visible and durable marking. In complex tunnel systems, route markings should be provided to help persons unfamiliar with the layout to find their way.

5.9.6 *Rules of usage*

Safety rules should be laid down for visits to the tunnel, drawing attention to communication, safety and evacuation facilities.

6 Standardization of plans for underground ducts in tunnels used jointly for pipelines and telecommunication cables

6.1 *Introduction*

This section describes the graphic representation of underground ducts in joint trenches or tunnels.

The graphic representation of underground ducts in joint tunnels is standardized in several countries, and this document therefore confines itself to a general presentation. The management of the network concerned is responsible for updating plans and documents.

Plans must contain all particulars required for the operation, maintenance and extension of underground ducts, as well as for their protection and continual operation during repairs.

6.2 *Terminology*

The term **underground duct** is defined in this Recommendation to mean a vector for the distribution of a fluid, connecting the place of production with the place of consumption or drainage. It covers pipelines for electricity as well as telecommunication cables.

6.3 *Field of application*

Underground duct plans form part of a general information system. These ducts, whether situated in public or in private areas, constitute public networks for distribution and drainage and for the protection of the environment.

6.4 *Rules applicable to underground duct plans*

6.4.1 *Scope of information*

Underground duct plans must contain, for the benefit of their users, complete and up-to-date information on:

- the characteristics of the various ducts;
- their location and level;
- their network connections.

6.4.2 *Characteristics*

Plans must contain all the particulars required for the operation, maintenance and extension of underground ducts, as well as for their protection and continual operation during repairs; they must correspond to the particular features of each network.

6.4.3 *Location and level*

It should be possible from the plans to determine the position of ducts and duct components accurately, to transpose it to other documents and to relate it unequivocally to official survey points. Measurements must be taken in conformity with current surveying rules.

6.4.4 *Network connections*

It should be possible to determine from the plans how ducts are connected to the network to which they belong. Overall plans or diagrams will often be required.

6.5 *Basic plan*

6.5.1 *Special rules*

The basic plan provides the basic reference for underground duct plans. Its purpose is to map the layout of areas where ducts are situated.

6.5.2 *Contents*

The basic plan essentially contains information on:

- fixed points (triangulation points, base points, levelling points);
- property limits, frontiers;
- buildings;
- types and boundaries of crops.

6.6 *Duct or network plans*

6.6.1 *Types of plan*

The network plan contains references to all the equipment and telecommand devices of a distribution or drainage network. Network plans are of the following types:

- drainage water;
- electricity;
- telecommunication installations;
- district heating;
- gas;
- collective antenna installations;
- water.

6.6.2 *Special rules*

Every duct or network plan must meet the operational requirements of the network concerned. The following rules shall apply:

- it must contain all legally required information;
- for ducts, it must give information on their development, construction, operation and maintenance;
- it must contain instructions for use in the event of breakdown or malfunction;
- it must supply operators and third parties with information on the location and level of ducts.

6.6.3 *Contents*

A duct plan generally comprises the following data:

Geometric data

- duct location;
- duct level.

Duct data

- fluid transported;
- managing enterprise;
- function;
- type and content;
- profile;
- dimensions;
- material;
- operational condition;
- construction or duct components;
- identification.

Auxiliary installation data

- Protective devices.

6.6.4 *Scale of plan*

The choice of scale depends on the density of ducts. The scale of the duct plan should correspond, if possible, to that of the basic plan drawn up in accordance with the survey.

The following scales are recommended: 1:100, 1:200, 1:250 or 1:500, according to the concentration of buildings in the area.

6.7 *Preparation of plans*

6.7.1 *Definition*

By **preparation of plans and data management** the capture, updating, processing and representation of all data relating to underground ducts is understood. Any information system for underground ducts can thus be run either manually or by computer.

6.7.2 *Surveys*

The principles of surveys are as follows:

Whenever ducts are laid or altered, their location and, if necessary, their level should be surveyed.

If excavations reveal ducts which were hitherto unknown or the location of which had been uncertain, these ducts must be surveyed. This rule also applies to ducts located by detection.

6.7.3 *Accuracy of location*

The accuracy of the points used to locate ducts must comply with land survey rules.

6.7.4 *Survey methods*

One of the following survey methods must be used:

- polar coordinates;
- orthogonal coordinates;
- distance resection;
- prolongations.

6.7.5 *Procedure for preparing plans*

- single-plan system. The basic plan and duct data should appear on the same medium. Ducts have to be copied onto the basic plan.
- system of separate superimposable plans. With this system, each level of data appears on a separate sheet. The basic plan, duct data and network data can appear as different data levels.

6.7.6 *Representation*

Ducts are represented graphically by means of conventional signs described in special standards.

6.7.7 *Writing*

Writing must be clearly legible and uniform and must be suitable for reduction and reproduction.

6.8 *Use of data processing systems – General analysis*

A very large volume of data on underground ducts needs to be captured, stored, updated, processed and reproduced, and they have to be extractable in different combinations. It is therefore advisable to use computer techniques, since this is the only way of establishing an integrated system of information on underground ducts. Such a system can meet various requirements, such as combining different data levels by the automatic process of separate superimposable plans; it can also produce extracts (plans, lists, etc.) with a diversified content.

An underground duct information system has to be designed as a continuous sequence of operations, including data capture in the field or in the office, storing and processing, and printing out of plans and lists.

6.9 *Maintaining plans up to date*

6.9.1 *Updating*

Duct plans cannot fulfil their purpose unless they are constantly updated. The following principles should be observed:

- data on new or modified ducts must be collected and processed as soon as work is completed;
- basic plans must be kept up to date.

6.9.2 *Access to localization data*

Localization documents should be available for consultation at any time between the completion of duct laying and the entry of data in the plan.

6.10 *Model plan*

6.10.1 *Content*

The model plan in Annex C shows distribution duct pipelines in addition to transport duct tunnels.

6.10.2 *Graphic representation*

The tunnels and pipelines should be drawn to scale, corresponding in width to the internal diameter of the tubes.

6.10.3 *Representation of ducts*

Since so many ducts and cables are either hung, laid or fixed inside tunnels, it is not possible to represent each duct individually. They are therefore represented in cross-sections of the tunnel, which are placed next to the pipeline or on separate sheets with an indication of their location.

Branches, splices, spurs and other details are entered either on the plans or in special files. The distribution ducts for the different fluids should be indicated by conventional signs.

ANNEX A

(to Recommendation L.11)

TABLE A-1/L.11

Safety plan against outside risks

Risk	Consequences	Level of risk	Security requirement	Possible preventive measures [a]		
				At source	During construction	In service
Incoming gas from parallel ducts or intersections	Explosion, fire, asphyxia or poisoning	Rare Caused only by a burst duct Damage will be extensive (to persons, ducts and tunnel)	Same as for load-bearing structure	Sealing or replacing gas ducts	Sealing duct exit between tunnel and ground Natural ventilation Forced ventilation (tunnel under pressure) Tunnel to be divided into segments, with fireproof partitions	Measure gas concentration before entering tunnel Check gas concentration regularly
Incoming water from outside	Possibility of drowning Damage to duct	Rare	Distribution security	Protection against flood water	Well-placed openings Leakproof doors, trap-doors and covers All pipes to be secured against upward thrust Efficient water drainage system	Monitoring system
Unstable ground foundation	Duct bursts, particularly at transit point from tunnel to ground	Foreseeable effects	Same as for load-bearing structure	Consolidation of foundation ground	Flexible fixtures Appropriate designs of duct transit points	Monitoring by measurement

[a] The above list of preventive measures is not exhaustive.

TABLE A-1/L.11 *(continued)*

Risk	Consequences	Level of risk	Security requirement	Possible preventive measures [a)]		
				At source	During construction	In service
Seismic tremors	Duct bursts, particularly at transit point from tunnel to ground	Variable probability according to regions Substantial effects	Continued operation of all ducts		Tremor-resistant fixtures Special design of duct exit points	
Effect of weapons, explosion impact	Duct bursts	In time of war, effects are likely to lead to serious damage	Continued operation of all ducts		Shock-resistant fixtures Appropriate design of duct exits	
Sabotage	Duct bursts Explosion Fire	Rare	Continued operation of all ducts		Lockable entry points	Entry control

[a)] The above list of preventive measures is not exhaustive.

TABLE A-2/L.11

Safety plan for risks inherent in tunnel ducts

Description of risks		Consequence	Level of risk	Security required	Possible preventive measures a)		
Network	Risk				At source	During construction	In service
Electricity	Fire, smoke	Physical injury Duct bursts Cables on fire Destruction of anticorrosion protective coatings and insulation	Rare Gives rise to personal risk and extensive material damage	For persons, same for load-bearing structures	Careful laying of ducts	Segments to be separated with fire-resistant partitions	Fire alarm system
	Toxic and corrosive fumes	Intoxication of persons Damage to ducts and metal elements			Restricted use of PVC-coated ducts Exclusion of PVC cable fixtures		
	Oil leakage from oil-filled cables	Pollution of groundwater and spring water	Rare, gives rise to indirect personal risk	For persons, same as for load-bearing structures	Oil-filled cables to be placed as high as possible in tunnel	Oil drainage device	Monitoring of oil pressure
Gas	Explosion and fire due to leak	Physical injury Duct bursts Tunnel damage	Rare Personal risk and extensive material damage	For persons, same as for load-bearing structures	Steel pipes to be used for ducts and welded joints to be checked	Natural ventilation Mechanical ventilation Gasproof and fireproof partitions	Regular checks for possible leaks Duct corrosion checks Regular gas concentration measurement Gas concentration to be measured at each inspection
	Presence of gas without explosion	Asphyxia and intoxication	Rare Physical injury				

a) The above list of preventive measures is not exhaustive.

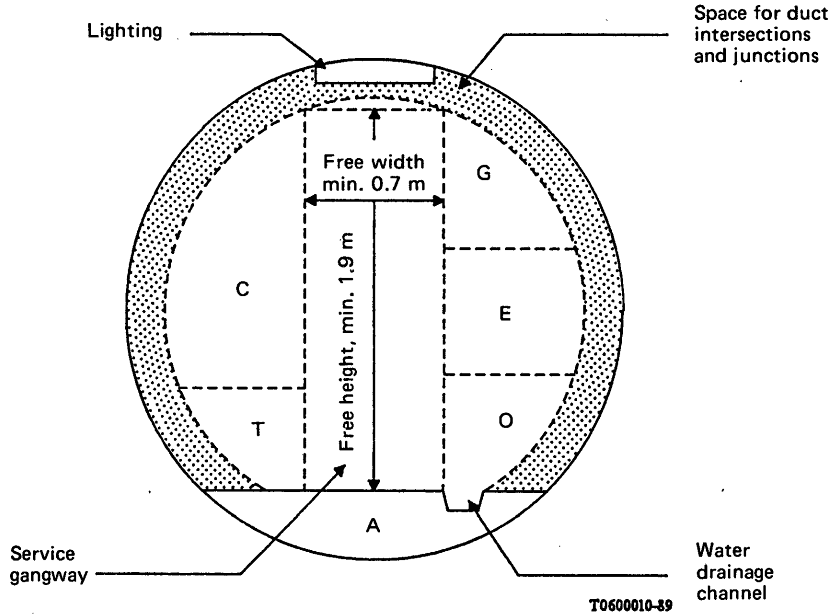
Description of risks		Consequence	Level of risk	Security required	Possible preventive measures [a]		
Network	Risk				At source	During construction	In service
Water	Tunnel flooding due to duct burst	Possibility of drowing Damaged ducts	Rare Personal risk and little material damage	For persons, same as for load-bearing structures	Careful design and construction of installation	Strong fixtures Automatic valves Effective water drainage system All pipes to be secured against upward pressure	Regular checks for possible leaks Corrosion checks Alarm system (with floater switch)
District heating	Escaping steam or hot water due to duct burst or leak	Physical injury Duct bursts and other damage to ducts due to rapid rise of temperature	Rare Extensive damage	For persons, same as for load-bearing structures	Careful installation of ducts	Shut-off valves at tunnel ends controlled from outside Remotely controlled shut-off valves Partitions	Alarm system
Drainage water	Partial flooding	Damage to ducts	Rare Little material damage	Limitation of material damage	Ducts to placed above the highest water level		
	Complete flooding of tunnel	Physical injury and material damage	Rare	For persons, same as for load-bearing structures	Leakproof and lockable access points and inspection holes	Ducts to be secured against upward pressure	

[a] The above list of preventive measures is not exhaustive.

ANNEX B

(to Recommendation L.11)

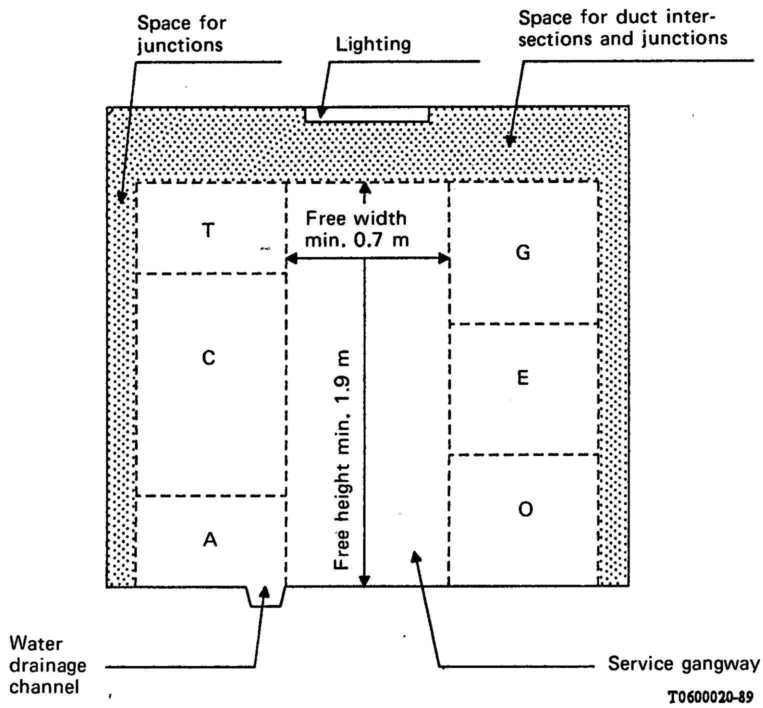
Examples of tunnel profiles



T	Telecommunication duct area (in tubes)
E	Power duct area
G	Gas duct area
O	Water duct area
C	District heating duct area
A	Waste water duct area

FIGURE B-1/L.11

Example of circular cross-section



T Telecommunication duct area (exposed cables)
E Power duct area
G Gas duct area
O Water duct area
C District heating duct area
A Waste water duct area

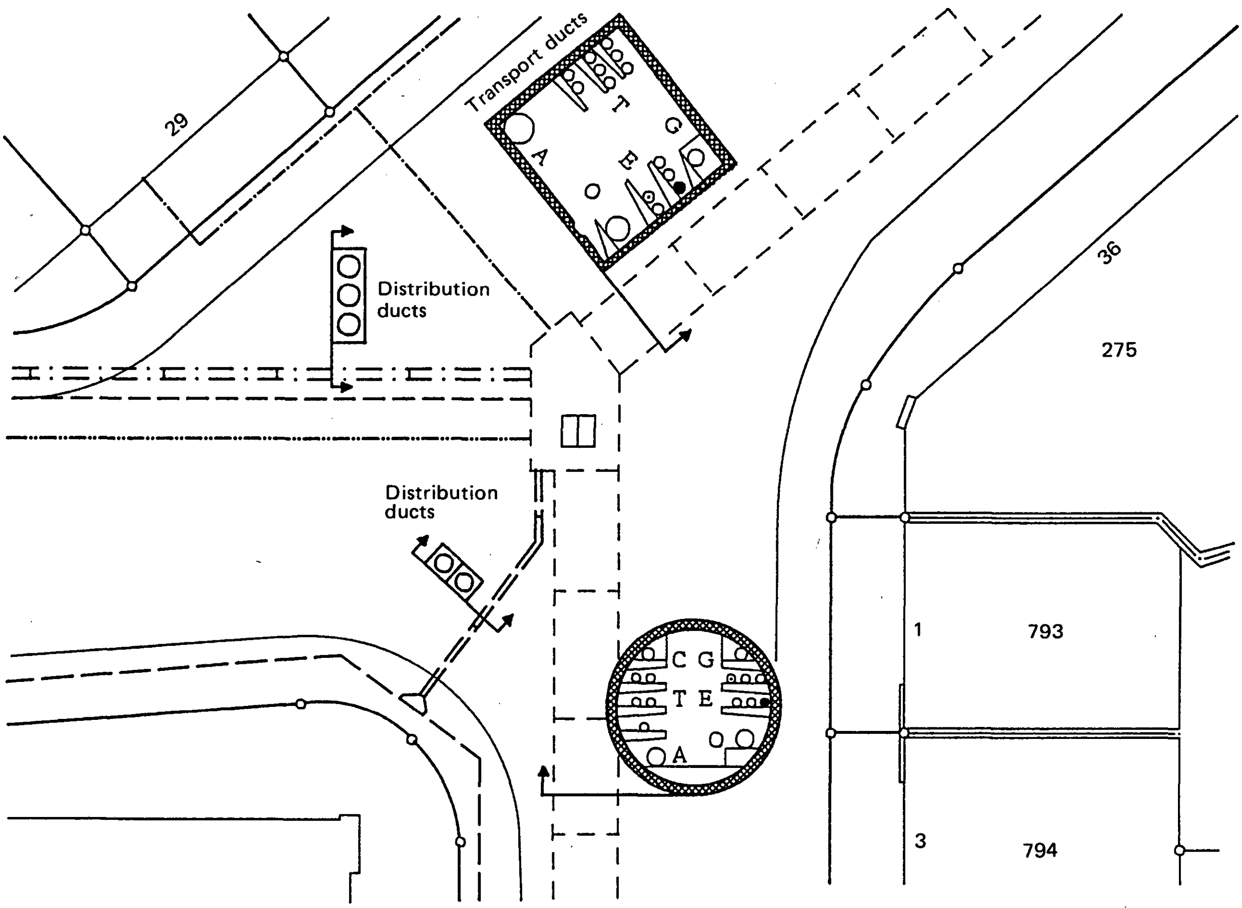
FIGURE B-2/L.11

Example of rectangular cross-section

ANNEX C

(to Recommendation L.11)

Model plan



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Convential signs

- Construction components or invisible installations
- Visible duct components
- Information taken from the land register (streets, plots, buildings, etc.)
- Water to be drained, A
- Electricity, E
- Telecommunications installations, T
- Gas, G
- District heating, C
- Collective antenna installations, V
- Water, O

FIGURE C-1/L.11

Model plan

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