INTERNATIONAL TELECOMMUNICATION UNION

CCITT

THE INTERNATIONAL
TELEGRAPH AND TELEPHONE
CONSULTATIVE COMMITTEE

YELLOW BOOK

VOLUME IX

PROTECTION AGAINST INTERFERENCE

RECOMMENDATIONS OF THE K SERIES

PROTECTION OF CABLE SHEATHS AND POLES

RECOMMENDATIONS OF THE L SERIES

VII^TH PLENARY ASSEMBLY
GENEVA, 10–21 NOVEMBER 1980

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REMARK

The Questions entrusted to each Study Group for the Study Period 1981-1984 can be found in Contribution No. 1 to that Study Group.

CCITT NOTE

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

PART I

Series K Recommendations

PROTECTION AGAINST INTERFERENCE

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

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PROTECTION AGAINST INTERFERENCE *

Recommendation K.1 (New Delhi, 1960)

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

Introduction

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

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

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

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

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

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

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

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

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

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

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

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

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

Recommendation K.2 (New Delhi, 1960)

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

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

Recommendation K.3 (New Delhi, 1960)

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

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

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

Recommendation K.4 (Geneva, 1964)

DISTURBANCE TO SIGNALLING

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

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

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

References

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

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

Recommendation K.5 (Geneva, 1964)

JOINT USE OF POLES FOR ELECTRICITY DISTRIBUTION AND FOR TELECOMMUNICATIONS

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

1) There are economic and aesthetic advantages to be derived from the joint use of poles by Administrations and electricity authorities.

2) When suitable joint construction methods are used, there is, nevertheless, some increased likelihood of danger by comparison with ordinary construction methods, both to staff working on the telecommunication line and to the telecommunication installation connected thereto. Special training of personnel working on such lines is highly desirable and especially when the electricity line is a high-voltage line.

3) The rules given in the *Directives* in connection with danger, disturbance, and staff safety should be complied with (see [1]).

4) Special formal agreements are desirable between the Administration and the electricity authority in the case of joint use of poles in order to define responsibilities.

5) If joint use is applied on short sections (of the order of 1 km), in most cases a few simple precautions may be enough to ensure that disturbances due to electric and magnetic induction are tolerable.

Reference

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

Recommendation K.6 (Geneva, 1964)

PRECAUTIONS AT CROSSINGS

Introduction

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

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

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

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

1 Line routed underground

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

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

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

2 Line left overhead

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

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

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

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

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

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

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

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

3.1 *Systems using voltages of 600 V or less*

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

3.2 *Systems using voltages of 60 kV or more*

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

Arrangements to be as in § 2.3, if necessary.

3.3 *Intermediate voltage systems*

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

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

Reference

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

DEVICES FOR PROTECTION AGAINST ACOUSTIC SHOCK

In unfavourable circumstances, sudden voltage bursts may occur across a telephone receiver and produce such strong sound pressure that there is danger to the ear and to 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 [1]).

The fitting of a device consisting of two rectifiers, in parallel and with opposite polarities, or other semi-conductor elements, has proved to be an effective and inexpensive means of eliminating sudden voltage surges in a telephone receiver and the consequent risk to the ear. In this case, both rectifiers are connected directly in parallel to the telephone receiver.

To conform to the design exigencies of other equipment, to enable a rapid check to be made of the performance of protective devices against acoustic shock, and to avoid excessive impairment of telephone transmission quality, it is recommended that these devices should have the following characteristics:

1) It is desirable for the protective device against acoustic shock to be designed so that it occupies a small space (so that it can be placed, for example, in the case of the operator's or subscriber's telephone receiver).

2) The device must be well made. Its electrical characteristics should not show significant changes under the temperature and humidity conditions to which it is subjected in service.

3) The design of the device must be adapted to the characteristics of the telephone receivers with which it will most often be associated, so that it does not overheat in service.

4) The device should be designed so that, when the protective device against excess voltages on the lines operates (e.g. striking and operation of gas-filled protectors), the amplitude of the sound pressure caused by the diaphragm of the telephone receiver should not exceed about 120 dB above $2 \cdot 10^{-4}$ microbar at 1000 Hz.

Note – Tests have shown that protective devices of the type mentioned above have properties such that this condition can be met without difficulty, if only pulses and not continuous overvoltages are concerned.

5) For certain protective devices used in association with a particular telephone set, Table 1/K.7 below gives limits for the attenuation measured with a sinusoidal signal of 800 Hz that should be achieved for various voltage levels applied to the line terminals of the telephone set concerned. The line impedance is assumed to be 600 ohms. For the purpose of these measurements, the receiver is replaced by a pure resistance of value corresponding to the modulus of the impedance of the receiver at 800 Hz, and the attenuation is given in terms of the ratio of the voltages, expressed in transmission units, across the terminals of that resistance, with and without the protective device in position across the resistance.

   The measurements should be carried out by means of an instrument indicating r.m.s. values (or, possibly, rectified average values).

   In testing any new type of device, it may be advisable to carry out similar measurements at frequencies between 200 Hz and 4000 Hz, to ensure that the average insertion loss is of the same order.

TABLE 1/K.7

Voltage level at line terminals (Level reference 0.775 V)	Attenuation
Decibels	Decibels
– 17.4	< 0.43
– 8.7	< 0.43
0	⩽ 1.7
+ 8.7	> 5.2
+ 17.4	> 10.4
+ 26.1	> 15.6

6) Administrations that so desire can determine the acceptance test limits to be specified for the supply of a device that they have found to be suitable for their own telephone sets and which meets the requirements of 5) above, by themselves making measurements of the insertion loss of a sample of that device between resistances representing the receiver and the associated circuit of their own telephone sets, and quoting the measurement results as limiting values of insertion loss measured between the resistance values used.

7) It should be noted that the harmonics produced while the device is operated as in 4) above, and resulting from the nonlinearity of its characteristic, may contribute to the sound pressure. However, harmful effects from the harmonics do not appear as long as the conditions in 5) above are met.

Reference

[1] CCITT *Directives concerning the protection of telecommunication lines against harmful effects from electricity lines*, Chapter I/6, p. 16, ITU, Geneva, 1963, 1965, 1974, 1978.

Recommendation K.8 (Mar del Plata, 1968)

SEPARATION IN THE SOIL BETWEEN TELECOMMUNICATION AND POWER INSTALLATIONS

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

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

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

ANNEX A

(to Recommendation K.8)

Information supplied by CIGRE (1964-1968)

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

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

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

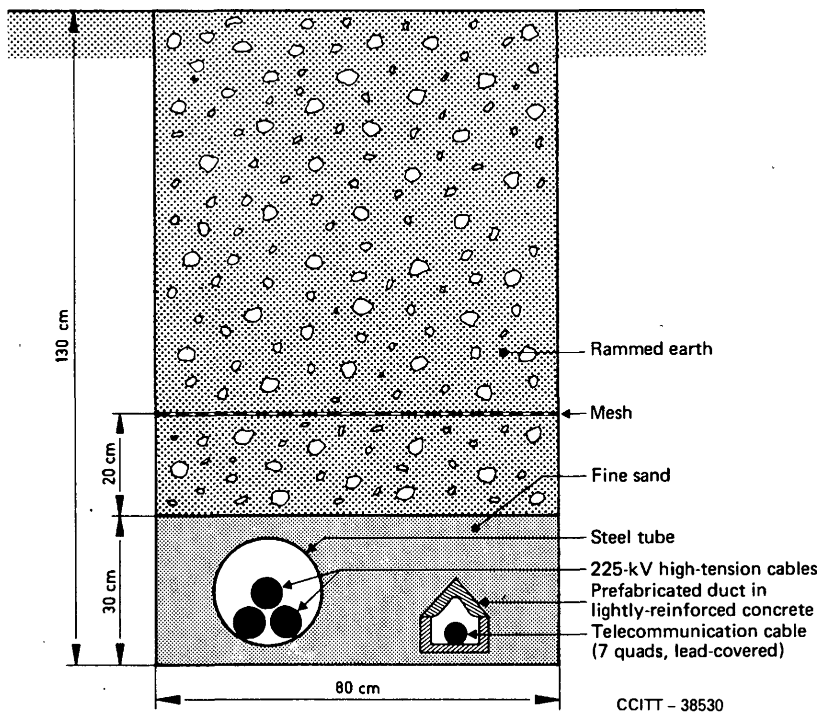

FIGURE A-1/K.8

Common trench for a power cable and a telecommunication cable

Recommendation K.9 (Mar del Plata, 1968)

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

1 General

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

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

2 A.c. electric traction lines

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

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

3 D.c. electric traction lines

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

4 Telecommunication cables

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

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

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

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

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

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

Recommendation K.10 (Mar del Plata, 1968)

UNBALANCE OF TELECOMMUNICATION INSTALLATIONS

In the interests of maintaining an adequate balance of telecommunication installations and of the lines connected to them, it is recommended that the minimum permissible value for the balance of telecommunication installations 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 circuit in Figure 1/K.10 should be used to measure the unbalance of telecommunications equipment.

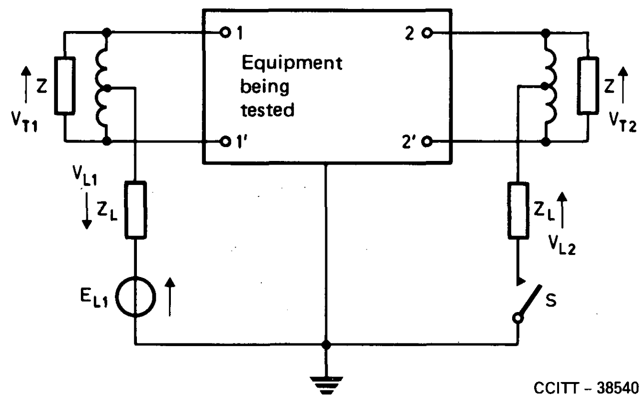

FIGURE 1/K.10
Test circuit

The following specification should apply in the audio frequency range: $Z_L = Z/4$ (see Recommendation Q.45) [1].

References

[1] CCITT Recommendation *Transmission characteristics of an international exchange*, Vol. VI, Fascicle VI.1, Rec. Q.45.

[2] CCITT – Question 13/V, Contribution COM V-No. 1 for the Study Period 1981-1984, Geneva, 1981.

Recommendation K.11

PROTECTION AGAINST OVERVOLTAGES

This Recommendation describes the way in which overvoltages may appear on telecommunications lines, the methods by which these overvoltages may be avoided or reduced, and the protection devices which may be used to safeguard the line and its terminal equipment. Further information is given in the manual cited in [1] and in the *Directives.*

1 Origin of overvoltages

Overvoltages may occur on lines due to the following causes:

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.

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1) See, in particular, Recommendation Q.45 [1], and also the outcome of further studies under Question 13/V [2].

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.

1.3 *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 2000 ms (occasionally even longer) according to the fault clearing system used on the power line.

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 (1 s or less) 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.

1.5 *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.

2 Avoiding overvoltages

2.1 Telecommunication lines may be shielded from lightning to some extent by adjacent earthed metal structures, e.g. power lines or electric railway systems. Cables of high dielectric strength are less likely to suffer damage due to lightning but may transmit surges to more vulnerable parts of the network. 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.

2.2 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.

2.3 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.

3 Need for protection

In spite of the avoidance measures described some overvoltages may still arise, depending on local conditions.

3.1 Lines in exposed situations and districts of high earth resistivity are more susceptible to lightning surges and high overvoltages may be frequent if the local keraunic level is high.

3.2 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.

3.3 The overvoltages may not only overstress the conductors or insulation along the line but may damage susceptible equipment at the line terminals. Fire hazards may arise when long-lasting induction contacts with power lines occur. Telecommunications staff and subscribers may need protection from electric shock.

3.4 When protection is chosen, a balance should be established between the probability of overvoltages and their estimated effects. The minimum acceptable service standard should be taken into account together with any trade-off advantages which may be achieved if particular protection methods are used.

4 Types of protective device

4.1 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.

This protection supplements that given by protective devices and, if the risk of overvoltages is very low, may be sufficient by itself.

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

Usually connected between each wire of a line and earth to provide protection in the range 800-1600 V. They are inexpensive but may need maintenance if operated frequently.

4.3 *Gas-filled protectors*

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. Operating voltages may be 90 V or more. The protectors are compact and will operate frequently without attention.

A full description and specification for gas-filled protectors appears in Recommendation K.12.

4.4 *Semiconductor protective devices*

Used in a similar way to carbon-electrode protectors or gas-filled protectors, 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.

4.5 *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.

4.6 *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.

5 Location of protective devices

5.1 When it is required to provide protection against lightning surges to underground cables and subscribers' equipment, overvoltage protectors are usually fitted at each end of overhead lengths of line. It may also be advisable to fit protectors at the junction of plant with high and low dielectric strengths. Connections to overvoltage protectors used against lightning should be as short as possible.

5.2 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. 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.

5.3 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 both ends of the affected length of line, or as near to this as practicable.

5.4 Overvoltage protectors used to safeguard exchange equipment should be fitted at the main distribution frame (MDF). Modern electronic equipment is vulnerable to surges even of comparatively low amplitude and additional protection may be fitted in the equipment itself. It is important that the various protection components in a line are coordinated to achieve a satisfactory result and that their operating characteristics are appropriate for the voltage resistibility of the equipment and line concerned.

5.5 For telecommunications lines which may come into contact with power lines, the safety of staff may be assured better by leaving the line connected, e.g. by not installing fuses in series with the line, and relying on the telecommunications earth to reduce the voltage at the MDF. If fuses or heat coils or both are used, they are usually fitted at the MDF. When both are used the fuse is on the line side of the heat coil.

6 Residual effects

When protection is used the following possible consequences should be considered.

6.1 *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.

6.2 *Transverse voltages*

Protective devices on the 2 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.

6.3 *Difficulties of coordination*

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.

6.4 *Effect on normal circuit operation*

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

6.5 *Modifying effects*

A protective device may safeguard one part of a line at the expense of another, e.g. if an 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 telecommunications earth.

6.6 *Circuit availability*

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

6.7 *Fault liability*

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

Reference

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

Recommendation K.12 (Geneva, 1972)

SPECIFICATION CLAUSES FOR THE REQUIREMENTS TO BE MET BY GAS DISCHARGE PROTECTORS FOR THE PROTECTION OF TELECOMMUNICATION INSTALLATIONS

Preamble

Protection of telecommunication lines against external disturbances (atmospheric discharges, exposure to electricity power lines and installations) is becoming more and more important. On the one hand, the introduction of solid state devices has increased the sensitivity of telecommunication installations, and on the other, the inevitable extension of power installations is increasing the risks which arise from this source.

Telephone Administrations and other users of telecommunication systems therefore need to have at their disposal high quality protective equipment of exceptional reliability and complete trustworthiness.

Lightning protectors are among the most commonly used protective devices.

This specification contains the basic requirements to be met by gas discharge protectors for the protection of telecommunication installations.

This specification covers both the performance and the reliability of gas discharge protectors.

Performance requirements may vary according to the use made of the gas discharge protector and tolerances may vary within more or less wide limits, but reliability is the essential factor. Whatever type of gas discharge protector is used, it must have an extremely high reliability.

1 General

1.1 Gas discharge protectors (sometimes referred to as rare gas arresters) are used in overhead and underground telecommunication lines to limit overvoltages due to atmospheric discharges or to the effects of electric power installations (magnetic induction, contact with electricity distribution lines), so as to avoid any danger to:

a) the telecommunication lines and the equipment connected therewith;

b) persons in contact with the lines or with part of the telecommunication installation.

In the following, the term *protectors* applies to gas discharge protectors.

1.2 These protectors limit the voltage by making a conductive connection – via an arc discharge in a sealed gaseous medium – between parts of the installation where the overvoltage occurs or with the earthing system, and thus provide a potential-equalizing bond resulting in a residual voltage corresponding to the residual voltage of the overvoltage protector.

The limiting effect is achieved as soon as the overvoltage exceeds the spark-over voltage of the protector with a resulting arc discharge and low residual voltage across the protector.

1.3 The robustness of a protector is characterized by the value of the discharge current and the time of passage of this current (the value of the current being below a certain limit resulting in mechanical destruction).

1.4 When an overvoltage protector is loaded with its rated discharge current, its electrical properties must remain within the specified tolerances after repeated discharges.

2 Scope

2.1 The requirements apply to protectors with one or several discharge gaps in a sealed gaseous medium used to limit overvoltages in telecommunication installations.

2.2 The requirements do not apply to protectors which are connected in series with voltage-dependent resistors in order to limit follow-on currents in electrical power systems.

2.3 The general provisions of this specification apply to all protectors in telecommunication systems, but it is recognized that in the case of those used in connection with impedances to reduce the discharge current, certain of the values quoted in the specification may require to be varied, and these must be separately defined by the user.

3 Definitions

3.1 spark-over

Spark-over of a protector occurs on electrical breakdown of the respective discharge gap.

3.2 d.c. spark-over voltage

The voltage at which the protector sparks over with slowly increasing d.c. voltage. It is a quantity which is used to indicate that a protector is suitable for use. This includes testing during its life.

3.3 nominal d.c. spark-over voltage of a protector

The voltage specified by the manufacturer to designate the protector (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.

3.4 **a.c. spark-over voltage of a protector**

The r.m.s. value of the sinusoidal voltage at a frequency of 15 Hz to 62 Hz, the rise of which causes the protector to spark over when the voltage is slowly increased.

It is essentially used to indicate the range of application of a protector in case of direct contact with, or magnetic induction from, a.c. power distribution lines.

3.5 **impulse spark-over voltage of a protector**

The impulse spark-over voltage of a protector is the highest voltage which appears across its terminals in the period between the application of an impulse of given wave shape and the time when current begins to flow.

3.6 **impulse spark-over voltage/time curve of a protector**

The impulse spark-over voltage/time curve of a protector is the curve which relates the impulse spark-over voltage to the time to spark over.

3.7 **alternating discharge current**

The r.m.s. value of an approximately sinusoidal alternating current flowing through the protector.

3.8 **nominal alternating discharge current**

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

3.9 **impulse discharge current**

The peak value of the impulse current flowing through the protector after spark-over.

3.10 **nominal impulse discharge current**

The peak value of the impulse current with a defined curve shape with respect to time for which the protector is rated.

3.11 **destruction characteristic**

Indicates the relationship between the value of the discharge current and its time of flow until the protector is mechanically destroyed (break, electrode short circuit). It is obtained from the average of measurements on several protectors.

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.

3.12 **residual voltage**

The instantaneous voltage appearing across the terminals of a protector during the passage of a discharge current.

A distinction is made between the residual voltage in the case of a glow discharge and the residual voltage in the case of an arc discharge, for it is a quantity which depends upon the type of discharge.

3.13 **glow current**

The current which flows after spark-over when the electrodes are surrounded by a glow.

3.14 **arc current**

The current which flows after spark-over when the gap of the protector is bridged by an arc.

3.15 **voltage/discharge current curve**

For alternating currents of a frequency from 15 Hz to 62 Hz, the voltage/discharge current curve indicates the relationship between the instantaneous values of voltage and current during the passage of discharge current.

3.16 **transverse voltage**

The transverse voltage of a protector with several gaps is the difference of the residual voltages of the gaps assigned to the two conductors of a telecommunication circuit during the passage of discharge current.

4 General requirements

4.1 The protector shall be constructed and rated so that there will be no danger to persons or to the surroundings during normal operation or if it becomes faulty.

In this respect attention should be paid to problems of inadmissible heating, of destruction due to overloading and to the avoidance of radiation in the case of pre-ionization by radioactive matter.

The mechanical construction of a protector, particularly in respect of the seal between metal and the envelope, is most important. In general, this seal should be such as to have a sufficiently large cross-sectional area so that heavy discharges will not shatter or crack the envelope or seal. This applies particularly in respect of feed-through leads.

It is also desirable that the construction of the protector shall be such that mechanical shocks do not alter its electrical characteristics.

4.2 The values of the striking voltages of the protectors shall be selected so that they:

4.2.1 are adapted to the dielectric strength of the insulation of the installation to be protected;

4.2.2 allow for the relevant regulations for the protection of persons against short-term overvoltages;

4.2.3 are well above the highest equipment working-voltage in order to avoid any disturbance to circuits under service conditions.

4.3 The insulation resistance and capacity of the protectors shall be such that the functioning of the telecommunication circuits is not impaired.

4.4 The protector shall not be maintained in operation by the line voltage after the surge has disappeared.

5 Terms and values designating the protectors

The electrical characteristics of the various types of protector are indicated by the following terms and values:

5.1 *Spark-over voltages as a function of time from the moment when the voltage is applied to the terminals to the moment when the discharge current begins to flow*

Characteristic $U_a = f(t)$. An example is given in Appendix I.

These spark-over voltages are:

5.1.1 the nominal d.c. spark-over voltage;

5.1.2 the impulse spark-over voltage in the presence of a standard impulse voltage as specified in § 7 below.

5.2 *Discharge-current carrying capacity as a function of the duration of the discharge*

The current carrying capacity is indicated by:

5.2.1 the nominal alternating discharge current for a defined time of flow of this current;

5.2.2 the nominal impulse discharge current with an impulse having a standard wave shape as specified in § 7 below;

5.2.3 the destruction characteristic (characteristic $I_d = f(t)$. An example is given in Appendix II).

5.3 *Residual voltages as a function of the discharge current* (characteristic $U_r = f(I_d)$. An example is given in Appendix III).

These residual voltages are indicated by:

5.3.1 the maximum residual voltage within the range of the glow discharge;

5.3.2 the residual voltage in the case of an arc discharge;

5.3.3 the maximum glow discharge current at which the residual voltage of the glow discharge changes into the residual voltage of the arc discharge.

5.4 *Characteristics used for designating a protector according to the kind of overvoltage to be limited*

5.4.1 For overvoltages at electrical power frequencies of 15 Hz to 62 Hz, the nominal values as specified in §§ 5.1.1, 5.2.1 and 5.3.3 above apply.

The characteristics of standard types of these protectors are listed in Table 1/K.12.

TABLE 1/K.12

Standard type No.	Characteristics		
	Nominal d.c. spark-over voltage (see § 5.1.1)	Nominal alternating discharge current (r.m.s. value) (see § 5.2.1)	Maximum glow discharge current (see § 5.3.3)
1	Choice of the nominal value with due regard to the provisions under § 4.2	5 A	< 0.5 A to 1.5 A
2		20 A	
3		50 A	

5.4.2 For overvoltages due to atmospheric discharges, the values specified in §§ 5.1.1 and 5.2.2 above apply.

The characteristics of standard types of these protectors are listed in Table 2/K.12.

TABLE 2/K.12

Standard type No.	Characteristics		
	Nominal d.c. spark-over voltage (see § 5.1.1)	Nominal impulse discharge current (see § 5.2.2)	Impulse spark-over voltage (see § 5.1.2)
4	Choice of the nominal value with due regard to the provisions under § 4.2	2.5 kA	For upper limits, see Tables 3/K.12, 4/K.12
5		10 kA	
6		20 kA	

5.4.3 For overvoltages occurring on the same telecommunication installation due to the effects of electrical power installations (power frequencies) and to atmospheric discharges, by combination of the values in respect of standard types 1 and 4 (standard types 1-4), 2 and 5 (standard type 2-5) and 3 and 6 (standard type 3-6).

5.5 *Tolerance limits of the nominal values*

5.5.1 The upper *and* lower limits (tolerance) of the d.c. spark-over voltage are determined by the requirement specified in § 4.2 above. These limits shall be observed even after a repeated flow of discharge currents with values as specified in Table 1/K.12 and Table 2/K.12 respectively.

5.5.2 As far as the other values are concerned, it is only necessary to state upper *or* lower limits, depending on the characteristics in question.

5.5.3 The limits make allowance for environmental influence and the location (room temperature, polarity, light).

Note – The limits are specified in *Type tests*, § 8 below.

6 General information on tests

6.1 The tests comprise:

6.1.1 type tests as specified in § 8 below to determine the electrical and mechanical properties of a type of protector;

6.1.2 acceptance tests as specified in § 9 below, i.e. sampling of the protector on delivery.

6.2 The electrical properties shall be assessed in accordance with statistical methods, because the physical processes of a discharge in a gaseous medium are subject to statistical variations. Every test shall be made on several specimens.

6.3 In the case of protectors with several discharge gaps in the same discharge envelope, the electrical properties are tested for each gap separately.

6.4 Testing of the mechanical properties includes the checking of the dimensions and of the durability of the connections to the fittings or contact plates attached to the protector. If the protectors are to be used in an environment having a high humidity, it may be advisable to check the corrosion resistance.

6.5 Thermal shock tests may be made on protectors if required by the user.

7 Standardized test voltages and currents

7.1 An impulse voltage of the form 5/65 (Definition of the wave shape according to [1] with a peak value of 5 kV is used for the impulse spark-over voltage tests (see § 5.1.2 above).

This impulse voltage may also be replaced by a voltage having a linear increase to 5 kV in 5 μs (voltage of virtual steepness of the impulse wavefront of 1 kV/μs).

Figure 1/K.12 shows an arrangement for testing with a voltage impulse having a wavefront with a virtual steepness of 1 kV/μs.

The test arrangements for impulse voltages must make allowance for the transient phenomena with impulses, such as cutoff frequency of the measuring equipment, matched termination of the test lead, etc.

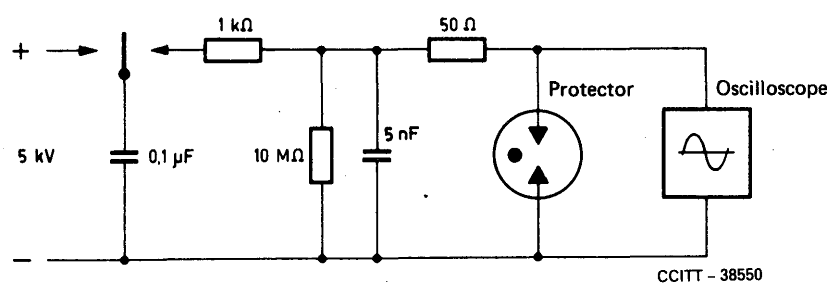


FIGURE 1/K.12

Testing arrangement producing a voltage impulse having a wavefront with a virtual steepness of 1 kV/μs

7.2 An impulse current of the form 8/20 (Definition of the wave shape according to [1]) with a peak value as listed in Table 2/K.12 above is used for the impulse current carrying capacity tests (see § 5.2.2 above).

7.3 The voltage used for making the d.c. spark-over voltage tests shall be a slowly increasing voltage having a maximum rate of increase of 10 kV/s.

8 Type tests

8.1 *Spark-over voltages*

8.1.1 *D.c. spark-over voltage*

Four measurements are made (two of each polarity) on all specimens used for tests under §§ 8.2.1 and 8.2.2 below before those tests are made. Assessment is done in accordance with Table 3/K.12.

TABLE 3/K.12

Test as specified under	D.c. spark-over voltage		Percentage of the measured values to be within the tolerance (see § 6.2)
	Nominal value of d.c. voltage (see § 5.1.1)	Limits of the d.c. voltage at 1 kV/μs (see § 5.5.1)	
§ 8.1.1	Choice of the nominal value with due regard to the provisions under § 4.2	± 20% a)	95% b)
§ 8.2.1			80% b)
§ 8.2.2			

a) This tolerance can be modified in accordance with the requirements specified in § 4.2 of this Recommendation.
b) In a given batch tested, any individual protector which is outside these tolerances must nevertheless spark over during the test.

8.1.2 *Impulse spark-over voltage*

An impulse voltage as specified in § 7.1 above is used to measure ten times (five in each direction) the impulse spark-over voltage of each of 20 protectors which have been tested and approved in accordance with § 8.1.1 above. Assessment is done in accordance with Table 4/K.12.

TABLE 4/K.12

Test as specified under	Impulse spark-over voltage		Percentage of the measured values to be within the tolerance (see § 6.2)
	Nominal value (see § 5.1.1)	Upper limits at 1 kV/μs (see § 5.5.2)	
§ 8.1.2	< 150 V	< 1 kV	80% a)
	150 V to 500 V	1 kV to 2 kV	
	500 V to 1500 V	2 kV to 3 kV	

a) In a given batch tested, any individual protector which is outside these tolerances must nevertheless spark over during the test.

8.1.3 If the envelope is light-transparent, these tests shall be made in darkness after the protectors have been stored in darkness for a sufficient time, to be determined for the type of protector concerned. Between successive measurements a time interval of a few seconds should be allowed.

8.2 *Discharge currents*

8.2.1 *Alternating discharge currents*

The nominal alternating discharge current (within tolerance limits of ± 10%) is used to test 20 protectors which have been tested and approved in accordance with § 8.1.1 above, as follows: the current is applied to each protector ten times for 1 s at intervals of 3 min. After cooling down, the d.c. spark-over voltage is measured and the results are assessed in accordance with Table 3/K.12.

If the user considers it to be necessary in case of protection against atmospheric discharges, measurements according to § 8.1.2 above shall also be made and the results assessed in accordance with Table 4/K.12.

8.2.2 *Impulse discharge current*

The nominal impulse discharge current (within the tolerance limits quoted in [1] is used to test 20 other protectors which have been tested and approved in accordance with §§ 8.1.1 and 8.1.2 above as follows: an impulse is applied to each protector ten times (five of each polarity) at intervals of 3 min. After cooling down, the d.c. spark-over voltage and the impulse spark-over voltage are measured and the results are assessed in accordance with Tables 3/K.12 and 4/K.12.

8.2.3 *Destruction characteristics*

The manufacturer shall indicate the destruction curve together with the dispersion of the measured values for every type of protector. If the user wishes the manufacturer to make a check of the destruction curve it shall be sufficient to make a test at one point on the curve, using three protectors. When a protector destroys itself in this test with alternating current it shall fail by short circuit.

8.3 *Voltage/discharge current curve*

The values specified in §§ 5.3.1, 5.3.2 and 5.3.3 above shall be measured (as shown in Figure 2/K.12) on three other protectors which have been tested and approved in accordance with § 8.1.1 above. For this purpose use shall be made of power frequency alternating current applied for a period of 3 s. The r.m.s. value of the applied voltage shall be between two and three times the nominal d.c. spark-over voltage, and the current should be limited to a value approximately twice that of the glow discharge current in Table 1/K.12.

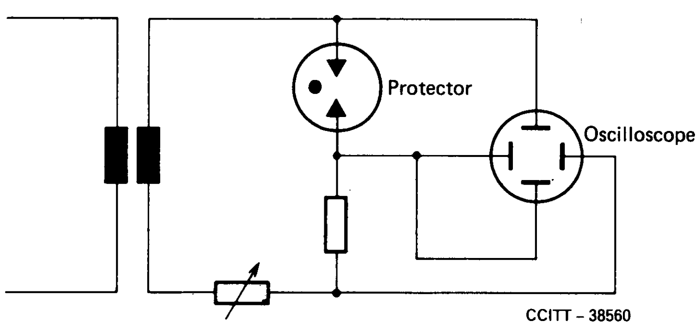


FIGURE 2/K.12

Testing arrangement for the characteristics mentioned under § § 5.3.1, 5.3.2 and 5.3.3

An oscilloscope with a camera attachment should be used for recording the results. The shutter of the camera should be opened before the current is switched on and should be left open for the full period of 3 s.

8.3.1 The residual voltage in case of a glow discharge is, in general, greater than 60 V. The maximum value shall not exceed 1.3 times the value of the d.c. spark-over voltage.

8.3.2 The residual voltage occurring in the case of arc discharge shall be less than 25 V.

8.3.3 The maximum discharge current occurring in the case of glow discharge (transition from glow to arc discharge) shall not exceed the value listed in Table 1/K.12.

The upper limits of these values should be taken from the oscillograms (see also Appendix III).

8.4 *Transverse voltage of three and more electrode protectors*

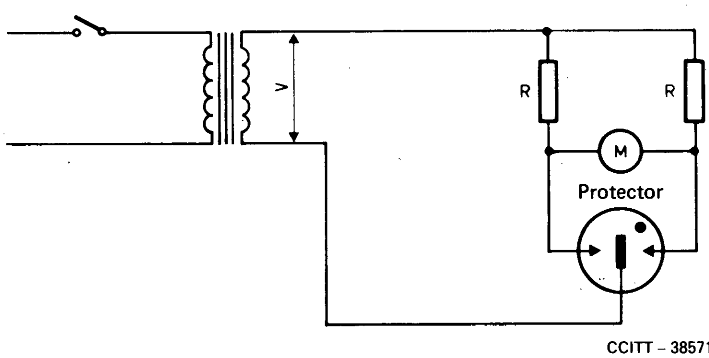
The following measurements shall be made between pairs of electrodes assigned to the two conductors of the same circuit and the common earth electrode.

Tests shall be made on ten protectors which have been tested and approved in accordance with §§ 8.1.1 and 8.1.2 above.

8.4.1 *Transverse voltage under a.c. conditions*

The average value of the transverse voltage shall be measured while both discharge gaps are simultaneously carrying an alternating discharge current. The measurement may be made with an arrangement as indicated in Figure 3/K.12. The r.m.s. value of the applied voltage should be between two and three times the nominal d.c. spark-over voltage, and the value of the resistors R should be such that the peak value of the current is approximately twice the maximum glow discharge current (transition from glow to arc discharge – see § 8.3.3 above). The duration of the discharge shall not exceed 3 s.

The maximum value of the average transverse voltage shall not exceed 45 V in nine out of the ten protectors tested.



Note – Voltmeter *M* should have a resistance of not less than 20 kΩ and a full scale deflection of 100 V approximately. It should be a moving coil and rectifier instrument, calibrated to read mean values.

If the meter is calibrated to read the r.m.s. voltage of sinusoidal supplies, the readings should be multiplied by 0.9 to give the mean value.

FIGURE 3/K.12

Testing arrangement for the characteristics of 3-electrode protectors referred to under § 8.4.1 (transverse voltage during alternating current discharge)

8.4.2 *Transverse voltage under impulse conditions*

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 4/K.12. The difference in time between the spark-over of the first gap and that of the second shall not exceed 0.2 μs in nine out of the ten protectors tested.

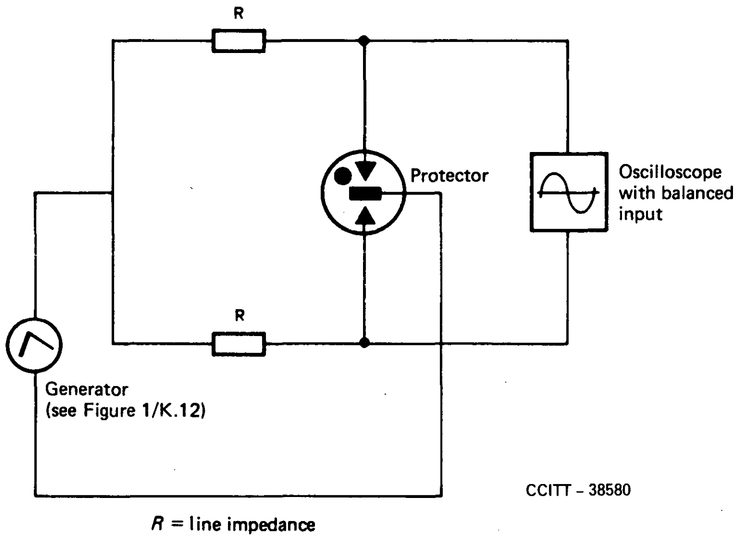


FIGURE 4/K.12

Testing arrangement for the characteristics of 3-electrode protectors referred to under § 8.4.2 (transverse voltage during an impulse discharge)

8.5 *Insulation resistance*

This shall be measured with suitable equipment at a voltage less than the d.c. spark-over voltage of the protectors after they have been in a humid atmosphere for 24 hours (at room temperature and about 83% relative humidity, for example in a saturated atmosphere over a saturated solution of potassium chloride). The insulation resistance shall be not less than 10^8 ohms after the tests set out in §§ 8.2.1 and 8.2.2 above have been made. The insulation resistance measurements shall be made on the same protectors used in those tests.

8.6 *Capacity*

The self-capacity shall be measured on three protectors. It shall be less than 10 pF.

8.7 *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 protectors and to a batch of protectors (for example, when packed in a cardboard box for dispatch, storage, etc.).

A type test is not required, provided the manufacturer indicates the kind and amount of the radioactive matter as well as the emerging radiation.

8.8 *Mechanical properties*

Testing of the mechanical properties may be made in accordance with the general indications set out in §§ 4.1, 6.4 and 6.5 above.

9 Acceptance testing

The number of protectors on which acceptance tests are made depends on the respective lot.

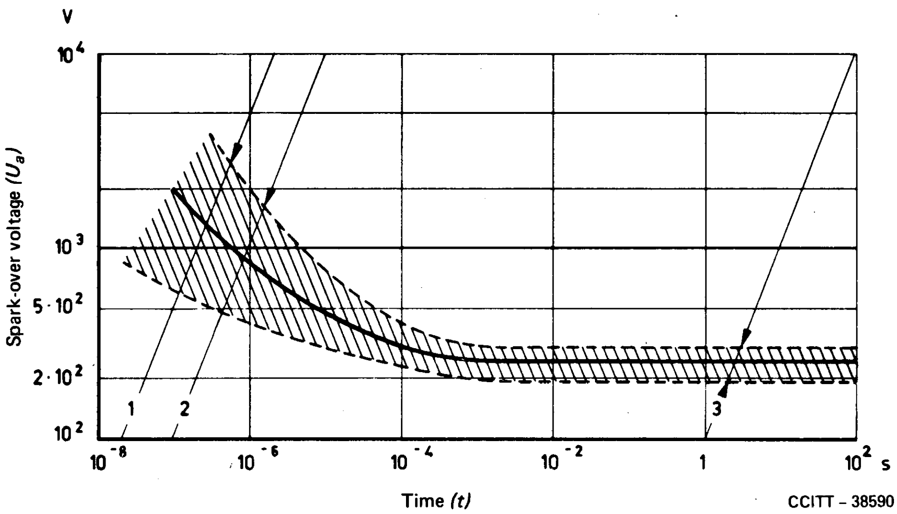
The following values apply only as a guide.

Lot	*Acceptance test*
Comprising up to 1 000 protectors	at least 20 protectors
Comprising up to 10 000 protectors	at least 50 protectors
Comprising up to 50 000 protectors	at least 100 protectors

The acceptance test involves the measurement of the d.c. spark-over voltage twice on each sample. Assessment is made in accordance with Tables 3/K.12 and 4/K.12.

APPENDIX I

Spark-over characteristic $U_a = f(t)$ (see § 5.1)

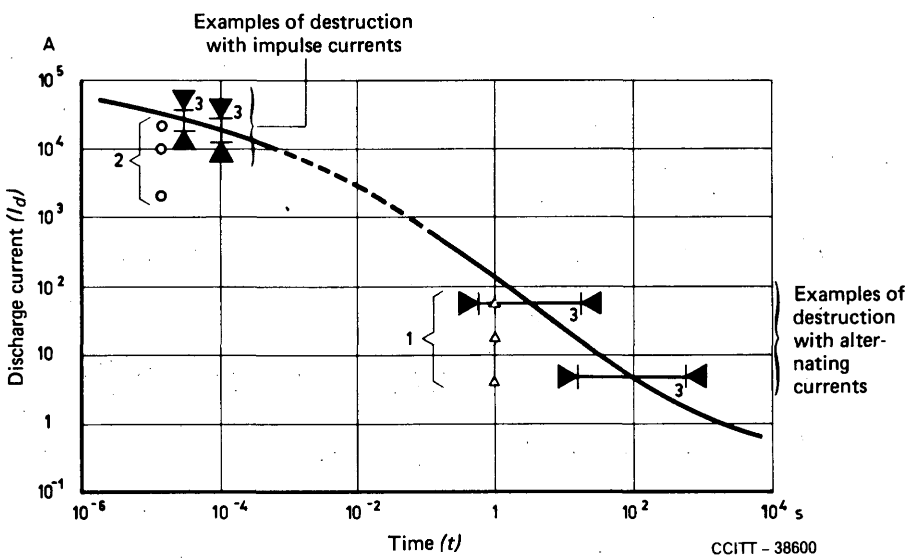


1. Example with 5 kV/μs	Test as specified under § 8.1.2, upper limit	
2. Example with 1 kV/μs		
3. Example with 100 V/s	Test as specified under § 8.1.1, tolerance	

FIGURE I-1/K.12

APPENDIX II

Discharge currents according to § § 5.2.1 and 5.2.2 and destruction curve $I_d = f(t)$ according to § 5.2.3



Current carrying capacity

1. Test as specified under § 8.2.1 with alternating discharge currents △

2. Test as specified under § 8.2.2 with impulse currents ○

Destruction

3. Mechanical destruction test as specified under § 8.2.3

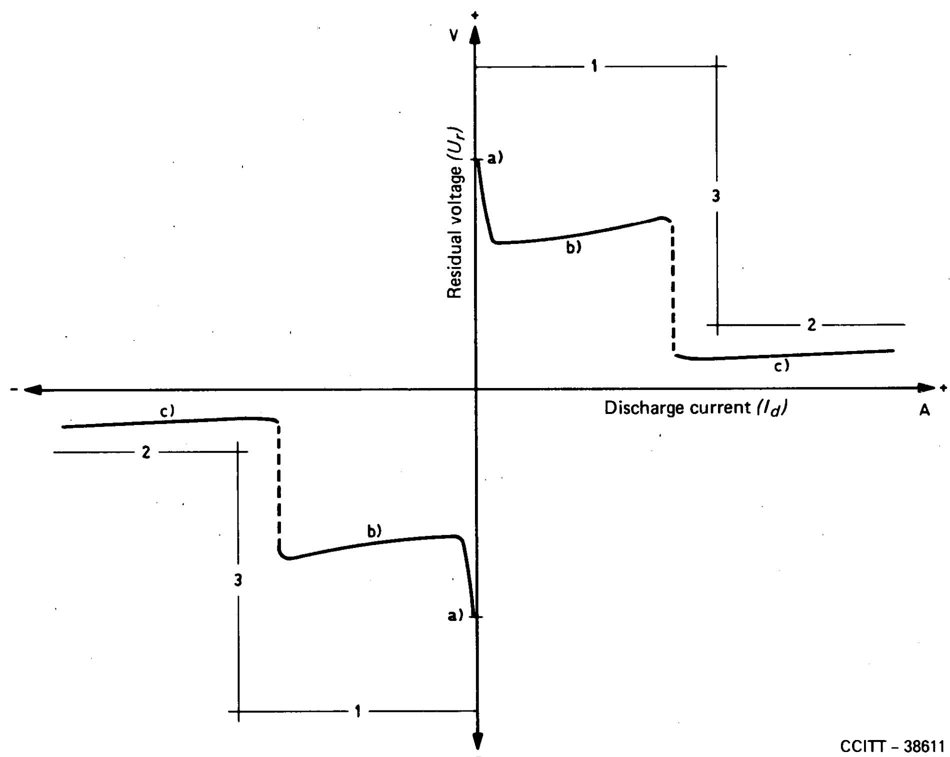
Margin of current at destruction by impulse currents

Margin of time at destruction by alternating currents

FIGURE II-1/K.12

APPENDIX III

Voltage discharge current curve $U_r = f(I_d)$ (see § 5.3)



a) Spark-over voltage
b) Residual voltage in the case of glow discharge, see § 5.3.1
c) Residual voltage in the case of arc discharge, see § 5.3.2

Upper limits

1. Test as specified under § 8.3.1
2. Test as specified under § 8.3.2
3. Test as specified under § 8.3.3

FIGURE III-1/K.12

Reference

[1] IEC publication No. 60/1962.

INDUCED VOLTAGES IN CABLES WITH PLASTIC-INSULATED CONDUCTORS

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

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

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

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

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

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

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

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

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

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

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

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

References

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

[2] *Ibid.*, Chapter XX.

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

Recommendation K.14 (Geneva, 1972)

PROVISION OF A METALLIC SCREEN IN PLASTIC-SHEATHED CABLES

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

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

the CCITT recommends that:

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].)

Reference

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

Recommendation K.15 (Geneva, 1972)

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

Preliminary recommendation

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

Introduction

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

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

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

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

The protective measures required depend partly on the following:

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

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

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

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

1 Methods of calculation

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

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

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

2 Limit values of overvoltages

2.1 *Longitudinal voltages caused by magnetic induction*

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

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

2.2 *Overvoltages caused by atmospheric discharges*

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

3 Protective measures

3.1 *Protection against overvoltages*

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

3.1.1 *Protection of conductors in cables*

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

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

3.1.2 *Protection of repeaters*

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

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

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

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

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

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

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

4.1 *General*

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

4.2 *Testing by impulse voltages*

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

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

4.3 *Testing by alternating voltages*

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

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

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

References

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

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

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

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

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

[6] *Ibid.*, Chapter IV, § 48.

[7] *Ibid.*, Chapter IV, § 53.

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

Recommendation K.16 (Geneva, 1972)

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

1 Summary

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

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

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

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

2 Advantages of the equivalent circuit

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

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

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

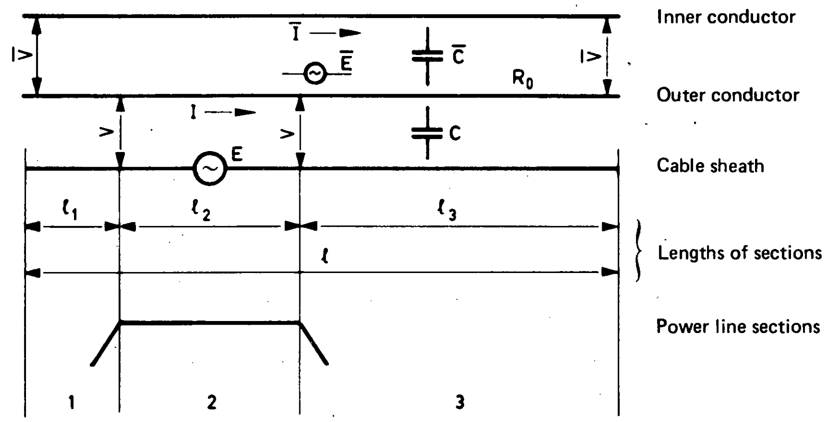
On the basis of the general assumption that a power-feeding section with the outer conductors at floating potential (not bonded to the cable sheath or to a grounding system) is exposed to induction along an arbitrarily located section, we can draw Figure 1/K.16 below, which shows the conventions and 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 ($\bar{E}$, $\bar{C}$, $\bar{V}$, $\bar{I}$) associated with the circuit *outer conductor – innerconductor* 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.

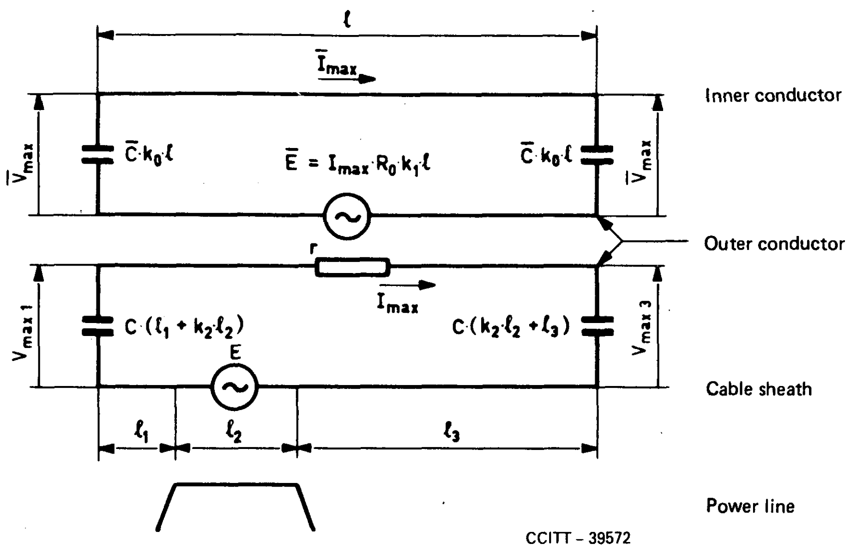


E = longitudinal voltage induced in the cable (volts)
$\bar{E}$ = longitudinal voltage in the coaxial tube (volts)
l_2 = length of the exposed section (km)
l_1, l_3 = lengths of the unexposed sections (km)
l = length of the power-feeding section (km) = $l_1 + l_2 + l_3$
$V, \bar{V}, I, \bar{I}$ = maxima of the voltages and currents to be determined
$C, \bar{C}$ = capacitances (F/km) effective per unit length
where
$C = \dfrac{C_{0s} \cdot l_s + C'_{0s}}{l_s}$ and $\bar{C} = \dfrac{C_{io} \cdot l_s + C_f}{l_s}$

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

FIGURE 1/K.16

Schematic representation of circuits



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

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

FIGURE 2/K.16

Equivalent circuit

The following comments will help to explain the simplified diagram:

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

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

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

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

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

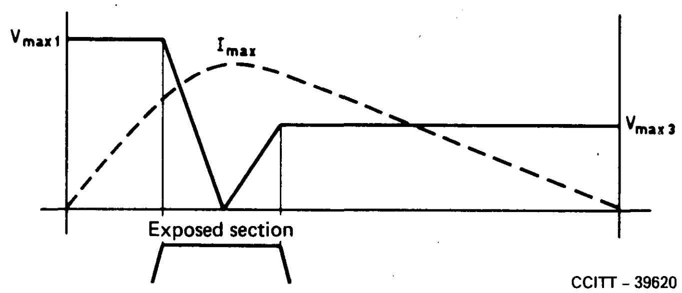


FIGURE 3/K.16

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

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

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

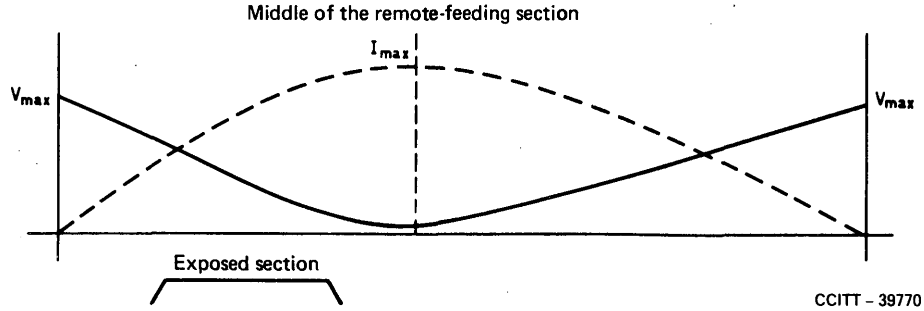


FIGURE 4/K.16

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

ANNEX A

(to Recommendation K.16)

Justification of the parameters included in the universally applicable equivalent circuit

A.1 *General case*

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

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

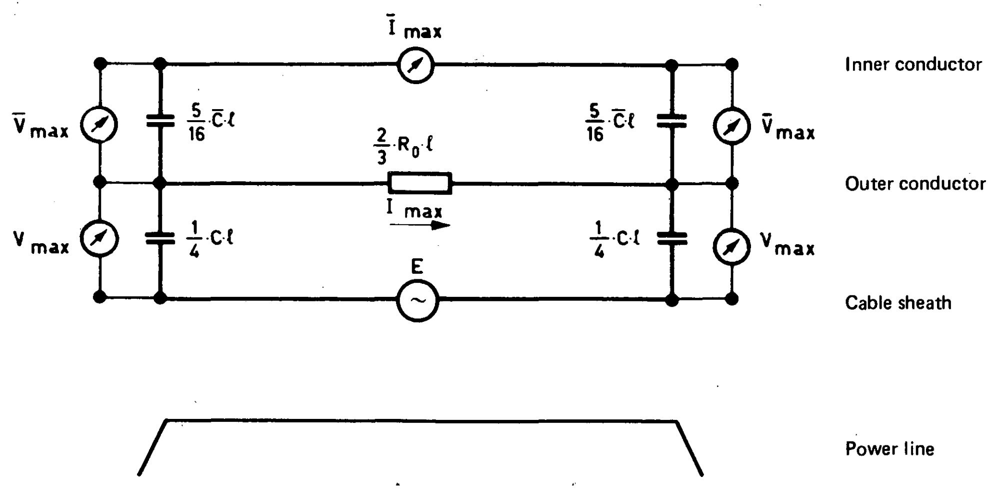
A.2 *First stage – Symmetrical exposure – Full calculation*

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

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

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

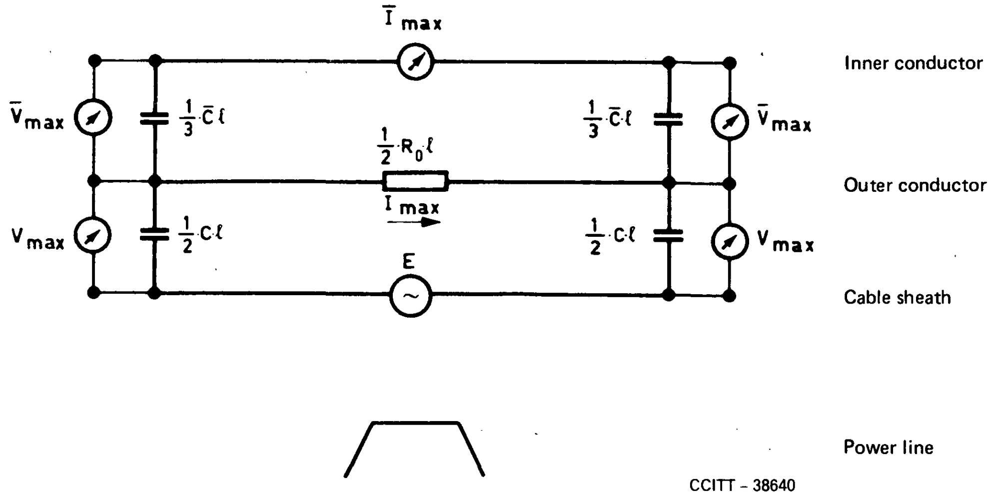
The equivalent circuits in Figures A-1/K.16 and A-2/K.16 can be used to calculate the maximum voltages and currents in two cases of symmetrical exposure; since these cases are both extremely exceptional, we should, at the same time, consider the general case of a dissymmetrical exposure of any length.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



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

FIGURE A-1/K.16

Uniform exposure to induction of the power-feeding section



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

FIGURE A-2/K.16

Partial exposure of short length in the middle of the section

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

A.4.1 *Circuit cable sheath – outer conductor*

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

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

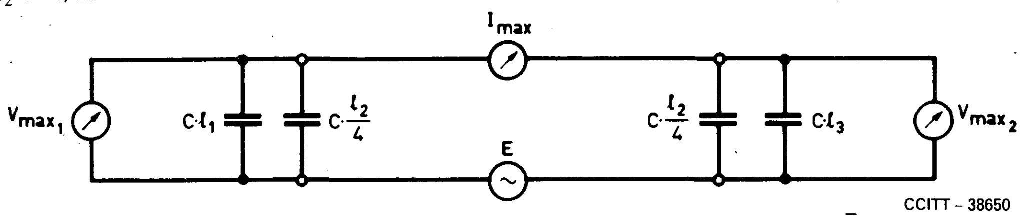


FIGURE A-3/K.16

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

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

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

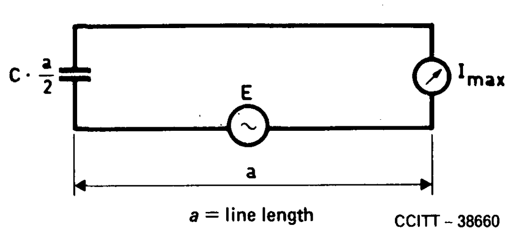


FIGURE A-4/K.16

Line with a short-circuit at one end

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

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

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

$C \cdot \frac{l_2}{4} > C \cdot \frac{l_2}{x} > 0$ 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 $l_2 \ll l/2$.

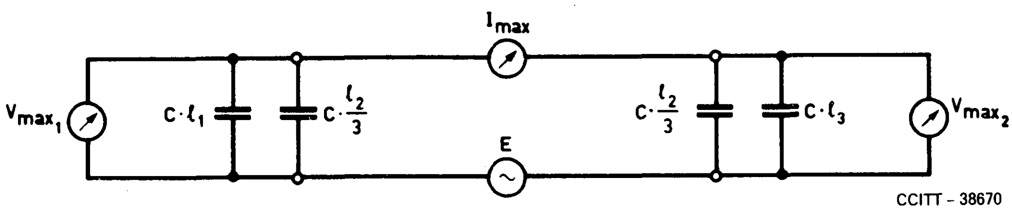


FIGURE A-5/K.16

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 $\overline{E}$ 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 $\overline{E}$. 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 $\overline{E}$ is given by the equation: $\overline{E} = I_{max} \cdot Z_t \cdot l$.

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.

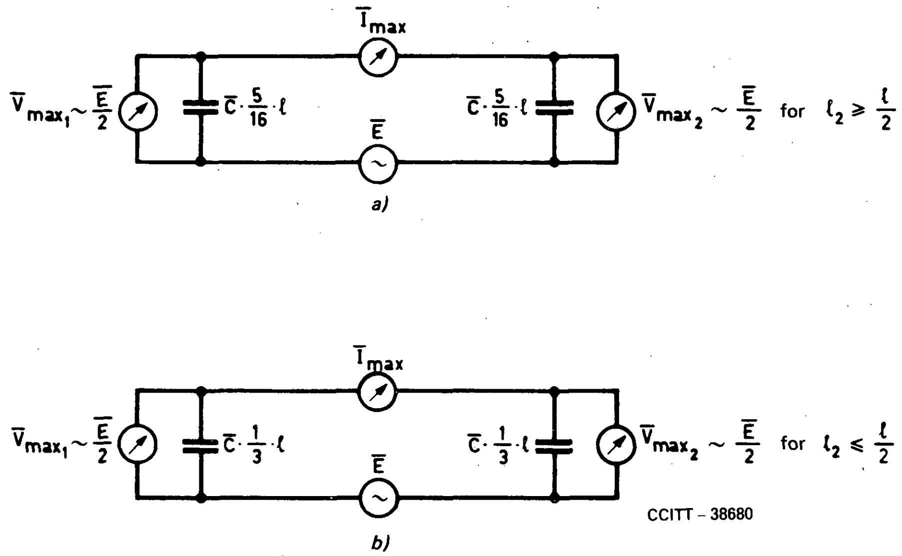


FIGURE A-6/K.16

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:

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

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

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

ANNEX B

(to Recommendation K.16)

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

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

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

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

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

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

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

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

Calculation scheme:

$$C l_1 = 0.12 \times 12 = 1.44\ \mu\text{F} \qquad C k_2 l_2 = 0.12 \times \tfrac{1}{3} \times 16 = 0.64\ \mu\text{F} \qquad C l_3 = 0.12 \times 36 = 4.32\ \mu\text{F}$$

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

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

$$I_{max} = \frac{1000\ \text{V}}{2170\ \Omega} = 0.461\ \text{A} \;\rightarrow \times \begin{cases} 1530\ \Omega = V_{max_1} = 705\ \text{V} \\ 640\ \Omega = V_{max_2} = 295\ \text{V} \\ 198.5\ \Omega = \bar{E} = 91.6\ \text{V} \end{cases}$$

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

$$\tfrac{1}{2} \bar{E} \approx \bar{V}_{max_1} \approx \bar{V}_{max_2} = 45.8\ \text{V}$$

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

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

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TABLE B-1/K.16

Comparison of the equivalent circuit determination with the accurately calculated maxima

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

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

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

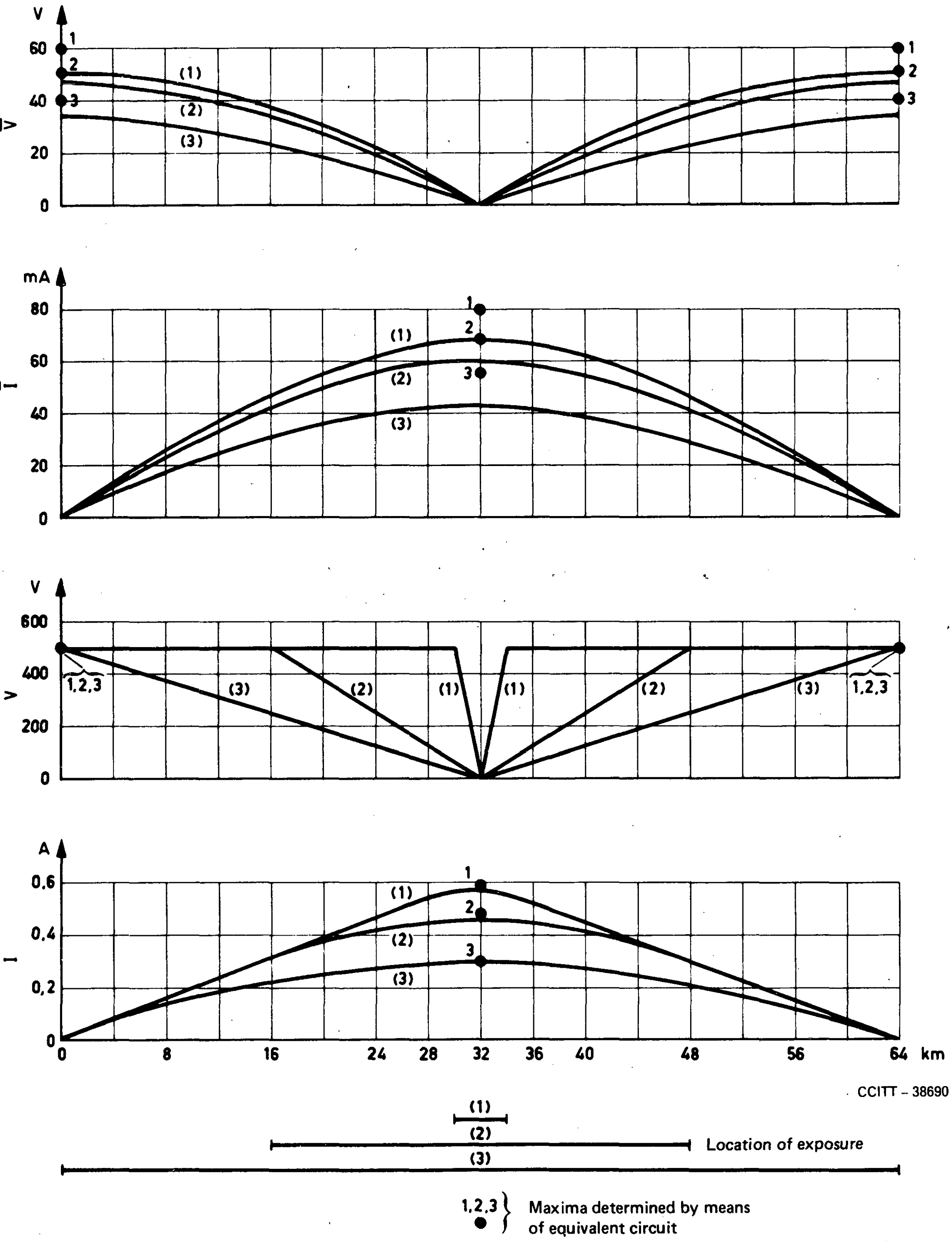


FIGURE B-1/K.16

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

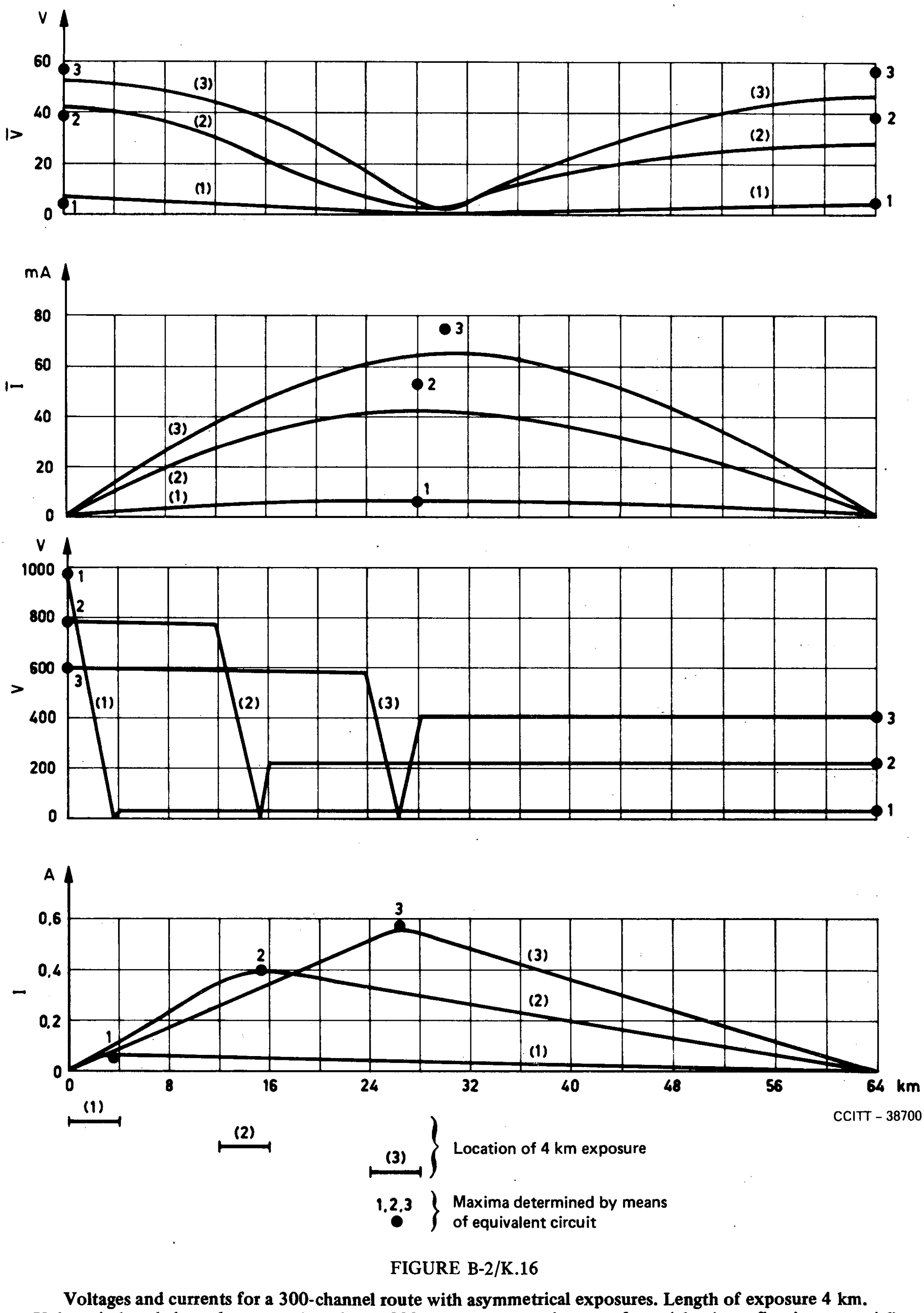


FIGURE B-2/K.16

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

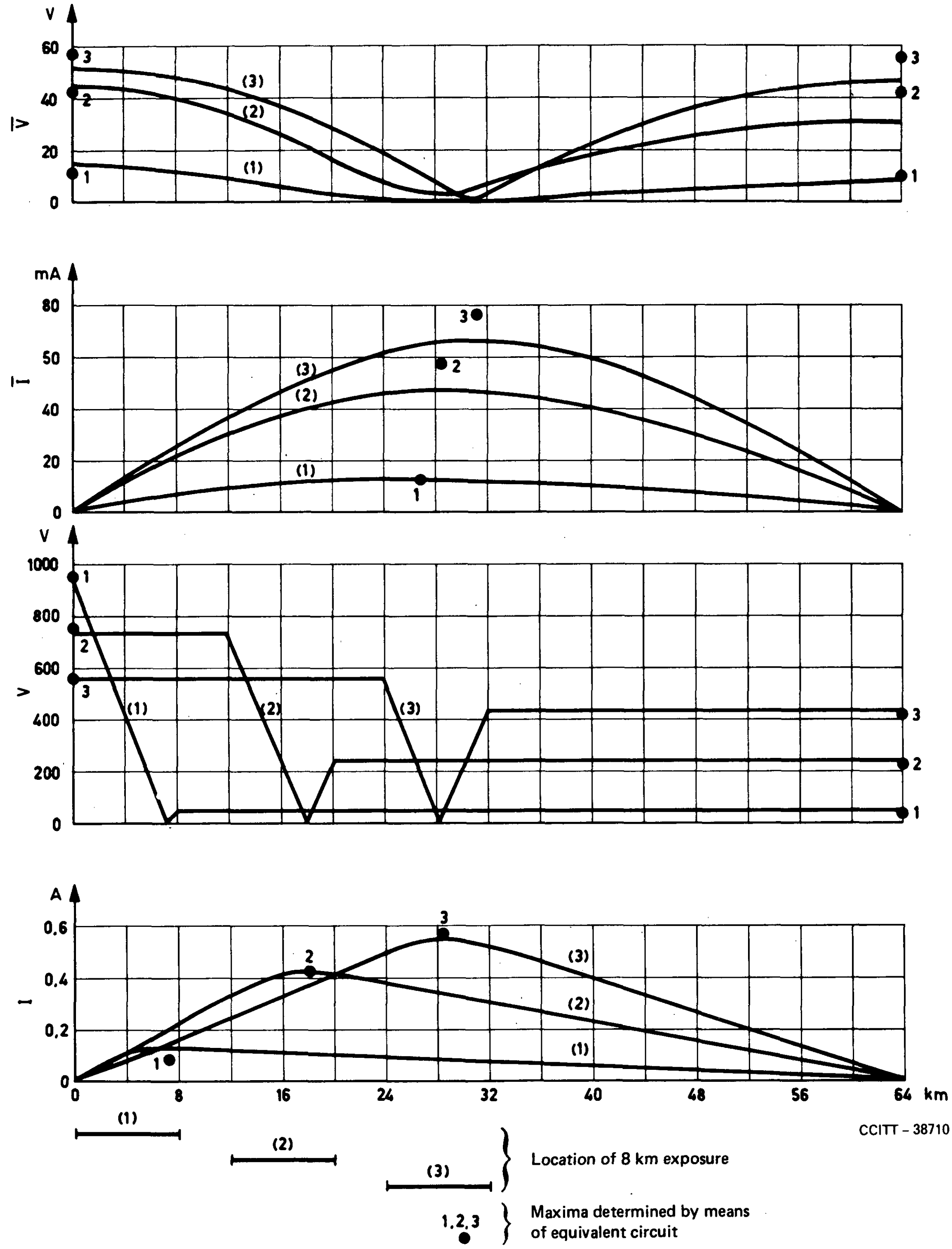


FIGURE B-3/K.16

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

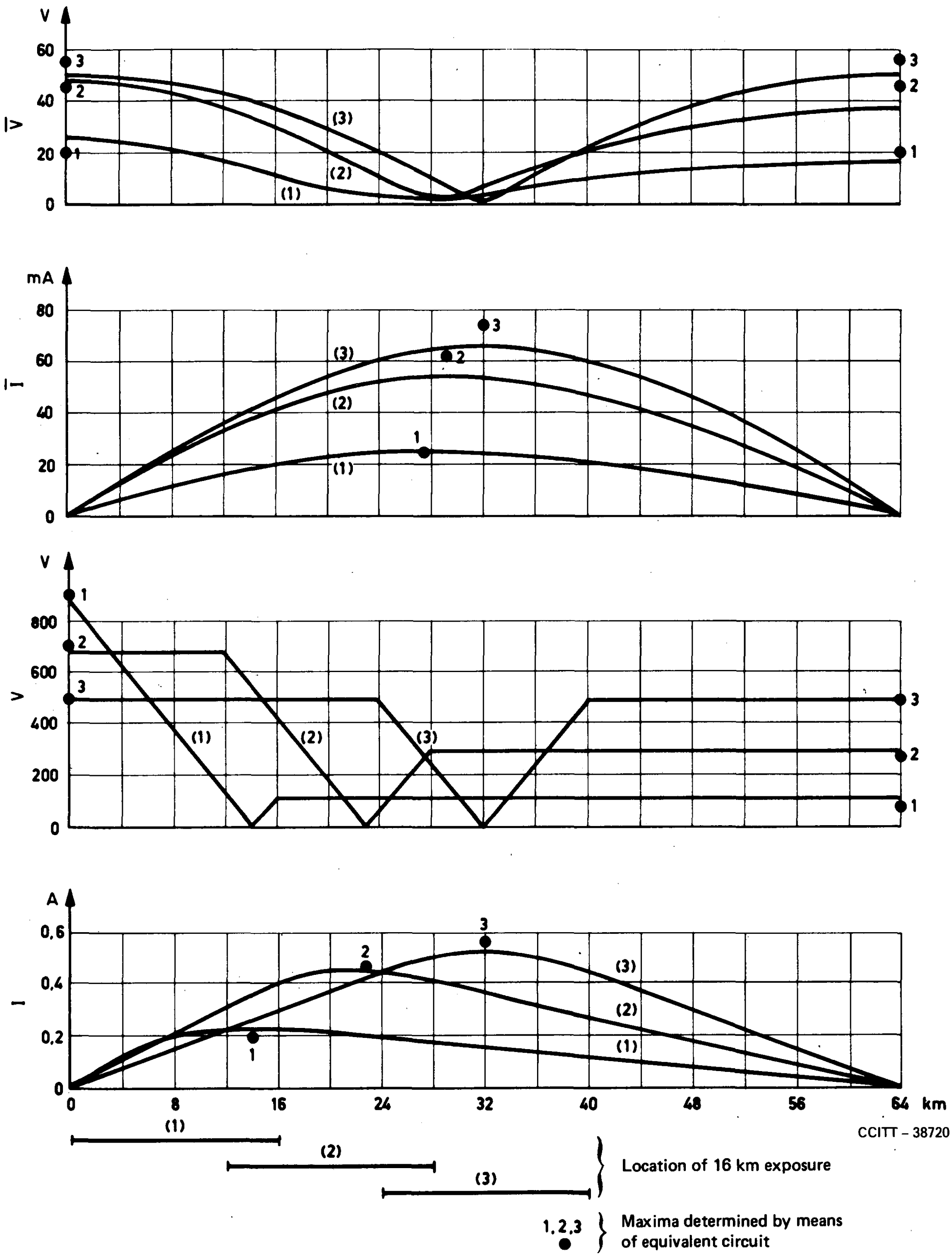


FIGURE B-4/K.16

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

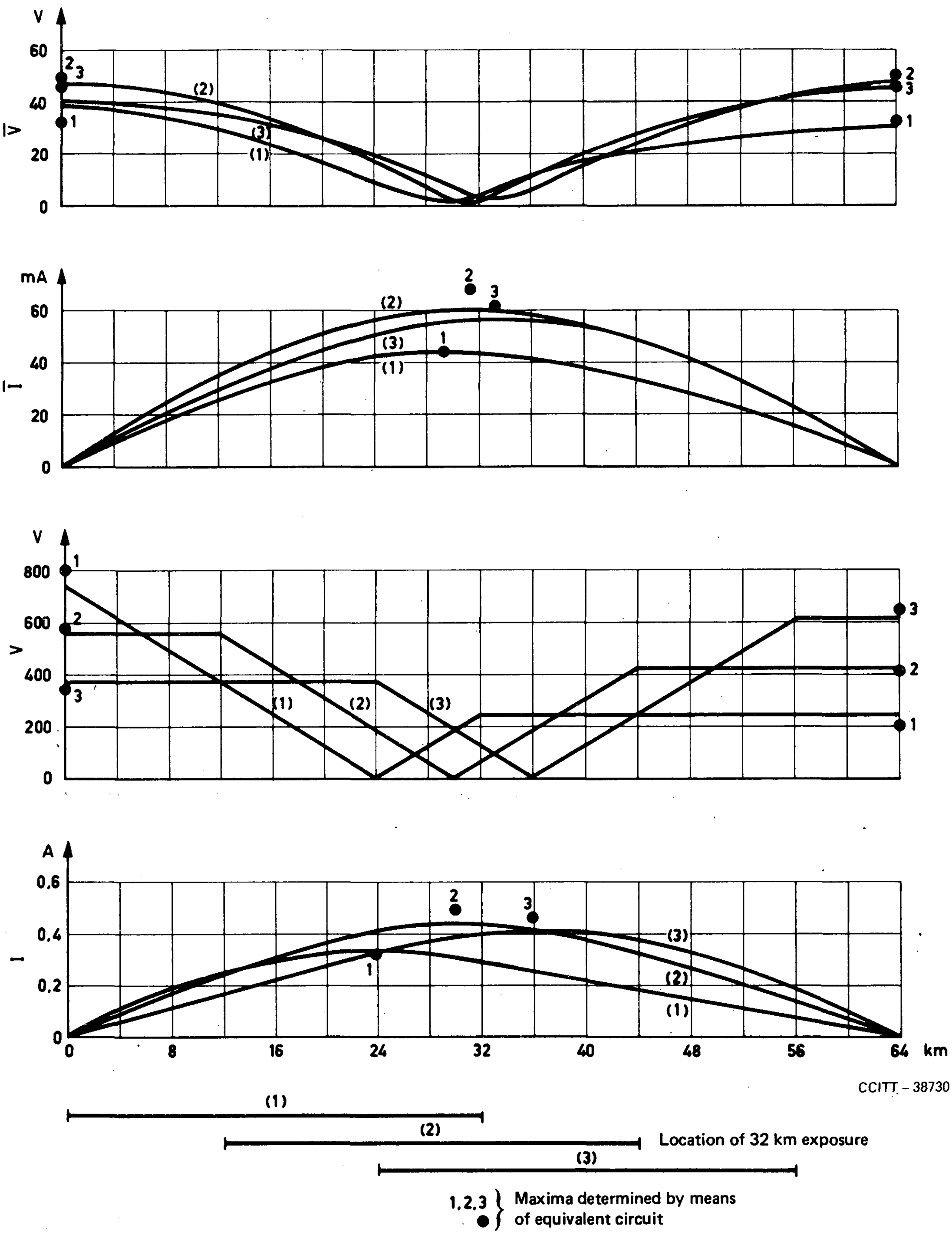


FIGURE B-5/K.16

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

ANNEX C

(to Recommendation K.16)

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

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

For the case of earthed outer conductors and inner conductors at a regulated potential with low-value earth decoupling capacitors, only the part of the diagram simulating the circuit *outer conductor – inner conductor* must be considered in the equivalent circuit, inserting logically the capacitance $\bar{C}$ 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.

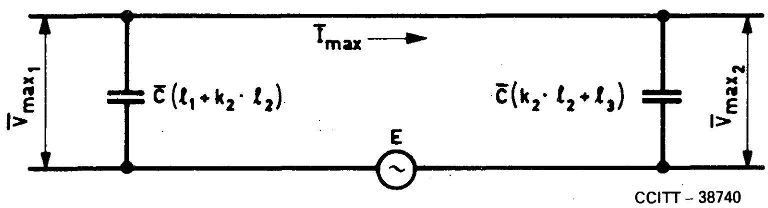


FIGURE C-1/K.16

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.

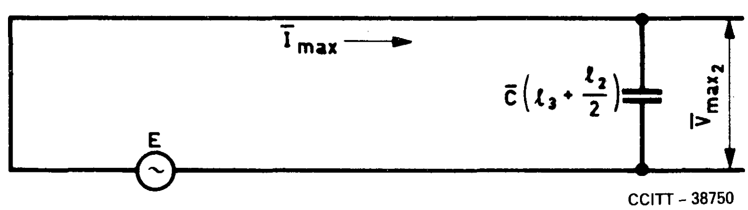


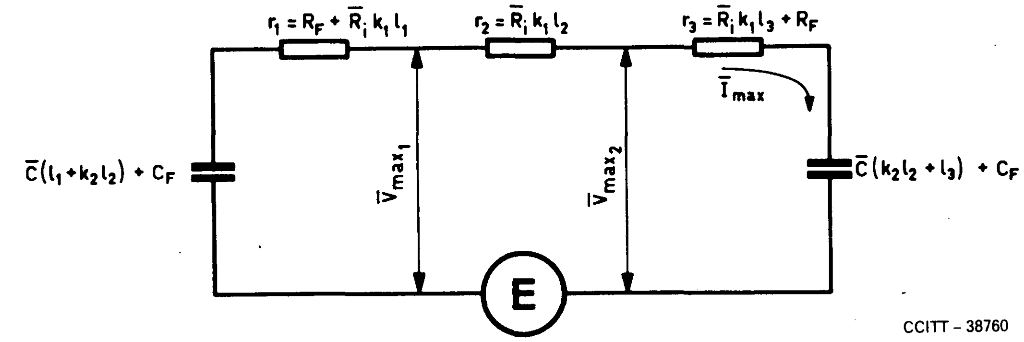
FIGURE C-2/K.16

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 $\bar{C}$ = 0.11 µF/km, R_i = 17 Ω/km, the decoupling impedance of the regulated supply systems being equivalent to a resistance R_F of 50 ohms in series with a capacitance C_F of 15 µF. The diagram is shown in Figure C-3/K.16.

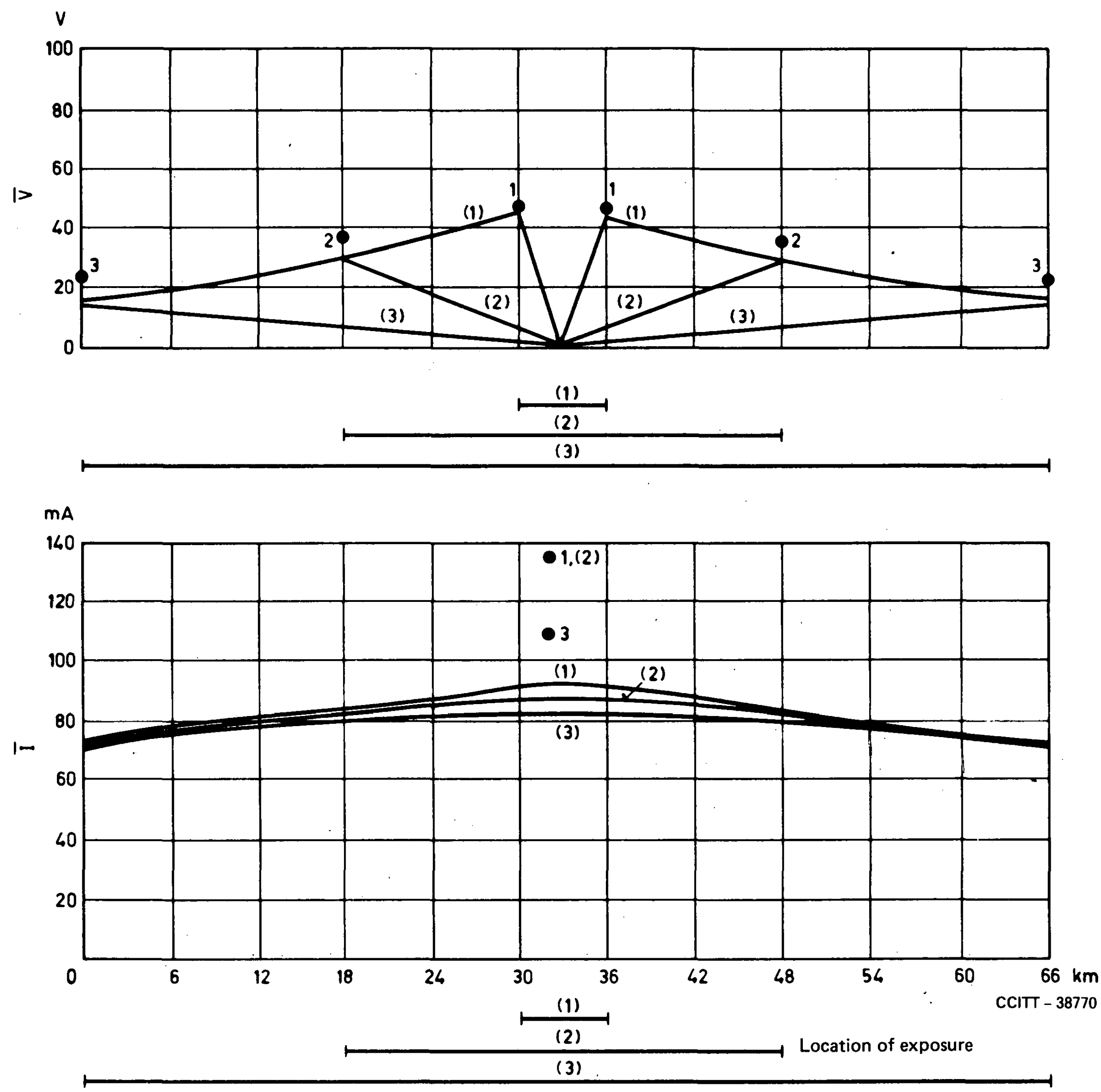


Note – $\bar{R}_i$ is the resistance per kilometre of the inner conductor plus the total resistance of all the repeater directional filters, expressed as a resistance value per kilometre.

FIGURE C-3/K.16

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

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

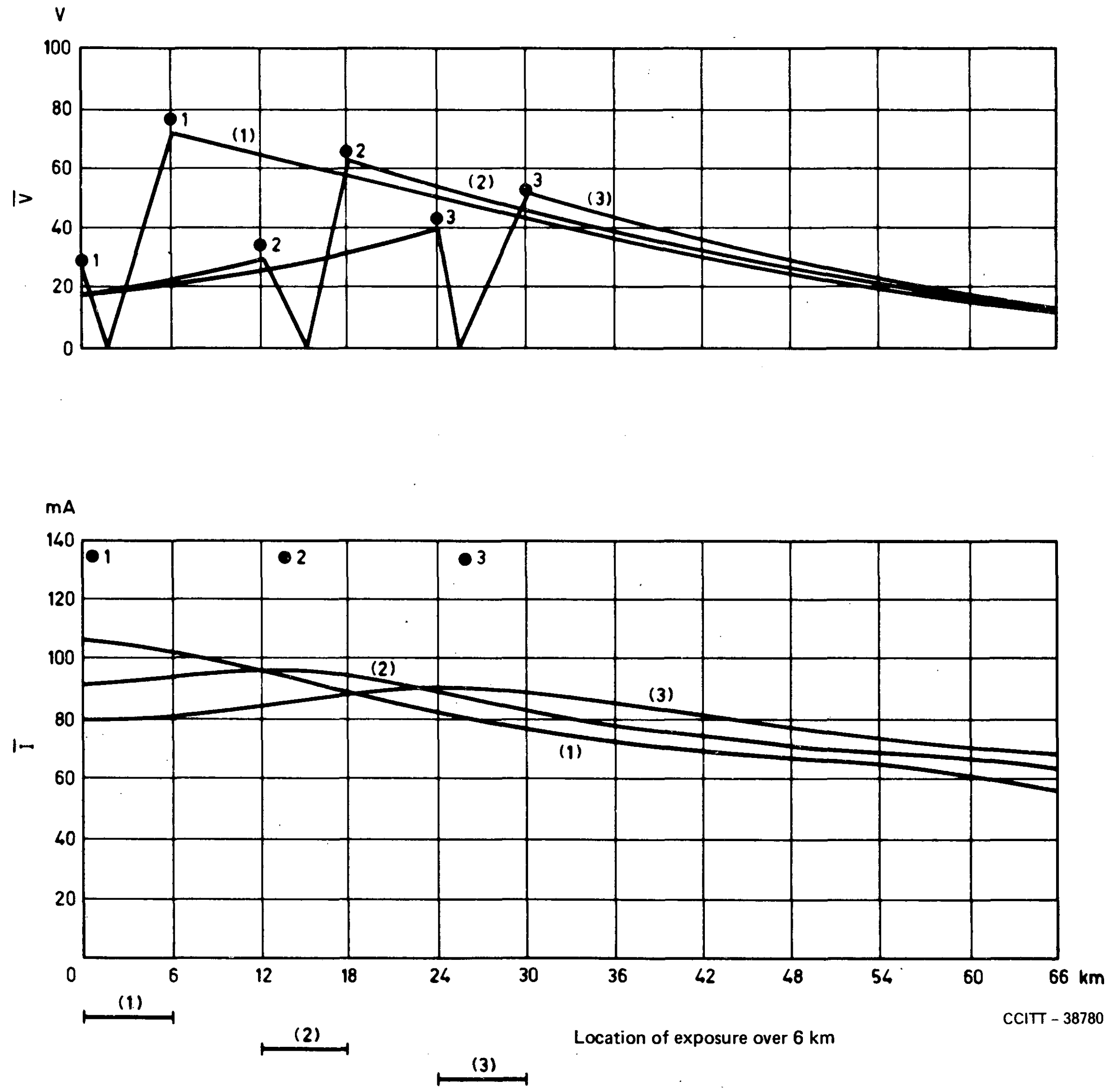


1, 2, 3 } Maxima determined by means
● } of equivalent circuit

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

FIGURE C-4/K.16

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

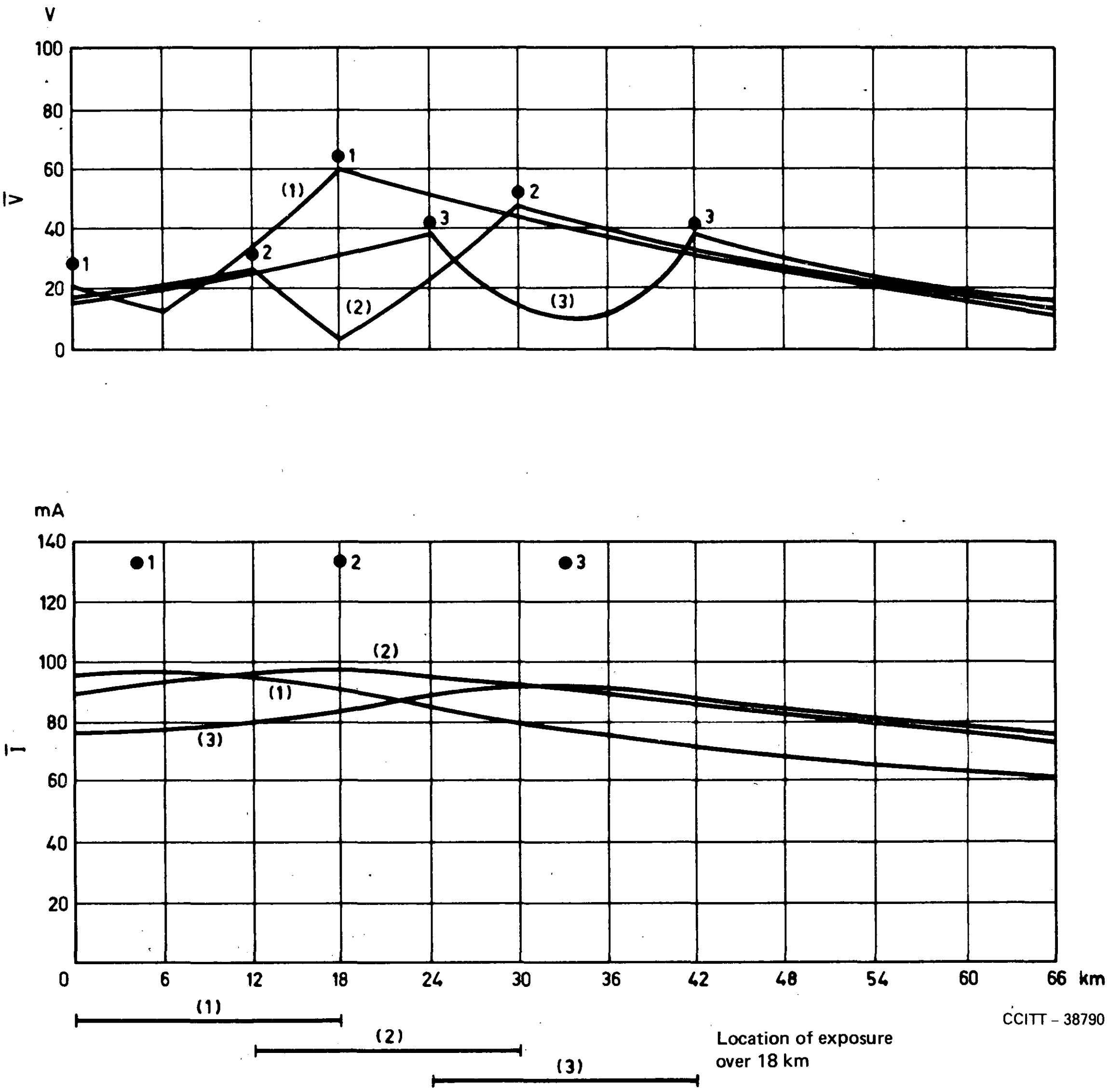


1, 2, 3 ● } Maxima determined by means of equivalent circuit

Length of exposure: 6 km
Inducing voltage : 100 V

FIGURE C-5/K.16

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

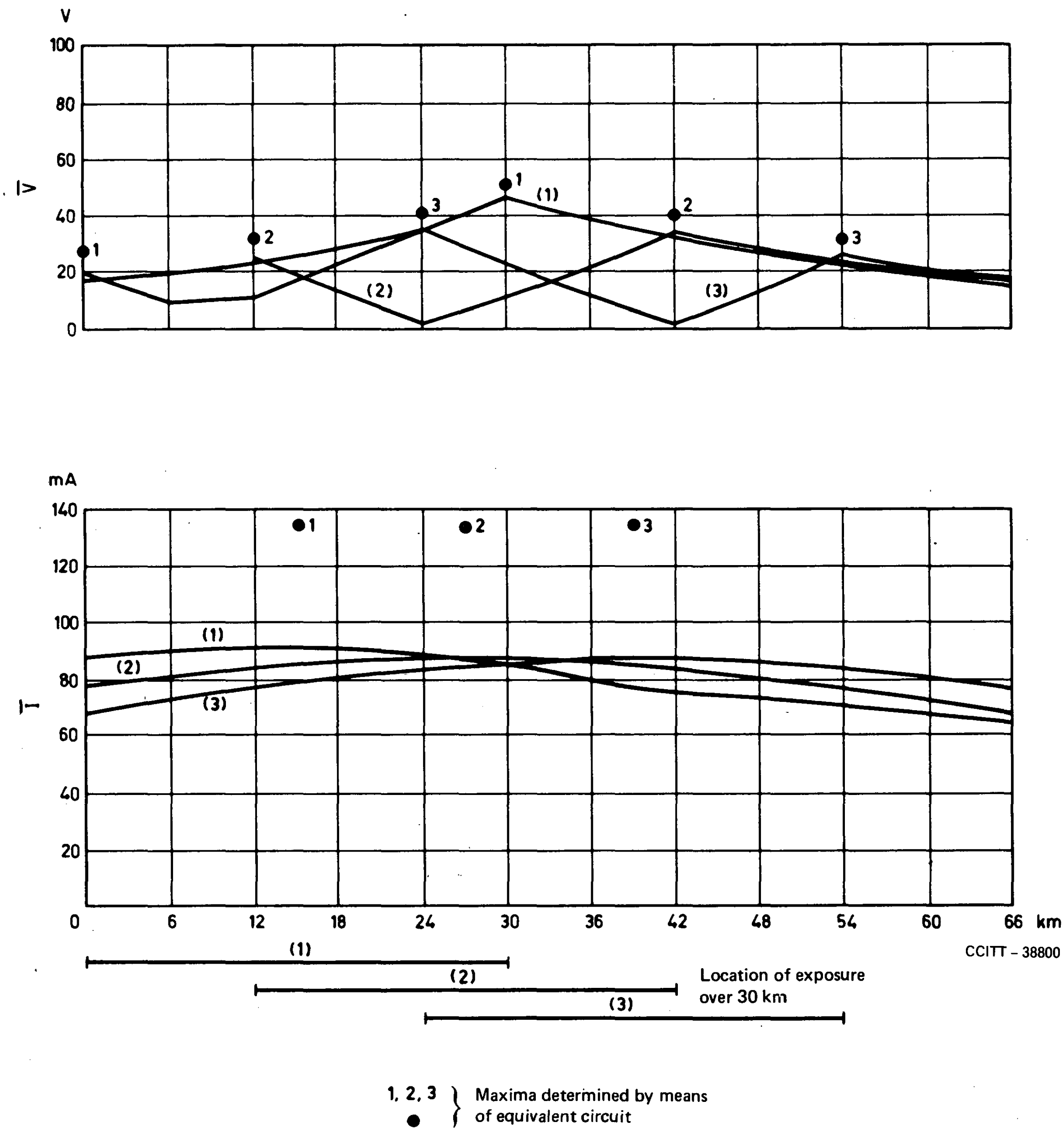


1, 2, 3 } Maxima determined by means of equivalent circuit
● }

Length of exposure: 18 km
Inducing voltage : 100 V

FIGURE C-6/K.16

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



Length of exposure : 30 km
Inducing voltage : 100 V

FIGURE C-7/K.16

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

References

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

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

Bibliography

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

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

Recommendation K.17 [1] (Geneva, 1976)

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

1 Introduction

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

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

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

In particular, this applies for:

a) current and voltage in the feeding circuit,

b) gain-frequency characteristic,

c) total noise,

d) bit error rate.

The tests consist of:

– prototype tests,

– acceptance tests.

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

1.3 *Prototype tests*

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

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

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

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.

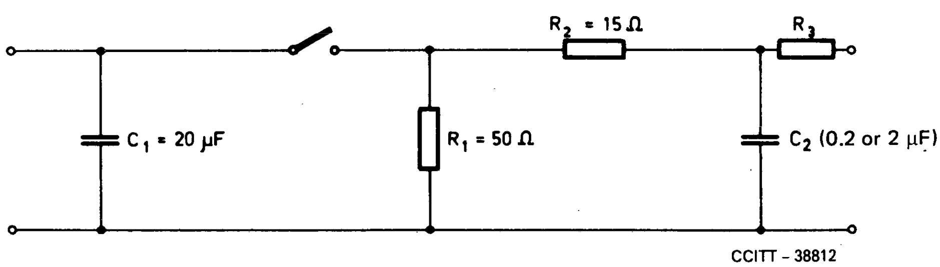


FIGURE 1/K.17
Diagram of an impulse generator

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 2	Test 3	Test 1 Test 2	Test 3	Test 1 Test 2	Test 3 [a]	Test 1 Test 2	Test 3 [a]
Column No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Waveform [b]	10/700	10/700	100/700	100/700	10/700	10/700	100/700	100/700	10/700	10/700	100/700	100/700
Load	0.1 coulomb	max. 0.1 coulomb	0.06 coulomb	max. 0.06 coulomb	0.03 coulomb	0.03 coulomb	0.03 coulomb	0.03 coulomb	0.1 coulomb	max. 0.1 coulomb	0.06 coulomb	max. 0.06 coulomb
Peak voltages	5 kV	5 kV	3 kV	3 kV	1.5 kV	1.5 kV	1.5 kV	1.5 kV	5 kV	5 kV	3 kV	3 kV
Short-circuit current	333 A		200 A		37.5 A		37.5 A		125 A		75 A	
Peak current in the power-feeding circuit		50 A		50 A		37.5 A		37.5 A		50 A		50 A
C_2	0.2 μF	0.2 μF	2 μF	2 μF	0.2 μF	0.2 μF	2 μF	2 μF	0.2 μF	0.2 μF	2 μF	2 μF
R_3	c)	c)	c)	c)	25 Ω	25 Ω	25 Ω	25 Ω	25 Ω	25 Ω	25 Ω	25 Ω
Number of pulses	10	10	2	2	10	10	2	2	10	10	2	2

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

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

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

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

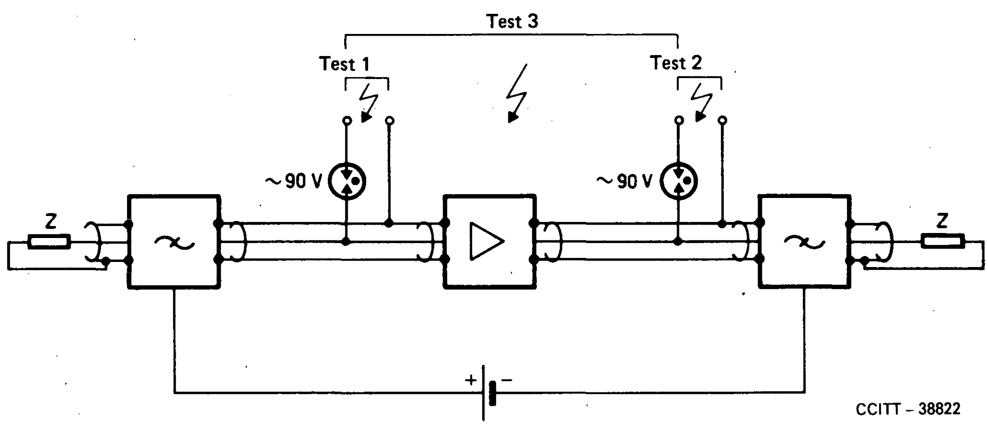
– *Test 1:* at the input of the repeater, with the output terminated by its characteristic impedance;

– *Test 2:* at the output of the repeater, with the input terminated by its characteristic impedance;

– *Test 3:* (longitudinal) between the input-side inner conductor and the output-side inner conductor of the repeater in the case of coaxial-pair repeaters (at the terminals of the feeding circuit, in the case of symmetric-pair repeaters).

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

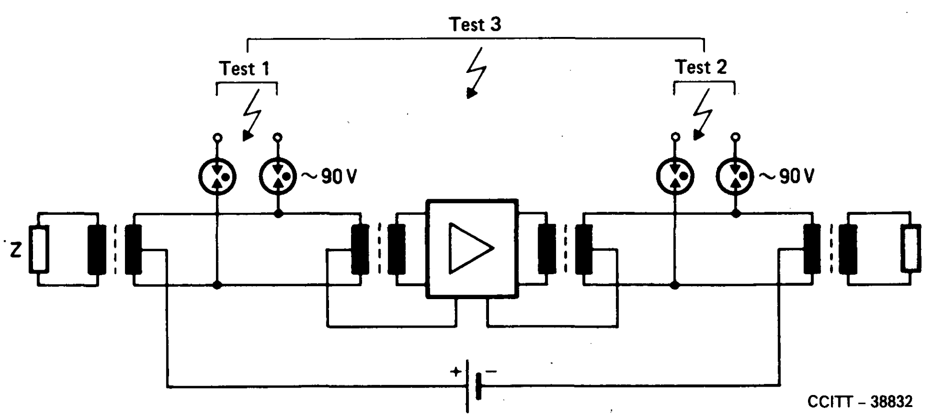
For these tests the circuit arrangement given in Figure 2/K.17 for coaxial pairs and in Figure 3/K.17 for symmetric pairs may be found helpful. To couple the impulse generator to the repeater, lightning protectors with a striking voltage of approximately 90 V may be used, as illustrated in Figures 2/K.17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



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

FIGURE 2/K.17

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



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

FIGURE 3/K.17

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

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

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

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

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

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

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

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

For tests specified under § 2.2, no power is applied to the repeater under test.

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 [2)]) until they do so.

2) 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 [2], 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* [3]

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.

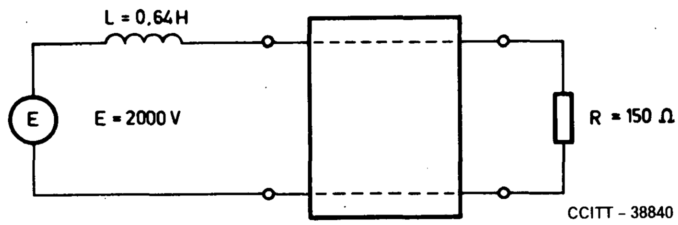


FIGURE 4/K.17
Example of test circuit for a.c. tests at 50 Hz

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

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

3.1.2 *Acceptance tests*

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

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

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

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

3.2 *Test conditions for repeaters used on symmetric pairs*

3.2.1 *Prototype tests*

3.2.1.1 *Tests at repeater input and output terminals*

3.2.1.1.1 *Impulse tests*

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

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

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

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

3.2.1.1.2 *A.c. tests*

A.c. tests are not specified.

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

3.2.1.2.1 *Impulse tests*

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

3.2.1.2.2 *A.c. tests*

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

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

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

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

3.2.2 *Acceptance tests*

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

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

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

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

References

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

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

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

Recommendation K.18

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

1 Introduction

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

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

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

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

2 Analysis of interference

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

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

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

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

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

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

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

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

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

where

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

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

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

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

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

f is the radio-wave frequency expressed in Hz.

Other constants and variables are shown in Annex A.

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

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

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

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

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

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

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

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

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

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

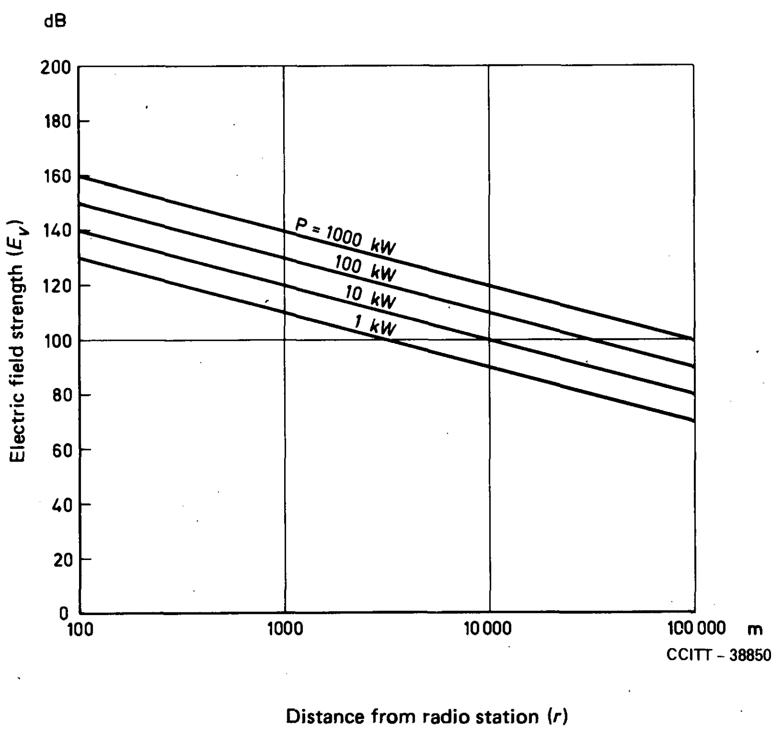
When the measured value is not available, the radio-wave electric field strength E_v can be calculated by Equation (2-4), taking into account the distance from the radio station and the power of the radio station transmitter (see [2]).

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

where

P is the radio station transmitting power (W)
r is the distance from radio station (m)
Z_0 is the intrinsic impedance of free space ($\approx 377\ \Omega$)

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



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

FIGURE 1/K.18

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

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

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

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

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

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

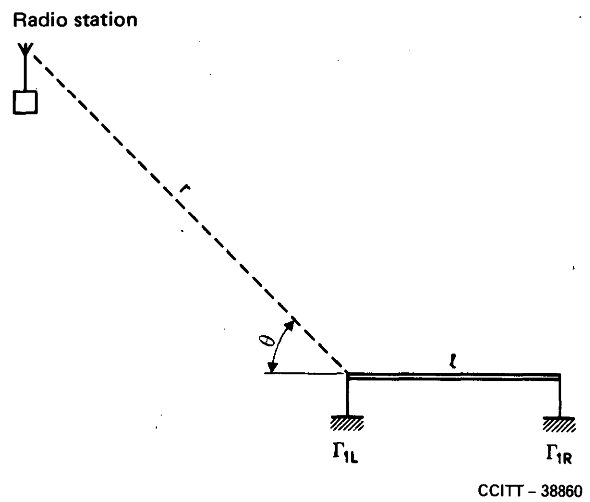
$$V_2(0) \approx V_2(l) = -35.0 \text{ dB}$$

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

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

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

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



$P = 100$ kW
$f = 500$ kHz
$r = 5$ km
$\theta = 45°$
$\sigma = 10$ mS/m

Telecommunication cable with aluminium sheath

diameter = 22 mm
thickness = 0.2 mm
α_{20} = 6 dB/km
β_2 = 1.4 β_0
$\Gamma_{1L} = \Gamma_{1R} = 0$

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.

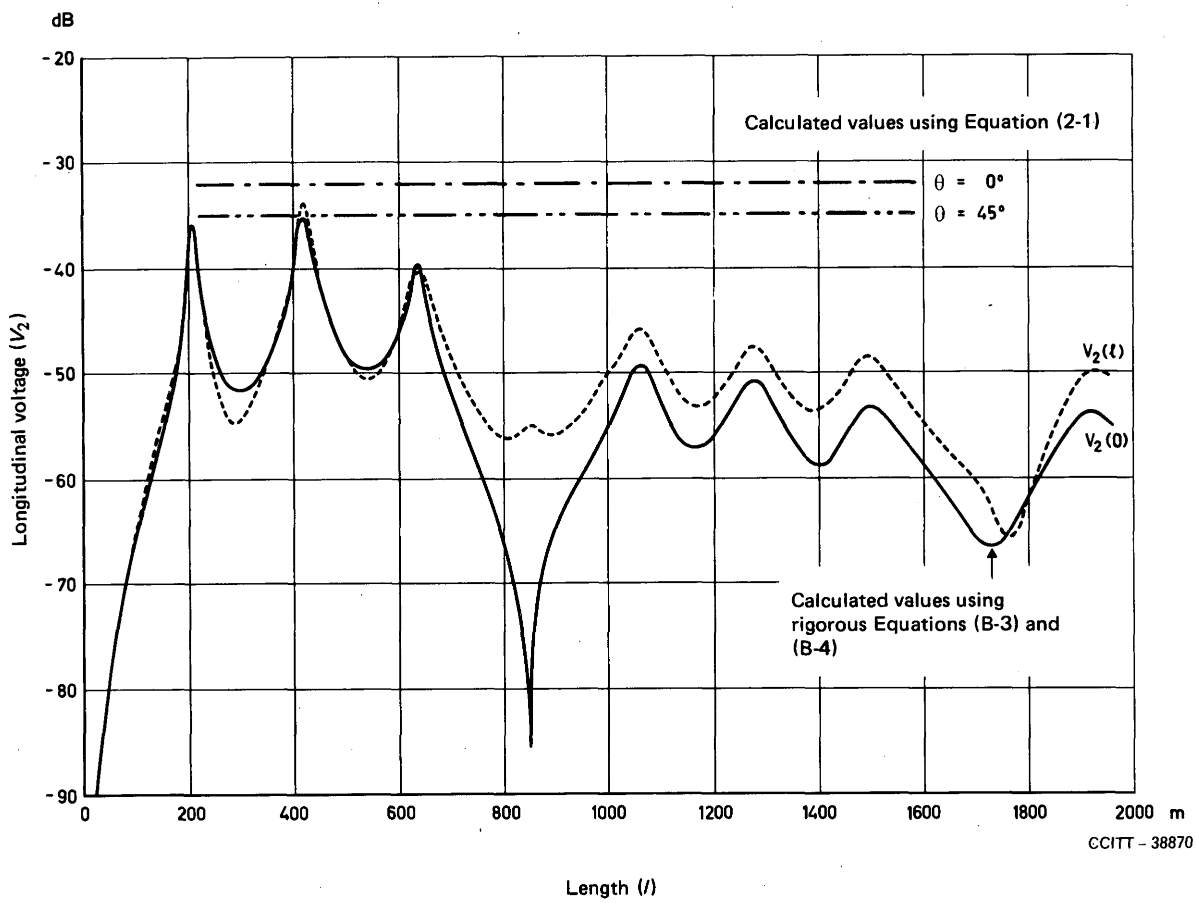


FIGURE 3/K.18

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 relate 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 $| Z_{01} | \ \Omega$, 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:

$$P = \frac{E_h}{E_v} = \left| \frac{1}{\sqrt{\varepsilon_r - \mathrm{j} \dfrac{\sigma}{\omega \varepsilon_0}}} \right| \approx \sqrt{\frac{\omega \varepsilon_0}{\sigma}} \qquad \text{(A-1)}$$

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 (m)

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)

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

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

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

$\Gamma_{2R} = \frac{Z_{02} - Z_{2R}}{Z_{02} + Z_{2R}}$ is the longitudinal circuit current reflection coefficient 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 $m = \mathrm{L}$) is the voltage in earth return circuit with mismatching at $x = 0$

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

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

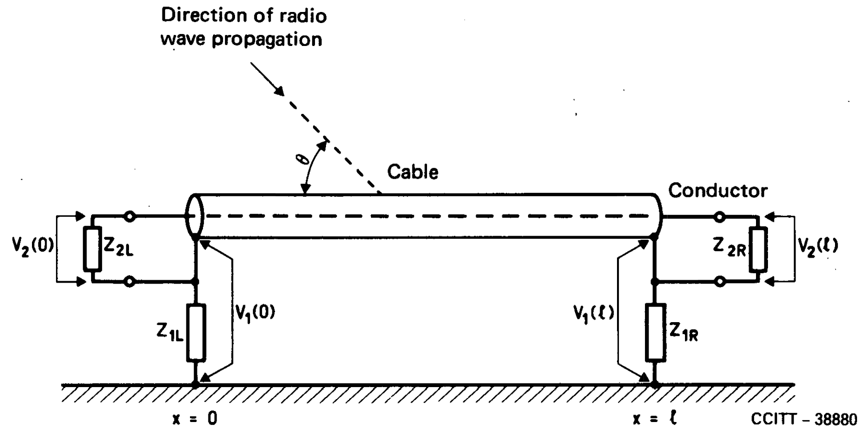


FIGURE A-1/K.18

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 to the radio station:

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

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

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

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

B.2 *Telecommunication cables with metallic screen*

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

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

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

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

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

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 $\leq \alpha_{20} \leq$ 30 dB/km, 1.2 $\beta_0 \leq \beta_2 \leq 3\,\beta_0$, 500 kHz $\leq f \leq$ 1.6 MHz, 10 mm $\leq d \leq$ 50 mm, $0° \leq \theta \leq 90°$, 0.1 mS/m $\leq \sigma \leq$ 500 mS/m and $-1 \leq \Gamma \leq 1$. 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 $\Gamma_1 \geq 0$ is considered, because $| Z_1 | \leq Z_{01}$ 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.

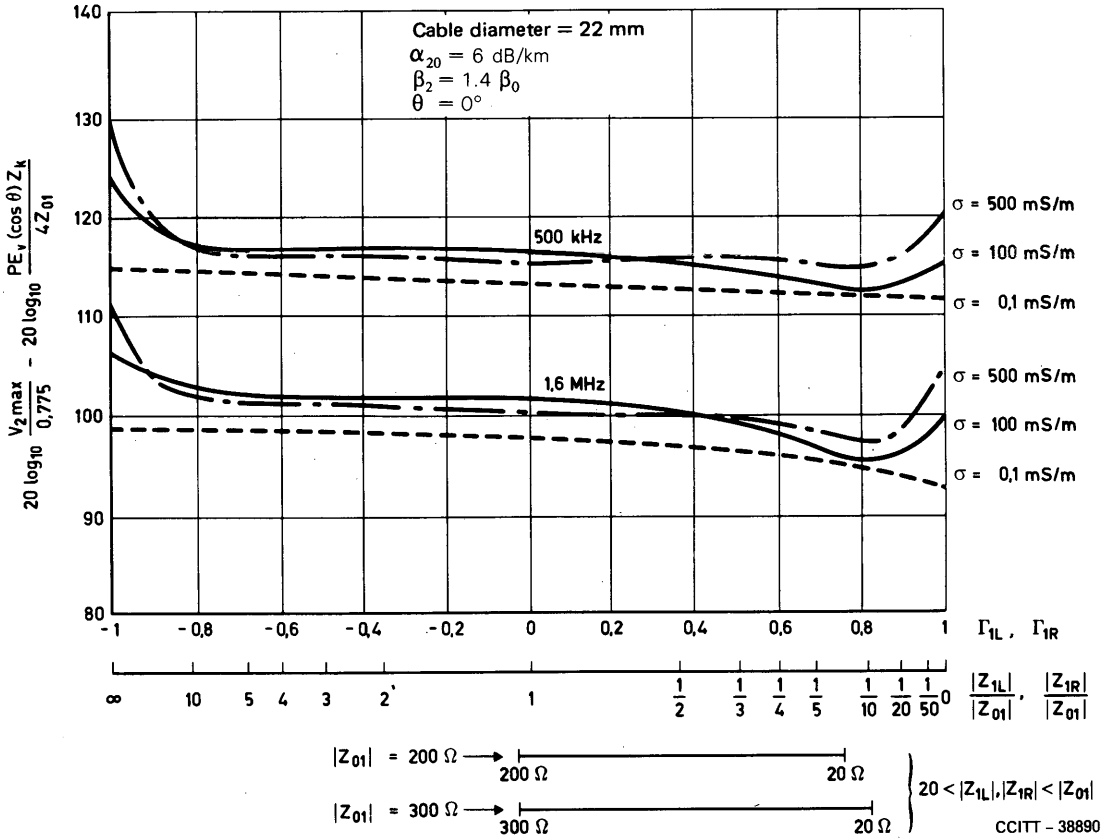


FIGURE C-1/K.18

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

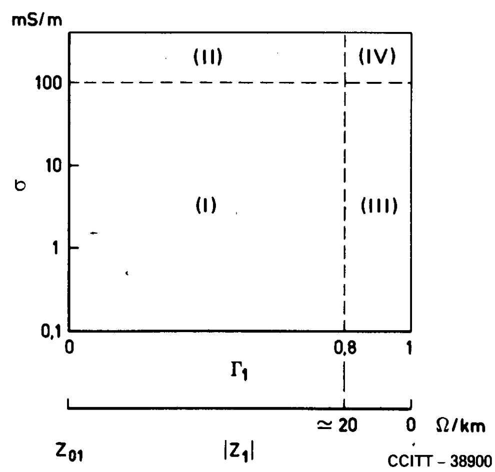


FIGURE C-2/K.18

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).

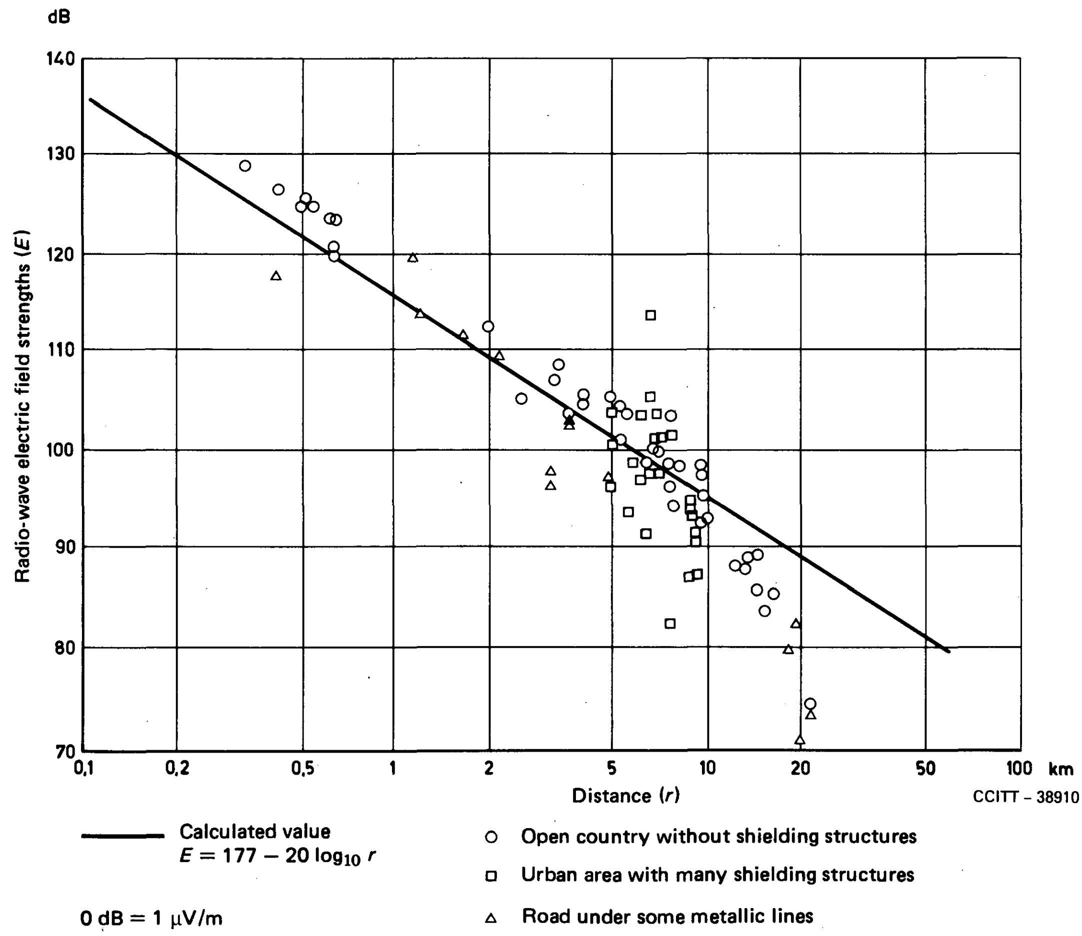


FIGURE D-1/K.18

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

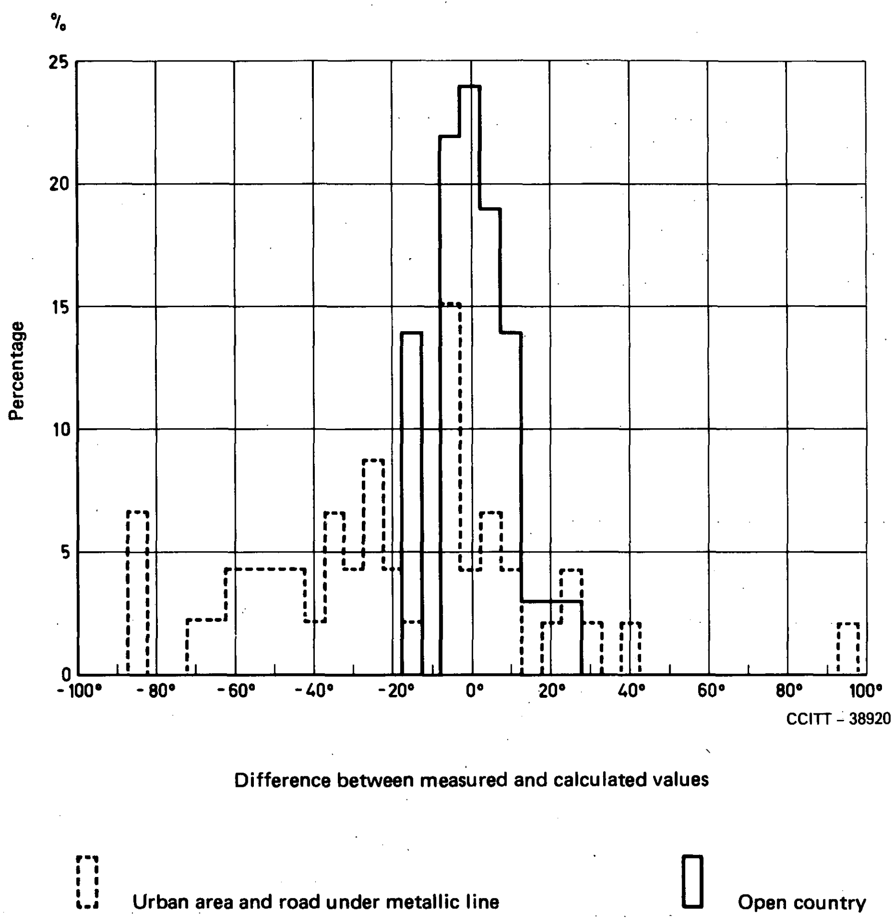


FIGURE D-2/K.18

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).

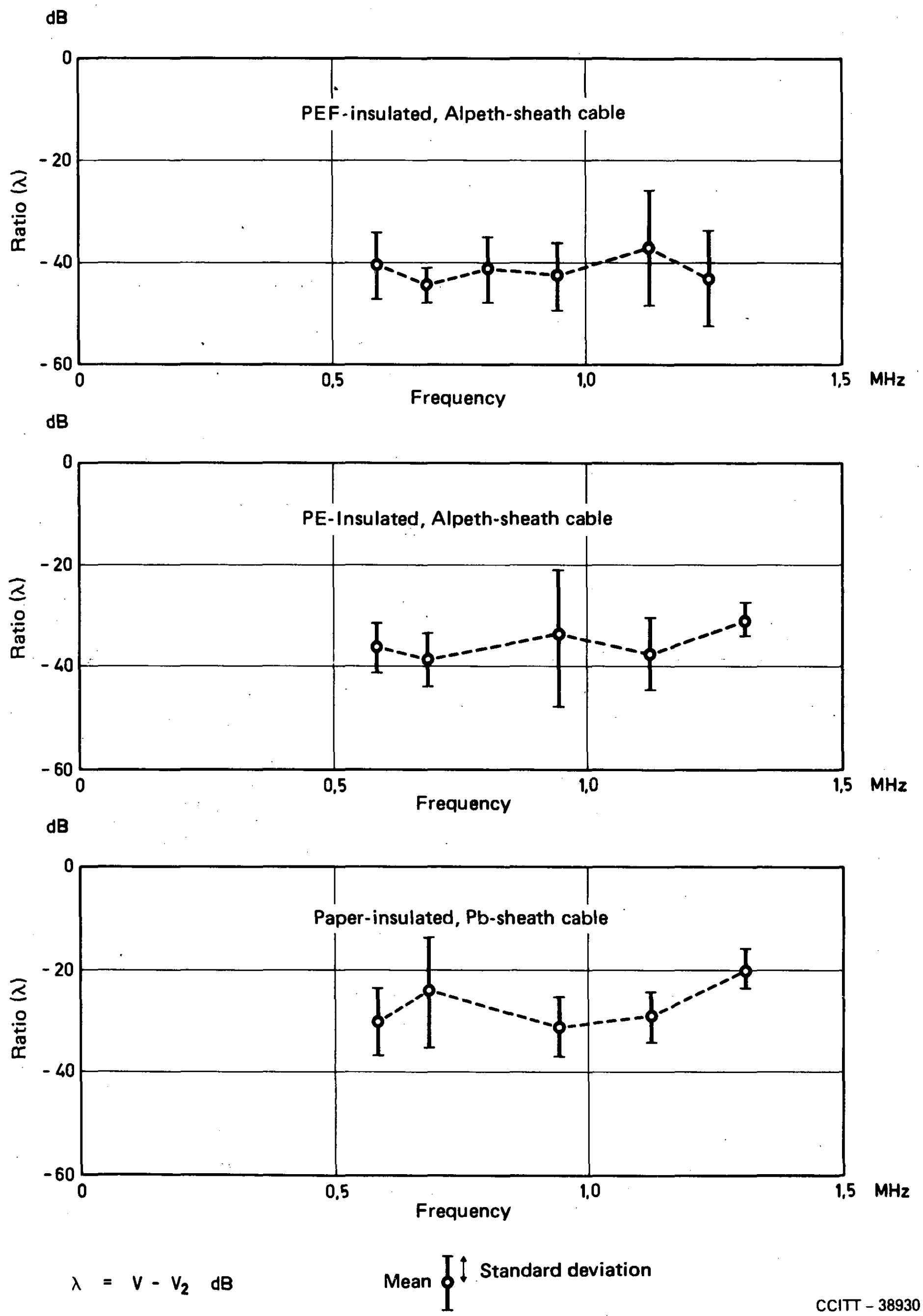


FIGURE E-1/K.18

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 transmission	LF MF Mainly MF	Several kW	– Up to several tens of km – In the case of subscriber carrier system interference up to nearly 1000 km has been reported. (0.03 to 1.8V/m)	– Mainly over-head cable with metallic screen (balanced pair, coaxial pair) – Cabling in building (between multiplex and antenna, between demodulation stages) – Open wire	Single tone or un-intelligible noise in demodulated telephone channel (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
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

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.

Recommendation K.19

JOINT USE OF TRENCHES AND TUNNELS FOR TELECOMMUNICATION AND POWER CABLES

1 General

The joint use of trenches and tunnels for telecommunication and power cables may, under favourable conditions, offer the following advantages:

- the overall costs are reduced;
- available space for underground services is used more efficiently;
- there is a reduced amount of roadway surfacing work and consequently less delay to traffic;
- the separation of power and telecommunication cables is more precisely assured.

2 Electrical safety

If power and telecommunication cables are not easily distinguished from each other they should be clearly marked.

Power cables should generally be buried deeper than telecommunication cables.

Power and telecommunication cables should be separated by a suitable distance according to:

a) the voltage of the power cable;

b) the type of the power cable;

c) the type of the telecommunication cable;

d) the nature of the separating material.

The minimum distance is often stipulated in national standards.

Under the following circumstances national standards may allow reduced distances:

- the power cable having a concentric neutral operates at low voltage and the telecommunication cable has an earthed armouring, or
- the cables are separated by concrete fillings or similar material

If there is danger to staff doing manual excavation, high voltage power cables should be protected by covers of suitable material (brick, concrete, etc.).

3 Electromagnetic induction

In order to avoid inadmissibly high danger and interference to telecommunication cables from power cables the *Directives* must be observed. Such effects are especially to be expected when:

a) the power cable belongs to a network with a directly earthed neutral;

b) the individual phase conductors of the power line are run in separate cables (e.g. three-phase single-core cables); or

c) the currents in the power lines have a high harmonic content.

Danger and interference are not to be expected when:

- the power cable works under normal operational conditions, and in case of three-phase single-core cable the individual phase cables are properly arranged and transposed; or

- the length of the parallel running is relatively small (e.g. some hundred metres).

Proper arrangement and transposition of phase conductors of the power cable system are effective for reducing electromagnetic induction.

Other metallic conductors in the tunnel (e.g. pipe-lines, concrete reinforcements) have normally a reducing effect on the induced longitudinal voltages. The magnitude of this screening factor depends to a great extent on the arrangement of the various installations in the tunnel and on the construction of the tunnel and can, therefore, only be determined for each individual case.

4 Other dangers

The joint use of trenches and tunnels may increase the exposure of telecommunications staff to other dangers such as:

- striking power cables during excavation;

- access difficulties and isolation problems while working inside tunnels;

- explosions due to leakage from gas pipes if these are also present in jointly-used tunnels;

- foul air accumulations in tunnels.

Suitable safe working methods to overcome such dangers should be incorporated in the joint working agreement.

5 Practical limitations

The successful use of joint trenches and tunnels requires a disciplined cooperation by all parties concerned. The duties and responsibilities of each party should be precisely defined. Special measures may be necessary to overcome limitations of space underground and to facilitate subsequent maintenance of the cables, and such special measures need to be agreed before the joint construction work commences.

PART II

Series L Recommendations

PROTECTION OF CABLE SHEATHS AND POLES

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Recommendation L.1

PROTECTION AGAINST CORROSION

The CCITT,

considering

(a) that the location of faults on underground cables and the repair of these faults can entail great expense,

(b) that the interruptions to service likely to be caused by the occurrence of these faults must be avoided with the greatest care,

(c) that even after a repair has been made as expertly as possible, the quality of the cable may be lessened and its normal life reduced,

unanimously recommends

that, when cables are laid, Administrations will find it in their interest to comply with the CCITT *Recommendations concerning the construction, installation and protection of telecommunication cables in public networks*, ITU, Geneva, revision 1974, amendments and additions, 1977.

Recommendation L.2

IMPREGNATION OF WOODEN POLES

The CCITT draws attention to the economic importance of impregnating the wooden poles carrying overhead telecommunication lines.

The CCITT has issued a manual entitled *The preservation of wooden poles carrying overhead telecommunication lines*, ITU, Geneva, 1974, with a view to providing Administrations, particularly those whose networks are not yet fully developed, with some information on impregnation processes.

This manual is based on a first draft drawn up in 1968-1972 by the Argentine Administration amended and completed on the basis of information supplied by the Administrations of Australia, Austria, Chile, France, Italy, Federal Republic of Germany, United Kingdom and Switzerland.

Recommendation L.3 (Mar del Plata, 1968)

ARMOURING OF CABLES

1 Type of armouring

1.1 The most common forms of armouring are:

a) *Tape armouring* – This consists of overlapping steel tape or tapes, applied in helical form with a short lay, over the cable sheath.

b) *Wire armouring* – This is formed from round, flat or trapezoidal steel wires applied helically around the cable sheath with a relatively long lay.

1.2 These two types of armouring are used in combination with other protective layers (jute, plastic) for constructional or mechanical reasons, or for protection against corrosion.

2 Choice of armouring

In deciding whether or not to use armouring and in choosing between the various types of construction, very careful consideration should be given to the local conditions of installation, such as:

a) whether the cables are laid in duct or direct in the soil;

b) whether the cables are laid in a trench alongside a road or on private land;

c) what material is used for the cable sheath;

d) whether other cables are or may be laid along the same run;

e) the nature of the soil: rocky, sandy, corrosive or not; presence of micro-organisms;

f) the depth of the trench, which in any case should not be less than 50 cm, and for large cables 80 cm;

g) the risk of induction;

h) the risk of attack by rodents or insects;

i) the degree of exposure to lightning;

j) whether the size and importance of the link justifies special precautions, in which case steel-wire armouring provides additional protection, particularly in manholes;

k) whether a long draw-in is required, e.g. crossings under rivers (as cases of this are infrequent, no need is envisaged for a new design of land cable incorporating a central strain wire).

3 Protection provided

With cables laid directly in the soil, armouring contributes to safe installation and reliability of operation by ensuring protection of the cables against:

a) mechanical damage caused by stones and excavation equipment or tools;

b) rodents and insects;

c) chemical or electrolytic corrosion;

d) effects of atmospheric discharges;

e) induction phenomena due to the proximity of power lines.

4 Tape armouring

Tape armouring is to be preferred for protection against damage by pointed digging tools, sharp stones, etc. It is also useful for providing magnetic screening for circuits within the cable, for which wire armouring is much less effective, because the air gaps between the individual steel wires, which are arranged circumferentially around the cable, greatly reduce the magnetic coupling between the armoured sheath and the conductors within the cable.

5 Wire armouring

Wire armouring gives considerable additional tensile strength to a cable and is useful where pulling-in stresses are high (long draw-in) or where high stresses arise from conditions of use, for example where there is ground subsidence in mining districts and where cables are run in water and bogs or in shafts leading to deep level locations.

6 General type of armouring

For cables with a metallic sheath of lead or aluminium, the type of armouring in most common use consists of two helical windings of steel tape between layers of impregnated paper and jute with an external protection of jute yarn or other fibre. This type of armouring ensures good protection in all five cases listed in § 3 above.

For plastic-sheathed cables, a light armouring may be used, formed of metallic tapes (steel, aluminium or copper) between two coverings of plastic material (polyethylene or PVC). Cables of this design are protected chiefly against the hazards mentioned in 3b) and 3c) above and to a certain extent against hazards 3a) and 3d) above.

7 Armouring for main cables

The major cables in a long-distance network are certainly best protected by a watertight metallic sheath and the conventional armouring described above but the price of such protection is relatively high.

The cost of cables can be reduced by using a thin welded-steel sheath protected against corrosion by a bituminous compound and a plastic covering. This protects the cable, though to a lesser degree, against hazards 3a), b), c), d) above; some protection against induction may be obtained by inserting conductor elements or copper or aluminium bonds under the steel sheath.

8 Cables in ducts

Experience shows that symmetric pair, coaxial pair or composite cables without armouring of any kind can be drawn into ducts in lengths of up to 300 metres, provided that the tensile stress is spread between the conductors and the components of the sheath. Thus, the steel-wire armouring formerly used may be dispensed with, except in certain special cases (important links, long draw-in, for example river crossings).

9 Corrosion considerations – cables with metal sheaths

Both tape and wire armouring are useful in mitigating corrosion attack; largely because they tend to keep the impregnated coverings lying beneath them in good order and so safeguard the metal sheath from the effects of differential aeration, etc.

10 Rodents and insects

Damage from rodents tends to be rather high in some areas; either tape or wire armouring will provide a safeguard, but this is an expensive method and the CCITT is studying the possibilities of some form of cheaper sandwich construction, say polyethylene – thin aluminium – coated steel – polyethylene. Insects might penetrate the outer layer, but would then come up against the metal. Assuming this stopped them, the metal would probably later fail by corrosion, but this would be of little importance if the metal were bonded to the inner and outer polyethylene tubes. Besides providing protection against most rodents and insects, such a type of construction might provide some measure of extra strength relatively cheaply.

11 Tropical countries

In tropical countries special attention must be paid to §§ 6 and 7 above and to the danger from micro-organisms.

In general, it is safe to dispense with armouring only when:

- cable is laid in duct;
- no magnetic screening is required, or where this is provided by some other metallic layer included for the purpose;
- when there is no risk of corrosion or where corrosion protection is provided by some other layer included for this purpose;
- in the case of directly buried cables, where the soil is homogeneous and contains no flints or rocks likely to damage the cable, and where there is no danger of damage by rodents and insects.

However, special local conditions may still make armouring necessary, even in the above cases.

Recommendation L.4 (Geneva, 1972, revised at Geneva, 1976)

ALUMINIUM CABLE SHEATHS

1 General

Because of the technological progress made in the use of aluminium, aluminium cable sheaths are being used on an increasing scale and their favourable characteristics can now be fully exploited.

These characteristics include:

- low density (almost a quarter that of lead);
- much higher mechanical strength than lead, so that the sheath is lighter not only because aluminium is lighter than lead, but because the thickness may be less than for lead;
- very high resistance to vibration;
- high conductivity, so that a better screening factor and more effective protection from overvoltages of atmospheric origin can be obtained.

It is now found that the stiffness of an aluminium sheath does not give rise to any additional serious problems during laying.

However, because aluminium is more vulnerable than lead to electrochemical and electrolytic corrosive action, aluminium cable sheaths and the joints between individual factory lengths (jointing sleeves and adjacent sections of cable) require a Class II (see [1]) outer protective covering of plastic material.

As can be seen from the foregoing, an aluminium sheath has many advantages over a lead sheath. The generalized use of aluminium for sheathing cables is therefore desirable, at least whenever cable costs would not be increased compared with the use of lead, and also whenever aluminium sheaths satisfy the technical requirements to a greater extent. The use of cables with aluminium sheaths is particularly interesting in the case of trunk cables.

2 Types of aluminium sheath

2.1 *Extruded sheaths*

This type of sheath is obtained by extruding the aluminium directly around the cable core. The press may be of the *continuous* type or not. If it is not continuous, care must be taken to ensure that no problems are caused in the zones affected by the intermittent nature of the process.

2.2 *Welded sheaths*

This type of sheath is made by applying around the cable core an aluminium strip which is longitudinally welded.

2.3 *Choice of sheath shape and thickness*

After the sheath has been extruded or welded it may either be shrunk on to the cable core (noncorrugated sheath) or corrugated by a variety of methods (corrugated sheath).

The sheath may be corrugated or noncorrugated, depending on the diameter of the cable core, the minimum radius of curvature during laying and on the mechanical characteristics of the aluminium used (see [2]). As a rough guide it can be stated that the sheath should be corrugated in the case of cables of more than 40-mm core diameter.

As stated in § 1 above the thickness of the metal used for aluminium sheaths is usually less than for lead sheaths.

The thicknesses given in Table 1/L.4 are suggested although the values given in this table apply to both extruded and welded sheaths; however, extruded sheaths may not be less than 0.9 mm and welded sheaths may not be more than 1.4 mm, that being the maximum thickness which can be welded by existing methods.

The use of lesser thicknesses than those indicated in Table 1/L.4 is not excluded and, conversely, in the case of coaxial cables without armouring, the thickness of metal for all sheaths may have to be increased to improve mechanical protection. The increase in the thickness may be as much as approximately 0.3 mm.

Values different from those given in Table 1/L.4 may, of course, be adopted in certain cases (for example, if extremely favourable screening factors are required).

TABLE 1/L.4

Suggested thickness

Core diameter (mm)		Metal thickness (mm)	
Minimum	Maximum	Noncorrugated sheaths	Corrugated sheaths [a)]
–	10	0.7 to 1.0	0.5 to 0.9
10	15	0.7 to 1.0	0.6 to 0.9
15	20	0.9 to 1.0	0.7 to 0.9
20	25	1.1	0.8 to 0.9
25	30	1.1 to 1.2	0.9
30	35	1.1 to 1.3	0.9 to 1.0
35	40	1.1 to 1.4	1.1
40	45	1.5	1.1 to 1.2
45	50	1.6	1.1 to 1.2
50	60		1.1 to 1.3
60	70		1.1 to 1.4
70	80		1.3 to 1.5

[a)] If it is intended to obtain approximately the same screening factor with a corrugated sheath as with a noncorrugated one, the thickness should be the same as with a noncorrugated sheath.

3 Protective coverings

As stated above, since aluminium used in an underground environment is more liable to corrosion than lead, an impermeable (Class II) covering should be provided in accordance with reference [1] to ensure the protection of the cable sheath and the jointing sections of individual factory lengths of cable (jointing sleeves and adjacent sections of cable).

Two types of plastic material can be used at present for protective coverings:

a) polyvinylchloride (PVC);

b) polyethylene.

Polyethylene is preferable since its general characteristics and its low permeability for water vapour give better protection to the aluminium.

To ensure that moisture which may have penetrated the protective covering (for example, because of a defect in the covering) does not spread along the surface of the sheath, extending the areas of corrosion, it is essential to apply a leakproof layer consisting of an adhesive tape or a suitable mixture.

The leakproof layer must adhere well to the aluminium, especially when PVC is used for the covering, since this material, unlike polyethylene, does not cling tightly to the sheath after extrusion.

In the case of corrugated sheaths, the bituminous mixture must fill the corrugations sufficiently to allow complete contact with the outer covering.

Special tests should be made of the efficiency of the leakproof layer. A common test consists in removing a part of the protective covering from a sample of the aluminium sheath and submitting it to electrolytic attack using an outside source of e.m.f. After some time, a check must be made to see whether the corrosion is confined to the place from which the protective covering was removed. The effectiveness of the protective covering can be assessed by means of a test to check the adhesion of the bituminous compound to both the aluminium sheath and the plastic covering.

To ensure the permanent effectiveness of the protective covering when cables are laid in areas exposed to lightning discharges (in particular as concerns avoiding perforations due to lightning discharges) the indications given in the manual cited in [3] should be taken into account.

4 Jointing of aluminium sheaths

Jointing is undoubtedly a more difficult operation for aluminium than for lead sheaths, although these difficulties have been minimized by improved techniques.

There are several methods of jointing aluminium sheaths:

- jointing by means of lead sleeves;
- jointing by means of lead rings or cones which are plumbed using a normal method or fixed with special glue to the aluminium sheath to permit subsequent soldering to lead sleeves;
- jointing by means of aluminium sleeves joined to the aluminium sheath by pressure welding (explosion, pressure or cold welding);
- other methods including the use of adhesive tapes and epoxy pastes.

The methods used for the jointing of aluminium sheaths must meet the conditions recommended in the booklet cited in [4].

For an aluminium-sheathed cable subjected to significant temperature variations, tensions due to cable contraction should not be borne by the joints as this can lead to joint failure, particularly with noncorrugated sheaths.

5 Cathodic protection

There are only a few isolated experimental results available giving experience of cathodic protection of aluminium sheaths.

References

[1] CCITT *Recommendations concerning the construction, installation and protection of telecommunication cables in public networks*, § 6.3, ITU, Geneva, revision 1974, amendments and additions, 1977.

[2] *Ibid.*, § 5.4.4.

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

[4] CCITT manual *Jointing of plastic-sheathed cables*, ITU, Geneva, 1978.

Recommendation L.5 (Geneva, 1972)

CABLE SHEATHS MADE OF METALS OTHER THAN LEAD OR ALUMINIUM

1 Types of metallic-sheathed cables

1.1 The most common form of metallic sheath used as an alternative to a lead or aluminium sheath is one of corrugated steel. This consists of a long steel strip, shaped into a tube round the cable core, welded by a suitable process (inert-gas arc, mains frequency or high frequency heating) along the longitudinal seam and then corrugated. Outer protection for the steel sheath is provided by means of a special viscous, anti-corrosion compound enclosing one or more plastic tapes and laid so that the troughs of the corrugations are completely filled. An external plastic covering is then extruded over the compound-protected steel to form a smooth outer covering.

1.2 For protection against induced currents the cable described in § 1.1 above may be used with aluminium or copper tapes laid longitudinally or helically beneath the corrugated steel sheath. Alternatively, a corrugated-copper sheath can be used in place of the corrugated-steel sheath.

2 Construction

2.1 The metallic strip is shaped into a long tube round the cable core, welded along the longitudinal seam and then corrugated.

2.2 Unprotected steel is particularly vulnerable to corrosion attack and the protection provided usually consists of a layer of compound in which may be embedded plastic tapes so that the corrugations are completely filled. An outer sheath of polyethylene or similar Class II covering (see reference [1]) is then extruded over the compound.

2.3 Armouring of the cable is not normally necessary, but may be provided in special cases.

3 Uses

Corrugated steel- or copper-sheathed cables may be used for all types of telecommunication cable and the following are the main considerationsinfluencing their use:

a) taking all factors into consideration (laying costs, duct space, cable cost, for example), and although the total diameter of the cable is greater than in the case of plastic, lead or noncorrugated-aluminium sheathed cables, telecommunication cables with steel sheaths may be more economical than lead-covered cables;

b) a steel sheath is not vulnerable to vibration caused by road or rail traffic;

c) a corrugated metal sheath has good flexibility;

d) a corrugated metal sheath with a smooth outer covering is easy to handle during installation;

e) the same type of cable can be laid direct in the ground or pulled into ducts;

f) such a sheath resists moderate crushing stresses and provides protection against most of the damage caused by stones or digging tools;

g) if the plastic covering of steel-sheathed cables is damaged, rapid corrosion may be expected.

Reference

[1] CCITT *Recommendations concerning the construction, installation and protection of telecommunication cables in public networks*, § 6.3, ITU, Geneva, revision 1974, amendments and additions, 1977.

Recommendation L.6 (Geneva, 1972)

METHODS OF KEEPING CABLES UNDER GAS PRESSURE

The CCITT draws attention to the improvements in service made possible by protecting telecommunication cables against the ingress of moisture when the sheath is perforated or damaged. To ensure that the circuits remain free of interruption until repairs can be completed, the CCITT recommends that Administrations recognize the utility of following the advice given in the manual *Protection of telecommunication cables by pressurization*, ITU, Geneva, 1970.

Recommendation L.7 (Geneva, 1976)

APPLICATION OF JOINT CATHODIC PROTECTION

1 General

By joint cathodic protection of several underground metallic structures is meant corrosion protection of these structures by means of common protective devices.

A joint protection system for several underground metallic structures is composed of electrical bonds between the structures and of common protective devices complying with cathodic protection and electrical drainage requirements.

Joint protection techniques enhance the reliability of buried structures, improve efficiency of cathodic protection devices and also reduce total investment and maintenance costs of the protective system.

2 Conditions for application of joint cathodic protection

It is practicable to apply joint cathodic protection of underground metallic plant when several different structures approach or cross each other and when it is necessary to avoid the harmful effects of the protected structure on neighbouring unprotected structures, provided that it is economical and there is no better means to avoid this influence. The harmful influence of cathodic polarization or protected plant on the neighbouring metallic structures occurs when:

a) measured potentials are lower or higher than the values recommended;

b) the danger of corrosion on neighbouring underground metallic structures is increased.

Joint protection of telecommunication cables with other structures can be reasonably applied in the cases when:

a) nearby underground structures are at a distance generally not exceeding 50 metres;

b) the buried plants cross each other;

c) the ground beds or reactive anodes of a cathodic protection system have a harmful influence on nearby unprotected plants.

Joint protection of telecommunications and power cables in accordance with reference [1] may be considered when the potential to earth of the telecommunications cable does not exceed the safe voltage required by local or national safety rules in the event of an earth fault or short circuit on the power supply system.

Joint cathodic protection should provide on the protected plants potentials which are within the values indicated in reference [1].

In the case of joint protection it may be possible to use devices which automatically control the current output of the cathodic protection equipment.

3 Conditions for electrical bonds

Special bonds are used to provide electric contact between jointly protected plants. Bonds may be direct, or provided with a resistor (to limit the current) or polarized.

Direct bonds may be used in the following cases:

a) when underground metallic structures of the same type are crossing or approaching each other;

b) when the provision of bonds between structures of different types does not reduce the efficiency of the primary cathodic protection system.

Resistor bonds which control the current applied to different types of plant should be used when potentials on these structures should be controlled.

Polarized bonds should be used:

a) for joint drainage and cathodic protection systems;

b) to prevent current flowing from a pipeline to telecommunication plant;

c) to protect against failure of the cathodic protection equipment.

Bonds should not be installed between buried structures and power supply cables and equipment unless it is safe to do so in the event of a faulton the power supply system and it is in accordance with local and national safety rules.

4 Monitoring the performance of joint cathodic protection devices

The performance of joint cathodic protection devices should be monitored by means of:

a) routine examination of protective devices and equipment;

b) routine measurements of interaction potential differences with the protection equipment switched on and switched off at all the plants incorporated in the joint protection system, in compliance with local accepted procedures.

When tests or changes are made on the joint cathodic protection system, the presence or agreement of the representatives of operating agencies whose underground structures are incorporated in the joint protection system is recommended.

Reference

[1] CCITT *Recommendations concerning the construction, installation and protection of telecommunication cables in public networks*, ITU, Geneva, revision 1974, amendments and additions, 1977.

Recommendation L.8 (Geneva, 1976)

CORROSION CAUSED BY ALTERNATING CURRENT

Laboratory experiments and the results of examinations of industrial installations show that stray alternating currents can cause corrosion.

However, other experiments on lead to compare the effects of direct current and alternating current by weight loss show that the corrosion effect due to a.c. is very slight compared with corrosion by d.c. A.c. corrosion appears in the form of pitting.

The following points should nevertheless be noted:

– the corrosion, although rare, occurs more readily with frequencies below the usual mains frequency of 50 Hz or 60 Hz;

– rectification may occur due to the nature of the soil or to the presence at the surface of the metals of oxides or polluting substances.

There is no practical way of finding out the current densities and the voltages at which corrosion occurs. The individual pitting that is usual, the fact that anodic and cathodic reactions occur on the same surface of the metals, and variations in the chemical characteristics of the environment make it impossible for any accurate concept or definition of critical current density to be worked out at present.

It seems reasonable to suggest that a.c. at low voltage is not usually harmful to steel or lead but may corrode aluminium in some cases.

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