Recommendation K.15

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

(Geneva, 1972)

Preliminary recommendation

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

Introduction

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

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

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

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

The protective measures required depend partly on the following:

— the value of the e.m.f. which may occur;

— the composition of the line, particularly when cable pairs are used;

— the arrangements made with regard to the outer conductor of coaxial pairs in relation to the metallic sheath of the cable (floating potential or earth);

— the type of power supply (d.c. or a.c.).

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

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

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

1 Methods of calculation

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

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

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

2 Limit values of overvoltages

2.1 *Longitudinal voltages caused by magnetic induction*

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

If the remote-feeding equipment raises the conductors permanently to a high potential with respect to the metallic sheath of the cable or to earth, it must be borne in mind that the induced voltage is superimposed on the power supply voltage (see [5]).

2.2 *Overvoltages caused by atmospheric discharges*

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

3 Protective measures

3.1 *Protection against overvoltages*

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

3.1.1 *Protection of conductors in cables*

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

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

3.1.2 *Protection of repeaters*

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

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

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

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

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

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

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

4.1 *General*

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

4.2 *Testing by impulse voltages*

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

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

4.3 *Testing by alternating voltages*

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

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

In systems where a permanently induced voltage may be expected due, for example, to the alternating current in railway lines, it is necessary to superimpose on the feed current an alternating current of the same frequency (50 Hz, 60 Hz, 16 | /3 Hz) and strength as that produced in the power-feeding section when the induced voltage has the value specified in [5]. During the flow of the induced current the hum modulation must be so small that the values for route sections suggested by Study Group XV in Question 11 are obtained.

References

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

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

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

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

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

Recommendation K.16

SIMPLIFIED CALCULATION METHOD FOR ESTIMATING THE EFFECT OF MAGNETIC INDUCTION FROM POWER LINES ON REMOTE-FED REPEATERS

IN COAXIAL PAIR TELECOMMUNICATION SYSTEMS

(Geneva, 1972)

1 Summary

The article mentioned in reference [1] contains a general treatise covering all possible cases of magnetic induction and permitting calculation of the location-dependent variation of the induced voltages and currents for full or partial exposure to induction of a route. This Recommendation gives general information on how to find an equivalent circuit which permits rapid estimation of the maxima of the voltages and currents in cable conductors for any length and location of exposure. The lumped capacitances and the transfer impedance of the equivalent circuit must be appropriately chosen. Only two groups of parameters are required here, depending upon whether the length of

the exposed section is shorter than, or equal to, or greater than half the length of the power-feeding section. The manner of switching from the complex formulae given in [1] to the simplified calculation is explained in Annex A.

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

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

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

2 Advantages of the equivalent circuit

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

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

In view of the unavoidable inaccuracy in calculating the induced longitudinal voltage used as reference quantity, a further error of up to about 20% is tolerated in the remainder of the calculation. The exact formulae can then be considerably simplified for all applications (since in practice Γ | (mu | fIl 2 and Γ
| (mu | fIl 2 nearly always holds) and corresponding equivalent circuits can be devised for each case. (The quantities Γ and Γ 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 (*E* |, *C* |, *V* |, *I* |) associated with the circuit *outer conductor—inner conductor* with a bar.

5 Universally applicable equivalent circuit

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

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

Figure 1/K.16 p.235

Figure 2/K.16 p.236

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* | fIk$_0$ | fIl 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 $C|_1$ and $C|_3$ 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 p.237

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 p.238

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 ± | 5° 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.

Figure A-1/K.16 p.239

Figure A-2/K.16 p.240

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 ($l_2 >> l/2$), 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 $l_2 >> l/2$.

FIGURE A-3/K.16 p.241

When, however, the exposed section is far shorter than the unexposed sections ($l_2 << l/2$) 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 p.242

This circuit diagram is obtained from one half of the configuration in Figure A.1/K.16, showing a line of length $l = 2a$, 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 (ω *C* | *(mu* | $_3$and ω *C* | *(mu* | $_1$, respectively), the effective lumped capacitance *C* | (mu | fIl$_2$/x associated with section 2 in the partial equivalent circuit must range between the limits:

$C \times$ [Unable to Convert Formula] $\frac{\text{f Il}}{f Ix}$ 2 $< C \times$ [Unable to Convert Formula] at the end with the shorter extension, and

$C \times$ [Unable to Convert Formula] $\frac{\text{f Il}}{f Ix}$ 2 > 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 $l_2 << l/2$.

Figure A-5/K.16 p.243

A.4.2 *Effective transfer impedance* |

The current *I* flowing in the circuit *cable sheath—outer conductor* produces a longitudinal voltage *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 *E* . This effective resistance, designated by Z_t | (mu | fIl , is called the effective transfer impedance. It replaces the resistance R_0 | (mu | fIl $E = I_{m\da\dx}$ | (mu | fIZ$_t$ | (mu | fIl .

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:

$$Z_t \times l =$$

[Unable to Convert Formula]

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 ($l_2 >> l/2$).

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

$$Z_t \times l =$$

The transfer impedance is often also called the coupling impedance of the metallic cable sheath.

[Unable to Convert Formula]

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 | (mu | fIl instead of *l*).

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:

$Z_t \times l$ = [Unable to Convert Formula] l_2 >> [Unable to Convert Formula]

$Z_t \times l$ = [Unable to Convert Formula] l_2 << [Unable to Convert Formula]

A.4.3 *Circuit outer conductor-inner conductor*

In the circuit *outer conductor—inner conductor* the longitudinal voltage 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 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 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 p.244 (Montage: resserrer figure si n´ecessaire

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 >>
[Unable to Convert Formula]
[Unable to Convert Formula]
respectively.

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

l_2 >> [Unable to Convert Formula] by l_2 > [Unable to Convert Formula]

l_2 << [Unable to Convert Formula] l_2 [Unable to Convert Formula]

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

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

ANNEX B

(to Recommendation K.16)

Practical examples of complete calculations and of the simplified calculation.

Case in which the outer conductors are at floating potential

To check the usefulness of this equivalent circuit for arbitrarily chosen partial exposures , the maxima of the voltages and currents were calculated by means of the equivalent circuit for some cases of exposures

completely calculated in [1] and the values determined were entered in the corresponding diagrams reproduced from this reference.

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

C = 0.12 μF/km; R_0= 6.2 Ω/km C = 0.2 μF/km; l = 64 km

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

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

A 64-km power-feeding section of a 300-channel system on small-diameter coaxial pairs, whose outer conductor is at a floating potential, is assumed to be exposed to a power line between the 12th and the

28th kilometre. The longitudinal voltage in the cable is assumed to be 1000 V, 50 Hz. The maxima of the voltages and currents appearing in the cable have to be assessed.

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

Figure CCITT-3525 p.245

H.T. [T1.16]

TABLE B-1/K.16

Comparison of the equivalent circuit determination with the accurately calculated maxima

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

Maxima Equivalent-circuit determination } Deviation from the exact calculation }	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 %
$V\,|_{max\ 1}$	**.** 48 V	45.8 V	—4.6 %
$V\,|_{max\ 2}$	37.5 V	45.8 V	**,** +22 %
$I\,|_{max}$	**0.4** 55 mA	61.5 mA	+11.8 %

Table B-1/K.16 (R´ecup.) [T1.16] p.246

This comparison shows that, with the exception of the value of $V_{m\backslash da\backslash dx\backslash d2}$, 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 $V_{m\backslash da\backslash dx\backslash d2}$ is of no practical importance since this involves the smaller of the two maxima of V .

FIGURE B-1/K.16, p.247

FIGURE B-2/K.16, p.248

FIGURE B-3/K.16, p.249

FIGURE B-4/K.16, p.250

FIGURE B-5/K.16, p.251

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 *C* instead of *C* . The resistance k_1 | fIR_0 | fIl 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 p.252

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 p.253

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 *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.

Figure C-3/K.16 p.254

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.

Figure C-4/K.16, p.255

Figure C-5/K.16, p.256

Figure C-6/K.16, p.257

Figure C-7/K.16, p.258

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 Starkstrombeeinfl"ussung 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.

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Recommendation K.17 | ' |

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

FROM EXTERNAL INTERFERENCE

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

1 Introduction

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

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

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

In particular, this applies for:

a) current and voltage in the feeding circuit,

b) gain-frequency characteristic,

c) total noise,

d) bit error rate.

See also Recommendations K.15 and K.16.
The tests specified in Recommendation K.17 can also be applied in a similar manner to terminal equipment, e.g. locally-fed repeaters, power separating filters, power feeding equipment, which are all affected in the same way as intermediate repeaters.

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.

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 p.

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

{
fBCharacteristics of waveforms to be used for the tests
}

{ Coaxial-pair repeaters (≥" 1.2/4.4 mm) } µ coaxial-pair repeaters (0.7/2.9 mm) }				Symmetric-pair repeaters		{	
	Prototype tests	Acceptance tests		Prototype tests	Acceptance tests	Prototype tests	Acceptance tests
	Test 1 Test 2 Test 1 Test 1a Test 2 Test 2a } Test 1 Test 1a Test 2 Test 2a }	Test 3 | ua) Test 3 Test 3	Test 1 Test 2 { Test 1 Test 2	Test 3 | ua) Test 3 | ua)	{ Test 1 Test 2	Test 3 | ua)	
Column No.		(1)	(2)	(3)	(4)	(5)	(6)
Waveform | ub)		10/700	10/700	100/700	100/700	10/700	10/700
Load		0.1 coulomb	max. 0.1 coulomb	0.06 coulomb	max. 0.06 coulomb	0.03 coulomb	0.03 coulo
Peak voltages		5 kV	5 kV	3 kV	3 kV	1.5 kV	1.5 kV
Short-circuit current		333 A		200 A		37.5 A	
{ Peak current in the power-feeding circuit }			50 A		50 A		37.5 A
C 2		0.2 µF	0.2 µF	2 µF	2 µF	0.2 µF	0.2 µF
R 3		c)	c)	c)	c)	25 Ω	25 Ω
Number of pulses		10	10	2	2	10	10

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.

Table 1/K.17 [T1.17], p.

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

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

— *Test 1a:* between input terminals of the repeater and conductive housing normally connected to earth in the case of symmetric pair repeaters;

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

— *Test 2a:* between output terminals of the repeater and conductive housing normally connected to earth in the case of symmetric pair repeaters.

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

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

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

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

Figure 2/K.17 p.

Figure 3/K.17 p.

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 | /3, 25, 50 or 60 Hz) is applied:

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

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

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

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

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

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

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

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

a) an alternating voltage of the appropriate frequency (50 Hz, 16 | /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 repeaters used for µ coaxial-pairs are tested, the maximum peak voltage need not exceed 5 kV.
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 |) until they do so.

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

3.1.1.1.2 *A.c. tests*

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 p.

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.

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.

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

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

3.1.2 *Acceptance tests*

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

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

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

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

3.2 *Test conditions for repeaters used on symmetric pairs*

3.2.1 *Prototype tests*

3.2.1.1 *Tests at repeater input and output terminals*

3.2.1.1.1 *Impulse tests*

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

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

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

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

3.2.1.1.2 *A.c. tests*

A.c. tests are not specified.

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

3.2.1.2.1 *Impulse tests*

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

3.2.1.2.2 *A.c. tests*

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

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

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

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

3.2.2 *Acceptance tests*

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

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

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

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

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

The following tests are applicable for all types of regenerators.

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

3.3.1 *Prototype tests*

3.3.1.1 *Impulse tests*

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

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

— *Test 1:* between terminals *a* and *b* of the power feeding path;

— *Test 2:* between terminal *a* of power feeding path and reference earth.

— *Test 3:* between terminal *b* of power feeding path and reference earth.

— *Test 4:* between both terminals *a* and *b* of power feeding path and reference earth.

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

H.T. [T2.17]
TABLE 2/K.17
Characteristic of waveforms to be used for impulse test of optical fibre systems

Impulse tests	
Prototype tests	Acceptance tests
Test 1 Test 2 Test 3 Test 4 Test 1 Test 4 . . }	{

Column No.	(1)	(2)
Waveform	10/700	100/700
Load	0.1 coulomb	0.06 coulomb
Peak voltages	5 kV	3 kV
Short circuit current	333 A	200 A
C 2	0.2 μF	2 μF
R 3	2.5 Ω	2.5 Ω
Number of pulses	10	2

Table 2/K.17 [T2.17], p.

Figure 5/K.17, p.

3.3.1.2 *A.C. tests*

3.3.1.2.1 *Short-term a.c. induction*

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

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

H.T. [T3.17]
TABLE 3/K.17
Currents and voltages for a.c. tests of optical fibre systems

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

Table 3/K.17 [T3.17], p.

3.3.1.2.2 *Steady state a.c. induction*

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

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

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

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

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

Figure 6/K.17, p.

3.3.2 *Acceptance tests*

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

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

References

[1] IEC publication No. 60-2 *High-voltage test techniques, Part 2: Test procedures* , Geneva, 1973.

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

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

Recommendation K.18

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

OF REDUCING INTERFERENCE

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

1 Introduction

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

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

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

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

2 Analysis of interference

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

— Earth resistivity is homogeneous and uniform.

— A cable or a wire is supported in a straight line at a constant height above the earth's surface.

— The metallic screen of a cable is earthed at both ends.

— The radio-wave electric field has a constant intensity and a constant incidence angle, and phase change along the cable is uniform.

— The radio wave is originally polarized vertically. However, while it propagates along the surface of the earth, a horizontal component is generated due to the finite conductivity of the earth.

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

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

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

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

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

$$V_2(0)\ \text{dB}\ [= V_2(l)] = 20 \log_{10} V_2(0) = 20 \log_{10} \frac{f\,IPE\ \ v\,f\,R\,(\cos\ \theta)Z\ \ K\,fR}{Z_{01}} - 30 \log_{10} f - 20 \log_{10} \alpha_{20} + 300 \quad (2\text{-}1)$$

where $l \geq" \frac{.5\ \beta\ \theta}{fIf \times \beta_2} \times 10^8$ (2-2)

$20\ \Omega < |\,|\ fIZ_{1R}\ |\,,|\,|\ fIZ_{1L}\ |\ \ |\,|\ fIZ_{01}\ |$ (2-3)

$\gamma_2 = \alpha_2 + j\beta_2$

$\alpha_2 = \alpha_{20} \sqrt{fIf\ |} \times 10^{-3}$ (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

$$l = \frac{.5\ \beta\ \theta}{fIf \times \beta_2} \times 10^8$$

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

$$l \geq" \frac{.5\ \beta\ \theta}{fIf \times \beta_2} \times 10^8 .$$

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]).

$E_v =$ [Unable to Convert Formula] $\sqrt{\frac{.5 P Z_0}{\pi}}$

(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 (=377 Ω)

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

Figure 1/K.18 p.

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:

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

l ≥" 210 m

Moreover, using $\theta = 0^{\circ}$ as the most severe value, the following is obtained:

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

l ≥" 210 m

Figure 2/K.18 p.

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 p.

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

$$V = \lambda \mid (mu \mid fIV_2$$

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 | | fI$Z_{0\backslash d1}$ | Ω, when earth conductivity is less than 0.1 S/m. If the screen thickness is increased to 1.0 mm the reduction is improved by a further 50-60 dB.

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

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

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

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

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

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

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

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

ANNEX A

(to Recommendation K.18)

Constants and variables used in Recommendation K.18

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

P =
[Unable to Convert Formula]
[Unable to Convert Formula]
[Unable to Convert Formula]

(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:

$$Z_K = \text{[Unable to Convert Formula]} \; R_{dc} \quad \Omega/\text{m}$$

(A-2)

where

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

K = [Unable to Convert Formula]

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

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

t is the thickness of metallic screen (m).

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

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

l is the cable length (m)

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

$Z_{0\backslash d1}$ is the earth return circuit characteristic impedance (Ω)

γ_1 is the earth return circuit propagation constant

$Z_{0\backslash d2}$ 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 at $x = 0$

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

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

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

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

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

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

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

Figure A-1/K.18 p.

ANNEX B

(to Recommendation K.18)

Induced longitudinal voltage calculation

B.1 *Telecommunication lines without metallic screen*

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

Induced longitudinal voltage at the end nearest the radio station:

$$V_1(0) = V_{10}(0) + V_{1L}(0) + V_{1R}(0)$$

$V_{10}(0) = —$ [Unable to Convert Formula] $\dfrac{— e^{(em(\gamma_1 + j\beta_0 \cos\theta)l}}{(*g_1 + j\beta_0 \cos\theta}$

$V_{1L}(0) = \dfrac{(em\,\Gamma_{1L}\left[1 — \Gamma_{1R}\ e^{(em\,2\gamma_1 f Il}\right]}{— \Gamma_{1L}\ \Gamma_{1R}\ e^{(em\,2\gamma_1 f Il}}$

$V_{1R}(0) = \dfrac{(em\,\Gamma_{1R}\ e^{(em\,\gamma_1 f Il}\left[1 — \Gamma_{1L}\right]}{— \Gamma_{1L}\ \Gamma_{1R}\ e^{(em\,2\gamma_1 f Il}}\ V_{10}(l)$

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

$V_1(l) = V_{10}(l) + V_{1L}(l) + V_{1R}(l)$

$V_{10}(l)$ = [Unable to Convert Formula] $e^{-j\beta_0 \cos\theta l} \dfrac{- e^{(em(\gamma_1 - j\beta_0 \cos\theta)l}}{(*g_1 - j\beta_0 \cos\theta}$

$V_{1L}(l) = \dfrac{(em\Gamma_{1L}\, e^{(em\gamma_1 f Il}\left[1 - \Gamma_{1R}\right]}{1 - \Gamma_{1L}\Gamma_{1R}\, e^{(em 2\gamma_1 f Il}} V_{10}(0)$ (B-2)

$V_{1R}(l) = \dfrac{(em\Gamma_{1R}\left[1 - \Gamma_{1L}\, e^{(em 2\gamma_1 f Il}\right]}{1 - \Gamma_{1L}\Gamma_{1R}\, e^{(em 2\gamma_1 f Il}} V_{10}(l)$

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:

$V_2(0) = V_{20}(0) + V_{2L}(0) + V_{2R}(0)$

V_{20} [Unable to Convert Formula] (0)