INTERNATIONAL TELECOMMUNICATION UNION

ITU-T K.18

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PROTECTION AGAINST INTERFERENCE

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

ITU-T Recommendation K.18

(Extract from the *Blue Book*)

NOTES

1 ITU-T Recommendation K.18 was published in Volume IX of the *Blue Book*. This file is an extract from the *Blue Book.* While the presentation and layout of the text might be slightly different from the *Blue Book* version, the contents of the file are identical to the *Blue Book* version and copyright conditions remain unchanged (see below).

2 In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Recommendation K.18

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

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

1 Introduction

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

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

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

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

2 Analysis of interference

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

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

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

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

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

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

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

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

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

where

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

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

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

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

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 earlies peak values along the cable length.

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

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

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

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

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

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

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

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

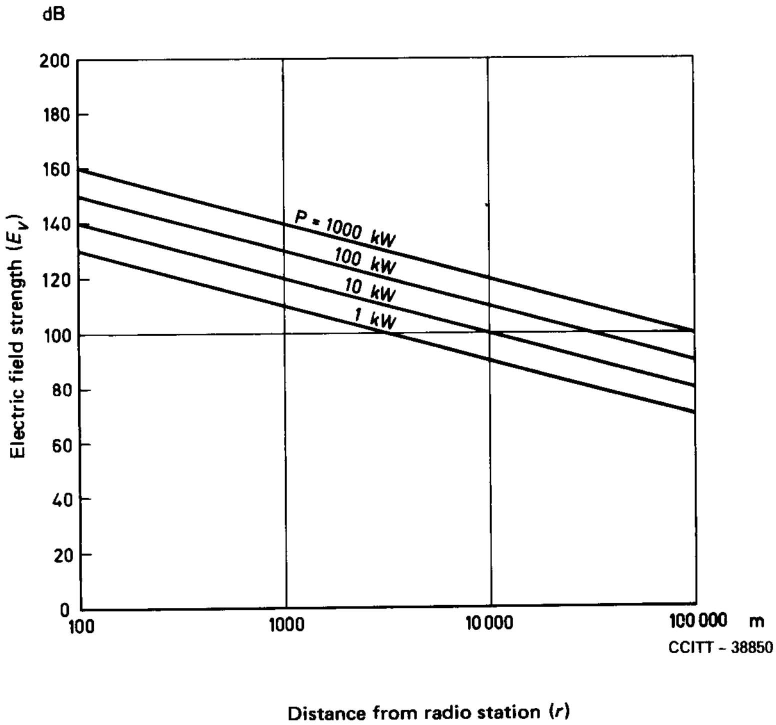
where

P is the radio station transmitting power (W)

r is the distance from radio station (m)

Z_0 is the instrinsic 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.



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:

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

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

Moreover, using θ = 0° as the most severe value, the following is obtained:

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

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

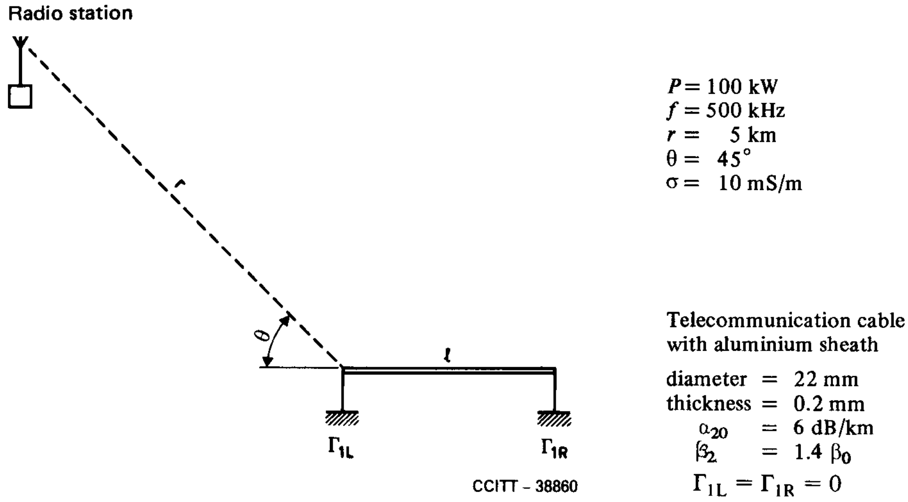


FIGURE 2/K.18

Relative position of radio station and telecommunication line

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

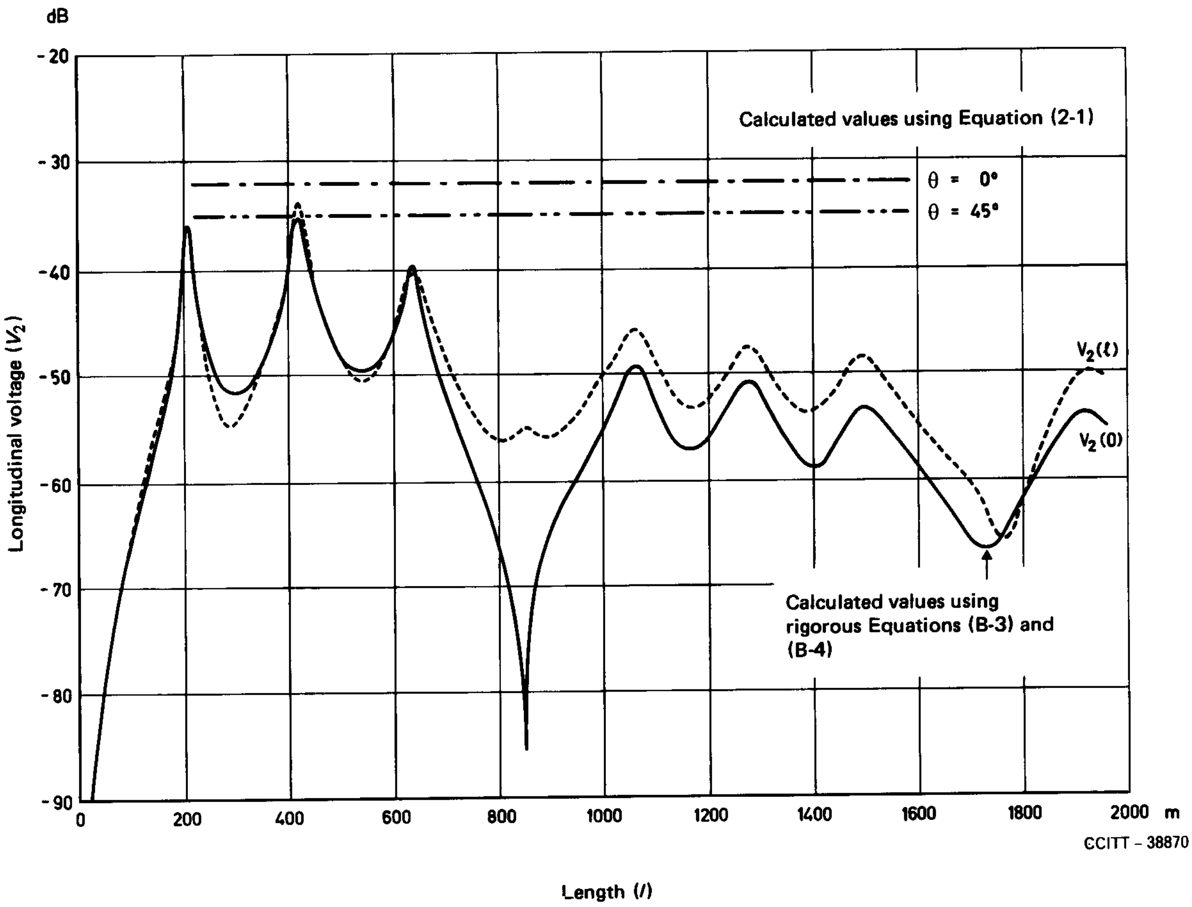


FIGURE 3/K.18

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

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

$$V = \lambda \cdot V_2$$

where

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

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

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

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

V = – 35 – 40 dB = – 75 dB

3 Reduction of interference

The following measures may be taken to minimize interference:

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

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

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

3.2.2 Conductors should be completely 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 mainteance personnel, a capacitor may be inserted between the conductors and the earth at suitable intervals within the induced section to bypass the induced current.

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

ANNEX A

(to Recommendation K.18)

Constants and variables used in Recommendation K.18

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

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

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 specific dielectric constant of free space (F/m)

Z_0 is the intrinsic impedance of free space (Ω)

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

σ is the earth conductivity (S/m)

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

f is the frequency of radio wave (Hz)

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

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

where

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

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

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

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

t is the thickness of metallic screen (m).

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

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

l is the cable length (m)

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

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

γ_1 is the earth return circuit propagation constant

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

γ_2 is the longitudinal circuit propagation constant

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

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

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

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

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

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

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

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

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

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

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

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

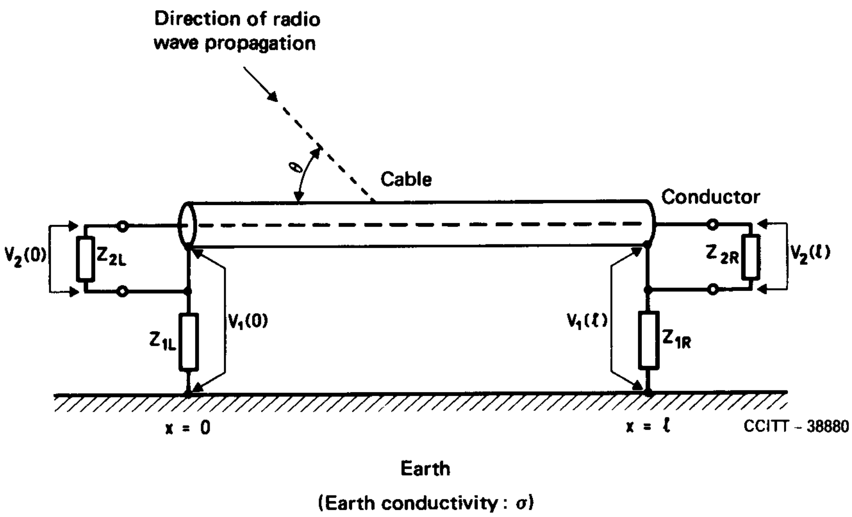


FIGURE A-1/K.18

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

ANNEX B

(to Recommendation K.18)

Induced longitudinal voltage calculation

B.1 *Telecommunication lines without metallic screen*

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

Induced longitudinal voltage at the end nearest the radio station:

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

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

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

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:

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

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) \\
&\mathrm{V}_{20}\,(l) \;=\; \frac{PE_V \cos\theta\, Z_K}{4\,Z_{01}} \left[\left\{ \frac{1}{\gamma_1 - \mathrm{j}\beta_0 \cos\theta} + \frac{1}{\gamma_1 - \mathrm{j}\beta_0 \cos\theta} \right\} . \right. \\
&\qquad . \frac{1 - \mathrm{e}^{-(\gamma_2 - \mathrm{j}\beta_0 \cos\theta)\, l}}{\gamma_2 - \mathrm{j}\beta_0 \cos\theta}\, \mathrm{e}^{-\mathrm{j}\beta 0 \cos\theta l} + \left\{ - \frac{1}{\gamma_1 - \mathrm{j}\beta_0 \cos\theta} + \right. \\
&\qquad + \frac{1}{1 - \Gamma_{1L}\,\Gamma_{1R}\,\mathrm{e}^{-2\gamma_1 l}} \left(\Gamma_{1L}\, \frac{1 - \mathrm{e}^{-(\gamma_1 + \mathrm{j}\beta_0 \cos\theta)\, l}}{\gamma_1 + \mathrm{j}\beta_0 \cos\theta} + \Gamma_{1L}\,\Gamma_{1R}\,\mathrm{e}^{-\mathrm{j}\beta_0 \cos\theta l}\, . \right. \\
&\qquad \left. \left. . \,\mathrm{e}^{-\gamma_1 l}\, \frac{1 - \mathrm{e}^{-(\gamma_1 - \mathrm{j}\beta_0 \cos\theta)\, l}}{\gamma_1 - \mathrm{j}\beta_0 \cos\theta} \right) \right\} \frac{1 - \mathrm{e}^{-(\gamma_2 - \gamma_1)\, l}}{\gamma_2 - \gamma_1}\, \mathrm{e}^{-\gamma_1 l} + \\
&\qquad + \left\{ - \frac{\mathrm{e}^{-(\gamma_1 + \mathrm{j}\beta \cos\theta)\, l}}{\gamma_1 + \mathrm{j}\beta \cos\theta} + \frac{1}{1 - \Gamma_{1L}\,\Gamma_{1R}\,\mathrm{e}^{-2\gamma_1 l}} \left(\Gamma_{1L}\,\Gamma_{1R}{}^{-2\gamma_1 l}\, . \right. \right. \\
&\qquad \left. \left. . \frac{1 - \mathrm{e}^{-(\gamma_1 + \mathrm{j}\beta_0 \cos\theta)\, l}}{\gamma_1 + \mathrm{j}\beta_0 \cos\theta} + \Gamma_{1R}\,\mathrm{e}^{-\mathrm{j}\beta_0 \cos\theta l}\,\mathrm{e}^{-\gamma_1 l}\, \frac{1 - \mathrm{e}^{-(\gamma_1 - \mathrm{j}\beta_0 \cos\theta)\, l}}{\gamma_1 - \mathrm{j}\beta_0 \cos\theta} \right) \right\} . \\
&\qquad \left. . \frac{1 - \mathrm{e}^{-(\gamma_2 + \gamma_1) l}}{\gamma_2 + \gamma_1}\, \mathrm{e}^{\gamma_1 l} \right] \\
&V_{2L}\,(l) \;=\; \frac{-\,\Gamma_{2L}\,\mathrm{e}^{-\gamma_2 l}\,\left[1 - \Gamma_{2R}\right]}{1 - \Gamma_{2L}\,\Gamma_{2R}\,\mathrm{e}^{-2\gamma_2 l}}\, V_{20}\,(0) \\
&V_{2R}\,(l) \;=\; \frac{-\,\Gamma_{2R}\left[1 - \Gamma_{2L}\,\mathrm{e}^{-2\gamma_2 l}\right]}{1 - \Gamma_{2L}\,\Gamma_{2R}\,\mathrm{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 ≤ α_{20} ≤ 30 dB/km, 1.2 $\beta_0 \le \beta_2 \le 3\ \beta_0$, 500 kHz ≤ f ≤ 1.6 MHz, 10 mm ≤ d ≤ 50mm, 0° ≤ θ ≤ 90°, 0.1 mS/m ≤ σ ≤ 500 mS/m and –1 ≤ Γ ≤ 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 $\Gamma_1 \ge 0$ is considered, because $|Z_1| \le Z_{01}$ 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.

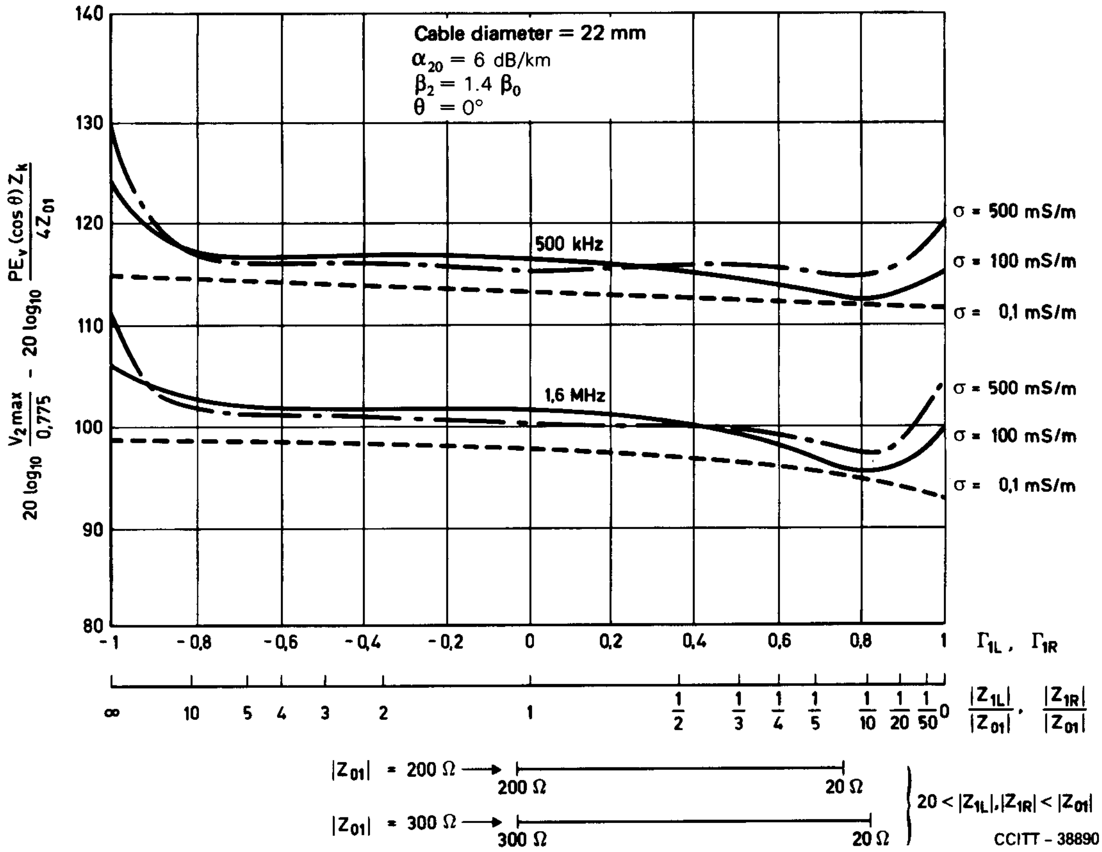


FIGURE C-1/K.18

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

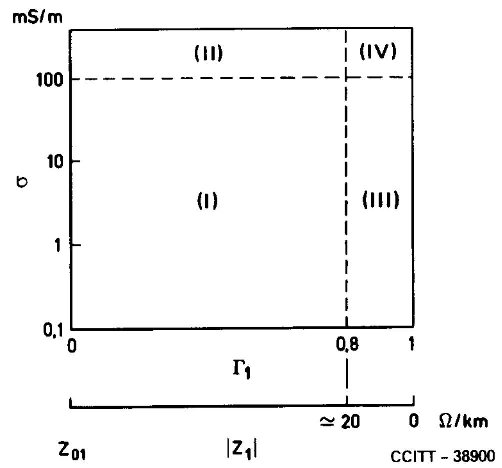


FIGURE C-2/K.18

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).

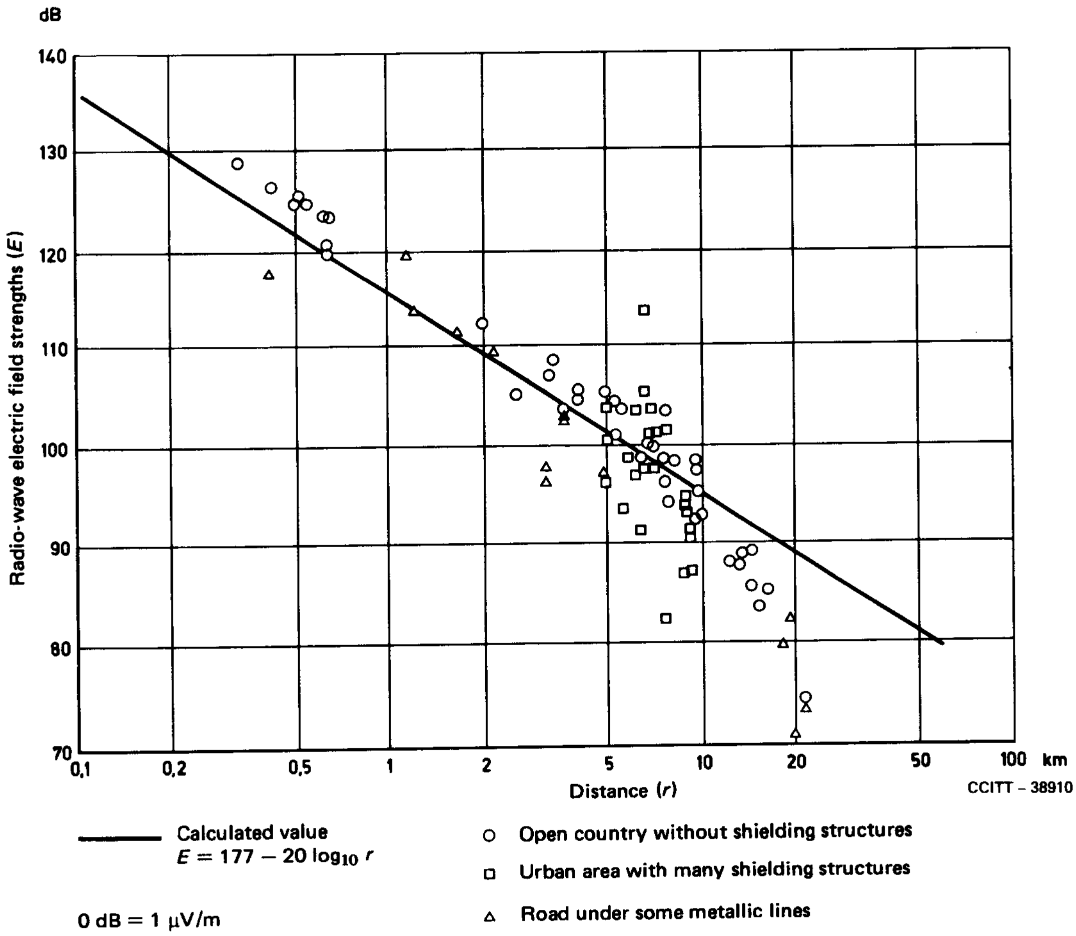


FIGURE D-1/K.18

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

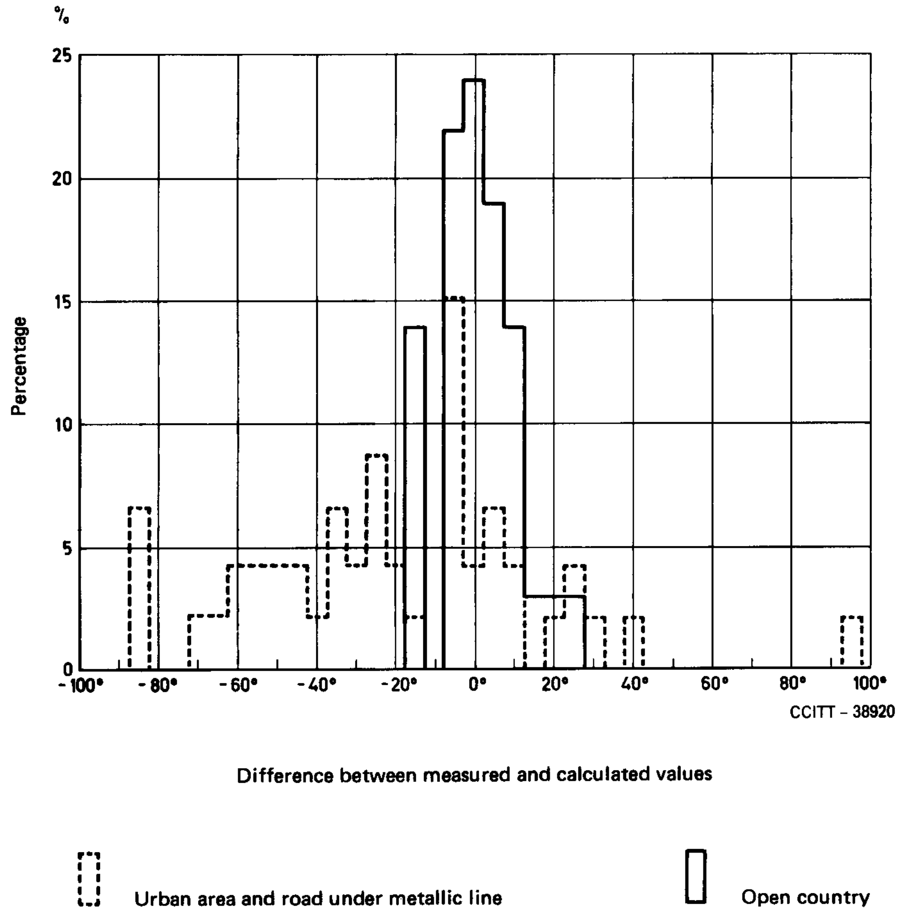


FIGURE D-2/K.18

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).

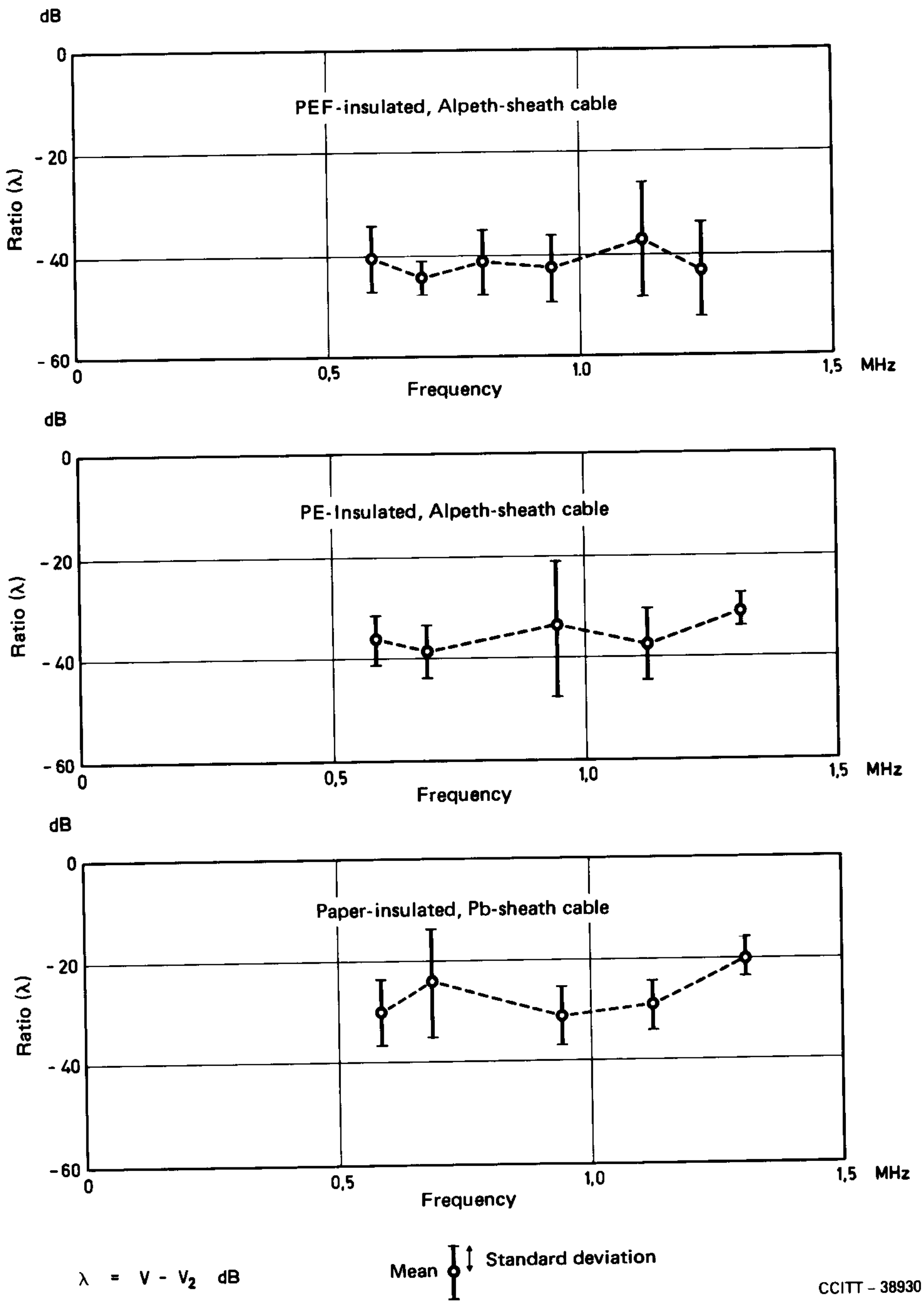


FIGURE E-1/K.18

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 inteligible noise from radio programme, at time unintelligible	– Insertion of capacitors (at input terminals of telephone set) – Replacement by cable with metallic screen, – Screening drop wire – Insertion of choke coil in circuit
High-frequency circuit e.g. carrier trans-mission	LF MF Mainly MF	Several kW	– Up to several tens of km – In the case of subscriber carrier system interference up to nearly 1000 km has been reported. (0.03 to 1.8 v/m)	– Mainly overhead cable with metallic screen (balanced pair, coaxial pair) – Cabling in building (between multiplex and antenna, between demodulation stages) – Open wire	Single tone or unintelligible noise in demodulated telephone channel (degradation of SNR in transmission system	– Improvement in shielding efficiency for cable, cabling, etc. – Improvement on earthing of cable sheath, repeater, terminal equipement, 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 – Additon of a compandor to the terminal end of the open-wire carrier circuit – Installation of a sufficiently balanced longitudinal choke coil to the carrier circuits
Radio frequency heating	MF (broad-casting)	–	Immediate vicinity of radio station antenna	– Open wire – Drop wire	Radio frequency burns	– Capacitor insertion between conductors and earth

ANNEX G

(to Recommendation K.18)

Radio wave interference to repeater station coaxial cabling and countermeasures

G.1 *Affected transmission systems and interference*

Interference has been experienced in carrier transmission systems in repeater stations due to radio-emissions.

When the induced radio wave frequency falls within the transmission frequency band, it causes single tone or unintelligible noise in the demodulated telephone channel. The interference is caused by induced currents in the outer conductors or screens of the coaxial cables in the repeater station.

Interfering frequencies of radio waves are mainly medium frequency (MF) and high frequency (HF) (of the order of 1-15 MHz).

G.2 *Electric field strength*

Radio wave interference occurs when the electric field strength exceeds 100 dBμV/m outside the station building or 80 dBμV/m inside the station building.

The degree of attenuation provided by the building depends on the form of construction used. In the case of a concrete building, for example, the attenuation may be 20-30 dB, at 1-15 MHz.

The electric field in the building is not homogeneous, and large variations, of about 20-30 dB, have been observed.

G.3 *Countermeasures*

One of the most efficient protective measures is the improvement of screening for coaxial cables. The screening efficiency for a coaxial cable depends on its transfer impedance (Z_T), and adopting a coaxial cable with lower transfer impedance is useful. For example, μ-metal screened coaxial cable (e.g. $Z_T \approx 0.01$ mΩ/m at 1 MHz) and triple-braided (screened) coaxial cable (e.g. $Z_T \approx 0.1$ mΩ/m at 1 MHz) have been used. For example, a 15-20 dB reduction can be obtained by replacing a double-braided coaxial cable with a triple-braided one.

The use of a low transfer impedance connection between the station cable and the equipment and the provision of good earthing arrangements in the repeater station also give benefits.

References

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[2] SCHULZ (E.), VOGEL (W.): Beeinflussung von Trägerfrequenz-Nachrichtensystemen durch hochfrequente Beeinflussungsquellen, *ETZ-A*, Bd. 85, H. 20, 1964.