TECHNICAL REPORT

TR CISPR 16-3

2000

AMENDMENT 1
2002-06

Amendment 1

Specification for radio disturbance and immunity measuring apparatus and methods –

Part 3:
Reports and recommendations of CISPR

Amendement 1

Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques –

Partie 3:
Rapports et recommandations du CISPR

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PRICE CODE T

For price, see current catalogue

FOREWORD

This amendment has been prepared by CISPR subcommittee A: Radio interference measurements and statistical methods.

The text of this amendment is based on the following documents:

CDV	Report on voting
CISPR/A/297/CDV	CISPR/A/329/RVC

Full information on the voting for the approval of this amendment can be found in the report on voting indicated in the above table.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until 2004. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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Add the following after subclause 5.2:

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Add the following new clause:

6 Reports on uncertainties in standardized emission compliance testing

6.1 Introductory note

Clause 6 of CISPR 16-3 is a collection of documents (reports) dealing with the issue of uncertainties in standardized emission compliance tests.

The primary goal of this clause is to give guidance to those who are involved in the development or modification of CISPR emission standards. In addition, this clause is useful background information for those who apply the standards in practice.

Subclause 6.2 is still under consideration. Subclause 6.2 will contain details on the scope of clause 6 and will present the general aspects of standards compliance uncertainty in emission testing. To compensate for the absence of 6.2, this introductory note on uncertainties in standardized compliance testing is given. This note can be deleted after subclause 6.2 is included in clause 6.

The term Standards Compliance Uncertainty (SCU) is used to distinguish the associated uncertainty contributions from those arising from the measurement instrumentation only.

In a standardized emission compliance test, the emission level of an electrical or electronic product is measured, after which compliance with the associated limit is determined. The measured level only approximates the true level to be measured, due to uncertainties in the influence quantities. However, in classical metrology, all relevant influence quantities are specified and the classical Measurement Instrumentation Uncertainty (MIU) can be identified. In EMC compliance testing, very relevant influence quantities turn out to be non-specified, while no quantitative information is available about their values. Hence, the estimate of the associated uncertainty will, in general, differ significantly from the estimate following the classical measurement uncertainty considerations. Therefore, the term Standards Compliance Uncertainty (SCU) has been introduced to distinguish between the uncertainties encountered during an EMC compliance test, and the classical Measurement Instrumentation Uncertainty (MIU) used in metrology.

NOTE The measurement instrumentation uncertainty budgets of various CISPR emission tests are published in CISPR 16-4.

Subclause 6.2 will give some general and basic considerations on the subject of SCU in emission tests and can be considered as an 'uncertainty handbook' on uncertainties in emission compliance testing. The following aspects will be addressed in this handbook.

a) The definition of SCU and that of some other relevant EMC and uncertainty specific terms.
b) The various classes of uncertainties that can be encountered for EMC testing and the distinction between SCU and MIU.
c) Description of the steps to be taken to incorporate uncertainty considerations for a certain purpose. In this subclause also, guidance is given on the application of SCU in the compliance criterion.

The guidance given in this handbook shall be used when modifying existing or when drafting new CISPR recommendations.

The result of the application of this handbook to existing or new CISPR recommendations will lead to proposals to improve and harmonize the uncertainty aspects of these CISPR recommendations. Such proposals will also be published as a report within this clause 6.

The structure of documents related to the CISPR SCU work is depicted in the figure below. Report 6.2 (under consideration) is the first part dealing with the basic and general aspects of the SCUs in EMC emission measurements. Subclause 6.3 contains the uncertainty considerations related to voltage measurements. Subclause 6.4 is reserved for SCU-consideration of radiated emission measurements.

Also for immunity tests, uncertainty work is projected. The SCU considerations of immunity tests differ from the emission SCU considerations at particular points. For instance, for an immunity test, the measurand is often a functional attribute of the EUT and not a quantity. This may cause additional specific problems. The SCU documents related to immunity tests will be published in a separate clause within CISPR 16-3.

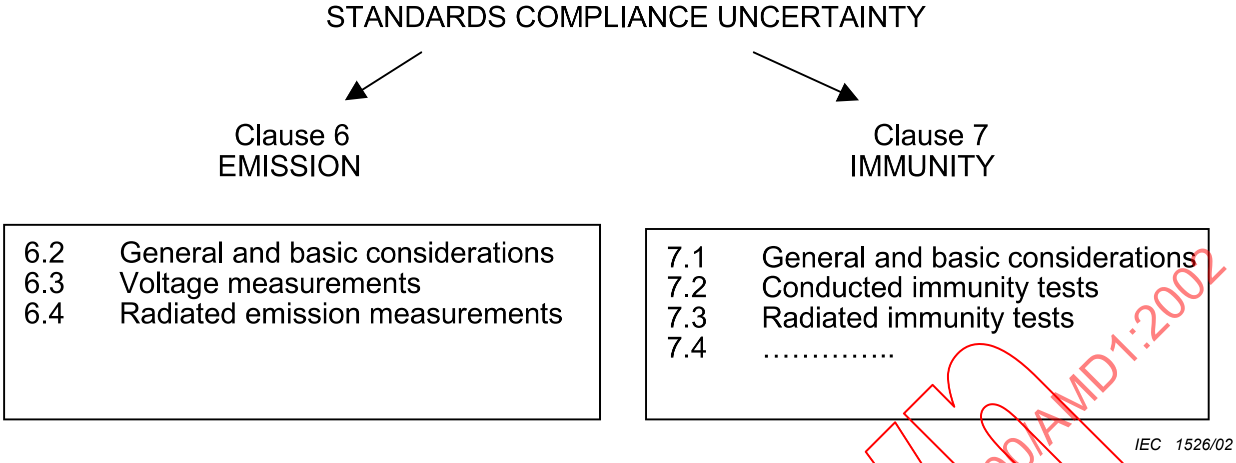

Figure 6.1-1 – Standards compliance uncertainty

6.2 General and basic considerations

Under consideration.

6.3 Voltage measurements

6.3.1 Introduction

This report deals with modeling of CISPR standardized voltage measurements in order to identify the possible contributions to the standards compliance uncertainty, with the exception of

a) product variability that is covered by the CISPR 80%/80% sampling procedure, and

b) test house induced uncertainties (see report 6.2).

After a discussion of the voltage measurement basics in 6.3.2.2, voltage measurements using a voltage probe are discussed in 6.3.3. Voltage measurements using a V-terminal artificial mains network applied to Class II appliances with only a mains cable are discussed in 6.3.4. Additional voltage measurements, for example, those on appliances equipped with a protective earth, appliances with more than one connected cable and appliances connected to ancillary equipment are under consideration.

6.3.2 Voltage measurements (general)

6.3.2.1 Introduction

Subclause 6.3.2.2 presents a consideration of the voltage measurements basics, followed by some remarks about voltage measurements using a voltage probe (6.3.3). After that, the most commonly used conducted emission measurement is discussed, i.e. the emission measurement using a V-type artificial mains network (6.3.4). Throughout the discussion, it is assumed that the EUT is a two-terminal device: only one two-wire mains cable is connected to the EUT. N-terminal devices (N > 2) with or without connections to ancillary equipment are under consideration.

6.3.2.2 Voltage measurements basics

6.3.2.2.1 Specification of the measurement loop

A voltage is always measured between two specified terminals. Figure 6.3 -1 illustrates such a measurement. U_{12} is the voltage of interest. The measurement leads transport the signal to the terminals 3 and 4 of the load impedance Z_L formed by the input impedance of the voltmeter, and U_{34} is the actual measured voltage. The EUT, leads and voltmeter load impedance form a loop of which the contour is denoted by C, and the loop area by S.

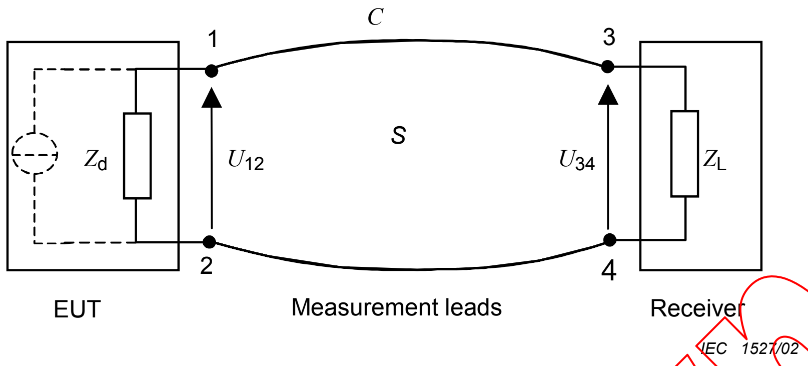

Figure 6.3-1 – Basic circuit of a voltage measurement

In particular when the internal impedance of the disturbance source is unknown (as is usually the case in compliance testing) care shall be taken that $Z_L >> Z_d$ otherwise the measured voltage depends in an unknown way on Z_L, thus creating large contributions to the standards compliance uncertainty. Consequently, Z_L has to be specified starting from estimated or measured values of Z_d of the class of subject EUTs.

NOTE 1 Specifying only one terminal, the 'hot' terminal, and assuming that the other terminal can be any point that is 'grounded' is only allowed in electrostatics, i.e. at d.c. (zero frequency) (see 6.3.3).

NOTE 2 Stray capacitances may limit the maximum value of Z_L (see 6.3.3).

6.3.2.2.2 Measurement loop constraint

The result of the voltage measurement has a physical meaning if, and only if, the circumference of the measurement loop, the contour C, is electrically small, i.e. if the circumference of the loop is small compared to the wavelength of the signal, or signal component to be measured.

If this condition is not satisfied, resonance effects will occur, creating large and undefined uncertainty contributions. These uncertainties may be reduced to an acceptable level placing the load impedance close to the terminals where the voltage has to be measured and to transport the measurement signal to the receiver via a transmission line, such as a coaxial cable. The characteristic impedance of that line should match the input impedance of the receiver. The possible mismatch is often expressed as a voltage standing wave ratio (VSWR). See also 6.3.4.6.2.

If the condition 'C electrically small' is satisfied, the use of a lumped element equivalent circuit to describe a voltage measurement is allowed. Unless indicated otherwise, it is assumed that this condition has been satisfied.

6.3.2.2.3 The measured voltage

Faraday's law is always applicable to a voltage measurement loop. For the loop given in figure 6.3-1 this means that

$$\oint_c \vec{E} \cdot \mathrm{d}\vec{l} = -\frac{\partial}{\partial t} \oiint_S \vec{B} \cdot \mathrm{d}\vec{s} \tag{6.3-1}$$

where the electric field $\vec{E}$ and the magnetic flux $\vec{B}$ are generated by the disturbance source inside the EUT, or by some ambient disturbance source. Unless specified otherwise, the latter source is assumed to be negligibly small; for example, the measurement set-up is sufficiently screened.

From equation (6.3-1) it follows that the voltage U_{34} is given by

$$U_{34} = \int_3^4 \vec{E} \cdot \mathrm{d}\vec{l} = U_{12} - \int_1^3 \vec{E} \cdot \mathrm{d}\vec{l} - \int_4^2 \vec{E} \cdot \mathrm{d}\vec{l} - \frac{\partial}{\partial t} \oiint_S \vec{B} \cdot \mathrm{d}\vec{s} \qquad (6.3\text{-}2)$$

where U_{12} is the voltage to be measured. In this equation the contribution of the magnetic field term to U_{34} often dominates. Therefore, the voltage measuring method shall include a sufficiently accurate description of the layout of the measuring leads.

A numerical example illustrating the importance of the influence of the physics described by Faraday's law on the measurand is given in annex 6.3-A.

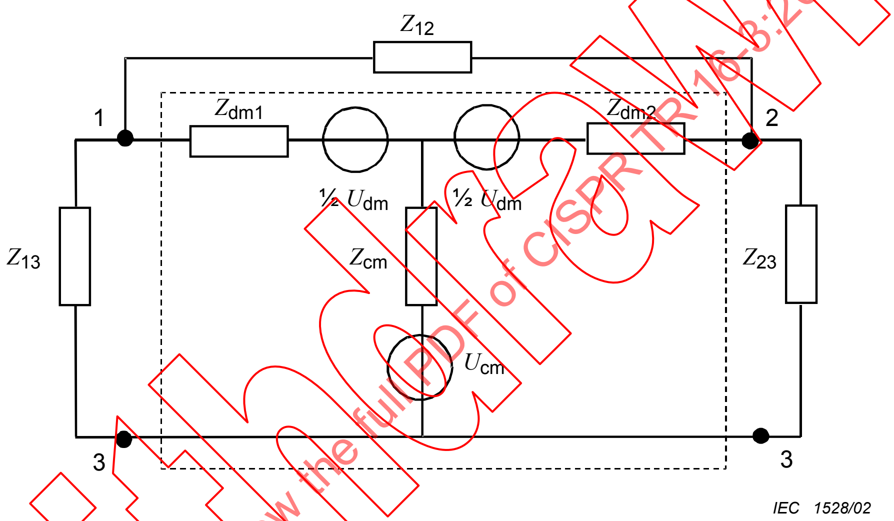

Figure 6.3-2 – Basic circuit of a loaded disturbance source (N = 2)

6.3.2.3 The disturbance source and types of voltage

At the interface the disturbance voltage is measured while the measurement loop constraints are satisfied. The source creating that voltage can be described by a lumped element n-port. Since differential-mode (DM) and common-mode (CM) phenomena are of importance, the number of terminals of the n-port equals N + 1, where N is the actual number of terminals. The additional terminal represents the surroundings of the source to which coupling via electric and magnetic fields is possible and to which the source may have a galvanic connection. It is the task of the standard drafter to define the surroundings in such a way that this additional terminal is a relevant reference point in the voltage measurement.

In this section N = 2 is assumed, so that a three-terminal network results and the equivalent circuit of figure 6.3-2 applies. An example of an EUT presenting an N = 2 disturbance source is

a) an appliance with only a two-wire mains lead, and

b) the voltage is to be measured at the mains connector terminals.

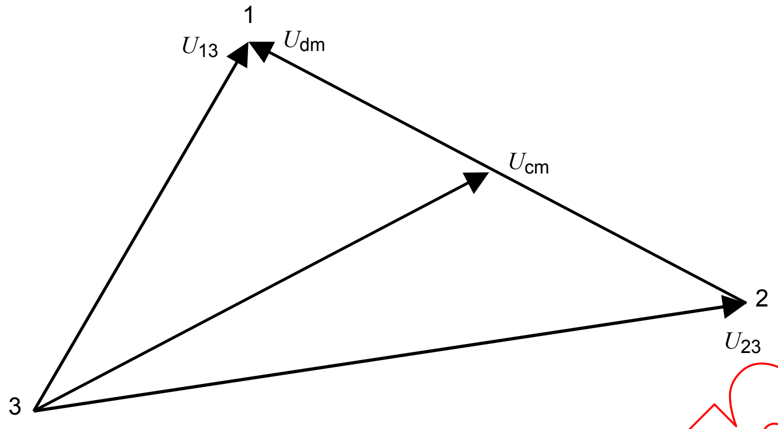

Figure 6.3-3 –Relation between the voltages

In figure 6.3-2, all elements are – in principle – frequency-dependent. Z_{dm1} and Z_{dm2} represent the internal impedance of the equivalent DM source with open-circuit voltage U_{dm}. In general, $Z_{dm1} \neq Z_{dm2}$ as at the frequencies of interest the circuit will seldom be symmetrical. Z_{cm} is the internal impedance of the equivalent CM source with open-circuit voltage U_{cm}. The load is represented by the impedances Z_{13} and Z_{23} between the actual terminals 1 and 2 and the reference 3, and the impedance Z_{12} between the actual terminals. Denoting the voltages across Z_{13} and Z_{23} by U_{13} and U_{23}, the relation between these voltages and U_{dm} and U_{cm}, is given in figure 6.3-3.

6.3.2.3.1 Interference probability

The DM- and the CM-conducted emission voltage level are, in general, a figure of merit for the interference potential of an appliance when the main coupling mechanism to the victim is crosstalk. In addition, the CM-conducted emission voltage level is generally also a figure of merit when the main coupling mechanism is (far-field) radiation. However, in the latter case, the CM current is generally a more direct figure of merit (see 6.3-B5). The so-called unsymmetrical conducted emission levels U_{13} or U_{23} give, in general, no information about the interference potential of an appliance. Additional information about the phase angle between U_{13} and U_{23} is needed to convert these voltages into the relevant voltages U_{dm} and U_{cm}. So in compliance probability studies, both the DM and CM properties of the disturbance signal have to be considered.

6.3.2.3.2 CM/DM and DM/CM conversion

The parasitic properties, for example, parasitic capacitance and stray inductance, of a voltage measuring device may cause an unwanted conversion of DM disturbances into CM disturbances, and vice versa. Therefore, the DM/CM or CM/DM conversion properties of a voltage-measuring device may play a part in uncertainty studies, in particular those of artificial or impedance simulation networks. The conversion properties may also be desired in the case where these properties dominate the compliance probability in actual situations. To give some examples:

a) If the device is used to simulate a telephone-subscriber line, the conversion properties should be related to the actual conversion properties of those lines.

b) If the device is used to investigate the conversion properties of telephone-subscriber lines, the conversion properties of the device shall not influence the results of that investigation.

c) If the device is used to characterize the CM-disturbance signal emitted by a given EUT via the telephone-subscriber line port, the DM/CM conversion properties of the device shall not influence the measurement results. In addition, the DM/CM conversion properties of the ancillary equipment, connected to that port during the emission test, shall not influence the measurement results.

6.3.3 Voltage measurements using a voltage probe

When using a voltage probe it is very important to specify the two terminals between which the voltage is to be measured. As already mentioned in note 1 of 6.3.2.2, specifying only one terminal, the 'hot' terminal, and assuming that the other terminal can be any point that is 'grounded' is only allowed in electrostatics, i.e. at d.c. (zero frequency). In the case of a two-terminal disturbance source, the circuit of figure 6.3-2 applies, where Z_{13}, Z_{12} and Z_{23} represent the generally unknown and unequal load impedances of the source, for example, those formed by the mains network. If, for example, the voltage between terminals 1 and 3 is measured, the input impedance of the voltage probe is in parallel with Z_{13} and in parallel with ($Z_{12} + Z_{23}$).

In addition, the layout of the measurement loop has to be specified to assure that the measurement loop constraint is met (6.3.2.2.2), as resonance effects contribute to the uncertainty in the voltage to be measured. That layout specification should be such that it minimizes the voltage that may be induced by the magnetic field emitted by the EUT itself. The latter voltage contributes to the uncertainty of the voltage to be measured. A numerical example is given in annex 6.3-A.

In the CISPR specifications [3] the voltage probe is a device having a large input impedance (for example, 1 500 Ω). As a consequence, attention has to be paid to the possible effect of the stray capacitance between the 'hot' input terminal of the probe and its surroundings. That capacitance reduces the effective input impedance of the probe (Z_{13}), thus creating an uncertainty contribution. In addition, if the input impedance is not very much larger than the source impedance (*a priori* unknown in a compliance test), an additional uncertainty may be introduced as a result of the uncertainty in the voltage division factor. Moreover, the loading by the voltage probe having an insufficiently large input impedance may cause an unbalanced loading of the disturbance source, and since generally $Z_{dm1} \neq Z_{dm2}$, this unbalance may differ when measuring the voltage between the terminals 2 and 3, compared to that between 1 and 3.

Finally, the unsymmetrical voltage measured by the probe is not a direct figure of merit for the interference potential of the EUT. Hence, it gives no information about the interference probability so the standardized use of the probe should be kept to an absolute minimum.

In summary, in a well-written standard both EUT terminals in the voltage-probe measurement shall be carefully specified, as well as the layout of the leads between these two terminals and the two terminals of the probe. Moreover, attention should be paid to the magnitude of the input impedance of the probe relative to the actual load impedance of the EUT disturbance source. In annex 6.3-B, attention is paid to possible improvements of CISPR standards.

6.3.4 Voltage measurement using a V-terminal Artificial Mains Network

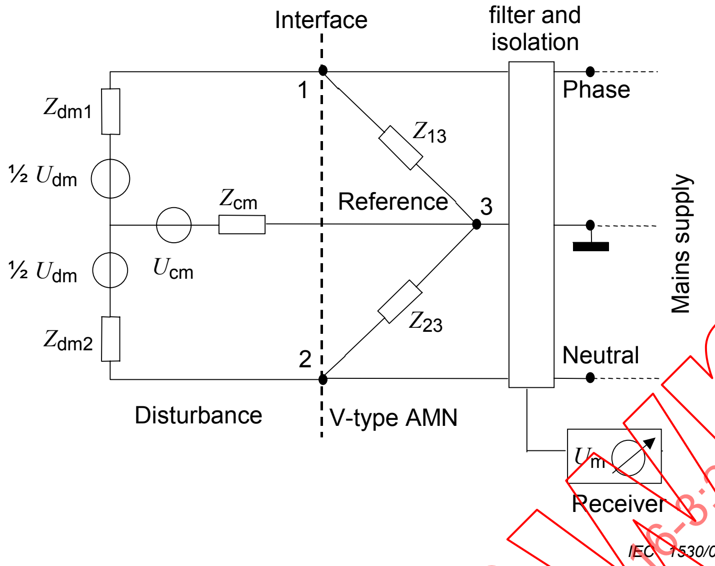

Figure 6.3-4 – Basic circuit of the V-AMN voltage measurement (N = 2)

6.3.4.1 Introduction

The V-terminal artificial network (V-AMN) essentially forms a T-network or π-network loading of the disturbance source. Throughout 6.3.4, it is assumed that the EUT is a two-terminal device: only one two-wire mains cable is connected to the EUT. Assuming a π-network loading, the basic circuit with the impedances Z_{13}, Z_{23} and Z_{12} as given in figure 6.3-2 applies at the interface of the measurement impedances. Subclause 4.1.1 of CISPR 16-1 specifies the two unsymmetrical impedances Z_{13} and Z_{23}, including the tolerance of the absolute value of these impedances. In 4.1.1 of CISPR 16-1, the shunt-impedance Z_{12} is a non-specified influence quantity; it seems that CISPR assumes that Z_{12} is always 'infinitely' large.

The basic circuit can be described as in figure 6.3-4. The filter and isolation between the measurement circuit and the mains terminals is, to some extent, also specified in CISPR 16-1. The unsymmetrical voltages across Z_{13} and Z_{23} have to be measured (see 2.2.3.1 for comments with regard to interference probability).

Valuable information about uncertainties associated with this type of measurement, that also may influence the calibration of the V-AMN, can be found in [9] and [12].

6.3.4.2 Basic circuit diagram of the voltage measurement

When reading the level U_m at the CISPR receiver, the circuit of figure 6.3-4 'reduces' to that of figure 6.3-5. In figure 6.3-5 U_d and Z_d, being non-specified influence quantities, represent the effective disturbance source at the interface formed by the subject unsymmetrical input terminal of the V-AMN and the reference of the voltage measurement set-up. The latter is normally the metal enclosure of the V-AMN. Z_{in} is the input impedance of the measurement set-up as experienced by the disturbance source. Z_{in} is a specified influence quantity that can be influenced by non-specified or by not sufficiently specified quantities (see 6.3.4.6). The factor $\alpha = U_m/U_{in}$, where U_{in} is the voltage across Z_{in}. This factor is, to a large extent, deterministic. In the absence of uncertainties, that is in the ideal situation, $Z_{in} = Z_{13} = Z_{23}$, for example, equal to 50 Ω in parallel with 50 µH, and α = 1.

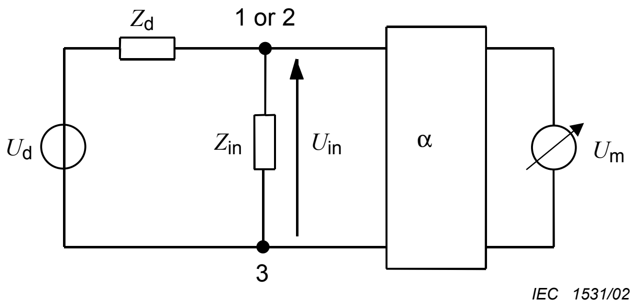

Figure 6.3-5 – Basic circuit of the V-AN measurement during the reading of the received voltage U_m (the numbers refer to figure 6.3-4)

6.3.4.3 Voltage measurement and standards compliance uncertainty

If U_{mt} is the true level of the voltage reading at the CISPR receiver in the ideal situation, U_{mt} is given by

$$U_{mt} = \frac{\alpha_0 Z_{13}}{Z_{d0} + Z_{13}} U_{d0} \tag{6.3-3}$$

where α_0 is the true value of α. Z_{d0} and U_{d0} are the true values of the disturbance source parameters when the source is loaded with the ideal impedance Z_{13}. However, in the actual set-up, the actual parameters are α, Z_{in}, Z_d and U_d, so the voltage reading U_m is given by

$$U_m = \alpha \frac{Z_{in}}{Z_d + Z_{in}} U_d \tag{6.3-4}$$

After substitutions of $U_m = U_{mt} + \Delta U_m$, $\alpha = \alpha_0 + \Delta\alpha$, $Z_{in} = Z_{13} + \Delta Z_{in}$, $Z_d = Z_{d0} + \Delta Z_d$ and $U_d = U_{d0} + \Delta U_d$ it follows from equation (6.3-3) and equation (6.3-4) that

$$\frac{\Delta U_m}{U_{mt}} = \frac{Z_{d0} + Z_{13}}{Z_d + Z_{in}} \left(\frac{\Delta\alpha}{\alpha_0} + \frac{\Delta U_d}{U_{d0}} \right) + \frac{Z_{d0}}{Z_d + Z_{in}} \left(\frac{\Delta Z_{in}}{Z_{13}} - \frac{\Delta Z_d}{Z_{d0}} \right) \tag{6.3-5}$$

if higher order terms in Δ are neglected. If knowledge is available about the actual value and deviations it may be possible to apply corrections [6]. For example, if from independent measurements it can be concluded that the actual value of Z_{13} shows a systematic difference with its ideal value and the difference is within the allowed tolerance of Z_{13}, the actual value may be inserted in equation (6.3-5).

In equation (6.3-5), ΔU_m can be identified as the compliance uncertainty margin, which depends on the non-specified influence quantities Z_d and U_d, and the specified influence quantities α and Z_{in} (i.e. the influence quantities that can be determined from independent measurements and do not depend on the EUT properties). Moreover, two sensitivity coefficients can be identified:

$$c_1 = \frac{Z_{d0} + Z_{13}}{Z_d + Z_{in}} \approx \frac{Z_{d0} + Z_{13}}{Z_{d0} + Z_{13}} = 1 \tag{6.3-6}$$

$$c_2 = \frac{Z_{d0}}{Z_d + Z_{in}} \approx \frac{Z_{d0}}{Z_{d0} + Z_{13}} = \frac{1}{1 + \rho\, e^{j\varphi}} \tag{6.3-7}$$

The latter coefficient clearly depends on the non-specified influence quantity Z_d.

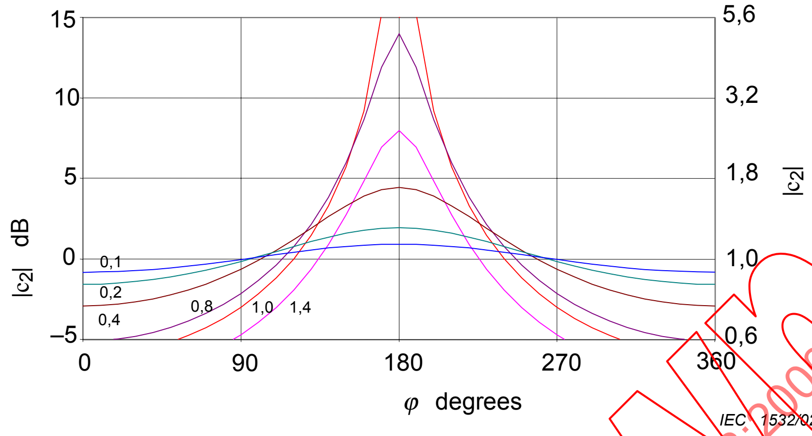

Figure 6.3-6 – The absolute value of the sensitivity coefficient c_2 as a function of the phase angle difference φ of the impedances Z_{13} and Z_{d0} for several values of the ratio $|Z_{13}/Z_{d0}|$.

In equation (6.3-7) $\rho = \rho_{13}/\rho_{d0}$ and $\varphi = \varphi_{13} - \varphi_{d0}$, which follow after writing $Z_{13} = \rho_{13}\exp(j\varphi_{13})$ and $Z_{d0} = \rho_{d0}\exp(j\varphi_{d0})$. Figure 6.3-6 presents the absolute value of c_2 for several values of ρ as a function of φ. It will be clear that additional information about Z_{d0} is needed to estimate c_2. However, that information is normally not available in a standardized compliance test. Hence, the standard drafters have to make an estimate when drafting a standard for a certain class of equipment, for example, by carrying out a statistical investigation during the development of a standard.

6.3.4.4 Combined uncertainty

It should be noted that in equation (6.3-5) all quantities are in linear units. Therefore, the combined uncertainty can be written as the root of the sum of the partial uncertainties squared (RSS) (see also report 6.2). In standardized EMC compliance testing, logarithmic units are commonly used for the quantities and their uncertainty margin. Converting to logarithmic units, it follows from equations (6.3-3) and (6.3-4) that

$$\frac{U_m}{U_{mt}}(\mathrm{dB}) = \frac{\alpha}{\alpha_0}(\mathrm{dB}) + \frac{Z_{in}}{Z_{13}}(\mathrm{dB}) + \frac{U_d}{U_{d0}}(\mathrm{dB}) - \frac{Z_d + Z_{in}}{Z_{d0} + Z_{13}}(\mathrm{dB}) \qquad (6.3\text{-}8)$$

so that

$$\Delta U_m(\mathrm{dB}) = \Delta\alpha(\mathrm{dB}) + \Delta Z_{in}(\mathrm{dB}) + \Delta U_d(\mathrm{dB}) - \Delta(Z_d + Z_{in})(\mathrm{dB}) \qquad (6.3\text{-}9)$$

The problem is the last term on the right-hand side of these two equations, since it is not possible to split up this term in one for Z_d and one for Z_{in}. So, in this case, there is no linear relationship between the various Δs and it is not correct to use the RSS as with equation (6.3-5). Additional information about Z_{d0} in relation to Z_{13} is needed to circumvent this problem. However, that information is normally not available in a standardized compliance test. Hence, the standard drafters have to give a procedure for solving this problem for a certain class of equipment.

6.3.4.5 The compliance criterion

The compliance criterion is normally not formulated for U_m but for U_{in}, the voltage across Z_{in}. The true value U_{int} is then given by $U_{int} = U_{mt}/\alpha_0$. If the compliance uncertainty margin is indicated by ΔU_{in}, the ratio $\Delta U_{in}/U_{int}$ can be calculated from $U_{int} + \Delta U_{in} = (U_{mt} + \Delta U_m)/(\alpha_0+\Delta\alpha)$.

6.3.4.6 Influence quantities

6.3.4.6.1 Introduction

In this subclause, the influence quantities playing a part in the CISPR V-terminal voltage measurement discussed in 6.3.4.3 to 6.3.4.5 will be considered in some detail, particularly in view of a possible improvement of CISPR standards dealing with this type of measurement. Note that the influence quantities may not be independent (see, for example, 6.3.4.6.4d) and e)), so not all phenomena are discussed in connection with each of the influence quantities.

The final standards compliance uncertainty study for voltage measurements on a two-terminal EUT using a V-terminal artificial mains network, shall start from the final model (the circuit description) depicted in figure 6.3-8.

6.3.4.6.2 The input impedance Z_{in}

In the ideal case, the input impedance $Z_{in} = Z_{13}$ (or Z_{23}), where Z_{13} is the specified input impedance of the V-AMN [3], a resistor R_{13} = 50 Ω in parallel with an inductor L_{13} = 50 µH. In the practical realization of the V-AMN, however, the actual input impedance may be influenced by

a) the actual value of the input impedance of the measuring receiver which in practice is assumed to represent R_{13}, plus the influence of the length of the transmission line between the V-AMN and the receiver. This effect can be characterized as a VSWR (see 6.3.2.2.2) and is discussed in detail in [7]. A procedure on how to characterize the VSWR is needed and a tolerance for this VSWR (in particular, *in situ*) has to be specified).

b) The influence of the unknown impedance of the mains network, which is in parallel with the specified input impedance (see figure 6.3-3). The isolation needed to avoid this influence is to be specified.

c) The influence of the circuit parallel to Z_{13} as formed by Z_{23} in series with the non-specified impedance Z_{12} (see figure 6.3-2). The latter impedance should be 'infinitely' large but will have a finite value in practice, so a specification is needed.

From this list of examples it will be clear that Z_{in} is not a completely specified influence quantity. (See also 6.3.4.6.4d)).

In 5.1.3 of [3] it is stated that for Z_{13} and Z_{23} a tolerance of 20 % is permitted around the absolute value of those impedances. In view of uncertainty contribution estimates, it is necessary to specify that tolerance in more detail, for example, as a tolerance of the absolute value of the impedance and a tolerance of the phase angle of that impedance (or that of its real and imaginary part), as was the case in CISPR 16 (1977) in the case of a V-AMN having 150 Ω input impedances.

6.3.4.6.3 The attenuation factor α

The attenuation factor α is a non-specified influence quantity. However, it is – in general – a deterministic quantity that can be derived from independent measurements. Therefore, for a given and fixed V-terminal voltage measurement set-up in which α has been determined, it can be considered as a specified influence quantity.

Contributions to Δα may stem from losses in the V-AMN (also determined by some of the aspects mentioned in section 6.3.4.6.2) and in the signal cable between V-AMN and receiver. Consequently, a specified procedure to determine α (in particular, *in situ*) is needed.

6.3.4.6.4 The effective disturbance source impedance Z_d

A marked difference between metrology measurements and EMC compliance measurements is that in the latter measurements the source impedance, Z_d, is a non-specified influence quantity.

From a comparison between the circuits of figures 6.3-4 and 6.3-5 it follows that if U_{13} is measured, Z_d is given by

$$Z_d = Z_{dm1} + \frac{Z_{cm}(Z_{23} + Z_{dm2})}{Z_{cm} + Z_{23} + Z_{dm2}} \tag{6.3-10}$$

as easily follows when applying Thevenin's theorem. In this relation, Z_{dm1}, Z_{dm2} and Z_{cm} are non-specified influence quantities. An important observation is that Z_d depends also on the CM-impedance Z_{cm}. Hence, the coupling to the surroundings of the EUT plays a part in the measurement result. In figure 6.3-7, this coupling is indicated by the parasitic capacitance C_{p1} between the relevant (electronic) parts of the EUT (so, as an example, not the plastic housing of that EUT) and the prescribed reference plane. In figure 6.3-8 also magnetic field coupling is included, where a mutual inductance, M, plays a part. Depending on the EUT properties (for example, the dimensions of conducting parts of that EUT) it may be needed to include other parasitic effects. The two examples given here (electric field coupling characterized by C_{p1} and magnetic field coupling characterized by M) are assumed to be relevant in all cases.

Five possible uncertainty contributions will be considered.

a) Parasitic capacitance variations

The emission standard specifies a distance, for example, 40 cm, between the housing of the EUT and the reference plane. However, the standard does not specify which side of the EUT housing has to face that plane. In figure 6.3-7 the dashed line represents the anther allowed position of the reference plane at the correct distance from the EUT housing. However, the resulting parasitic capacitance is now $C_{p2} \neq C_{p1}$. Hence, the (allowed) variation of the parasitic capacitance contributes to the standards compliance uncertainty.

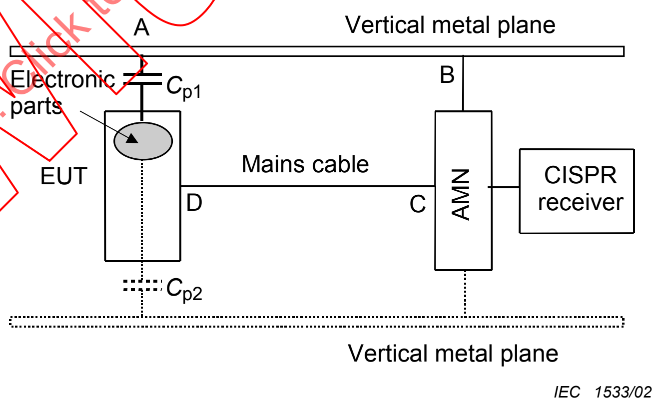

Figure 6.3-7 – Variation of the parasitic capacitance, and hence of the CM-impedance, by changing the position of the reference plane (non-conducting EUT housing)

The C_p variation can be reduced by replacing the vertical reference plane at the specified distance by a horizontal reference plane at that distance below the set-up and requiring that the EUT is always positioned at its normal feet.

b) Measurement loop constraint

Figure 6.3-4 is applicable at the interface of the specified measurement impedances. To identify relevant uncertainty contributions, the complete set-up has to be considered where a mains cable is present and the distance between EUT and AMN is specified, for example, 80 cm. So in practice a CM-loop exists, in figure 6.3-7 the loop ABCDA. At sufficiently high frequencies and sufficiently extended EUTs, for example, a fluorescent tube in its luminaire may be starting to violate the measurement loop constraint (6.3.2.2.2), thus creating resonant-like phenomena and the associated uncertainty contributions.

c) LC series circuit

In figure 6.3-7, the loop ABCDA can also be seen as an LC series circuit. Major contributions to the inductance stem from the mains cable and the specified ground bonding strap between V-AMN and the reference plane. In figure 6.3-7 the capacitance is represented by C_{p1}, and, more generally, by C_p in figure 6.3-8. This circuit plays a part in the CM impedance (see equation (6.3-10)). As a consequence, Z_d is sensitive to the total loop inductance as well, hence it is sensitive to the actual layout of the mains cable between EUT and V-AMN. In particular, when meandering of the mains cable is needed, variations in the electrical loop properties may be large. Experimental results [10] show a variation of several dBs when the method of meandering is varied. Hence, meandering is another source of uncertainties and a detailed specification of the method of meandering is needed. See also 6.3.4.6.5b) and c).

d) LC parallel circuit

In practice, also the parasitic capacitance between the V-AMN and the reference plane (see C_{AMN} in figure 6.3-8) may play a part. Then the parallel resonance of the inductance of the ground bonding strap and this parasitic capacitance may be resonant within the measurement frequency range, thus influencing in an unknown way the CM impedance. In other words, a contribution may be made to the variation of the results that can amount up to several dB [9]. In addition, the voltage difference between the reference point of the voltage measurements and the point on the reference plane where the strap is connected, is no longer zero, as has been tacitly assumed in the CISPR standards. So the afore-mentioned variation may also be interpreted as a variation in Z_{in} (6.3.4.6.2). The latter is an example of the statement made in 6.3.4.6.1 that the influence quantities are not always independent.

The contribution of the variation to the standards compliance uncertainty can be avoided by specifying an *in situ* measuring method, for example, one based on [9] to improve the set-up in such a way that a possible resonance is outside the frequency band considered in the compliance test.

e) Magnetic field coupling of parallel current loops

Another example of the statement made in 6.3.4.6.1 that the influence quantities are not always independent is the magnetic field coupling of loop-1 and loop-2 (see figure 6.3-8). This coupling that also influences the effective CM impedance, will be discussed in connection with U_d in 6.3.4.6.5.

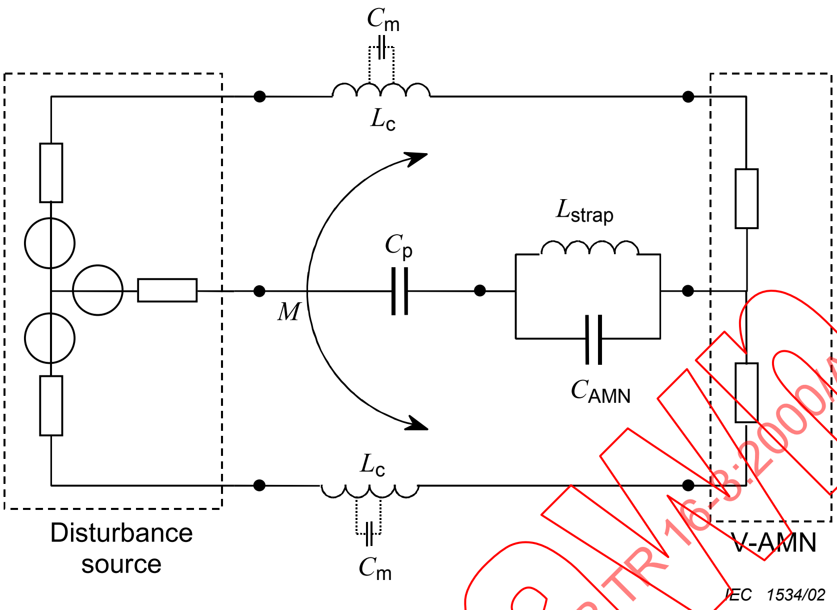

Figure 6.3-8 – Influence quantities in between the EUT (disturbance source) and the V-AMN

6.3.4.6.5 The effective open-circuit voltage source U_d

A marked difference between metrology measurements and EMC compliance measurements is that in the latter measurements the open-circuit voltage of the source is a non-specified influence quantity.

The open circuit voltage U_d depends on

a) the non-specified open-circuit voltages U_{dm} and U_{cm} (see figure 6.3-4);

b) a contribution U_{ind} which may arise from an induction by the fields emitted by the product under test and is described by Faraday's law (see 6.3.2.2.3 and annex 6.3-A);

c) a contribution U_{Zt} which may arise via the transfer-impedance Z_t of the cable between the product under test and the V-AMN and that of the circuitry inside the V-AMN, i.e. contributions related to CM/DM and DM/CM conversion.

a) U_{dm} and U_{cm}.

Since U_{dm} and U_{cm} are non-specified influence quantities their long-term stability may be very poor. In this case 'long-term' has to be compared with the measuring time of the emission measurement. Effects like warming-up time and in-rush period may influence that stability in an unknown way, thus giving rise to uncertainty contributions. On the other hand, this long-term stability may be sufficient, but the measurement time may be short compared to the possible variations of U_{dm} and U_{cm} due to the various modes of operation of the EUT resulting in mode-related values of U_{dm} and U_{cm}. Again, uncertainty contributions may result.

When a source is loaded, a feedback mechanism may cause a change of the source properties. This phenomenon is, for example, very well known in transistor circuits and, in the h-parameter description of a transistor, is quantified by the reverse parameter h_r. In resonant circuits this effect is normally called 'pulling'. The effect may cause a change in the amplitude and/or the frequency characteristic of the disturbance signal. There are no physical reasons to assume that this kind of a feedback mechanism is not present for the DM and CM components of the disturbance source. Hence, the feedback effect gives rise to the uncertainty contributions ΔU_{dm} and ΔU_{cm}. The effect can only be quantified when performing dedicated measurements. In metrology, where the open-circuit voltage, the source impedance and the load impedance are specified influence quantities, this effect is normally negligible as long as the loading of the source is within the specified values.

b) U_{ind}

In particular since the CM-loop illustrated by the ABCDA in figure 6.3-7 plays a part in the voltage measurement, it is important to consider contributions of the unwanted induced voltage (6.3.2.2.3) as the loop has a relatively large area. That area, and hence the induced voltage, depends on the layout of the set-up, and thus on the layout of the mains cable and its possible meandering. See also annex 6.3-A.

c) U_{Zt}

The contribution U_{Zt} stems from the conversion of a DM disturbance into a CM disturbance and is determined by the properties of the mains cable between the product and the V-AMN and by the circuitry inside the V-AMN. The latter contribution can be made negligibly small by setting proper DM/CM and CM/DM conversion limits for the V-AMN in CISPR 16-1.

The mains cable influence can be expressed in terms of the cable transfer impedance that in the case of a two-wire mains cable can be written as [11]

$$Z_t = R_c + j\omega(L_c - M) = R_c + j\omega(1-k)L_c \qquad (6.3\text{-}11)$$

where R_c is the resistive part of Z_t (about 10 mΩ per metre cable), L_c the inductive part of Z_t (about 1 µH per metre cable). The constant $k = M/L_c$, where M is the mutual inductance between the two loops formed by one of the wires, part of the disturbance source, the ground plane and part of the V-AMN (see figure 6.3-8). This constant ranges from about 0,6 (relatively wide separation) to 0,8 (relatively small separation). Since the transfer impedance of the cable between the product under test and the V-AMN is normally a non-specified influence quantity, the contribution to ΔU_{Zt} is generally unknown, so uncertainty contributions result. By considering the Kirchhoff equations for the circuit of figure 6.3-8, it will be clear that the magnetic coupling between the two loops also influences the effective CM impedance.

NOTE The cable transfer impedance effect hardly plays a part in normal metrology measurements as the leakage of the wanted signal to the surroundings is normally so small that it will be difficult to measure. On the other hand, very small leakage may easily be large enough to cause the product not to comply with the emission limit.

When the layout of the cable between EUT and V-AMN contains meanders, the way these meanders are put influence L_c and M. Moreover, at the higher frequencies, a capacitive cross-talk over the meander part of the mains cable (in figure 6.3-8 schematically represented by C_m) may play a part. As already mentioned, a non-specified meander layout may create relevant uncertainty contributions [10].

6.3.5 Bibliography

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Annex 6.2-A

Numerical example of the consequence of Faraday's law

To demonstrate the importance of the physics described by Faraday's law, discussed in 6.3.2.2.3 and in particular when a voltage probe is used, it is assumed that the EUT has to comply simultaneously with

a) the voltage limits at load and control terminals as given in table 2b of CISPR 15 [6.3-A1], to be verified by means of a voltage probe measurement, and

b) the radiated EM-disturbance limits as given in table 3 of CISPR 15 [6.3-A1], to be verified by means of the large-loop antenna (LLA) system.

To keep the calculations very simple, it is assumed that the loop formed by the 'hot' EUT terminal, the voltage-probe tip, the probe input circuit, the ground lead of the probe to the second EUT terminal, and the EUT circuit between its two terminals, can be described by a segment of a circular area.

It is assumed that the ambient field is negligibly low and that the non-negligible magnetic field emitted by the EUT itself, which may influence the measurement result (see equation (6.3-2)), stems from the near field of a small magnetic dipole. That dipole is assumed to be located at the centre of the EUT and at the centre of the mentioned circular area, while the vector of the dipole moment is perpendicular to that area. In the LLA system this dipole moment, m_H, is indirectly measured if the EUT is at the centre of the loop antenna in which the current I_m is measured. The relation between m_H and I_m is well approximated by [6.3-A2]

$$I_m = \frac{\mu_0 \, m_H}{D_a L_a} \quad \text{or} \quad m_H = \frac{D_a L_a I_m}{\mu_0} \qquad (6.3\text{-A1})$$

where D_a is the diameter of the large loop antenna and L_a the inductance of that loop.

The magnitude of the voltage induced in the segment $U_i = \omega \, \Phi$, where Φ is the magnetic flux through the segment. If the segment is defined by $\{\phi_0, R_1, R_2\}$, where ϕ_0 is the arc-angle, R_1 the inner radius of the segment and R_2 its outer radius, and the magnetic near-field component is given by

$$H_\theta = \frac{m_H}{4\,\pi\, r^3} e^{j\omega t} \qquad (6.3\text{-A2})$$

U_i can be written as

$$U_i = \frac{\mu_0 \;\omega\; m_H}{4\,\pi} \int_0^{\phi_0} \int_{R_1}^{R_2} \frac{r}{r^3} \,\mathrm{d}\phi \,\mathrm{d}r = \frac{\omega \; D_a L_a \; I_m \; \phi_0}{4\,\pi} \left(\frac{1}{R_1} - \frac{1}{R_2} \right) \qquad (6.3\text{-A3})$$

Note that due to the assumed orientation of the dipole moment with respect to the segment area, only H_θ contributes to U_i.

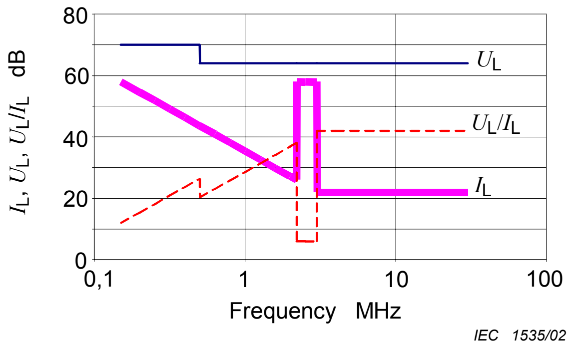

Figure 6.3-A1 – Voltage and current limits as given in CISPR 15, tables 2b and 3, and the ratio U_L/I_L

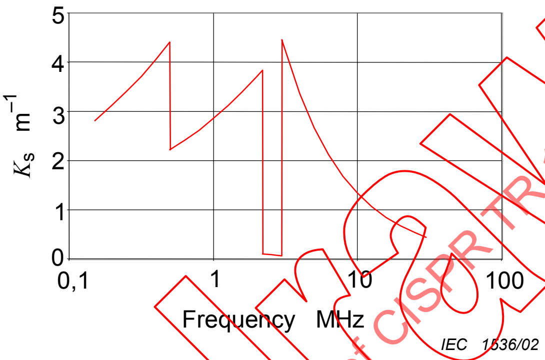

Figure 6.3-A2 – Factor K_s derived from the data in figure 6.3-A1 and equation (6.3-A4)

Assume that I_m has the limit value I_L as given in table 3 of [6.3-A1] (see figure 6.3-A1) and that U_i just equals the limit value U_L as given in table 2b of [6.3-A1] (see figure 6.3-A1). Then the factor K_s representing the segment parameters $\{\phi_0, R_1, R_2\}$ that make $U_i = U_L$, is given by

$$K_s = \phi_0\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{2}{D_a L_a f}\,\frac{U_L}{I_L} \approx \frac{1{,}06 \cdot 10^5}{f}\,\frac{U_L}{I_L} \qquad (6.3\text{-A4})$$

where $f = \omega/2\pi$. The numerical value follows when taking D_a = 2 m and the approximate value L_a= 1,5πD_a. Figure 6.3-A2 gives the results for K_s as a function of frequency.

From equation (6.3-A4) or figure 6.3-A2 it follows, for example, that at 10 MHz K_s= 1,34. Assuming ϕ_0 = 30°≡ π/6 rad and R_1= 10 cm, it follows that R_2 = 13 cm. Then the resulting segment area, giving rise to an unwanted induced voltage equal to the voltage limit, amounts to only 21 cm^2. This clearly illustrates the need to specify the measurement loop in detail.

References annex 6.3-A

[6.3-A1] *Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment*, CISPR 15, 1996

[6.3-A2] *A large loop antenna for magnetic field measurements*, J.R. Bergervoet, H. van Veen, Proc. Intern. Symp. on EMC, Zurich, March 1989, pp. 29–34. (The antenna proposed in this paper has been standardized by CISPR – see CISPR 16-1, Ed.2, 1999, annex P)