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Electromagnetic compatibility (EMC) - Part 2: Environment - Section 3: Description of the environment - Radiated and non-network-frequency-related conducted phenomena

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Electromagnetic compatibility (EMC)

Part 2:
Environment
Section 3: Description of the environment – Radiated and non-network-frequency-related conducted phenomena

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC)

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FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

This section of IEC 1000-2, which has the status of a technical report, has been prepared by IEC Technical Committee No. 77: Electromagnetic compatibility between electrical equipment including networks.

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

CD	Report on Voting
77(SEC)103 and 103A	77(SEC)106

Full information on the voting for the approval of this section can be found in the Voting Report indicated in the above table.

This report is a Technical Report of type 3 and is of a purely informative nature.

It is not to be regarded as an International Standard.

INTRODUCTION

IEC 1000 is published in separate parts according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (in so far as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 9: Miscellaneous

Each part is further subdivided into sections which can be published either as International Standards or Technical Reports.

This document has the status of a Basic EMC Publication in accordance with IEC Guide 107.

ELECTROMAGNETIC COMPATIBILITY (EMC)

Part 2: Environment

Section 3: Description of the environment – Radiated and non-network-frequency-related conducted phenomena

1 General

1.1 *Scope and object*

This Technical Report describes the electromagnetic environment. It is intended as a basis to achieve electromagnetic compatibility in system and equipment design, using test standards (techniques and limits), and mitigation methods (including installation practices), which satisfactorily take account of undesirable effects that otherwise might result from unintended electrical and electronic equipment interactions.

This report is primarily concerned with the characteristics and levels of electromagnetic fields and of non-network-frequency-related conducted emissions from unintentional sources of interference. Its application is part of the process of achieving electromagnetic compatibility of systems; this requires the immunity characteristics of equipment to be considered together with any normal or special equipment or cable installation practices that may be required. Trade-offs should be made between physical separation, filtering and shielding when considering equipment installation and design, in order to achieve emission and immunity characteristics which meet system requirements.

1.2 *Reference document*

IEC 1000-2-1: 1990, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 1: Description of the environment – Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems.*

2 General considerations

There are various approaches that can be used for describing the environment. Classification in terms of typical environmental locations such as urban, industrial, residential and commercial may have some meaning in that each of these tends to imply some general characteristics of the environment on which compatibility levels may be based. However, it must be recognized that equipment not normally associated with a particular class of environment may indeed affect any specific location.

For the above reason, the approach taken in this report is to state the electromagnetic levels expected from particular sources or classes of sources. The level expected at a particular location must then be determined with reference to the sources existing at that location.

At the same time it should be recognized that one cannot always identify all sources that may affect a particular environment. Such is the case, for example, with conducted disturbances in a power system generated at large distances, for example large distant nonlinear industrial loads or unpredictable exceptionally severe lightning strokes. It is meaningful to make a distinction between public supply and industrial or private networks.

The quality of service at the point of common connection due to remote users will depend upon the capacity of the network and the loads connected to it that an individual consumer knows little about. Voltage fluctuations can be caused by load switching as well as by system faults and lightning strokes. Within a consumer's system, residential or industrial, the low frequency effects of local loads can be predicted. In general, one would expect the remote sources to limit the quality of service delivered to a particular consumer location, and that any given system should perform properly in the absence of local sources. This is assuming that the quality of service is otherwise satisfactory. Local sources can be expected to have more significant effects in possible system and device degradation.

2.1 *Coupling between emitting and susceptible devices*

The major reason for considering electromagnetic compatibility is the existence of devices (equipment, systems) which show susceptibility to electromagnetic emission from other devices.

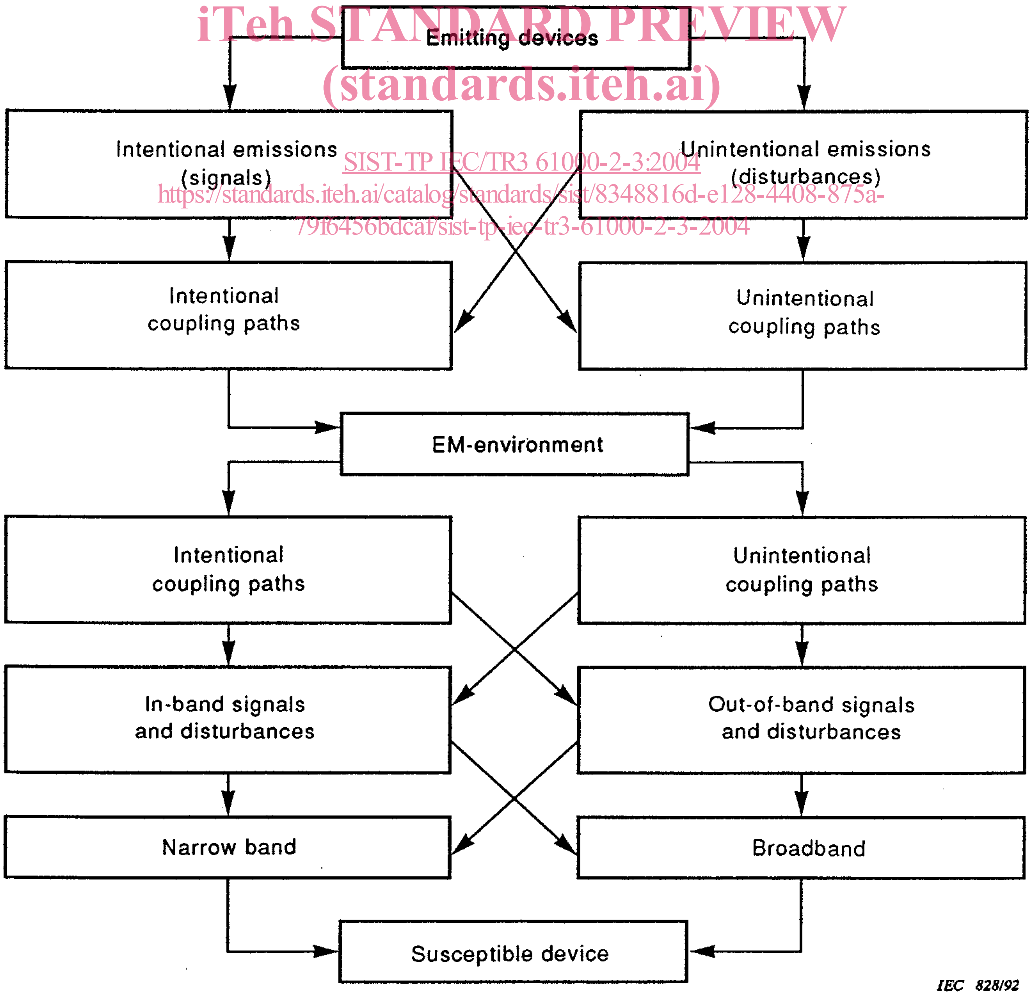

Figure 1 – Coupling paths between emitting and susceptible devices

Emitting devices may have intentional emissions, such as a radio-frequency broadcasting signal, or unintentional emissions, such as the magnetic field produced by the deflection coils of a video display unit. Through various coupling paths such emission may reach the site where a susceptible device is located as shown in figure 1, thereby establishing the electromagnetic environment for that device. The subdivisions shown in this figure are important for a description of the electromagnetic environment. Moreover, the technical possibilities available to prevent or solve an interference problem are related to these subdivisions, as are also the relevant EMC specifications.

The susceptible device may be exposed to the electromagnetic environment via intentional coupling paths, such as the aerial of a radio receiver, or via unintentional coupling paths such as the recording head of a video tape recorder, a signal cable or a mains cable. Both types of coupling paths, intentional and unintentional, may carry disturbances having frequency components in the frequency band designated for the desired signal of the susceptible device, and disturbances having components outside that band. The disturbances received may be considered narrow band or broadband. For example, the disturbance from a switched-mode power supply operating at 40 kHz is narrow band when measured with a CISPR receiver in the frequency range 10 kHz to 150 kHz since the receiver bandwidth is 200 Hz and the harmonic components are measured separately when tuning over the frequency range. However, the same disturbance is broadband for a video system with a 5 MHz bandwidth because of the harmonics of the 40 kHz signal. The terms broadband and narrow band are always determined by the bandwidth over which the disturbance is detected or measured. Hence, the same source can be both broadband and narrow band.

2.2 *Units and decibels*

The decibel (dB) was originally defined as the ratio *r* of two powers P_1 and P_2 dissipated in a resistance *R* expressed as a logarithmic unit as follows:

$$r(\text{dB}) = 10 \log_{10}\left(\frac{P_1}{P_2}\right) = 10 \log_{10}\left(\frac{V_1^2/R}{V_2^2/R}\right) = 20 \log_{10}\left(\frac{V_1}{V_2}\right)$$

where P_1 and P_2 are measured or determined under identical conditions. Hence, *r* can be expressed in terms of the associated voltages V_1 and V_2 as indicated in the above equation.

If V_2 is chosen to be a unit value, for example 1 µV, and V_1 is expressed in terms of that unit, then *r* gives the magnitude of V_1 expressed in "dB with respect to 1 µV", normally abbreviated to *r* (dB(µV)). This latter approach is widely used in the field of EMC. Hence, if *Y* is a unit value then *X*(dB(*Y*)) is defined as:

$$X(\text{dB}(Y)) = 20 \log_{10}\left(\frac{X}{Y}\right)$$

Certain conventions exist for the choice of *Y*. Here are some examples:

a) In the case of conducted emissions, the voltage is expressed in dB(μV), i.e. decibels above 1 μV; and the current in dB(μA), i.e. in decibels above 1 μA. For example, 120 dB(μV) corresponds to 10^6 μV or to 1 V.

b) In the case of radiated emission, the electric field strength is expressed in dB(μV/m) and the magnetic field strength in dB(μA/m). For example, 34 dB(μV/m) corresponds to 50 μV/m. In statutory measurements and CISPR recommendations, the magnetic field strength *H* at frequencies below 30 MHz is usually expressed in dB(μV/m), the unit of the electric field strength *E*, where dB(μA/m) would be more appropriate. In such cases, the magnetic field *H* expressed in dB(μA/m) and in dB(μV/m) satisfies the relation:

$$H\,(\mathrm{dB}(\mu\mathrm{A/m})) = H\,(\mathrm{dB}(\mu\mathrm{V/m})) - 51{,}5\,(\mathrm{dB}(\Omega))$$

where 51,5 dB(Ω) = $20 \log_{10} Z_0$ when $Z_0 \approx 377\ \Omega$ and $Z_0 = E/H$.

The wave impedance $Z_0 \approx 377\ \Omega$ applies only to the case of a plane electromagnetic wave. However, this is not relevant here as the measurement display is calibrated in such a way that the signal induced by the magnetic field *H* in the magnetic field antenna, is interpreted as a signal produced by an electric field of strength $E = Z_0H$. See also 3.1.2.

In the case of large conducted disturbances, the use of nonlinear surge diverters precludes the application of dB units and analytical methods which are based on a linearity hypothesis.

3 Source, coupling and susceptor models, and their limitations

When electrical and electronic devices and coupling paths are examined in detail, they can be found to be extremely complex. In order to deal with them in a practical way, simplification is necessary. This is done through the method of developing models. Disturbance sources emit by mechanisms of conduction, induction and radiation. Coupling paths may occur through conduction, induction or radiation, and most usually by combinations of these phenomena.

3.1 *Source models*

3.1.1 *Conducted emissions*

For conducted emission, the source can often be considered as a two-port or three-terminal device. Figure 2 shows noise sources in differential mode (V_{DM}) and in common mode (V_{CM}). Connection points 1 and 2 can be identified as, for example, the neutral and the phase of a mains connection, or as the connection points of a desired signal of a control line. Connection point 0 represents the reference of the source, formed for example by the protective earth, the steel reinforcement in a building, or a metal chassis. In many cases it may be necessary to consider the source as an *N*-port network, as in the case where a multi-wire flat cable is involved.

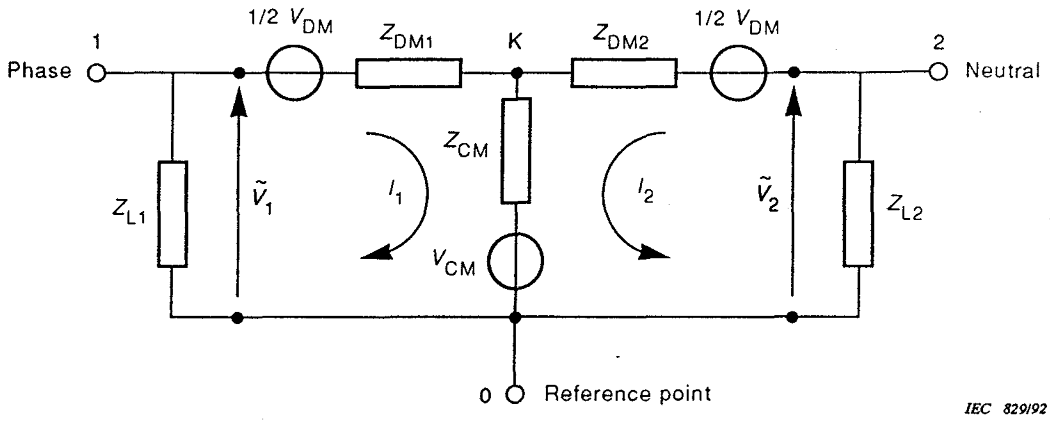

Figure 2 – Source model for conducted emission
(Source loaded by Z_{L1} and Z_{L2})

The voltages V_{DM} and V_{CM} are complex voltages having desired as well as disturbance components. However, the desired voltage from the source, whether this is a power line or a signal line, is predominantly represented in the V_{DM} component. The disturbance voltage components of V_{DM} and V_{CM} may be of equal importance.

The relatively simple lumped representation in figure 2 is valid when the connection points 1, 2 and 0 are at such short distances from each other that, at all frequencies to be considered, no wavelength or field-induction effects play a noticeable role. The common-mode source amplitude and impedance are represented by V_{CM} and Z_{CM} respectively. The differential-mode source amplitude and impedance are represented by two sources of amplitude ½V_{DM} and by the impedances Z_{DM1} and Z_{DM2}. It should be noted that, in general, Z_{DM1} is not equal to Z_{DM2}. Equal values occur only by chance or when special measures have been taken in the construction of the system involved. If the source is unloaded ($Z_{L1}= Z_{L2}= Z_{L12} = \infty$), the nodal point K is in the "electrical middle", however this is not normally the case when the source is loaded because of $Z_{L1} \neq Z_{L2} \neq Z_{L12}$. As a result, the common-mode current I_{CM} may be determined by both V_{CM} and V_{DM}. The current I_{CM} is equal to the half vector- sum of I_1 and I_2, like V_{CM} in figure 3 is half the vector -sun of V_1 and V_2.

An example of the relation between the open-circuit voltages V_{DM}, V_{CM}, V_1 and V_2 is given in figure 3.

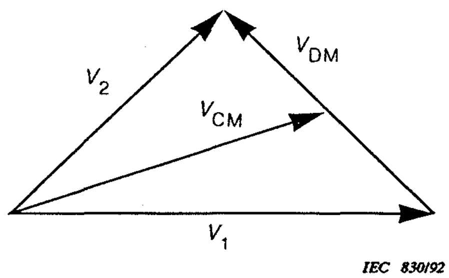

Figure 3 – Relation between V_{CM}, V_{DM}, V_1 and V_2 for the unloaded situation

In figure 4 relations are given between the voltages $\tilde{V}_{CM}$, $\tilde{V}_{DM}$, $\tilde{V}_1$ and $\tilde{V}_2$, for the loaded situation.

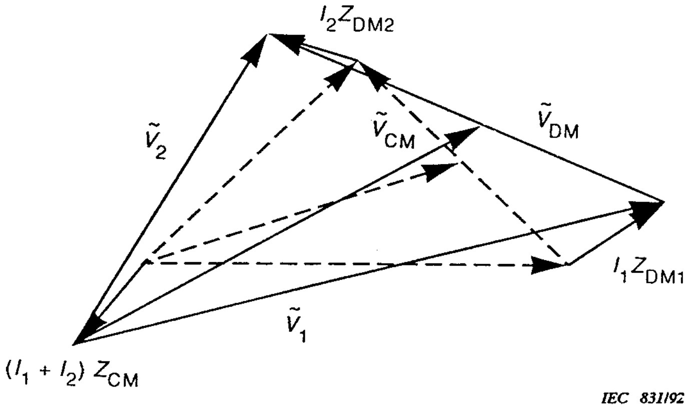

Figure 4 – Relations between the voltages $\tilde{V}_{CM}$, $\tilde{V}_{DM}$, $\tilde{V}_1$ and $\tilde{V}_2$, for the loaded situation

Low-level conducted disturbance voltages are typically measured using an artificial network having a well-defined load impedance. For example, the CISPR V-terminal network has $Z_{L12} = \infty$ and $Z_{L1} = Z_{L2}$ with $Z_{L1} = 150\ \Omega$, or $50\ \Omega\ //\ 50\ \mu H$ or $50\ \Omega\ //\ 5\ \mu H$. These values are considered to relate to the (average) absolute value of the impedance presented by the real mains, which depends, among other things, on the mains current for which the network has been designed. It is important to note that the artificial mains networks mentioned here are not valid for all applications, for example the case of the propagation of transients.

It must therefore be recognized that measurements of emission from sources are of a limited nature. For example, to determine compliance with a conducted emission limit, the measurement is made with a specified terminating impedance. No direct measurement of the source impedance is made. Thus, when a given source is placed in a circuit which presents an impedance to it which is different from the measurement impedance, the actual emission will differ from that measured. Such variations must be anticipated by system EMC engineers when designing compatible systems.

3.1.2 *Radiated emissions*

Radiated emission levels are usually stated in terms of electric (*E*) and magnetic field (*H*) levels, expressed in dB(μV/m) and dB(μA/m). Particular sources differ in the relative magnitudes of each of these components and their variations with distance.

In the so-called far-field region of a source the distance between the source and the point of observation of the field is much larger than $\lambda\ /(2\pi)$, where λ is the wavelength of the field, and larger than the dimensions of the source. At such distances, and in the absence of nearby reflecting objects, the *E* and *H* fields are perpendicular to each other and perpendicular to the direction of propagation of the wave. In addition, there is a fixed relation between the magnitudes of *E* and *H*, which makes statements of electric field strength and magnetic field strength equivalent. In the far field and free space $E/H \approx 377\ \Omega$ and the field levels fall off inversely with distance from the source.

In the near-field region of the source, the distance between the source and the point of observation is either much smaller than $\lambda/(2\pi)$ or smaller than the dimension of the source or both. The relation between the *E* and *H* fields now depends on the wavelength of the disturbances, the actual position in the near-field region and the type of source.

A simple model used for radiation is the dipole which may be of electric or magnetic types, (see figure 5). This model exhibits an inverse cubed variation of the field strength of its dominant component (electric field for an electric dipole, magnetic field for a magnetic dipole) at nearfield distances. For such sources a statement of the "dipole strength" would enable calculation of the field components (both electric and magnetic) at any distance. However, it is more usual to measure the dominant component at a fixed distance, without making reference to the source strength.

Figure 5a – Electric dipole strength = $l \cdot I_e$

Figure 5b – Magnetic dipole strength = $A \cdot I_m$

Figure 5 – Electric and magnetic dipole elements

In case of radio transmitters, the gain of the antenna in the intended coupling path and the net power P_t transferred to the antenna are usually known. As the antenna gain is always directional with respect to the antenna, the gain normally referred to is that associated with the direction of maximum radiation.

The effective or equivalent radiated power, *ERP*, of an antenna is defined as:

$$ERP = G_r P_t$$

where G_r is the antenna gain relative to the maximum directivity G_h of a half wave dipole.

The electric field strength produced by an antenna at a distance r in the far field of the antenna is expressed as:

$$E = \sqrt{\frac{ZG_h \cdot ERP}{4\pi r^2}} = 7\,\frac{\sqrt{ERP}}{r}$$

where G_h = 1,64 and Z, the wave impedance of the medium, equals 377 Ω in free space.

It follows that:

$$\sqrt{\frac{ZG_h}{4\pi}} = 7\ \Omega^{1/2}$$

The term "effective or equivalent isotropically radiated power, *EIRP*", is also used for the antenna. The relation between *ERP* and *EIRP* is given by:

$$EIRP = G_h\ ERP.$$

3.2 *Coupling models*

The phenomena involved in transferring electromagnetic energy from a source to a susceptor are, in general, very complex. Exact calculation of the energy transferred in particular cases may therefore be difficult. However, in many cases the important coupling may be described in terms of comparatively simple models. These models are divided into three main classes: common-impedance coupling, coupling by induction (near-field) and radiative (far-field) coupling.

3.2.1 *Common-impedance coupling*

This type of coupling is also referred to as conductive coupling. It occurs when currents or a portion of the currents associated with a source and susceptor share a common path. Typically the common path may be represented by a resistance, an inductance or a capacitance or by a combination of any of these. Two of many examples that can be cited are the sharing by the source and receptor of 1) a common power mains, and 2) a common ground current return path.

Resistive coupling

The resistive part of the common impedance R_c is determined by the conductor material and by the skin effect as a result of which the resistive part becomes frequency dependent. For a straight round conductor of diameter d one has:

$$R_c / R_{dc} \approx d / 4\delta \qquad \text{when} \quad \delta \ll d$$

$$\text{and} \quad R_c / R_{dc} \approx 1 \qquad \text{if} \quad \delta \gg d$$

where R_{dc} is the d.c. resistance of the conductor and δ the skin depth given by:

$$\delta = \sqrt{\frac{2}{\omega \mu \sigma}}$$

where ω is the angular frequency of the signal, μ the permittivity and σ the conductivity of the conductor material.