SLOVENSKI STANDARD
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Electromagnetic compatibility - Basic immunity standard - Conducted disturbances induced by radio-frequency fields - Immunity test

Electromagnetic compatibility - Basic immunity standard - Conducted disturbances induced by radio-frequency fields - Immunity test

Elektromagnetische Verträglichkeit - Störfestigkeits-Grundnorm - Leitungsgeführte Störgrößen, induziert durch hochfrequente Felder

Compatibilité électromagnétique - Norme fondamentale d'immunité - Perturbations conduites induites par des champs radioélectriques - Essai d'immunité

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English Version

Electromagnetic compatibility - Basic immunity standard - Conducted disturbances induced by radio-frequency fields - Immunity test

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CENELEC

European Committee for Electrotechnical Standardization
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FOREWORD

This European Prestandard has been prepared by Working Group WG02 of CENELEC Technical Committee TC 110, based on the draft publication IEC CDV 65A/77B(Secretariat)145/110, 1992-12.

The document was approved by TC 110 on 12 May 1993.

NOTE: When the corresponding DIS prepared by IEC has successfully passed the IEC/CENELEC parallel vote and has been ratified as EN, the present ENV will be immediately withdrawn.

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1. Scope

This standard relates to the immunity requirements of equipment to the electromagnetic field coming from intentional RF-transmitters.
The equipment, having at least one metallic interface, is coupled to disturbing radio-frequency (RF) fields via the cables connected thereto e.g. power mains, signal lines, earth connections.

The object of the test method in this standard is to determine the immunity of electrical and electronic equipment to conducted RF-disturbances in the frequency range 9 kHz up to 80 MHz, this being a good indication of its immunity to radiated RF-fields.

Note: Test methods are defined in this section for measuring the effect that conducted disturbing signals, induced by electromagnetic radiation, has on the equipment concerned. The simulation and measurement of these conducted disturbances is not adequately exact for the quantitative determination of effects. The test methods defined are structured for the primary objective of establishing adequate repeatability of results at various facilities for qualitative analysis of effects.

This standard defines:

- recommended test levels;
- test equipment;
- test set-up;
- test procedure.

2. Normative references

The following standard contains provisions which, through reference in this text, constitute of this International Standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of valid International Standards.

- IEC 50(161): 1990, International Electrotechnical Vocabulary - Chapter 161: Electromagnetic compatibility.
- IEC CISPR Publication 16: 1987, CISPR specification for radio interference measuring apparatus and measurement methods.

3. General

The electromagnetic field coming from intentional RF-transmitters may act on the whole length of cables connected to an installed equipment.
The dimensions of the disturbed equipment, mostly a sub-part of a large system, are assumed to be small compared with the wavelengths involved.
The in-going and out-going leads: e.g. mains, communication lines, interface cables, mostly several wavelengths long, will act as receiving antennas; these provide the field induced disturbing currents to flow also across the victim equipment.

The test method described in this standard simulates such currents by direct injection of the disturbing signal on the EUT ports. The principle of the test set-up is illustrated in Fig. 1.

In real installations, disturbances will act on all cables simultaneously, with a range of different amplitudes and relative phases; they can only be approximated in this method by using a coupling and decoupling device to apply the disturbing signal to one cable at a time while keeping all other cables non-excited, Fig. 2.

Coupling and decoupling devices are defined by their characteristics given in clause 6.2. Any coupling and decoupling device fulfilling these characteristics can be used. The coupling and decoupling networks in Annex A3 are only examples of commercially available networks.

4. Definitions

For the purpose of this International Standard, the following definitions, together with those in IEC 50 (161) apply.

4.1. Artificial hand:
An electrical network simulating the impedance of the human body under average operational conditions between a hand held electrical appliance and earth.
The construction shall be in accordance with IEC CISPR publication 16, see also Fig.10.

4.2 Auxiliary equipment (AE):
Equipment necessary to provide the EUT with the signals required for normal operation and equipment to verify the performance of the equipment under test.

4.3 Clamp injection:
Clamp injection is obtained by means of a clamp-on "current" injecting device on the cable.
- Current clamp: Current injecting transformer with purely inductive coupling.
- Electromagnetic clamp (EM-clamp): Injection device with combined capacitive and inductive coupling.

4.4 Common-mode impedance:
The ratio of the common-mode voltage and the common-mode current at a certain port. This common-mode impedance can be determined by applying a unity common-mode voltage between the terminal(s) or screen of that port and a reference plane (point). The resulting common-mode current is then measured as the vectorial sum of all currents flowing through these terminal(s) or screen.

4.5 Coupling factor:
The ratio between the open circuit voltage (emf) obtained at the EUT-port of the coupling (and decoupling) device divided by the open circuit voltage obtained at the output of the test generator.

4.6. Coupling network:
Electrical circuit for transferring energy from one circuit to another with a defined impedance.

Note: *Coupling and decoupling devices can be integrated into one box (Coupling/ Decoupling Networks (CDN)) or they can be in separate networks (commonly clamp injection).*

4.7. Decoupling network:
Electrical circuit for preventing test-signals applied to the EUT from affecting other devices, equipment or systems that are not under test.

4.8. (EUT) Equipment under test:
Equipment to which the test signals are applied.

4.9 Ground reference plane (GRP):
A flat conductive surface whose potential is used as a common reference.
The conductive plane shall extend the projected geometry of the EUT and the coupling and decoupling devices used by at least 0,2 m on all sides. For table-top equipment, this metal plane can be placed on a table.

4.10. Test generator:
A generator (RF-generator, modulation source, attenuators, broadband power amplifier and filters) capable of generating the required signal, see Fig. 3.

4.11. Source electromotive force (emf):
- Twice the voltage of the matched output value (IEEE)
- The voltage at the terminals of the ideal voltage source in the representation of an active element, see also Fig.1.

4.12 U_{mr} (measurement result):
Voltage reading of measurement equipment.

4.13 Verification equipment:
An RF-oscilloscope, spectrum analyzer or selective voltmeter and "150-to-50 Ω adaptors" to check the modulation depth of the disturbing signal and to set the test levels. An impedance meter or RF-network analyzer may be necessary to check the test generator's output impedance and to verify the coupling and decoupling device parameters.

4.14 Voltage standing wave ratio (VSWR):
The ratio of the maximum to the minimum amplitude of the corresponding component of the field (voltage or current) appearing along the line in the direction of propagation.

5. Test levels

The preferential range of test levels is given in table 1.

TABLE 1: Test levels

Frequency range	150 kHz - 80 MHz	
Level	Voltage level (emf) U_o [dBuV]	U_o [V]
1	120	1
2	130	3
3	140	10
X[1]	special	

Note 1: X is an open level

The open circuit test levels (emf) of the unmodulated disturbing signal, expressed in r.m.s., are given in Table 1. For testing of equipment, this signal is 80% amplitude modulated with a 1 kHz sinewave to simulate actual threats. The effect of amplitude modulation is given in Fig. 4. Guidance for selecting test levels is given in Annex A2.

Note: IEC 801-3 / IEC 1000-4-3 also defines test methods for establishing the immunity of electrical and electronic equipment against radiated electromagnetic energy. It will cover frequencies above 80 MHz. Product committees may decide to choose a lower or higher transition frequency, Annex A1.

For induced disturbances caused by electromagnetic fields coming from intentional RF-transmitters in the frequency range 9 kHz to 150 kHz, no requirements are given in this standard.

6. Test equipment

6.1. Test generator

The test generator includes all equipment and components for supplying the input-port of each coupling network with the required disturbing signal at the required signal level to obtain the test levels given in Table 1 at the EUT-port's common-mode point of that coupling network. This comprises (see Fig.3.):

- RF-signal generator(s) G1 capable of covering the frequency band of interest and of being amplitude modulated by a 1 kHz sine wave with a modulation depth of 80%. They must have either an automated sweep capability of $\leq 1{,}5 \cdot 10^{-3}$ decade/s and/or manual control, <u>or</u> in the case of RF-synthesizers, they must be programmable with frequency-dependent step sizes and dwell times.

- Attenuator T1 (typically 0...40 dB) of adequate frequency rating to control the disturbing test source output level. T1 may be included in the RF-generator.

- RF-switch, S1, by which the disturbing test signal can be switched on and off when measuring the immunity of the EUT. S1 may be included in the RF-generator and is optional.

- Broadband power amplifier(s) PA may be necessary to amplify the signal if the output power of the RF-generator is insufficient.

- Low-pass (LPF), high-pass filters (HPF) may be necessary to avoid problems caused by (sub-)harmonics if the EUT is a receiver of some kind. When required it shall be inserted in-between the broadband power amplifier, PA, and the attenuator T2.

Attenuator, T2, (fixed = 6 dB, Zo = 50 Ω), with sufficient power ratings. T2 must reduce the mismatch from the power amplifier to the network and must be located as close as possible to the coupling network.
Note: *T2 may be included in a coupling and decoupling network and can be left out if the output impedance of the broadband power amplifier remains within the specification under any load condition.*

Characteristics of the test generator without modulation are given in table 2.

TABLE 2: Characteristics of the test generator

Output impedance:	50 Ω , VSWR ≤ 1,2
Harmonics and distortion:	≤ -15 dB below carrier level
Amplitude modulation:	internal or external, 80 (± 5) % in depth by a 1 kHz (± 10 %) sine wave.
Output level:	sufficiently high to cover test level. *See also Annex A4*

6.2. Coupling and decoupling devices

Coupling and decoupling devices shall be used for appropriate coupling of the disturbing signal (over the entire frequency range, with a defined common-mode impedance at the EUT-port) to the various cables connected to the EUT.

The coupling and decoupling devices can be combined into one box (so called: coupling/decoupling network; CDN) or can consist of several parts. The main coupling and decoupling device parameter, the common-mode impedance seen at the EUT-port, is specified in table 3.

For all (power) supply connections (AC & DC) coupling and decoupling networks (CDNs) are compulsory. Guidance for selecting the appropriate injection method for I/O, telecom and control lines is given in clause 7.3.

Whenever a product committee decides that a certain kind of coupling and decoupling device is more appropriate for cables connected to its family of products, then that choice (justified on a technical basis) takes precedence. If it concerns CDNs other than those listed in this standard, then that CDN shall be described in the product (family) standard.

TABLE 3: Main coupling and decoupling device parameter.

	Frequency band	
Parameter	150 kHz - 26 MHz	26 - 80 MHz
$\lvert Z_{ce} \rvert$	150 ± 20 Ω	150 +60/ -45 Ω

Nor the argument of $\lvert Z_{ce} \rvert$ nor the decoupling factor between the EUT-port and the AE-port are specified separately. These factors are embodied in the requirement that the tolerance of $\lvert Z_{ce} \rvert$ shall be met with the AE-port open or short circuited to ground (where unscreened cable coupling and decoupling networks are used).

Note: *The clamp injection method which uses the EM-clamp with the decoupling network, annex A5, does not meet the requirements on* $\lvert Z_{ce} \rvert$. *However it can provide reproducible test results, see clause 7.4.*

6.2.1 Direct injection

The disturbing signal, coming from the test generator, is galvanically injected to screened and coaxial cables via a 100 Ω resistor. In-between the auxiliary equipment (AE) and the injection point a decoupling network, clause 6.2.4, shall be inserted as close as possible to the injection point, Fig.5a.
For certain simple screened cable configurations, the decoupling circuit together with the 100 Ω resistor can be combined into one box, see example S1, annex A3.

6.2.2. Coupling and decoupling networks

These networks comprise the coupling and decoupling network in one box and can be used for specific unscreened cables e.g.: M1, M2, M3, T2, T4, AF-2, see Annex A3 for the basic features. The networks shall not unduly affect the functional signals. Constraints shall be specified in the (functional) product standards. Typical concepts of the coupling and the decoupling networks are given in Fig.5b and 5c.

6.2.2.1 Coupling and decoupling (power) supply networks

All (power) supply connections shall be provided with coupling and decoupling networks. The disturbing signal shall be coupled to the supply lines, using type 801-M1 (single wire), -M2 (two wires) or -M3 (three wires), or equivalent networks, see Annex A3. Similar networks can be defined for a 3-phase power mains system. The coupling circuit is given in Fig.5b. All wires going from the EUT to the AE circuitry should be coiled on common-mode cores (excluding M1) to prevent saturation (current compensated chokes). The decoupling network part is identical to the one described in clause 6.2.4.

If in real installations the supply wires are individually routed, separate coupling and decoupling networks 801-M1 shall be used and all input ports shall be treated separately.

If the EUT is provided with other earth terminals (e.g. for EMC purposes or high leakage currents), they shall be connected to the ground reference plane:

- through the coupling and decoupling network 801-M1 when it is allowed. In this case, the (power) supply shall be provided through the 801-M3 network.
- when it is not allowed to have an 801-M1 network in series with that earth terminal for EMC or other reasons, the earth terminal shall be directly connected to the ground reference plane. In this case the 801-M3 network shall be replaced by an 801-M2 network to prevent an RF short-circuit by the protective earth conductor within the CDN. When the equipment was already supplied via an -M1 or -M2 network, these shall remain in operation.

6.2.2.2. Coupling and decoupling to unscreened balanced lines

For coupling and decoupling disturbing signals to an unscreened cable with balanced lines, a T2-network or T4-network shall be used as coupling and decoupling network. Fig. A3.4, A3.5a and A3.5b in Annex A3 show some possibilities.

- T2 for a cable with 1 symmetrical pair (2 wires)
- T4 for a cable with 2 symmetrical pairs (4 wires)

Note: *Other T-networks can be used, if they are suitable for the intended frequency range and satisfy the requirements of clause 6.2.*

For balanced multi-pair wires, clamp injection can be used.

6.2.2.3. Coupling and decoupling to unscreened non-balanced lines

For coupling and decoupling disturbing signals to an unscreened cable with non-balanced lines, the coupling and decoupling networks described in Annex A3, Fig A3.3, can be used.

- 801-AF2 for a cable with 2 wires

For non-balanced multi-wire cables, clamp injection is more appropriate.

6.2.3 Clamp injection

With clamp injection devices, the coupling and decoupling functions are separated. Coupling is provided by the clamp-on device while the common-mode impedance and the decoupling functions are established at the auxiliary equipment. As such, the auxiliary equipment becomes part of the decoupling devices. Clause 7.4 will give guidance for proper application.

6.2.3.1 Current clamp

This device establishes an inductive coupling to the cable connected to the EUT. For example, with a 5:1 turn ratio, the transformed common-mode series impedance can be neglected with respect to the 150 Ω established by the auxiliary equipment. In this case, the test generator's output impedance (50 Ω) is transformed into 2 Ω. The common-mode impedance seen at the EUT port will be determined by the auxiliary equipment setup.

Note: *It is commonly necessary to position the cable through the centre of the clamp to minimize capacitive coupling.*

6.2.3.2 EM-clamp

The EM-clamp establishes both capacitive (intentional) and inductive coupling to the cable connected to the EUT and is described in Annex A5. Below 10 MHz, the common-mode impedance seen at the EUT port will be determined by the auxiliary equipment setup. Above 10 MHz, it will be mainly determined by the EM-clamp itself.

6.2.3.3 EM-clamp with decoupling network

Whenever the test setup conditions for the auxiliary equipment cannot be met, clause 7.3 diagram 1, the EM-clamp with the decoupling network shall be used. Hereby, a decoupling network, as suggested in annex A5, shall be inserted in-between the EM-clamp and the auxiliary equipment. Under this setup condition, the common-mode impedance requirement can no longer be met at frequencies below 10 MHz but reproducibility is assured.

6.2.4 Decoupling network

Normally, the decoupling network comprises several inductors to create a high impedance over the frequency range. This is determined by the ferrite material used and an inductance of at least 280 µH is required at 150 kHz. The reactance shall remain high, ≥ 260 Ω up till 26 MHz and ≥ 150 Ω above 26 MHz. The inductance can be achieved either by having a number of windings on a single ferrite ring core or by using a number of ferrite ring cores over the cable, Fig.5c and Annex A5.

Decoupling networks shall either be used with direct injection or with untested cables connected to the EUT and/or AEs. When using the decoupling network in combination with the EM-clamp the decoupling network as suggested in annex A5 is preferred.

6.3 Verification of the common-mode impedance at the EUT-port of coupling and decoupling devices

Coupling and decoupling devices are characterized by the common-mode impedance seen at the EUT port, $|Z_{ce}|$. Its correct value ensures the reproducibility of the test results.

The coupling and decoupling devices and the impedance reference plane, Fig.7b shall be placed on a ground reference plane of which the size exceeds the projected geometry of the set-up on all sides by at least 0,2 metre.

A network analyzer or impedance meter shall be used with a 50 Ω reference impedance. The network analyzer shall be calibrated (with open circuit, short circuit and a 50 Ω load) at the impedance reference plane. It is necessary to make a short connection (L ≤ 30 mm) between the impedance reference connection and the EUT-port terminals. The principle of Fig.7c and the geometry of Fig.7b shall be used to verify $|Z_{ce}|$.

The coupling and decoupling networks shall meet the impedance requirements of sub-clause 6.2 table 3, while the input port is terminated with a 50 Ω load and the AE-port is sequentially loaded in common-mode with a short circuit and an open circuit condition (when applicable). The latter ensures a proper decoupling factor and makes the setup of the auxiliary equipment (e.g. grounded or floating inputs) insignificant.

In the cases where clamp injection or direct injection is used, it is unrealistic to verify the common-mode impedance for each AE-setup connected to the EUT. Normally, it will be sufficient to follow the guidance for proper operation as given in clauses 7.4 and 6.2.1.
In case of dispute, verification and further adjustments to the AE-setup shall be carried out to establish the impedance requirements as defined in clause 6.2, table 3.

6.3.1 Coupling factor of the "150-to-50 Ω adaptors"

Two "150-to-50 Ω adaptors" of identical construction are required. The proposed construction is given in Fig.7f. The adaptors shall be placed on a ground reference plane the size of which exceeds the projected geometry of this set-up on all sides by at least 0,2 metre. The coupling factor is measured according to the principle of Fig.7d. Its value shall be in the range of 9,5 ± 0,5 dB (theoretical value 9,5 dB caused by the 150-to-50 Ω impedance ratio) when measured in a 50 Ω system. If necessary, the cable attenuation of the test set-up shall be compensated for. Precision attenuators at the inputs and outputs of receivers and generators are recommended.

6.4. Setting of the test generator

For the correct setting of the unmodulated test level the procedure in clause 6.4.1 shall be applied. Hereby it is assumed that the test generator, the coupling and decoupling devices and the "150-to-50 Ω adaptor" comply with the requirements of clauses 6.2 and 6.3.1.

The test generator shall be set next with an unmodulated carrier. After the correct setting the modulation shall be switched on and checked using the verification equipment, preferably an RF-oscilloscope.

During the tests the modulation shall remain switched on.

6.4.1 Setting the output level at the EUT-port of the coupling device

The test generator shall be connected to the RF-input port of the coupling device. The EUT port of the coupling device shall be connected in common-mode through the 150-to-50 Ω adaptor to a measuring equipment having a 50 Ω input impedance. The AE-port shall be loaded in common-mode with a 150-to-50 Ω adaptor, terminated with 50 Ω. The setup is given in Fig.8 for all coupling and decoupling devices.

When the EM-clamp is used with the decoupling network, the output level setting is carried out at the EUT-port while the decoupling network is installed at the AE-port side of the EM-clamp.

With direct injection to screened cable, the 150 Ω load at the AE-port is not required as the screen will be connected to the ground reference plane at the AE-port side.

Using the above mentioned setup, the test generator shall be adjusted to yield the following reading on the measuring equipment.

$U_{mr} = U_0 / 6 \pm 25$ %, in linear quantities or

$U_{mr} = U_0 - 15{,}6$ dB ± 2 dB in logarithmic quantities