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Alternative (Ecological) Method for Measuring Electronic Product Immunity to External Electromagnetic Fields

RATIONALE

This technical report covers technology, products, or processes which are mature and not likely to change in the foreseeable future.

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INTRODUCTION

At present, there are some standards such as SAE ARP1972, IEC 61000-4, CISPR Publication 24, etc. that regulate methods for measuring the immunity of radio and electronic products to external electromagnetic fields. The same idea is in the basis of these methods: generation of an electromagnetic field of a given strength, using a generator and radiating equipment (antenna, TEM-cell, etc.), within some volume where the equipment under test is placed. The immunity of the product to external electromagnetic fields is evaluated on the product response to the effect generated.

The methods defined in these standards have an inherent shortcoming: to realize them, the anechoic chambers (very often of large volume) or the open test sites (polygons) that are specially equipped and organized in special areas. Also, the powerful generating equipment and radiating systems are required. The method described herein is an alternative to these methods. It can be practically considered ecological, as its utilization needs no powerful radiating systems and generation equipment. In addition, this method can be easily utilized outside anechoic chambers.

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1. SCOPE:

This method is used to define the immunity of electric and electronic apparatus and equipment (products) to radiated electromagnetic (EM) energy.

This method is based on injecting the calibrated radio frequency currents (voltages) into external conductors and/or internal circuits of the product under test, measuring the strength of the EM field generated by this product and evaluating its immunity to the external EM field on the basis of the data obtained.

The method can be utilized only when it is physically possible to connect the injector to the conductors and/or circuits mentioned before.

The method allows:

Evaluating immunity of the product under test to external EM fields of the strength equal to a normalized one;

Calculating the level of external EM field strength at which the given (including maximum permissible) induced currents or voltages are generated in the equipment under test, or solving the “opposite” task;

Finding potentially “weak” points of the product design (housing, shield, etc.), through which EM energy can enter inside the product.

The method capabilities mentioned above define the sphere of its application:

Measurements of electronic product immunity to external EM fields at different conditions (polygons, laboratories, in-situ) as an alternative to direct test methods;

Operating instruments for a designer working out the product of a given immunity to external EM fields.

This method can’t be directly applied to evaluate the immunity of the equipment under test to the pulse electromagnetic fields. But it can be used to get the initial data necessary to solve this task.

2. NORMATIVE REFERENCES:

The text of this document includes references to the following normative documents:

SAE ARP1972 – Procedure of immunity measurement

IEC 60050-161:1990 – International Electrotechnical Vocabulary – Chapter 161: Electromagnetic compatibility

IEC 61000-4-3: 1995 – Electromagnetic compatibility (EMC) – Part 4: Test and measurement technology – Clause 3: Tests on immunity to radiated EM field

Amendment A1 to IEC 61000-4-3:1998

3. DEFINITIONS:

The terms and definitions defined in IEC 61050-161 are used in this document.

4. GENERAL:

Electromagnetic emissions generated while operating stationary radio transmitting equipment, handheld radio stations, RF devices, industrial electric equipment and other sources affect the conductors connected to electronic products and internal electric circuits. Therefore the necessity to evaluate their immunity to such effects appears.

The direct method of evaluation of the electronic product immunity to the external electromagnetic fields is the following. Using a generator and radiating equipment, the radio frequency field of the given strength is generated. The equipment under test is placed into this field. The products' response to the RF field is defined by objective (measuring the induced currents and voltages) or subjective methods. This product response served for evaluation of the product immunity to the external effect of the given level.

To realize the direct evaluation method the special polygons, where electromagnetic fields of high strength can be generated, or anechoic chambers are required.

Moreover, powerful generating and radiating equipment is required. Therefore the expense to carry out the direct evaluation methods are essential, and only specialized test centers can afford such tests.

The suggested method for the evaluation of electronic product immunity to the external RF field is the alternative method towards the direct one.

4. (Continued):

The essence of this method is that the product under test is not exposed in the external electromagnetic field. The product itself under the influence of the exciting signal generates the relatively low electromagnetic field. The product immunity to the external electromagnetic field which level is defined in the direct method is evaluated on the basis of this exciting signal and the level of the field generated.

According to this alternative method, the calibrated low-level signals are injected into the accessible external product conductors and/or its internal circuits. The level of this field is measured using a small antenna and measuring receiver. Using this data for the given (in the direct method) electromagnetic field level, the current and/or voltage induced while such effects are calculated and also the opposite operation (definition of the effect level that generates the given current and/or voltage) is solved.

The reciprocal theorem is the theoretical basis of the alternative method. This theorem is correct not only for the usual quadrapole, but for the case when the input circuit of the measuring receiver is the output ports of the quadrapole, and the circuit where the current and/or voltage is injected is the quadrapole input circuit. The connection between input and output ports is provided by electromagnetic fields and the parameters of the medium between the mentioned ports can change arbitrarily from point to point.

To realize the alternative method of evaluation of electronic product immunity to the external RF field, a low-noise generator, a measuring receiver and a small antenna are required. At this, the tests can be satisfied not only in the anechoic chamber or at the polygon, but also at the open test site and in the laboratory. These advantages made the alternative method easy to use. In addition, it can be a working instrument for a designer of electronic products.

The theoretical basis for the measuring method defined in this document and the formula derivation are described in Appendix A.

According to this method the immunity of electronic products to the external RF EM fields is measured as follows:

1. If e.m.f. U_0 is injected into any circuit of the equipment under test then the current I that will be induced by the external electromagnetic field in the same circuit is calculated.

2. If the current I_0 is injected into any circuit of the equipment under test then the voltage U that will be induced by the external electromagnetic field in the same circuit is calculated.

4.1 Definition of the Currents Induced and the Equipment-Under-Test Immunity:

The evaluation of the current I that will be induced by the external electromagnetic field in any circuit is satisfied as follows:

a. A calibrated sine-wave voltage of a proper (low) amplitude U_0 at the frequency F is injected into one of the conductors connected to the equipment under test or into one of its electric circuits;

b. Using an antenna and a measuring device, the EM field strength generated by the equipment under test into the external environment is measured over each of the equipment coordinate surfaces. Maximum value $E_{m\ max}$ and also maximum voltage at the input of the measuring receiver $U_{0\ max}$ or maximum current $I_{0\ max}$ at the input circuit of the measuring receiver (input impedance R_{in}) are defined ($U_{0\ max} = I_{0\ max} R_{in}$).

If a dipole is used as the measuring antenna the measurement are made for both horizontal and vertical antenna polarization. Then, using the data received ($E_{m\ max}$, $U_{0\ max}$ or $I_{0\ max}$), the necessary calculations for the product circuit where the e.m.f. U_0 was injected are made.

4.1.1 Evaluation of the Equipment-Under-Test Immunity to the External Electromagnetic Field of a Given Strength: The evaluation of the product-under-test immunity at the frequency F to the external EM fields of normalized strength E_{norm} is satisfied using the following:

If technical documentation on the product to be tested includes permissible values of the current I_{max} induced in the circuit, into which the test effect U_0 was injected, then the product is considered resistive (having immunity) to external EM fields E_{norm} when

$$I'_{\max} > \frac{U_{0\max}}{\beta^2 R_{in}} \cdot \frac{E_{norm}}{E_{m\max}} \cdot \alpha_1 \qquad \text{(Eq.1)}$$

where:

$\alpha_1 = U_{0\ max}/U_0$

β = the height of the measuring antenna used, normalized to about 1 m

4.1.2 Evaluation of the External Electromagnetic Field Strength Causing the Given Current Induced: The level of the external EM field strength E causing a given current I induced in a circuit into which the test effect U_0 was injected before is defined using the following.

If the value I is given, then E is defined by the formula:

$$E = \frac{I \cdot R_{in} \cdot E_{m\max} \cdot \beta^2}{U_{0\max} \cdot \alpha_1} \quad \text{(Eq.2)}$$

4.1.3 Evaluation of the Product-Under-Test Immunity When the Permitted Level of the Induced Current is Not Given for the Equipment Circuit Which e.m.f. U_0 was Injected into: If the technical documentation on the product to be tested doesn't include the maximum value of the current I_{max} induced into the conductor connected to the product (or its internal circuit) then the product is considered resistive (possessing immunity) to external EM fields E_{norm} when after repeated injection of the voltage

$$U_{0norm} = U_0 \cdot \frac{E_{norm}}{E_{m\max}} \quad \text{(Eq.3)}$$

this equipment operates with the given/proper quality.

4.2 Definition of the Voltages Induced and the Equipment-Under-Test Immunity:

The evaluation of the voltage U that will be induced by the external electromagnetic field in any circuit is satisfied as follows.

a. Calibrated sine-wave current of a proper (low) amplitude I_0 at the frequency F is injected into one of the conductors connected to the equipment under test or into one of its electric circuits;

b. Using an antenna and a measuring device, the EM field strength generated by the equipment under test into the external environment is measured over each of the equipment coordinate surfaces. Maximum value $E_{m\,max}$ and also maximum voltage at the input of the measuring receiver $U_{0\,max}$ or maximum current $I_{0\,max}$ at the input circuit of the measuring receiver (input impedance R_{in}) are defined ($U_{o\,max} = I_{0\,max} R_{in}$).

If a dipole is used as the measuring antenna, the measurements are made both for horizontal and vertical antenna polarization. Then, using the data received ($E_{m\,max}$, $U_{0\,max}$ or $I_{0\,max}$), the necessary calculations for the product circuit where the current I_0 was injected to, are made.

4.2.1 Evaluation of the Equipment-Under-Test Immunity to the External Electromagnetic Fields of the Given Strength: The evaluation of the test product immunity at the frequency F to external EM fields of normalized strength E_{norm} is satisfied using the following:

If technical documentation on the product to be tested includes permissible values of the voltage U_{max} induced in the circuit into which the test effect I_0 was injected then the product is considered resistive (having immunity) to external EM field E_{norm} when

$$U'_{max} > U_{0\max} \cdot \frac{E_{norm}}{\beta^2 E_{m\max}} \cdot \alpha_2 \qquad \text{(Eq.4)}$$

where:

$\alpha_1 = I_{0\ max}/I_0$

4.2.2 Evaluation of the External Electromagnetic Field Strength Causing the Given Voltage Induced: The level of the external EM field strength E causing a given voltage U induced in a circuit into which the test effect I_0 was injected before is defined using the following.

If the value U is given, then E is defined by the formula:

$$E = \frac{U \cdot E_{m\max} \cdot \beta^2}{U_{0\max} \cdot \alpha_2} \qquad \text{(Eq.5)}$$

4.2.3 Evaluation of the Product-Under-Test Immunity When the Permitted Level of the Induced Current is Not Given for the Equipment Circuit Which the Current I_0 was Injected Into: If the technical documentation on the product to be tested doesn't include maximum values of the voltage U_{max} induced into the conductor connected to the product (or its internal circuit) then the product is considered resistive (possessing immunity) to external EM field E_{norm} when after repeated injection of the current

$$I_{0norm} = I_0 \cdot \frac{E_{norm}}{E_{m\max}} \qquad \text{(Eq.6)}$$

this equipment operates with the given/proper quality.

4.2.3 (Continued):

NOTE: All steps described in the clause 4 should be satisfied:

a. at all frequencies defined in the immunity standard

b. for all physically accessible conductors connected to the product (its internal electric circuits) for which the permissible values of the induced current I_{max} and the induced voltage U_{max} are given

4.3 Definition of the Potentially "Weak" Points of the Product Design:

To define potentially "weak" points of the product design, through which electromagnetic energy could enter the product, the measuring antenna is scanned over its coordinate surfaces and the points, where radiated EM fields at the frequency F is maximum: $E_{m\,max1}$, $E_{m\,max2}$, $E_{m\,max3}$, etc., are found. Then if the values I_{max} or U_{max} are known, the minimum necessary improvement b (dB) of the product housing shielding effectiveness is defined (using the largest of the measured values E_{mmax}) on the basis of:

$$\Delta b = 20\lg\left[\frac{U_{0\max}}{\beta^2 \cdot R_{in}} \cdot \frac{E_{norm}}{E_{m\max}} \cdot \frac{\alpha_1}{I'_{\max}}\right] \text{ (dB)} \qquad \text{(Eq.7)}$$

or

$$\Delta b = 20\lg\left[\frac{U_{0\max}}{\beta^2} \cdot \frac{E_{norm}}{E_{m\max}} \cdot \frac{\alpha_2}{U'_{\max}}\right] \text{ (dB)} \qquad \text{(Eq.8)}$$

This procedure and the calculations are carried out at all frequencies at which the given immunity of the product to be designed is regulated.

If the values I_{max} or U_{max} are not given (not known) then a new test effect of the level defined by Equation 3 or 6 is injected into the product. If at this non-regulated (non-permissible) change of the product performance occurs, then the effect level should be reduced to the value U_{min} or I_{min} at which the normal product operation is restored.

4.3 (Continued):

Then minimum necessary improvement of shielding effectiveness at the found “weak” points of the product housing is defined:

$$\Delta b = 20\lg\frac{U_{0norm}}{U_{\min}} \text{ (dB)} \qquad \text{(Eq.9)}$$

or

$$\Delta b = 20\lg\frac{I_{0norm}}{I_{\min}} \text{ (dB)} \qquad \text{(Eq.10)}$$

5. MEASURING SET-UP, DEVICES AND EQUIPMENT:

Structural diagram of the measuring set-up is shown in Figure 1.

As it could be seen from the structural diagram shown in Figure 1 in order to form the calibrated test effect, a radio frequency (RF) generator 1 is used. The signal from its output through transmission line 2 goes to the injector 3. Using unit 3 the test effect is injected into conductors connected to the product under test 4 or its internal circuits. Near the housing of the product 4 the measuring antenna 5 is installed. It is connected to the measuring receiver 7 through a transmission line that transmits the output signal of antenna 6.

The unit 8 for evaluation of the test product performance can be connected to the product 4 when necessary.

5.1 Radio Frequency Generator:

The radio frequency (RF) generator should scan/sweep the measuring frequency band defined by the immunity standard for the equipment under test.

The requirements for stability and frequency tuning accuracy are the same as in the standard regulating the measurements of the product immunity using a direct method.

The RF generator should generate the calibrated test effect level required for measuring $E_{m\ max.}$ The generator may provide for automatic or manual frequency adjusting within the given test frequency band. The generator output signal level can be increased using additional amplifiers when necessary. The RF generator should provide signal amplitude modulation of 1 kHz, depth 80% and also other modulation types that are used when measuring the immunity of electronic products by a direct method.

5.1 (Continued):

It's very convenient to use the signal source built into the measuring device (which frequency is the device tuned frequency) as an RF generator. Some measuring devices (interference meters) are equipped with such generators with the proper output. The RF generator should have a device that allows measuring the output voltage.

5.2 Test Effect Transmission Line:

The test effect transmission line (TETL) is used to provide decoupling between the RF generator and the injector.

To make measurements more precise, the TETL should include: an electronic optical converter, an optical conductor and an optical electronic converter.

There are no special requirements for these devices but the dynamic range should be at least 10 dB.

At frequencies below 30 MHz a standard coaxial cable with a shield effectiveness of at least 40 dB can be used as the TETL.

The input impedance of the TETL should be matched with the output impedance of the RF generator and the TETL operating frequency range should correspond to the measuring frequency band. The TETL should be calibrated. The method of calibration is defined in the Appendix B.

5.3 Injector:

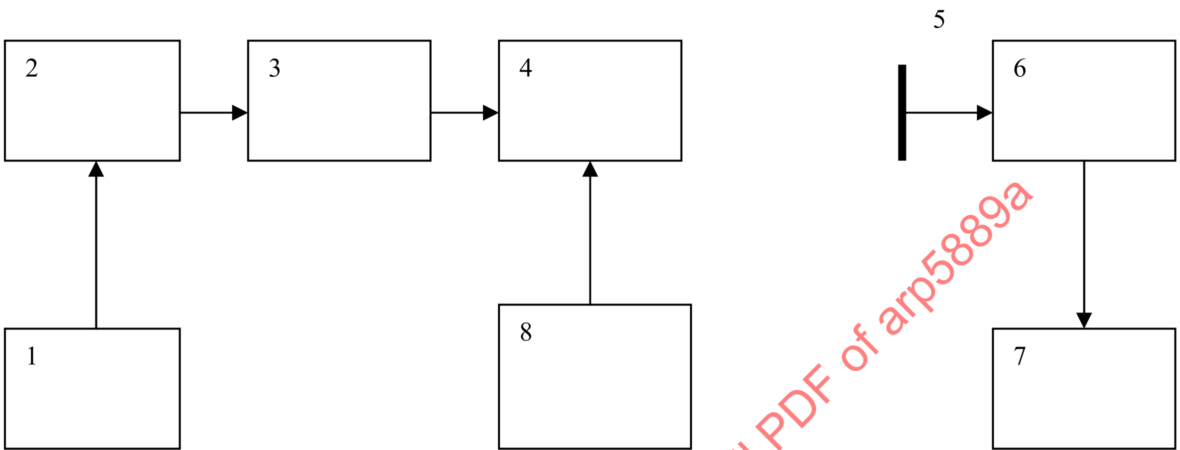
The injector is intended to inject the test effect (voltage or current) of a proper amplitude within a given frequency band into a conductor connected to the product under test (or in its internal electric circuit).

The connection of the injector to the product under test should not disturb the product performance.

A decoupling capacitor is the simplest device to inject e.m.f. U_0.

An inductor is a convenient device to inject the current I_0. In practice, a small-sized probe described in Publication 16-1 CISPR can be used as the injector.

The injector should be calibrated. In practice, all circuits "TETL – injector" are calibrated.



1 – RF generator
2 – Test effect transmission line (TETL)
3 – Injector
4 – Product under test
5 – Antenna
6 – Antenna output signal transmission line (AOSTL)
7 – Measuring device
8 – Device for evaluation of the product-under-test performance

FIGURE 1 - Structural Diagram of the Set-Up to Measure Electronic Product Immunity

5.4 Antenna:

The antenna should be one with horizontal or vertical polarization or an isotropic antenna of the size not more than 0.1 m.

The antenna attachment unit should provide the change of antenna position (polarization) and its height scanning. It should also provide antenna scanning over coordinate surfaces of the product under test.

5.5 Antenna Output Signal Transmission Line:

The antenna output signal transmission line (AOSTL) is intended to connect the antenna to the measuring device. Its structure and application are the same as for AOSTL defined in 5.2.

The dynamic range of AOSTL should be at least 10 dB. The AOSTL should be calibrated in accordance with Appendix B.

5.6 Measuring Device:

The measuring device should provide measurement of voltages at the antenna output within the frequency band defined in clause 4. The measuring receiver (interference meter) or spectrum analyser should meet the requirements of CISPR Publication 16-1. The measuring device should provide automatic or manual adjustment of the measurement frequency.

6. TEST METHODS:

6.1 Test Conditions:

Measurements can be satisfied at the open measuring sites (polygons) in laboratories, at manufacturing facilities or plants, in-if the levels radiated while testing don't exceed the values permitted by the national regulations (Norms and Standards).

Due to comparatively low levels of EM field strengths generated while testing it's not necessary to carry out tests in shielded rooms. Anechoic chambers are also not required because of the same reason. The compliance of EM fields generated while testing to the national limits for industrial radio interferences can be provided at any conditions. With this, one should get convinced that the level of external radio interference field strength at the measurement frequencies is at least 6 dB lower than the levels of EM field strengths generated at the test area when exciting electric circuits of electronic products. If it's impossible to avoid the influence of the radio station fields on the measurement results (e.g., by adjusting the frequency of the test signal and/or increasing its level) a shielded room or anechoic chamber could be required.

6.1 (Continued):

During measurements, floor-standing EUT is placed on the insulating support of 0.1 m. Other test products being installed on a table of insulating material of 0.8 m height. The insulating support and the table are placed on the ground plane.

If due to technical reasons the EUT can't be tested other than in-situ, this product should be tested in-situ (i.e., without using a support or table).

Immunity measurements are satisfied when the product under test is in the same operating modes that were provided while testing by the direct method or in other modes as defined in technical documentation on the products.

The test temperature and relative humidity should be recorded in the test report.

6.2 Test Procedure:

If the product standard includes permissible levels of the current I_{max} or voltage U_{max} induced in the proper conductors (circuits) then the measurements are carried out only at successive injections of the test effect into the proper conductors (circuits).

If the product standard doesn't define the proper conductor connected (internal electric circuit) for which permissible values of the current I_{max} or the voltage U_{max} induced by EM field are determined then the measurements are carried out when connecting in turn to each accessible conductor (electric circuit) through the injection unit. At this, one should find out what conductor (electric circuit) being affected makes the EUT the most sensitive to the effect. The "volume" of the necessary tests can be reduced to a high degree if the recommendations of the product's principal designer are followed.

If other than permissible induced current/voltage level (I_{max} or U_{max}) criteria for evaluation of the product-under-test performance being affected with the external EM fields are used, then the test effects are successively injected only into those product conductors connected (internal circuits) that are defined in the product technical documentation or recommended by the product's principal designer. If such information is not available, the test effects are injected into all accessible product conductors (internal circuits).

The tests are carried out within the frequency band defined in the standard. Frequency steps should be not more than 1% of the previous frequency if the product standard doesn't require other values.

To adjust the calibrated test effect levels and to switch (change) the input units (if necessary), short time breaks should be made.

If the immunity standard for the product under test specifies to use a modulated RF field then the effect to be injected should also be a modulated one. The modulation should be on when tuning the measuring receiver to the injected signal frequency.

6.2 (Continued):

The measuring time at each frequency should be not less than the response time of the product under test on the test effect.

More attention should be paid to the frequencies and the points of the surfaces scanned with the measuring antenna, at which the product immunity to the external EM field is the lowest.

During the tests the performance of the EUT should be checked in all modes defined for the tests.

Special test programs are recommended for the tests. If necessary some preliminary tests can be made to prove the program validity.

The test results should be recorded in a proper test report.

APPENDIX A
THEORETICAL BASIS OF AN ALTERNATIVE (ECOLOGICAL) METHOD FOR MEASURING ELECTRONIC PRODUCT IMMUNITY TO EXTERNAL ELECTROMAGNETIC FIELDS

This method is based on reciprocity theorem.

a. The theorem version with an e.m.f. source is formulated: "If any e.m.f. U_0 that belongs to any electric circuit loop produces current I_0 in another loop of this circuit then the same e.m.f. U_0 being transferred to the second loop will produce current I_0 of the same value in the first loop".

Let's consider Figure 1. U_0 in this picture is e.m.f. applied to the external or internal loop of a circuit of the product under test. The insertion of this e.m.f. makes the product under test generate an electromagnetic field $E_{m\ max}$. If in this situation the measuring antenna connected to the measuring receiver with an input impedance R_{in} is installed in the vicinity of the product then $E_{m\ max}$ will produce voltage $U_{0\ max}$ at the receiver input, that in its turn, generates current $I_{0\ max}$ in the input circuit of the measuring receiver. Then, according to the reciprocity theorem, if the external electromagnetic field E_{Uo} causes voltage U_0 at the receiver input, then current $I_{0\ max}$ is induced in the external or internal (depending on the point of e.m.f. connection) circuit of the product under test.

So we have:

$$\begin{array}{cc} E_{Uo} & I_{0\ max} \\ E_{norm} & x \end{array} \qquad \text{(Eq.A1)}$$

where x is a current induced by the external electromagnetic field of normalized (given) value E_{norm} in the product under test.

From Equation A1:

$$x = I_{0\max} \cdot \frac{E_{norm}}{E_{Uo}} \qquad \text{(Eq.A2)}$$

Equation A2 can be transformed to Equation A3 if reciprocal factor $_1$ = $U_{0\ max}/U_0$ is entered into consideration:

$$x = \frac{U_{0\max}}{R_{in}} \cdot \frac{E_{norm}}{E_{m\max}} \cdot \alpha_1 \qquad \text{(Eq.A3)}$$