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Electromagnetic compatibility (EMC) –

Part 4-33:
Testing and measurement techniques – Measurement methods for high-power transient parameters

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-33: Testing and measurement techniques – Measurement methods for high-power transient parameters

FOREWORD

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International Standard IEC 61000-4-33 has been prepared by subcommittee 77C: High power transient phenomena, of IEC technical committee 77: Electromagnetic compatibility.

It has the status of a basic EMC publication in accordance with IEC Guide 107.

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

FDIS	Report on voting
77C/156/FDIS	77C/160/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. 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- withdrawn;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.

INTRODUCTION

IEC 61000 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 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts and published either as International Standards or as technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example: 61000-6-1).

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-33: Testing and measurement techniques – Measurement methods for high-power transient parameters

1 Scope

This part of IEC 61000 provides a basic description of the methods and means (e.g., instrumentation) for measuring responses arising from high-power transient electromagnetic parameters. These responses can include:

- the electric (*E*) and/or magnetic (*H*) fields (e.g., incident fields or incident plus scattered fields within a system under test);
- the current *I* (e.g., induced by a transient field or within a system under test);
- the voltage *V* (e.g., induced by a transient field or within a system under test);
- the charge *Q* induced on a cable or other conductor.

NOTE The charge Q on the conductor is a fundamental quantity that can be defined at any frequency. The voltage *V*, however, is a defined (e.g., secondary) quantity, which is valid only at low frequencies. At high frequencies, the voltage cannot be defined as the line integral of the E-field, since this integral is path-dependent. Thus, for very fast rising pulses (having a large high-frequency spectral content) the use of the voltage as a measurement observable is not valid. In this case, the charge is the desired quantity to be measured.

These measured quantities are generally complicated time-dependent waveforms, which can be described approximately by several scalar parameters, or “observables”. These parameters include:

- the peak amplitude of the response,
- the waveform rise-time,
- the waveform fall-time (or duration),
- the pulse width, and
- mathematically defined norms obtained from the waveform.

This International Standard provides information on the measurement of these waveforms and on the mathematical determination of the characterizing parameters. It does not provide information on specific level requirements for testing.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-161, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

IEC 61000-2-9, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 9: Description of HEMP environment – Radiated disturbance*

IEC 61000-2-10, *Electromagnetic compatibility (EMC) – Part 2-10: Environment – Description of HEMP environment – Conducted disturbance*

IEC 61000-4-20, *Electromagnetic compatibility (EMC) – Part 4-20: Testing and measurement techniques – Emission and immunity testing in transverse electromagnetic (TEM) waveguides*

IEC 61000-4-23, *Electromagnetic compatibility (EMC) – Part 4-23: Testing and measurement techniques – Test methods for protective devices for HPEM and other radiated disturbances*

IEC 61000-4-25, *Electromagnetic compatibility (EMC) – Part 4-25: Testing and measurement techniques – HEMP immunity test methods for equipment and systems*

3 Terms and definitions

For the purposes of this part of IEC 61000, the following terms and definitions, together with those in IEC 60050-161 apply.

3.1
electrically small
refers to the size of an object relative to the wavelength of the electromagnetic field. When the object is much smaller than the wavelength, it is said to be electrically small

3.2
equivalent area
an intrinsic parameter of a magnetic flux sensor (loop) that relates the open circuit voltage of the sensor to the time rate of change of the magnetic flux density linking the sensor

3.3
equivalent height
an intrinsic parameter of an electric field (dipole) sensor, which relates the measured voltage across the terminals of the sensor to the E-field component exciting the sensor

3.4
free-field sensor
an electromagnetic field sensor used at a location distant from any scattering body or ground plane

3.5
high power electromagnetic
HPEM
the general area or technology involved in producing intense electromagnetic radiated fields or conducted voltages and currents which have the capability to damage or upset electronic systems. Generally these disturbances exceed those produced under normal conditions (e.g. 100 V/m)

3.6
measurement chain
one or more electrical devices connected together for the purpose of measuring and recording an electromagnetic signal

3.7
Nyquist frequency
the Nyquist frequency is the bandwidth of a sampled signal, and is equal to half the sampling frequency of that signal. If the sampled signal represents a continuous spectral range starting at 0 Hz (which is the most common case for speech recordings), the Nyquist frequency is the highest frequency that the sampled signal can unambiguously represent

3.8
pre-pulse
refers to a portion of an impulse-like transient waveform that occurs at a time before the time of the primary peak

3.9
sensor
a transducer that senses a particular electromagnetic quantity (such as an electric or magnetic field, a current or a charge) and converts it into a voltage or current that can be measured. Typically, this is the first element in a measurement chain for EM measurements

3.10
waveform norm
a parameter that is determined from a mathematically well-defined operation on a waveform or signal (such as an integration of the waveform), which yields a scalar number that permits a comparison of various waveforms or their effects

3.11
waveform parameter(s)
a single parameter that denotes a waveform characteristic (such as the rise time of the waveform), which is difficult to cast into the waveform norm formalism, yet which is useful in describing a response

3.12
–dot
a suffix (as in I-dot), which denotes the derivative with respect to time of the quantity (I), implying that the measurement is proportional to the time rate of rise of the response (I)

4 Measurement of high-power transient responses

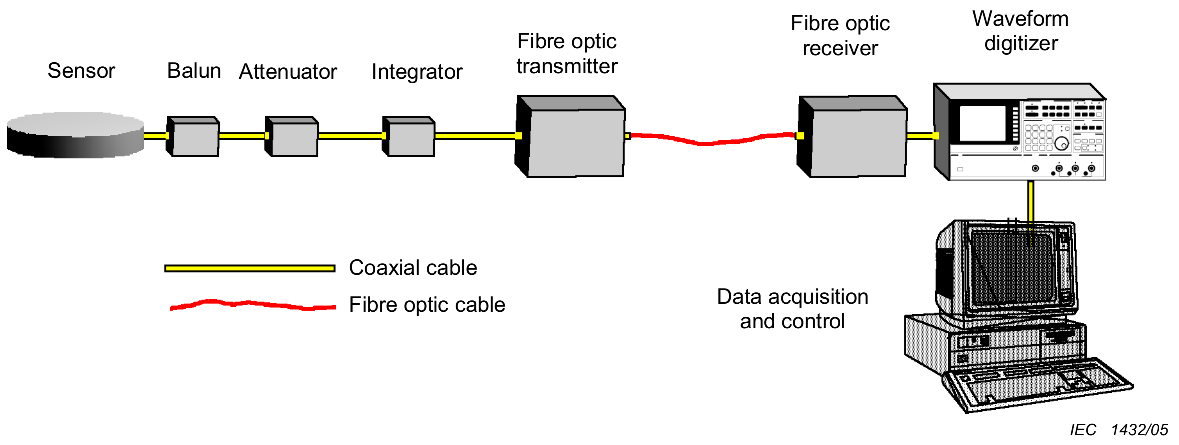
This standard is concerned with the measurement and description of high-power transient signals resulting from a high altitude nuclear detonation (referred to as the high altitude electromagnetic pulse – HEMP) or from the use of a transient source (or pulser) producing high-power electromagnetic (HPEM) fields. Typically, the physical quantities being measured include the electric (E) and magnetic (H) fields in (or near) a facility or test object, or the induced current and charge (or voltage) on conducting wires entering into the facility or test object.

This clause of the standard describes the overall measurement techniques for these transient responses, and in Annex A, suggests several waveform parameters and norms that shall be used to characterize the measured responses. Many of the measurement methods and equipment may also be used for measuring time harmonic (i.e., frequency domain) signals; however, this application is not considered further in this document, as we shall be concerned with only the measurement of transient signals.

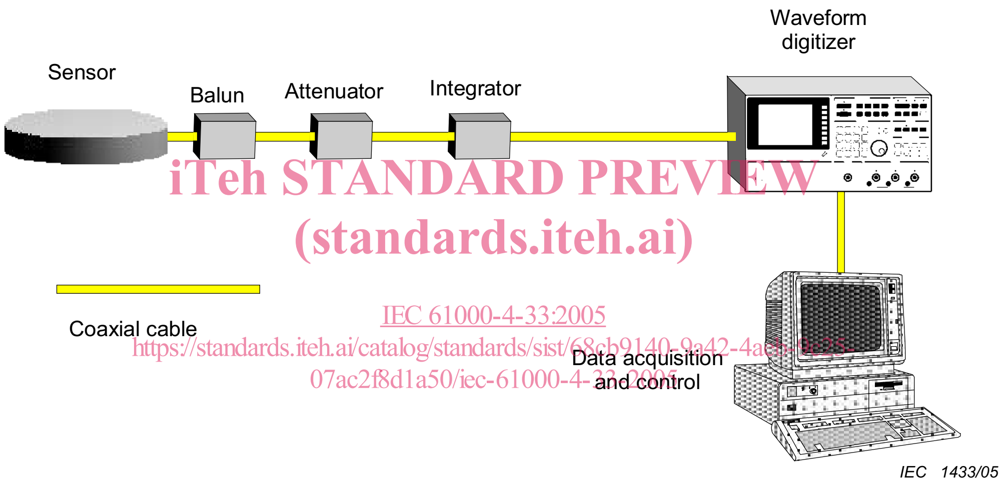
4.1 Overall measurement concepts and requirements

The measurement of transient response quantities is realized by using a number of transient signal processing elements linked together in a sequential manner. Referred to as a "measurement chain", this collection of equipment will detect, process, transmit and record measured transient responses, so that they can be used after the test is finished to analyse a measured quantity or the electrical behaviour of the system under test.

Figure 1 shows two typical instrumentation chains that shall be used for measuring high-power transient responses. The measurement chain shown in Figure 1(a) contains the following elements.



(a) **Instrumentation chain using a coaxial cable and fibre optics**



(b) **Instrumentation chain with only coaxial signal lines**

Figure 1 – Illustration of a typical instrumentation chain for measuring high-power transient responses

- Coaxial cable – this element provides an electrical connection between the various elements of the measurement chain, at a constant impedance (typically 50 Ω). An alternative to this element is the fibre-optics transmission system discussed below.
- Sensor – a device that converts the measured quantity (EM field, current, or charge) into a voltage that can be measured.
- Balun – a device that operates as a matching transformer to ensure that the sensor is well adapted (matched) to the coaxial signal line. This device also helps to suppress common-mode signals.
- Attenuator – a signal reduction device installed in-line to reduce the sensor signal strength if it is too large.
- Integrator – an active or passive device to integrate in time the sensor output. This is needed because in some cases, a sensor will respond to the time rate of change (e.g., the derivative) of the measurement quantity. (Signal integration can also be performed in software.)
- Fibre optics transmitter – a device to convert the measured fast transient electrical signal to a modulated optical signal, which can be transmitted away from the vicinity of the sensor to a distant recording device.

- Fibre optics cable – a non-conducting fibre cable that can be routed in and around the system under test to permit the transmission of the optical signal to the distant optical receiver.
- Fibre optics receiver – a device that receives the modulated optical signal from the transmitter, demodulates it and recovers the imbedded information from the sensor.
- Waveform digitiser – this is the detector in the measurement chain, which receives the sensor electrical analogue signal, converts it into a stream of digital data and then passes these data on to a recording device.
- Data acquisition and control computer – the main logic processor to conduct the measurements and store and analyse the results.

Additional information on each of these elements in the measurement chain will be provided later in this clause.

Not all of the elements of the measurement chain in Figure 1(a) are always necessary. For example, the attenuator shall be required only if the sensor response is so large that it tends to over-drive the fibre optics (FO) transmitter and cause signal distortions. Similarly, some sensors may have a self-contained integrator, so that the integrator element in the measurement chain shall be omitted.

Figure 1(b) illustrates a case where the entire measurement chain is interconnected only by a coaxial cable. The FO system is not present in this case, perhaps due to some special feature of the signal being measured:

- the dynamic range of the desired signal is larger than that provided by the FO transmit/receive equipment,
- the measured pulse is much faster than the transmission capabilities of the FO system, or
- perhaps the cost of the FO system is prohibitive.

Regardless of the configuration of the measurement chain, there are several basic measurement principles that must be recognized during the course of performing the measurements. These are as follows.

- The measurement sensor always perturbs the EM field in its vicinity (or influences the local current and/or charge densities). It can be shown that if a sensor were designed to not perturb the field, it would register a zero response.
- The use of a measurement chain can “load” the system or circuit being measured, so that the obtained reading may not be the true response.
- The measurement chain can be used to measure both near field and far field responses. Typically, a field sensor will measure only one of the three orthogonal E- or H-field components, and whether the observation point is in the near-zone or the far zone is unimportant in describing the responses. In the far-zone, the E/H ratio of the principal (transverse) field components is equal to the impedance of free-space (377 Ω), but in the near zone this E/H relationship is not maintained.
- The sensor shall be calibrated to provide a suitable relationship between its electrical output and the response quantity it is measuring.
- In addition to the sensor, the remainder of the measurement chain can also add errors to an EM field quantity being measured, and such errors shall be minimized. Such errors can arise both from secondary scattering from the measurement equipment (which adds an error in the fundamental EM field quantities being measured), and from a perturbation of the response provided by the sensor as it propagates through the measurement chain (say, from external common-mode currents on a coaxial cable affecting the internal signal through the shield transfer impedance). The use of the FO transmission system is one way of minimizing this unwanted perturbation. Other ways include a careful routing of the coaxial cable so as to minimize pick-up, the use of ferrite beads on the coax to attenuate induced currents, additional shielding over the coaxial lines, and keeping the length of the coax line as short as possible.

- Calibration procedures shall be applied to all elements of the measurement chain. The integrator functions ideally only over a particular frequency band. The coaxial cable has increasing loss as the frequency increases. Each of these facts shall be taken into account in developing an end-to-end calibration of the measurement chain.
- The measurement system noise shall be determined and its effects on the measured response quantities shall be quantified.
- Once a "raw" waveform is measured and digitised by the recording device, the calibration function shall be applied and a "corrected" response waveform determined.
- After the corrected waveform is determined, it shall be summarised by one or more waveform parameters, or norms, identified in Annex A.

Details and requirements for each of these measurement chain elements will be discussed in 4.3.

4.2 Representation of a measured response

The measured, corrected and digitised waveform that is ultimately recorded by the data acquisition computer is usually a complicated function of time. To easily distinguish between one waveform and another, and to relate a particular waveform to a possible effect on a system or facility, one or more scalar numbers representative of the waveforms shall be used. In this manner, only a few numbers, as opposed to the entire data record of the transient waveform, can summarize the essence of a waveform.

In describing the response waveform in this manner, there are two classes of numbers that shall be used. Waveform parameters are numbers that are immediately obvious from an examination of the transient response, such as the peak amplitude. Waveform norms, on the other hand, are mathematically defined scalar parameters that require a numerical processing of the total waveform. The energy contained in the waveform is an example. In this clause of the standard, each of these types of waveform parameters is defined.

Annex A of the present standard provides additional information on how measured transient waveforms can be characterized.

4.3 Measurement equipment

As noted in Figure 1 there are four major elements to the measurement system. These include:

- the response sensor that measures an electrical parameter (EM field component, a current, or a charge) and converts it into a voltage;
- the transmission system that transports the measured voltage from the sensor to the detection equipment;
- the detection (or digitisation) system that takes the received voltage response and converts it into a digital format for processing and storage; and
- the computer controlling the measurement process and performing data processing and storage.

4.3.1 The measurement chain

Each of these measurement chain elements can affect the amplitude and wave shape of the recorded signal, and it is important to understand and control such perturbations. As an example, consider the case of a transient EM field described by its E-field component $E_o(t)$ striking the field sensor in Figure 1(a), and producing a transient response at the recording device given as $R_{\text{measured}}(t)$. As noted in [1][1], the relationship between the transient response and excitation is given by a convolution (*) operation as

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[1] Figures in square brackets refer to the Bibliography.

$$R_{\text{measured}}(t) = E_o(t) * T(t), \tag{1}$$

where $T(t)$ is the impulse response of the measurement system. Given the measured response $R_{\text{measured}}(t)$, the goal is to determine the excitation $E_o(t)$, and [1] represents this process symbolically as the deconvolution (1/*) operation

$$E_o(t) = R_{\text{measured}}(t)\ (1/*)\ T(t). \tag{2}$$

In [1], various techniques that may be used to evaluate this deconvolution operation to determine $E_o(t)$ are discussed, with one of them being recasting equations (1) and (2) in the frequency domain through the use of Fourier transforms, and then using the transfer function concept [2] to deconvolve the excitation function.

Denoting the Fourier transforms of the measured transient response and the excitation E-field at the sensor by $\tilde{R}_{\text{measured}}(f)$ *and* $\tilde{E}_o(f)$, respectively (see Annex A), the frequency domain equivalent of equation (1) is expressed as

$$\tilde{R}_{\text{measured}}(f) = \tilde{T}(f)\tilde{E}_o(f), \tag{3}$$

where now the convolution operation becomes a simple multiplication by the Fourier spectrum of the transfer function $\tilde{T}(f)$. In the frequency domain, the deconvolution operation of equation (2) is given as the inverse of equation (3) as

$$\tilde{E}_o(f) = \tilde{T}(f)^{-1} \cdot \tilde{R}_{\text{measured}}(f). \tag{4}$$

NOTE In this standard, transient quantities are represented using the notation *F(t)*, and the corresponding Fourier spectral density is $\tilde{F}(f)$.

This deconvolution is easily carried out, as long as the transfer function spectrum $\tilde{T}(f)$ is not zero at any real frequency *f*. Once the spectrum of the excitation field is determined, the transient behaviour of this field component may be determined by taking an inverse Fourier transform.

As noted in Figure 1(a), the measurement chain consists of several different elements, each of which contributes to the overall transfer function $\tilde{T}(f)$. Because each element in the chain is designed to function at a constant impedance level (typically 50 ohms), the end-to-end transfer function of the measurement chain $\tilde{T}(f)$ can be evaluated as the product of individual complex-valued, frequency dependent transfer functions for each element in the measurement chain. In this manner, the overall transfer function is given as

$$\tilde{T}(f) = \tilde{T}_{\text{digitiser}}(f) \cdot \tilde{T}_{\text{fibre optics}}(f) \cdot \tilde{T}_{\text{integrator}}(f) \cdot \tilde{T}_{\text{attenuator}}(f) \cdot \tilde{T}_{\text{balun}}(f) \cdot \tilde{T}_{\text{sensor}}(f). \tag{5}$$

To determine the spectrum of the excitation field from equation (4) it is necessary that the transfer function $\tilde{T}(f)$ be known. Methods for determining this transfer function accurately (both in magnitude and phase over a wide frequency range) will be discussed in Clause 6 of this standard. In many instances, however, the various transfer function components in equation (5) are designed to be very simple functions of frequency or even constants over a wide frequency band, and this makes the overall transfer function very simple.

Subclause 4.3.2 in this standard and Annex B discuss several different types of sensors that provide output responses that are related to an excitation function (like an incident field or induced current.) The responses of these sensors are seen to be of two basic types: one which has an output that is approximately proportional to the excitation quantity and another,