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Electromagnetic compatibility (EMC) - Part 1-3: General - The effects of high-altitude EMP (HEMP) on civil equipment and systems

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Electromagnetic compatibility (EMC) –

Part 1-3: General – The effects of high-altitude EMP (HEMP) on civil equipment and systems

Compatibilité électromagnétique (CEM) –

Partie 1-3:
Généralités – Effets des impulsions électromagnétiques à haute altitude (IEM-HA) sur les matériels et systèmes civils

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 1-3: General – The effects of high-altitude EMP (HEMP) on civil equipment and systems

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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Technical reports do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful by the maintenance team.

IEC 61000-1-3, which is a technical report, 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 technical report is based on the following documents:

Enquiry draft	Report on voting
77C/109/CDV	77C/121/RVC

Full information on the voting for the approval of this technical report 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 3.

This document, which is purely informative, is not to be regarded as an International Standard.

The committee has decided that the contents of this publication will remain unchanged until 2007. 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 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 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: IEC 61000-6-1).

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 1-3: General – The effects of high-altitude EMP (HEMP) on civil equipment and systems

1 Scope

The purpose of this part of IEC 61000 is to describe the effects that have occurred during actual and simulated electromagnetic pulse testing throughout the world. These effects include those observed during the high-altitude nuclear tests conducted by the United States and the Soviet Union in 1962, and the HEMP simulator tests conducted by many countries during the years after atmospheric testing ended. In addition to direct effects, this technical report also contains information on HEMP coupling to “long lines” as it is important to verify that particular levels of currents and voltages can be induced by HEMP on these lines; this provides a basis for direct injection testing of electronic equipment. It should be noted that, in most cases, the electrical equipment tested or exposed did not contain the sensitive electronics in use today. Also it should be emphasized that all tests and exposures did not produce failure of the equipment; factors such as the geometry of the HEMP interaction and the electromagnetic shielding of the equipment are variables that can produce differing results. The description of these effects is intended to illustrate the seriousness of the possible effects of HEMP on modern electronic systems.

2 Reference documents

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 60050-161:1990, *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*. Basic EMC publication

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

IEC 61000-4-32: *Electromagnetic compatibility (EMC) – Part 4-32: Testing and measurement techniques – HEMP simulator compendium.* Basic EMC publication[1]

3 Definitions

For the purposes of this part of IEC 61000, the following definitions, together with those in IEC 60050(161) apply.

3.1
attenuation
reduction in magnitude (as a result of absorption and scattering) of an electric or magnetic field or a current or voltage; usually expressed in decibels

[1] To be published.

3.2
aperture point-of-entry
aperture port-of-entry
aperture points-of-entry including intentional or inadvertent holes, cracks, openings or other discontinuities in a shield surface

NOTE Intentional aperture points of entry are provided for personnel and/or equipment entry and egress and for ventilation through an electromagnetic barrier.

3.3
common mode voltage
mean of the phasor voltages appearing between each conductor and a specified reference, usually earth or frame

[IEV 161-04-09]

3.4
conductive point-of-entry
conductive port-of-entry
penetrating conductor, electrical wire, cable or other conductive object, such as a metal rod, which passes through an electromagnetic barrier

3.5
electromagnetic compatibility
EMC (abbreviation**)**
ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[IEV 161-01-07]

3.6
electromagnetic disturbance
any electromagnetic phenomenon which may degrade the performance of a device, equipment or system

[IEV 161-01-05, modified]

3.7
electromagnetic interference
EMI (abbreviation)
degradation of the performance of a device, transmission channel or system caused by an electromagnetic disturbance

[IEV 161-01-06, modified]

NOTE Disturbance and interference are respectively cause and effect.

3.8
(electromagnetic) shield
electrically continuous housing for a facility, area, or component used to attenuate incident electric and magnetic fields by both absorption and reflection

3.9
(electromagnetic) susceptibility
inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

NOTE Susceptibility is a lack of immunity.

[IEV 161-01-21]

3.10
high-altitude electromagnetic pulse (HEMP)
electromagnetic pulse produced by a nuclear explosion outside the earth's atmosphere

NOTE Typically above an altitude of 30 km.

3.11
medium voltage (MV) power line
power line with a nominal a.c. voltage above 1 kV and not exceeding 35 kV

3.12
point-of-entry (PoE)
port-of-entry (PoE)
physical location (point) on an electromagnetic barrier, where EM energy may enter or exit a topological volume, unless an adequate PoE protective device is provided. A PoE is not limited to a geometrical point. PoEs are classified as aperture PoEs or conductive PoEs according to the type of penetration. They are also classified as architectural, mechanical, structural or electrical PoEs according to the functions they serve

3.13
power lines
lines originating from the power supply (alternating or direct voltage)

3.14
transient
pertaining to or designating a phenomenon or a quantity which varies between two consecutive steady states during a time interval short compared with the time-scale of interest

[IEV 161-02-01]

NOTE A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave with the first peak occurring in either polarity.

3.15
voltage surge
transient voltage wave propagating along a line or a circuit and characterized by a rapid increase followed by a slower decrease of the voltage

[IEV 161-08-11]NOTE The time parameters of a voltage surge are defined as follows:
• the rise time between 10 % and 90 % of the peak value (10 %/90 % rise time) according to IEV 161-02-05; and
• the duration at 50 % of the peak value between increase and decrease of the wave (50 %/50 % duration).

4 General considerations

A high-altitude (above 30 km) nuclear burst produces three types of electromagnetic pulses that are observed on the earth's surface:

early-time HEMP (t < 1 µs) (fast);

intermediate-time HEMP (1 µs < t < 1 s) (medium);

late-time HEMP (t > 1 s) (slow).

Historically most interest has been focused on the early-time HEMP that was previously referred to as simply “HEMP”. Here we will use the term high-altitude EMP or HEMP to include all three types of waveforms. The term NEMP[2] covers many categories of nuclear EMPs including those produced by surface bursts (SREMP)[3] or created on space systems (SGEMP)[4].

2 NEMP: Nuclear Electromagnetic Pulse

3 SREMP: Source Region EMP

4 SGEMP: System Generated EMP

5 Overview of effects experience

5.1 Atmospheric testing introduction

During the era of nuclear device testing in the atmosphere, there have been documented cases where unusual electrical effects have been noted by those involved in the test programmes. In particular, Enrico Fermi has been credited with being the first person to mention the presence of electrical effects at large distances where the direct effects of blast and shock were not effective. While it is noted that different types of electromagnetic pulse (EMP) are created depending on the height of the burst, the effects of high-altitude EMP (HEMP) are of the greatest interest due to the substantial distances over which effects may occur. High-altitude EMP occurs when the nuclear detonation is higher than an approximate altitude of 30 km above the earth's surface.

While the number of high-altitude tests performed by the United States and the Soviet Union was not large (in the order of 10), most of the effects noted were from the U.S. Starfish event above Johnston Island in the Pacific Ocean and the three Soviet Union tests over Kazakhstan in 1962. In all of the reported cases, the effects that occurred were not the result of planned experiments but were mainly effects (malfunction and damage) on civil electronics equipment that were reported and later analysed to confirm that the effects were related to the particular nuclear test.

In the following clauses, several effects will be reviewed from the US high-altitude test series in 1962. In particular, problems were noted in the input circuits of radio receivers, surge arresters triggered unexpectedly on an aircraft with a trailing wire antenna, and 30 strings of streetlights reportedly failed simultaneously during the Starfish experiment [1].[5] The streetlight case is the best documented and analysed, and this will be discussed in 6.1.

Regarding the experience of the Soviet Union in the fall of 1962, failures of several long-line systems, including power and telecommunications, were reported [2]. The failures of the protection devices on a 500-km-long telecom line are also well documented and are discussed in 6.2.

5.2 Simulator testing introduction

Beginning in the late 1960s and continuing through the present time, HEMP simulators have been built by over 10 countries throughout the world. These early-time HEMP simulators are designed to produce a bounded or radiating transient electromagnetic (EM) field in a defined test (or “working”) volume (IEC 61000-4-32). The objective of most of these simulator tests was to evaluate the immunity or susceptibility of equipment and systems to HEMP disturbances. While the HEMP waveforms that are produced in the various simulators have some variation in their waveform characteristics, the standardized electric field waveform today is described as a 2,5/25 ns waveform with an amplitude of 50 kV/m (IEC 61000-2-9).

While the HEMP simulators produce reasonable representations of the incident electric and magnetic field transient pulses in a limited volume, the actual HEMP is a plane wave field with no significant variation over tens of kilometres in extent. In HEMP simulators, the fields experience losses as they propagate from the pulser, and the test volumes where the fields exhibit the correct behaviour typically vary from a few to tens of meters. Because of this fact, and the fact that no simulator produces the full range of field polarizations and angles of incidence at the earth's surface, field simulator immunity tests do not provide complete results. This is especially true in the case of cables, which are attached to systems under test. It is very difficult to test a system cable PoE properly during a HEMP simulator field test. For this reason, *conducted* environment tests, which are applied to conductive PoEs, should be performed (see IEC 61000-2-10, for example), and results of these types of tests are also described in this technical report.

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5 Figures in square brackets refer to the bibliography.

As is well known, most of the system and equipment testing in HEMP field simulators involves military equipment, which is not the subject of this technical report. On the other hand, civil electronic and power-line equipment have occasionally been tested, and the results of five well-documented sets of experiments are reported in 7.1, 7.2, 7.3, 7.4, and 7.5.

As indicated above, this technical report will also consider the reported experience of conducted testing. A review of some recent information concerning high-voltage power-line equipment testing is discussed in clause 8.

6 Atmospheric nuclear testing experience

6.1 United States atmospheric test experience – Starfish test

The Starfish nuclear device, with a yield of approximately 1 MT, was detonated about 400 km above Johnston Atoll during the night of 8 July 1962 at approximately 11:00 p.m. Hawaiian local time (0900 GMT, 9 July 1962). The line-of-sight distance from the event detonation to the Hawaiian Island of Oahu was approximately 1 400 km. See figure 1 for a more detailed description of the geometry of the burst.

Figure 2 presents the headline on the front page of the New York Tribune, European Edition -- "U.S. Fires Atomic Blast 200 Miles Over Pacific" [3] The test was described as "probably the most grandiose military-scientific experiment in history", and it "triggered spectacular space fireworks over thousands of miles for six minutes….". In Hawaii the "dazzling white burst was followed by surges of most of the colours of the rainbow, from greens and brilliant yellows through orange and glowing blood reds." Aurora lights were observed in Somoa, 2 000 miles south of the test site and in New Zealand, 4 000 miles away. It was thought that these coloured lights were due to the "dumping of space radiation particles normally held in the Van Allen belts around the earth". The article also mentions that the Atomic Energy Commission in the United States reported that two satellites were in orbit to record the effects of the blast.

In terms of the electromagnetic effects that were reported, the New York Tribune article mentions the following items:

– Radio communications were blacked out for times up to 30 min due to ionospheric disruptions.

– The geomagnetic field measured by the Geodetic Survey in Honolulu showed a very sharp departure at the time of detonation followed by five or six minutes of activity with a gradual return to normal within about 30 min. The sudden impulse was much greater than expected by the local scientist.

– In Hawaii, burglar alarms and air-raid sirens went off at the time of the test shot. Some streetlights were extinguished while others came on. "There was no immediate explanation for the electrical malfunctions."

After the test there were also reports in the local Honolulu newspapers that streetlights in different parts of Oahu had gone out at the time of the test. The Honolulu Star-Bulletin on 9 July 1962 reported on their front page that "the City-County Street Lighting Department said today shock waves from the Johnston Island nuclear blast blew out fuses in several areas of the Island last night". Some reports indicated that 30 strings of lights had failed [4]. The results described below are from a technical report written by Dr Charles Vittitoe in 1989 in which he studied one of the specific circuits that failed [5].

A summary of the Vittitoe findings is that the estimated 5,6 kV/m incident peak HEMP electric field produced sufficient current flow in the lighting circuit (see figure 3) to damage a disk cut-out in the secondary of an isolation transformer. This transformer is believed to have a rating of 4 kV with a disk cutout failure level of up to 1 200 V (at 60 Hz). For a HEMP-induced voltage waveform, the failure level was estimated by Vittitoe to be five times higher. In terms of current, the operating current was 6,6 A and the failure level was expected to begin at 14 A, while the calculated HEMP-induced common mode current was 140 A. Vittitoe concluded that the HEMP fields and induced currents were consistent with the failures