

American National Standard Guide for Electrostatic Discharge Test Methodologies and Acceptance Criteria for Electronic Equipment

C63[®]

Accredited Standards Committee C63[®]—Electromagnetic Compatibility

Accredited by the
American National Standards Institute

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American National Standards Institute

Secretariat

Institute of Electrical and Electronics Engineers, Inc

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Abstract: Expanded explanations, best practices, and guidance for avoiding the pitfalls associated with electrostatic discharge (ESD) testing to IEC and other international ESD standards are provided and should be considered a supplement to these standards, rather than a replacement. Unique ESD test procedures related to connecting charged peripherals to equipment in use are also included.

Keywords: air discharge, ANSI C63.16, contact discharge, coupling plane, direct discharge, electrostatic discharge (ESD), ESD event, ESD immunity, ESD simulator, ESD test criteria, indirect discharge

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Introduction

This introduction is not part of ANSI C63.16-2016, American National Standard Guide for Electrostatic Discharge Test Methodologies and Acceptance Criteria for Electronic Equipment.

This guide is intended to provide supplemental information for performing electrostatic discharge (ESD) testing to other established ESD standards by including information and test procedures that are not covered in those documents.^a It strives to improve product quality through proper operation in actual equipment installations. The suggestions provided herein should not be construed as mandatory and they should not be applied arbitrarily to all types of electronic equipment. Performance or acceptance test levels are not given in this guide. The specification of performance or acceptance levels for any particular type of electronic equipment remains the responsibility of the manufacturer and the users of the particular equipment.

The original 1993 version of this guide described air discharge and direct metallic contact discharge testing methodologies using two ESD simulation models, the human body with metal object model (hand/metal) and the furniture discharge model. Indirect contact testing to coupling planes was also described. Test descriptions for floor-standing and tabletop electronic equipment were given. The use of statistical criteria to determine the number of test trials based on the confidence factor desired and various pass/fail categories was described.

This latest version of ANSI C63.16 includes the following changes:

- a) Addition of unique new material on testing of charged peripherals being connected to a system and system components being placed in a docking station.
- b) Replacement of reference to specific ESD models with more generic descriptions of ESD simulators representing various ESD discharge models and provision of better guidance on the use of these simulators.
- c) Addition of information on the use of preliminary investigatory testing to identify test points, methods for visually documenting the location of those test points, and the use of a stepped approach in ratcheting up the test voltage to determine failure thresholds.
- d) Elimination of the information on ESD waveforms and waveform verification procedures in deference to IEC 61000-4-2 and other ESD standards as appropriate.
- e) Deletion of recommendations for furniture discharge testing and the use of statistical criteria for determining the number of test trials based on the desired confidence factor.

Because of the complexity of ESD, the variations in types of electronic equipment, and the many different actual use environments, it is a necessity for the reader to review and understand this guide in its entirety prior to commencing equipment testing.

^a Information on references can be found in Clause 2.

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1. Overview

1.1 Scope

This guide provides electrostatic discharge (ESD) test considerations that a manufacturer should use in assessing the expected ESD effects on products in a wide range of environments and customer use. The focus is well beyond that used to simply show that a product complies with a local, regional, or international standard or regulation. The following are included: charged peripheral testing, connector pin testing, and details on the use of ESD simulators. Finally, suggestions for assuring the safety of those who apply the ESD discharge are provided. The annexes include information on test method selection and more background on air and contact discharge for those who want to further understand the differences in these methods.

This guide is not applicable to manufacturing, service, or maintenance of equipment. Personnel who perform these activities should be trained to avoid ESD effects or damage to the equipment.

In summary, this guide has test techniques beyond those that are commonly used (e.g., IEC 61000-4-2), and hence it can be a significant tool for increasing the immunity of products to ESD events.¹

¹ Information on references can be found in Clause 2.

1.2 Purpose

This guide is intended for use by product manufacturers' internal or third-party electromagnetic compatibility (EMC) test laboratories that perform ESD immunity tests on products. It is intended to supplement and complement test methods commonly used for demonstrating compliance with ESD requirements such as IEC 61000-4-2. For completeness, the test methods and parameters described herein reference that ESD standard. The complementary test methods provided herein extend the application of ESD testing and can serve as a resource in the development of ESD test plans. This extension of testing requires more time than that needed to perform tests to international ESD standards such as IEC 61000-4-2. The payoff is that this additional ESD investigation is expected to significantly reduce the number of customer complaints by revealing responses that are not found with the usual ESD testing prescribed in existing international standards. This guide also recommends test criteria for applying ESD events and for evaluating equipment exposure and responses to ESD. The actual test levels and acceptable performance depend on criteria set by the equipment manufacturer, which might be based on customer ESD performance experience with the product and the risk of failure in a wide variety of product use environments in which ESD events have different probabilities of occurrence.

2. References

The following references are intended to assist the user of this guide and are listed here because they have direct application to this guide. The information in each of these standards as applied in this guide is to be considered informative. For all C63 documents referenced in this guide, the latest version applies. For non-C63 documents with no date specified herein, the latest version applies. Regional documents should be checked for any variations from the international standards referenced herein.

ANSI C63.14-2014, American National Standard Dictionary of Electromagnetic Compatibility (EMC) including Electromagnetic Environmental Effects (E3).²

IEC 61000-4-2, Electromagnetic compatibility (EMC)—Part 4-2: Testing and measurement techniques—Electrostatic discharge immunity test.³

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this guide, the following terms and definitions apply. ANSI C63.14 and the *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁴

actual ESD events: Non-simulated electrostatic discharges (ESDs) that occur in the intended environment of the electronic equipment.

air discharge method: A method of ESD testing in which the charged electrode of the ESD simulator approaches the equipment under test (EUT) or coupling plane regardless of the conductivity of the ESD receptor. The discharge is actuated by the dielectric breakdown of the air to the EUT or the coupling plane.

² ANSI publications are available from the American National Standards Institute (<http://www.ansi.org/>).

³ IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch/>). IEC publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org/>).

⁴ The *IEEE Standards Dictionary Online* is available at: <http://ieeexplore.ieee.org/xpls/dictionary.jsp>.

antistatic material: A material exhibiting properties that minimize charge generation when rubbed against or separated from the same or other similar material.

arrangement: The physical layout of all the parts of the EUT, local associated equipment (AE), and any associated cabling within the measurement or test area.

associated equipment (AE): The equipment needed to exercise and/or monitor the operation of the EUT.

bleed strap: a conductor containing a 470 k Ω series resistor near each end and used to bleed the charge off the EUT or coupling planes between successive ESD test events.

calibration: The set of operations that establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known values of a measurand (ISO/IEC 17025:2005).

configuration: The operational conditions of the EUT and AE, consisting of the set of hardware elements selected to comprise the EUT and AE, mode of operation used to exercise the EUT and arrangement of the EUT and AE.

contact discharge method: A method of ESD testing in which the electrode of the ESD simulator is in firm contact with a conductive surface of the EUT or coupling plane prior to discharge. The discharge is actuated by a switching device (i.e., a relay) within the simulator.

controlled ESD environment: An environment in which an attempt is made to maintain charge levels on humans and objects below a certain level. Typical control measures include humidity controls, equipment earth grounding, use of antistatic materials, ionized air, and high-resistance discharge paths for humans.

coupling plane: A metal plate to which discharges are applied to simulate electrostatic discharge to objects adjacent (vertically or horizontally) to the EUT.

degradation of performance: An undesired departure in the operational performance of any device, equipment, or system from its intended performance. (IEC 60050-161:1990 [ed. 1.0]) (See also IEC 60050-161-01)

NOTE—The term *degradation* can apply to temporary or permanent malfunction.⁵

direct application: A test in which ESD is applied to the surface or structure of the EUT.

NOTE—Applies to both air and contact discharges.

electromagnetic compatibility (EMC): The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

electrostatic discharge (ESD): A transfer of electric charge between bodies of different electric potential in proximity or through direct contact. (IEC 60050-161:1990 [ed. 1.0])

energy storage capacitor: A capacitor in the ESD simulator representing the capacity of a human body and that charges to the test voltage value.

NOTE—This element may be provided as a discrete component or a distributed capacitance.

equipment under test (EUT): A device or system being evaluated for compliance that is representative of a product to be marketed.

⁵ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

ESD event: The occurrence of a single ESD.

ESD receptor: The surface (or target) of the object at rest being subjected to the ESD event.

ESD response: The EUT reaction to ESD.

ESD simulator: A testing device used to simulate an ESD event.

ESD test voltage: The amplitude (usually expressed in kV) of the initial electrostatic voltage that exists prior to discharge.

exerciser: A device used to operate the EUT.

failure: The inability of a product to meet its operating specification.

hand/metal ESD: An ESD from an intruding human hand that occurs from an intervening metal object such as a ring, tool, key, etc. *Syn.:* **hand/metal discharge.**

holding time: The interval of time within which the decrease of the test voltage due to leakage, prior to the discharge, is not greater than 10% when measured with an instrument that has a dc resistance greater than 1016 Ω and a capacitance less than 10 pF.

human/touch ESD: The ESD that occurs directly from a human fingertip, without the presence of any metallic structure in the ESD path.

immunity (to a disturbance): The ability of a device, equipment, or system to perform without degradation in the presence of an electromagnetic disturbance.

indirect application: A test in which ESD is applied to a coupling plane in the vicinity of the EUT to simulate personnel discharge to objects that are adjacent to the EUT.

intruder: A body that is in motion in an ESD event. The intruder is usually, but not necessarily, charged relative to its surroundings. It is always at a potential different from that of the receptor.

peripheral: Equipment that can be used with the EUT, whether necessary AE or optional devices.

NOTE—Examples of optional peripheral devices include battery packs, external memory, and other equipment not essential to exercise or monitor the operation of the EUT.

reference ground plane (RGP): A flat, conductive surface whose potential is used as a common reference.

rise time: The interval of time between the instants at which the instantaneous value of a pulse first reaches the specified lower and upper limits.

NOTE—Unless otherwise specified, the lower and upper values are fixed at 10% and 90% of the pulse magnitude.

simulated ESD: An ESD that originates from an ESD simulator.

simulator approach speed: The rate at which an air discharge ESD simulator approaches the EUT or coupling plane.

table ESD test: An indirect application in which ESD is applied to the horizontal coupling plane (HCP).

uncontrolled ESD environment: An environment in which no attempt is made to maintain charge levels on humans and objects below a certain level.

undesirable response rate: The percentage of undesirable ESD responses exhibited by the EUT when subjected to a specific number of ESD events.

verification: Confirmation by examination and provision of objective evidence that specified requirements have been met.

3.2 Acronyms and abbreviations

AE	associated equipment
ANSI	American National Standards Institute
CISPR	Comité International Spécial des Perturbations Radioélectriques (International Special Committee on Radio Interference)
EMC	electromagnetic compatibility
eSATA	external serial advanced technology attachment
ESD	electrostatic discharge
EUT	equipment under test
HCP	horizontal coupling plane
HDMI	high definition multimedia interface
I/O	input/output
IEC	International Electrotechnical Commission
IEEE	The Institute of Electrical and Electronics Engineers
LAN	local area network
RGP	reference ground plane
RH	relative humidity
USB	universal serial bus
VCP	vertical coupling plane
VGA	video graphics array

4. Cautions for test operators

The ESD simulator is a high-voltage instrument. Some are capable of producing voltage levels up to 25 kV. Although the energy level of a single discharge at this voltage is below that which is considered lethal for a normal, healthy adult, this energy level can give the user an unpleasant shock or cause a physiological reaction, pain or muscle spasm, which can result in injury. Radio-frequency (RF) fields that have the

potential to cause damage to medical implants can also be generated by ESD simulators. Therefore, there is an inherent danger when performing ESD tests.

Operating and working around high-voltage instruments or devices requires a high degree of responsibility, care, and common sense. Normal high-voltage laboratory practices should be exercised when performing these tests. Personnel who are not involved in the testing should not be in the immediate area during ESD testing. The ESD simulator manufacturer's cautions should be followed.

WARNING

ESD testing can be hazardous to wearers of electronic life-support equipment and medical implants. Personnel with pacemakers, medical implants, heart problems, nervous disorders, or similar problems should not operate ESD simulators or be present in the immediate area during ESD testing.

5. Laboratory test conditions

5.1 General

The intent of ESD testing in the laboratory is to simulate both the level and type of ESD occurrences that are expected to be experienced by the product in use. This simulation is intended to be representative of, but not necessarily identical to, actual ESD.

In order to reduce the effect of environmental parameters on the test results, ESD testing should be performed under the conditions specified in this clause.

5.2 Climatic conditions

Climatic conditions appropriate for ESD testing of the EUT should be specified by the manufacturer. The following ranges of conditions are typical (see IEC 61000-4-2):

- a) Temperature: 15 °C to 35 °C (59 °F to 95 °F)
- b) Relative humidity (RH): 30% to 60%
- c) Atmospheric pressure: 86 kPa to 106 kPa

NOTE 1—Tests can be performed outside the typical range of climatic conditions. However, the results could be significantly affected by increased RH and variations in temperature.

NOTE 2—It might be more difficult to maintain these climatic conditions during in situ testing.

The actual environmental conditions existing during the test should be recorded on the data sheet (see 8.3).

5.3 Electromagnetic conditions

The ambient electromagnetic conditions should be such as not to influence the results of ESD testing.

5.4 Test site description

5.4.1 General

Care should be exercised when selecting a site at which to perform ESD testing. The ESD impulse produces a broad spectral distribution of energy, and these emissions can cause damage or malfunction of unprotected equipment in the immediate area. Also, other equipment in the immediate area can interfere with the ESD test. The ESD test site, therefore, should be located in an area that is of sufficient size so that there is adequate distance from other equipment to reduce the potential for interference.

Accordingly, it is recommended that a clear-area radius of at least 0.8 m be provided around the EUT and to any other metallic structure, including walls, so as not to impact the ESD test. Where possible, the EUT should be placed in a dedicated room with electrical isolation from unrelated equipment. The dedicated room can be an environmental room, which is typically a fabricated metal structure that would enable control of temperature and RH levels in the test environment. Because RH levels at the low end of the typical climatic conditions specified in 5.2 are more likely to reveal ESD response or failure, it is recommended that the EUT be evaluated at those lower RH levels. In addition, the low end of the typical RH levels specified in 5.2, or lower as reported from customer sites, might be necessary to evaluate, duplicate, or troubleshoot field issues.

5.4.2 Size of reference ground plane (RGP)

An RGP of sufficient size to provide a continuous reference for the EUT, ESD simulator, and operator should be provided as part of the test site. The RGP on the floor should extend beyond the edges of the EUT at least 0.5 m for equipment up to 1 m in height, as well as for a tabletop test. The RGP should be connected to the protective grounding system. Local safety regulations should always be met. See 6.3.2 for information on EUT ground connections. For EUTs that consist of both tabletop and floor-standing equipment, the RGP should extend at least 0.5 m beyond all parts of the EUT.

5.4.3 Insulator materials

An insulating support $0.5 \text{ mm} \pm 0.05 \text{ mm}$ in thickness, having a relative dielectric constant of 3 to 6, is used to separate the EUT and its associated cabling from metallic surfaces such as the horizontal coupling plane (HCP) for table-top equipment and the RGP for floor-standing equipment. The insulating material should be of sufficient strength to last a reasonable period of time and be resistant to being pierced by a sharp edge of the EUT. In addition, an insulating pallet, 5 cm to 15 cm in thickness, may be placed beneath floor-standing equipment.

6. Test methods

6.1 Test method guidance

6.1.1 ESD simulator

The test procedures in this guide are based on the use of an ESD simulator (sometimes called an ESD gun or ESD pistol). The particular simulator used should be appropriate for the EUT, the applicable standard, and the conditions in the EUT's intended use environment. Simulators are available that represent the

hand/metal discharge model and the human/touch discharge model. Simulators representing other relevant ESD discharge models might be available. See Clause 9.

6.1.2 Air or contact ESD methods

Air discharges, contact discharges, or both might be appropriate when testing EUTs. The user of this guide should review the advantages and disadvantages of each method, as described in Annex A, prior to selecting which test method to use. However, the general guidance for selecting the discharge method(s) used is as follows:

- a) For EUTs with conductive surfaces, the contact discharge method should be used on those surfaces.
- b) For EUTs with insulating surfaces, the air discharge method should be used on those surfaces.
- c) When performing indirect ESD testing using coupling planes, the contact discharge test method should be used.

6.2 Application of the discharges

Discharges should be applied to all selected test points with the EUT operating normally. These test methods may also be applied to EUTs in a nonoperational state (e.g., not connected to an ac power source) to check for destructive responses. Direct contact discharges and air discharges, as well as indirect contact discharges to coupling planes, should be applied where appropriate as determined by the particular EUT and test points selected (see 6.4.3).

EUT response can be affected by the polarity of the discharge. Both polarities of discharge (positive and negative) should be used during exploratory testing to determine their effect on the EUT.

6.3 Laboratory test setup

6.3.1 General

Tests performed in laboratories are the preferred method for use in following this guide. However, unique in situ tests are acceptable under the limited conditions specified in 6.5.

6.3.2 EUT configuration

6.3.2.1 General

The EUT should be configured in a manner representative of the equipment as typically used. A product that is marketed to be operated as a stand-alone device should be tested by itself. Conversely, a product designed and marketed to be operated as part of a multiunit system should be tested in an arrangement with peripherals, accessories, connecting cables, etc., attached and operating in a manner representative of actual use. Configuration of the equipment also includes exercising the equipment in all representative operating modes during the testing process. Multiple samples of the EUT should be available so that if one fails, a substitute EUT can be used to continue the testing. If the EUT needs to be connected to an exerciser during the test, the exerciser should be immune to ESD to facilitate a valid test.

Ground connections other than those specified in the installation specifications should not be used during testing. Some EUTs might not have a ground connection. Examples include battery-operated equipment, with or without a battery charger (ungrounded power cable), and double-insulated equipment.

The EUT configuration, cables, modes of operation, and software used should be documented in the test report (see Clause 8). The disposition of the power and signal cables should be representative of typical installation practice. Less than maximum cable lengths are allowed. The cable lengths and layout used should also be documented.

6.3.2.2 Tabletop equipment

The test setup for tabletop equipment uses a nonconductive table, 1.6 m by 0.8 m, and 0.8 m high, standing on the RGP. An HCP of the same size as the standard tabletop is placed on the tabletop. The test setup also includes a vertical coupling plane (VCP), 0.5 m square, that is movable so that it can be spaced 0.1 m from the various sides of the EUT.

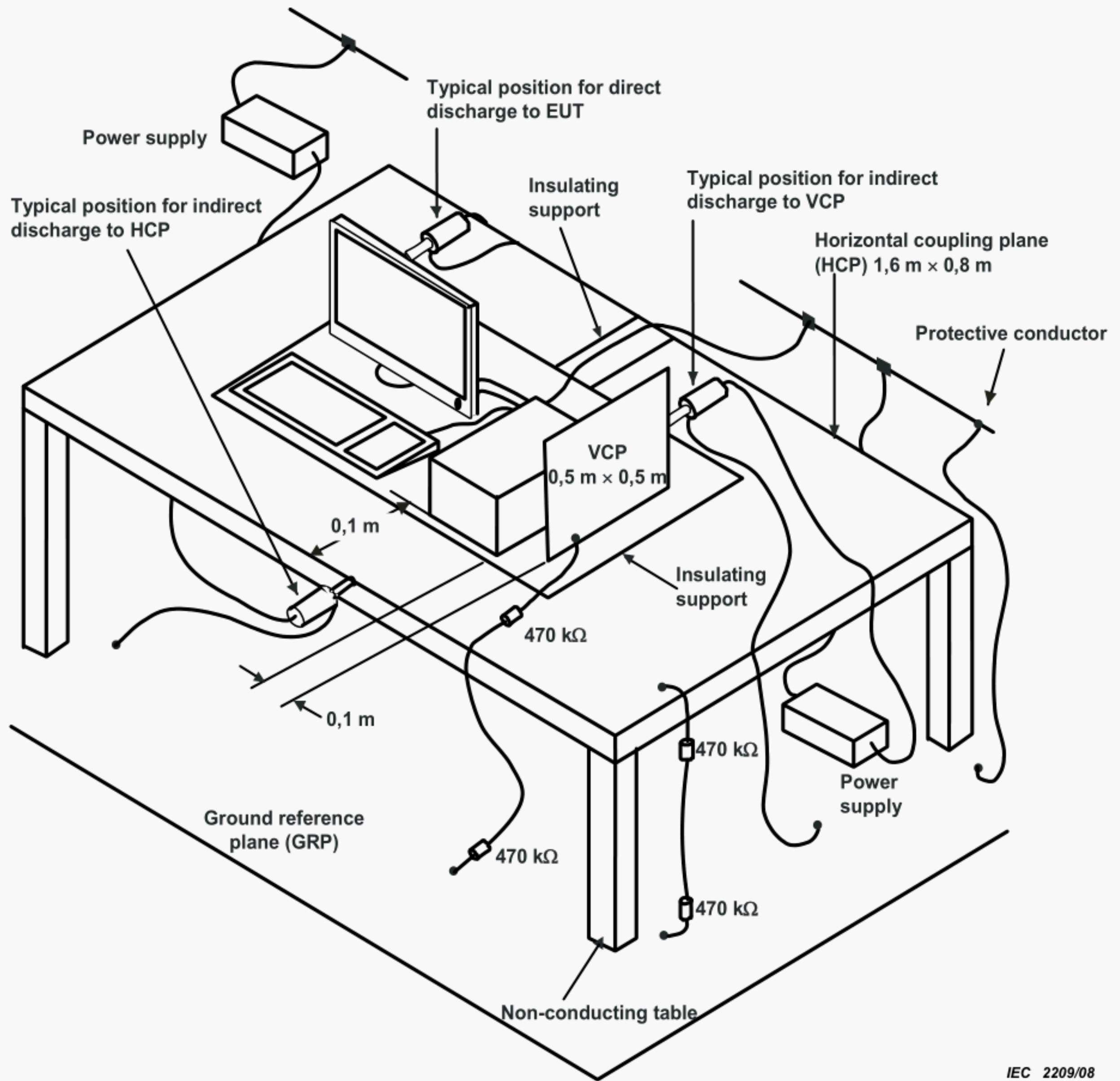
The EUT and cables are isolated from the tabletop or coupling plane by an insulating support $0.5 \text{ mm} \pm 0.05 \text{ mm}$ in thickness with the characteristics specified in 5.4.3. An example of the test setup for tabletop equipment having a ground connection to the mains is shown in Figure 1. A corresponding example of the test setup for tabletop equipment without a ground connection to the mains is shown in Figure 2.

If the EUT is too large to be located 0.1 m minimum from all sides of the HCP, an additional, identical HCP at the same height above the RGP is used, placed 0.3 m from the first, with the short sides adjacent. The HCPs are not bonded together, other than via the resistive straps to the RGP.

Any mounting feet associated with the EUT should remain in place.

The RGP is often made of two pieces by necessity. These two pieces should be joined by a low-impedance counter-sunk “strap” joint with a conductive gasket used at the interface to provide a low-impedance connection between the halves. A 10 mm bolt with washer and nut is often affixed up through the plane for a convenient connection to the ESD simulator power supply and the local green-wire ground. The edges of the 1.8 m x 2.6 m plane should be secured to the floor to prevent a trip hazard.

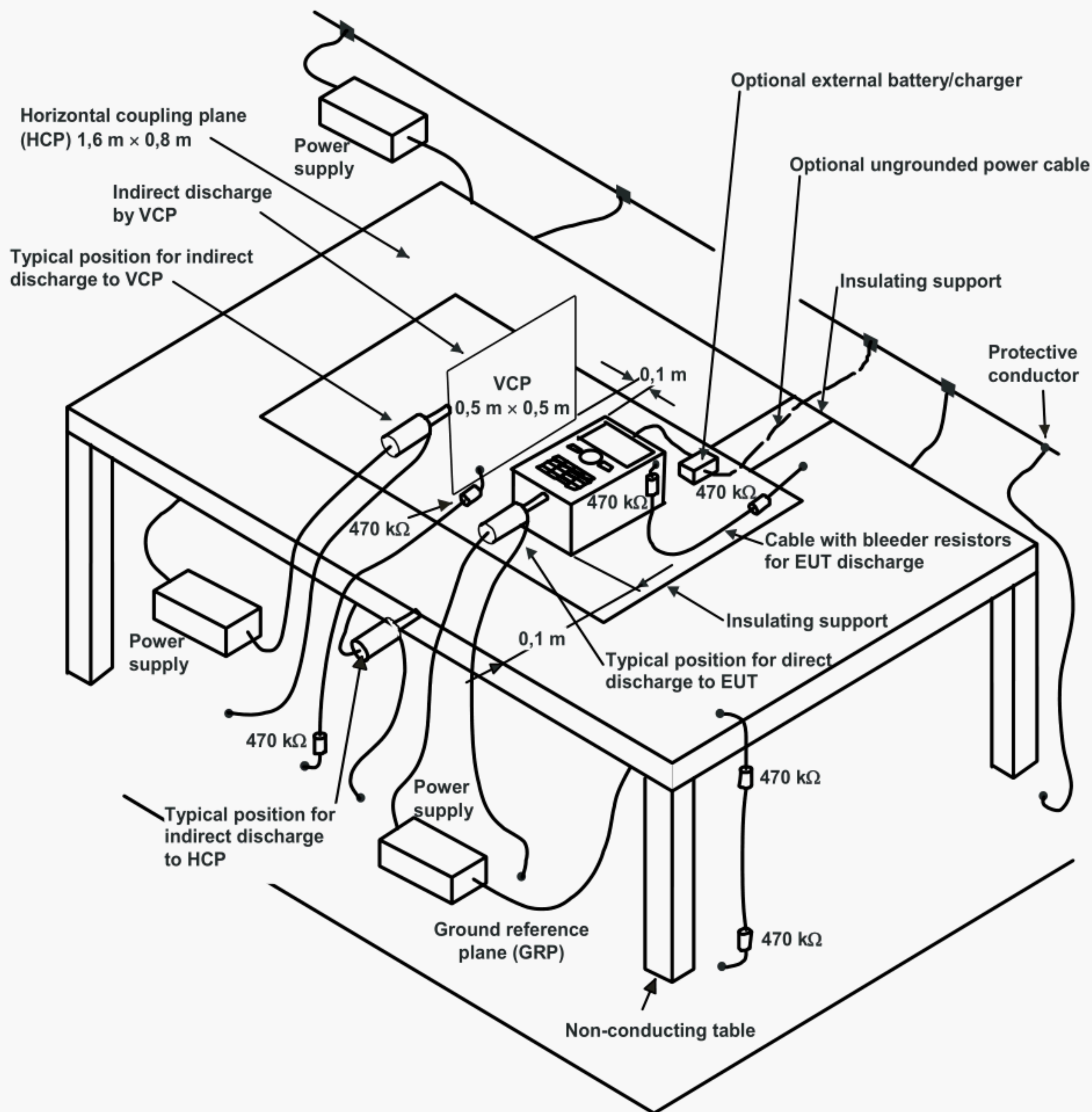
The “insulating support” noted in Figure 4 of IEC 61000-4-2 is placed under the tabletop EUT and its associated cabling. The thickness is specified as $0.5 \text{ mm} \pm 0.05 \text{ mm}$. It should be immune to variations in relative humidity and resistant to deformation and cracking. It should ideally have a dielectric constant near 1. An example would be a clear polycarbonate sheet. The length and width dimensions are not critical, but the support should provide insulation under the EUT and all associated cabling. A sheet the size of the HCP is allowed.



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Figure 1—Test setup for grounded tabletop equipment—Laboratory tests



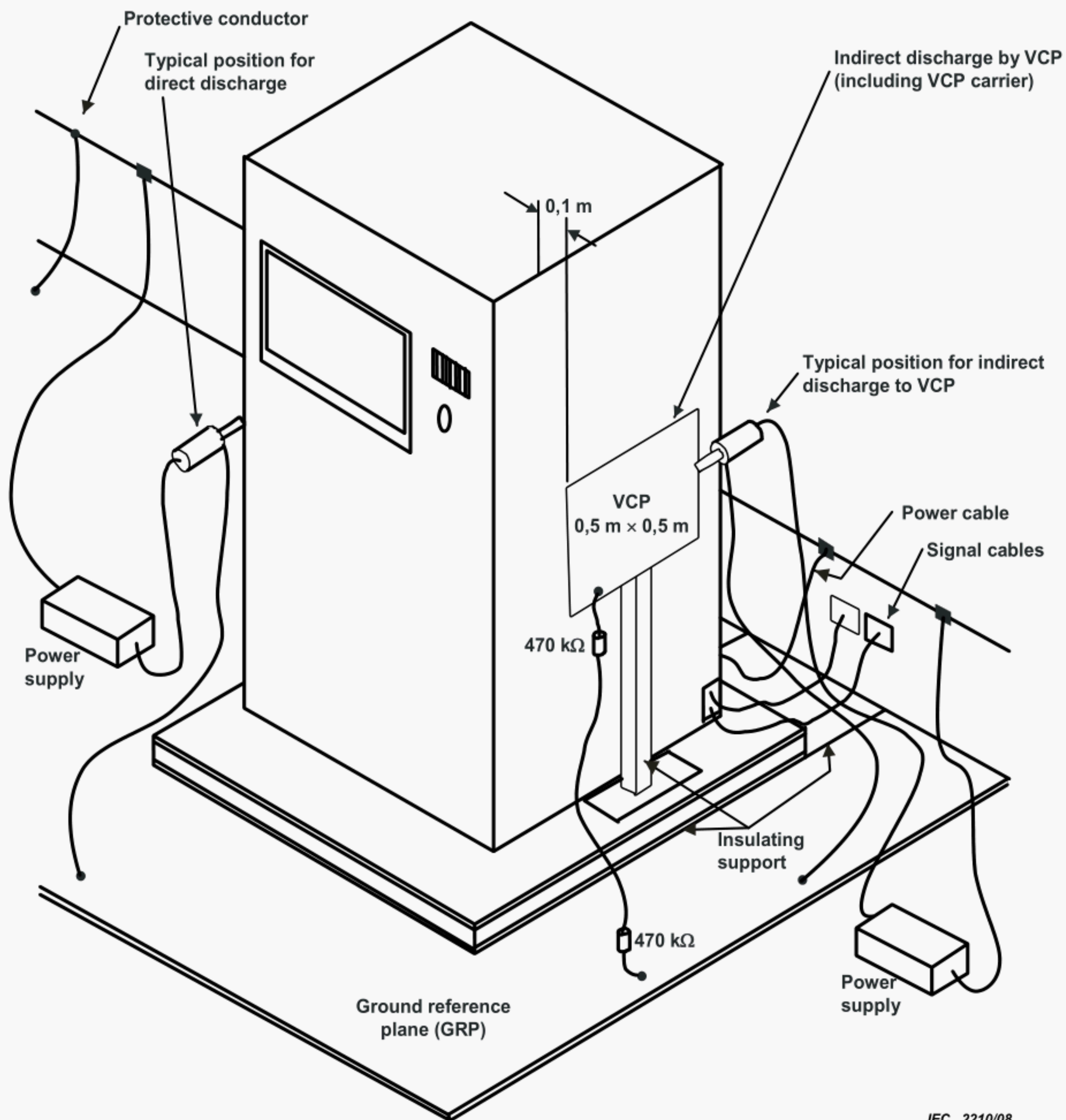
IEC 2211/08

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Figure 2—Test setup for ungrounded tabletop equipment—Laboratory tests

6.3.2.3 Floor-standing equipment

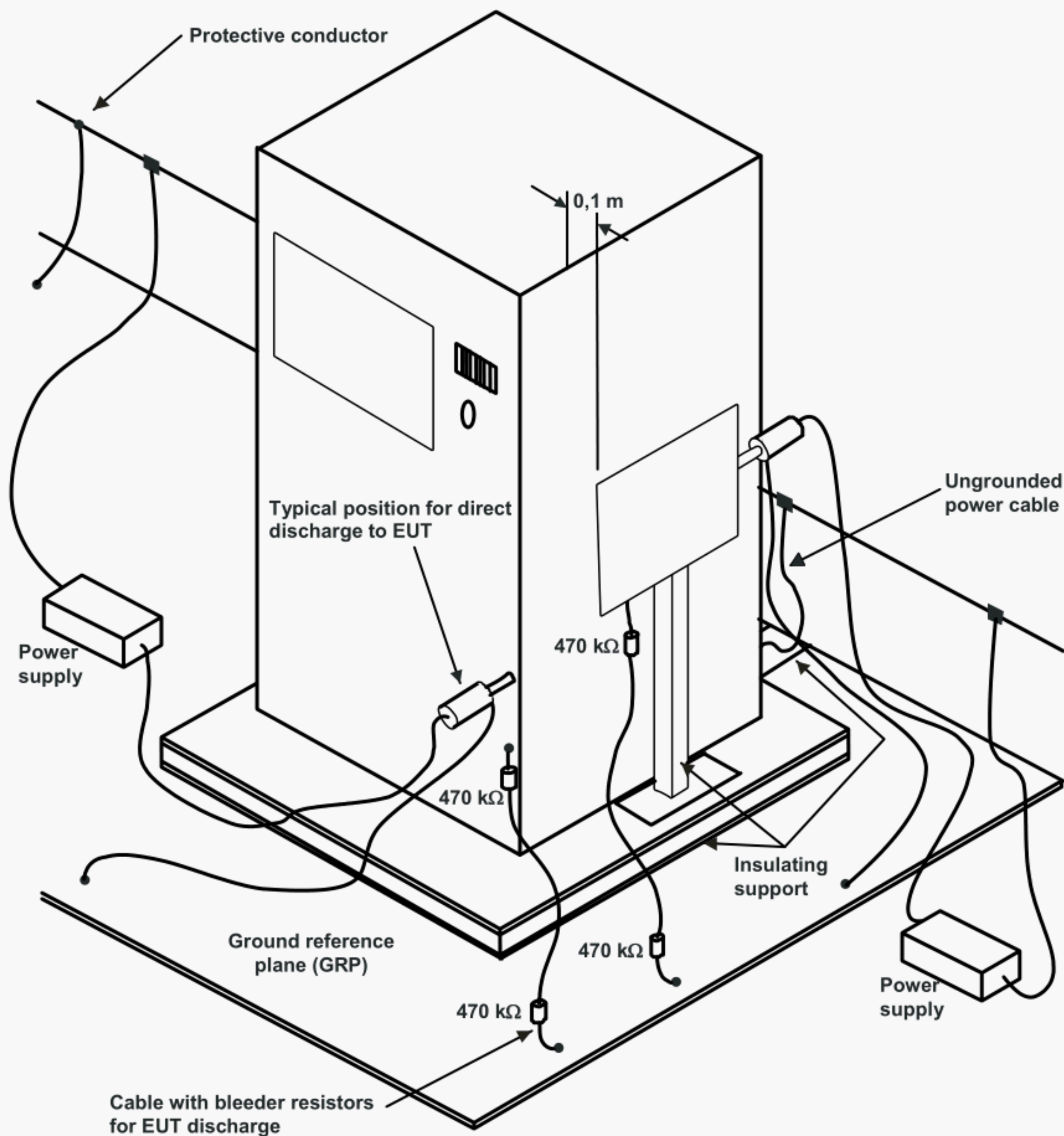
The EUT and cables are isolated from the RGP by an insulating support $0.5 \text{ mm} \pm 0.05 \text{ mm}$ in thickness with the characteristics specified in 5.4.3 and placed directly on top of the RGP. An additional insulating pallet, 5 cm to 15 cm in thickness (a typical wooden pallet is 15 cm thick), may be used on top of the 0.5 mm insulator to support the EUT. Any mounting feet, rollers, or wheels that are part of the EUT should remain in place. A VCP, 0.5 m square, is spaced 0.1 m from the EUT. It is movable so that it may be placed on various sides of the EUT and raised or lowered as appropriate. Refer to Figure 3 for a typical setup of floor-standing equipment having a ground connection to the mains. Figure 4 shows a corresponding setup for floor-standing equipment without a ground connection to the mains.



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Figure 3—Test setup for grounded floor-standing equipment—Laboratory tests



IEC 2212/08

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Figure 4—Test setup for ungrounded floor-standing equipment—Laboratory tests

6.3.3 Simulator return cable

The discharge return cable required in ESD simulators is connected to the RGP as shown in Figure 1 through Figure 4. A cable longer than 2 m might be necessary to apply discharges to selected points. When testing such points while using a longer cable, the excess length over 2 m should be bundled non-inductively off the RGP to avoid additional loops in the test circuit. For all discharge return cable lengths used, the simulator should meet its specified waveform requirements. The connection of the simulator return cable to the RGP and all bonding should be of low impedance at high frequencies. The discharge return cable of the simulator (if required) should be positioned at least 0.2 m from the EUT while the

discharge is being applied. This is necessary to prevent radiation from this cable from affecting the test results. The end of the discharge return cable connected to the simulator might be closer to the EUT.

Ideally, the 2 m ground return cable used during calibration should be used during the test. Moving the grounding point as required to allow complete EUT coverage would be one solution. For large EUTs, this might require moving the GRP to accommodate discharges to selected test points.

Adding an extension to the simulator discharge return cable should be avoided because this could alter the discharge waveform characteristics and cause excessive radiation from the cable. Bundling of this cable can also cause changes to the shape of the waveform.

6.3.4 VCP/HCP coupling to RGP

The coupling plane is connected to the RGP via a bleed strap to prevent charge buildup. The 470 k Ω resistors at each end of the bleed strap are needed to reduce the current so that it does not generate a field that might corrupt the measurement. The resistors should have a withstand voltage greater than 50% of the applied voltage to prevent breakdown.

The bleed strap should be securely connected to the conductive ground plane. Because the current that is flowing on the bleed path is small (for example, 15 kV divided by 940 k Ω is \sim 16 mA), there is no need to have a complex circuit for connection to the RGP.

6.4 Laboratory test procedures

6.4.1 EUT software

Choose test software for the EUT that exercises the modes of normal operation. Where it is impractical to exercise all modes, e.g., because of EUT complexity, exercise either of the following:

- a) Many operating modes selected randomly
- b) Specific modes expected or known to exhibit the most susceptibility, using good engineering judgment

As the complexity of the EUT decreases, the probability of evaluating all or most modes of operation increases.

6.4.2 Automatic retry

When testing an EUT that has automatic retry or specified operator intervention retry, the ESD pulse repetition rate may be adjusted so that after an EUT response has occurred, at least one ESD-free retry operation is allowed before another discharge is applied. This measure is necessary to allow the EUT an opportunity to clear a recoverable response, should one occur. If another ESD event is permitted prior to the retry operation, the EUT would be denied this opportunity and might instead log an error requiring operator attention. Permitting the EUT one error-free operation avoids this.

When excessive retry times occur during execution of the test program (i.e., greater than 5% of the total time), that portion of the test program exhibiting this characteristic should be disabled after successful retry verification to allow the rest of the software and electronics to be exposed to ESD.

6.4.3 Test points

6.4.3.1 Selection of test points

The electrostatic discharges should be applied to the EUT at any operator-accessible points and, in the case of tabletop equipment, also to the edge of the HCP supporting the EUT and to the vertical edge of the VCP.

The EUT test points to be considered should include the following locations, as applicable:

- a) Representative points in the control or keyboard area and any other point of man-machine communication devices such as switches, knobs, buttons, and other operator-accessible areas, e.g., cable connectors.
- b) Exterior metal surfaces, whether grounded or electrically isolated from ground. This should include metal plated decorative bezels, badges, labels, and nameplates.
- c) Areas on insulated enclosures that are nearest to conductive portions of the enclosed circuitry.
- d) Other points that are likely to be touched by the human body, such as any surface of a portable product, or by another charged surface, especially near enclosure seams and apertures.
- e) Additional mechanical connections, such as metal sleeves that mate with studs in base units in EUTs that are designed to be docked (e.g., laptops, personal music players, phones).
- f) Connector pins if they are likely to be handled or touched in the EUT's intended environment, as described in 6.4.3.2. Examples are exposed battery or battery-charger contacts, signal pins on USB connectors, or docking contacts on portable devices.

The choice of test levels is specific to the product and its intended environment.

6.4.3.2 Accessible parts

Accessible parts are those that are typically touched by the user during the operation and/or maintenance of the product. It is noted that, in general, this means recessed pins that are not easily touched by the user should not be subject to the ESD test. However, if there is a condition where these pins might be touched, the test should be performed. Examples of pins to be ESD tested can be found in 7.2.2.3. An example of a pin connection that should not be subject to an ESD event is a signal pin that is recessed behind a protective metallic cowl, collar, or backshell, which itself is subject to discharges. In any case, this judgment is specific to the product.

It is prudent for unused pin sockets to have a cover to hide sensitive circuit pins in case there is a nearby ESD discharge that might have a path into the unused connection. Low-level signal pins (e.g., USB connectors) are not used as test points because of the low probability of actual ESD contact. Large exposed connector pins and terminals (e.g., battery connectors) that might be contacted by the user may be used as test points, depending on the EUT's intended application and the terminals' accessibility.

6.4.3.3 Selection and application of test levels to test points

Investigatory testing is used for guidance in the selection of test points. Because the frequency content delivered in air discharge changes both with arc length and test voltage, gradually-increasing voltage levels should be applied during investigatory testing. Beginning the investigation at lower test levels reduces the chance of EUT damage and increases the likelihood that upsets are noted.

Air discharge investigation on accessible nonconductive parts of the EUT is performed first, followed by contact discharge investigation on conductive and accessible parts of the EUT and the edges of the VCP

and HCP. This is accomplished by setting the ESD generator alternately to air and contact discharge modes and 20 discharges per second so upsets can be noted quickly. The object of this testing is to indicate susceptible areas of the EUT so that more detailed testing can be performed in those areas.

The voltage is set to a lower level (e.g., 2 kV) and the air discharge tip is oriented perpendicular to the nonconductive areas of the product being investigated and scanned at various separation distances to identify candidate test points. If no upsets are noted at the initial test voltage, the voltage is increased to the next level (e.g., 4 kV) and the investigation continues.

Contact discharge investigation on conductive parts of the EUT is evaluated similarly, starting at a lower test level and performed at the same 20 Hz repetition rate. Sensitive points or areas that indicated an upset during the investigations are thus identified as nonconductive (air) and conductive (contact) test points for final compliance testing.

6.4.3.4 Identification of test points

Test points selected for contact discharge and air discharge during investigatory testing should be indicated either by stick-on arrows applied to the EUT or arrows and labels added to photographs of the EUT. Color coding or shading can be used to distinguish between contact and air discharge test points.

6.4.3.5 Additional considerations

When selecting test points, the discharges should be applied to all equipment and peripherals that form the EUT system. Special consideration should be given to the intended operating environment of the EUT (e.g., range of relative humidity, likelihood of customer contact). This might require an environmental test chamber or test lab area for controlling relative humidity, which should be verified using a calibrated hygrometer.

Additional guidance on selecting test points:

- a) Investigate surfaces that might become vulnerable to discharges if the EUT is uniquely installed or handled (e.g., wall mounted).
- b) Painted metal surfaces are considered “insulating” for purposes of testing and should only be subjected to air discharges. However, painted metal surfaces near connectors might be subject to scratching in the process of connecting and disconnecting cables. In addition, paint on enclosure feet or flat bottom surfaces of heavy equipment might be easily scratched in normal handling. If the paint in such areas can be easily scratched, the paint should be penetrated and contact discharges should also be applied.
- c) The application of discharges to any point of the equipment that is accessible only during maintenance is not required unless agreed upon by the manufacturer and the purchaser.
- d) Consideration should be given to the dimensions of the EUT. Larger EUTs likely require more test points. If the EUT is excessively large (e.g., multiple cabinets, large machine) it might be necessary to identify test points across broad surfaces that, while not regularly subject to user handling, might come into contact with other discharge sources (e.g., rotating-brush machinery, equipment carts). Field experience with similar products should also be considered.
- e) Complex or large EUT surface areas raise additional considerations:
 - 1) A complex layout can be composed of either an EUT that is large with extensive surface areas or one that is part of a system of two or more components (racks, shelves, and adjacent cabinets or associated equipment). In these situations, ESD test points for contact or air discharge should be clustered on these large surfaces at any opening or near any penetrations for ventilation, cabling, plug-in modules or cards, or interface devices. When performing

discharges to a vertical coupling plane 10 cm away from these surfaces, the plane should be moved along the surface to provide complete coverage.

- 2) The coupling plane should be placed at least near the same opening or penetrations as for the air or contact discharge noted above.

6.4.3.6 Applicability of test results and potential mitigations

This guide applies only to ESD testing. How the manufacturer changes the product to make it survive an ESD event is up to the manufacturer and may include, but is not limited to:

- a) If hardware damage occurs, then it is likely that hardware mitigations are needed.
- b) If only system upset occurs, then it is likely that software mitigations (modifications) could be sufficient; however, hardware mitigations might be needed as well.

6.4.4 Direct application of discharge to the EUT

6.4.4.1 Test voltage steps

Incrementally increasing test levels are required to expose the product to the full range of waveform amplitudes and frequency content. Some products have a tendency to exhibit susceptibility responses when exposed to some ESD voltages but not others (King [B3]⁶).

When performing air discharge testing, the test voltage should be increased in steps from the minimum to the selected test severity level. The lower test level has a faster current rise time that might disrupt the operation of the device. It is also helpful to start contact discharge testing at a low voltage level and increase in steps to the maximum specified test level if it is desirable to determine the threshold of failure.

In the absence of other requirements, it is recommended to use 1 kV steps for contact discharge and 2 kV steps for air discharge. The lower test level starting point is suggested to be at 2 kV or 4 kV. The final severity level should not exceed the manufacturer's specified value or the required compliance level in order to avoid damage to the equipment.

6.4.4.2 Time between ESD events

The time interval between successive single discharges should be as long as necessary to determine whether a system failure has occurred. An initial value greater than 100 ms is recommended. Higher repetition rates can be used (shorter time intervals) as long as the requirements of 6.4.2 and 6.4.4.6 are met.

Higher repetition rates are advantageous to those who want to perform multi-trial ESD testing in order to expedite the test time (Pratt [B4]).

6.4.4.3 Location of ESD simulator

The ESD simulator is positioned so that the discharge tip is perpendicular to the EUT's surface for direct discharge, and parallel to the coupling plane (either HCP or VCP) for indirect discharge. An indirect discharge should be applied to the edge of the coupling plane with the ESD simulator oriented coplanar with the coupling plane (see Figure 1).

⁶ The numbers in brackets correspond to those of the bibliography in Annex C.

6.4.4.4 Electrode connection for contact discharge method

In the case of direct contact discharges, the tip of the discharge electrode is placed in contact with a conducting point on the EUT before the discharge switch is actuated. The direct contact discharge test method is normally not applied to insulating surfaces. For exceptions, see 6.4.3.5.

6.4.4.5 Speed of approach for air discharge method

The speed of approach of the discharge electrode is a critical factor in the rise time and amplitude of the ESD event (Daout and Ryser [B1]). The speed of approach should be between 0.1 m/s to 0.5 m/s for any tabletop or floor-standing test. While this might be the speed that theoretically is needed, it is not practically verifiable unless a mechanical transport device is used. An alternative to using such a transport device is to start from a fixed separation distance from the device (not at varying distances). From this starting distance, the tester moves the ESD simulator toward the device at varying speeds. For example, this starting separation distance could be 20 cm to 40 cm away from the device. Successive approaches from this starting separation distance can be traversed in approximately 1 s to the point where an arc occurs. The simulator should not be stopped when the arc occurs, but rather should be followed through until the electrode touches the surface (without causing mechanical damage) (Pratt, Rhoades, and Staggs [B5]) and/or the point at which a device error, significant performance degradation, or damage occurs.

6.4.4.6 EUT charge buildup

If the EUT has conductive or nonconductive surfaces that acquire a charge, such surfaces need to be discharged between successive ESD pulses. This is particularly important when testing EUTs that do not have a ground connection. A bleed strap is recommended for discharging conductive surfaces. The bleed strap may remain connected to the conductive surface of the EUT if it does not affect the test results. The other end of the bleed strap should be connected to the HCP when testing tabletop equipment (see Figure 2) and to the RGP when testing floor-standing equipment (see Figure 4). A bleed strap with a conductive brush, typically with carbon fiber bristles, added to the EUT end of the bleed strap is recommended for discharging nonconductive surfaces. The conductive brush may also be used for discharging conductive surfaces.

The discharge of the EUT between pulses can be enhanced by placing an air ionizer near it.

A noncontacting electrostatic voltmeter may be held within an inch or less of the EUT surface to measure the residual charge. Such a meter does not itself perturb, load, or equalize the charge, but it can be used to determine if air ionizers and ESD brushes are effective in removing the charge.

6.4.5 Indirect application of the discharge

Discharges to objects placed or installed near the EUT are simulated by applying the discharges of the ESD simulator to a coupling plane (HCP or VCP) as shown in Figure 1 through Figure 4.

The contact discharge mode is the preferred method for performing indirect ESD testing.

6.4.5.1 HCP under EUT (tabletop test)

Discharges should be applied to the HCP at points on each side of the EUT. The ESD pulse should be applied to the center of the edges of the HCP (see Figure 1 and Figure 2).

6.4.5.2 VCP

A practical implementation of a VCP consists of a rigid metal plate with nonconductive 10 cm long spacers mounted on one side and a nonconductive handle on the other side. One such VCP is shown being held against the side of a floor-standing EUT in Figure 5a. A similar implementation is shown in Figure 5b with the handle fitted over a wedge-shaped wooden support for testing tabletop equipment. Examples of this latter implementation being used with flat-sided and irregularly-shaped EUTs are shown in Figure 5c and Figure 5d. Discharges should be applied to the center of the vertical edges of the VCP (see Figure 1 through Figure 4).



a) Floor-standing EUT



b) Tabletop implementation



c) Flat-sided tabletop EUT



d) Irregularly-shaped tabletop EUT

Figure 5—VCP examples

6.5 In situ testing

6.5.1 In situ test setup

In situ tests are more difficult to instrument and perform. However, ESD tests are recommended in this instance to show any vulnerability of systems installed at the customer premises. Examples include large systems of multiple cabinets and manufacturing equipment that require in situ assembly. Therefore these tests are used primarily when the equipment (product) being tested is assembled only at a customer premises and not at any test facility. The results are only applicable to the unique installation where the ESD testing is performed.

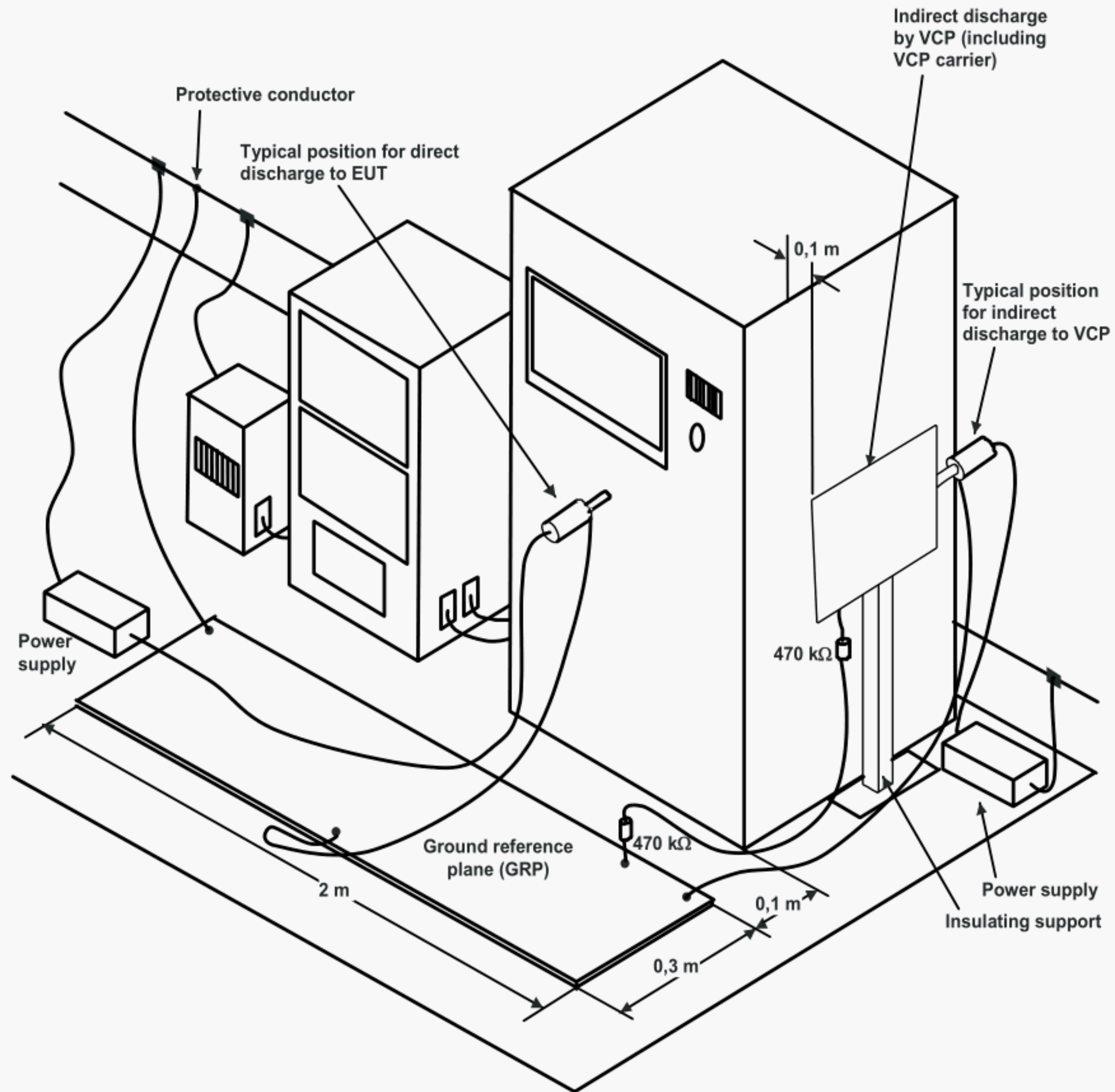
NOTE 1—It should be considered that other collocated equipment might be adversely affected during these tests.

The equipment or system should be tested in the final installed configuration. In order to facilitate a connection for the discharge return ground cable, a RGP should be placed on the floor of the installation close to the EUT at about 0.1 m distance. The RGP should satisfy the requirements of 5.4.2. Where this is not possible because of insufficient space, a smaller plane may be used.

The RGP should be connected to the facility ground. Where this is not possible, the RGP should be connected to the ground terminal of the EUT.

The discharge return cable of the ESD simulator should be connected to the RGP at a point close to the EUT. Where the EUT is installed on an ungrounded metal table, the table should be connected to the RGP via a strap with a 470 k Ω resistor located at each end to prevent a buildup of charge. An example of the setup for in situ testing is shown in Figure 6.

NOTE 2—See 6.3.4 for bleed strap resistor information.



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Figure 6—Example of test setup for in situ tests

6.5.2 In situ test procedure

EUT software, automatic retry, selection of test points, direct application of discharges, and indirect application of discharges follow the recommendations in 6.4.1, 6.4.2, 6.4.3, 6.4.4, and 6.4.5, respectively. In the case where the manufacturer has indicated specific test points, those should be included in the list of test points that are investigated. As stated above, indirect discharges from objects near the EUT are simulated using the HCP and VCP as shown in Figure 1 through Figure 4.

7. Unique ESD test procedures

7.1 General

This clause identifies unique ESD test procedures applicable to the mating of charged devices with uncharged devices. Charged peripheral testing is designed to simulate the effects of a charged auxiliary device being mated to the EUT and includes direct pin injection, connector shell contact discharge testing, and charged peripheral insertion. Charged EUT testing is designed to simulate a charged EUT being mated to a grounded peripheral or associated equipment.

An ESD simulator with a fast rise time tip (see Clause 9) is recommended for some of the tests in the following subclauses.

7.2 Charged peripheral and associated equipment testing

7.2.1 Overview

This procedure evaluates the effect of charged peripherals and associated equipment or battery packs being attached to a system and is performed through direct pin injection, connector shell contact discharge, or charged peripheral insertion.

7.2.2 Direct pin injection

7.2.2.1 Direct pin injection test setup

For direct pin injection testing, the EUT should be configured with minimal cabling, connecting only that cabling required for operating and verifying the functionality of the device. The EUT should be connected to mains ground during the test to allow bleed-off of ESD charge. The connection to mains ground should be accomplished through attachment of a 3-wire ac adapter/power supply, or through the use of an attached mains grounded peripheral (monitor, printer, etc.).

7.2.2.2 Direct pin injection test procedure

An ESD simulator with the normal rise time discharge module and contact discharge tip specified in IEC 61000-4-2 is recommended for direct pin injection testing of all ports except the audio port, which should be tested using the fast rise time discharge tip. Ten discharges of each polarity at each required voltage should be applied.

The contact discharge should be applied directly to the pin under test where possible. Breakout cables can be used to allow access to individual pins if necessary, but should not exceed 10 cm in length. Each pin of each required port should be tested.

Refer to Figure 7 for typical performance of direct pin injection testing.



USB port



Battery port

Figure 7—Typical direct pin injection

7.2.2.3 Direct pin injection examples

Examples of ports on computers and similar electronic equipment where the use of direct pin injection testing is applicable include Ethernet, USB, eSATA, HDMI, audio, video, battery, etc. Test levels of ± 1 kV or ± 2 kV are recommended to screen for extreme vulnerability. Higher test levels might be necessary for some environments.

7.2.3 Connector shell contact discharge

7.2.3.1 Connector shell contact discharge test setup

For connector shell contact discharge testing, the EUT should be configured with minimal cabling, connecting only that cabling required for operating and verifying the functionality of the device. The EUT should be connected to mains ground during the test to allow bleed-off of ESD charge. The connection to mains ground should be accomplished through attachment of a 3-wire ac adapter/power supply, or through the use of an attached mains grounded peripheral (monitor, printer, etc.).

7.2.3.2 Connector shell contact discharge test procedure

An ESD simulator with a fast rise time discharge tip and contact discharge tip is recommended for connector shell contact discharge testing. Twenty discharges of each polarity should be applied at the required voltage with the contact discharges applied directly to the connector shell of the port under test.

Refer to Figure 8 for performance of typical connector shell contact discharge testing.



Figure 8—Typical connector shell contact discharge testing

7.2.3.3 Connector shell contact discharge examples

Examples of ports on computers and similar electronic equipment where the use of connector shell contact discharging testing is applicable include Ethernet, USB, eSATA, HDMI, audio, video, battery, etc. Maximum test levels of ± 4 kV are recommended. The test levels are typically higher than those used for direct pin injection testing (7.2.2.3).

7.2.4 Charged peripheral insertion

7.2.4.1 Charged peripheral insertion test setup

For charged peripheral insertion testing, the EUT should be configured with minimal cabling, connecting only that cabling required for operating and verifying the functionality of the device. The EUT should be connected to mains ground during the test to allow bleed-off of ESD charge. The connection to mains ground should be accomplished through attachment of a 3-wire ac adapter/power supply, or through the use of an attached mains grounded peripheral (monitor, printer, etc.).

7.2.4.2 Charged peripheral insertion test procedure

An ESD simulator with an air discharge tip is recommended for charged peripheral insertion testing. To avoid the charge being dissipated through the operator, the charged device should be properly insulated at the point where the operator grasps the device. Polyimide tape or other similar insulation is suitable for this purpose. Additionally, it is recommended that the operator wear a high-voltage insulating (rubber) glove during performance of the test.

With the ESD simulator set for the test voltage, apply discharges to the device to be inserted into the EUT until it is fully charged. This is indicated by the ability to bring the ESD simulator air discharge tip directly into contact with the device without a further discharge occurring. The preferred device for testing to USB ports and combo ports that include USB functionality would be a typical USB memory key.

NOTE—The key should include a full metal shield over the barrel, as opposed to recently available, mostly plastic USB keys.

For other ports, use a coiled cable of approximately 2 m overall length, properly insulated at the test end to allow the test operator to grasp the cable without draining the charge. The cable should be of the same type as the port that is to be tested.

Quickly perform the insertion of the charged peripheral or charged cable into the port under test. One hundred repetitions of the charge/insertion process should be applied at each polarity and test voltage.

Figure 9 illustrates charged peripheral insertion and typical devices used in charged peripheral testing.

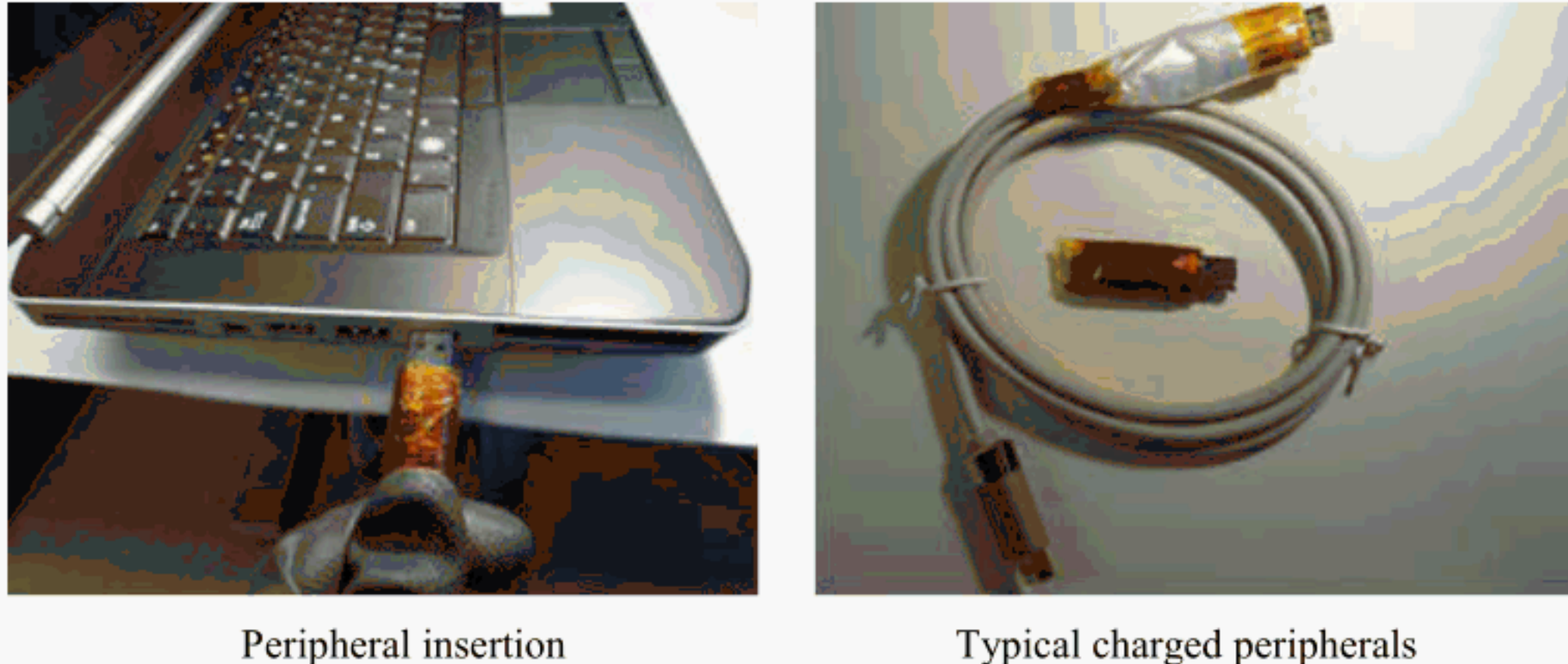


Figure 9—Charged peripheral insertion testing

7.2.4.3 Charged peripheral insertion testing examples

Examples of ports on computers and similar electronic equipment where the use of charged peripheral insertion is applicable include Ethernet, USB, eSATA, HDMI, audio, video, battery, etc. Maximum test levels of ± 6 kV to ± 12 kV are recommended.

7.3 Charged EUT testing

7.3.1 Overview

Laptop computers, tablets, cordless and mobile telephones are examples of EUTs that can acquire a charge by virtue of being carried by a person walking across a carpeted surface or coming into contact with a charged object (e.g., a foam cup). The EUT is then discharged when it is connected to peripheral or other associated equipment that has a connection to ground. Examples of peripherals and associated equipment include, but are not limited to, power charging adapters, docking stations, network connections, and USB, HDMI, serial, parallel, IEEE Std 1394 connected devices.

7.3.2 Charged EUT test setup

If the EUT is capable of battery-powered operation, it should be powered up and running on battery power. If it is capable of being in more than one operational mode, for example, a sleep mode and an active mode, it should be tested in each operational mode. No I/O ports should be populated. The peripheral or other associated equipment to which the EUT is to be connected should be set up in a typical configuration. For example, if a portable computer is to be mated with a docking station, the docking station should have at least the following peripherals connected:

- power supply
- external display

- LAN
- keyboard
- mouse

7.3.3 Charged EUT test procedure

An ESD simulator with an air discharge tip is recommended for charged EUT testing. One person holds the EUT using high-voltage insulating gloves while a second person charges the EUT to the specified test voltage. This is normally done by applying discharges to an exposed metallic contact on the EUT. With the ESD simulator set for the test voltage, apply discharges to the EUT until it is fully charged. This is indicated by the ability to bring the ESD simulator air discharge tip directly into contact with the EUT without a further discharge occurring.

Test levels from ± 2 kV to ± 12 kV or higher are recommended. A typical application would start at 2 kV and increment to 4, 8, and 12 kV to detect common field issues. Engineering judgment can be applied to determine the specific threshold of failure including levels higher than those specified to duplicate field issues.

To determine the suitability of the exposed metallic contact for EUT charging, the contact should have continuity with other metallic contacts on the EUT, e.g., the shell of an I/O port to a screw head located elsewhere on the EUT. Caution should be taken to avoid applying discharges directly to connector pins.

The EUT is then connected with peripheral or associated equipment and checked for functionality. Ten repetitions of the charging/discharging process should be made at each polarity and test voltage. This process should be repeated for each peripheral and associated equipment that can be connected to the EUT.

Figure 10 illustrates the typical charged EUT test procedure.



EUT unmated



EUT being charged

Figure 10—Charged EUT test procedure

8. Test reports

8.1 General

The purpose of test documentation is to increase the likelihood that the testing can be reproduced and to assist the manufacturer in increasing the immunity of the product by identifying the areas of the EUT that are vulnerable to ESD events. This information would then facilitate improvement in ESD protection at such locations before the product reaches the user. It is also useful when products are composed of parts supplied by vendors where the assembler has better assurance of ESD overall protection if the supplied parts are appropriately tested for ESD immunity, which might be in a test fixture that emulates the use conditions of the subassembly in the end product.

In the context of this guide, a test report might document one of a sequence of tests (with a separate report for each test in the sequence) that are used to come to a conclusion regarding the best ESD protection.

8.2 Minimum content of a test report

In order to improve repeatability of results when performing a test or a sequence of tests, the tester should record the following:

- a) Product identification (model number, serial number, firmware version, date of manufacture, and revision level)
- b) Configuration of the product, including modes of operation, attached peripherals, and operating position (upright, lying down)
- c) Arrangement of interface cables
- d) Cable characteristics such as length and shielding
- a) Software used to exercise the product during testing
- b) Diagrams or photographs of the arrangement of the product and interconnected units
- c) Diagrams or photographs indicating the discharge points
- d) Number of discharges per discharge point (minimum 10)
- e) Other pertinent description, such as any situation where the effect of discharges might be due to discharges applied simultaneously to different points on the product

Many of the above can best be captured in test data sheets, which generally identify the most sensitive points of a product to ESD events.

8.3 Additional content of a test report

8.3.1 Overview

There are other important items that should be recorded and that should be part of the reports generated as such testing continues. What follows are the most important additional items that can affect the test results.

8.3.2 Environmental data

As a control measure, test personnel should record the test site ambient temperature, relative humidity, and date for each test in the sequence of tests. It is particularly critical that the RH is controlled during the full duration of the test. The RH should be entered on the data sheet at the start and at the end of each test to show that the RH was within manufacturer tolerances.

8.3.3 Simulator description

A description of the ESD simulator is needed, including the type, manufacturer, serial number, calibration date, and any other pertinent information necessary to duplicate the test. The position of the simulator discharge return cable should also be documented using diagrams or photographs of the arrangement.

8.3.4 Acceptable product performance

To judge improvements in product ESD immunity, there has to be criteria for acceptable performance when ESD testing is performed. The acceptance criteria should be determined and documented prior to the start of the test sequence, so it is clear what is acceptable and what needs further immunity review. This means that the response of the product at each test level, condition, and discharge point should be fully documented. Test conditions include identification of air or contact discharge, ESD simulator type, voltage levels, polarities, discharge rates, and number of discharges. The error rate is an example of an EUT response to be evaluated that can provide valuable diagnostic information.

9. ESD simulator considerations

Correlation of the results of an ESD evaluation is extremely important. This is particularly so when tests are to be conducted using ESD simulators of different manufacture or when testing is expected to extend over a long period of time. It is essential that repeatability be a driving factor in the evaluation.

IEC 61000-4-2 offers detailed ESD waveform specifications and validation guidance on measuring them. Other industry-specific standards that reference it (e.g., ISO 10605 [B2]) also give detailed information on ESD waveform verification using different discharge network values than required in IEC 61000-4-2. The ISO document also requires triangular dressing of the 2 m ground return strap, thus keeping it off the floor and away from the target. While these other specifications of voltage waveforms for contact-mode testing are welcome, it should be noted that different models or implementations of ESD simulators might still produce differing results even though all were within specified tolerances. Seeking additional ESD simulators that meet the same waveform specifications is not necessary.

Users trying to replicate field failures or customer complaint scenarios sometimes use alternate accessories or test methods. For this purpose, ESD test simulators are available with two tips for contact discharge testing. One tip is typically used to comply with the rise time specified in IEC 61000-4-2 of 0.85 ns, and one offers a faster rise time of approximately 0.25 ns.

Two ESD test simulator discharge tip geometries are specified in IEC 61000-4-2. One is a sharply-pointed tip to be used for contact discharge testing. The other is a rounded tip to be used for air discharge testing. Some ESD simulators are capable of providing discharges at up to 30 kV, well above the values identified in IEC 61000-4-2. The same sharply-pointed tip geometry is used for contact discharge testing at these higher voltages. However, a third tip geometry with a larger rounded end is sometimes used for air discharge testing at higher voltages to reduce the amount of leakage charge from the tip prior to the main discharge event. Examples of all three simulator tip geometries are shown in Figure 11.

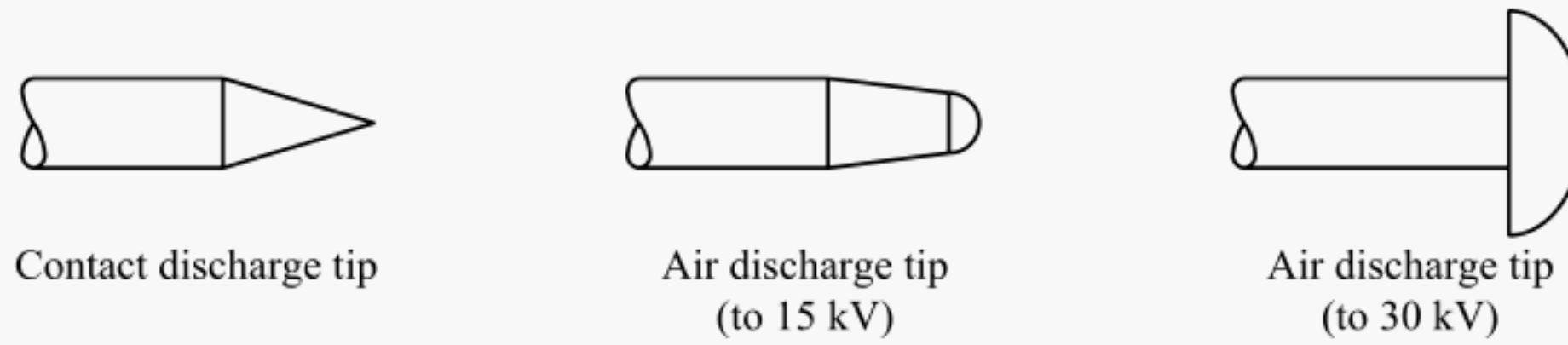


Figure 11 —ESD simulator tip geometries

Annex A

Test plan and data sheet examples

A.1 Test plan

It is recommended that an ESD test plan be drafted prior to the execution of an ESD test. The test plan should be drafted with the participation of the customer so that configuration variables (EUT operation, selection of test points, placement of auxiliary equipment, etc.) can be specified. An example test plan providing details on the EUT, the customer, and the applicable standards is shown in Table A.1.

A.2 Data sheet

The ESD test report should provide:

- A description of the product and its configuration and test arrangement
- The environmental conditions
- Identification of test points and number of discharges at each test point
- The ESD simulators used and the applied voltage levels
- The response of the EUT for each test condition (see Clause 8)

An example data sheet in spreadsheet format is available for download.⁷ Users of this guide are encouraged to modify the spreadsheet as appropriate to meet their individual needs. Table A.2 shows the cover sheet portion of the spreadsheet where information about the EUT, its power supply and peripherals, the relevant ESD specification, personnel involved in testing, etc. should be recorded. The cover sheet also provides a key for use in identifying test results and examples of acceptance criteria that can be associated with ESD test levels on the subsequent data sheets. Table A.3 shows the first few rows of the data sheet for recording the air discharge test results. There are corresponding data sheets for contact discharge tests and for tests involving the horizontal and vertical coupling planes. Places for recording the identification of the EUT, test iteration number, date and time of testing, environmental conditions, and testing personnel are provided. The voltage levels specified in IEC 61000-4-2 are used for this example, with spaces provided to identify the acceptance criteria for each voltage level. However, each EUT is unique in its application and intended environment; the voltage levels used and acceptance criteria should be determined when developing the test plan in consultation with the person responsible for the product.

⁷ The spreadsheet is available from: <http://standards.ieee.org/downloads/C63/C63.16/C6316ExampleESDDataSheet.xls>.

Table A.1—Test plan example

ESD Test Plan	
Project Name:	Engineering Contact:
Markets and Applicable Standards:	
<ul style="list-style-type: none"> — IEC 61000-4-2 — Other applicable standards 	
Configuration Description (attach applicable drawings or photographs):	
<ul style="list-style-type: none"> — Mode of operation — Cable configuration, if any — Software description, if any — Exposed contacts, if any — Operating position (upright, lying down, etc.) — Required auxiliary equipment, if any — Identification of test points — Number of discharges per test point (minimum 10) — Other pertinent description 	
Failure Criteria Description Specific to EUT	
<ul style="list-style-type: none"> — EUT operation beyond manufacturer's specifications — Loss of function — Degradation of operation — Disruption of user interface — Reset — Non-recoverable disruption — Other behavior outside the EUT's normal function 	

Table A.2—Example ESD data cover sheet

ESD Data Cover Sheet			
EUT:	Iteration Number:	Date:	Test Request No:
Model No:	Specification:		Technician:
Serial No:			Engineer:
Power Supply:	Rating: Vac Hz	Peripheral 1:	
Vendor:	Model:	Vendor:	Model:
Peripheral 2:		Peripheral 3:	
Vendor:	Model:	Vendor:	Model:
<p>Test Results Key:</p> <p>ND = No Discharge; EUT meets criteria but unable to generate ESD events at this test point.</p> <p>PD = Partial Discharge; EUT meets criteria but only intermittently able to generate ESD events at this test point.</p> <p>OK = EUT meets the acceptance criteria at this test point.</p> <p>X = EUT does not meet the acceptance criteria at this test point.</p> <p>Performance Category Definitions: <i>(provided as examples; other EUT-specific performance categories can be defined)</i></p> <p>A = The EUT continues to operate as intended with no degradation of performance.</p> <p>B = The EUT continues to operate as intended after completion of the test. However, some degradation of performance is allowed during the test as long as there is no loss of data or operator intervention required to restore normal function.</p> <p>C = Temporary loss of function is allowed if full EUT function can be restored by operator intervention after the test.</p> <p>Note: Hardware failures (damage) are not acceptable for any of the performance categories above.</p>			

Table A.3—Example ESD data sheet for test results

ESD Data Sheet 1: Air Discharge											
EUT:	Iteration Number:					Date:				Start Time:	
Technician:	Temperature: °C					Relative Humidity: %				Barometric Pressure: kPa	
Test Point Number and Location	Performance Category (insert A, B, or C as described above)									Comments	
	Voltage Level (kV), minimum 10 discharges at 1 PPS max										
	+2	+4	+8	+15	+X	-2	-4	-8	-15		

NOTE—The spreadsheet is available: <http://standards.ieee.org/downloads/C63/C63.16/C6316ExampleESDDataSheet.xls>.

Annex B

Test method guidance—Air or contact discharge

B.1 Test method selection

The particular test method (air or contact, see 6.1.2) selected as appropriate for EUT evaluation should be determined by first establishing an intended result for the information to be gained from the ESD test. The following clauses provide an overview of the two approaches, in conjunction with the advantages and disadvantages of each approach.

B.2 Air discharge

B.2.1 Overview

The air discharge method virtually replicates ESD as it would occur in the actual environment. In effect, this means the following:

- a) Impulse waveforms are allowed (and expected) to vary significantly from pulse to pulse.
- b) Impulse current delivered to the EUT varies from pulse to pulse.
- c) Size of the air gap at the time of breakdown changes depending on the characteristics of the EUT surfaces that, in turn, might alter the actual voltage at which the ESD occurs to the EUT.

B.2.2 Air discharge advantages

The advantage of the air discharge method is that EUT responses are caused by phenomena that are similar to actual ESD events. This means that for a given ESD test voltage, one ESD pulse might cause an EUT response, while another pulse might not. When the EUT does respond, that response might be different from discharge to discharge (King [B3]). As a result, the test provides an estimate of the performance of the EUT in its actual operating environment. Another benefit is that any insulating surfaces or air gaps in the EUT that prevent ESD can be evaluated for breakdown voltage. Finally, air discharge simulates the nonlinear relationship between amplitudes of ESD voltage and current found in natural ESD.

B.2.3 Air discharge disadvantages

The major disadvantage to the air discharge ESD method is that, in practice, performance of the method might result in a tedious test series. The air discharge test might require several hours of test time because of the need to apply (possibly) hundreds of ESD pulses to an EUT in order to fully (adequately) evaluate and understand the responses of the EUT and their probabilities of occurrence. Apart from the disadvantage of test time, the EUT might respond inconsistently to the ESD excitations. This produces serious repeatability problems in the test results, requiring further ESD tests to ultimately determine the performance profile of the EUT.

B.3 Contact discharge

B.3.1 Overview

The contact discharge method simulates ESD, but it does not replicate all of the characteristics of the actual ESD phenomena. The contact discharge method provides a more repeatable ESD test simulation. In effect, this means the following:

- a) Impulse waveforms are controlled to not vary significantly from pulse to pulse.
- b) Impulse current delivered to the EUT remains relatively consistent from pulse to pulse.
- c) Variability that would be associated with the air gap is avoided.

B.3.2 Contact discharge advantages

The major advantage of the contact discharge method is that the consistency and repeatability of the ESD test waveforms usually result in consistent and repeatable EUT performance. The contact discharge test method is less tedious than the air discharge method because it can be performed in a more automated manner, with the impulses applied to the EUT at a relatively fast pulse repetition rate. In practice, the use of the contact discharge method permits the evaluation of EUT susceptibility to ESD to be made in a manner that significantly conserves test time.

B.3.3 Contact discharge disadvantages

The major disadvantage of the contact discharge method is that it relies on the surface conductivity at the point of test application and thus does not evaluate the breakdown (standoff) ESD voltage of EUT surfaces or the air gap distances between the ESD source and internal conductive members. Contact discharge testing also does not provide an estimate of EUT response to actual-use ESD voltages because the random variations in the ESD waveform that exist in nature are not reproduced. Finally, the ESD voltage and current become directly proportional during these tests, whereas the relationship between voltage and current in naturally-occurring ESD is nonlinear.

B.4 EUT surfaces

B.4.1 Overview

The decision on which test method to use may be based partly on whether the surfaces of the EUT are conductive or nonconductive.

B.4.2 Conductive surfaces

Conductive surfaces and coupling planes are typically tested using the contact discharge test method.

B.4.3 Nonconductive surfaces

For insulating surfaces, the air discharge method (by its inherent nature) is predominantly used. The air discharge method is also useful in determining the breakdown voltages of surfaces that have a conducting

substrate (subsurface), with an insulating surface layer. If the contact discharge method is used in this latter situation by penetrating the insulating surface layer, it might result in excess current being applied to the EUT, compared to the current in air discharge because the arc path impedance is missing. For fully-insulating surfaces, the contact discharge test method may be used, but it is an indirect application performed by applying contact ESD to a coupling plane that is adjacent to the nonconductive surface under evaluation.

B.5 Indirect ESD tests

When performing indirect ESD testing, contact discharge is typically used.

Annex C

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⁹ ISO publications are available from the ISO Central Secretariat (<http://www.iso.org/>). ISO publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org/>).

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