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**Resistibility tests for telecommunication  
equipment exposed to overvoltages and  
overcurrents – Basic Recommendation**

ITU-T Recommendation K.44

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## **ITU-T Recommendation K.44**

### **Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation**

#### **Summary**

This Recommendation seeks to establish fundamental testing methods and criteria for the resistibility of telecommunication equipment to overvoltages and overcurrents.

Overvoltages or overcurrents covered by this Recommendation include surges due to lightning on or near the line plant, short-term induction of alternating voltages from adjacent electric power lines or electrified railway systems, earth potential rise due to power faults, and direct contacts between telecommunication lines and power lines.

Major changes compared with the 2000 version of this Recommendation include:

- replacing the longitudinal test with a port to earth test;
- the introduction of an external port to external port test;
- adding internal port requirements.

#### **Source**

ITU-T Recommendation K.44 was approved by ITU-T Study Group 5 (2001-2004) under the ITU-T Recommendation A.8 procedure on 29 July 2003.

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## **ITU-T Recommendation K.44**

### **Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation**

#### **1 Scope**

This basic Recommendation describes resistibility tests for all telecommunication equipment against overvoltages and overcurrents for use by network operators and manufacturers.

This Recommendation applies to all telecommunication equipment connected to external or intra-building metallic conductors. It should be read in conjunction with ITU-T Recs K.11 and K.39 which deal with the general economic and technical aspects of protection.

This Recommendation does not specify either test levels or particular acceptance criteria for specific equipment.

The appropriate test levels and test points are contained in the specific product family or product Recommendation.

Therefore, this Recommendation has to be used together with the product family or product Recommendation dealing with the resistibility requirements relevant to the equipment to be tested.

If a product family or product Recommendation or clauses of it differs from this basic Recommendation, the product family or product Recommendation applies. As product Recommendations are updated, they should be coordinated with and refer to ITU-T Rec. K.44.

This Recommendation assumes that the earthing and bonding configurations comply with the appropriate Recommendation related to the type of installation.

The tests are type tests and, although they are applicable to a complete system, it is recognized that they may be applied to individual items of equipment during development and design work. In performing the tests, it is necessary to take into account any conditions, either in the unit under test or elsewhere, which may affect the results.

ESD testing is not covered by this Recommendation and IEC 61000-4-2 should be followed.

#### **2 References**

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

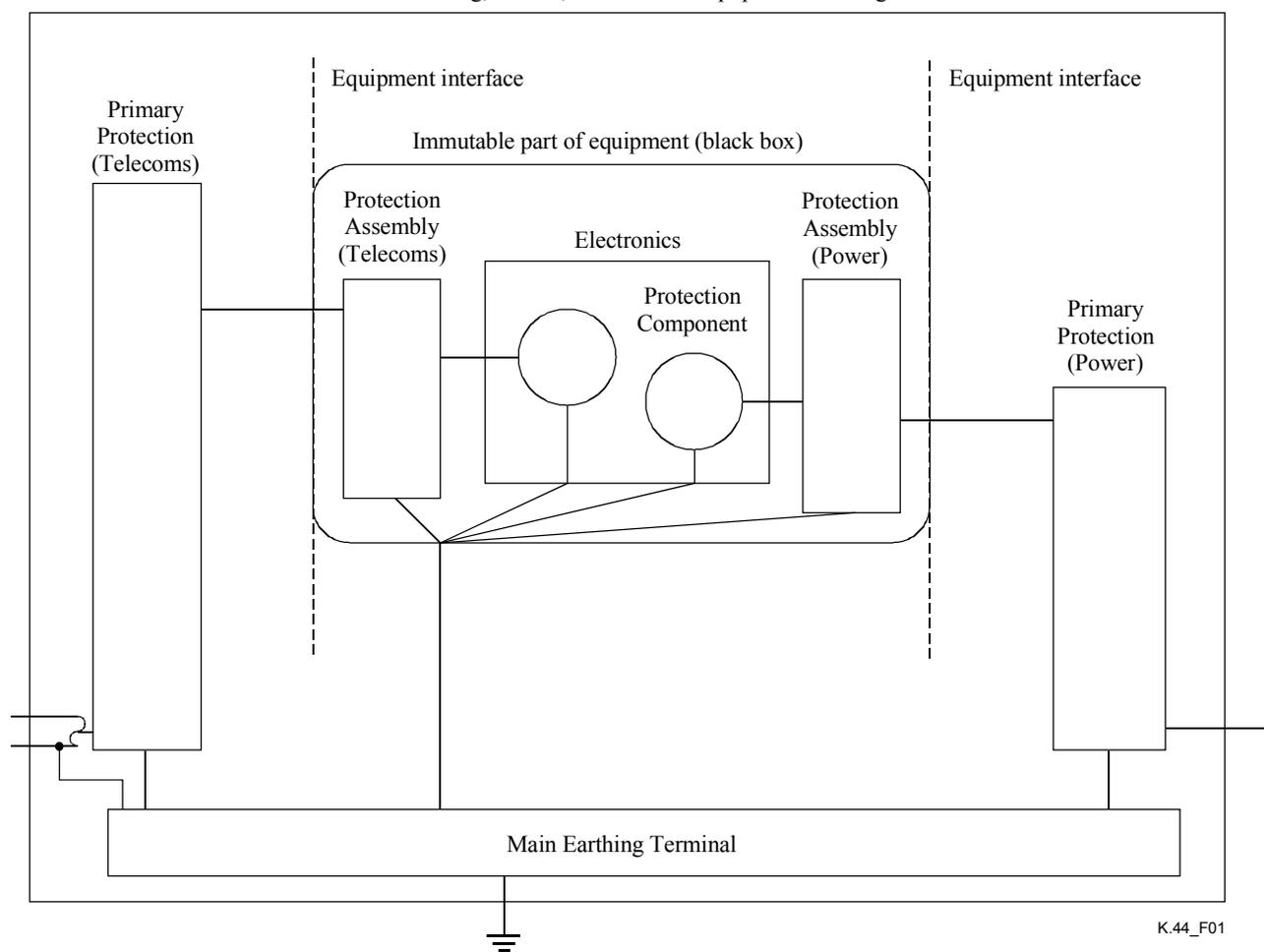
- ITU-T Recommendation K.11 (1993), *Principles of protection against overvoltages and overcurrents*.
- ITU-T Recommendation K.12 (2000), *Characteristics of gas discharge tubes for the protection of telecommunications installations*.
- ITU-T Recommendation K.27 (1996), *Bonding configurations and earthing inside a telecommunication building*.
- ITU-T Recommendation K.28 (1993), *Characteristics of semi-conductor arrester assemblies for the protection of telecommunications installations*.

- ITU-T Recommendation K.31 (1993), *Bonding configurations and earthing of telecommunication installations inside a subscriber's building.*
- ITU-T Recommendation K.35 (1996), *Bonding configurations and earthing at remote electronic sites.*
- ITU-T Recommendation K.39 (1996), *Risk assessment of damages to telecommunication sites due to lightning discharges.*
- ITU-T Recommendation K.40 (1996), *Protection against LEMP in telecommunications centres.*
- IEC 60060-1:1989, *High-voltage test techniques. Part 1: General definitions and test requirements.*
- IEC 61000-4-2:1999, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test.*
- IEC 61000-4-5:2000, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 5: Surge immunity test.*
- IEC 61643-1:2002, *Surge protective devices connected to low-voltage power distribution systems – Part 1: Performance requirements and testing methods.*

### **3 Definitions and abbreviations**

#### **3.1 Definitions**

To assist in understanding the various definitions, refer to Figure 1. This figure shows elements associated with protecting the equipment that may be in an installation. Not all of these elements are expected to be used in an installation.



NOTE – The arrangement of the blocks and bonding conductors inside of the building, shelter, structure or equipment housing is to assist in their identification and does not infer an optimum physical arrangement from a protection point of view.

**Figure 1/K.44 – Illustration of protection elements**

This Recommendation defines the following terms:

**3.1.1 resistibility:** Resistibility is the ability of telecommunication equipment or installations to withstand, in general, without damage, the effects of overvoltages or overcurrents, up to a certain, specified extent, and in accordance with a specified criterion.

NOTE – Criteria for damage are set in clause 9.

**3.1.2 Surge Protective Device (SPD):** A device that is intended to mitigate surge overvoltages and overcurrents of limited durations. It may consist of a single component or have a more complex design, where several functions are integrated. It contains at least one non-linear component.

**3.1.3 primary protection:** Primary protection is applied using an SPD to protect an interface of the equipment, at the location where it diverts most of the stressful energy from propagation into the equipment. This SPD must be accessible, removable and connected to equipotential bonding.

**3.1.4 agreed primary protection:** Agreed primary protection is a type of SPD that is used to protect the equipment based on an agreement between the manufacturer and the network operator. Agreed primary protection may be a specific SPD or a range of SPDs which comply with a particular Recommendation or specification. The agreed primary protection can be nothing if it has been agreed that no external protection elements need to be used for the equipment.

**3.1.5 inherent protection:** Inherent protection is that protection which is provided at an equipment interface either by virtue of its intrinsic characteristics, by specific design, or by suitable protection components.

**3.1.6 high current carrying protection components:** A high current carrying protection component is a SPD that is designed to conduct/divert the majority of the surge energy, once it has operated, away from the circuit it is protecting. High current carrying protection components are mainly used as primary protection components, but in some cases may be integrated into the equipment as inherent protection.

**3.1.7 specific energy:** Specific energy  $W_{sp}$  is a measure of the energy available from power induction or power frequency earth potential rise and is equal to the energy that would be dissipated in a resistor of  $1 \Omega$ . It is defined as the square of the induced current ( $I_{a.c.}$ ) multiplied by the time  $t$  that the current flows:

$$W_{sp} = (I_{a.c.})^2 \times t \quad (3-1)$$

The specific energy from a test generator is determined by applying a short circuit to the output terminal of the generator.

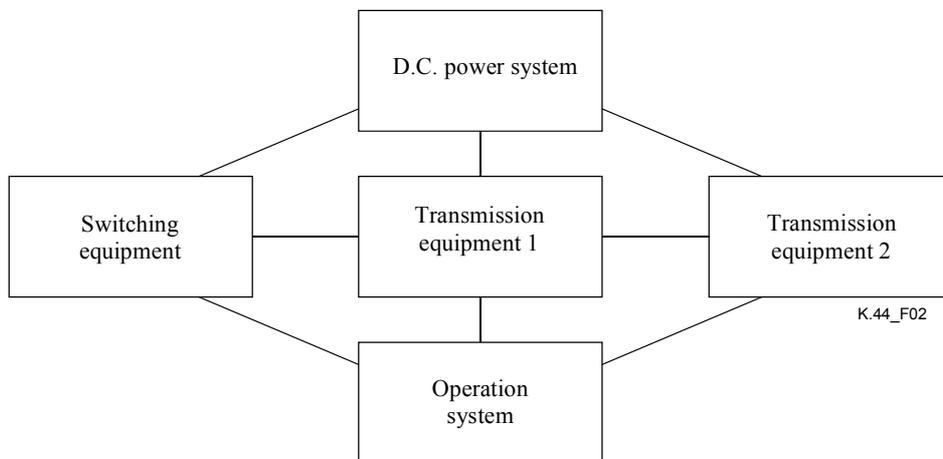
**3.1.8 coordination element:** A coordination element is an element between the primary protection and the inherent protection to prevent the inherent protection from unduly affecting the primary protection from operating.

**3.1.9 special test protector:** The special test protector is a component or circuit used to replace the agreed primary protector for the purposes of confirming coordination. The special test protector ensures that the voltage at the input of the equipment will be higher during the test than in service and provides a level of guarantee that the equipment will be protected by the addition of primary protection.

**3.1.10 dedicated power feed:** A dedicated power feed is a power feed provided by a dedicated cable which leaves the building.

**3.1.11 external ports:** An external port is a particular interface of the specified equipment, which is directly connected to metallic conductors extending beyond the building or shelter boundary.

**3.1.12 internal ports:** An "Internal port" is a particular interface of the specified equipment, which is connected to metallic conductors which do not leave the building or shelter. These interfaces connect to cables which interconnect system blocks, see Figure 2.



**Figure 2/K.44 – System blocks**

**3.1.13 protection coordination:** The act of ensuring that all the protection elements, internal and external to the equipment, react in such a way so as to limit the amount of energy, voltage or current to levels such that damage does not occur to protection elements or equipment.

**3.1.14 Customer Premises Equipment (CPE):** Equipment intended to be directly connected to the termination of a public telecommunication network in a customer's premise.

**3.1.15 Access Network (AN):** Part of the overall telecommunication network that is located between a telecommunication centre and the customer premise building.

**3.1.16 Trunk Network (TNW):** A part of the telecommunication system that is located between two telecommunication centres.

**3.1.17 telecommunication centre:** A telecommunication centre is a telecommunication facility where the earthing and bonding is in accordance with ITU-T Rec. K.27.

**3.1.18 remote power feed:** A remote power feed is a power feed provided by symmetric signal pairs or inner conductors of coaxial circuits simultaneously used for signal transmission. The supply of the operating voltage to customer terminal equipment is not a remote power feed.

**3.1.19 coupling element:** A coupling element is a low impedance component used to connect the surge generator to the port being tested or to couple an untested port to ground.

**3.1.20 decoupling element:** A decoupling element is a component with a suitable impedance to reduce the level of energy being conducted into associated equipment or termination.

**3.1.21 termination component:** A termination component is a component used to simulate the connection of associated equipment to a tested or untested port.

## 3.2 Abbreviations

This Recommendation uses the following abbreviations:

a.c. alternating current

AN Access Network

ANE Access Network Equipment

CPE Customer Premises Equipment

d.c. direct current

dpf dedicated power feed

EPR Earth Potential Rise

ESD Electrostatic Discharge

EUT Equipment Under Test

GDT Gas Discharge Tube

IEC International Electrotechnical Commission

ISDN Integrated Services Digital Network

ITU-T International Telecommunication Union – Telecommunication Standardization Sector

LE Local Exchange

LI Line Interface

LT Line Termination

MDF Main Distribution Frame

MOV Metal Oxide Varistor

n.a.	not applicable
NT	Network Termination
o/c	open circuit
pfv	power feeding voltage
PTC	Positive Temperature Coefficient resistor
RSE	Remote Switching Equipment
SPD	Surge Protective Device
SSA	Solid State Arrester
TCE	Telecommunication Centre Equipment
TNW	Trunk Network
USB	Universal Serial Bus

### 3.3 Symbols

This Recommendation uses the following symbols:

$U_c$	d.c. charge voltage of the surge generator
$U_{c(max)}$	Maximum d.c. charge voltage of the surge generator
$U_{a.c.(max)}$	Maximum a.c. (open) voltage for the a.c. voltage tests

## 4 Overvoltage and overcurrent conditions

Aspects of overvoltage or overcurrent covered by this Recommendation are:

- surges due to lightning strokes on or near to the line plant;
- large currents in common wiring or components when overvoltages or overcurrents occur simultaneously on a number of lines;
- large currents flowing into the equipment when high current carrying protection components, which eliminate the need for primary protection, are integral to the equipment;
- short-term induction of alternating voltages from adjacent electric power lines or electrified railway systems, usually when these lines or systems develop faults;
- earth potential rise due to power faults;
- direct contacts between telecommunication lines and mains power lines;
- transient surges on mains-voltage lines;
- the potential difference which can occur between a TT or IT Power system and the Telecommunication system.

## 5 Resistibility requirements (basic and enhanced)

Telecommunication lines, remote (dedicated) power feeding lines and mains power lines are more or less influenced in the practical environment by lightning or power lines. The several degrees of influence and protection measures are described in ITU-T Rec. K.11. With reference to the resistibility of telecommunication equipment connected to metallic conductors, there may be different resistibility requirements in different environments. It is for Administrations or network operators to select the appropriate resistibility requirement, from the product family or product Recommendations. In the interest of reducing the number of equipment designs, only the basic and enhanced requirements are recommended.

## **5.1 Basic resistibility requirement**

The equipment needs to be suitable for use in environments with a low exposure, and this is achieved by the inherent protection of the equipment. The equipment also needs to be suitable for use in environments with a higher exposure, and this is achieved by inherent protection of the equipment and added agreed primary protection.

## **5.2 Enhanced resistibility requirement**

Where the basic resistibility requirements are not sufficient due to environmental conditions, national regulations, economic and technical considerations, installation standards or grade of service requirements, network operators may request the enhanced resistibility requirement.

## **6 Equipment boundary**

The variations of different types of equipment make it necessary for the equipment to be seen as a "black-box" having several ports, a, b, c, d, e and f, etc. and E (Earth). It is possible that some protective devices have already been provided in the equipment, either on the printed circuit board, etc. or connected to its ports. For the purpose of these tests, manufacturers are expected to define the boundaries of the "black-box" and any protective device which is included must be considered as an immutable part of the equipment (small exchange in street cabinet, Multiplexor, CPE, etc.). Where high current carrying protection components are used within the equipment, see 10.1.1. Where any auxiliary telecommunication wire is provided, e.g., to an extension, or as a signalling earth, these wires should be seen to extend the number of terminal to be tested, e.g., a, b, c, d, e and f, etc. and E for Earth.

## **7 Test conditions**

### **7.1 Test types**

Four types of tests need to be performed on equipment and these are:

- transverse (line to line);
- external port to earth;
- external port to external port;
- internal port to earth.

#### **7.1.1 Transverse**

Transverse tests should be performed on all external symmetric pair port types of the equipment. The test is performed with some untested ports, of each port type, terminated.

#### **7.1.2 External port to earth**

Port to earth tests should be performed on equipment with external ports and either an earth connection or internal ports. This test is performed with all untested ports (both internal and external) terminated and then repeated with each type of internal port, grounded via a coupling element, in turn.

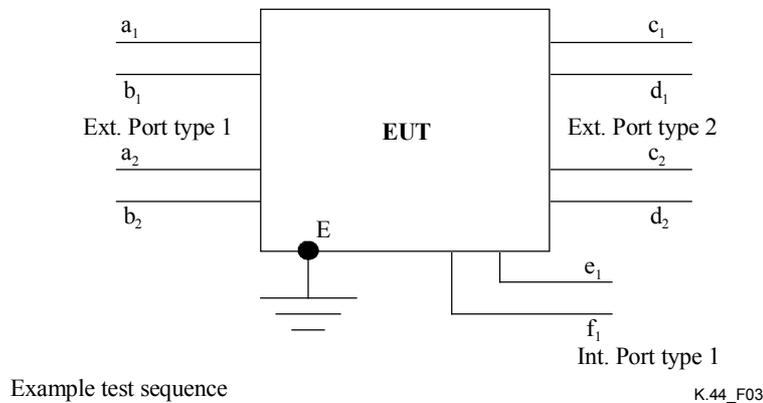
#### **7.1.3 External port to external port**

Port to port tests should be performed on equipment with more than one external port. When the equipment is designed to be used with a connection to ground, the product recommendation specifies when the test is to be performed. This test is performed with all untested ports (both internal and external) terminated, with each type of external port, including a port of the same type, grounded via a coupling element, in turn.

It is necessary in external port to external port testing to consider the following as the second port

- 1) other lines/pairs of the port type being tested (e.g. pair 1 to pair 2 of port type 1);
- 2) lines/pairs of other port types (e.g. pair 1 of port type 1 to pair 1 of port type 2).

An example of a test sequence is provided in Figure 3.



Example test sequence

- $a_1 - b_1$  (transverse test)
- $a_1/b_1 - E$  (external port to earth test)
- $a_1/b_1 - E$  with  $e_1/f_1$  coupled to  $E$  (external port to earth test with one internal port coupled to ground)
- $a_1/b_1 - c_1/d_1$  with  $E$  disconnected (external port to external port test with one external port coupled to ground)
- $e_1/f_1 - E$  (internal port to earth test)

**Figure 3/K.44 – Example of a test sequence**

#### 7.1.4 Internal port to earth

Internal port to earth tests are performed on all internal port types. This test is performed with some untested ports, of each port type, terminated.

#### 7.2 Test conditions

The following conditions apply to all the tests specified in clause 10.

- 1) All tests are type tests and are tested under standard operating conditions unless otherwise specified in the product family or product Recommendation.
- 2) The ports at which tests on the equipment are to be applied should be identified by the manufacturer:
  - $a$  and  $b$ ,  $c$  and  $d$ ,  $e$  and  $f$ , etc. for different single symmetric pair ports;
  - $a_1$  to  $a_n$  and  $b_1$  to  $b_n$ ,  $c_1$  to  $c_m$  and  $d_1$  to  $d_m$ ,  $e_1$  to  $e_p$  and  $f_1$  to  $f_p$ , etc. for different multiple symmetric pair ports;
  - inner and outer for coaxial cable ports;
  - $dpf1$  and  $dpf2$ , etc. for dedicated power feed ports;
  - $L1$ ,  $L2$ ,  $L3$  and  $N$  for mains power ports; and
  - $E$  for Earth.
- 3) Tests shall be performed with the equipment operating, the only exception to this is during the power contact test. Note, If the power contact test is performed without the equipment powered, it must not affect the test result. The equipment shall be tested in any operating state of significant duration, see A.2.4. To prove compliance, the equipment may need to be tested with both the tested and untested ports terminated, and with untested ports coupled to ground, see A.5 and I.1.5.

- 4) Terminations for the tested and untested ports include auxiliary equipment e.g., LI, LT, NT, CPE, a power supply, a simulator or a passive termination. If it is not necessary to have the auxiliary equipment connected to verify that the EUT will resist the test voltage, the test may be performed without the auxiliary equipment connected. Where different terminations may occur, e.g., with or without primary protection, these terminations need to be considered, refer to I.1.5. Decoupling elements are used to prevent the surge damaging the associated equipment or termination.
- 5) Ports may need to be tested with a finite number of untested ports of the same and different types grounded, to confirm that the equipment fulfils the specified acceptance criteria. Coupling elements are used to ground the appropriate port as required in 6) and 7) below.
- 6) External port to earth tests shall be performed without coupling to ground on the untested ports and also with each type of internal port coupled to ground in turn.
- 7) External port to external port tests shall be performed with each type of external port, including a port of the same type, coupled to ground in turn.
- 8) Each test shall be applied the number of times indicated in the product family or product Recommendation. The polarity of lightning surge tests should be reversed between consecutive surges. The time interval between consecutive tests on the same port should be approximately one minute. The tests shall also be applied at longer time intervals, if necessary, to confirm that the equipment fulfils the specified acceptance criteria for surges which occur at intervals exceeding one minute. An example of this is to confirm that the equipment passes when all surges are applied to PTCs at normal operating temperature.
- 9) When the transverse test is applied between two terminals, one of the terminals shall be connected to the surge generator and the other terminal shall be connected to earth. The test shall then be repeated with the terminals transposed.
- 10) Power induction tests should be made at the frequencies of the electric power system or the electrified railway systems used in the country of application.
- 11) In all cases where a maximum voltage, current or specific energy is specified, tests shall also be made at lower values, if this is necessary, to confirm that the equipment fulfils the specified acceptance criteria for any voltage, current or specific energy up to the maximum value specified. Where product Recommendations allow reduced testing, e.g., power contact tests, as many tests as necessary shall be performed, to confirm that the equipment fulfils the specified acceptance criteria.  

NOTE – Particular components which need to be considered during testing include the primary protector, switching or foldback type inherent protectors, PTCs and fuses.

Where fuse resistors are used, tests shall be applied at a range of test levels to ensure that the worst case is tested.
- 12) A new primary protection component may be used after the completion of each test sequence.
- 13) Cards shall be tested in one or more slots as is necessary to confirm that the equipment fulfils the specified acceptance criteria.
- 14) If a card has two or more identical ports, only one port needs to be tested, for single port tests.
- 15) Adjacent cards should not be affected in any way by surges on the card/port under test.

## **8 Protection coordination**

### **8.1 General**

For equipment installed in a more exposed environment, it is current practice to protect ports, connected to external metallic conductors, with primary protectors such as GDTs, SSAs or MOVs. The best place for the insertion of the primary protection is the border of the building, shelter or equipment housing. This is not always possible but every attempt should be made to place the primary protection as close as possible to the entry point of the cables into the building, shelter or equipment housing. The characteristics of these primary SPDs shall comply with the requirements of ITU-T Recs K.12, K.28 or IEC 61643-1.

Primary protection coordination is required to ensure compatibility of the equipment with the primary protection.

### **8.2 Lightning**

To have achieved coordination for protection against lightning surges, the following must occur:

- The inherent protection within the equipment must provide protection up to the voltage at which the agreed primary protection operates for generator voltages less than the  $U_{c(max)}$  specified in the product family or product Recommendation.
- Between this voltage and a generator voltage of  $U_{c(max)}$  the primary protection must operate and protect the equipment.
- The equipment must comply with specified criterion of the product family or product Recommendation.
- To check that coordination has been achieved for protection against lightning surges, a special test protector is used in place of the primary protector during the lightning surge tests, see 8.4. During a test, at a generator voltage less than or equal to the  $U_{c(max)}$  specified in the product family or product Recommendation, the special test protector must operate. This is to provide some guarantee that the primary protector will operate and protect the equipment for surges  $> U_{c(max)}$ .

#### **8.2.1 Primary SPDs with a switching characteristic**

Coordination is achieved with a switching type SPD, when the special test protector, see 8.4.1, is activated with a  $U_c$  below the maximum level specified in the relevant product family or product Recommendation, for testing with agreed primary protection, and the equipment complies with the specified criterion of that Recommendation.

#### **8.2.2 Primary SPDs with a clamping characteristic**

Coordination with a clamping type SPD is achieved when the equipment complies with specified criterion of the product Recommendation when tested with the special test protector, see 8.4.2, when tested at the maximum test voltage and current of the coordination test, i.e., when the primary SPD is conducting maximum current.

### **8.3 Power induction, earth potential rise and power contact**

Protection against power induction and EPR, as a result of a power fault to ground, is achieved by the inherent protection within the equipment or in combination with the agreed primary protection.

Protection against power contacts is achieved by the inherent protection of the equipment.

The input impedance to ground of both the a and b inputs of some equipment may be low when the inherent overvoltage protection is activated. In this case, the voltage across the impedance to ground, caused by the current that flows during power induction or EPR, may be too low to activate

the primary protection. If the primary protection is not activated, attention should be paid to the level of energy which may have to be dissipated within the equipment.

## **8.4 Special test protector**

The special test protector shall have similar behaviour to that of the agreed primary protector.

### **8.4.1 Switching type protector**

The d.c. operating voltage of the special test protector shall be equal to 1.15 times the specified maximum d.c. operating voltage, after life test value, of the agreed primary protector. The tolerance of this firing voltage is  $\pm 5\%$ . It should also have a similar impulse to d.c. operating ratio as the agreed primary protector. The manufacturer may use a special test protector with a higher operating voltage.

### **8.4.2 Clamping type protector**

The clamping voltage of the special test protector shall be equal to 1.15 times the specified maximum clamping voltage of the agreed primary protector. The tolerance of this clamping voltage is  $\pm 5\%$ . The manufacturer may use a special test protector with a higher operating voltage.

### **8.4.3 Multistage modules**

When the primary protection is a multistage module, replace the primary protection with a special test module which uses components according to 8.4.1 and 8.4.2.

## **9 Acceptance criteria**

Two acceptance criteria are recognized:

- Criterion A – Equipment shall withstand the test without damage or other disturbance (such as corruption of software or misoperation of fault-protection facilities) and shall operate properly within the specified limits after the test. It is not required to operate correctly during the test.
- Criterion B – A fire hazard shall not arise in the equipment as a result of the tests. Any damage, if it occurs, shall be confined to a small part of the equipment.

## **10 Tests**

The test generators, test circuits, coupling and decoupling elements, and port terminations are provided in Annex A.

Certain considerations which justify the test proposals are stated in Appendix I. The response of equipment to surges may be modified by the input impedance of the equipment. To explain this effect, Appendix I includes an example circuit and instantaneous levels of voltage at different points in the circuit to show the effect of input impedance. These values are included for illustration only and do not form any part of this Recommendation.

The port types shown in Table 1 are considered. Remote power feeds share the same port as the signal port.

**Table 1/K.44 – Port types**

Port type		Test type	Example
External	Symmetric pair	Lightning	Analogue customer interface
		Power induction and earth potential rise	ISDN basic-rate interface Remote power feeding circuits
		Mains power contact	xDSL interface
	Coaxial cable	Lightning	ISDN primary-rate interface
		Power induction and earth potential rise	Remote power feeding circuits
	Dedicated power feed (a.c., d.c.)	Lightning	Optical network unit/termination power feed interface
		Power induction and earth potential rise	
	a.c. mains power	Lightning	a.c. mains power
Earth potential rise and neutral potential rise			
Internal	Unshielded cable	Lightning	
	Shielded cable (including coax)	Lightning	
	Floating d.c. power interface	Lightning	
	Earthed d.c. power interface	Lightning	

A summary of the applicable tests is given in Table 2. The numbers given in the "Port Type" columns, e.g., 10.1.2, refer to the appropriate clause number in this Recommendation which discusses this test. The letters "n.a." mean the test is not applicable. The words "Under study" mean that the ITU-T is still studying this test. The term "Single" or "Multiple" refers to the number of ports tested. For a single port test, the test is applied to one port only. For a multiple port test, the surge is applied to the number of ports specified simultaneously. The heading and term "Transverse", Port to earth OR Port to External Port refers to whether the surge is applied transversely (i.e., line to line, line to shield or in differential mode) port to earth (line to ground or in common mode) OR port to external port (port to port with the earth reference floating). There is a heading for Basic test level and Enhanced test level, refer to clause 5 for information.

**Table 2a/K.44 – Applicable tests for external ports**

Test type	No. of ports simultaneously tested	Longitudinal/transverse test	Primary protection	Port type			
				Symmetric port	Coaxial port	Dedicated power feed port	Mains power port
Lightning voltage	Single	Transverse	No	10.1.1.1	Under study	10.3.1	10.4.1
		Port to earth	No	10.1.1.1		10.3.1	10.4.1
		Port to external port	No	10.1.1.1		10.3.1	10.4.1
		Transverse	Yes	10.1.1.1		10.3.1	10.4.1
		Port to earth	Yes	10.1.1.1		10.3.1	10.4.1
		Port to external port	Yes	10.1.1.1		10.3.1	10.4.1
	Multiple	Port to earth	No	10.1.1.2		n.a.	n.a.
		Port to external port	No	10.1.1.2		n.a.	n.a.
		Port to earth	Yes	10.1.1.2		n.a.	n.a.
		Port to external port	Yes	10.1.1.2		n.a.	n.a.

**Table 2a/K.44 – Applicable tests for external ports**

Test type	No. of ports simultaneously tested	Longitudinal/transverse test	Primary protection	Port type			
				Symmetric port	Coaxial port	Dedicated power feed port	Mains power port
Lightning current	Single	Transverse	No	n.a.	Under study	n.a.	n.a.
		Port to earth	No	10.1.2		10.3.2	n.a.
		Port to external port	No	10.1.2		10.3.2	n.a.
		Transverse	Yes	n.a.		n.a.	n.a.
		Port to earth	Yes	n.a.		n.a.	n.a.
		Port to external port	Yes	n.a.		n.a.	n.a.
	Multiple	Port to earth	No	10.1.2		n.a.	n.a.
		Port to external port	No	10.1.2		n.a.	n.a.
		Port to external port	No	10.1.4		10.3.3	n.a.
Power induction and earth potential rise	Single	Transverse	No	10.1.4	10.3.3	10.4.3 Under study	
		Port to earth	No	10.1.4	10.3.3	10.4.3 Under study	
		Port to external port	No	10.1.4	10.3.3	10.4.3 Under study	

**Table 2a/K.44 – Applicable tests for external ports**

Test type	No. of ports simultaneously tested	Longitudinal/transverse test	Primary protection	Port type			
				Symmetric port	Coaxial port	Dedicated power feed port	Mains power port
Power induction and earth potential rise	Single	Transverse	Yes	10.1.4	Under study	10.3.3	n.a.
		Port to earth	Yes	10.1.4		10.3.3	Under study
		Port to external port	Yes	10.1.4		10.3.3	Under study
Neutral potential rise	Single	Port to earth	No	n.a.		n.a.	10.4.4
		Port to external port	No	n.a.		n.a.	10.4.4
Mains power contact	Single	Transverse Longitudinal	No	10.1.5		10.3.4	n.a.
		Port to earth	No	10.1.5		10.3.4	n.a.
		Port to external port	No	10.1.5		10.3.4	n.a.

**Table 2b/K.44 – Applicable tests for internal ports**

Test type	Primary protection	Port type			
		Unshielded cable	Shielded cable	Floating d.c. power interface	Earthed d.c. power interface
Lightning voltage	No	10.5.1	10.5.2	10.5.3	10.5.4

## **10.1 External symmetric pair port**

### **10.1.1 Lightning voltage**

For equipment with high current carrying protection components, which eliminates the need for primary protection, the following applies:

- If this component is removable, an exception to clause 6 applies and, it shall be removed and replaced by the special test protector for both the inherent and coordination tests, see 8.4.
- If this component is not removable, all tests are performed with the protection provided and the manufacturer must provide a test report to show that the inherent and coordination tests were performed with the special test protector during the design tests.

#### **10.1.1.1 Single port**

The single port lightning test is to check that each port of the equipment has the required level of overvoltage resistibility. Both longitudinal and transverse tests shall be performed.

#### **10.1.1.2 Multiple ports**

The multiple ports lightning surge test is to check that the equipment has the required level of resistibility when an overvoltage surge occurs on n ports simultaneously, which can result in a high current flowing into a common component or part of the equipment.

The number or percentage of ports to be tested simultaneously is to be specified in the product family or product Recommendation.

### **10.1.2 Lightning current**

The overcurrent test checks that the equipment has the required level of inherent resistibility when high current carrying protection components are installed within the equipment to eliminate the need for primary protection. This test checks the coordination of high current protectors, integral to the equipment, with connectors and printed circuits tracks, etc. The overcurrent test is to be specified in the product family or product Recommendation.

When applying the test to multiple wires, care should be taken to ensure that the current is divided equally between the wires. Particular care should be taken to ensure that the operation of one or more protectors does not prevent the operation of the other protectors.

### **10.1.3 Power induction and earth potential rise**

Both longitudinal and transverse tests shall be performed.

If the equipment has high current carrying protection components, which eliminates the need for primary protection, the following applies:

- If this component is removable, an exception to clause 6 applies and, it shall be removed and replaced by the special test protector for both the inherent and coordination tests, see 8.4.
- If this component is not removable, all tests are performed with the protection provided and the manufacturer must provide a test report to show that the inherent and coordination tests were performed with the special test protector during the design tests.

#### **10.1.4 Mains power contact tests**

Both longitudinal and transverse tests shall be performed. If the equipment has high current carrying protection components which eliminates the need for primary protection, the following applies:

- Perform the test with the protection as supplied by the manufacturer. Ensure that the protection operates during the test. This may require selecting a line with a protector which has a low firing voltage. It is not necessary to confirm protector operation if one or more of the following apply:
  - The equipment manufacturer, during the equipment design, has chosen the protector firing voltage so that the protector will not operate for power contact.
  - The equipment input impedance prevents the power contact voltage, at the input of the equipment, from exceeding the specified minimum firing voltage of the protector type.
- If this component is removable, an exception to clause 6 (equipment boundaries) applies and it shall be removed and replaced by the special test protector, see 8.4, and the tests repeated.

If this component is not removable, the manufacturer must provide a test report to show that the tests were repeated with a protector with a firing voltage equal to the specified minimum d.c. firing voltage during the design tests.

#### **10.2 External coaxial port**

The ITU-T is studying the test requirements for coaxial cable ports.

#### **10.3 External d.c. and a.c. dedicated power feeding ports**

##### **10.3.1 Lightning voltage**

Both longitudinal and transverse tests shall be performed.

##### **10.3.2 Lightning current**

The overcurrent test checks that the equipment has the required level of inherent resistibility when high current carrying protection components are installed within the equipment to eliminate the need for primary protection. This test checks the coordination of high current protectors integral to the equipment, with connectors and printed circuits tracks, etc. The overcurrent test is to be specified in the product family or product Recommendation.

##### **10.3.3 Power induction and earth potential rise**

Both longitudinal and transverse tests shall be performed.

##### **10.3.4 Mains power contact**

Both longitudinal and transverse tests shall be performed.

#### **10.4 External a.c. mains power port**

##### **10.4.1 Lightning voltage**

Both longitudinal and transverse tests shall be performed.

Three types of primary protector SPDs are known to exist for use on the electricity supply mains and these are:

- 1) clamping (MOV) type;
- 2) switching (spark gap);

3) a combination of both.

Because of the different characteristics of these SPDs, a manufacturer may need to check that this equipment coordinates with all three types.

#### **10.4.2 Earth potential rise**

The ITU-T is studying the need for a test to check resistibility of the equipment from the earth potential rise which can occur when a High Voltage (HV) earth fault occurs on the substation providing mains power to the equipment.

#### **10.4.3 Neutral potential rise**

This test applies only on request of the network operator, and when the neutral is not connected to the protective earth (i.e., a TT or IT mains system). An example of such a configuration is described in clause II.5.

### **10.5 Internal ports**

#### **10.5.1 Unshielded cable**

The lightning voltage test is to check that the equipment port has the required level of overvoltage resistibility. Only a longitudinal test is performed.

#### **10.5.2 Shielded cable**

The lightning voltage test is to check that the equipment port has the required level of overvoltage resistibility. Only a longitudinal test is performed.

#### **10.5.3 Floating d.c. power interface**

The lightning voltage test is to check that the equipment port has the required level of overvoltage resistibility. Only a longitudinal test is performed.

#### **10.5.4 Earthed d.c. power interface**

The lightning voltage test is to check that the equipment port has the required level of overvoltage resistibility. Only a longitudinal test is performed.

## **Annex A**

### **Test schematics**

#### **A.1 Introduction**

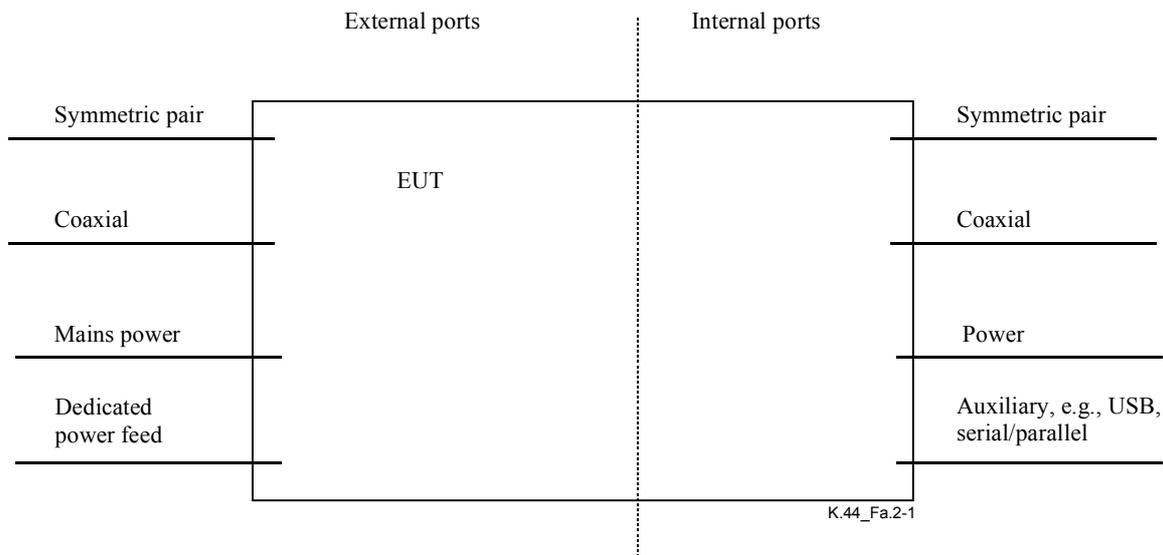
Equipment needs to be tested in all likely states and conditions. This means that the test specified in each line of the test table may need to be performed many times.

To ensure repeatability of testing by test houses and manufacturers, it is necessary to ensure that the tests are performed in the same way. Following are the generator circuits, coupling, decoupling and powering circuits, the termination of untested ports, and the connection to the equipment under test (EUT).

#### **A.2 Equipment**

##### **A.2.1 Equipment ports**

Figure A.2-1 shows the possible ports of a piece of equipment.



NOTE 1 – Not all ports need to be tested but they may need to be terminated.

NOTE 2 – In this figure, "External ports" means ports connected to cables which exit the building and "Internal ports" means ports connected to cables which remain within the building.

**Figure A.2-1/K.44 – Equipment ports**

It is necessary to consider the differences between external ports and internal ports. Internal ports on the EUT are connected to cables that terminate on equipment having the same earth reference as the EUT. External ports on the EUT, on the other hand, can be connected to cables that terminate on equipment with a different earth reference, e.g., in another building. This means that current may be conducted into one external port and out another external port.

### **A.2.2 Equipment type**

Equipment may be of two general types: earthed and floating. Generally, telecommunication centre equipment will be of the earthed type. Access network equipment and customer equipment may be either type.

### **A.2.3 Protection type**

Protecting equipment from high current surges is achieved by either installing primary protection or using equipment with integral high current protection. Generally, telecommunication centre equipment will be protected by primary protection installed on the MDF. Access network equipment may be protected using either method. Customer equipment would normally be protected by installing primary protection.

### **A.2.4 Equipment conditions and states**

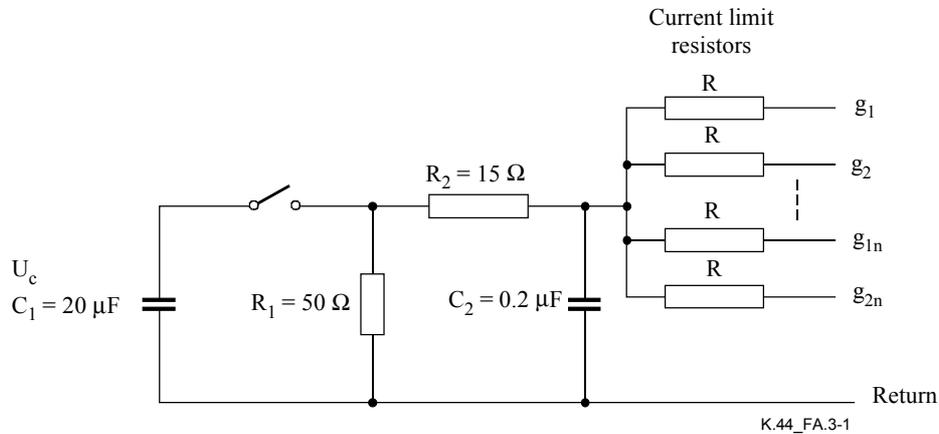
As the components in the equipment, which are connected to the equipment port under test, may vary depending on which state the equipment is in, the equipment must be tested in all operating states of significant duration. Examples of equipment states that may need to be considered include:

- Handset "On hook" and "Off hook";
- Power feed "On" and "Off";
- During ring;
- During a line test cycle, etc.

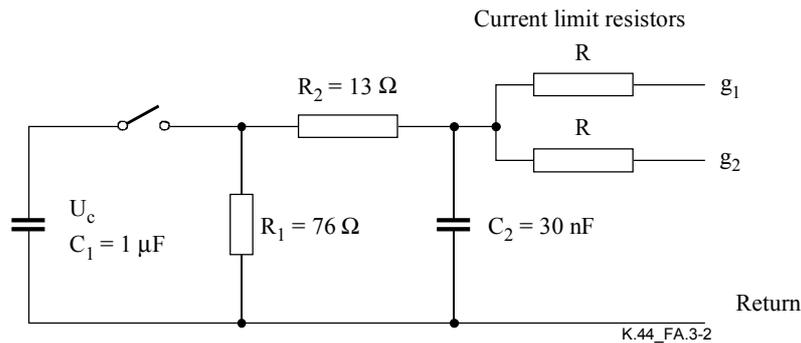
### A.3 Test generators

Examples of circuits of test generators, which can be used to generate the waveshapes specified in A.4, are contained in Figures A.3-1 to A.3-6. While the components shown should give the correct waveshape, they may require adjustment.

Alternative test generators may be used providing they give the same result.

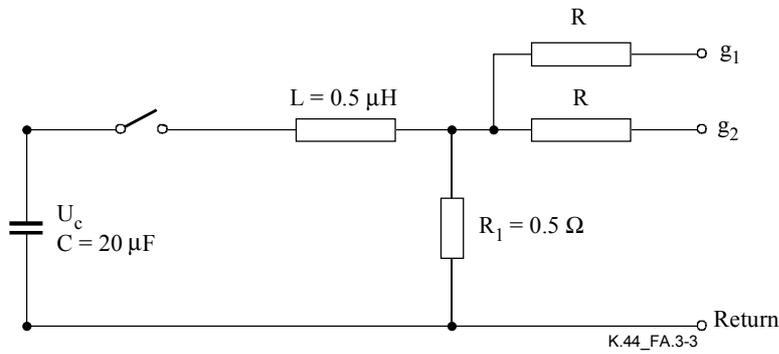


**Figure A.3-1/K.44 – 10/700  $\mu$ s voltage surge generator**



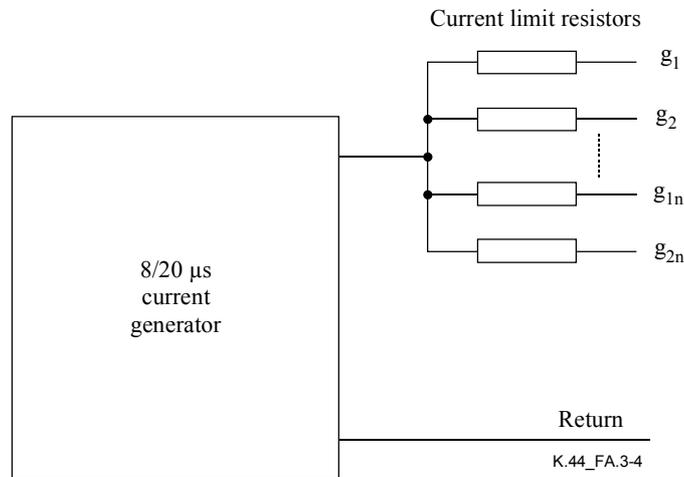
**Figure A.3-2/K.44 – 1.2/50  $\mu$ s voltage surge generator**

The test generator may be a combination wave generator according to IEC 61000-4-5 (Figure A.3-5) or an equivalent 1.2/50  $\mu$ s voltage surge generator.



L is small and mostly parasitic inductance of the wiring, may need to be adjusted to give the required front time of 2 μs.  $U_c$  is adjusted to give required o/c output voltage.

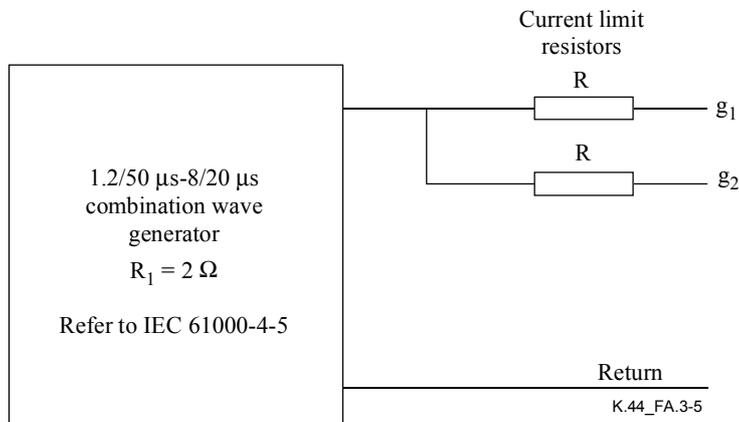
**Figure A.3-3/K.44 – 2/10 μs voltage surge generator**



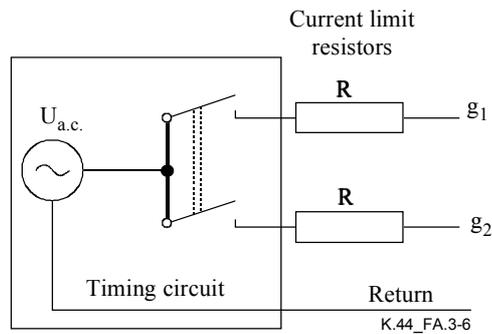
**Figure A.3-4/K.44 – 8/20 μs current generator**

The test generator may be:

- a combination wave generator according to IEC 61000-4-5 (Figure A.3-5);
- any 8/20 surge current generator of 8/20 μs waveshape.



**Figure A.3-5/K.44 – Combination wave generator**



For the value of R, refer to the appropriate test table in the appropriate product Recommendation.

NOTE – If national regulations require it, the maximum current may be limited.

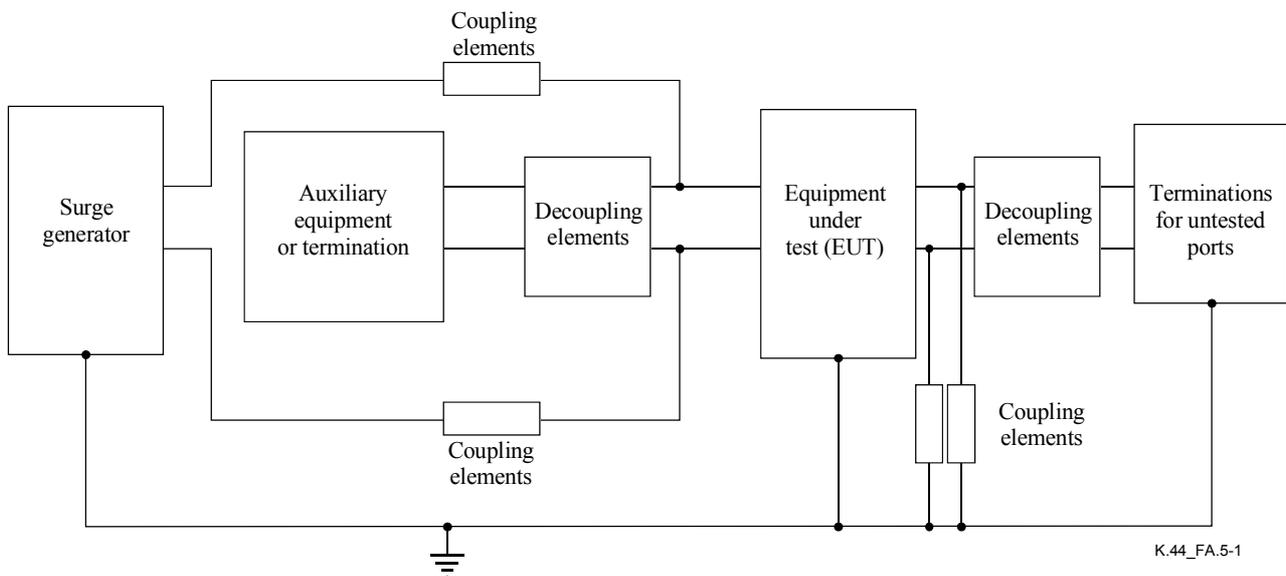
**Figure A.3-6/K.44 – Power induction, power contact and rise of neutral potential generator**

#### A.4 Waveform generation

Where circuit values are provided use this circuit. Where generator circuits are not given, refer to the quoted IEC standard or IEC 60060-1 for guidance on verifying the waveshape.

#### A.5 Powering, coupling, decoupling and terminations

The surge generator, powering, coupling and decoupling elements, the EUT and terminations are connected as shown in Figure A.5-1.

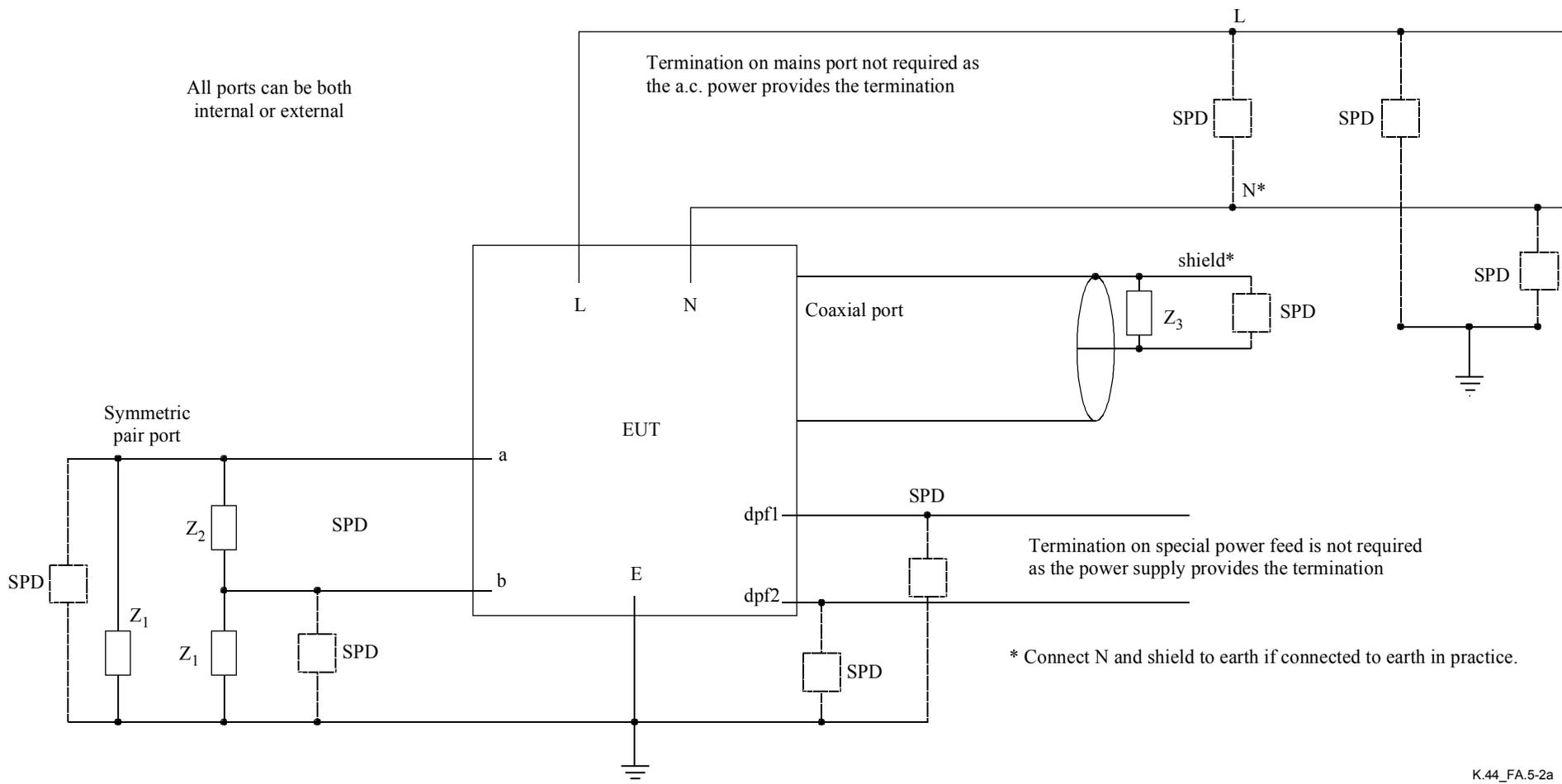


**Figure A.5-1/K.44 – Block diagram of a typical test set-up**

Coupling elements are used to connect the surge generator to the EUT, and to connect other ports/lines to ground during port to port testing. The coupling element, if required, can be an MOV, a GDT, a capacitor or any other element with an operating voltage in excess of the maximum EUT working voltage. The coupling element should be considered as an integral part of the test generator and should not significantly affect the open circuit voltage nor the short circuit current. It may be necessary to increase the test voltage to compensate for voltage drop in coupling elements. There are a number of ways of connecting coupling elements to ground and some examples are shown in Figure A.5-2b.

Decoupling elements are used to reduce the surge energy, which would otherwise enter the powering equipment, associated equipment or terminations. The decoupling elements, if necessary, can be an impedance that blocks the surge energy from entering the line simulator (e.g., resistance of 200  $\Omega$  or greater for symmetric pair circuits, inductance or chokes) but still allowing power and signalling to take place to the EUT. The equipment is powered via the mains or dpf port, etc. through an appropriate decoupling network, e.g., isolation transformer or chokes, etc.

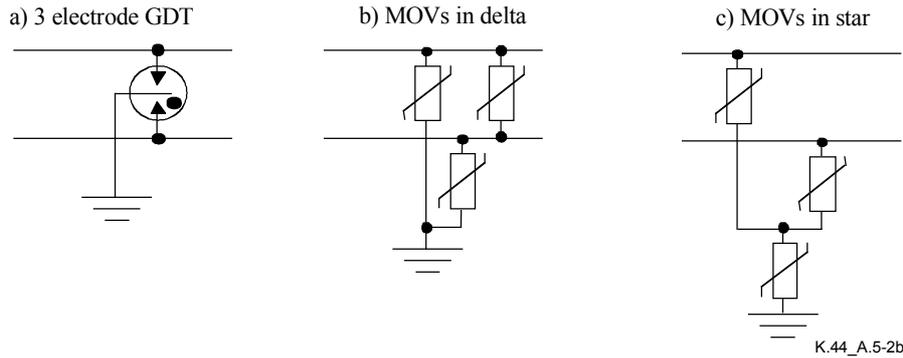
An example of terminations of untested ports is given in Figure A.5-2a. All ports, including the test port would normally be terminated in some way. Decoupling elements are used to prevent damage to the associated equipment or termination. When required for the test, the appropriate untested port is coupled to ground by using a coupling element.



$Z_1$ ,  $Z_2$  and  $Z_3$  are the nominal terminations for a working system or associated equipment. The SPDs are used to couple the required untested port to ground in turn.

K.44\_FA.5-2a

**Figure A.5-2a/K.44 – Example of termination and coupling to ground of untested port**



**Figure A.5-2b/K.44 – Examples of connecting coupling elements to ground**

## **A.6 Test schematics for different types of ports**

### **A.6.1 Symmetric pair ports**

Figures A.6.1-1a and A.6.1-1b give the schematic for applying transverse surges. Figure A.6.1-2 gives the schematic for applying surges port to earth. Figure A.6.1-3 gives the schematic for applying surges from an external port to an external port.

### **A.6.2 Coaxial ports**

See Figures A.6.2-1 and A.6.2-2.

### **A.6.3 a.c. or d.c. dedicated power feed ports**

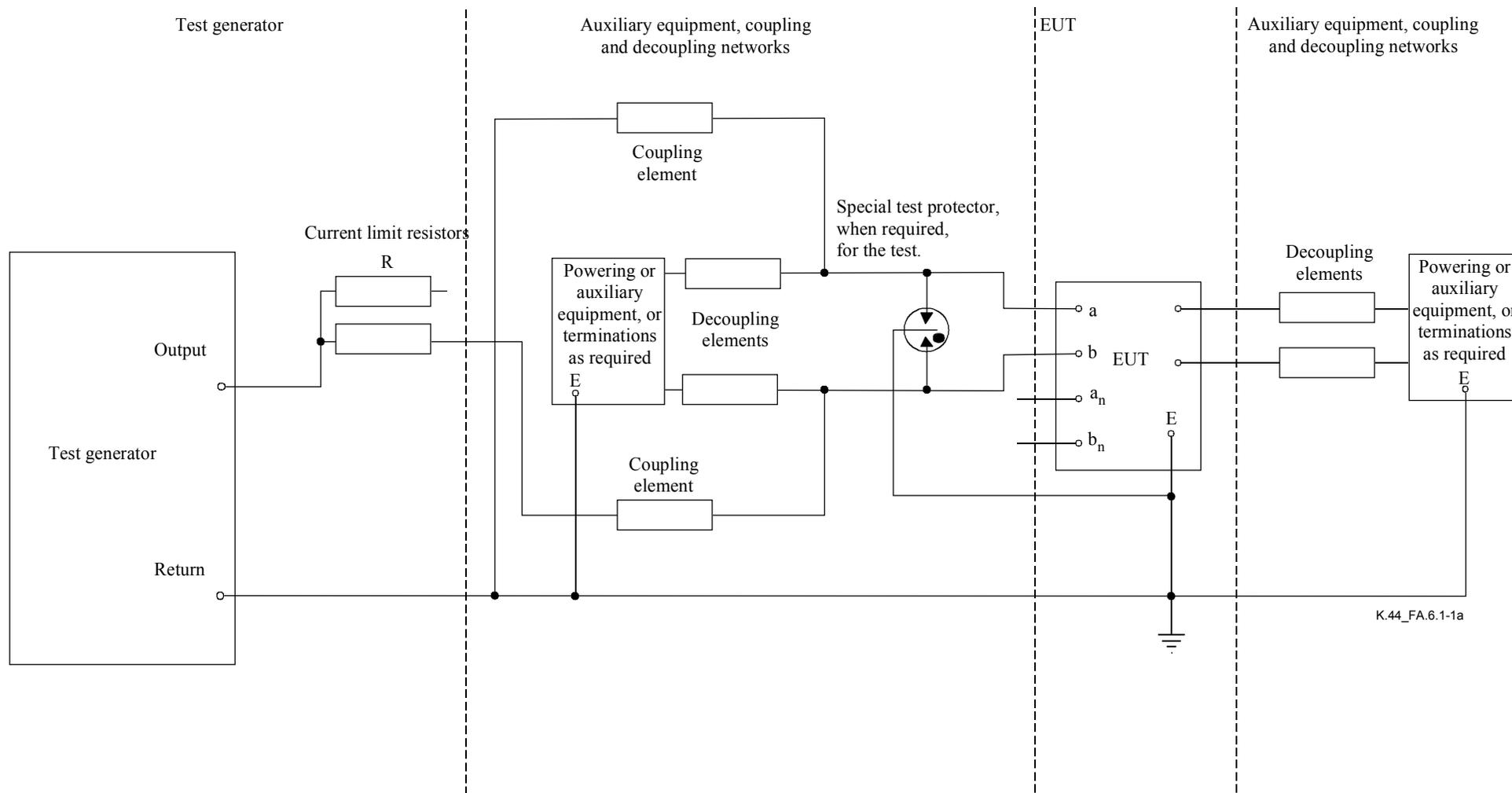
Figures A.6.3-1a and A.6.3-1b give the schematic for applying transverse surges. Figure A.6.3-2 gives the schematic for applying surges port to earth. Figure A.6.3-3 gives the schematic for applying surges from an external port to an external port.

### **A.6.4 Mains power ports**

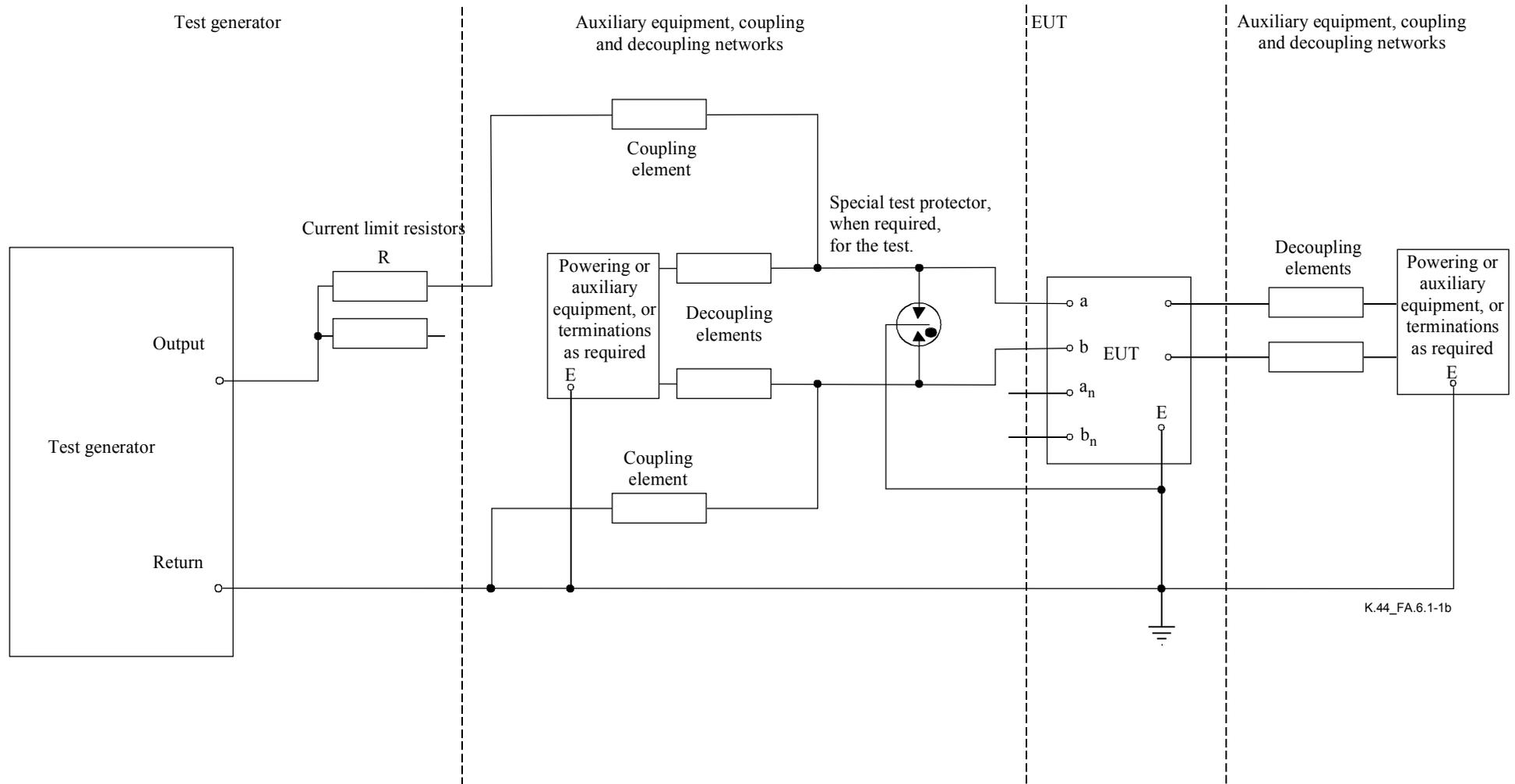
Figure A.6.4-1 gives the schematic for applying transverse surges. Figure A.6.4-2 gives the schematic for applying surges port to earth. Figure A.6.4-3 gives the schematic for applying surges from an external port to an external port.

### **A.6.5 Internal shielded cable ports**

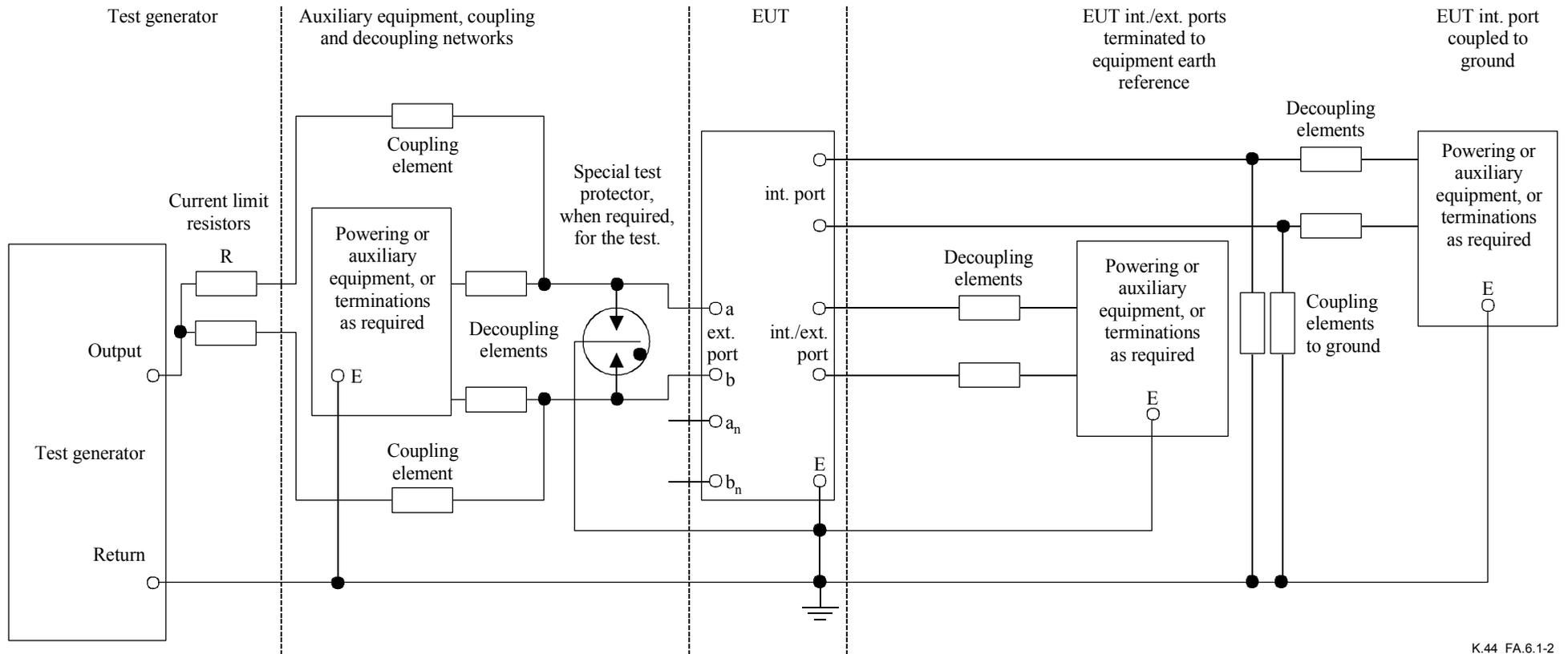
See Figures A.6.5-1 and A.6.5-2.



**Figure A.6.1-1a/K.44 – Example of test circuit for a transverse overvoltage or overcurrent on a single external symmetric pair port (a – terminal to ground)**

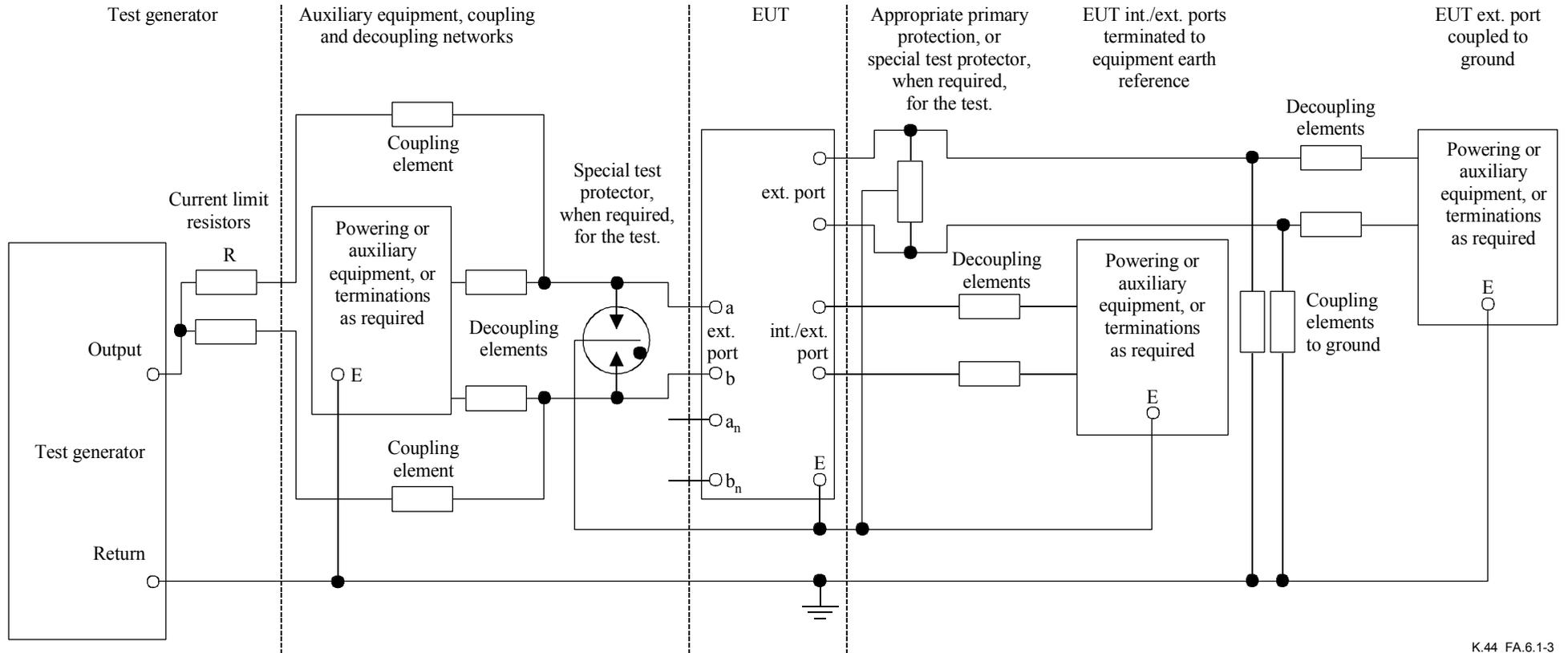


**Figure A.6.1-1b/K.44 – Example of test circuit for a transverse overvoltage or overcurrent on a single external symmetric pair port (b – terminal to ground)**



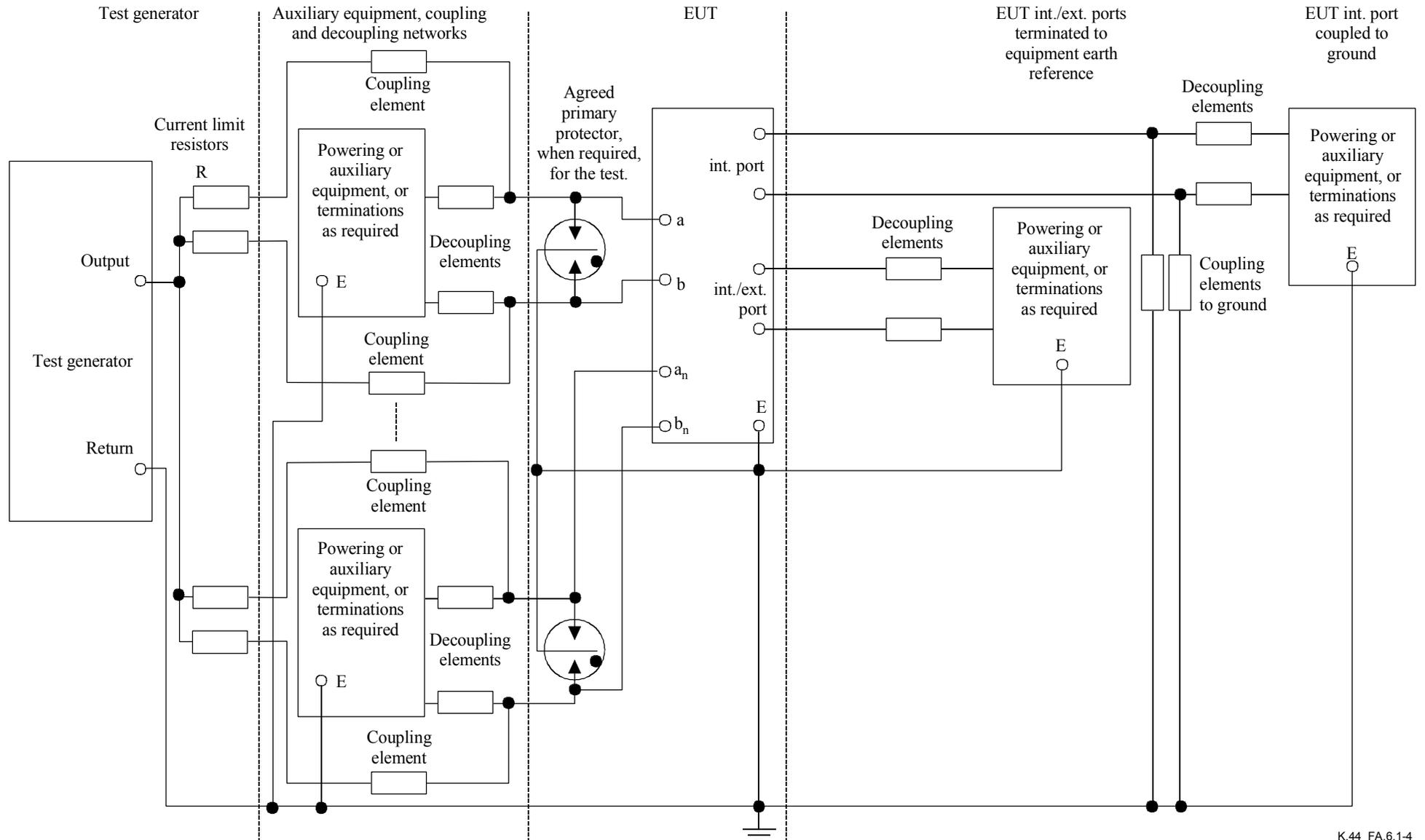
**Figure A.6.1-2/K.44 – Example of test circuit for overvoltage or overcurrent on a single external symmetric pair port to earth**

K.44\_FA.6.1-2



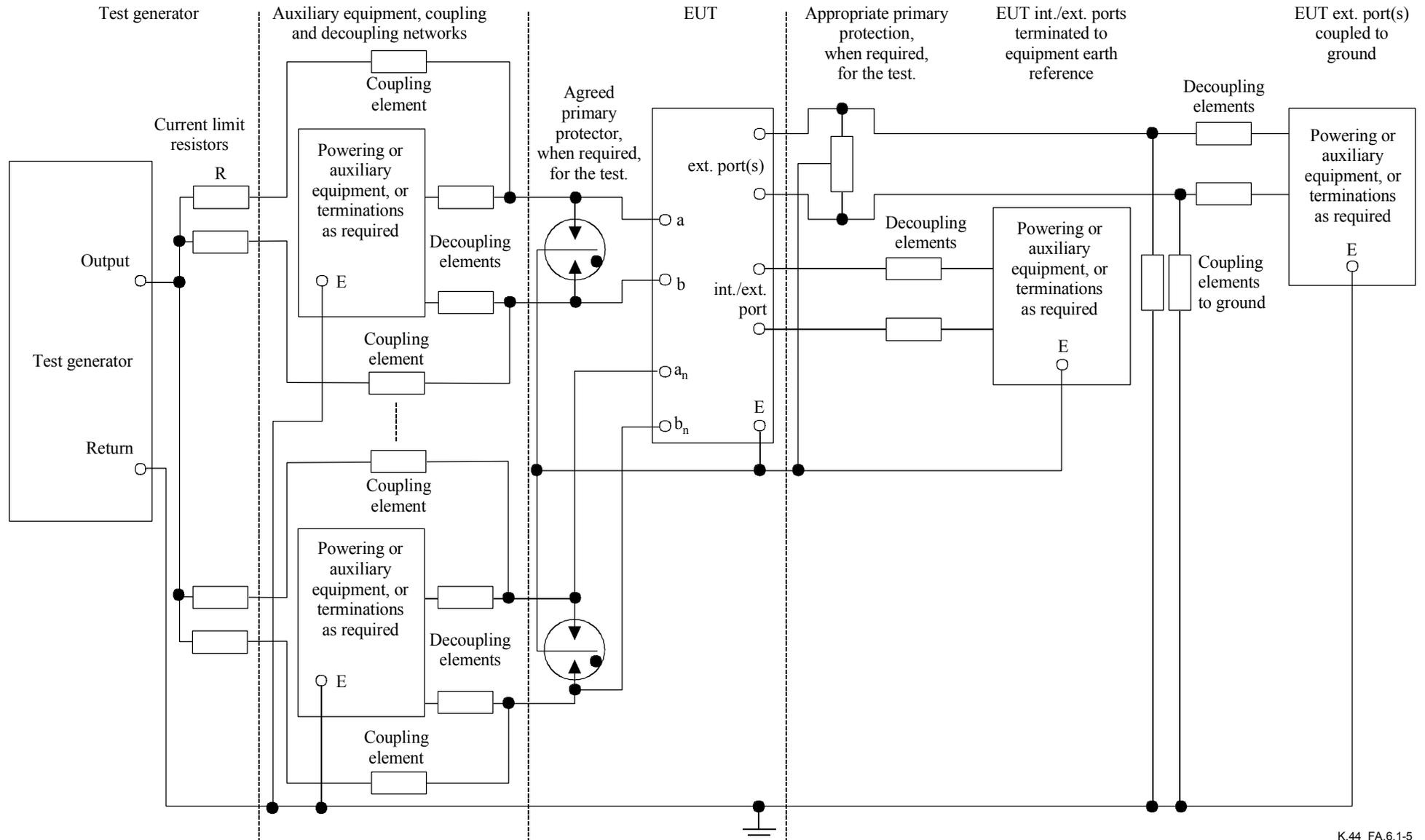
K.44\_FA.6.1-3

**Figure A.6.1-3/K.44 – Example of test circuit for an overvoltage or overcurrent on a single external symmetric pair port to another external port**



K.44\_FA.6.1-4

**Figure A.6.1-4/K.44 – Example of test circuit for a longitudinal overvoltage or overcurrent on multiple external symmetric pair ports to earth**



K.44\_FA.6.1-5

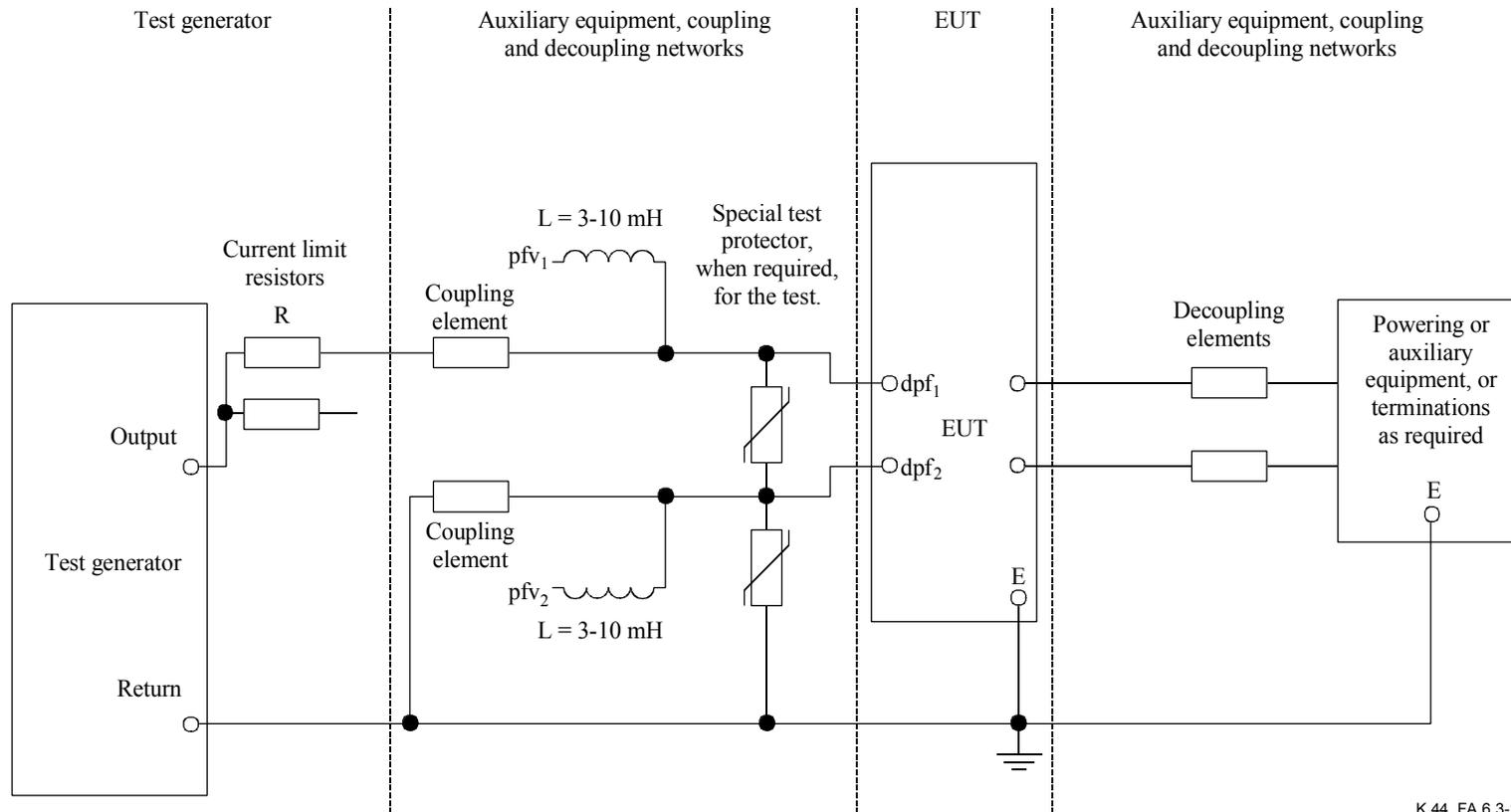
**Figure A.6.1-5/K.44 – Example of test circuit for a longitudinal overvoltage or overcurrent on multiple external symmetric pair port to another external port**

*NOTE – This figure is under study and has not been included*

**Figure A.6.2-1/K.44 – Example of test circuit for a transverse overvoltage or overcurrent on a single external coaxial port**

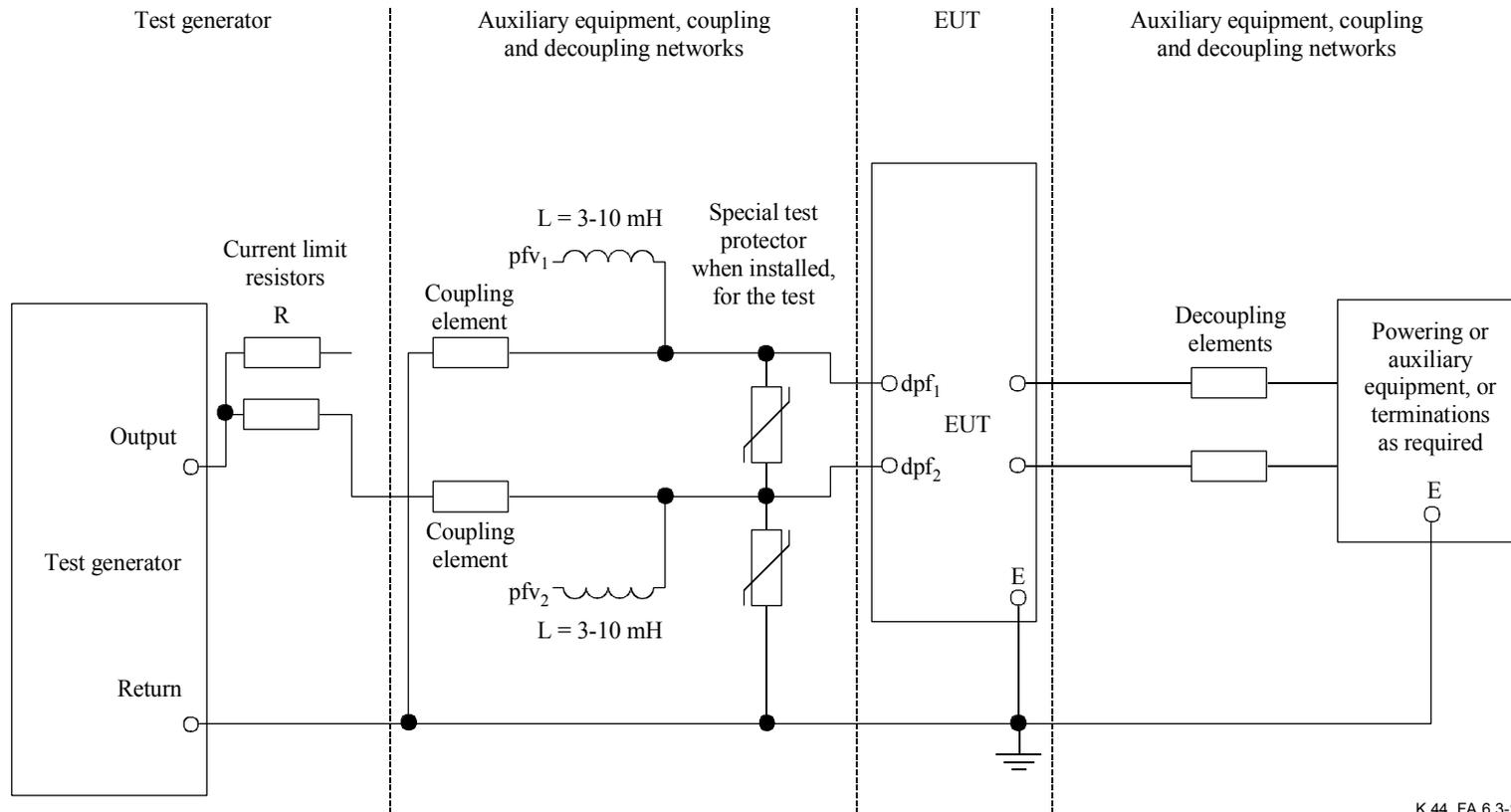
*NOTE – This figure is under study and has not been included*

**Figure A.6.2-2/K.44 – Example of test circuit for an external coaxial shield current test**



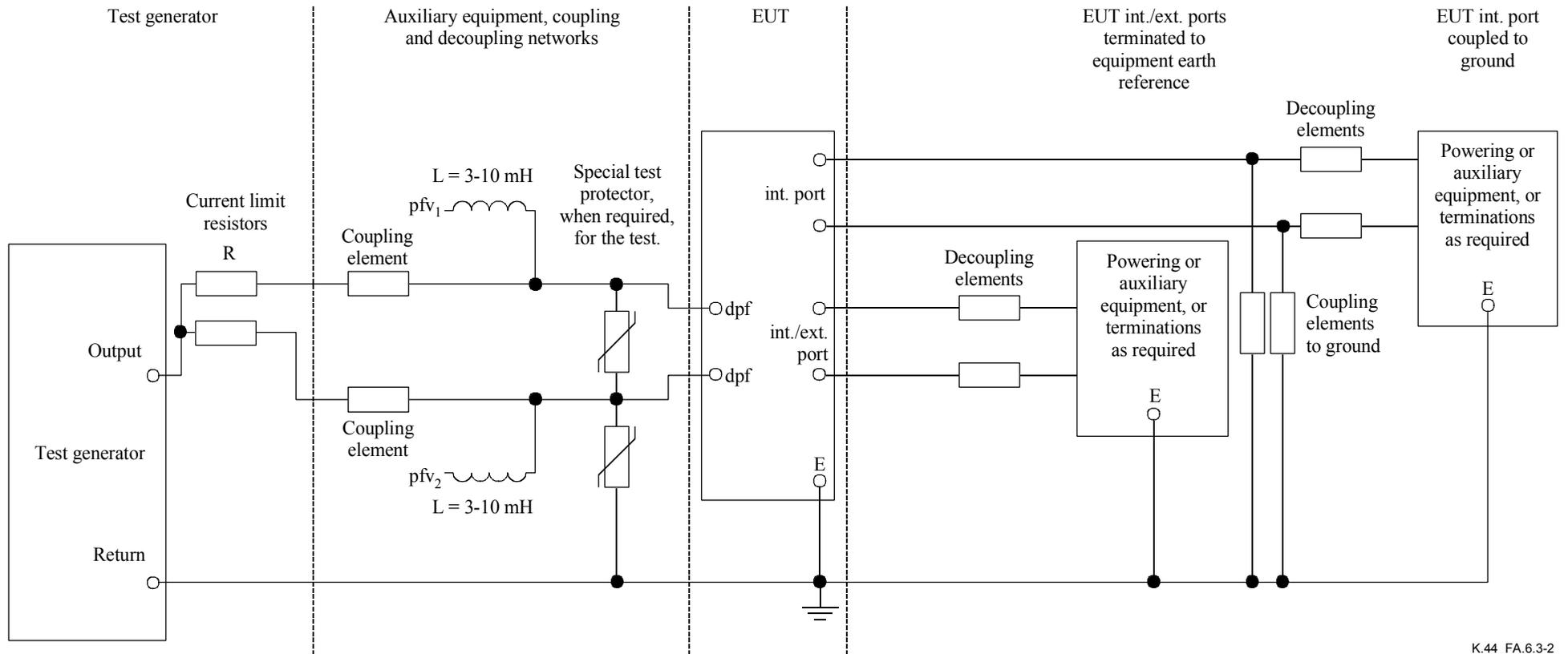
K.44\_FA.6.3-1a

**Figure A.6.3-1a/K.44 – Example of test circuit for a transverse overvoltage or overcurrent on a single external dpf port (dpf2 grounded)**



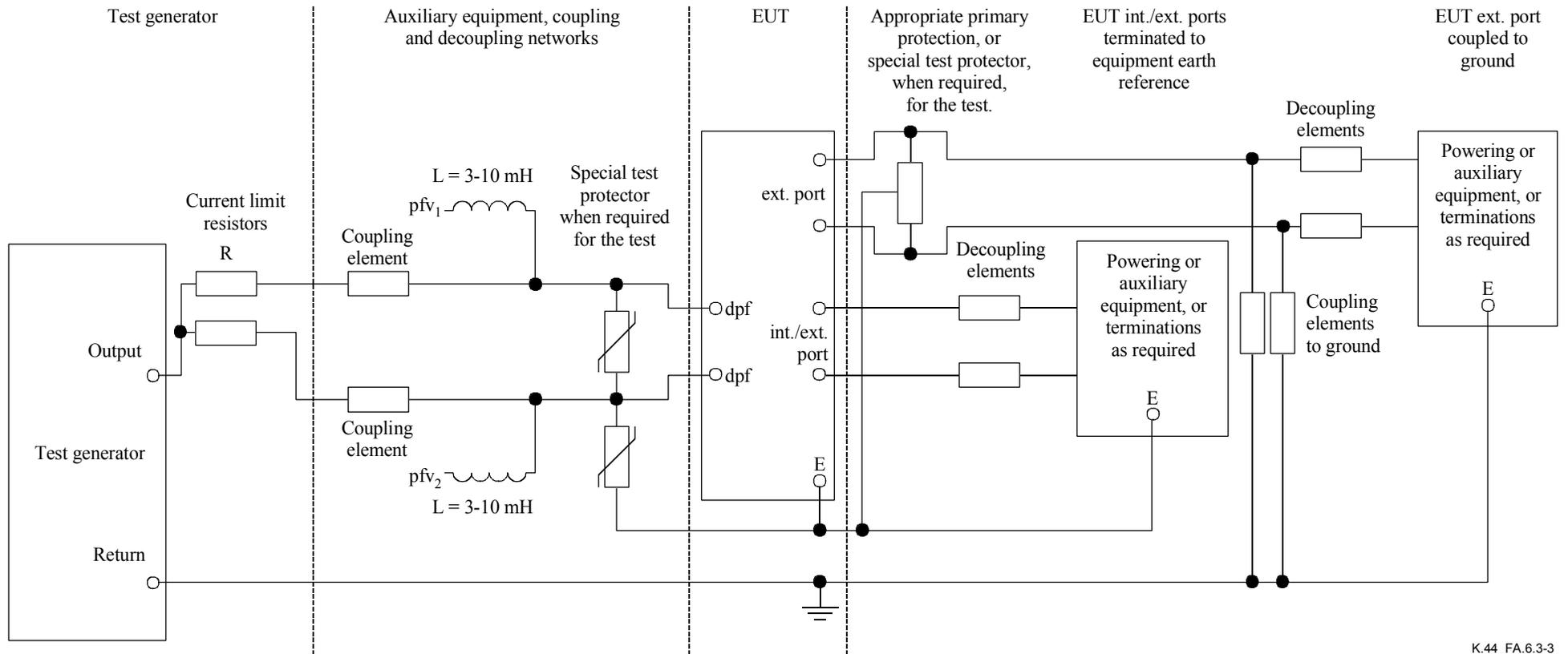
K.44\_FA.6.3-1b

**Figure A.6.3-1b/K.44 – Example of test circuit for a transverse overvoltage or overcurrent on a single external dpf port (dpf1 grounded)**



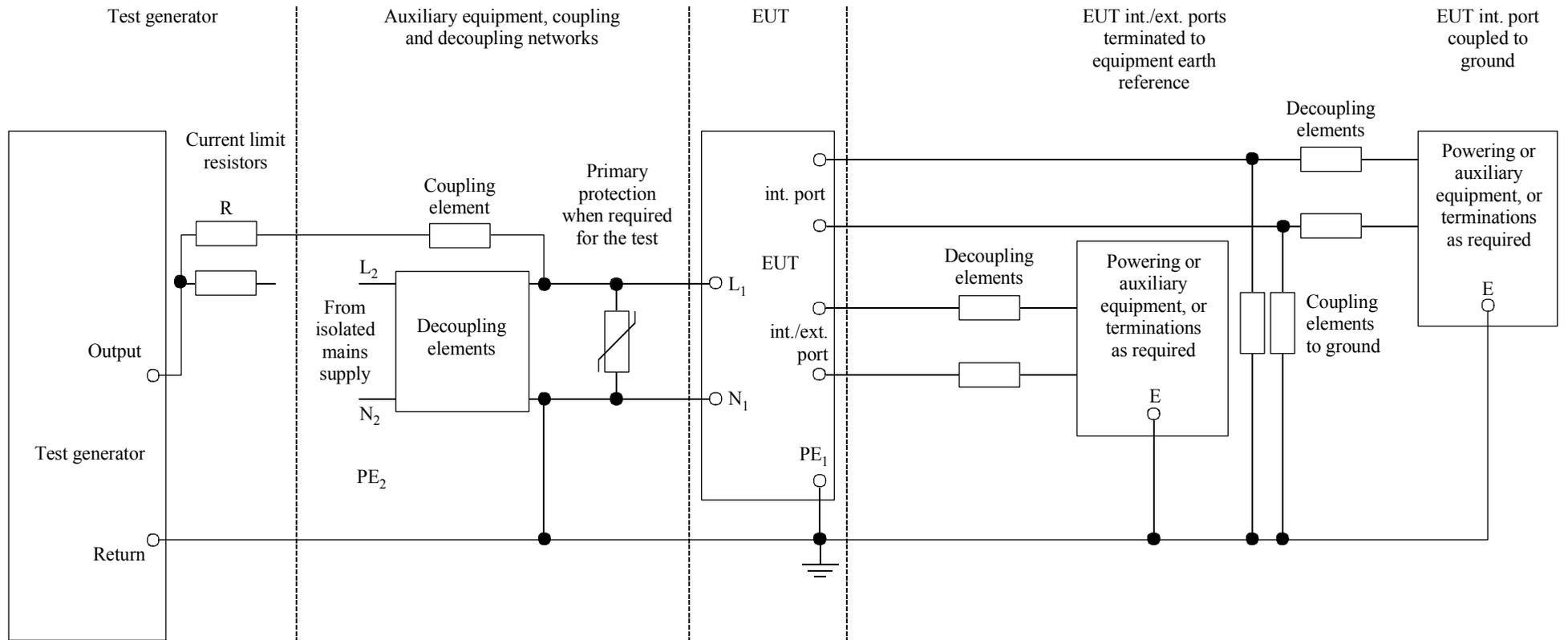
K.44\_FA.6.3-2

**Figure A.6.3-2/K.44 – Example of test circuit for an overvoltage or overcurrent on a single external dpf port to earth**



K.44\_FA.6.3-3

**Figure A.6.3-3/K.44 – Example of test circuit for an overvoltage or overcurrent on a single external dpf port to external port**

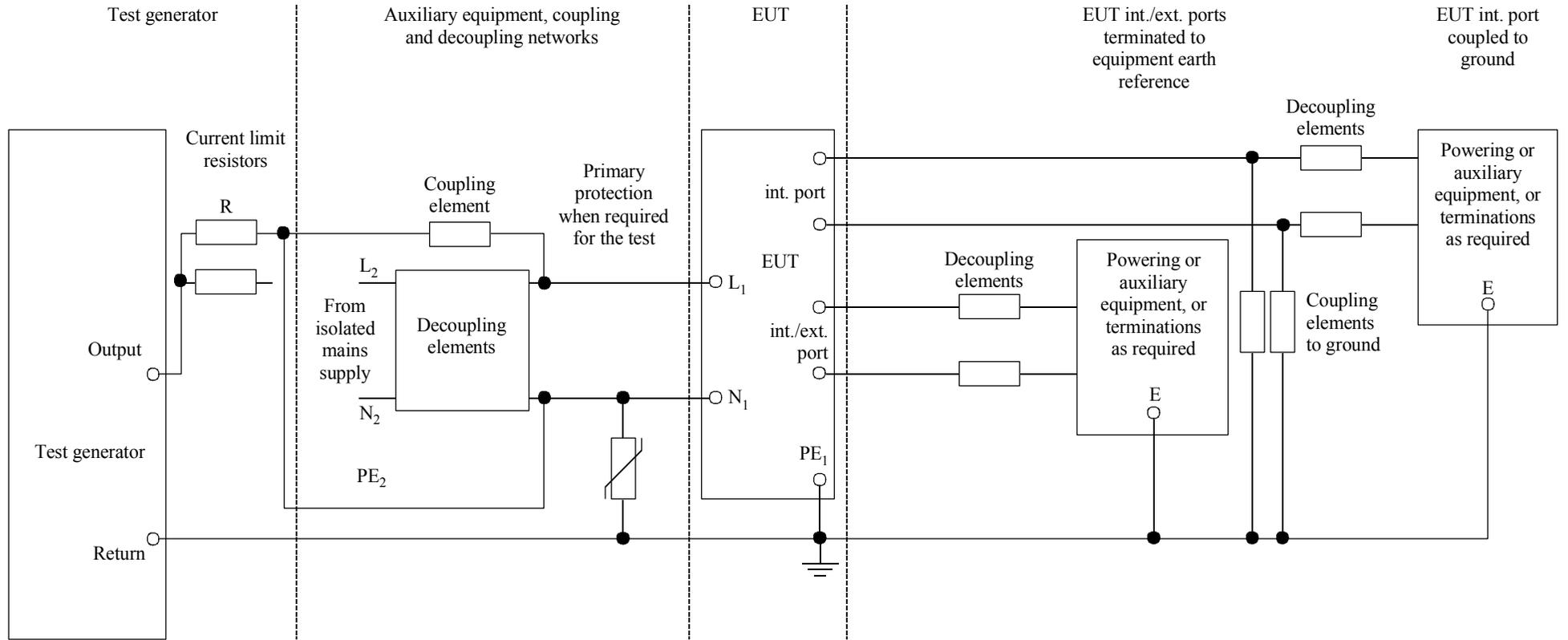


K.44\_FA.6.4-1

NOTE 1 – Total lead length, per SPD, to connect the primary protection shall be 1 metre.

NOTE 2 – The decoupling elements could be an isolating transformer with added inductance in each output leg.

**Figure A.6.4-1/K.44 – Example of test circuit for a transverse overvoltage or overcurrent on an external mains port**

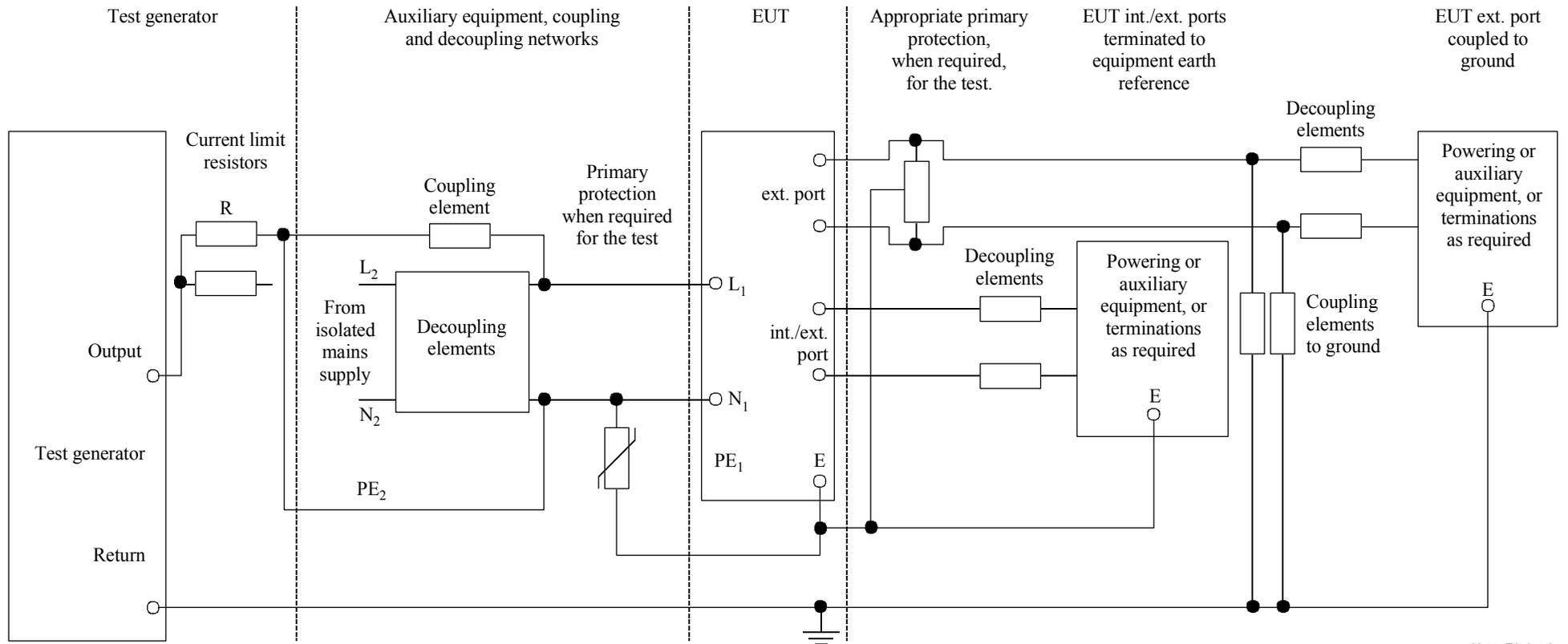


K.44\_FA.6.4-2

NOTE 1 – Total lead length, per SPD, to connect the primary protection shall be 1 metre.

NOTE 2 – The decoupling elements could be an isolating transformer with added inductance in each output leg.

**Figure A.6.4-2/K.44 – Example of test circuit for an overvoltage, overcurrent and rise of neutral potential on an external mains port to earth**

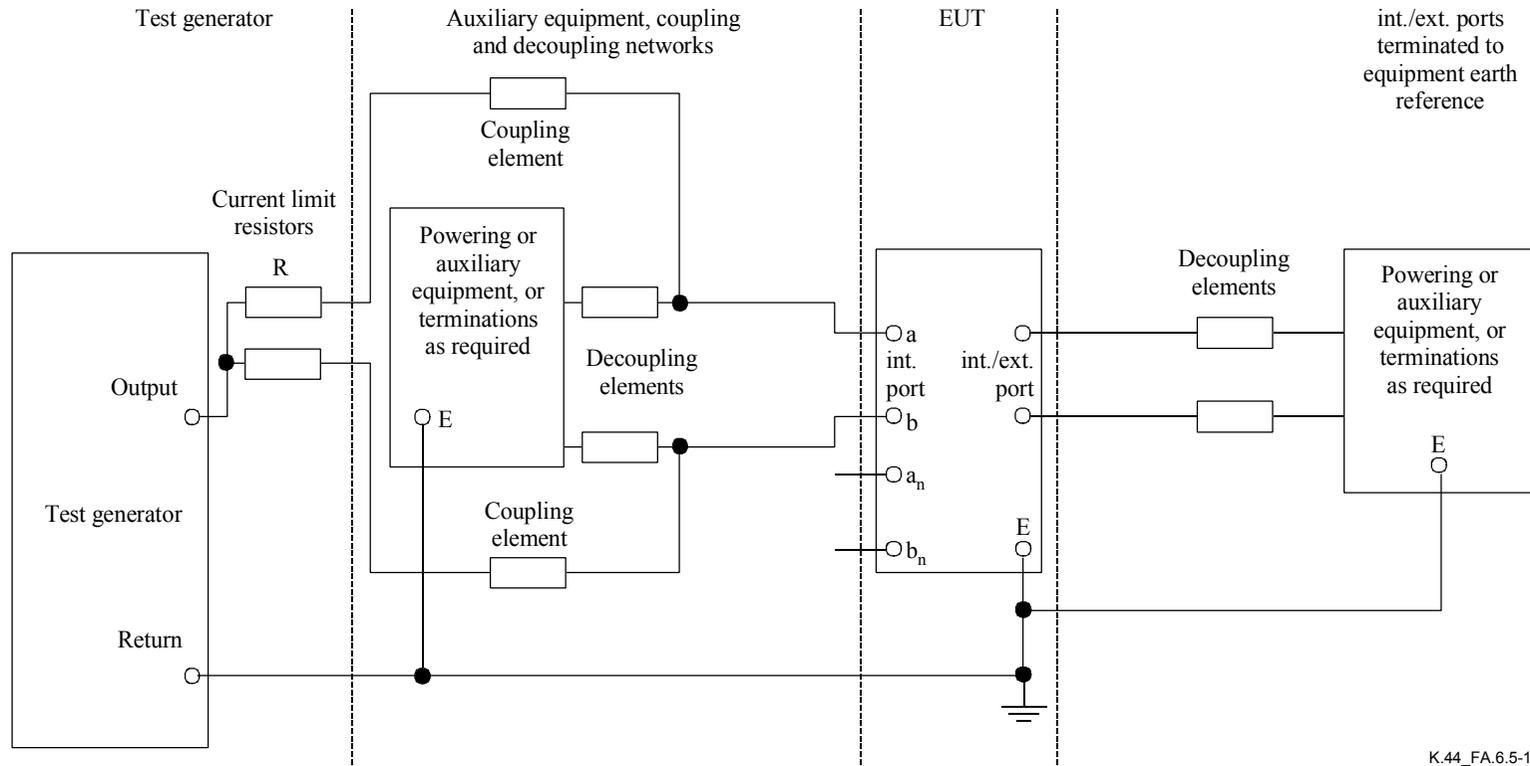


K.44\_FA.6.4-3

NOTE 1 – Total lead length, per SPD, to connect the primary protection shall be 1 metre.

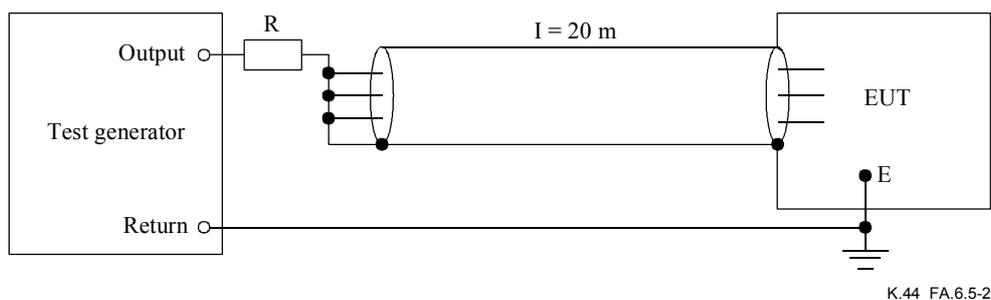
NOTE 2 – The decoupling elements could be an isolating transformer with added inductance in each output leg.

**Figure A.6.4-3/K.44 – Example of test circuit for an overvoltage, overcurrent and rise of neutral potential on an external mains port to external port**



K.44\_FA.6.5-1

**Figure A.6.5-1/K.44 – Example of a test circuit for internal unshielded cables**



For repeatability of measurement, it is recommended that the test be performed on an earth reference plane, with the cable laid on the ground plane in a snake pattern. All conductors are connected together and with the shield. (Reason: in worst case, inserted protective elements in the counterpart equipment, not included in this test set-up, can cause short circuit termination.)

**Figure A.6.5-2/K.44 – Example of test circuit for internal shielded cable ports**

## Appendix I

### Explanations which illustrate test conditions

#### I.1 Testing

##### I.1.1 General

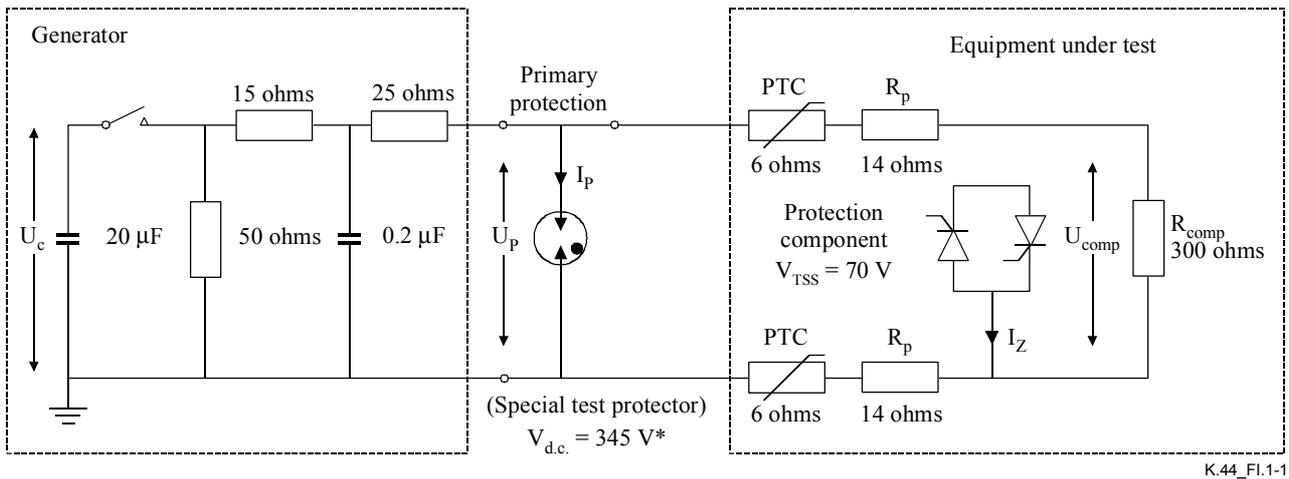
To check that the equipment fulfils the specified acceptance criteria for all voltage and current levels up to the maximum test level, it is necessary to either test at a large range of test voltages/currents from 0 to the maximum level specified, or to perform "intelligent testing". Clauses I.1.2-I.1.4 provide information on intelligent testing which minimizes the number of test levels but ensures that sufficient tests are performed.

##### I.1.2 Lightning surge tests

To check that no damage windows exist within the equipment, it is necessary to perform tests at specific test voltages. These specific test voltages are determined by the operating points of such components as the primary protector (GDT or SSA) and switching protective devices within the equipment. Examples of these test voltages are illustrated using an example of a linecard with a 20  $\Omega$  fusible resistor and a switching type inherent protector. This example linecard, along with the test generator and the primary protector, is shown in Figure I.1-1. Apart from the test generator, all the circuit layout and component values have been chosen only for explanatory purposes and are not put forward as some recommended practice.

When the charging voltage  $U_c$  is progressively raised, the different components are subjected to different voltages, currents and energies. The choice of the components of the circuit is determined by:

- The maximum voltage across the component.
- The maximum current through the component.
- The maximum energy that will be absorbed by the component (the integral voltage current for the duration of the pulse).



\* Special test protector for 230 V primary protector.

NOTE – In practice  $R_p$  may vary from 10-100 ohms and  $R_{slic}$  may also have different values.

**Figure I.1-1/K.44 – Example linecard with designated voltages and currents**

The above circuit is an example of a linecard with a low input impedance when the inherent protection operates. The equipment is nominally protected in exposed areas with an SSA or a GDT on the MDF. It is assumed that it will be protected with a 230 V GDT and the primary protector has been replaced with a GDT with a 345 V d.c. sparkover voltage as described in 8.4.1 (i.e.,  $300 V_{dcmx}$  multiplied by 1.15). The circuit shown is for a transverse test, see Figure A.5.1-2a. To keep the circuit simple, no coupling or decoupling elements, or associated equipment, have been shown. The figures shown are for positive polarity surges only. The 300 ohm resistor  $R_{comp}$  represents the transverse impedance of the components to be protected.

$R_p$  is the protection resistor. Its value may vary in practice from 10 to 100  $\Omega$ . This resistor performs two functions. Firstly, it is designed to fuse in case of power contact to prevent a fire. Secondly, it provides a buffer impedance between the primary protection and the inherent protection to achieve coordination. It becomes the input impedance (resistance) of the EUT when inherent protection turns on.  $R_p$  can be a resistor, PTC or some kind of hybrid device. In some applications, it is possible that the PTCs and resistors  $R_p$  will be at the MDF with the primary protection. Note, having PTCs and resistors  $R_p$  at the MDF is not a recommended practice as some operators may have MDFs that do not accept series impedance. Also, it is better for the PTCs to be at the temperature of the linecard. However, there may be some circumstances where PTCs or other types of overcurrent protection need to be installed on the MDF, see ITU-T Rec. K.30 for guidance.

$R_{comp}$  is the resistance of the circuit. Its value may vary with current and frequency. However, it is usual that the maximum current which flows through  $R_{comp}$  is less than 0.2 A. This current is negligible compared to the current which is conducted by the inherent protection when it operates.

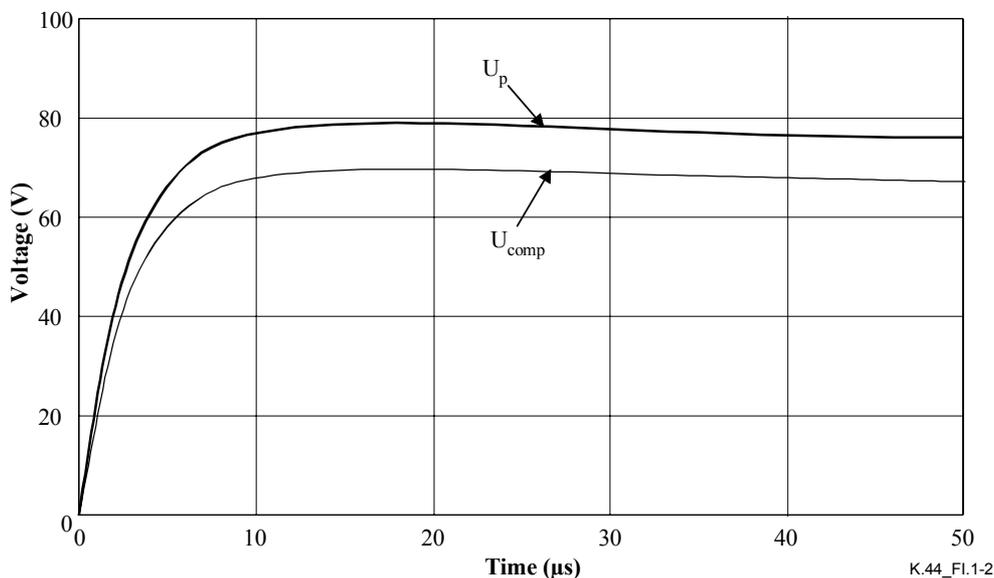
The inherent protection is a PNP type device.

When negative surges are applied, the thyristor will turn on if the voltage across it exceeds its switching voltage, usually around 70 V. After the thyristor turns on, the voltage drop is only 1 or 2 V.

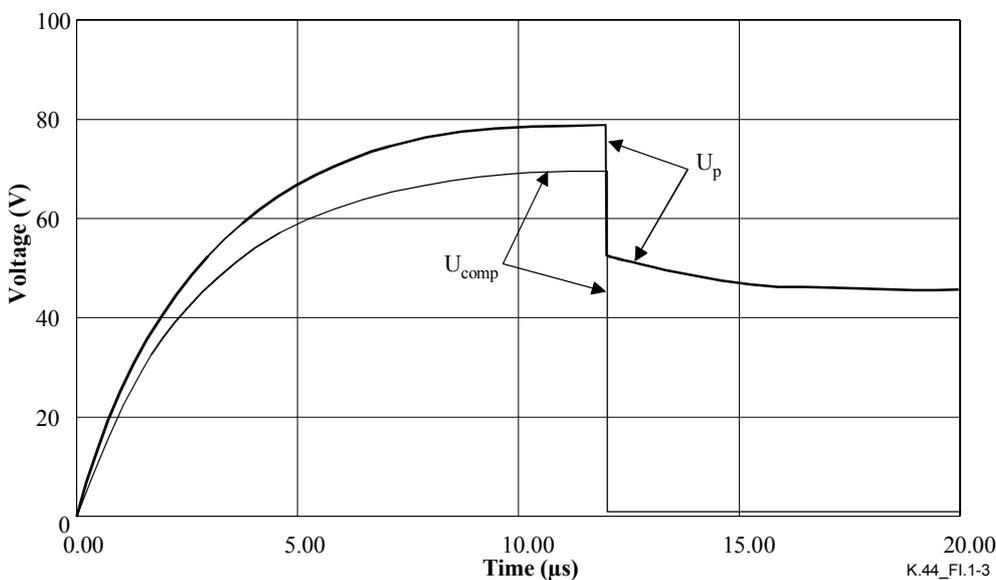
For a  $U_c$  to produce a  $U_{comp} =$  zero to 69 V, no current flows in the thyristor, see Figure I.1-2. This is the point of worst stress for the components and 10 surges of alternate polarity should be applied. With a  $U_c$  to produce a  $U_{comp} = 70$  V, the inherent protection operates and current is conducted through the PTCs and the 14  $\Omega$  resistors, see Figure I.1-3. This will limit the voltage across the components to be protected to 70 V. The voltage across the PTCs and the 14  $\Omega$  resistors and the current through the PTCs and the resistors will increase until the charging voltage is just below the

activation level of the primary protection, see Figure I.1-4. This is the point of maximum stress for the PTCs and the 14  $\Omega$  resistors and 10 surges of alternate polarity should be applied.

When the primary protection is activated, the voltage  $U_p$  drops to a low value (typically about 25 V). The current  $I_z$  flowing into the equipment falls to a very low value and becomes practically independent of  $U_c$ .

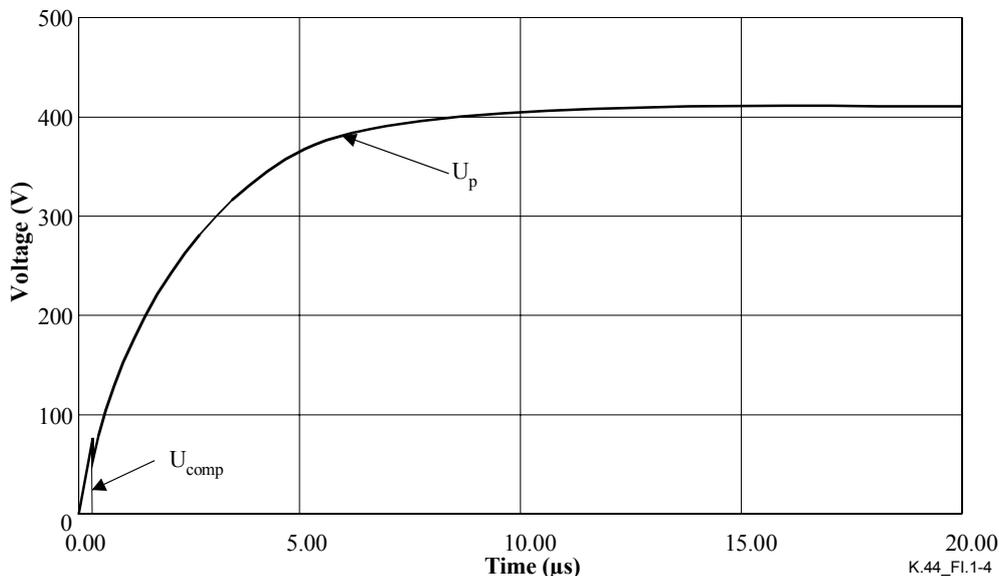


**Figure I.1-2/K.44 – Voltages with  $U_c$  to give a  $U_{comp}$  of 69 V**



**Figure I.1-3/K.44 – Voltages with  $U_c$  to give a  $U_{comp}$  of 70 V**

Figure I.1-4 shows the maximum full wave 10/700  $\mu\text{s}$  voltage which appears at the input of the equipment. Figure I.1-5 shows the protector operating during the tail of the wave. The 10/700  $\mu\text{s}$  firing voltage is the value of  $U_p$  which just causes the protector to operate, i.e., the 10/700  $\mu\text{s}$  firing voltage of the protector is 420 V.



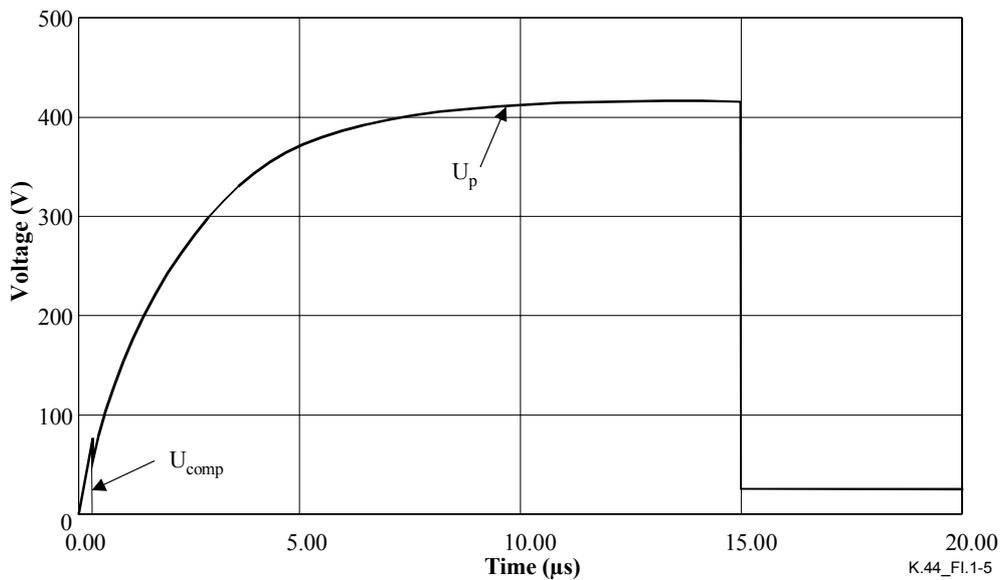
**Figure I.1-4/K.44 – Voltages with  $U_c$  set to cause a  $U_p$  just below the sparkover voltage of the GDT**

Figure I.1-5 shows the measured voltage  $U_p$  across the primary protection and the voltage across the PTCs and the 14  $\Omega$  resistors for a charging voltage  $U_c$  of 855 V and a GDT with a d.c. breakdown voltage of 345 V, the firing voltage of the special test protector used when the agreed primary protector is a 230 V GDT. The different currents can be calculated from the voltages. The primary protector used was activated after 15  $\mu\text{s}$  and the maximum voltage across the GDT was 420 V.

It should be noted that if the primary protection is not activated during the rising edge, it can still be activated during the decay period as the voltage remains initially almost constant during the decay period. When the GDT is activated during the decay period, the breakdown voltage is lower and approaches the d.c. breakdown voltage.

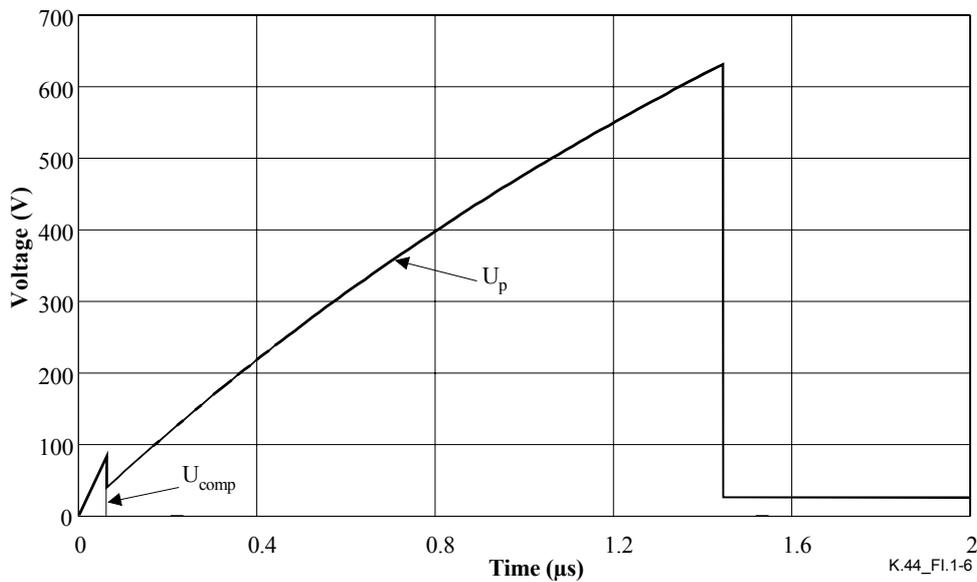
Figure I.1-6 shows the measured voltage  $U_p$  across the primary protection and the voltage across the PTCs and the 14  $\Omega$  resistors for a charging voltage  $U_c$  of 4 kV. The primary protection was activated after 1.5  $\mu\text{s}$  and the maximum voltage across the GDT is 632 V. Although the voltage is higher, the amount of energy that is passed to the equipment is lower.

Figure I.1-7 shows the measured voltage  $U_p$  across the primary protection and the voltage across the PTCs and the 14  $\Omega$  resistors for a charging voltage  $U_c$  of 10 kV. The primary protection was activated after 0.5  $\mu\text{s}$  and the maximum voltage across the GDT is 690 V. Although the voltage is higher, the amount of energy that is passed to the equipment is lower.

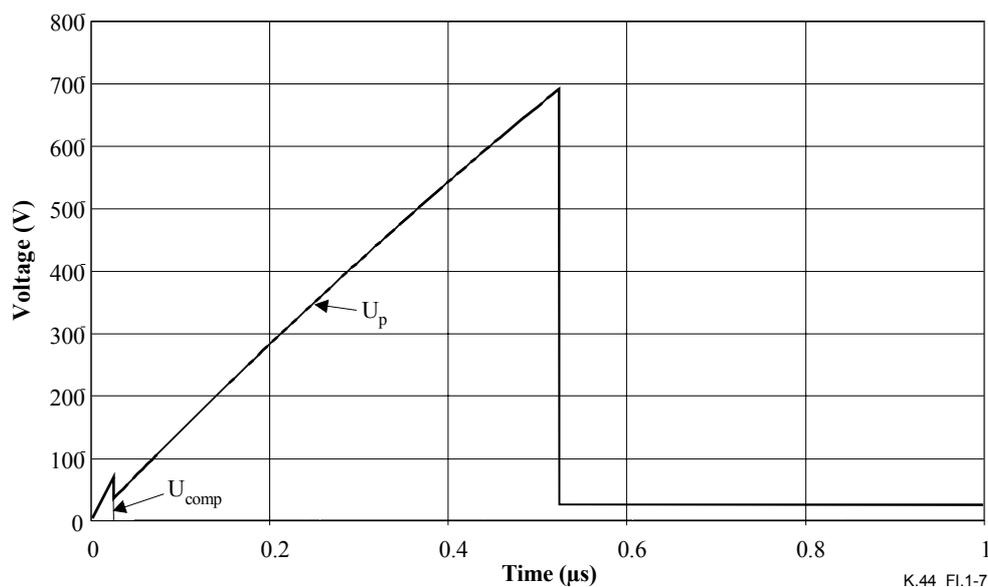


**Figure I.1-5/K.44 – Voltage  $U_p$  across the special test protector for a charging voltage  $U_c$  of 855 V**

This example with six different charging voltages shows the importance of the knowledge of the characteristics of the primary protection and the inherent protection in order to assure a proper coordination between primary and inherent protection, and the equipment.



**Figure I.1-6/K.44 – Voltage  $U_p$  across the special test protector for a charging voltage  $U_c$  of 4 kV**



**Figure I.1-7/K.44 – Voltage  $U_p$  across the special test protector for a charging voltage  $U_c$  of 10 kV**

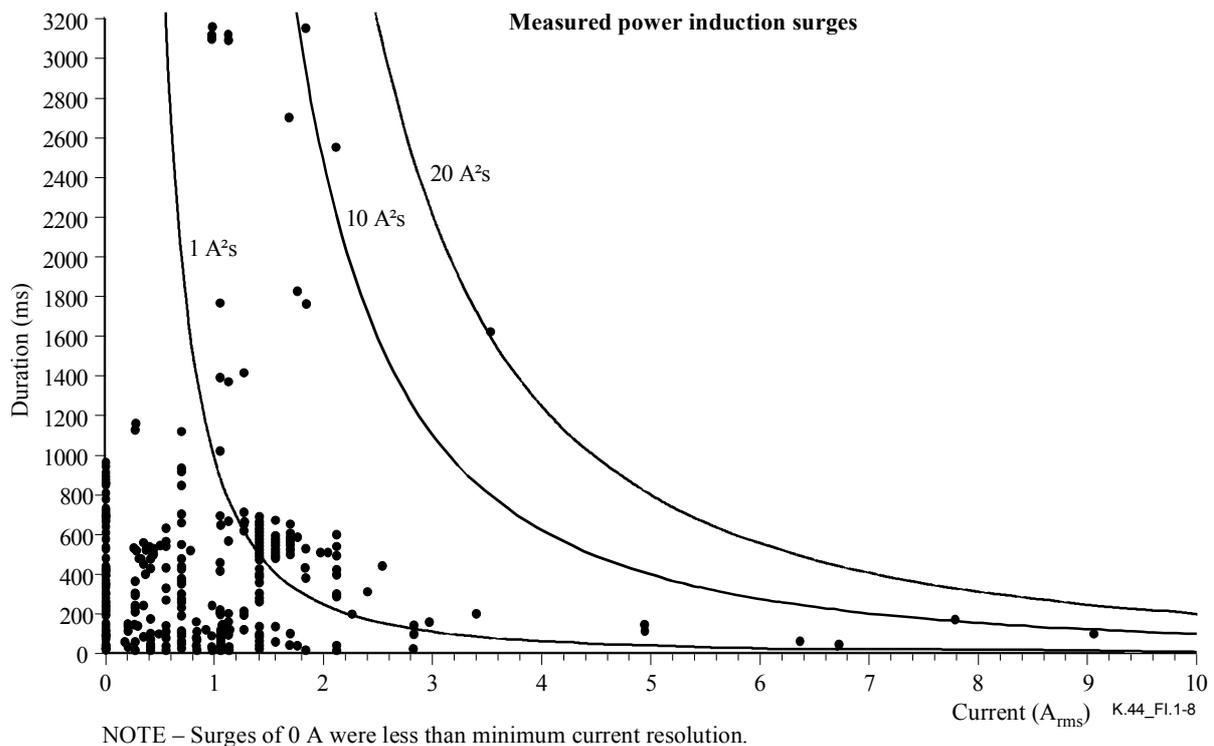
### I.1.3 Power induction

Induced voltages are more likely to occur on long lines, and in the common case where customers' lines do not provide a low resistance to earth, induced voltages  $E$  may be considered to have a high source impedance consisting of a  $600 \Omega$  wire resistance in series with a  $0.33 \mu\text{F}$  line to earth capacitance as shown in Figure I.1-9. The telephone is represented by a  $100 \Omega$  resistance and the hook-switch. The GDTs shown in Figure I.1-9 are needed only on lines in exposed areas. However, because of the liberalization of CPE, such protectors may also be present on less-exposed lines. These GDT fire at the customer line end in the short-term power induction case and short-circuit the telephone and the line capacitances. Therefore, the test circuit given in Figure A.3-6 consists only of the induced voltage  $E = U_{a.c.}$  and the wire resistances  $R$ .

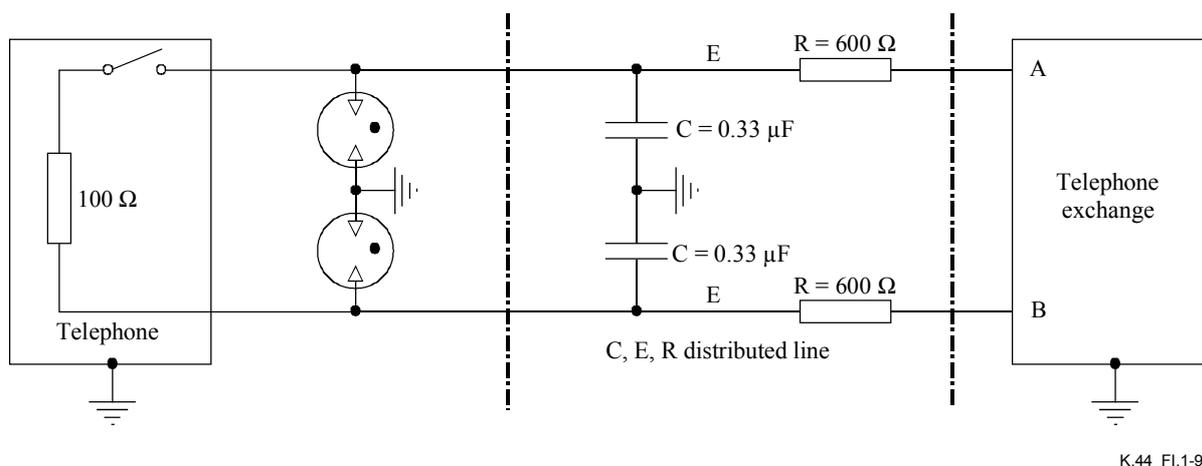
Field experience showed that a large number of linecards in some exchanges were damaged by power induction during thunderstorm days. The damages appeared only in exposed rural areas. The currents induced on such lines, and causing the linecard damages, were measured in a few cases and showed values between 4 and 6 A and duration between 200 and 500 ms, i.e., specific energy values up to  $10\text{-}20 \text{ A}^2\text{s}$ . Figure I.1-8 shows measurements of power induction in Australia.

These overcurrents with high specific energy values were estimated as rare events; therefore, it was agreed that the induction test, with agreed primary protection, should simulate an overcurrent with a specific energy of  $1 \text{ A}^2\text{s}$  for the basic requirement and  $10 \text{ A}^2\text{s}$  for the enhanced requirement.

Considering that most test laboratories only had available a test circuit with a maximum test voltage of 600 V, it was decided to define, for the basic requirement induction test, this maximum voltage value  $U_{a.c.(max)} = 600 \text{ V}$  and to increase the test duration up to 1 s.

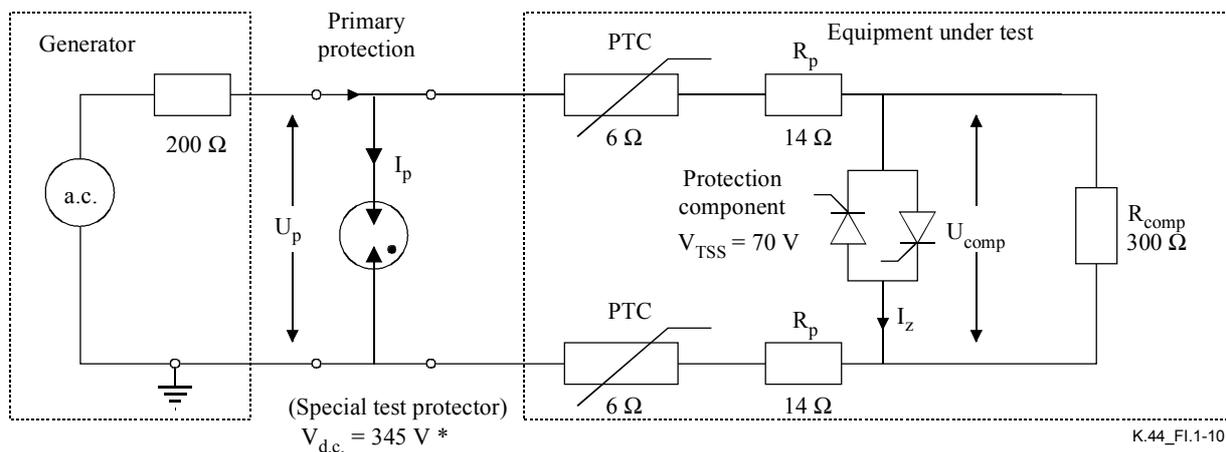


**Figure I.1-8/K.44 – Power induction overcurrents measured in Australia**



**Figure I.1-9/K.44 – Equivalent circuit of a telecommunication line during power induction**

As with the lightning surge testing, it is also necessary to be aware of the need to test at specific voltage levels when performing power induction tests. An example of a linecard circuit utilizing a PTC and switching protector is shown in Figure I.1-10. During testing, the following points were monitored,  $V_p$ ,  $I_p$ ,  $U_{comp}$  and  $I_z$ , to illustrate the operation of various components. The monitoring internal to the equipment was done to help designers and testers to understand the issues to consider when testing the equipment. It is not necessary to monitor internal to the equipment during type approval testing.



\* Special test protector for 230 V primary protector.

NOTE – In practice  $R_p$  may vary from 10-100 Ω and  $R_{slc}$  may also have different values.

**Figure I.1-10/K.44 – Example circuit**

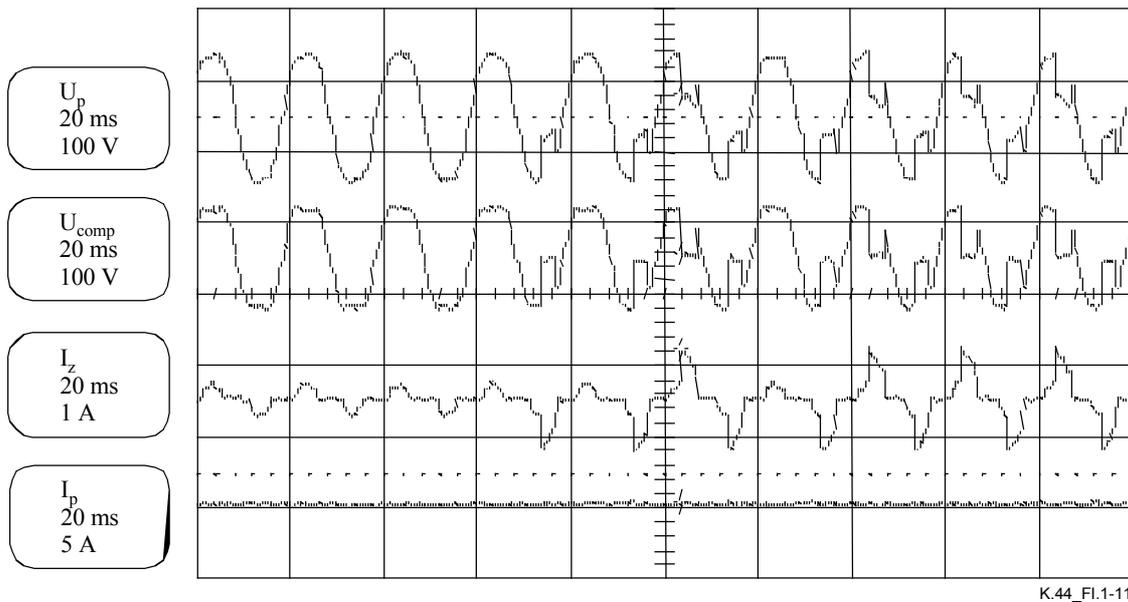
As the test voltage is increased, it is noticed that the switching devices start to operate at the peak of the voltage, see Figure I.1-11. A generator voltage just below that which operates the inherent protection for switching and foldback type inherent protection, is the point of maximum voltage stress for the components to be protected. Five surges should be applied with the generator voltage set just below that which operates the inherent protection. Note, for clamping type inherent protection, the maximum voltage stress generally occurs for generator voltages just below that which operates the primary protector, i.e., maximum current through the inherent protector. In this case, five surges should be applied with the generator voltage set just below that which operates the primary protector.

As the voltage is increased further, it is noticed that the switching devices operate for the whole test period, but there is insufficient heating of the PTC to cause it to operate, see Figure I.1-12. Five surges should be applied with this generator voltage. As  $U_{a.c.}$  is increased further, the PTC operates at the end of the test period. In some cases, the value of  $U_{a.c.}$  may not be high enough to operate the special test protector, see Figure I.1-13. Five surges should be applied with this generator voltage.

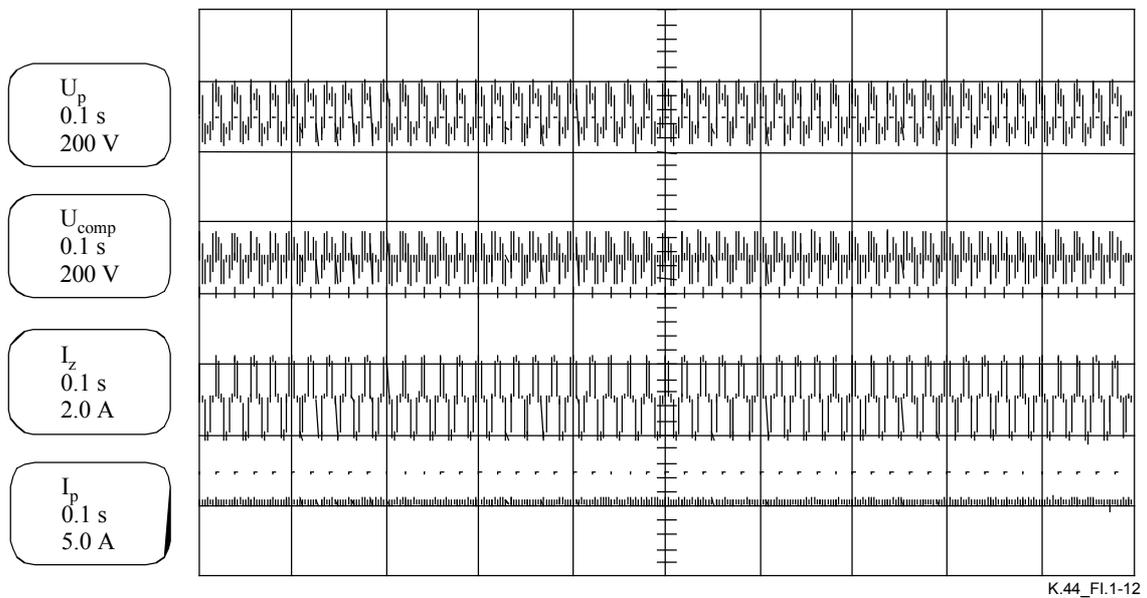
As  $U_{a.c.}$  is increased further, the special test protector will begin to operate, see Figure I.1-14. Five surges should be applied with this generator voltage. In some cases, the  $U_{a.c.}$  required to cause the PTC to operate will be sufficient to cause the special test protector to operate. In this case, it is necessary to apply five surges at a voltage level which causes the PTC to just operate, and cause operation of the special test protector, at the end of the test duration.

It is also necessary to apply five surges with the generator set to  $U_{a.c.(max)}$ , as this is the point of maximum current stress for the PTC.

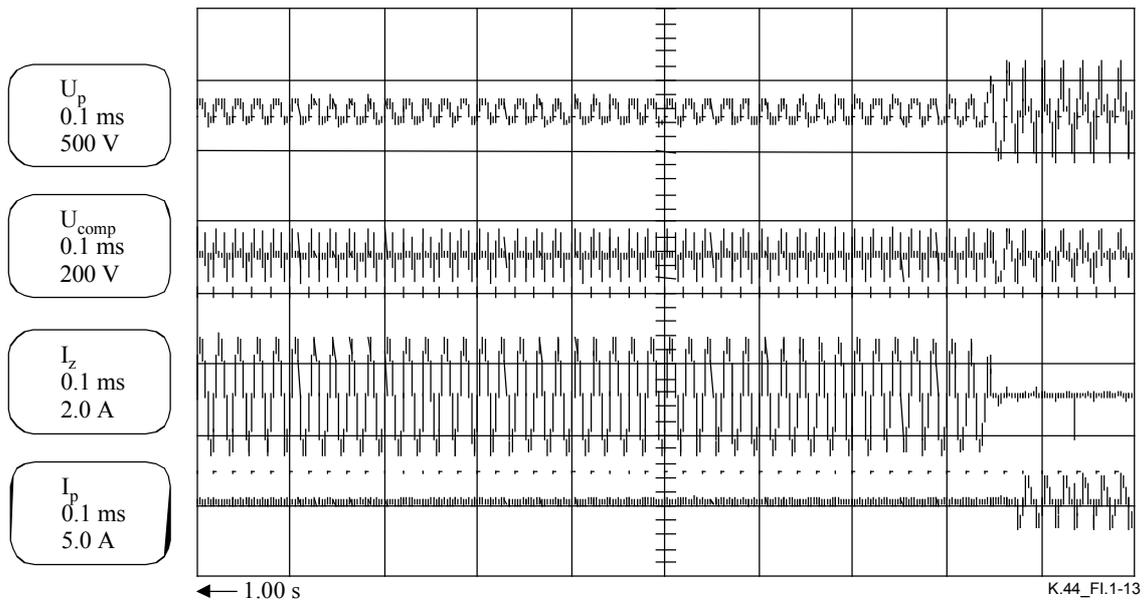
In all cases where the PTC operates, it may be necessary to wait approximately 15 minutes between surges to allow the PTC to cool.



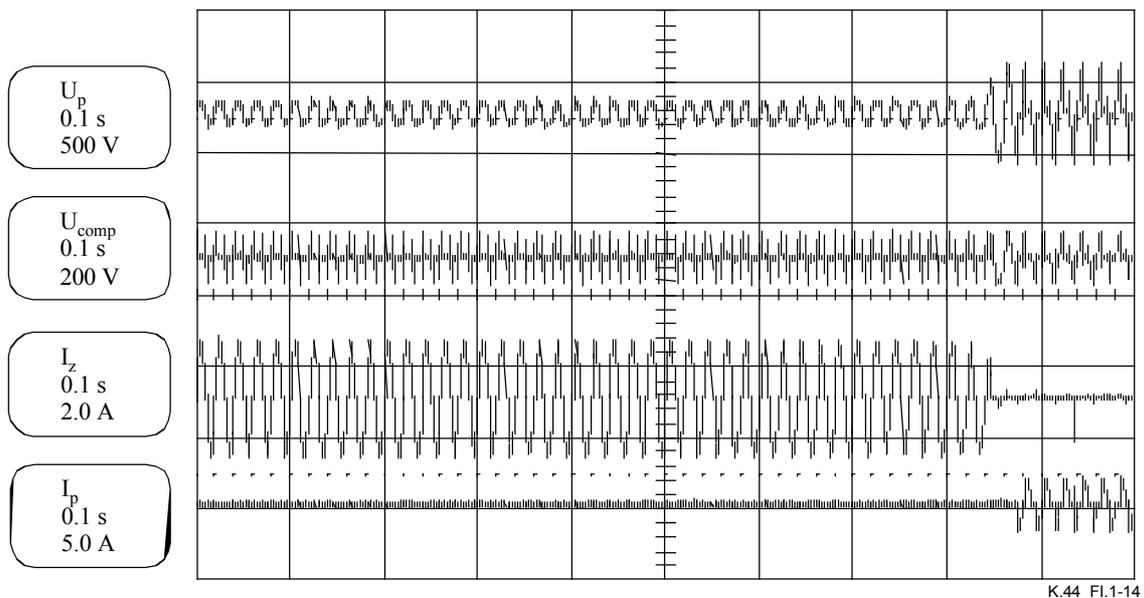
**Figure I.1-11/K.44 –  $U_{a.c.} = 127 V_{rms}$ , Switching inherent protector starts to operate**



**Figure I.1-12/K.44 –  $U_{a.c.} = 200 V_{rms}$ , Switching inherent protector operating, but not PTC**



**Figure I.1-13/K.44 –  $U_{a.c.} = 220 V_{rms}$ , PTC operates at end of test (2s), below firing voltage of special test protector**



**Figure I.1-14/K.44 –  $U_{a.c.} = 280 V_{rms}$ , Special test protector operating**

#### I.1.4 Mains power contact

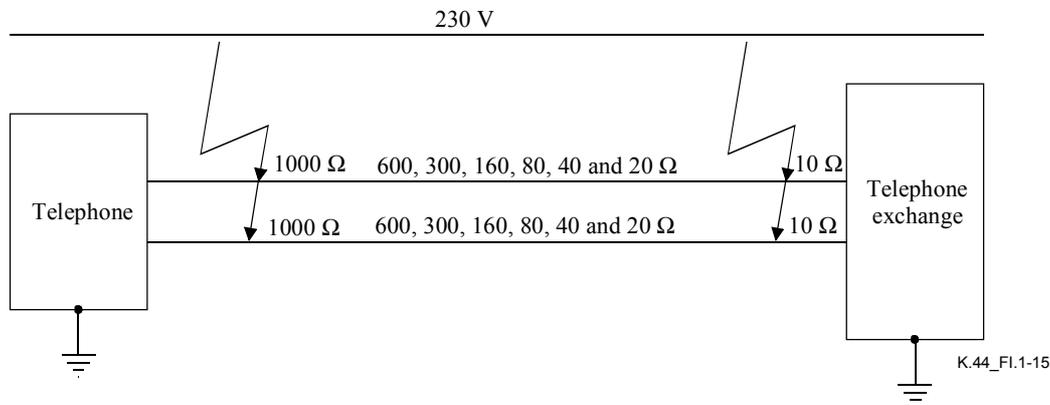
Mains power contact surges can occur up the amplitude of the mains voltage. The maximum voltage is nominally  $240 V_{rms}$ . The resistance from the source from the equipment is thought to be anywhere from  $10 \Omega$  to  $1000 \Omega$ .

Direct contact with electrical mains power can occur through network lines or cable faults, faulty or unapproved CPE or other causes. The contact may not cause the operation of a power system circuit breaker. The a.c. currents resulting from direct contact may make effective protection both difficult and expensive. As such events are rare, equipment is not required to withstand overvoltages or overcurrents arising from direct contacts, but may fail in an acceptable manner.

The following particular dangers to equipment may arise:

- A contact near to the equipment where the combined resistance of the cable circuit and equipment termination is low and a high current flow occurs. This condition is simulated in the test in Figure I.1-15 by a resistance of 10 Ω. The test current may be limited to lower values according to national regulations.
- A contact at the maximum distance from the equipment where the combined resistance of the cable circuit and equipment termination is high, and a small but harmful current flows continuously. This condition is simulated by a resistance of 1000 Ω.
- Experience shows that, in reality, with values between 10 and 1000 Ω, equipment is most susceptible to damage and fire hazard from current overheating.

Mains power contact generally has a source voltage equal to the local mains voltage. The resistance between the source and the linecard consists of the line resistance and the fault contact resistance. Experience has shown that the worst-case situation can occur over a narrow resistance range. To ensure that the worst-case condition is checked, the following test resistor values are used: 10 Ω, 20 Ω, 40 Ω, 80 Ω, 160 Ω, 300 Ω, 600 Ω and 1000 Ω.



**Figure I.1-15/K.44 – Mains power contact mechanism**

It was agreed during the study period to perform the power contact with these 8 resistor values as a result of a problem experienced by British Telecom. However, because the power contact test has a duration of 15 minutes, it was decided that testing with all eight resistors was too onerous and that the choice of intermediate resistors should be up to the person performing the test. There was also some discussion on reducing the test duration where it does not affect the test result. In this case, some guidance needs to be given on choosing the test resistor and test duration.

There are two known design methods for complying with the power contact test and these are: use of a fusible link, or use of a PTC in series with the line current. For both the fuse link and the PTC, the worst case, from a circuit point of view, is the test resistor which results in maximum transfer of energy into the circuit. This can be determined by testing with all test resistor values and determining the maximum energy with an oscilloscope by measuring the voltage at the input of the circuit, and current flowing into the circuit, and then integrating the product of the voltage and current with time.

- a) A fusible link or resistor is designed to overheat and break open, interrupting excessive current flow into the equipment. Where minimal testing is to be performed, the test should be performed with the test resistor which causes the maximum energy dissipation in the circuit. Where it is proven that the resistor will not contract and reconnect the circuit when it has cooled, the test may be stopped once the current is interrupted.

- b) A PTC is designed to go high resistance when an excessive current flows through it. The worst-case current for a PTC is the lowest resistor, i.e., the highest peak current. Where minimal testing is to be performed, the test should be performed with the test resistor which causes the maximum energy dissipation in the circuit, and with the 10  $\Omega$  resistor.

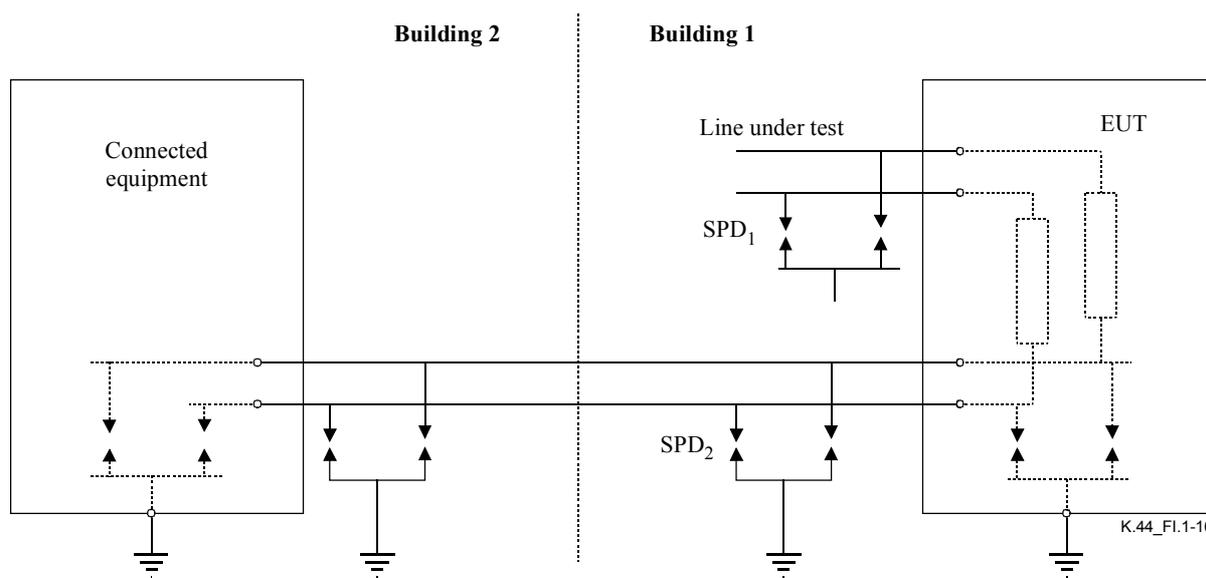
Generally, once a PTC has operated, the current will be limited to low values and there will be no change for the remainder of the test. However, there have been cases where the PTC has started to breakdown at the end of the duration which can cause excessive heating and the possibility of a fire. Also, there have been cases where the PTC forms a relaxation oscillator with a long time constant. However, where it is proven that the PTC will not fail within the test time, or that there is no other factor which will alter the test result, the test may be stopped once the current has stabilized at a low value, which will prevent an overheating situation.

If the worst-case resistor cannot be determined, the test should be performed with all resistor values.

### I.1.5 Terminations and SPDs on untested ports

Figure A.2-1 shows the possible ports of a complex piece of equipment.

This equipment has both external and internal ports and the influence of these on the port being tested has to be considered. The EUT may be connected to associated equipment within the same building, via internal cables, or to equipment in another building, via an external cables. SPDs may be used on both types of ports, see Figure I.1-16.



**Figure I.1-16/K.44 – Terminations and SPDs on equipment**

During testing, ports will need to be both terminated by connection to associated equipment, or by a terminating impedance or resistance, AND connected to ground by a coupling element in turn. It is necessary to consider the differences between external ports and internal ports. Internal ports are considered to be connected to equipment that has the same reference point as the equipment being tested. External ports, on the other hand, can be connected to equipment with a different earth reference, e.g., in another port. This means that current may be conducted into one external port and out another external port.

Issues to consider when terminating the equipment or grounding a port are:

- 1) When there is a possible low impedance path from the port being tested to an untested port, the possibility of the protector on the untested port operating first needs to be considered. This is done by using a special test protector on the tested port and a protector with the minimum allowed d.c. sparkover voltage on the untested port.
- 2) When there is more than one type of untested port, only one type of untested port should be terminated or have SPDs added at a time. The reason for this is that a low impedance path to one type of untested port may prevent current flow to another type of untested port.
- 3) Where one port may be connected internally to another port, e.g., under some operating conditions or power fail conditions, this port should be tested with the other port terminated and protected.
- 4) Where the equipment has high current carrying protection components, which eliminates the need for primary protection, it is necessary to remove the GDT, on the port under test, and replace it by the test protector as described in 8.2, 8.3 and 8.4. This is to ensure that coordination has been achieved. During testing of this port, the integral protector is to be left in situ for non-tested ports. If this component is not removable, all tests are performed with the protection provided and the manufacturer must provide a test report to show that the inherent and coordination tests were performed with the special test protector during the design tests.
- 5) Tests may need to be applied with the following four combinations of termination and coupling to ground of the untested ports, i.e.:
  - a) no termination and no coupling to ground;
  - b) no termination, couple the port to ground;
  - c) no coupling to ground, add a termination;
  - d) both coupling to ground and a termination.

It is necessary in port to port testing to consider the following as the second port:

- 1) other lines/pairs of the port type being tested;
- 2) lines/pairs of other port types.

## **1.2 Range of lightning and power induction test levels**

### **1.2.1 Lightning**

#### **1.2.1.1 Inherent test levels**

The range of test voltages used in product Recommendations for the inherent resistibility test levels could be from 1.0 kV to 5.0 kV. Traditionally a test voltage of 1.0 kV has been used in large telecommunication buildings. This is because the majority of surges will be less than 1.0 kV and it is relatively easy to install reliable primary protection on the MDF when required. A figure as high as 5.0 kV could be considered for CPE as they are in a far less controlled environment and it is far more difficult to install GDTs.

#### **1.2.1.2 Coordination test levels**

The maximum test level for the coordination requirement has traditionally been 4.0 kV. However, recent measurements have shown that surge levels in excess of 7.0 kV do occur. An optional test level of up to 10.0 kV is allowed. The higher test level has a higher dU/dt. This results in a higher firing voltage of the primary protector and higher capacitive charging currents in the equipment.

## **I.2.2 Power induction test levels**

### **I.2.2.1 Inherent test levels**

Traditionally the inherent test has been  $0.2 \text{ A}^2\text{s}$  for equipment in telecommunication centres and CPE. With the liberalization of customer premises, the use of primary protection is less certain and the inherent test level may need to be higher for CPE, e.g.,  $1.0 \text{ A}^2\text{s}$ .

### **I.2.2.2 Inherent/coordination test levels**

Traditionally the test level, for the test with primary protection, was  $1.0 \text{ A}^2\text{s}$ . An enhanced test level of  $10 \text{ A}^2\text{s}$  has been introduced to take into account that some countries have higher levels of power induction, maximum level of power induction into short lines ( $200 \Omega$ ) or the need for a high grade of service due to changing regulatory requirements.

The method of specifying the requirements for equipment may need to be different. ITU-T Rec. K.20 (1996) specified a  $U_{c(\text{max})}$  of  $600 \text{ V}$  through  $600 \Omega$  for 1 second. Measurements have shown that the range of time for which the fault current flows is from 0 to 3.2 seconds and that the current flowing in a telecommunication circuit can vary from 0 to  $9 \text{ A}_{\text{rms}}$ , see Figure I.1-8. Tests on a resistor have shown that its specific energy rating decreases with increasing current for a constant specific energy. This shows that the inherent/coordination test has to be performed at the maximum current which occurs.

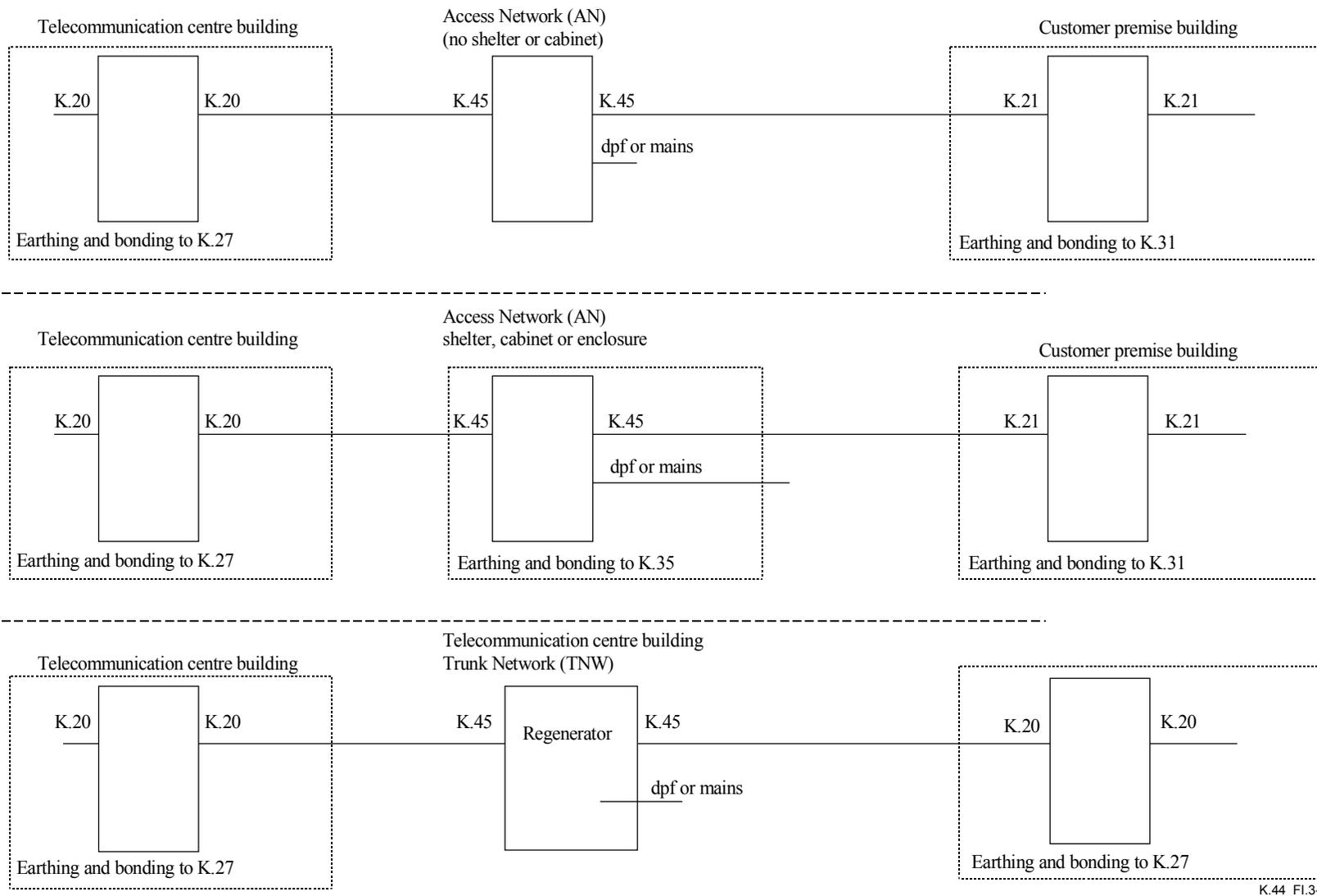
## **I.3 Relationship between ITU-T Rec. K.44 and other product or product family Recommendations**

ITU-T Rec. K.20 is for the equipment that is installed in a telecommunication centre. There is a proper grounding system and metal structure written in ITU-T Rec. K.27, so the environment is not so exposed. However, due to the large number of telecom cables, total current which flows into the building will be large.

ITU-T Rec. K.21 is for the equipment that is installed in a customer's premises where the grounding and bonding system is poor. The earth resistance may be high, or no earth system may be provided.

ITU-T Rec. K.45 is for the equipment that is installed between the telecommunication centre and the customer's premises building. The grounding system is not as good as a telecommunication centre, but the system is under the control of an operator. There is some merit in that the small structure allows ideal equipotential bonding.

Figure I.3-1 shows an example of the location of the equipment and Recommendations to be applied. If the equipment is used in more than one location, it has to be tested according to all relevant Recommendations.



**Figure I.3-1/K.44 – Example configuration of a telecommunication network showing the border between a telecommunication centre, the access/trunk network and a customer's premise**

## Appendix II

### Supplementary information for manufacturers and operators

#### II.1 Introduction

The following information is under study by ITU-T. It has been provided in this appendix for the information of manufacturers and operators and to promote discussion on these topics.

#### II.2 Primary protection coordination

The effects of the operation of primary protection are described in ITU-T Rec. K.11.

To ensure the coordination of the protection components with the equipment, it is necessary to check that:

- 1) the equipment will not be damaged by worst-case voltages that may appear between the input terminals and between an input terminal and the equipment ground reference;
- 2) the equipment will not be damaged or interfered with by the operation of the primary protection over the complete range of surge voltages.

The operation of primary protection with a switching characteristic has two effects:

- It limits the maximum voltage applied to the equipment and hence, depending on the internal impedance of the equipment, the maximum current which the equipment must withstand.
- It produces a very rapid change of voltage and current, which by inductive or capacitive effects can reach sensitive parts of the equipment not apparently exposed to line voltages.

##### II.2.1 Primary protection does not operate

For surge voltages where the primary protection is not activated, attention should be paid to the value of the currents that can flow in the internal cabling network. Large currents in the internal cabling network may disturb other equipment. ITU-T Rec. K.27 describes earthing and bonding inside a telecommunication building and ITU-T Rec. K.11 treats coordination with electrical protection devices.

##### II.2.2 Primary protection does operate

Lightning surge simulation requires special attention to be paid to:

- a change in the operating voltage of GDTs with voltage rate of rise;
- potential differences developed across the protection frame and any associated earth wiring due to high current flow;
- the fast  $dU/dt$ , caused by the operation of the GDT, which may damage sensitive components or cause misoperation (equipment lockup or corruption of data in memories).

To check coordination with primary protection, attention must be paid to the operating principles of the GDT. Firstly, the 10/700  $\mu$ s firing voltage of GDT, see Figure I.1-4, is generally higher than the d.c. firing voltage but generally less than the 1 kV/ $\mu$ s firing voltage. Secondly, the d.c. firing voltage, and hence the 10/700  $\mu$ s firing voltage, can vary considerably for the same protector type. For example, the d.c. firing voltage of a 230 V GDT is allowed to vary from 180 V to 300 V (K.12).

For these reasons, primary protection coordination is checked by replacing the agreed primary protector with a special test protector. The d.c. firing voltage of the special test protector is to be equal to 1.15 times the specified maximum d.c. firing voltage of the agreed primary protector. The tolerance on the firing voltage is  $\pm 5\%$ . For a 230 V primary protector the firing voltage of the

special test protector is  $345 \text{ V} \pm 17 \text{ V}$ . This test protector is used for both the lightning, power induction and power contact tests. The special test protector should have a similar characteristic to the agreed primary protector.

### II.2.3 Principles of coordination

It is written in ITU-T Rec. K.11 that:

- No device exists which has the characteristics for ideally suppressing all voltages and currents connected with disturbances.
- It is sometimes necessary to use more than one protective device.

Generally, high-current devices operate slowly and there remains a residual voltage. Fast-operating semiconductor devices operate fast enough but can only handle smaller energy than high-current devices. Therefore, it is necessary to have a ladder circuit to reduce the surge energy step by step to the level which is harmless to the equipment. This type of protection is called multistage protection.

Figure II.2-1a shows the principle of protection by a ladder circuit.

A primary protector is applied at the location of the border such as an MDF external to the EUT. The most stressful energy is bypassed to ground at this point. An inherent protector is inside of EUT, and it diverts the residual energy of the primary protector. There may also be a third protector inside the EUT that is part of the black box.

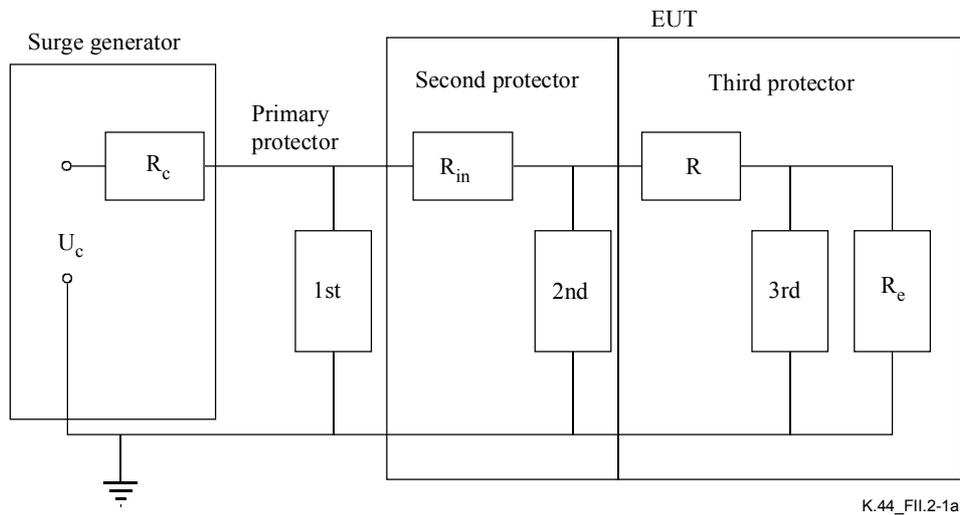
It is important that there should be resistance between the protectors so as not to connect to each other directly and then the circuit looks like a ladder. Considering the coordination between primary and inherent protection, there should be resistance  $R_{in}$ . This  $R_{in}$  is virtually the same as the input resistance of the EUT when the inherent protector such as a PNP device or a diode turns on and connects  $R_{in}$  to ground. Figure II.2-1b shows the equivalent circuit when the inherent protector turns on. If there is no resistance between the primary and inherent protector, only the protector which has the lower turn-on voltage will operate. In this case, only the inherent protector operates and it prevents the operation of the primary protector, so coordination is not achieved.  $R_{in}$  is necessary to increase the voltage across the primary protector high enough to cause the primary protector to operate.

The point is that the inherent protector usually turns on at a lower voltage than the primary protector at the MDF. At first, the current flows into the black box and generates voltage across the inherent protector and it turns on. Then the current that flows through  $R_{in}$  and the inherent protector generates the voltage across the primary protector.

Therefore, the inherent protector is not a subsidiary but an essential device because it usually operates earlier than the primary protector and protects the following components. The voltage drop across the coordination resistance, due to the current flowing in the inherent protector, operates the primary protector which bypasses the majority of the surge energy to ground.

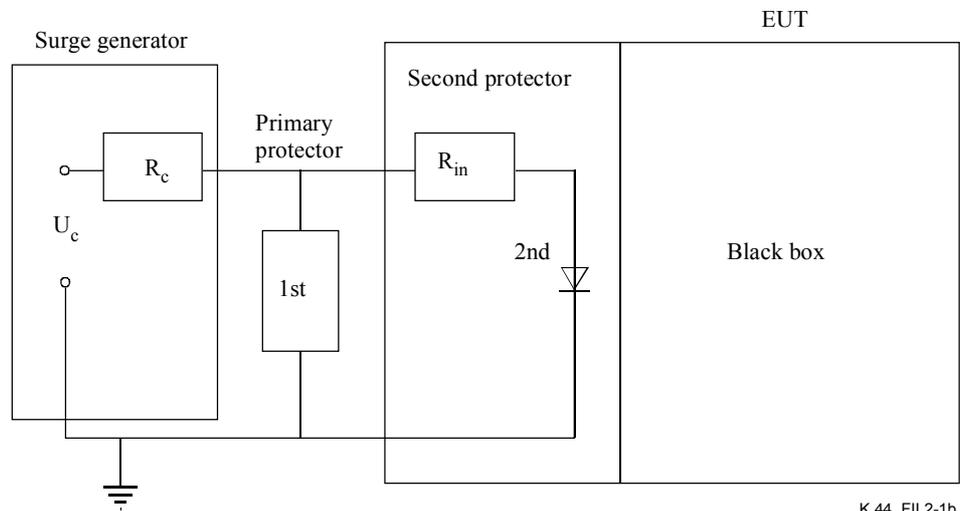
In a traditional circuit using a bulky transformer or coil inside the EUT, it is possible that there is no inherent protector. The sum of the resistance,  $R_{in}$  plus  $R_e$ , is high enough so that the primary protector turns on without much current flowing into EUT. Figure II.2-1c shows such an equivalent circuit.

If there is an inherent protector, such as semiconductor SPD in EUT, it usually operates faster than the primary protector at the MDF. If there is no resistance between the primary and the inherent protector, the operation of the inherent protector disturbs the operation of the primary protector. Coordination is achieved when there is sufficient resistance between the protectors, and the voltage drop across the resistance allows the primary protection to operate correctly. When coordination is designed correctly, EUT is not damaged up to maximum test level. Above the maximum test level, the primary protector must operate for lightning surges.



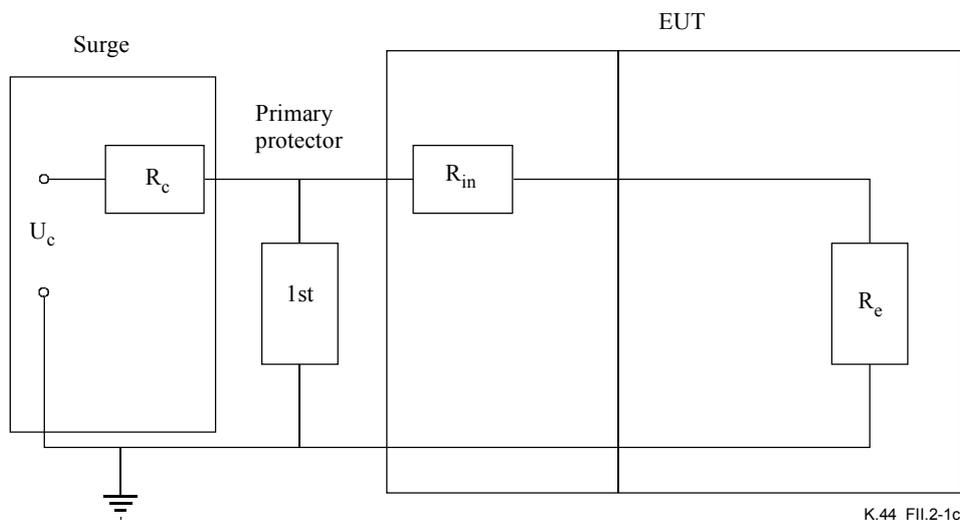
K.44\_FII.2-1a

**Figure II.2-1a/K.44 – Principle of protection by ladder circuits**



K.44\_FII.2-1b

**Figure II.2-1b/K.44 – Equivalent circuit when the second protector turns on**



K.44\_FII.2-1c

**Figure II.2-1c/K.44 – Robust circuits with no second protector**

## II.2.4 Coordination testing of switching and clamping SPDs

IEC TS 61312-3 contains information on the theory of coordination. The following text contains the specific tests that need to be performed to confirm coordination.

There are four combinations of SPDs and these are shown in Figure II.2-2.

**Figure II.2-2a:** To perform coordination testing of the SPDs in Figure II.2-2a, it is necessary to perform the following tests:

- 1)  $U_c$  set to produce a waveshape just under the firing voltage of the primary protection (maximum energy into inherent protector);
- 2)  $U_c$  set to  $U_{c(max)}$  (worst case dV/dt and highest peak current into inherent protection).

**Figure II.2-2b:** To perform coordination testing of the SPDs in Figure II.2-2b, it is necessary to perform the following tests:

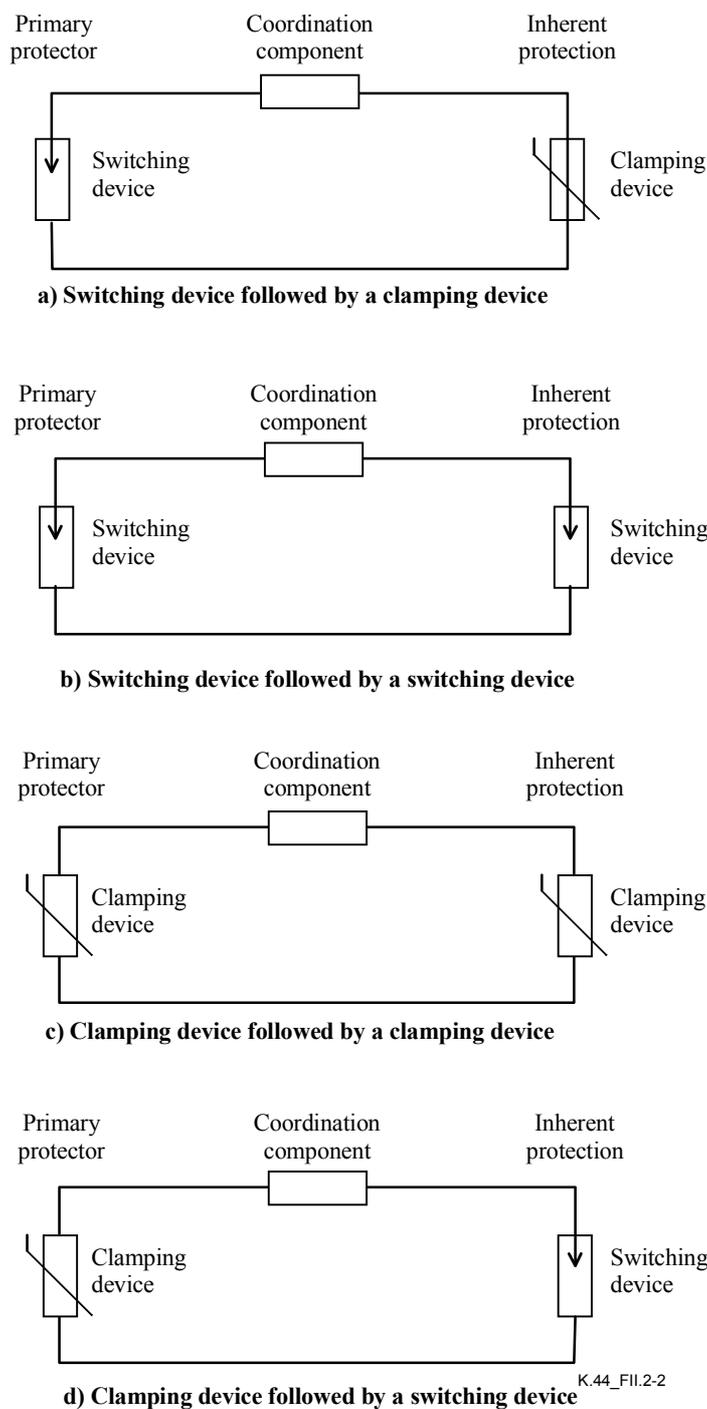
- 1)  $U_c$  set to produce a waveshape just under the firing voltage of the inherent protection (maximum energy into electronics);
- 2)  $U_c$  set to produce a waveshape just under the firing voltage of the primary protection (maximum energy into inherent protector);
- 3)  $U_c$  set to  $U_{c(max)}$  (worst case dV/dt and highest peak current into inherent protection).

**Figure II.2-2c:** To perform coordination testing of the SPDs in Figure II.2-2c it is necessary to perform the following test:

- 1)  $U_c$  set to  $U_{c(max)}$  (worst case dV/dt and highest peak current into inherent protection).

**Figure II.2-2d:** To perform coordination testing of the SPDs in Figure II.2-2d, it is necessary to perform the following test:

- 1)  $U_c$  set to produce a waveshape just under the firing voltage of the inherent protection (maximum energy into electronics);
- 2)  $U_c$  set to  $U_{c(max)}$  (worst case dV/dt and highest peak current into inherent protection).



**Figure II.2-2/K.44 – Combinations of SPDs**

## II.3 MDF voltage at the input of equipment

### II.3.1 General

The firing voltage of a GDT depends on  $dU/dt$ . If  $R_p$  is known, the  $dU/dt$  of  $U_{si}$  can be calculated by SPICE transient simulation. Using the firing voltage versus  $dU/dt$  information in the GDT data sheet, the actual firing voltage for each condition can be simulated. Figure II.3-3 shows the simulation results for a 1 m MDF cable between the GDT and the equipment and a 1 m MDF earth cable. It shows that GDT operates at a higher voltage in a shorter period of time when  $U_c$  is high. If  $U_c$  is small, GDT operates at a lower voltage in a longer period of time.

Figure II.3-4 shows the same simulation but with a 10 m MDF cable between the GDT and the equipment and a 10 m MDF earth cable. The inductance of the 10 m MDF cable and the 10 m earth cable is almost 10  $\mu\text{H}$  respectively. The total inductance of 20  $\mu\text{H}$  can be an effective low pass filter for the high speed residual voltage caused by GDT operation. The MDF cable suppresses the high  $dU/dt$  surge caused by operation of the GDT. This simulation shows that the test lead between the surge generator and the EUT has to be short, e.g., less than 2 m.

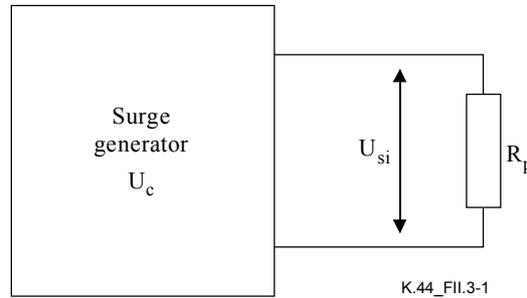


Figure II.3-1/K.44 – A model to calculate the  $dU/dt$  of  $U_{si}$

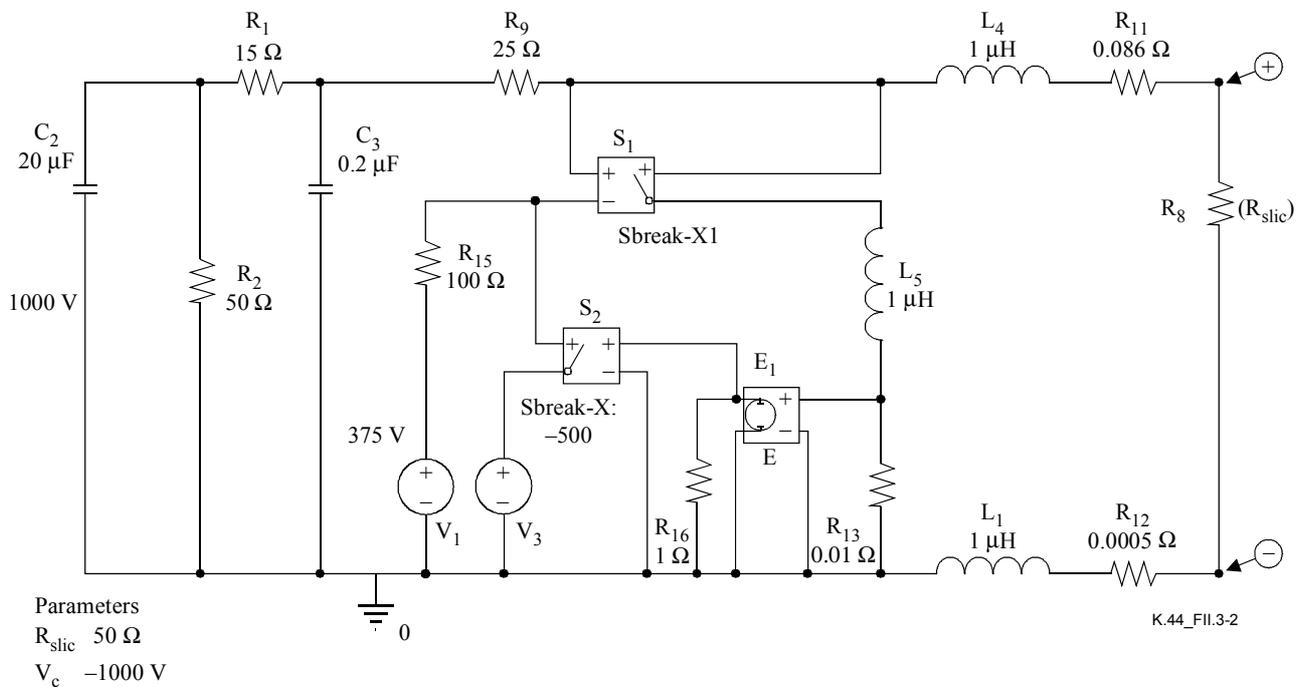
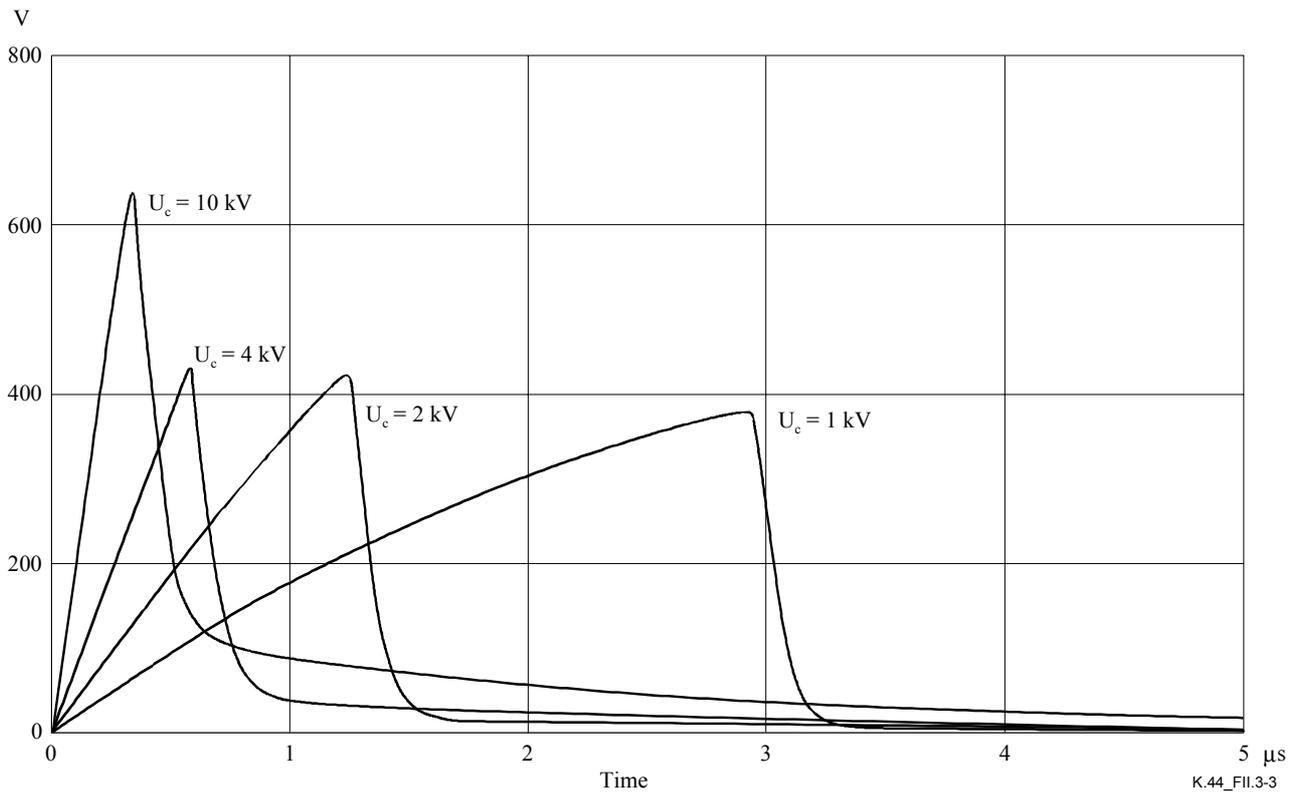
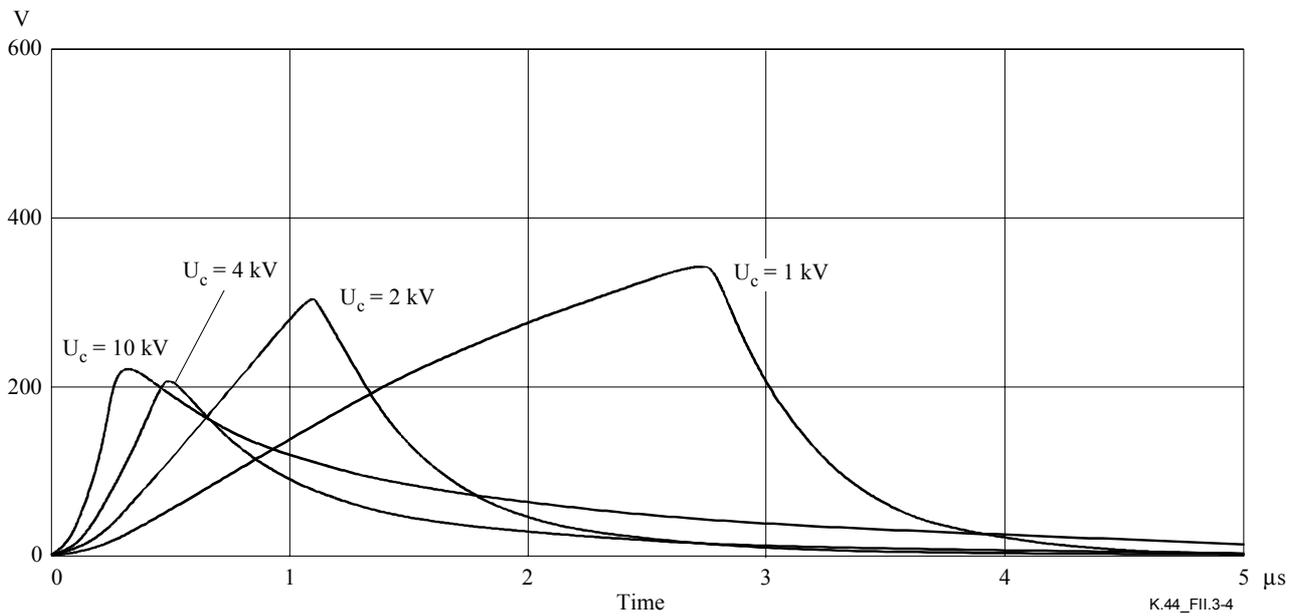


Figure II.3-2/K.44 – The Spice model used to calculate the reduced voltage at the equipment input due to the impedance of the MDF cable



**Figure II.3-3/K.44 – MDF cable is 1 m**



**Figure II.3-4/K.44 – MDF cable is 10 m**

### II.3.2 MDF earth wire voltage drop

The inductance of the MDF cable between the primary protector and the EUT has a good effect for high  $dU/dt$  surges, but the inductance of the MDF earth cable has the opposite effect. This is **particularly** so when it is considered that the current from all GDTs, which have operated, flows in the MDF earth cable. Inductance is a function of the length of the cable and does not change much if the diameter of the cable is changed. The length of MDF earth cable cannot be zero, so there is always inductance. The voltage drop caused by the MDF earth cable is due to the surge current which flows after the GDT operates. The voltage drop of MDF earth cable appears at the input of the equipment, so it is necessary to have a bonding configuration which will have the minimum possible inductance and resistance. Figure II.3-5 shows where inductance of the MDF earth cable exists.

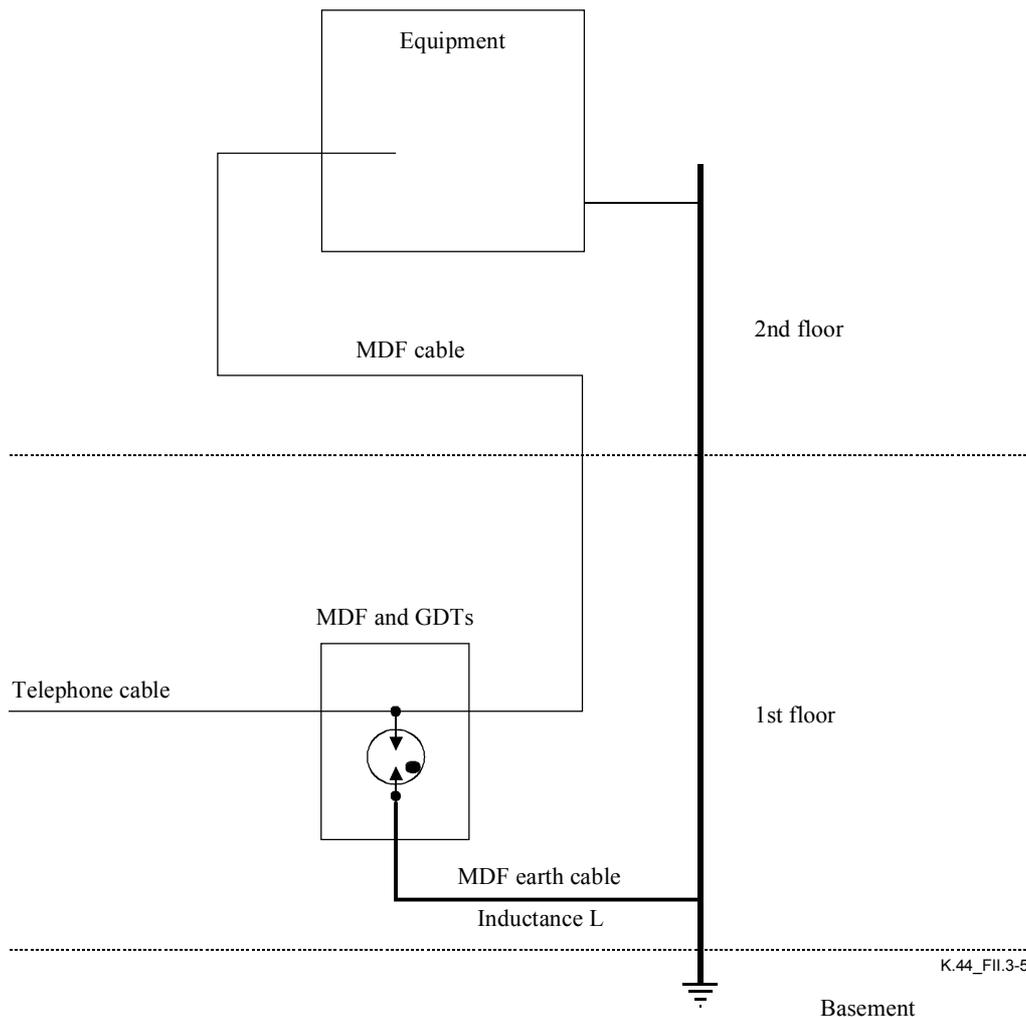
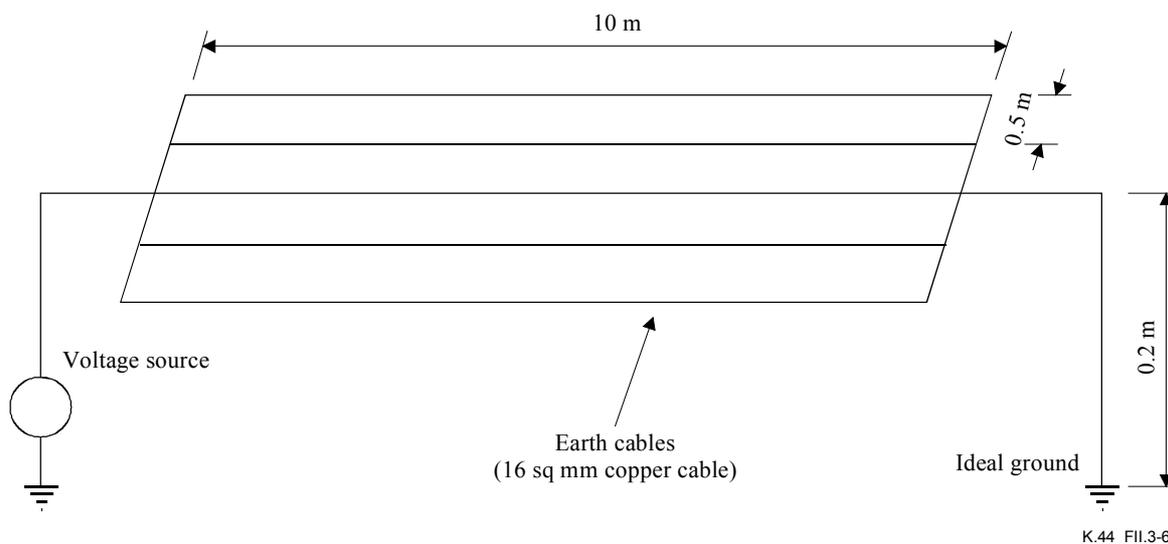


Figure II.3-5/K.44 – Inductance of MDF earth cable

When there is significant length of MDF earth cable, as shown in Figure II.3-5, a multiple cable or mesh configuration is desirable.

Multiple cables which are not tied together but separately connected will reduce the inductance nearly  $1/N$  where  $N$  is the number of cables. See Figure II.3-6.



**Figure II.3-6/K.44 – Use of multiple earth wires to reduce inductance**

The inductance calculated using ACCUFIELD simulation is shown in Table II.3-1.

**Table II.3-1/K.44 – Inductance versus number of conductors**

N (Number of conductors)	Total inductance
1	10.89 $\mu\text{H}$
2	6.16 $\mu\text{H}$
3	4.39 $\mu\text{H}$
5	3.05 $\mu\text{H}$

### II.3.3 Earth voltage drop test

Where there is an external protection frame and/or an earth wire connecting it to the earth bar, high currents flowing in the protection frame or the earth wire will cause a voltage drop at the input of the equipment, see Figure II.3-7.

Damage due to an earth voltage drop has been observed in the United Kingdom and Australia.

#### II.3.3.1 United Kingdom's example of earth voltage drop problem

Some small switching systems installed at customers' premises have suffered damage due to the potential difference created by the earth bonding wires of the protection and switching equipment. The bonding for the protection was typically routed over an indirect route to the main earth terminal. The equipment protective earth was connected to the power system wiring earth, and hence the main earth terminal. Due to differences in impedance, a large potential difference was developed between the equipment line terminals and the protective earth of the equipment. This resulted in a small flash-over from the circuitry to the equipment chassis, damaging the equipment. The solution was to bond the protection as close to the equipment as possible using the correct d.c. sparkover voltage protectors, such that mains could not get on the line in the event of a power fault on the equipment earth.

#### II.3.3.2 Australian example of an earth voltage drop problem at customer premises

Australia has suffered a lot of lightning damage to small customer switching systems as a result of potential differences occurring in the telecommunication line and the mains power supply due to the length of the bond wire between the protection frame and the main earth terminal. Where it was not

possible to reduce the bond wire length to less than a few metres, a combined telecommunication and mains port protection unit has had to be installed at the equipment. These protection units are very expensive, costing in the order of USD 150.

### II.3.3.3 Australian example of an earth voltage drop problem at a telecom centre

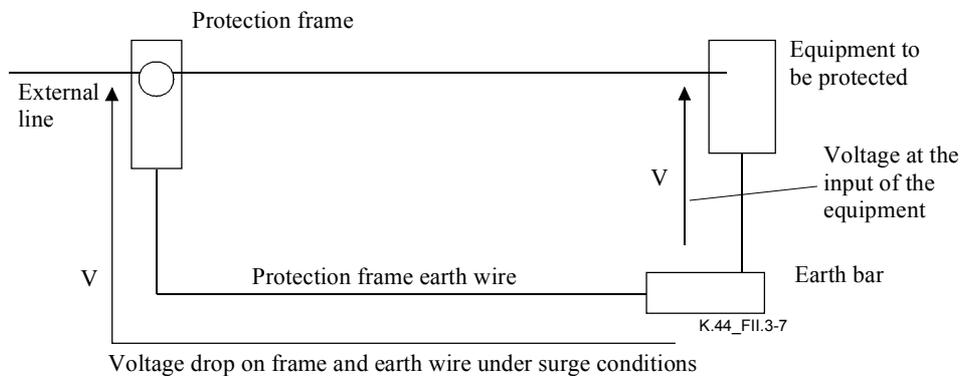
Telstra has experienced damage to equipment installed in a telecommunication centre and protected by primary protection. Investigation of the problem showed that a breakdown was occurring between the wiring from the MDF and the chassis of the equipment. The breakdown voltage between the wire and the chassis was approximately 1.5 kV for a 10/700  $\mu$ s waveshape. This proves conclusively that earth voltage drops of 1.5 kV and greater can occur in practice. Rather than change the earth wiring in the exchange, different equipment was used to perform the function. These exchanges are earthed in accordance with ITU-T Rec. K.27 and the equipment is in an IBN. There needs to be a balanced approach between installation practices, resistibility of equipment and the addition of external protection.

### II.3.3.4 Possible test for resistibility to earth voltage drop

As shown in II.3.2, the most significant voltage occurs when a single earth wire is used to connect the protection frame to the earth bar. Earth voltage drop is less of a problem across the protection frame due to the parallel down conductors in the frame, and is also less of a problem when multiple earth wires are used to connect the frame to the earth bar.

This test is not applicable if one or more of the following occurs:

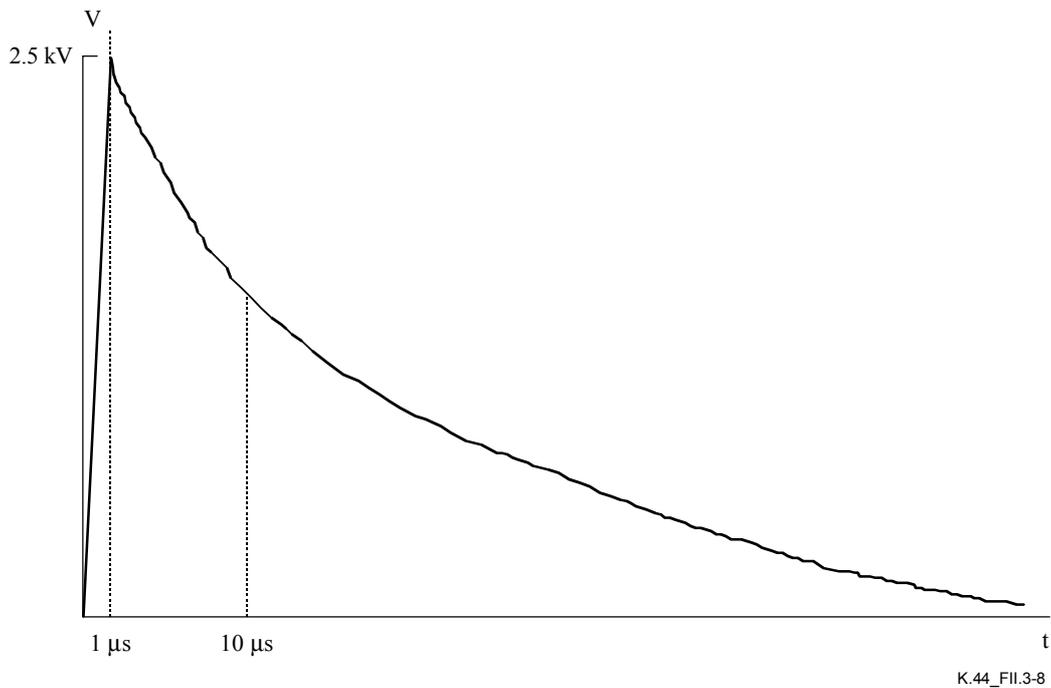
- The equipment earth reference conductor is connected to the base of the protection frame.
- Shielded cables are used between the protection frame and the equipment.
- A mesh BN earthing system is used.
- The protection frame is directly connected to the CBN by short conductors (<1 m).



**Figure II.3-7/K.44 – Voltage drop in earth wires**

Table II.3-2 and the generator in Figure II.3-9 are based on the test Surge 4, specified in 4.5.7 of Bellcore specification GR1089 CORE. The Bellcore test is widely used in North America. The Bellcore test has a maximum peak open circuit amplitude of 2.5 kV.

The approximate surge voltage generated by a surge current being conducted in a bond wire is shown in Figure II.3-8.

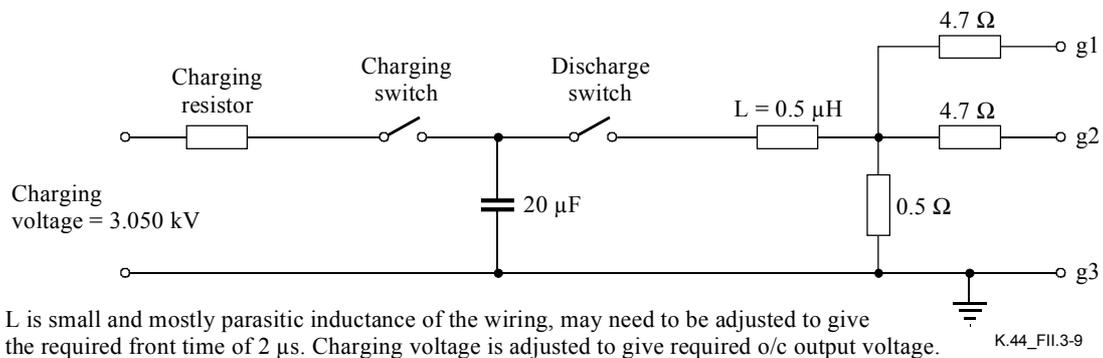


**Figure II.3-8/K.44 – Earth voltage drop**

The circuit in Figure II.3-9 produces a 2/10 μs waveshape and may be used to reproduce this effect. An approximate magnitude of the voltage which may occur is given in Table II.3-3.

**Table II.3-2/K.44 – Test voltage**

Description	$U_{c(max)}$
Large external frame, with a small number of down conductors or long earth wire (<10 m) in a building or large shelter	2.5 kV
External frame in a cabinet with a medium length single earth wire (<3 m)	1.5 kV
Small external frame with a short earth wire (<0.5 m)	Test not required. The voltage at the input of the equipment is assumed to be less than that which occurs for tests 1.1 and 1.2 in Table 1a/K.45.



**Figure II.3-9/K.44 – 2/10 μs current surge generator**

**Table II.3-3/K.44 – Earth voltage drop test**

Test No.	Test description	Test circuit	Test level	Number of tests	Agreed primary protection	Acceptance criteria	Comments
1.1	Earth wire voltage drop	Figures II.3-9 and A.5.1-1	See Table II.3-2	5	5 of each polarity	A	Applies only to equipment where there is a large protection frame and/or a single earth wire between the primary protection and the common earth point.

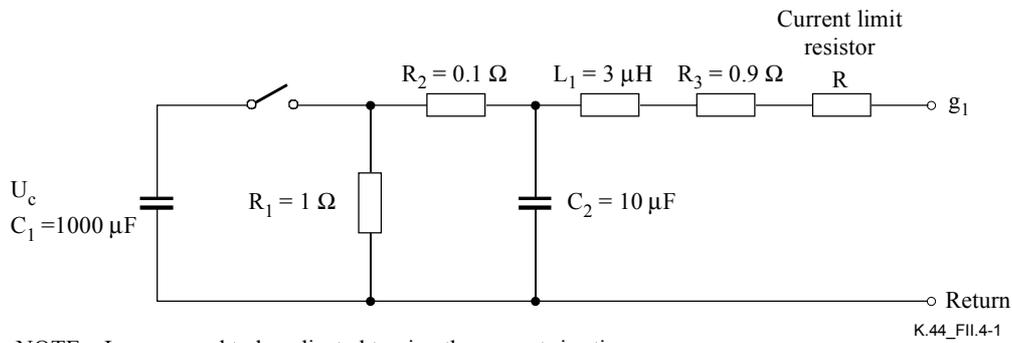
#### **II.4 Current test on mains ports**

When lightning strikes a building or shelter housing telecommunication equipment, the current waveshape is considerably longer than the 8/20  $\mu$ s waveshape traditionally used to test mains ports. Studies in Germany have shown that the current waveshape involved in a direct strike can have a 1/2 value of up to 350  $\mu$ s. An example in the Mitigation handbook titled "Malfunction of circuit breaker due to lightning" shows that mains power line surges can have long tails. Tests on switchmode power supplies have shown that a 350  $\mu$ s tail can cause damage, whereas a 20  $\mu$ s tail does not. There is no paper documenting this damage. It was, therefore, proposed that a 10/350  $\mu$ s be used to check coordination of primary protection with the equipment being tested. While this has been discussed in ITU-T, agreement for this test could not be obtained. This test remains under study. The coordination test in the product Recommendations requires an 8/20  $\mu$ s waveshape.

The proposed test is shown in Table II.4-1.

**Table II.4-1/K.44 – Coordination test for mains ports to simulate a direct strike to the building or shelter**

1.x.a	Direct lightning mains port coordination L-N	Figures II.4-1 and A.5.4-2/K.44	$I_{(max)} = 10 \text{ kA}$ $R = 0 \Omega$	5 of each polarity	Agreed primary protector (mains)	A Note, a switching protector must operate at $I_{(max)}$
1.x.b	Direct lightning mains port coordination L+N-E	Figures II.4-1 and A.5.4-1/K.44	$I_{(max (L+N))} = 10 \text{ kA}$ $R = 0 \Omega$	5 of each polarity	Agreed primary protector (mains)	A Note, a switching protector must operate at $I_{(max)}$



NOTE –  $L_1$  may need to be adjusted to give the correct rise time.

**Figure II.4-1/K.44 – 10/350  $\mu$ s current surge generator**

## II.5 Earth and neutral potential rise

### II.5.1 Background

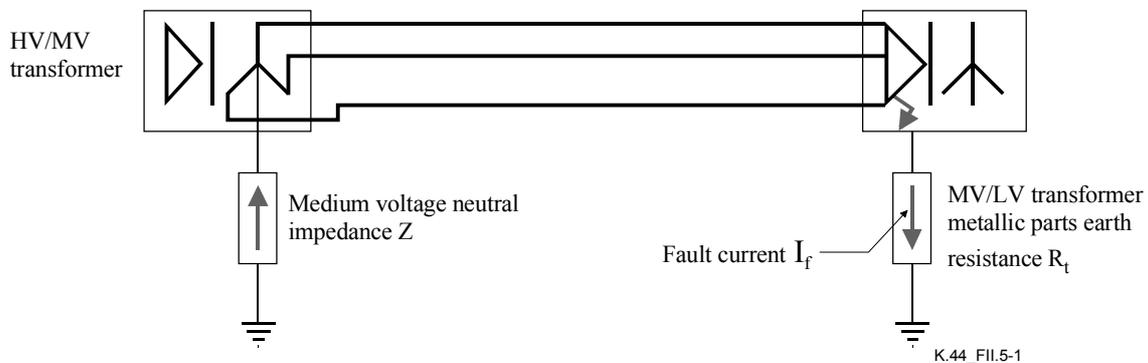
Depending on Low Voltage public distribution network design, some risks such as Neutral potential rise and lightning surge transfer may occur on Low Voltage power plant.

### II.5.2 Explanation

Earth and Neutral potential rise happens mainly when the MV/LV transformer insulation is broken, or Spark Gaps operate to prevent transformer destruction by a lightning induction or direct strike to the line. An important 50 Hz current flows and the earth potential rises.

#### II.5.2.1 Earth potential rise

The first point is to understand the way to limit earth potential rise (EPR) when a fault occurs on the power plant. See Figure II.5-1.



**Figure II.5-1/K.44 – Factors affecting the fault current**

The worst-case fault current  $I_f$  is obtained when neglecting HV line impedance and coupling between transformer's metallic parts earth and other earthing systems as neutral earth.

$$I_f = U / \sqrt{3 \cdot (Z + R_t)}$$

where  $U$  is the voltage between Medium Voltage active conductors.

The rise of earth potential at the MV/LV transformer is  $EPR = R_t \cdot I_f$ . (Note LV = Low Voltage)

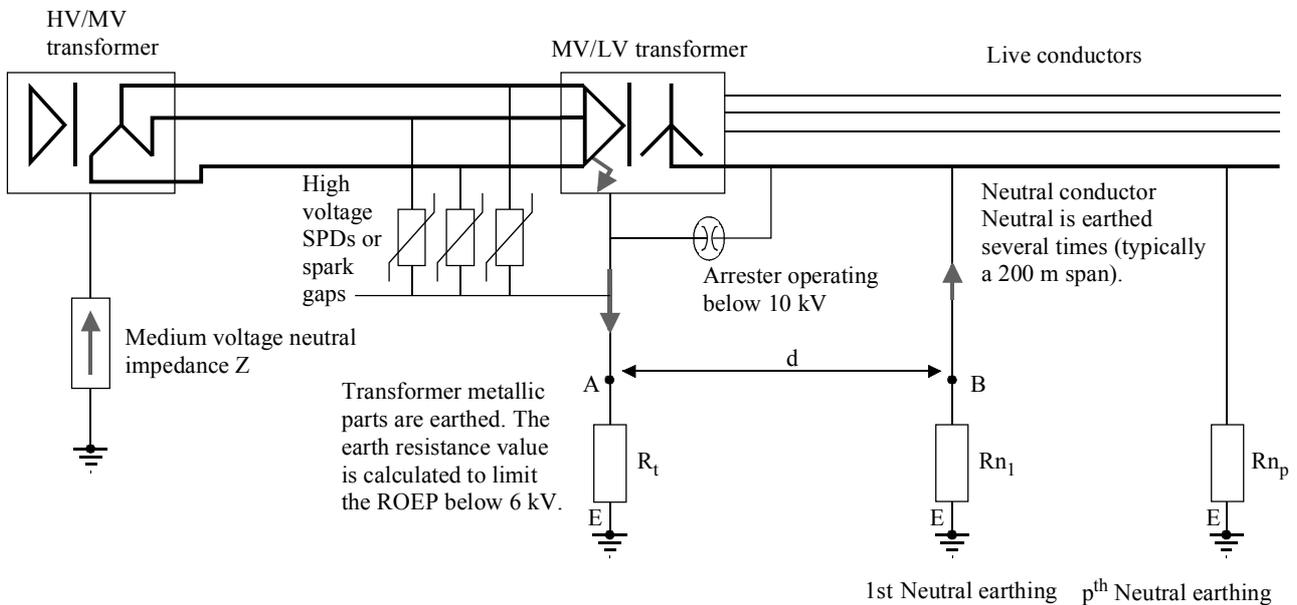
In France, this EPR value is limited to 6 kV.

## II.5.2.2 Neutral potential rise

### II.5.2.2.1 Coupling between transformer and neutral earth systems

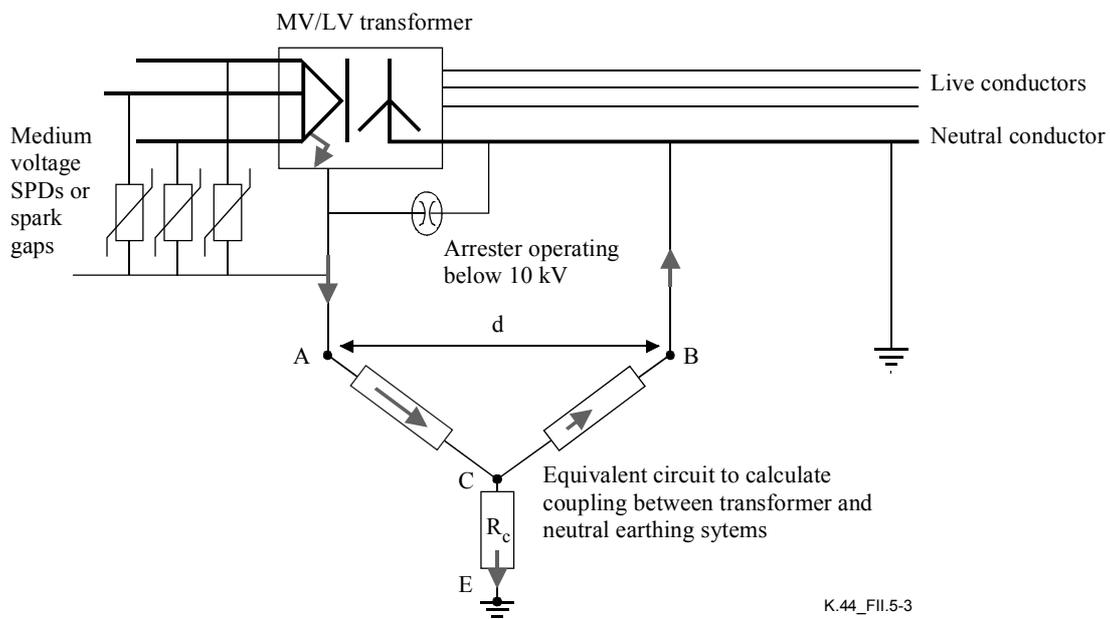
Because of the design of Neutral earthing, Neutral potential rises by conductive coupling when Medium Voltage is connected accidentally to ground.

National regulations may fix limits for this rise of neutral potential (for example 1500 V in France). See Figures II.5-2 and II.5-3.



K.44\_FII.5-2

Figure II.5-2/K.44 – Coupling into LV neutral



K.44\_FII.5-3

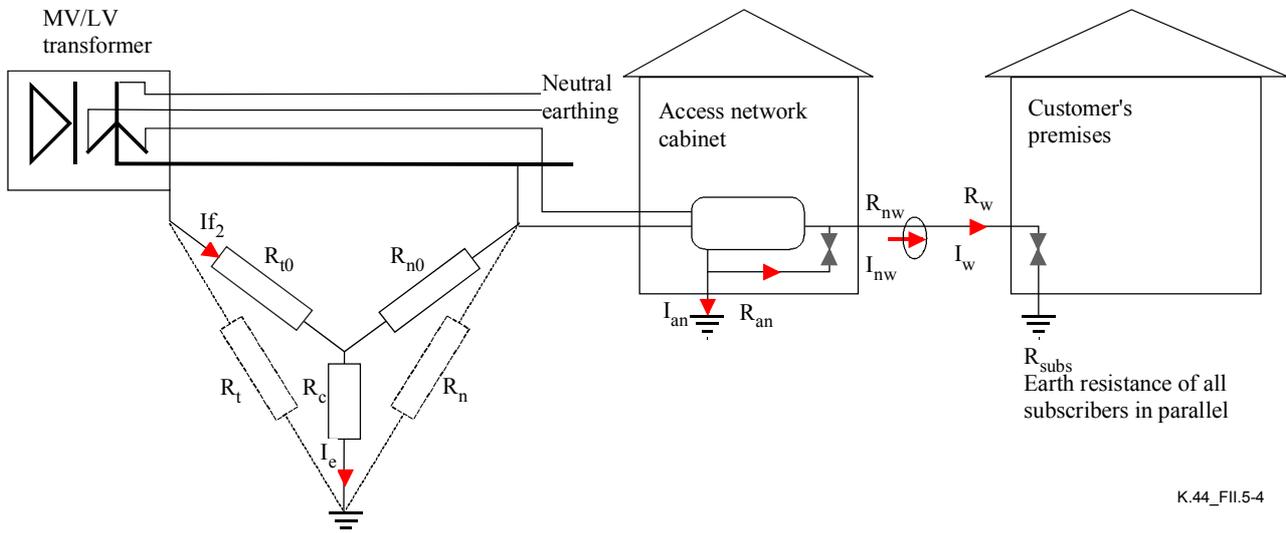
Figure II.5-3/K.44 – Limiting EPR by earthing design

The coupling resistance  $R_c = \rho \cdot l / 2 \cdot \pi \cdot d$  is adjusted by varying  $d$  to obtain a rise of neutral potential below 1500 V or a coupling ratio ( $V_{AE}/V_{BE}$ ) below 15% when a fault occurs.

When the soil has a high resistivity, the calculated resistance values may sometimes not be achieved and the rise of earth potential may be higher than 1500 V.

### II.5.2.3 Currents that may flow through equipment

See Figure II.5.4.



**Figure II.5-4/K.44 – Mechanism of current flow through equipment**

The results of the calculation when it is assumed that:

- 28 customers are connected with the same symmetric pairs (length 5 km, wires diameter 0.4 mm);
- the equivalent resistance of all their earthing systems in parallel is 2  $\Omega$ ;
- the access network cabinet earth resistance is 50  $\Omega$ ;
- the power system characteristics are  $Z = j40 \Omega$ ,  $R_t = 30 \Omega$ ,  $R_n = 15 \Omega$ ,  $d = 8 \text{ m}$ ;
- the soil resistivity is 300  $\Omega \cdot \text{m}$ ;

show that tens of Amps may flow through the equipment (disruptive discharge between mains port and equipment earth) to the Access Network cabinet earthing system.

Current may also flow either directly by telecommunication line SPDs (if they are installed, and in case of disruptive discharge between mains port and equipment earth) or through the equipment (disruptive discharge between the mains and telecommunication ports) to the customer's premises,  $I_w$  is about 1 A.

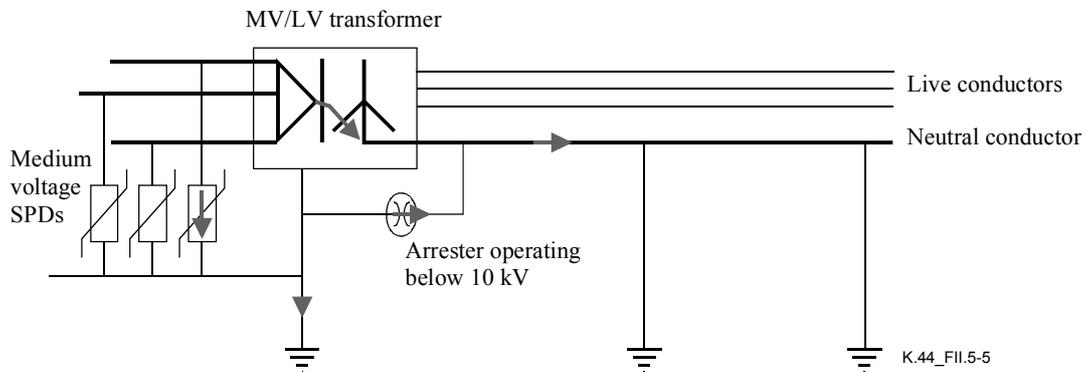
Note that the calculation is based on the same principle when replacing in Figure II.5-4 the customer's premises by a telecommunication centre, or the Access Network cabinet by the customer's premises.

#### II.5.2.4 Surge transfer

The lightning induced or direct surges transfer from Medium Voltage to Low Voltage may occur mainly if:

- 1) the transformer insulation breakdown is prevented by bypassing it with an arrester;
- 2) the transformer insulation between medium and low voltage windings is broken.

See Figure II.5-5.



**Figure II.5-5/K.44 – Transfer of overvoltage on to neutral**

The surge will be followed by a significant 50 Hz current in case 1 when spark gaps are used and always in case 2.





## SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series B	Means of expression: definitions, symbols, classification
Series C	General telecommunication statistics
Series D	General tariff principles
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
<b>Series K</b>	<b>Protection against interference</b>
Series L	Construction, installation and protection of cables and other elements of outside plant
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