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SERIES K: PROTECTION AGAINST INTERFERENCE

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# Ethernet port resistibility testing for overvoltages and overcurrents

Recommendation ITU-T K.147

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## Ethernet port resistibility testing for overvoltages and overcurrents

## Summary

Ethernet, using twisted pair cabling, is a ubiquitous communications link, which also can act as a powering feed. Usually, Ethernet is implemented as a star network and terminal ports can be independently tested for resistibility. Where equipment has multiple independent Ethernet ports, such as central hubs, switches, or repeaters, then testing is required for inter-port resistibility.

Resistibility testing needs to test for lightning transients coupled into a network by magnetic induction, earth potential rise, resistive coupling and transient coupling by a voltage limiting operation of surge protective functions or flashover. The voltage limiting operation may convert common-mode surges into differential-mode surges in the signal path. It is also possible for alternating current (AC) mains power faults to couple into the network.

Recommendation ITU-T K.147 covers the different "IEEE 802.3 Ethernet" implementations, their configurations, how surges are coupled into the system and what surge mitigation measures are used. Following this overview, the rational for the different surge and power fault test circuit approaches and when they are specified is given.

## History

| Edition | Recommendation | Approval | Study Group | Unique ID[*] |
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## Keywords

Configurations, IEEE Ethernet, K Recommendation applicability, surge coupling, test circuits, test levels, variants.

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## 1 Scope

This Recommendation provides the rational for the Ethernet port testing found in [ITU-T K.20], [ITU-T K.21], [ITU-T K.44], [ITU-T K.45] and [ITU-T K.117]. Topics covered are:

- IEEE 802.3 Ethernet;
- IEEE Ethernet configurations;
  - Data only
  - Power over Ethernet (PoE), and power over data line (PoDL);
- overvoltage and overcurrent events coupling into the Ethernet system;
- lightning surge resistibility test circuit approaches;
- power fault resistibility test circuit approaches;
- resistibility test circuit applicability to [ITU-T K.20], [ITU-T K.21], [ITU-T K.44], [ITU-T K.45] and [ITU-T K.117].

## 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 K.20] Recommendation ITU-T K.20 (2019), *Resistibility of telecommunication equipment installed in a telecommunication centre to overvoltages and overcurrents.*

[ITU-T K.21] Recommendation ITU-T K.21 (2019), *Resistibility of telecommunication equipment installed in customer premises to overvoltages and overcurrents.*

[ITU-T K.44] Recommendation ITU-T K.44 (2019), *Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation.*

[ITU-T K.45] Recommendation ITU-T K.45 (2019), *Resistibility of telecommunication equipment installed in the access and trunk networks to overvoltages and overcurrents.*

[ITU-T K.117] Recommendation ITU-T K.117 (2016), *Primary protector parameters for the surge protection of equipment Ethernet ports.*

[IEEE 802.3] IEEE 802.3 (2018), *IEEE Standard for Ethernet.*

## 3 Definitions

### 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

**3.1.1 Ethernet** [b-OED]: A system for connecting a number of computer systems to form a local area network, with protocols to control the passing of information and to avoid simultaneous transmission by two or more systems.

**3.1.2 IEEE Ethernet term glossary** [IEEE 802.3]: See Annex A.

### 3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

**3.2.1 power over data line (PoDL)**: Ethernet system consisting of one power sourcing equipment (PSE) and one powered device (PD) that provides power across a balanced single twisted-pair link section.

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

| | |
|---|---|
| AC | Alternating Current |
| AT | Ampere-Turns |
| AWG | American Wire Gauge |
| DC | Direct Current |
| DTE | Data Terminal Equipment |
| EMC | Electro-Magnetic Compatibility |
| EPR | Earth Potential Rise |
| GDT | Gas Discharge Tube |
| LAN | Local Area Network |
| LPS | Lightning Protection System |
| MDI | Media Dependent Interface |
| MIB | Management Information Base |
| MPS | Multimedia Priority Service |
| NAS | Network Attached Storage |
| PD | Powered Device |
| PE | Protective Earth |
| PHY | Physical Layer |
| PI | Power Interface |
| PoDL | Power over Data Line |
| PoE | Power over Ethernet |
| PSE | Power Sourcing Equipment |
| SPC | Surge Protective Component |
| SPD | Surge Protective Device |

STPE Screened Twisted-Pair Ethernet

## 5 Conventions

None.

## 6 IEEE Ethernet overview

### 6.1 General

The IEEE did not invent Ethernet, but the IEEE's prodigious work since the publication of [IEEE 802.3] in 1985 has made, for many, the IEEE's Ethernet standards the reference documents. Over the years IEEE 802.3, now simply titled "IEEE Standard for Ethernet", has grown as a result of maintenance, incorporation of other IEEE 802.3xx standards and the addition of amendments. IEEE 802.3-2018 has 5600 pages and a PDF file size of 93.6 MB. In addition, there are seven IEEE 802.3 amendments. By using an Ethernet twisted-pair link section to also deliver power simplifies system implementation in automotive, industrial, commercial, healthcare and domestic environments. This Recommendation looks at configurations for direct current (DC) powering over twisted-pair link Ethernet cables, power delivery levels, system transient overvoltages and possible protective measures against system transients.

### 6.2 Power delivery Ethernet systems

Figure 1 shows Ethernet system arrangements for feeding power over a connecting twisted-pair link cable. There are three main elements in such systems; Ethernet equipment capable of supplying DC power, called a power sourcing equipment (PSE), and a twisted-pair link section connecting the PSE to the Ethernet equipment being powered, which is called a powered device (PD) The top block diagram shows a PSE directly connecting to a PD. The middle block diagram shows how an Ethernet system can be made into a power over Ethernet (PoE) system by adding a midspan PSE power injector. The bottom block diagram shows how combined PD plus PSE equipment can be used to daisy chain multiple equipment to extend reach or to have several PDs or both. Such a daisy chain arrangement could also be used for power over data line PoDL.

It is important that the PSE power capability is at least equal to the maximum PD power demand. The PD maximum power demand is given by the PD signature, which can be hardwired or a software-controlled value. The PSE interrogates the PD signature to determine if it can supply the required maximum power demand before powering. Clause 8 lists the PoE and PoDL class values defining equipment type, voltage, current and power levels.

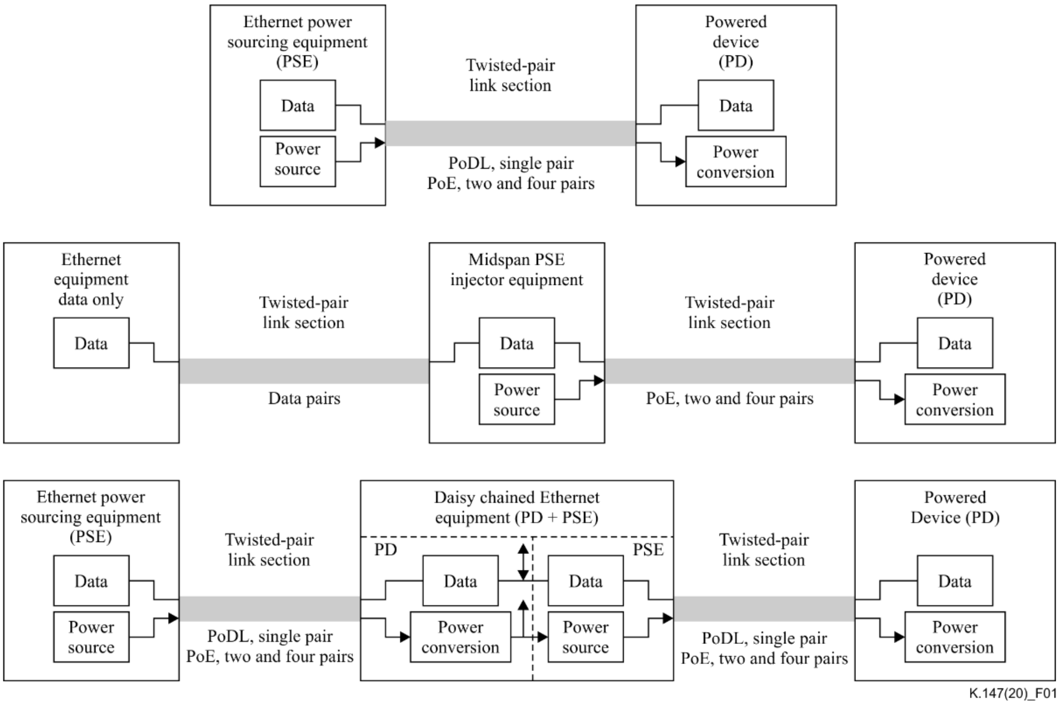


**Figure 1 – Power over Ethernet (PoE) and power over data line (PoDL) example system block diagrams**

## 6.3 Twisted pair usage

Figure 2 shows the various data and powering conductor allocations. For PoDL systems using a single twisted pair and data rates ≤ 1 GB/s, terminals 1 and 2 are used for data and DC powering. In a four twisted-pair PoE link segment, for data rates that are ≥ 1 GB/s all pairs, terminals 1 and 2, 3 and 6, 4 and 5 and 7 and 8 are used for data and for data rates that are < 1 GB/s two pairs, terminals 1 and 2 and 3 and 6 are used for data.

PoE power delivery has more options. Supplying power over two pairs can be done in alternate mode A, using terminals 1 + 2 and 3 + 6 or in alternate mode B, using terminals 4 +5 and 7 + 8. Alternate mode A has combined data and powering on the same two pairs, while alternate mode B only has separate data and powering pairs for data rates < 1 GB/s and combined data and powering for data rates ≥ 1 GB/s. Supplying power over all four pairs is simultaneous use of alternate mode A and alternate mode B. Generally, the simultaneous alternate modes will be in paralleled operation, but in certain cases they can operate independently to supply two different PD powering requirements.

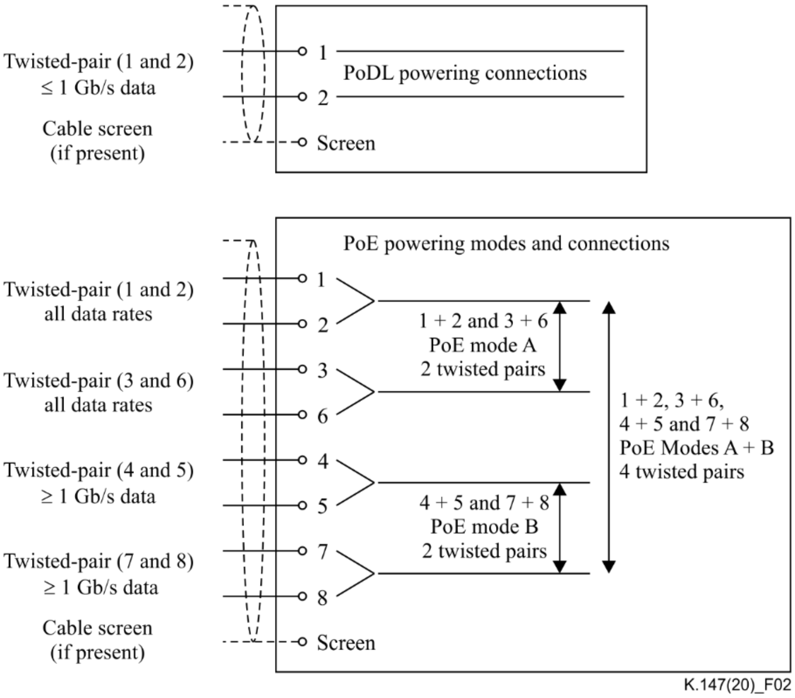


**Figure 2 – Twisted-pair link connections for PoDL and PoE**

## 6.4 Power injection and extraction

In the PoDL case, where a single twisted pair (two conductors) is used, some form filtering is required, power needing a low-pass filter and data requiring a high-pass filter as shown in Figure 3. In its simplest form, series inductors could be used for low-pass power filtering and series capacitors for high-pass data filtering.

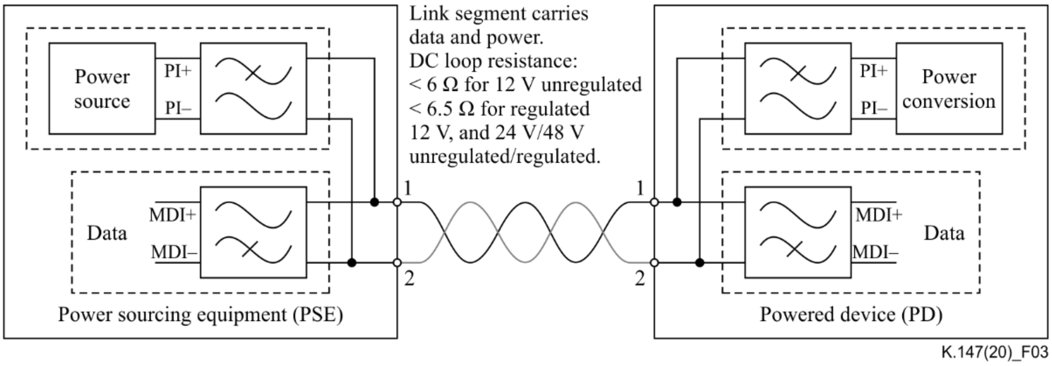


**Figure 3 – PoDL data and power filtering example**

In the PoE case, where each pair can be a power feed or return, a centre tap on the usual isolating data transformer provides feed or return connection for data pairs. If there is no data on the powering pairs then the twisted-pair terminals can be connected together. Figure 4 shows both situations.

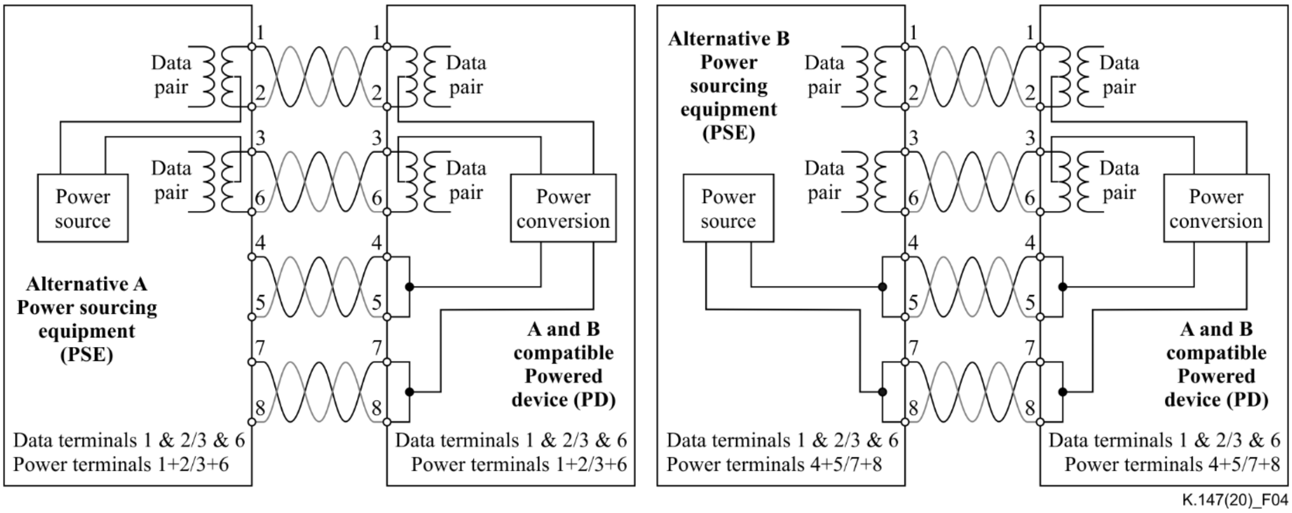


**Figure 4 – PoE power source injection and power conversion extraction examples**

## 6.5 IEEE 802.3 content

Examples of superseded Ethernet powering standards now incorporated in IEEE 802.3-2018 are [b-IEEE 802.3af], [b-IEEE 802.3at] and [b-IEEE 802.3bu].

A historical list of [IEEE 802.3] versions, since 1998, can be viewed at [b-802.3 Archive].

In addition, the [IEEE 802.3] is modified by publication of Amendments. Amendment 2 to [b-IEEE 802.3bt] and Amendment 5 to [b-IEEE 802.3cg] cover Ethernet powering:

[IEEE 802.3] and some Amendments are available as free downloads as detailed in Annex B.

## 6.6 Terminology

As pointed out in clause 6.5, [b-IEEE 802.3af], [b-IEEE 802.3at] and [b-IEEE 802.3bu] are all superseded as they have been incorporated into IEEE 802.3. For example, reference to [b-IEEE 802.3af] should no longer be used, rather [IEEE 802.3] Type1 PSE/PD (supplying/requesting Class 0 to Class 3 power levels over 2 twisted pairs).

Annex B.1 is a glossary of IEEE 802.3 terms for data rates, system items and PSE/PD types. Clause 7 defines the electrical levels that correspond to the various types and classes.

Confusingly, used Ethernet acronyms not mentioned in IEEE Standards abound. Examples are:

PoE (up to 15.4 W source, 2 pairs) Power over Ethernet — PoE is not in [IEEE 802.3]. However, PoE is in [b-IEEE 802.3bt], but as a generic classification for all forms of multiple twisted-pair Ethernet.

PoE+ (up to 30 W source, 2 pairs) is an acronym associated with [b-IEEE 802.3at], but it is not in [IEEE 802.3].

4PPoE (up to 90 W source, 4 pairs) an acronym associated with [b-IEEE 802.3bt], but it is not in IEEE [b-IEEE 802.3bt].

There are several proprietary powered Ethernet solutions. These variants can have compatibility issues with IEEE Ethernet.

## 6.7 Ethernet circuit configurations

Annex B shows the various [IEEE 802.3] DC power feed circuits listed in Table 1.

**Table 1 – IEEE 802.3 DC power feed circuits**

| Annex B Figure | Ethernet data rate | Powering pairs | IEEE 802.3 Figures | Powering pair usage | Midspan PSE injector |
|---|---|---|---|---|---|
| B.1 | 100BASE-T1/<br>1000BASE-T1 | 1 | 104–3 | C1 | |
| B.2 | 10BASE-T1S/<br>10BASE-T1L | 1 | 104–3 | C1 | |
| B.3 | 10BASE-T/<br>100BASE-TX | 2 | 33–4, 145–4 | C1 or C2 | |
| B.4 | ≥1000BASE-T | 2 | 33–5, 145–5 | C1 | |
| B.5 | 10BASE-T/<br>100BASE-TX | 2 | 33–6, 145–8 | C1 or C2 | Yes |
| B.6 | ≥1000BASE-T | 2 | 33–9, 145–5 | C1 | Yes |
| B.7 | 10BASE-T/<br>100BASE-TX | 4 | 145–6 | C1 and C2 | |
| B.8 | ≥1000BASE-T | 4 | 145–7 | C1 | |
| B.9 | 10BASE-T/<br>100BASE-TX | 4 | 145–10 | C1 and C2 | Yes |
| B.10 | ≥1000BASE-T | 4 | 145–11 | C1 | Yes |
| C1 = Power and data on same pair, C2 = Power and data in separate pairs | | | | | |

## 7 PoE and PoDL class voltage, current and power levels

### 7.1 Single twisted-pair (PoDL) power classes

**Table 2 – PoDL Class code matrix**
**(based on [IEEE 802.3] Table 104–1 and Table 104–1a)**

| PoDL Class code | PSE (max) V | PSE (min) V | Current (max) mA | PD (min) V | PD (max) W | Loop resistance (max) Ω | PSE Notes | Standard |
|---|---|---|---|---|---|---|---|---|
| 0 | 18 | 5.6 | 101 | 4.94 | 0.5 | 6 | 12 V unregulated | [b-IEEE 802.3cg] 104.2 Link segment for resistance [IEEE 802.3] Table 104–1 |
| 1 | 18 | 5.77 | 227 | 4.41 | 1 | 6 | | |
| 2 | 18 | 14.4 | 249 | 12 | 3 | 6.5 | 12 V regulated | |
| 3 | 18 | 14.4 | 471 | 10.6 | 5 | 6.5 | | |
| 4 | 36 | 11.7 | 97 | 10.3 | 1 | 6.5 | 24 V unregulated | |
| 5 | 36 | 11.7 | 339 | 8.86 | 3 | 6.5 | | |
| 6 | 36 | 26 | 215 | 23.3 | 5 | 6.5 | 24 V regulated | |
| 7 | 36 | 26 | 461 | 21.7 | 10 | 6.5 | | |
| 8 | 60 | 48 | 735 | 40.8 | 30 | 6.5 | 48 V regulated | |
| 9 | 60 | 48 | 1360 | 36.7 | 50 | 6.5 | | |
| 10 | 30 | 20 | 92 | 14 | 1.23 | 65 | 25 V | [b-IEEE 802.3cg] 104.2 Link segment for resistance see [b-IEEE 802.3cg] Table 104–1a |
| 11 | 30 | 20 | 240 | 14 | 3.2 | 25 | | |
| 12 | 30 | 20 | 632 | 14 | 8.4 | 9.5 | | |
| 13 | 58 | 50 | 231 | 35 | 7.7 | 65 | 54 V | |
| 14 | 58 | 50 | 600 | 35 | 20 | 25 | | |
| 15 | 58 | 50 | 1579 | 35 | 52 | 9.5 | | |

## 7.2 Multiple twisted-pair (PoE) power classes

**Table 3 – PoE Class code matrix**
**(based on IEEE 802.3 Tables 33–1, 33–7, 33–11, 33–18, 145–16, 145–26, 145–27 and 145–29)**

| PoE Class code | PSE Type[d] | PSE voltage (max) V | PSE voltage (min) V | PSE nominal power W[c] | Powering pairs used | Total current (max) A | PD voltage (min) V | PD power (max) W[c] | Loop resistance (max) Ω[a] |
|---|---|---|---|---|---|---|---|---|---|
| 0 | No PD Type signature, defaults to Class 3 | | | | | | | | |
| 1 | 1, 2, 3, 4 | 57 | 44, 50, 50, 52 | 4 | 2 | 0.09 | 42.8 | 3.84 | 20 |
| 2 | 1, 2, 3, 4 | 57 | 44, 50, 50, 52 | 7 | 2 | 0.15 | 42 | 6.49 | 20 |
| 3 | 1, 2, 3, 4 | 57 | 44, 50, 50, 52 | 15.4 | 2 | 0.35 | 39.9 | 13 | 20 |
| 4 | 1, 2, 3, 4 | 57 | 44, 50, 50, 52 | 30 | 2 | 0.60 | 42.5 | 25.5 | 12.5 |
| 5[b] | 3, 4 | 57 | 50, 52 | 45, 43 | 4, [2×2] | 0.90, [0.87] | 44.3, [41.1] | 40, [35.6] | 6.25, [2×12.5] |
| 6 | 3, 4 | 57 | 50, 52 | 60 | 4 | 0.87 | 42.5 | 51 | 6.25 |
| 7 | 4 | 57 | 52 | 75 | 4 | 1.20 | 42.9 | 62 | 6.25 |
| 8 | 4 | 57 | 52 | 90 | 4 | 1.45 | 41.1 | 71.3 | 6.25 |

[a] Maximum DC twisted-pair loop resistance from IEEE 802.3 Table 33–1 (Types 1 & 2) and IEEE 802.3cg Annex 145C (Types 3 & 4).

[b] Class 5 power feeding can be a single power feed, using all 4 pairs, or two independent power feeds, each using 2 pairs. Parameters for two feed operation are shown in brackets e.g. [2x2].

[c] PSE allocated power values and PD requested power values may be software adjusted in 0.1 W steps.

[d] Type 1 can work with classes 0-3; Type 2 can work with classes 0-4; Type 3 can work with classes 0-6; and Type 4 can work with classes 0-8.

# 8 Surges on Ethernet systems

## 8.1 Surge coupling mechanisms

[b-ITU-T K.39] *Risk assessment of damages to telecommunication sites due to lightning discharges* states there are four main coupling mechanisms for surges to couple into networks and equipment:

- Direct coupling (permanent or transient)
- Magnetic coupling
- Electric coupling
- Electromagnetic coupling

## 8.2 Direct coupling – permanent

Resistive coupling may be a permanent coupling like differential earth potential rise (EPR), or transient coupling like the operation of a surge protective device (SPD) or a side flash. Use of inappropriate SPDs can often cause Ethernet equipment failure.

Figure 5 depicts a lightning strike to uniform resistivity soil where the lightning current spreads out radially and a series of concentric (dashed) equipotential rings can be mapped. If two earth rods, A and B, are positioned on a strike radial and on different equipotential rings there will be a difference in EPR between them. Equipment bonded to A and equipment bonded to B will have the differential EPR between them and this is applied to any connecting link between the A and B equipment. If the link has a cable screen a high potential-equalising current will flow in the screen.

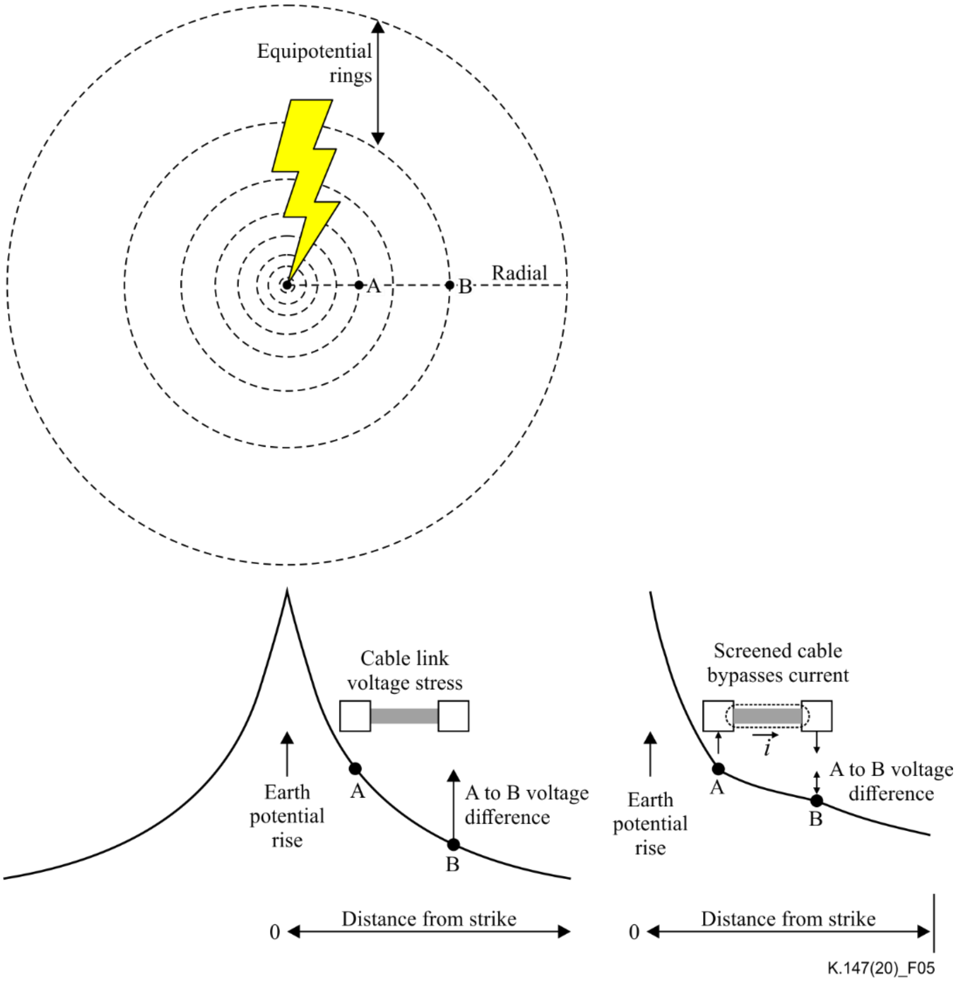


**Figure 5 – Lightning EPR example**

## 8.3 Direct coupling – transient

### 8.3.1 Voltage limiters

Operation of equipment surge protective components (SPCs) or external SPDs can couple transients into a protected service or service transients can be injected into the equipotential bonding network causing localised voltage rise due to bonding conductor inductance.

Voltage limiters are used to protect insulation from breakdown and components from failing. Voltage limiting must not operate under steady state conditions. Depending on the voltage-limiting technology, temporary overvoltage size, and duration, the voltage limiter may or may not operate. Under surge conditions, for fast- and slow-front surges, voltage limiting occurs. To pass the [IEEE 802.3] DC 500 V insulation resistance test any voltage limiter connected from the Ethernet twisted pairs to the local earth should only operate at DC > 500 V. A by-product of this is under power cross conditions, where the local AC mains contacts the unearthed (floating) Ethernet link conductors, any voltage limiter to earth will not operate and draw current. Figure 6 is a simplified version of a [b-IEC 60099-5] diagram illustrating how AC distribution equipment insulation withstands changes with time and how voltage limiting prevents insulation breakdown.

Strangely, the [b-IEC 62368-1] safety standard stipulates that any gas discharge tube (GDT), used for live to protective earth, L-PE and for neutral to protective earth, N-PE, protection must have a voltage withstand at least equal to the equipment insulation, which completely negates the purpose of adding protection, [b-M. J. Maytum].

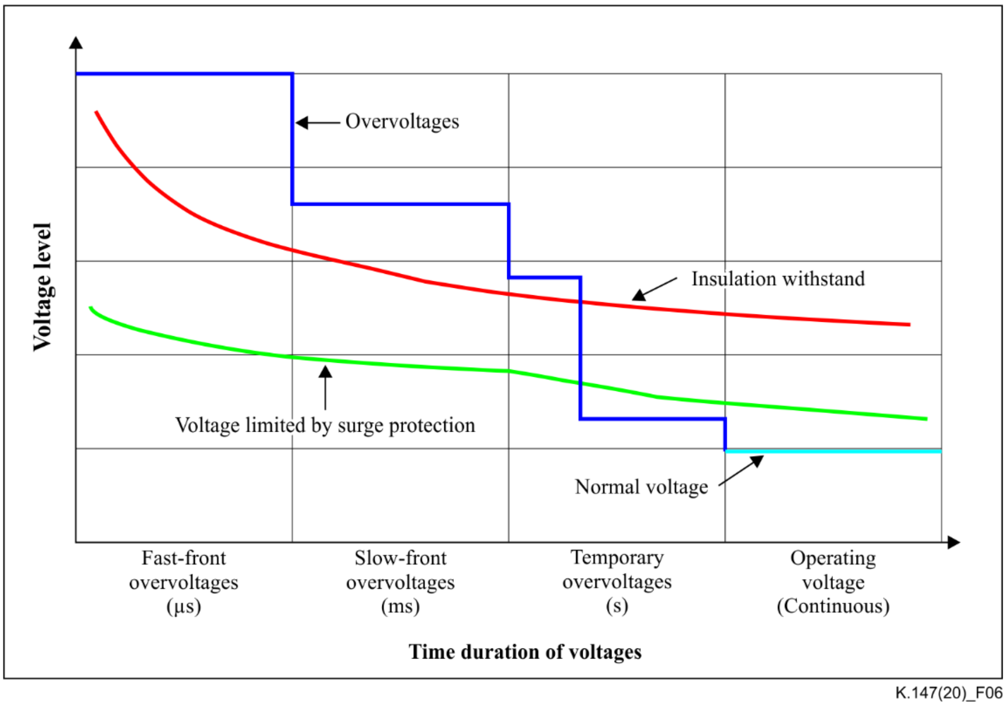


**Figure 6 – AC system overvoltage level, insulation withstand and voltage limiting variation with time**

Figure 7 shows three undesirable consequences of SPD operation for an AC mains service. If a large EPR occurs the SPD can couple that surge onto the protected service as shown by the left circuit of Figure 7. The centre circuit of Figure 7 shows how current surges on the service are diverted by the SPD into the local earthing system causing local PE inductive surge voltages. The right circuit of Figure 7, for 3-wire (L1, L2 and N) single-phase installations, common in Japan and the USA, shows how SPDs applied to one L-N pair can cause surge voltage differences between equipment connected to L1-N and L2-N. SPDs applied to communications services can cause similar events to the left and centre circuits.

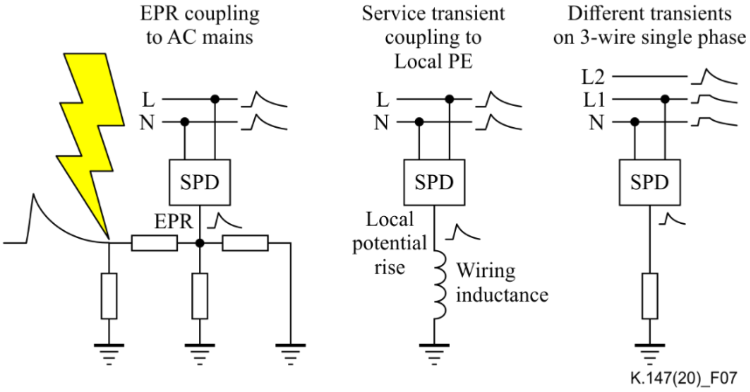


**Figure 7 – SPD coupling of EPR voltage (left), injecting surge current into the local earthing system (centre) and causing differential surge on 3-wire single-phase mains (right)**

When a common-mode surge occurs on the cable conductors, asynchronous operation of the voltage limiting can result in the creation of a large differential surge. Figure 8 shows a circuit that produces common mode to differential mode conversion. Generator G is charged to 2 kV and produces a 5/75 voltage waveshape. Equal value resistors, R1 and R2, feed the common-mode surge to cable conductor A and B. Gas discharge tubes (GDTs), GDTA (520 V sparkover voltage) and GDTB (540 V sparkover voltage), limit the maximum conductor voltages. Resistor R3, between the conductors, represents the port termination and the mutual conductor coupling.

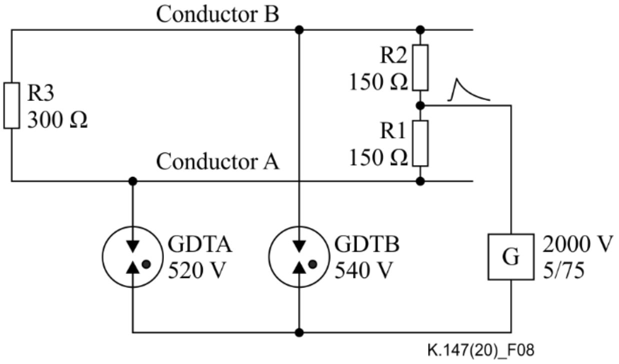


**Figure 8 – Example circuit causing common mode to differential-mode surge conversion**

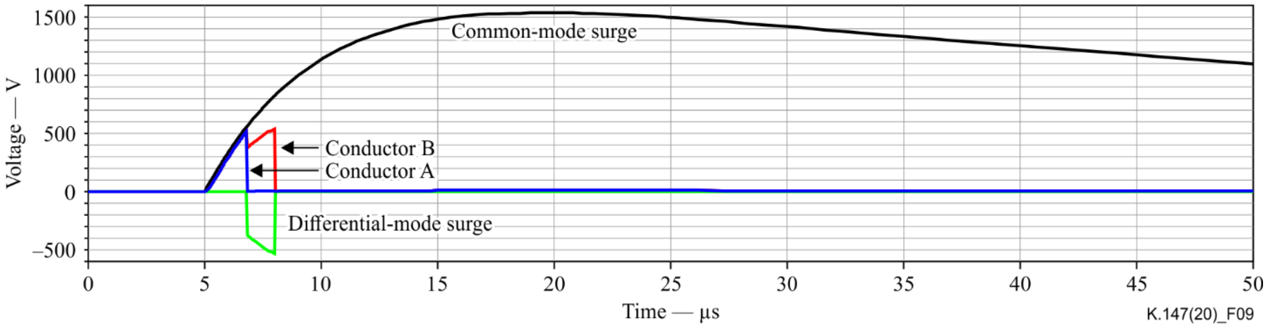


**Figure 9 – Surge voltages**

Figure 9 shows the common-mode surge voltage (black line) at the junction of R1 and R2 peaks at just over 1500 V. When the surge voltage reaches 520 V, GDTA sparks over, lowering the conductor A voltage to about 10 V (red line). Via resistor R3 the conductor B voltage (red line) is reduced at GDTA sparkover and subsequently the conductor B voltage rises at a slower rate than before. When the conductor B voltage reaches 540 V, GDTB sparks over, lowering the conductor B voltage to about 10 V (red line). During the time between sparkovers there is a large differential voltage of about 450 V for over a microsecond between the conductors (green line, shown inverted for clarity).

Changing the individual two-electrode GDTs for a single chamber three electrode GDT might be expected to fix the asynchronous operation problem, but, because the first part of a three electrode GDT to sparkover reduces the voltage on the other part, there is still asynchronous operation as described in [b-Gazivoda-Nikolic].

### 8.3.2 Capacitance

Surge conditions can result in the charging and discharging of circuit capacitors and these currents may cause disruptions in circuit operation. The inherent capacitance of isolation barriers may need to be considered where they are in series, as shown in Figure 10.

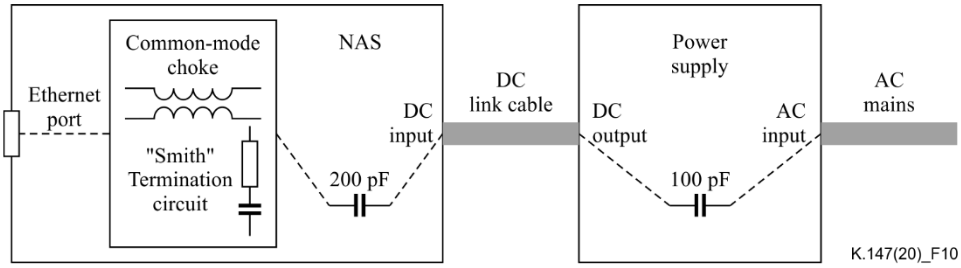


**Figure 10 – Example of network-attached storage (NAS) and power supply capacitances**

If the Ethernet port has a series common-mode choke, then there is no low impedance path for capacitive current flow. If the Ethernet port has a "Smith" termination circuit, then a low impedance path for capacitive current flow exists. In this case, the Ethernet transformer isolation barrier will have 100/(200 +100) = 1/3 of the mains transient voltage across it.

### 8.4 Magnetic coupling

Transient magnetic fields will induce voltages and, in low impedance circuit loops, currents in the cabling. Transient magnetic fields caused by lightning can be from the lightning itself or the lightning current flowing in the lightning protection system (LPS), down conductor on the side of a building. Inside the building, network cabling can run parallel and quite close to an external LPS down conductor. The down conductor mutual coupling inductance, M, to the network cabling can be several µH. Figure 11 shows an example situation where a lightning current or the current in an LPS down conductor radiates a transient magnetic field that couples with open-circuit and short-circuit twisted-pair loops. The lightning current is a 100 A peak, 5/75 current impulse coupled to each loop type by a mutual inductance of 5 µH. The time graph of Figure 11 shows the lightning current (green line), a short-circuit loop conductor current (blue line) and the open-circuit loop end-to-end cable voltage (red line).

In the open-circuit loop, the induced voltage will be dependent on 5 µH×(di/dt), where di/dt is the lightning rate of current change with time. The time graph green line is the lightning current, the blue line is the current in any loop and the redline is the cable end-to-end voltage. The peak voltage is 110 V indicating an initial lightning current di/dt of 110/5 = 22 A/µs. After the lightning current peaks, the decreasing current has a negative di/dt producing a cable voltage about −5 V. Had the lightning current peak been 10 kA the peak voltage would be 11 kV. The peak cable voltage is balanced, for example, the power sourcing equipment (PSE) end would be −5.5 kV and the powered device (PD) end would be 5.5 kV. However, if the PSE power source is connected to earth or an SPD is applied at the PSE end, then the other cable end would experience nearly 11 kV as shown in Figure 12.

In the short-circuit loops, the total circuit ampere-turns (AT), will try to oppose the lightning current magnetic field AT. The time graph green line is the lightning current and the blue line is a short-circuit loop conductor current. The peak loop current is 46 A, but decays more rapidly than the lighting current.

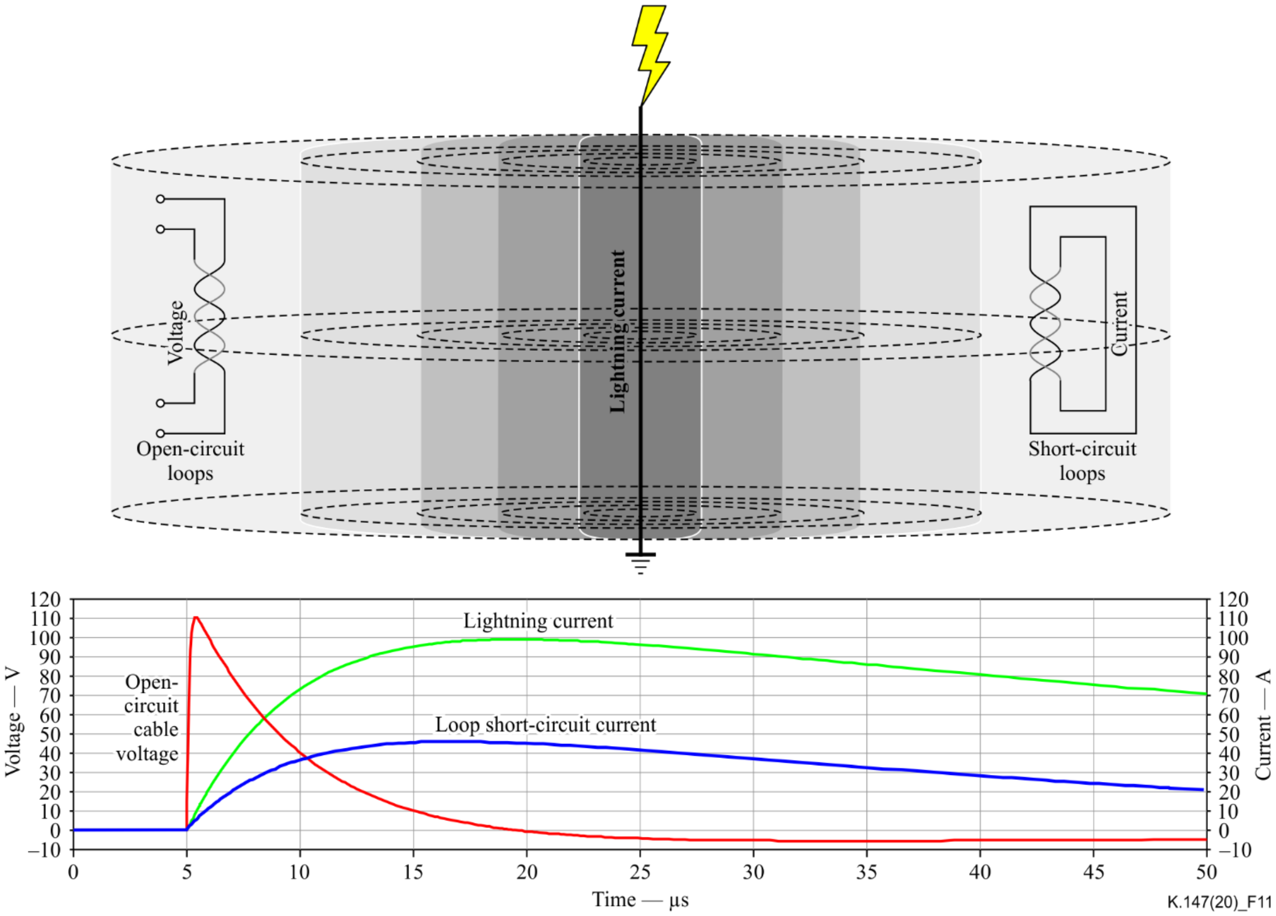


**Figure 11 – Magnetically induced cable voltage and current from lightning current**

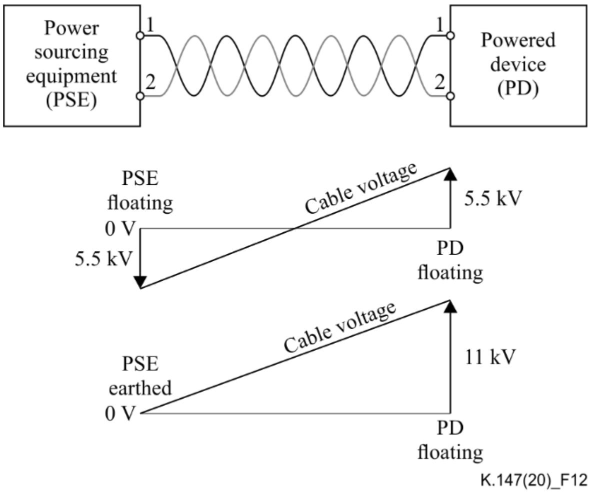


**Figure 12 – PSE and PD port voltages due to magnetic coupling**

## 8.5 Electric and electromagnetic coupling

Transient electric fields can couple into systems possibly causing interference and equipment lock up rather than damage. Electromagnetic fields from transmitting devices can create interference and possibly equipment lock up rather than damage.

### 8.6 Surge resistibility design approaches

Adequate surge resistibility can be achieved by the use of surge mitigating components having linear technology or non-linear technology or a combination of both component types. [b-ITU-T K.96] provides an overview of surge mitigation functions and technologies (except for screened cable technology).

Ethernet isolation transformers, [b-ITU-T K.126], usually have a withstand voltage rating that will survive the expected common-mode surge voltages. Where the surge voltage levels are unknown or the transformer withstand voltage rating is too low, paralleled connected voltage limiters may be used to prevent transformer insulation breakdown, see Figure 6. Common-mode chokes are also effective means of mitigating common mode surges and reducing electro-magnetic compatibility (EMC) problems.

Switching voltage limiters use gas discharge, [b-ITU-T K.99], or solid-state thyristor technologies. Clamping voltage limiters use metal oxide varistor, [b-ITU-T K.128], or PN-junction, [b-ITU-T K.103], technologies. All technologies can be used for voltage limiting of the link segment conductors to PE or between conductors. The most appropriate technology depends on the application. For example, in low voltage, signal applications, the high capacitance of the metal oxide varistor and the poor fast wave front protection level of 90-volt or lower gas discharge tubes can result in operational or surge problems.

Overcurrent limiters use either thermal or current level technology. The response of thermal overcurrent protectors is relatively slow, limiting their use to power fault conditions or the short-circuit condition of a DC power supply see [b-ITU-T K.144] (positive temperature coefficient thermistors) and [b-ITU-T K.140] (fuses). Electronic current limiters, which operate on current level, can be used to limit the surge currents in signal circuits.

## 9 Resistibility test circuits

### 9.1 Lightning resistibility

Table 4 shows the Ethernet test configurations presented in Annex C for [ITU-T K.44] (Figures C.1 to C.10) for equipment ports and [ITU-T K.117] (Figures C.11 to C.19) for SPDs and mid-span PSE devices. Lightning tests are Figures C.3 to C.5 and Figures C.8 to C.16. The remaining Figures are for power cross (Figure C.7), insulation resistance (Figures C.6, C.17 and C.18) and voltage drop (Figure C.19).

**Table 4 – Ethernet tests**

| Figure | Title | Purpose | Conductors |
|---|---|---|---|
| C.1 | Combination wave generator based on K.44 A.3-5 | Impulse | N/A |
| C.2 | Power induction, power contact and rise of neutral potential generator based on K.44 A.3-6 | AC | N/A |
| C.3 | Termination and coupling to earth of untested Ethernet ports based on K.44 A.6.7-1 | Terminations | All |
| C.4 | Ethernet port, including PoE variants, common-mode voltage withstand test circuit based on K.44 A.6.7-3a | Common-mode-current hogging | All |
| C.5 | Ethernet port, including PoE variants, common mode to differential mode conversion surge test circuit based on K.44 A.6.7-4 | Common-mode to differential-mode conversion | All |
| C.6 | Ethernet port, including PoE variants, DC insulation resistance test circuit based on K.44 A.6.7-3 | Insulation | All |

### Table 4 – Ethernet tests

| Figure | Title | Purpose | Conductors |
|---|---|---|---|
| C.7 | Ethernet port, including PoE variants, power cross test circuit based on K.44 A.6.7-7 | Power cross | All |
| C.8 | PoE port powering pair transverse/differential surge test circuit based on K.44 A.6.7-2 | Powering differential | Power |
| C.9 | Ethernet port differential-mode surge test circuit including PoE variants based on K.44 A.6.7-5 | Data port differential | Data |
| C.10 | Ethernet screened cable port screen connection high current bonding test based on K.44 A.6.7-6 | High current | Screen |
| C.11 | Impulse limiting voltage under common-mode surge conditions | Common-mode-current hogging | All |
| C.12 | Single twisted-pair differential-mode surge test circuit | Differential | Pairs |
| C.13 | Power feed differential-mode surge test circuit | Powering differential-mode | Powering pairs |
| C.14 | Twisted-pair common mode to differential-mode voltage surge conversion test circuit | Common-mode to differential-mode conversion | All |
| C.15 | Power feed pair common mode to differential mode surge conversion test circuit | Common-mode to differential-mode conversion | Powering pairs |
| C.16 | Screen bonding test | High current | Screen |
| C.17 | Test circuit to measure the insulation resistance of an SPD with a PE terminal or screen terminals, or both | Insulation | Pairs |
| C.18 | Test circuit to measure the insulation resistance of an isolating transformer SPD without a PE terminal | Insulation | Pairs |
| C.19 | Test circuit to measure the PoE SPD d.c. input/output voltage drop | Item powering loss | All |

## 9.2 Power fault resistibility

The Figure C.7 power cross test is for direct contact with the local AC mains. As the highest domestic AC mains peak voltage is below 400 V, Ethernet ports passing the DC 500 V insulation test do not require power cross testing.

## 9.3 PoDL testing

Standard PoE Ethernet test circuits assume the link connection has 4 twisted pairs. As PoDL only uses a single twisted pair not all of the standard PoE Ethernet test circuits will be applicable. The latest PoDL [b-IEEE 802.3cg] will probably require modified test levels.

[b-IEEE 802.3cg] defines a 10 MB/s PoDL system having a short reach version (10BASE-T1S, at least 15 m), for such things as automotive and in-cabinet applications, and a long reach version (10BASE-T1L at least 1 km) for such things as industrial process control, building automation, web cameras, access control and sensors. Daisy chaining and multidrop configurations are also possible as described in [b-802.3cg Guide].

Figure 13 for 10BASE-T1L has been constructed using the data from Tables 146B–1 and 104–1a. There are two graphs; one for PSE voltages between 50 V to 58 V and the other for PSE voltages between 20 V to 30 V. The horizontal axis is link segment length in metres and the vertical axis is the PD power. Horizontal lines show the six power classes, 10 through 15 of Table 2. The sloping long-dashed lines are conductor American wire gauge (AWG) values for a 20 V to 30 V source powering. The sloping short-dashed lines are conductor AWG values for a 50 V to 58 V source powering. [b-IEEE 802.3cg] does not necessarily use standard Ethernet cable conductor sizes, but can be much larger to get the link distance.

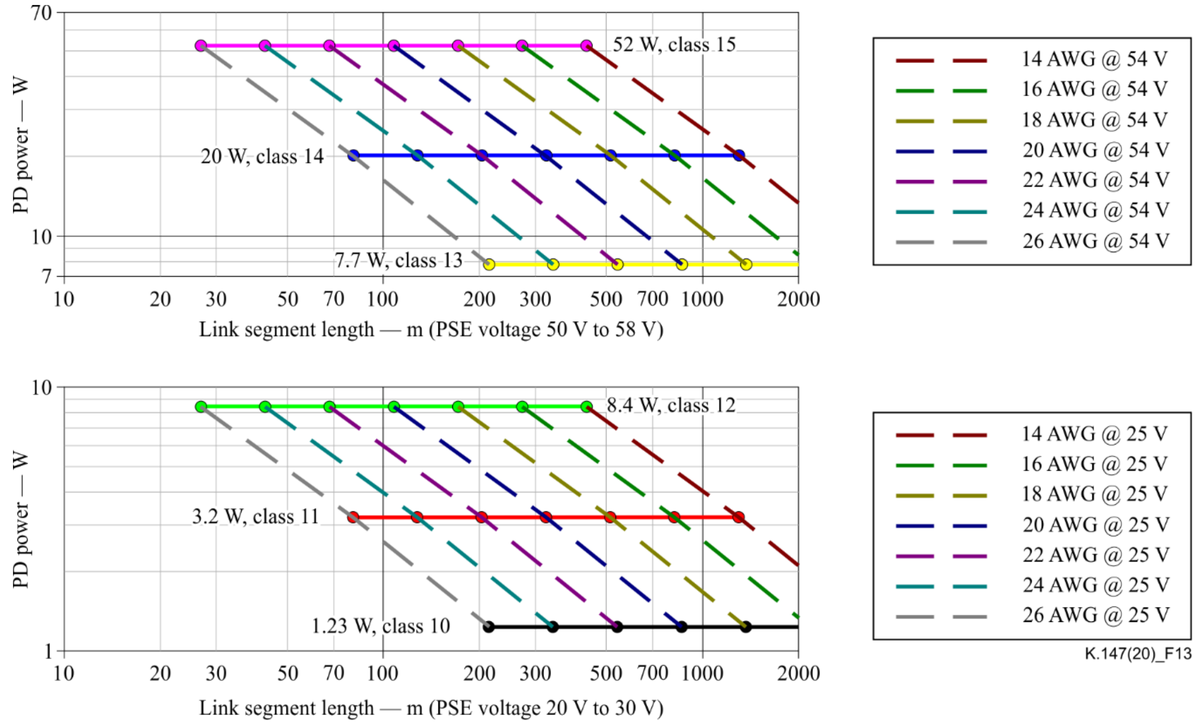


**Figure 13 – IEEE 802.3cg power-distance capability for Classes 10 to 15**

Figure 13 shows the trade-off between conductor AWG and distance. For example, on the blue line (20 W, Class 14 and nominal 54 V source powering) the following values can be obtained:

- 14 AWG allows a 1300 m link section
- 18 AWG allows a 515 m link section
- 22 AWG allows a 200 m link section
- 24 AWG allows a 128 m link section
- 26 AWG allows an 80 m link section

By interpolating between Classes, the maximum power at a given link can be deduced. For example, the maximum PD power delivered for Classes 13 to 15 at 1000 m by 14 AWG is about 25 W.

PoDL clause 104.6.1 (isolation) specifies that the PD port has ≥ 1 MΩ insulation resistance measured at DC 5 V ± 20%. This value is much lower than the PoE value of ≥ 2 MΩ, measured at DC 500 V. Considering 10BASE-T1L cable link distances of 1 km and the resultant possibility of coupled voltage transients, it is recommended that designers should consider using the PoE isolation voltage values for Type E PDs. There are no PoDL PSE isolation values specified, because the PSE can have an earth connection, which would double the magnetically coupled transient voltages at the PD as shown in clause 8.4. A 1 km link may be susceptible to power induction and hence require an extra test for this.

# Annex A

# IEEE 802.3 term glossary

(This annex forms an integral part of this Recommendation.)

## A.1 IEEE 802.3 glossary

### A.1.1 Data transfer

The following terms related to data transfer are defined in [IEEE 802.3]:

- 10BASE-T
- 10BASE-T1L
- 10BASE-T1S
- 100BASE-T
- 100BASE-T1
- 100BASE-T4
- 1000BASE-T
- 1000BASE-T1

### A.1.2 System elements

The following terms related to system elements are defined in [IEEE 802.3]:

- dual-signature PD
- link section
- midspan
- midspan PSE
- master physical layer (PHY
- PoDL PD
- PoDL PSE
- PoDL regulated PSE
- PoDL unregulated PSE
- Powered device (PD)
- Power over Ethernet (PoE)
- Power sourcing equipment (PSE)
- slave physical Layer (PHY)
- single-signature PD

### A.1.3 Equipment types

The following terms related to equipment types are defined in [IEEE 802.3]:

- Type 1 PoE PSE
- Type 1 PoE PD
- Type 2 PoE PSE
- Type 2 PoE PD
- Type 3 PoE PSE
- Type 3 PoE PD

- Type 4 PoE PSE
- Type 4 PoE PD
- Type A PoDL system
- Type B PoDL system
- Type C PoDL system
- Type D PoDL system
- Type E PoDL system

### A.1.4 IEEE Standard downloads

Under the GET Program™ – GET 802® Standards new IEEE 802® standards can be freely downloaded after they have been published in PDF for six months. The IEEE GET Program™ https://ieeexplore.ieee.org/browse/standards/get-program/page, shows the February 2020 GET 802® Standards available for download are:

- 802.3-2018 (IEEE 802.3cj) – IEEE Standard for Ethernet (5600 pages, 93.5 MB)
- 802.3cb-2018 - IEEE Standard for Ethernet – Amendment 1: Physical Layer Specifications and Management Parameters for 2.5 Gb/s and 5 Gb/s Operation over Backplane
- 802.3bt-2018 - IEEE Standard for Ethernet Amendment 2: Physical Layer and Management Parameters for Power over Ethernet over 4 pairs (304 pages, 1 MB)
- 802.3cd-2018 – IEEE Standard for Ethernet – Amendment 3: Media Access Control Parameters for 50 Gb/s and Physical Layers and Management Parameters for 50 Gb/s, 100 Gb/s, and 200 Gb/s Operation
- 802.3cc-2017 – IEEE Standard for Ethernet - Amendment 11: Physical Layer and Management Parameters for Serial 25 Gb/s Ethernet Operation Over Single-Mode Fiber
- 802.3.1-2013 – IEEE Standard for Management Information Base (MIB) Definitions for Ethernet
- 802.3.2-2019 (IEEE 802.3cf) – IEEE Standard for Ethernet – YANG Data Model Definitions

Ethernet powering is covered in the 802.3-2018 and 802.3bt-2018 standards.

### A.1.5 Pending IEEE 802® standard downloads

The following standards were approved in November 2019 and should be available in GET 802® Standards soon:

- IEEE Std 802.3cg-2019-11-07 - IEEE Standard for Ethernet - Amendment 5: Physical Layer Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors.
- IEEE Std 802.3cn-2019-11-07 50 Gb/s, 200 Gb/s, and 400 Gb/s over greater than 10 km of single-mode fibre.

# Annex B

## Ethernet twisted-pair DC power feeds

(This annex forms an integral part of this Recommendation.)

### B.1 Introduction

This annex summarizes the listed IEEE Std. 802.3 DC power feed circuits shown in Table B.1.

Note that the figures shown in this annex are functionally equivalent to the referenced [IEEE 802.3] figures but have been redrawn for consistency and clarity.

**Table B.1 – IEEE 802.3 DC power feed circuits**

| Annex B Figure | Ethernet data rate | Powering pairs | IEEE 802.3 Figures | Powering pair configuration | Midspan injector |
|---|---|---|---|---|---|
| B.1 | 100BASE-T1/ 1000BASE-T1 | 1 | 104–3 | C1 | |
| B.2 | 10BASE-T1S/ 10BASE-T1L | 1 | 104–3 | C1 | |
| B.3 | 10BASE-T/ 100BASE-TX | 2 | 33–4, 145–4 | C1 or C2 | |
| B.4 | ≥1000BASE-T | 2 | 33–5, 145–5 | C1 | |
| B.5 | 10BASE-T/ 100BASE-TX | 2 | 33–6, 145–8 | C1 or C2 | Yes |
| B.6 | ≥1000BASE-T | 2 | 33–9, 145–5 | C1 | Yes |
| B.7 | 10BASE-T/ 100BASE-TX | 4 | 145–6 | C1 and C2 | |
| B.8 | ≥1000BASE-T | 4 | 145–7 | C1 | |
| B.9 | 10BASE-T/ 100BASE-TX | 4 | 145–10 | C1 and C2 | Yes |
| B.10 | ≥1000BASE-T | 4 | 145–11 | C1 | Yes |
| C1 = Power and data on same pair, C2 = Power and data in separate pairs | | | | | |

### B.2 Powering over one twisted-pair

In this case, both power and data share the same twisted-pair, see Figures B.1 and B.2.

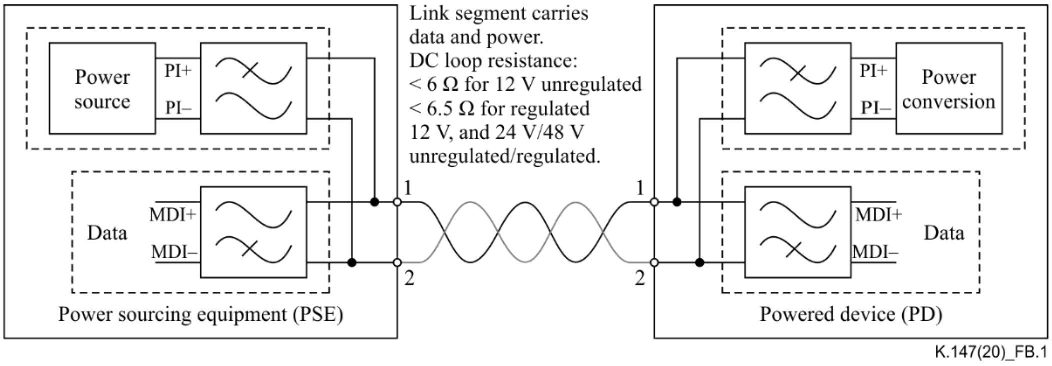


**Figure B.1 – 100BASE-T1/1000BASE-T1 1-pair PoDL system block diagram based on IEEE 802.3-2018 Figure 104–3**

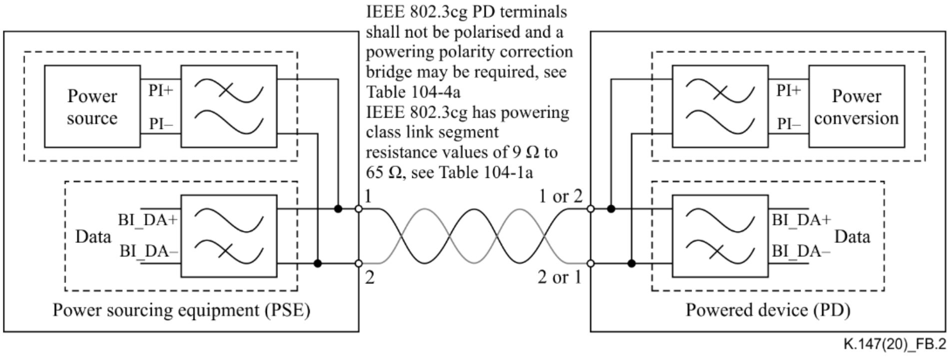

IEEE 802.3cg PD terminals shall not be polarised and a powering polarity correction bridge may be required, see Table 104-4a
IEEE 802.3cg has powering class link segment resistance values of 9 Ω to 65 Ω, see Table 104-1a

Figure B.2 – 10BASE-T1S/10BASE-T1L 1-pair PoDL system block diagram
based on IEEE 802.3cg–2019 Figure 104–3

## B.3 Powering over two twisted pairs

In this case, powering uses two twisted pairs, one pair for feed and the other pair for return, these may be shared with data in the alternative A configuration or be separate in the alternative B configuration, see Figures B.3, B.4, B.5 and B.6.

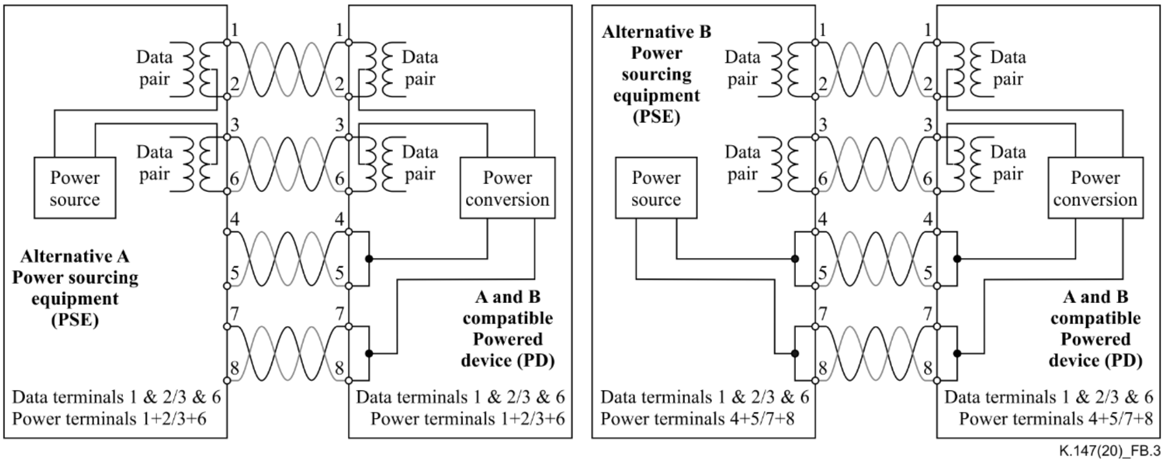


Figure B.3 – 10BASE-T/100BASE-TX 2-pair PoE A and B alternatives
based on IEEE 802.3–2018 Figure 33–4 and IEEE 802.3bt-2019 Figure 145–4

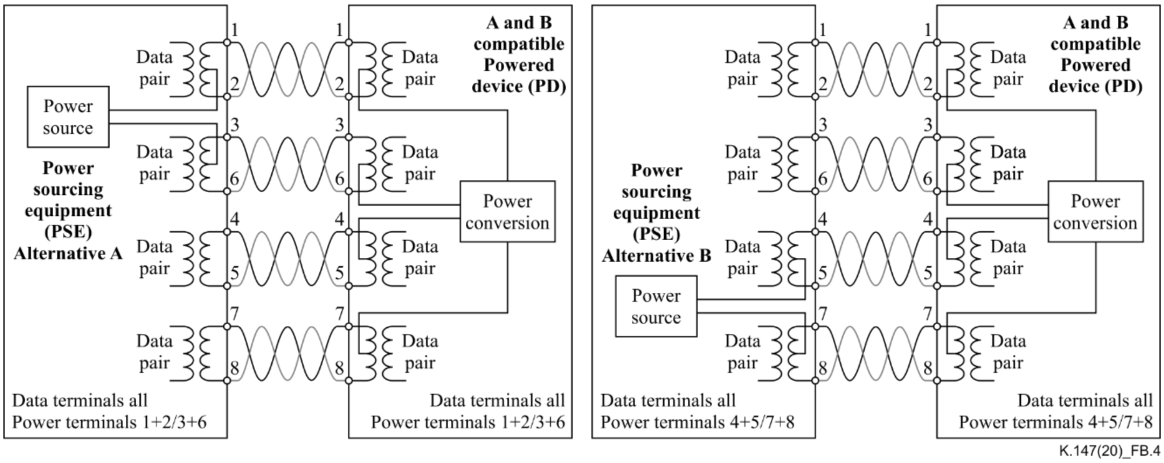


Figure B.4 – 1000BASE-T 2-pair PoE A and B alternatives
based on IEEE 802.3–2018 Figure 33–5 and IEEE 802.3bt–2019 Figure 145–5

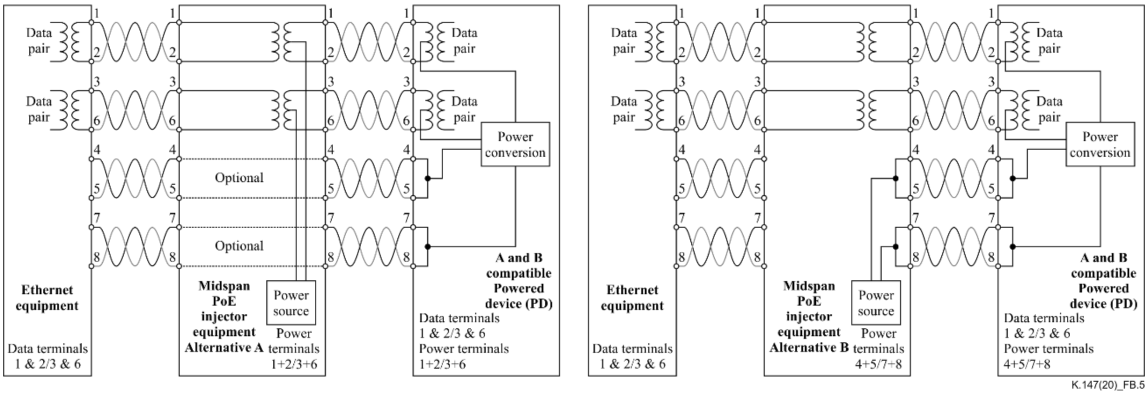


**Figure B.5 – 10BASE-T/100BASE-TX 2-pair midspan PoE injector, A and B alternatives based on IEEE 802.3–2018 Figure 33–6 and IEEE 802.3bt–2019 Figure 145–9**

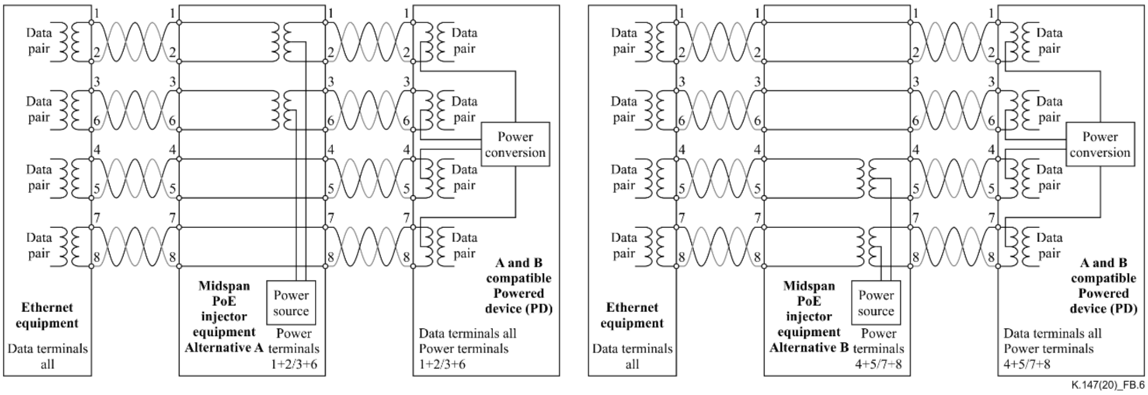


**Figure B.6 – 1000BASE-T 2-pair PoE injector, A and B alternatives based on IEEE 802.3–2018 Figure 33–7 and IEEE 802.3bt–2019 Figure 145–8**

## B.4 Powering over four twisted pairs

In this case, powering uses four twisted pairs, two pairs for feed and the other two pairs for return, with power and data on every twisted-pair, see Figures B.7, B.8, B.9 and B.10.

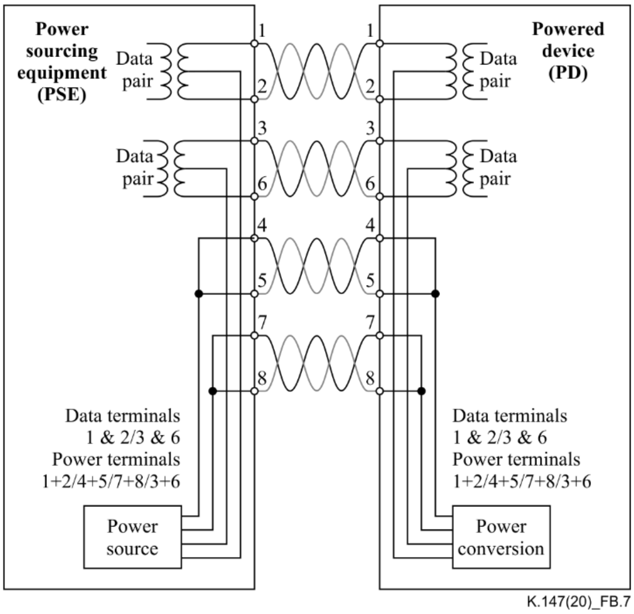


**Figure B.7 – 10BASE-T4/100BASE-TX 4-pair PoE based on IEEE 802.3bt–2019 Figure 145–6**

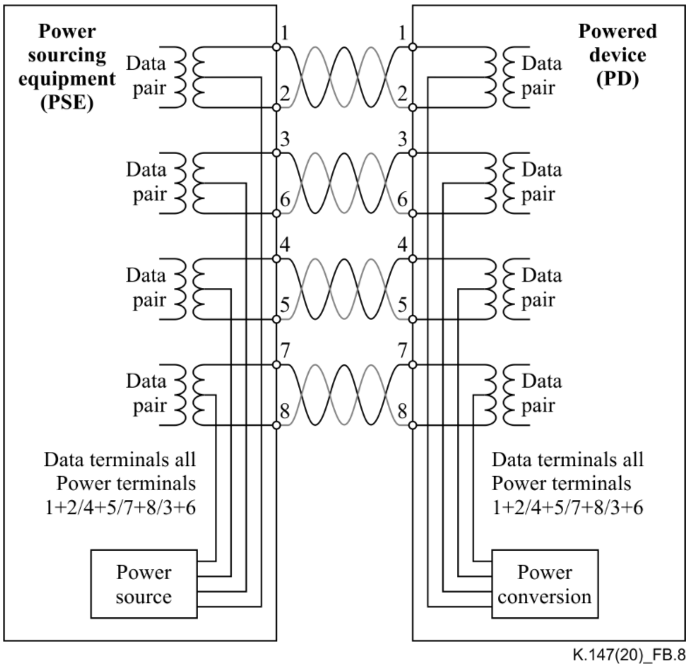


**Figure B.8 – 1000/2.5G/5G/10GBASE-T 4-pair PoE based on IEEE 802.3bt–2019, Figure 145–7**

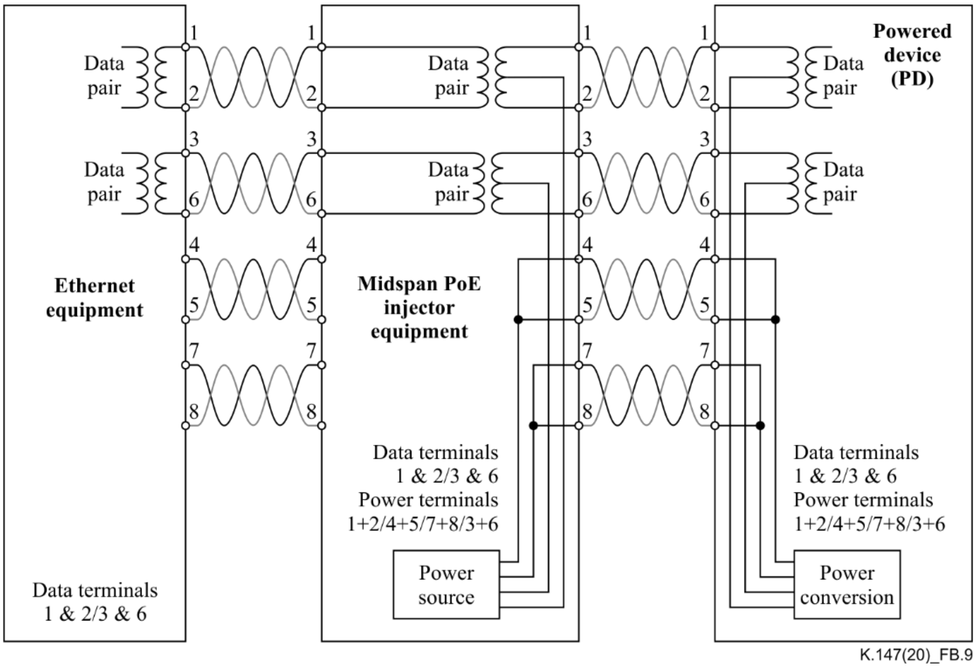


**Figure B.9 – 10BASE-T/100BASE-T 4-pair PoE injector based on IEEE 802.3bt-2019, Figure 145–10**

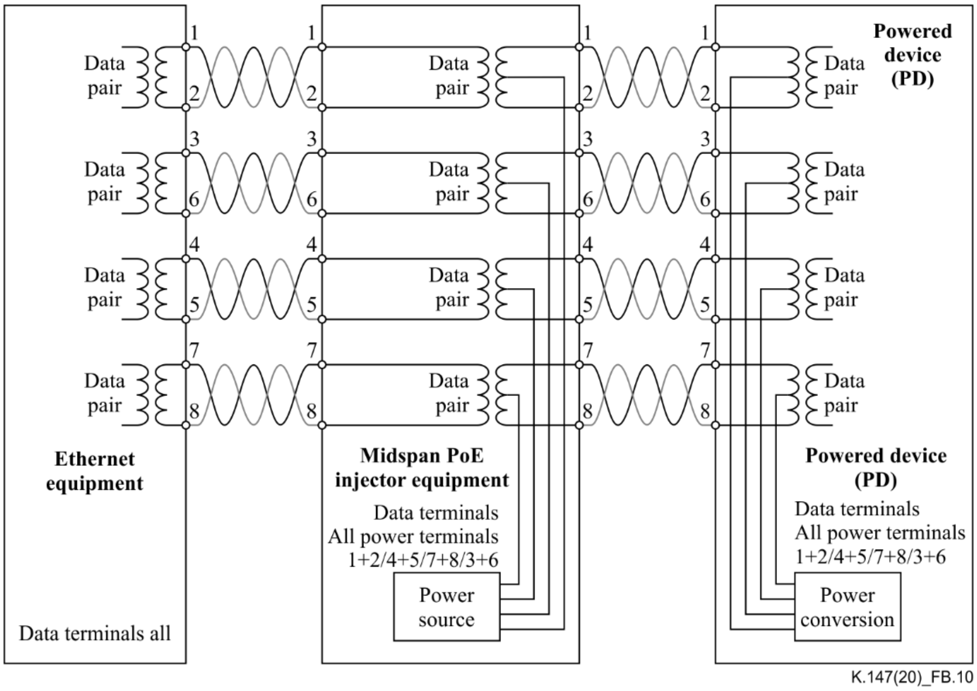


Figure B.10 – 1000/2.5G/5G/10GBASE-T 4-pair PoE injector based on IEEE 802.3bt-2019, Figure 145–11

# Annex C

## Ethernet surge test circuits based on ITU-T K-series Recommendations

(This annex forms an integral part of this Recommendation.)

### C.1 Introduction

The circuits in this annex are based on the following ITU-T K Recommendations:

- [ITU-T K.20]
- [ITU-T K.21]
- [ITU-T K.44]
- [ITU-T K.45]
- [ITU-T K.117]

Test levels are location dependent and specific values are given in [ITU-T K.20] (telecommunication centre), [ITU-T K.21] (customer premises) and [ITU-T K.45] (access and trunk networks). Ethernet ports are classified as either internal ports, whose connection cables are entirely within the building, or external ports, whose connection cables leave the building. Testing covers lightning surges, AC mains power cross, DC insulation resistance and screened cable connection bonding.

### C.2 Test generators

### C.2.1 1.2/50-8/20 generator

Figure C.1 shows a combination wave generator.

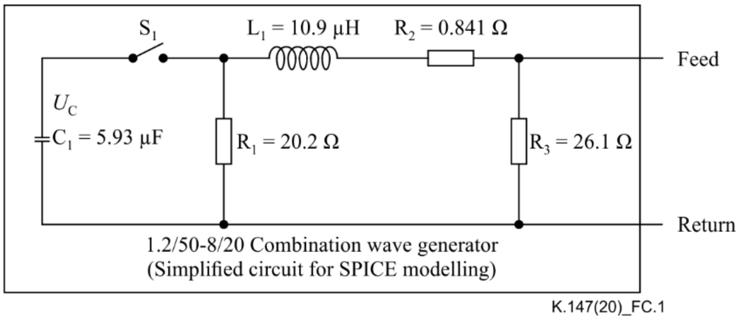


Figure C.1 – Combination wave generator based on K.44 Figure A.3-5

### C.2.2 AC generator

Figure C.2 shows an AC generator.

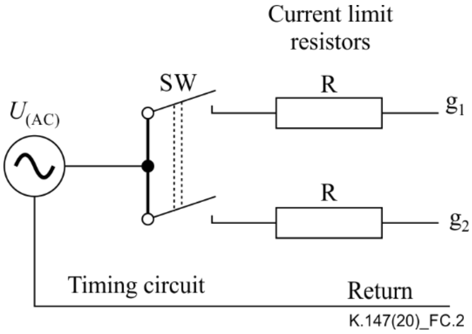


Figure C.2 – Power induction, power contact and rise of neutral potential generator based on K.44 Figure A.3-6

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

## C.3 Untested port termination and coupling network

Figure C.3 shows termination and coupling to earth of untested Ethernet ports.

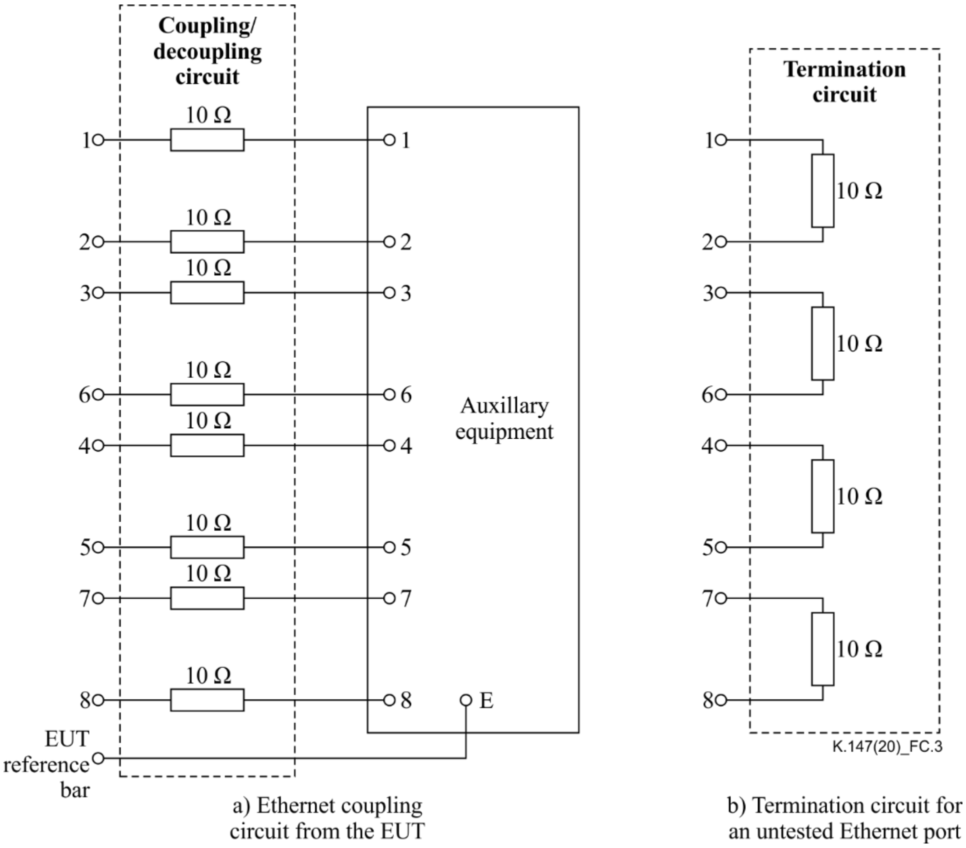


**Figure C.3 – Termination and coupling to earth of untested Ethernet ports based on K.44 Figure A.6.7-1**

## C.4 Common-mode test circuits

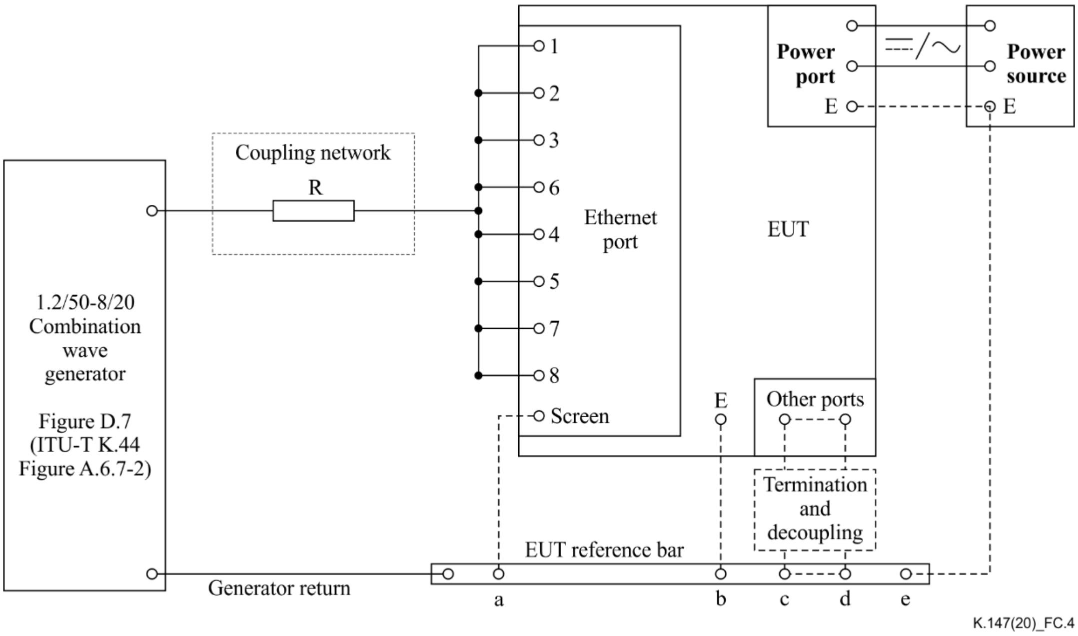


**Figure C.4 – Ethernet port, including PoE variants, common-mode voltage withstand test circuit based on K.44 Figure A.6.7-3a**

In Figure C.4 the single resistor feed maximises the current into protected terminals that current hog. If there is no protective function then the insulation withstand voltage is verified.

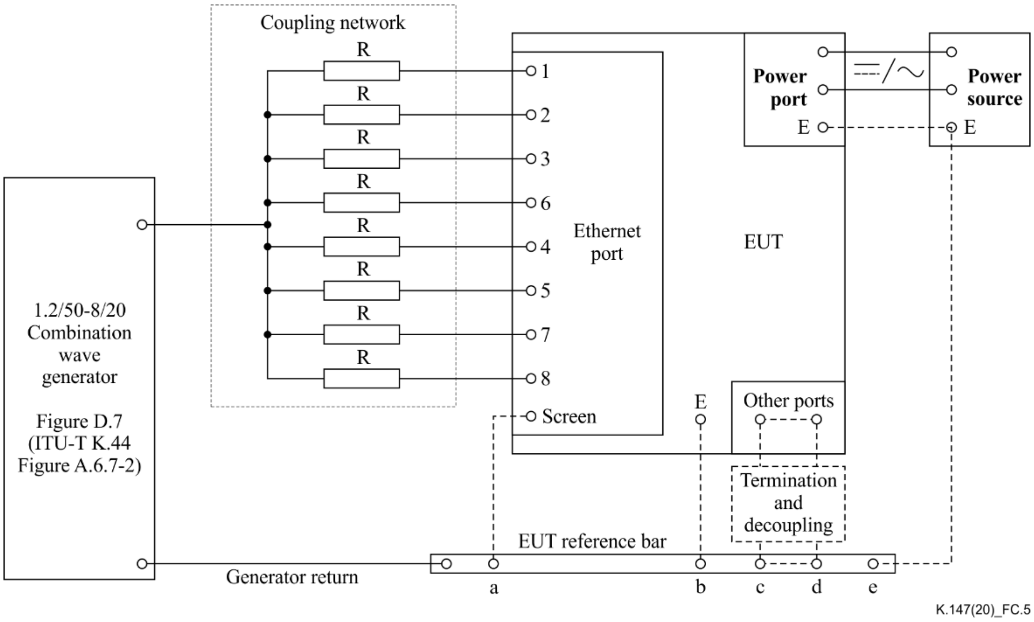


**Figure C.5 – Ethernet port, including PoE variants, common mode to differential mode conversion surge test circuit based on K.44 Figure A.6.7-4**

In Figure C.5, feeding each terminal with its own resistor checks if any voltage-limiting function causes a damaging common mode to differential mode conversion.

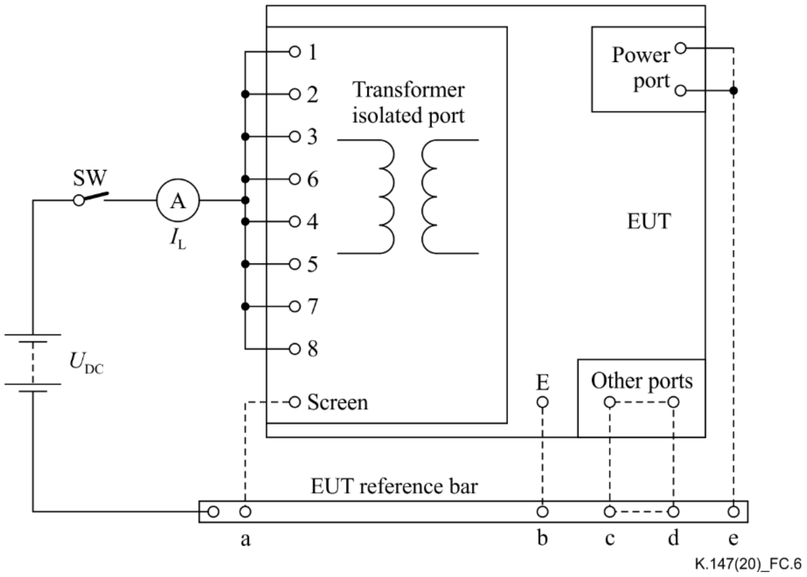


**Figure C.6 – Ethernet port, including PoE variants, DC insulation resistance test circuit based on K.44 Figure A.6.7-3**

Figure C.6 keys are:

$U_{DC}$ = DC test voltage (limited to 100 mA)

SW = Switch closed for current measurement

A = A meter used to measure leakage current, IL

Insulation resistance = $U_{DC}/I_L$

a = RJ45 screen cable connection

b = EUT protective or functional earth connection

c to d = terminals of all other signal ports

e = Power port terminals

Figure C.6 represents the DC 500 V test is used to measure the insulation leakage current, which [IEEE 802.3] requires to be below 250 µA.

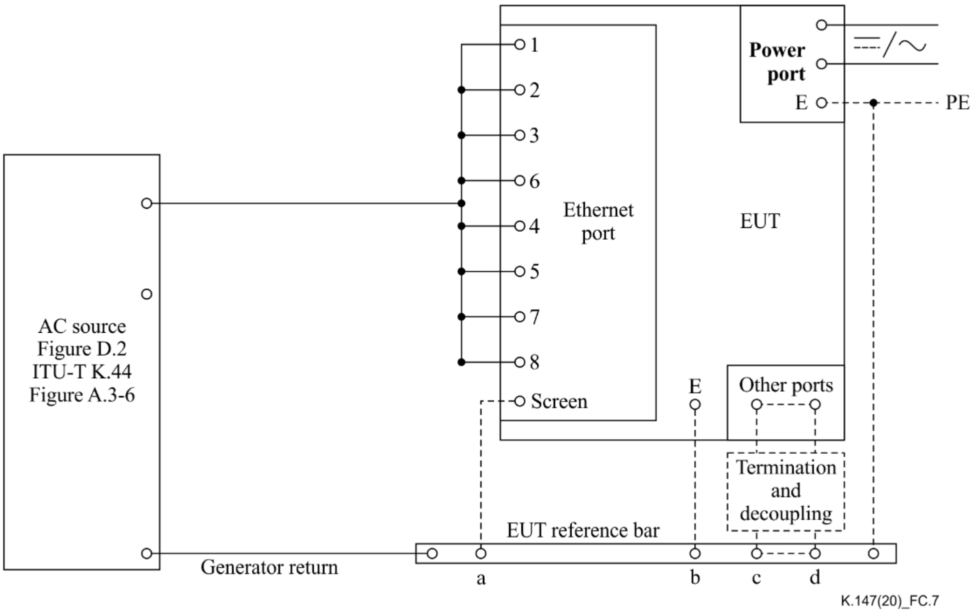


Figure C.7 – Ethernet port, including PoE variants, power cross test circuit based on K.44 Figure A.6.7-7

The test shown in Figure C.7 is only applied to any Ethernet port that fails the DC 500 V insulation resistance test in any polarity. Ports passing the DC 500 V insulation resistance test will not conduct appreciable current when AC mains voltages of up to AC 350 V are applied.

## C.5 Differential-mode test circuits

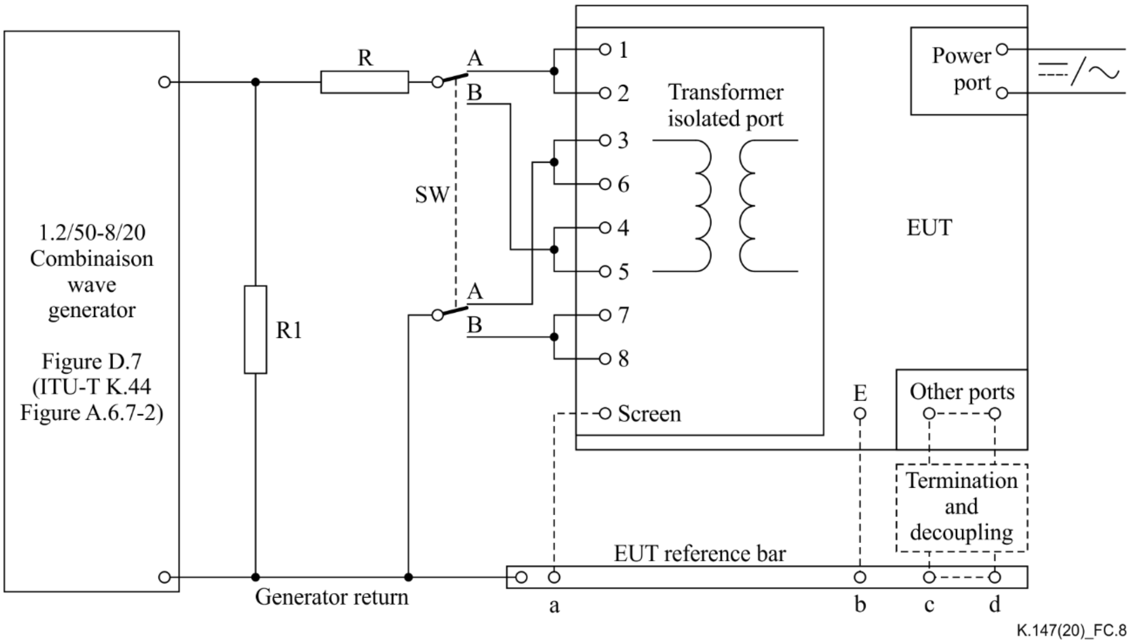


Figure C.8 – PoE port powering pair transverse/differential surge test circuit based on K.44 Figure A.6.7-2

Figure C.8 keys are:

SW in position A: Test PoE Mode A powering terminals 1/2-3/6

SW in position B: Test PoE Mode B powering terminals 4/5-7/8

a = RJ45 screen cable connection

b = EUT protective or functional earth connection

c to d = Terminals of all other signal ports

1, 2, 3, 4, 5, 6, 7 and 8 are Ethernet RJ45 pin numbers

R = 10 Ω series current limiting resistor

R1 = 10 Ω shunt resistor

In Figure C.8, for PSE, midspan power injection equipment and PD ports, test in switch (SW) positions A and B. If the PSE specifies the powering pairs, then the testing is only done on those pairs. This configuration verifies PSE or PD powering resistibility.

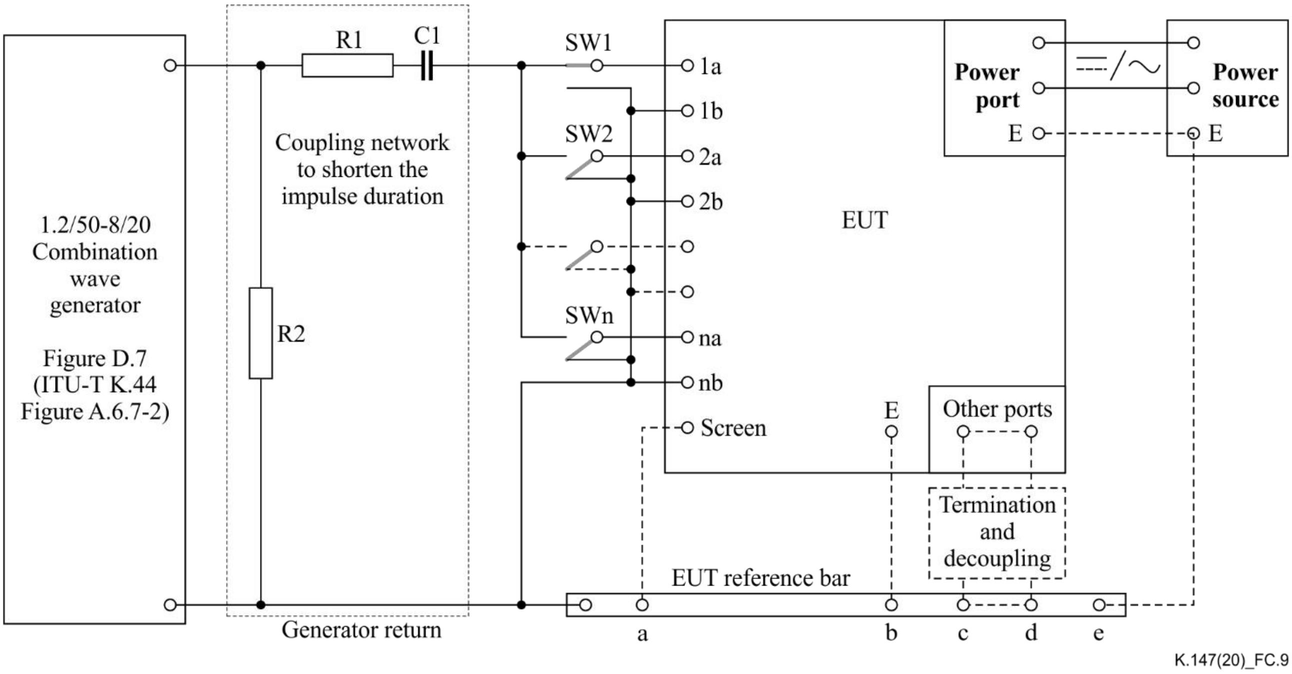


**Figure C.9 – Ethernet port differential-mode surge test circuit including PoE variants based on K.44 Figure A.6.7-5**

Figure C.9 keys are:

Twisted-pair terminal pairs are 1a + 1b, 2a + 2b through to na + nb served by switches SW1, SW2 through to SWn, respectively

For each terminal pair, when the switch is up one terminal is connected to the coupling network. When the switch is down that terminal is connected to functional earth

a = RJ45 screen cable connection for screened twisted-pair Ethernet (STPE) connections

b = EUT protective or functional earth connection

c to d = Terminals of all other signal ports

R1 = R2 = 10 Ω

C1 = 0.5 µF, ±10 %, 5 kV, equivalent series resistance (ESR) < 0.5 Ω, inductance < 1 µH, different parasitic values are acceptable provided di/dt requirements are met

The initial rate of rise of the short-circuit current, di/dt, at 2.5 kV generator charging voltage shall be 60 A/µs ±10 A/µs in the first 0.5 µs

Figure C.9 tests the resistibility of Ethernet port data terminals under high di/dt conditions. Resistor R1 and capacitor C1 shorten the surge time to avoid applying too much port energy. This test is conducted on each terminal pair selected by having that pair switch up and the remaining switches down. Surging is done with alternating polarities.

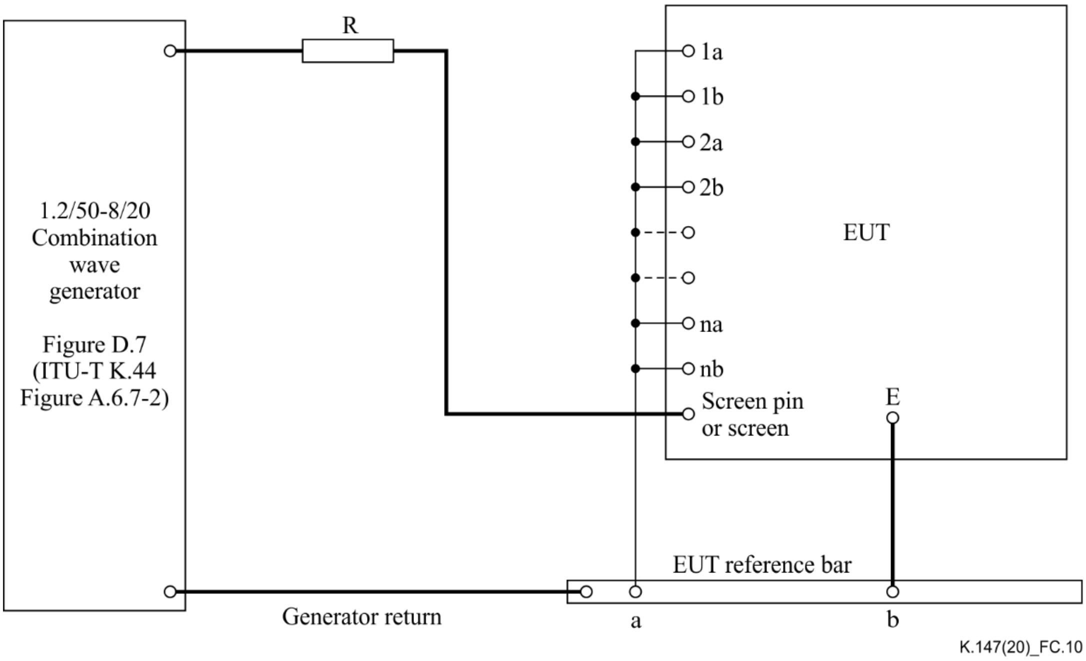


**Figure C.10 – Ethernet screened cable port screen connection high current bonding test based on K.44 Figure A.6.7-6**

This high current surge test verifies that the equipment current capability to earth is adequate.

## C.6 Ethernet intermediate link connections

Intermediate link connections are items like connectors, SPDs, Midspan PoE power injectors and daisy chained PDs. Each of these items will have two ports. For example, Ethernet SPDs tend to have two ports, one for cable connection and the other for equipment connection. Special testing is required for these two-port devices as there is a need for additional loads to be attached to the port that are not being directly tested. Such testing is covered by Recommendation ITU-T K.117 (12/2016): Primary protector parameters for the surge protection of equipment Ethernet ports. Figure C11 is functionally similar to Figure C.4.

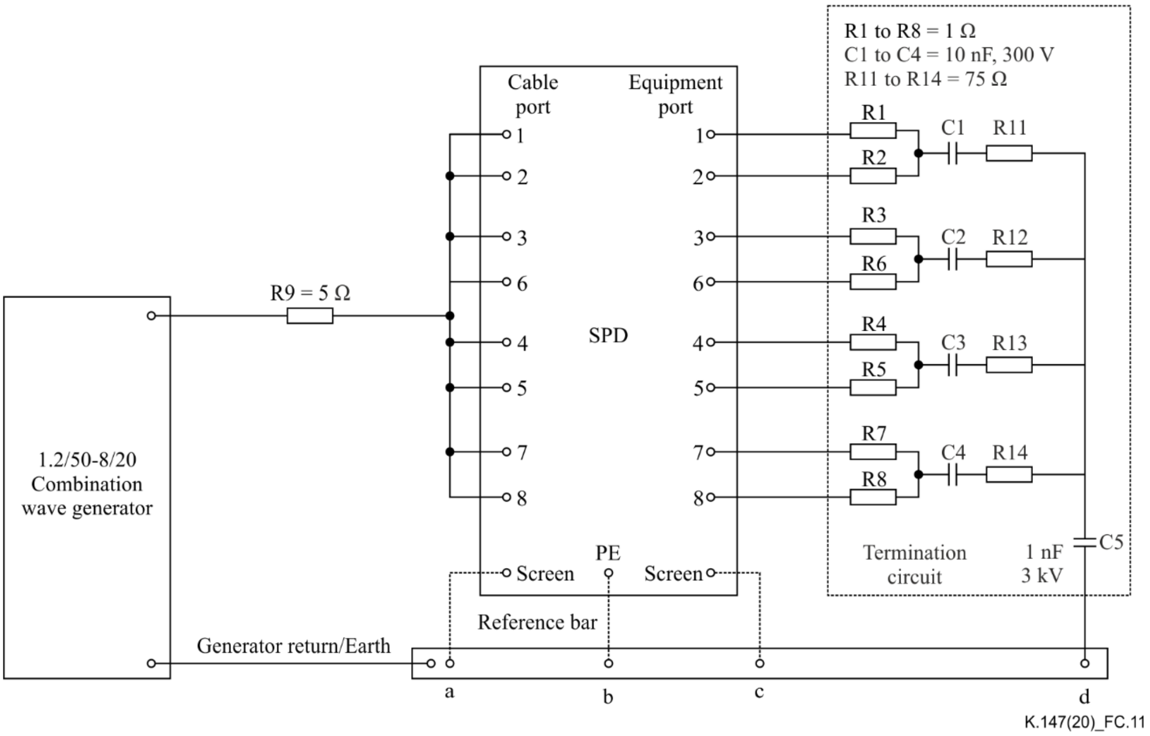


Figure C.11 – Impulse limiting voltage under common-mode surge conditions

Figure C12 is functionally similar to Figure C.8, but for a single twisted pair.

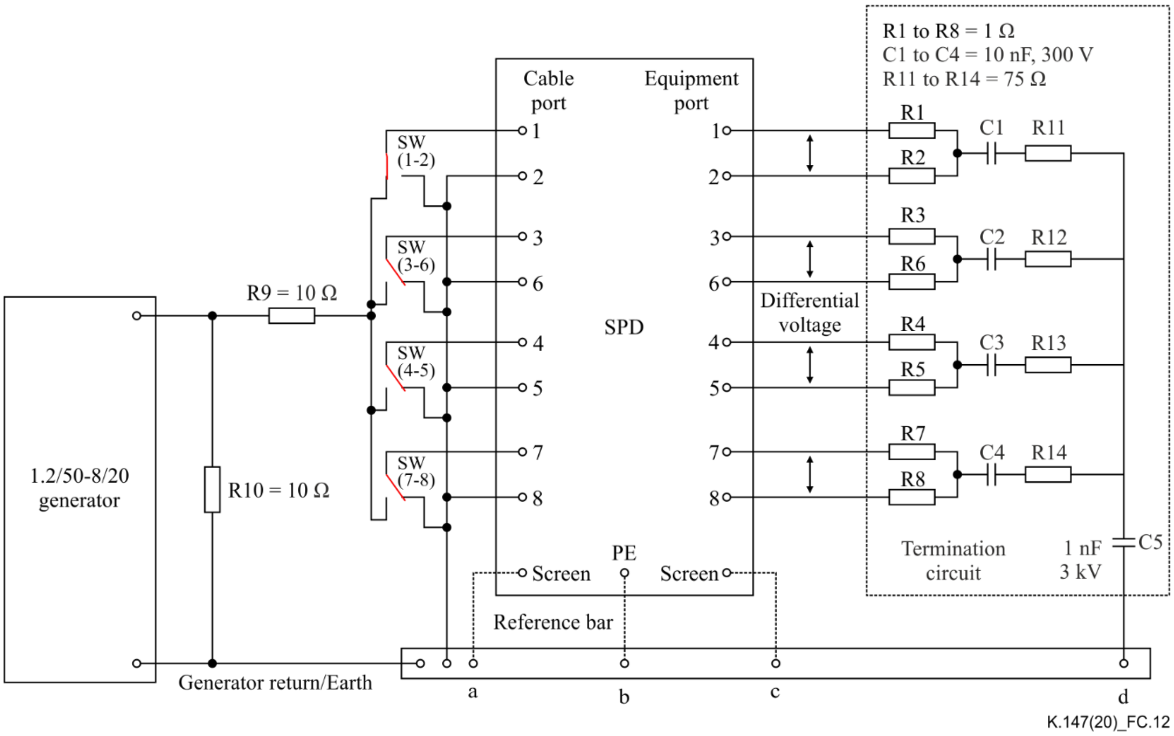


Figure C.12 – Single twisted-pair differential-mode surge test circuit

Key

SW = Double pole, two position selector switch

D5, D10 = SMAJ58A or equivalent 400 W avalanche breakdown diodes

R9, R10 = 10 Ω

D1 to D4, D6 to D9 = B1100/B Schottky rectifier diodes or equivalent 1 A, 100 V diodes

C1, C2 = 100 nF, 100 V

Figure C.13 shows a power feed differential-mode surge test circuit.

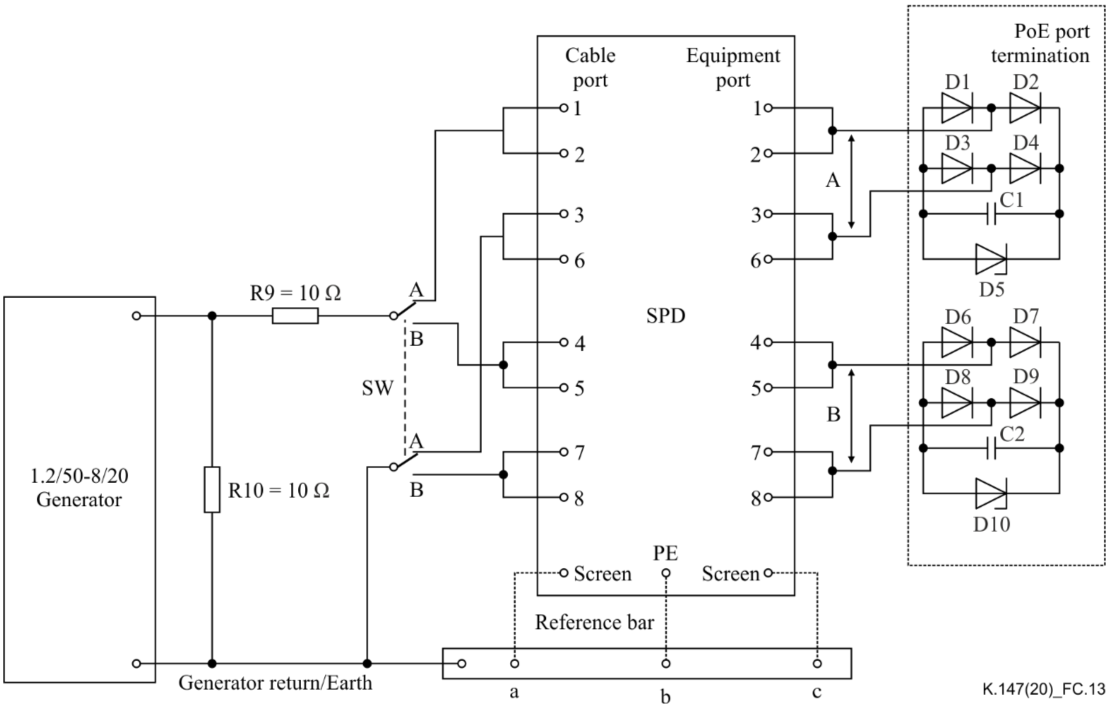


**Figure C.13 – Power feed differential-mode surge test circuit**

Figure C.14 shows ae twisted-pair common mode to differential-mode voltage surge conversion test circuit.

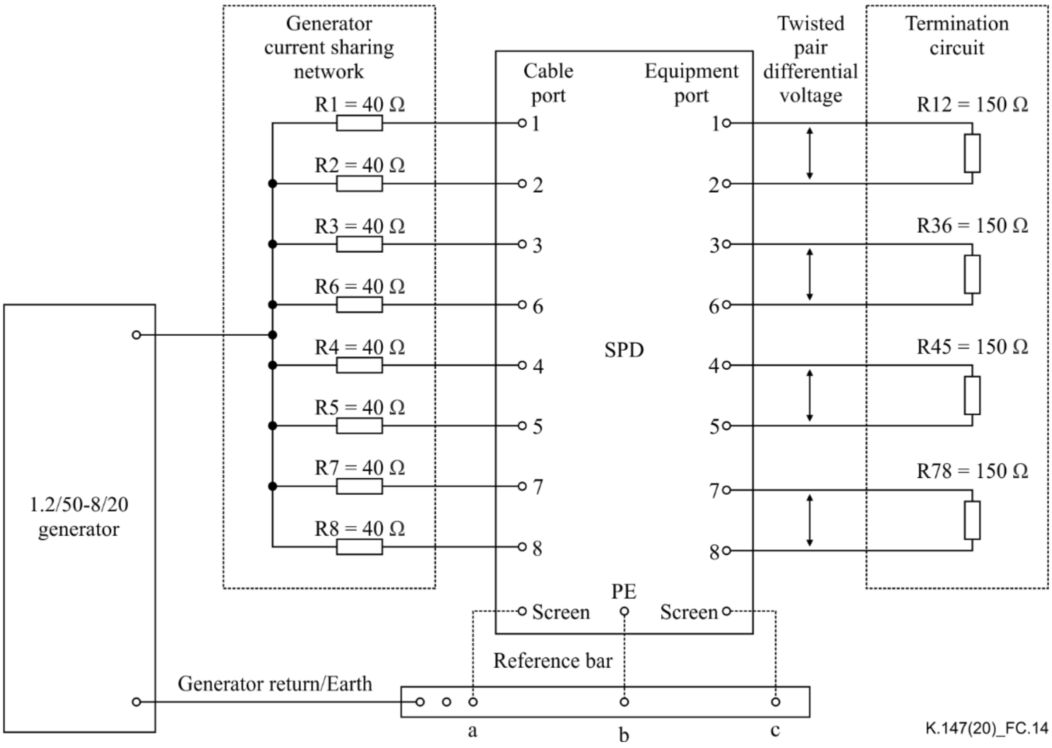


**Figure C.14 – Twisted-pair common mode to differential-mode voltage surge conversion test circuit**

Figure C.15 shows a power feed pair common mode to differential mode surge conversion test circuit.

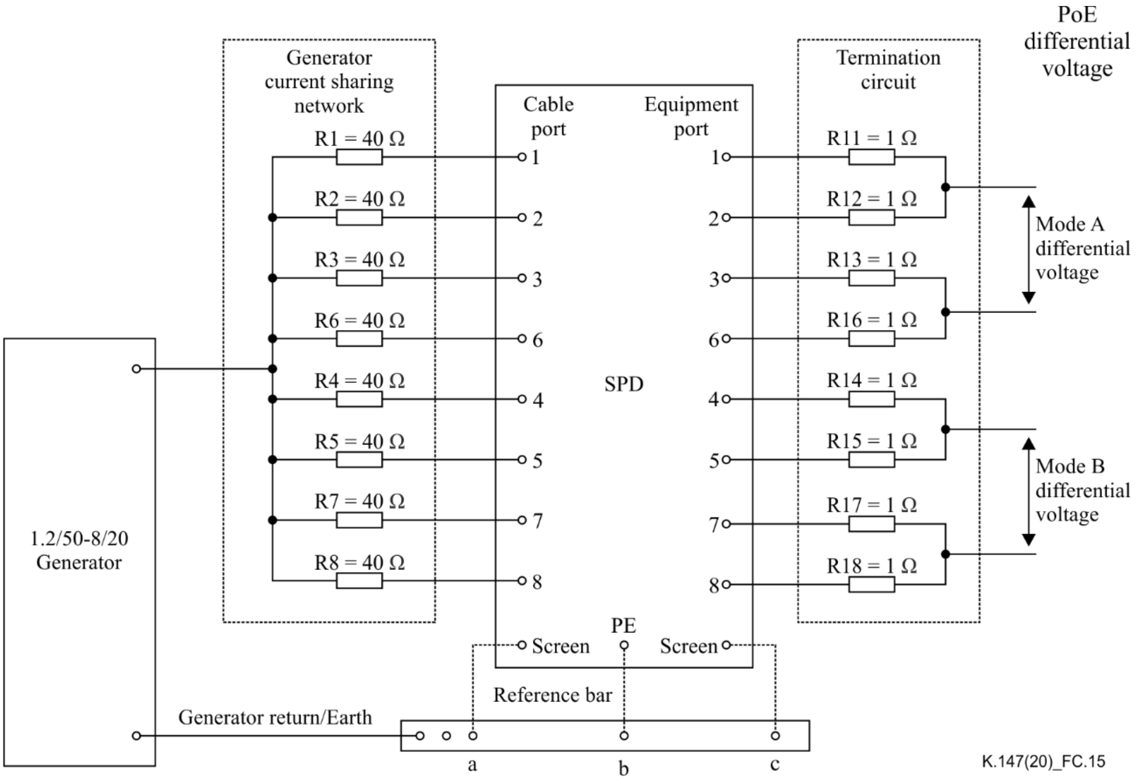
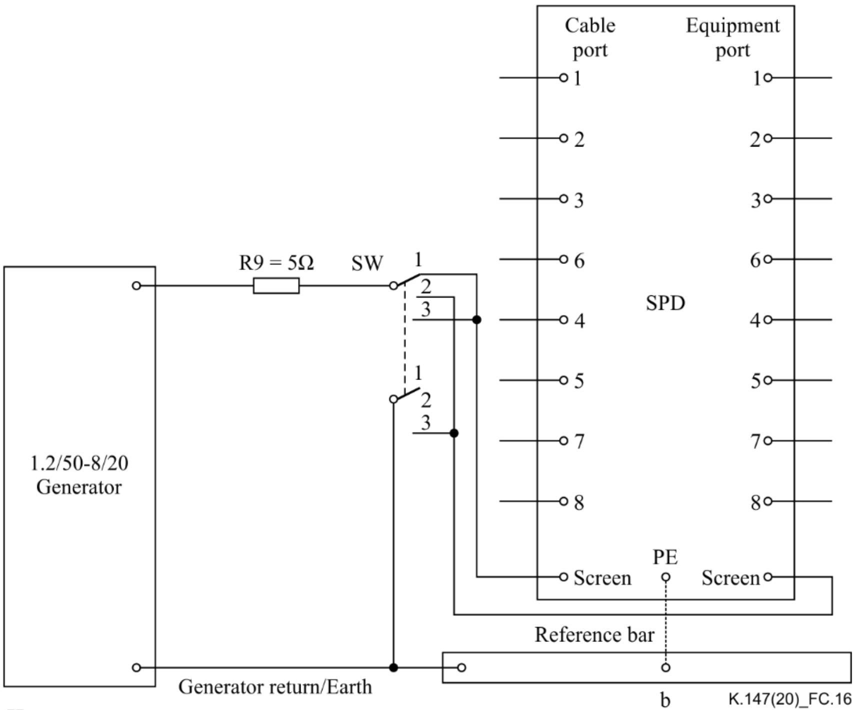


**Figure C.15 – Power feed pair common mode to differential mode surge conversion test circuit**

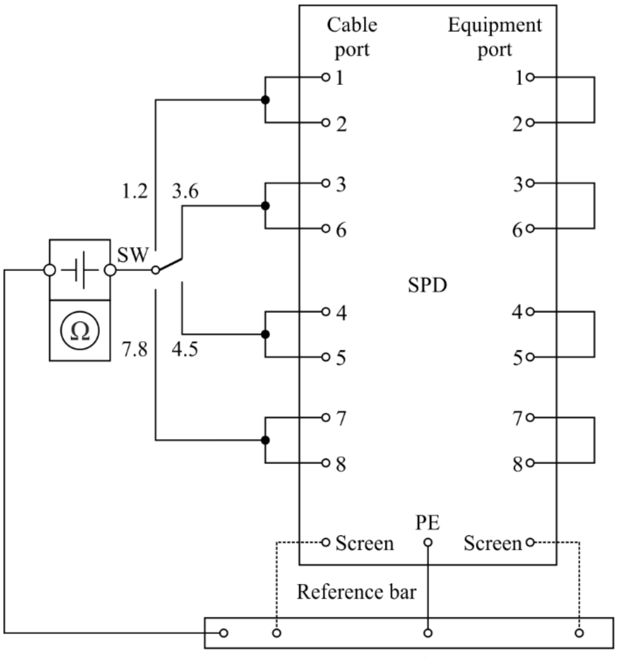
Figure C.16 shows a screen bonding test.



Key
SW = Double pole, three position selector switch R9 = 5Ω

**Figure C.16 – Screen bonding test**

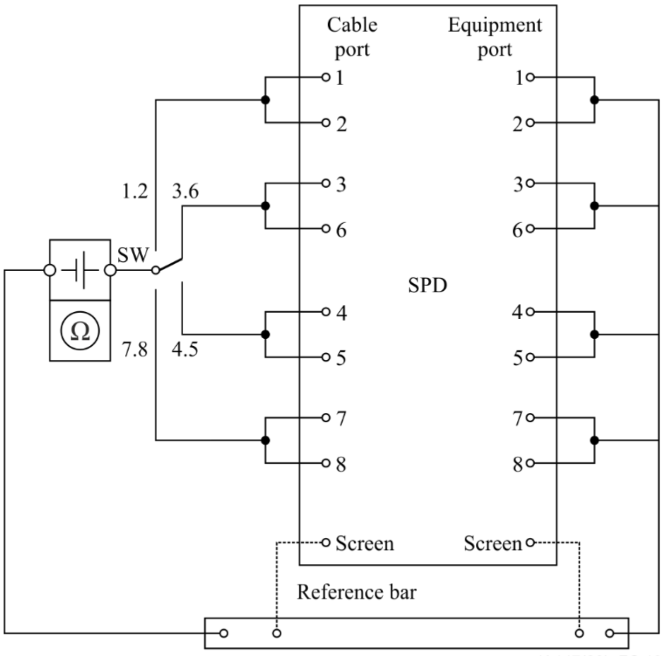
Figure C.17 shows a test circuit to measure the insulation resistance of an SPD with a PE terminal or screen terminals, or both.



Key
SW = Four position selector switch Ω = IR meter with defined d.c. bias

**Figure C.17 – Test circuit to measure the insulation resistance of an SPD with a PE terminal or screen terminals, or both**

Figure C.18 shows a test circuit to measure the insulation resistance of an isolating transformer SPD without a PE terminal.



Key
SW = Four position selector switch Ω = IR meter with defined d.c. bias

**Figure C.18 – Test circuit to measure the insulation resistance of an isolating transformer SPD without a PE terminal**

Figure C.19 shows a test circuit to measure the PoE SPD d.c. input/output voltage drop.

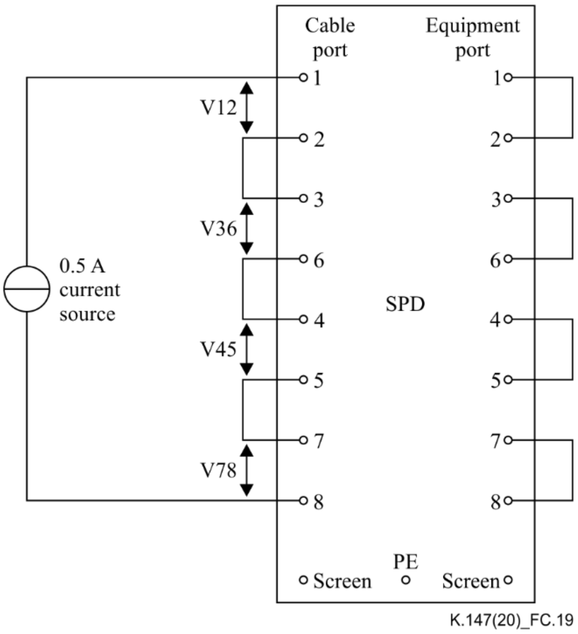


**Figure C.19 – Test circuit to measure the PoE SPD d.c. input/output voltage drop**

# Appendix I

## IEEE 802.3 Working Group reference materials

(This appendix does not form an integral part of this Recommendation.)

### I.1 Overview

The IEEE 802.3 Ethernet Working Group web page [b-802.3 WG] lists active projects, additional information, other information, published standards and contact information. This Appendix selects items relevant to this Recommendation. IEEE 802.3 is constantly evolving and readers are advised to visit the [b-802.3 WG] to view the latest information on IEEE 802.3.

### I.2 Active projects

In May 2020 the active project list notable entries are:

- IEEE P802.3cr Isolation (Maintenance #14) Task Force.
  - Scope: Replace references to the IEC 60950 series of standards with appropriate references to the IEC 62368 series and make appropriate changes to the standard corresponding to the new references. Also see [b-R. V. White]
- IEEE P802.3cv Power over Ethernet (Maintenance #15) Task Force.
  - Scope: This project implements editorial and technical corrections, refinements, and clarifications to clause 145, Power over Ethernet, and related portions of the standard. No new features are added by this project.

### I.3 Additional information

This area contains event information, communications channels and presentations. Presentations of interest are:

- [b-802.3 PoE]
- [b-802.3 automotive]
- [b-802.3 PoDL]

### I.4 Other information

This area contains information on operating procedures, rules, patents, copyright and participation policy.

### I.5 Published standards

This area contains information on published IEEE 802.3 standards and completed work of task forces, study groups and ad hocs. Notable entries are:

- [b-802 Isolation]
- [b-802.3au]
- [b-802.3 4-pair PoE]
- [b-802.3 cable]
- [b-802.3cg PoDL]
- [b-802.3 Daisy chain]
- [b-802.3 10BASE-T1]
- [b-802.3cg Guide]

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