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SERIES K: PROTECTION AGAINST INTERFERENCE

Ethernet port surge voltages and currents

ITU-T K-series Recommendations – Supplement 23

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Supplement 23 to ITU-T K-series Recommendations

Ethernet port surge voltages and currents

Summary

The level and duration of the local area network (LAN) lightning surges depends on the lightning current waveform and the coupling mechanism. In Supplement 23 to ITU-T K-series Recommendations, Ethernet port voltages and currents due to magnetic and direct surge coupling are studied. Port currents due to insulation capacitance, the Smith termination, and insulation voltage limiting, are quantified and discussed and a simple model for these current paths is derived.

History

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Keywords

802.3, direct coupling, insulation, isolation, magnetic coupling, overvoltage protection, Smith termination.

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Ethernet port surge voltages and currents

1 Scope

This Supplement simulates Ethernet port voltages and currents due to magnetic and direct surge coupling. Examples of the resultant equipment port impulse current paths for a Smith termination, capacitance and insulation voltage limiting, are shown and discussed.

2 References

[ITU-T K.147] Recommendation ITU-T K.147 (2020), *Ethernet port resistibility testing for overvoltages and overcurrents*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 clearance [b-ITU-T K.95]: Shortest distance in air between two conductive parts.

3.1.2 creepage distance [b-ITU-T K.95]: Shortest distance along the surface of a solid insulating material between two conductive parts.

3.1.3 insulation [b-ITU-T K.95]: Electrical separation between circuits or conductive parts provided by clearance or creepage distance or solid insulation or combinations of them.

3.1.4 insulation, barrier [b-IEEE C37.20.2]: Insulation material used primarily to separate one item or area from another item or area within the equipment.

3.1.5 insulation coordination [b-ITU-T K.96]: Mutual correlation of insulation characteristics of electrical equipment taking into account the expected micro-environment and other influencing stresses.

3.1.6 isolation [b-IEEE 1100]: Separation of one section of a system from undesired influences of other sections.

3.1.7 solid insulation [b-IEC 60664-2-1]: Solid insulating material interposed between two conductive parts.

3.2 Terms defined in this Supplement

This Supplement defines the following term:

3.2.1 earth loop: Potentially detrimental loop formed when two or more points in an electrical system that are connected to their local earth potential and are also interconnected by earth referenced conductors, which creates a loop that will carry current if the local earths are not at the same potential.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

EPR Earth Potential Rise

LAN Local Area Network

LPS Lightning Protection System

PD Powered device

PoDL Power over Data Line

PoE Power over Ethernet

PSE Power Sourcing Equipment

SPC Surge Protective Component

SPD Surge Protective Device

SPE Single Twisted-pair Ethernet

5 Conventions

Isolation is the combination of insulation and any components that bridge the insulation barrier. Ethernet port isolation is what insulation coordination and safety standards call functional insulation, that is insulation between conductive parts which is necessary only for the proper functioning of the equipment. Shorting functional insulation does not create a safety hazard.

6 Earth loop current reduction

Reasons for [b-IEEE 802.3] to specify link segment isolation are evidenced in previous IEEE 802.3 ballot responses. Most often mentioned is that isolation transformers ensure that earth loops are not created between local area network (LAN) equipment. Thus, the cable segment link between equipment is essentially floating, see Figure 1. The screen of a screened cable can create an equipment earth loop and should be tested for impulse current carrying capability.

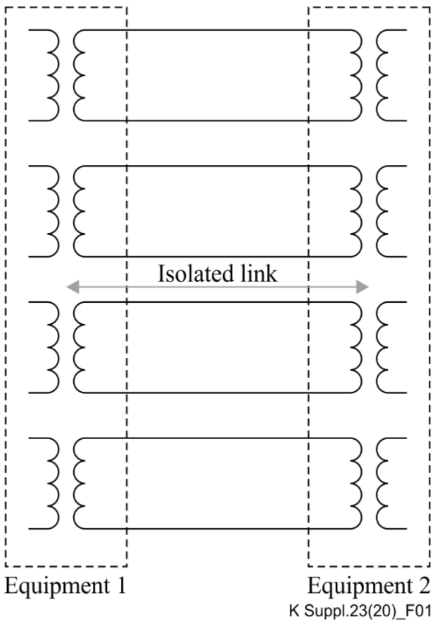

Figure 1 – Equipment earth loop broken by isolation transformers

An earth loop is created when the protective earths of the equipment are not at the same potential. At 50 Hz/60 Hz, probably the maximum expected earth loop voltage is AC mains potential. For AC 230 V mains, the peak voltage would be, after allowing for a +10% tolerance, 230×1.1×1.414 = 358 V. [b-IEEE 802.3] checks for earth loop resistance with a DC 500 V test where the insulation resistance must be greater than 2 MΩ.

A side benefit of the insulation resistance test is that if the Ethernet cable conductors come into contact with AC mains conductors there will be no major current flow because the Ethernet link is not connected to earth.

A further use for the DC 500 V test is to check that the insulation or insulation bridging have not been damaged by simulated overvoltage and overcurrent tests.

7 Overvoltage and overcurrent events

7.1 General

[ITU-T K.147] *Ethernet port resistibility testing for overvoltages and overcurrents* discusses the four main coupling mechanisms for surges to couple into networks and equipment:

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

Most coupled events cause a common-mode surge voltage. For convenience, the following examples mainly simulate a magnetically coupled common-mode surge, but the results will be similar for other types of coupled common-mode surges.

For an unscreened twisted pair Ethernet cabling link, which is floating, the cable acts as an antenna developing a voltage dependent on the rate of change of any magnetic fields it is exposed to. Fields from nearby lightning strikes or struck lightning protection systems (LPSs) adjacent down conductors are likely to result in high cable voltages.

7.2 Magnetic coupling

A simple way of visualising magnetic coupling is as a multi-winding transformer where the lightning stroke current flows in the primary winding, L1, which is loosely coupled to the other windings, L2a to L2h, that are in series with the cable conductors, see Figure 2.

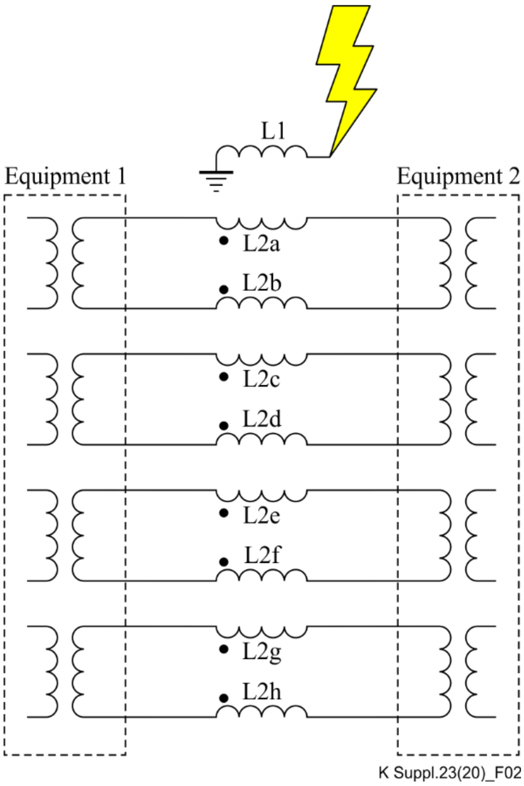

Figure 2 – Lightning current magnetic coupling

Figure 3 shows an example where a 260 A, 5/75 lightning impulse, which is the average waveshape for the first negative stroke of a negative lightning flash, causes an induced cable voltage of 3.4 kV. The amplitude of the lightning voltage will be dependent on the current waveform and the coupling factor between the lightning current and the cable. The maximum voltage is produced during the front (rise) time of the impulse current. As the instantaneous voltage is proportional to the current di/dt, the peak voltage is reached in under a 1 µs, thereafter the voltage decays to zero when the current reaches its peak value. After the peak current, the voltage polarity reverses to a much lower value of voltage as the current is reducing at a much lower di/dt rate.

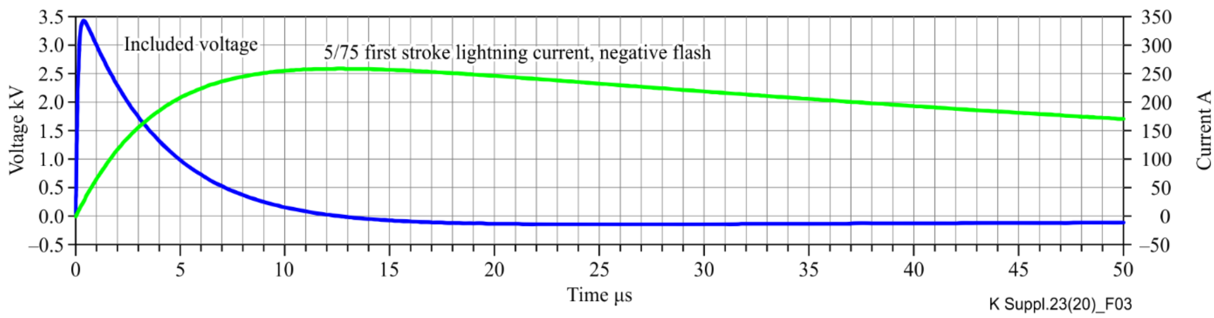

Figure 3 – Induced cable voltage from a negative lightning stroke

Figure 4 shows the resultant cable end voltages. The cable voltages are balanced, with one end reaching +3 kV and the other end reaching −3 kV. This example introduced the induced voltage at the segment link (cable) centre and uses a total cable delay time of 0.5 µs, meaning that the total impulse reflection time will be 1 µs for the end to end to end round trip. A delay time of 0.5 µs would be typical for an Ethernet "cat 5" cable length of about 100 m. As the cable is unterminated the impulse reflections show as ringing on the waveform.

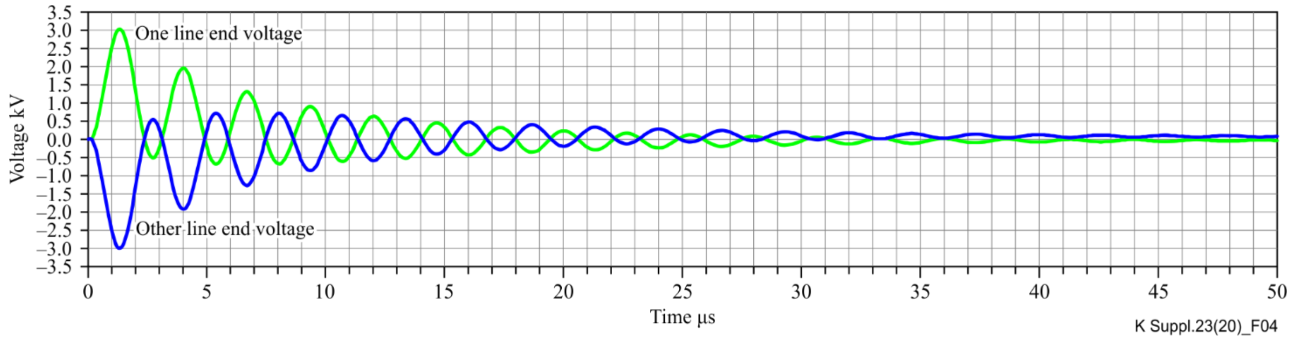

Figure 4 – End transmission line (cable) voltages

Figure 5 shows what happens when one end of the cable is earthed. The other end of the cable receives the full end-to-end voltage of the cable. The other end of the cable receives the full end-to-end voltage of the cable. The resultant open-circuit cable end voltage reaches 3.7 kV. Without reflections, the voltage would have been twice the voltage of Figure 4, i.e., 4.8 kV. Cable end earthing can be caused by surge protective device (SPD) operation or using an earthed powering source in a midspan power sourcing equipment (PSE) or using an earthed powering source in a power over data line (PoDL) PSE.

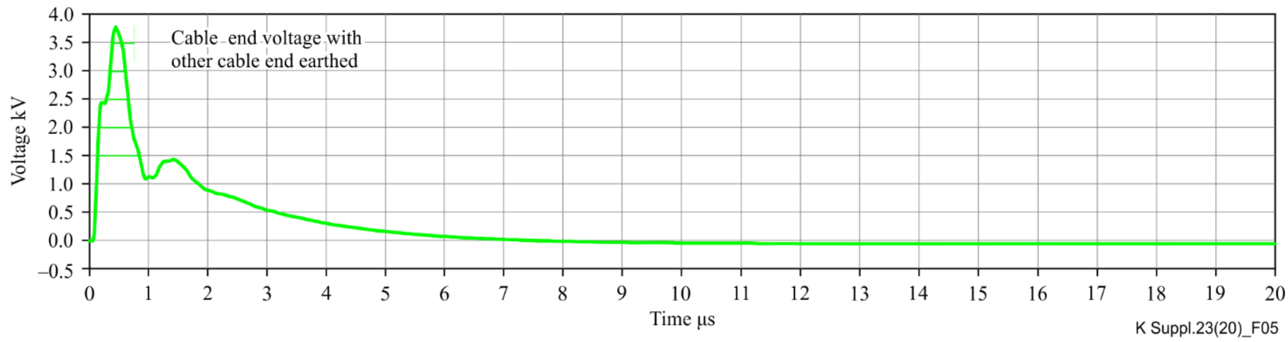

Figure 5 – Voltage when one end of cable earthed

8 Impulse current paths

8.1 General

Besides the insulation barrier paths of solid insulation, creepage distance and clearance distance, there are other impulse current paths across the isolation such as:

– Smith termination circuit

– Insulation barrier overvoltage protective circuit

Insulation breakdown often damages the insulation, carbonisation leading to a low value of insulation resistance. Whereas the insulation breakdown current may not have a well-defined current path, the Smith termination and overvoltage protection current paths can be set by careful design not to cause damage to the port electrical circuits.

8.2 Smith termination circuit

An example Smith termination circuit for four twisted pairs in a power over Ethernet (PoE) system is shown in Figure 6. The connection to a twisted pair is made at the centre tap of the line-side of the signal isolating transformer. The purpose of the 10 nF capacitors is to block the PoE system powering voltage. Non-PoE systems can be directly connected to the 75Ω resistors without the 10 nF capacitors. PoDL systems using a single (twisted) pair Ethernet (SPE) can be terminated in a similar manner, but the termination circuit design will depend on the SPE signal and powering injection and extraction arrangements.

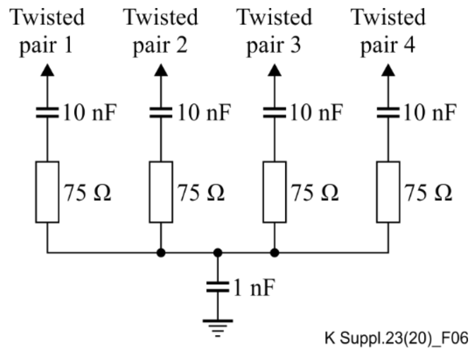

Figure 6 – Smith termination for four twisted pairs in a PoE system

Figure 7 is an example of a Smith termination voltage and total current for a floating cable having a 0.5 µs delay. The peak positive current is about 16 A, meaning each of the eight conductors in the four twisted pairs carries a peak Smith termination current of about 2.0 A. For a single twisted pair, the peak Smith termination current in each conductor would be about 8 A. The peak cable end voltage is still about 2.3 kV.

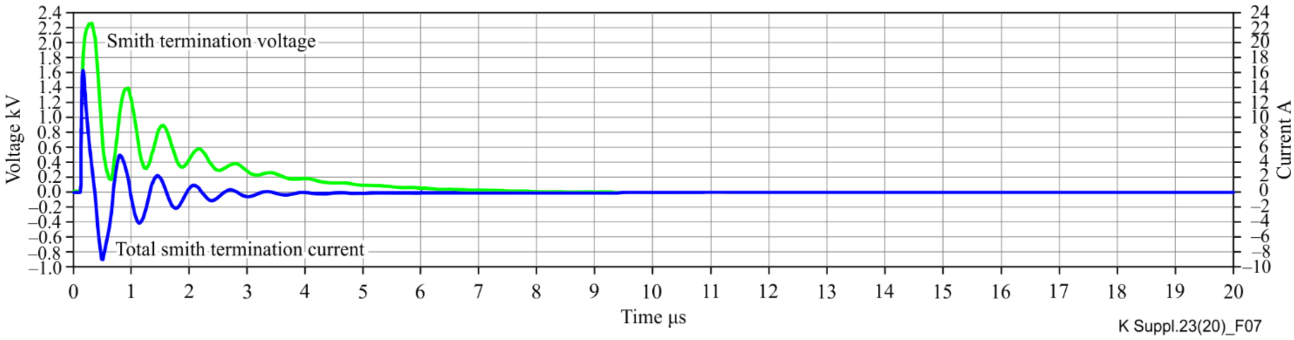

Figure 7 – Smith termination voltage and total 1 nF capacitor current for a 0.5 µs delay cable

8.3 Insulation barrier overvoltage protective circuit

Figure 8 shows a generic surge protective component voltage limiting circuit for a PoE system using four twisted pair powering. The connection to a twisted pair is made at the centre tap of the line-side of the signal isolating transformer. The 40 V surge protective component (SPC) limits the powering pairs maximum voltage to 80 V and the 1 kV SPC limits the insulation voltage to about 1 kV. It is important that a single protective function bridges the insulation otherwise there is a danger of common-mode to differential-mode surge conversion. To account for component failure the 1 kV SPC could be made up from two, series connected, 600 V SPCs.

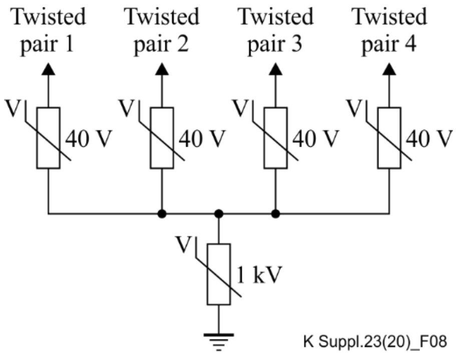

Figure 8 – PoE voltage limiting circuit

Figure 9 shows the 1 kV SPC voltage and current together with the Smith termination current. The SPC peak voltage is just over 1 kV with a peak current of nearly 50 A in a 1 µs time period. For four twisted pairs, the individual conductor peak protection currents will be about 6 A. Some 10 A of peak current is drawn by the Smith termination subsequently followed by peak currents of under 2 A caused by the voltage ringing. For four twisted pairs, the individual conductor Smith termination peak currents will be about 1.0 A.

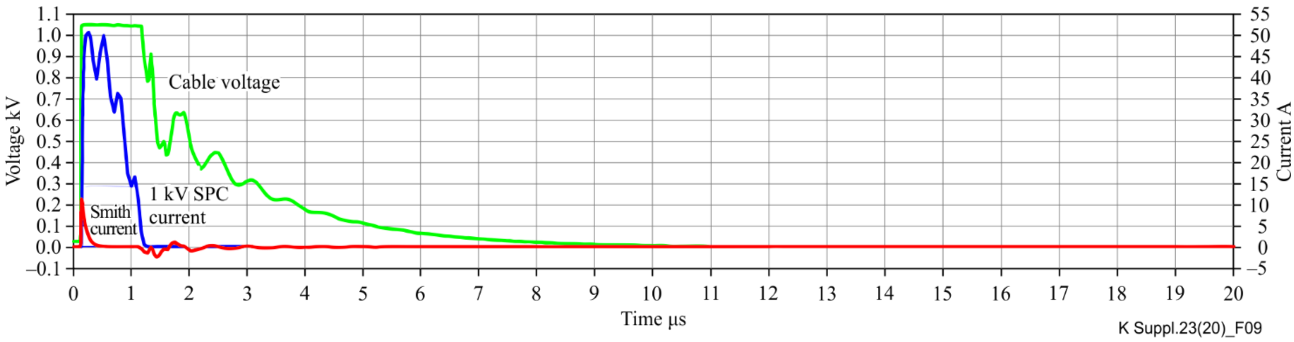

Figure 9 – 1 kV SPC voltage and current and Smith termination current

9 Direct coupling

Direct coupled surges tend to be longer than magnetically coupled surges. A direct coupled 2.5 kV, 5/75 earth potential rise (EPR) surge event was simulated by applying it to the earth return of the Figure 8 voltage limiting circuit, see Figure 10. Figure 11 shows the resulting cable voltage, which reaches 1.4 kV, the 1 kV SPC current and the Smith termination current.

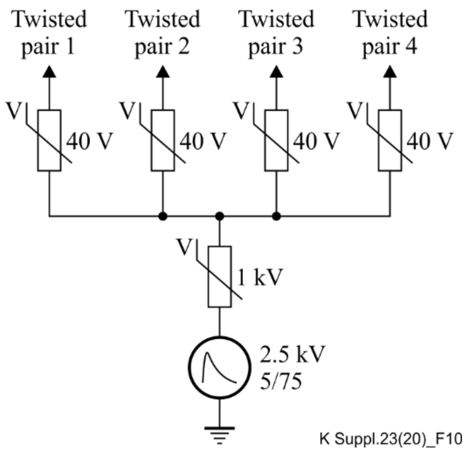

Figure 10 – EPR applied via overvoltage protection

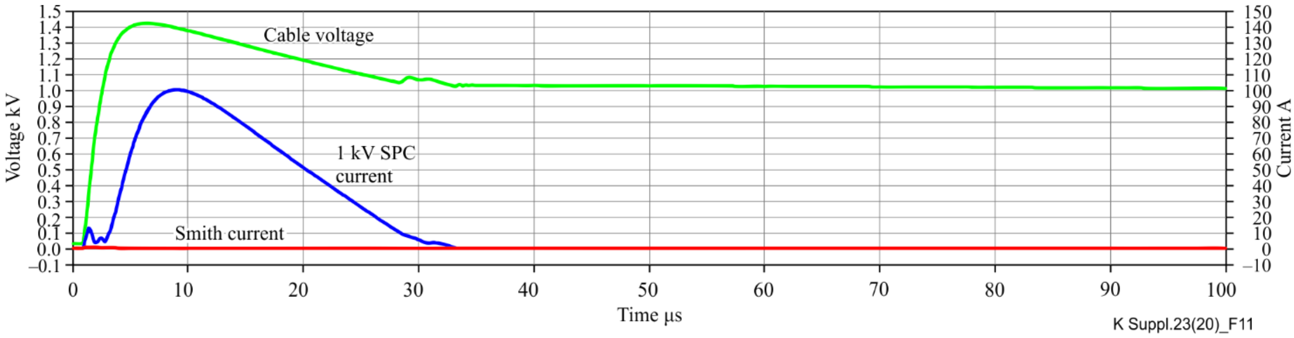

Figure 11 – Cable voltage with applied EPR surge

After about 30 µs, when the 2.5 kV, 5/75 voltage impulse decays to about 1 kV, the voltage limiter stops EPR conduction. During conduction time the 1 kV SPC peak current is 100 A. Because of the slow voltage rise, the Smith termination peak current is only 0.7 A.

Figure 12 shows the conditions at the other end of the cable. Here, the overvoltage limiter circuit peak current amplitude and duration (100 A and 30 µs) are similar to those of the coupling overvoltage protector at the other end of the cable. The limited cable voltage is about 1 kV and the Smith termination peak current is 1.3 A.

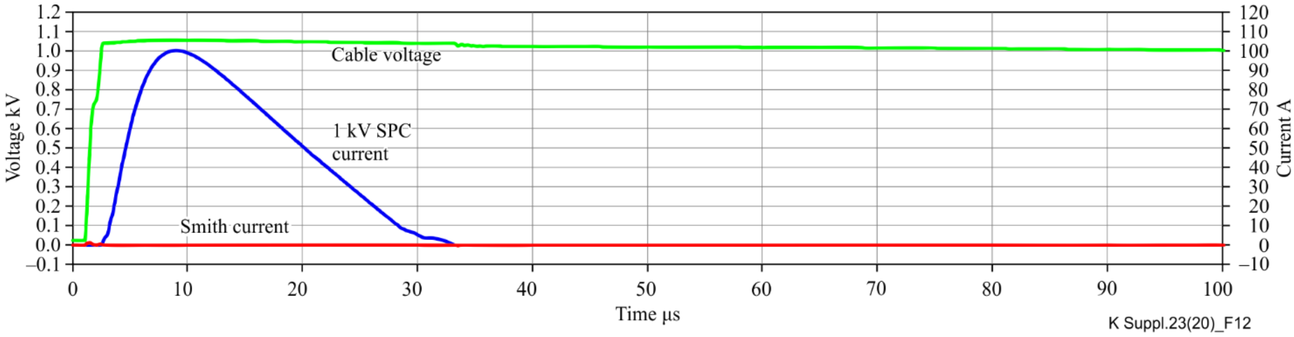

Figure 12 – EPR surge at other cable end

10 Inter-port impulse levels

Japan was the first to recognised that AC mains surges could be electrically (capacitively) coupled to the Ethernet port and implemented a test for it. This topic is discussed in [ITU-T K.147].

11 IEEE 802.3 – isolation tests

[b-IEEE 802.3] has many clauses titled "Isolation" or "Electrical isolation". Three electrical strength test approaches are generally specified; AC, DC and impulse. Neither of the AC nor DC test values and methods represent the actual field electrical environment of a LAN.

Two different impulse tests are can be found, the most common being a 2400 V, 1.2/50 impulse, but PoE uses a 1500 V, 10/700 impulse.

The 10/700 impulse originated in the ITU-T in about 1976 and is applicable for long distance, earth referenced, telephone lines where the dispersion in the cable results in a slow 10 µs front time and a long decay time of 700 µs. As the LAN links are much shorter and floating the use of this waveshape is inappropriate to simulate the electrical transient field environment of a LAN.

The 1.2/50 impulse originated for testing insulation. As shown in clause 7.2, magnetically coupled LAN voltages are fast front time (< 1 µs) and a short 50 % decay time (< 5 µs). Although not ideal, the 1.2/50 is the closest international standard waveform to use for common-mode surging.

However, as defined, [b-IEEE 802.3] prospective current from the 1.2/50 voltage generator is not specified. If a standard combination wave generator, 1.2/50-8/20, is used the prospective current is too high, possibly leading to vaporisation of printed wiring tracks.

The ITU-T K-series of Recommendations for Ethernet port surge resistibility testing uses different test voltages and methods to those found in the [b-IEEE 802.3] electrical strength tests.

12 Summary

Insulation, separating conductive parts at different electrical potentials, can be a combination solid insulation, surface creepage distance and clearance distance. Isolation, separating one section of a system from undesired influences of other sections, is the parallel combination of insulation and any other items that bridge the insulation barrier.

Under impulse conditions, the currents that flow between the Ethernet port and earth can have four paths as shown in Figure 13. Insulation breakdown can damage the insulation, and carbonisation from breakdown can lead to a low value of insulation resistance. Whereas the insulation breakdown current may not have a well-defined current path, the Smith termination, overvoltage protection and any cable screen connection have defined current paths through the bridging components and the printed wiring. These paths can be configured by careful design to not cause damage to the port electrical circuits.

It is important not to confuse isolation and insulation in testing. Insulation breakdown should not occur under field impulse conditions. This can be prevented by having an insulation withstand voltage greater that the expected electrical transient environment or by using a bridging SPC with a lower operating voltage than the insulation withstand voltage. The SPCs used must have an adequate surge current capability for the diverted current (see Figure 10 and Figure 11). Current can flow during impulse conditions, provided that the current flow does not damage the equipment.

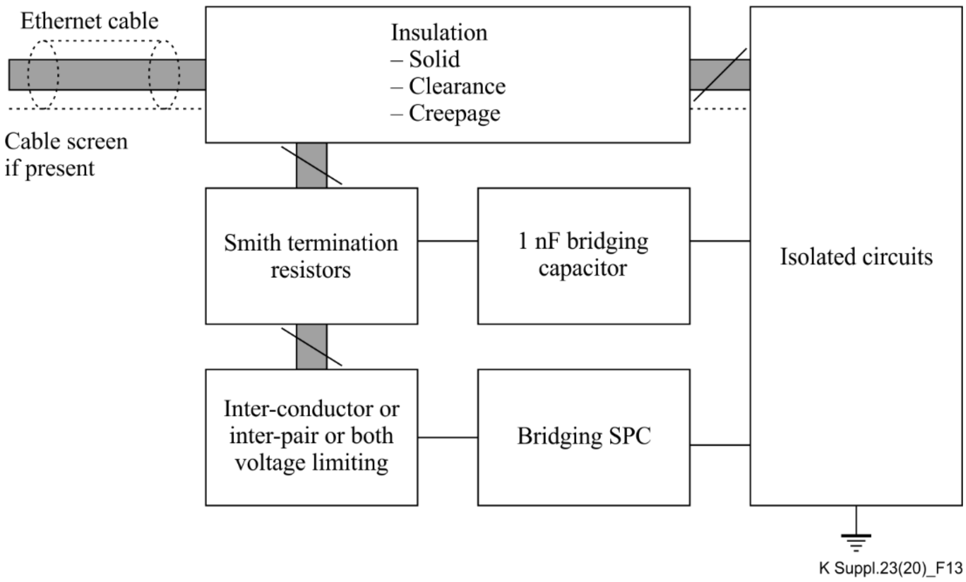

Figure 13 – Ethernet port to earth current paths

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