ETHERNET port surge testing – Test levels and configurations

Summary
Analysis of field failures from fibre connected entertainment hubs showed very high levels of surge must have occurred. This document uses those results to formulate Ethernet test levels and configurations for home networks.

Warning
The document content is of a general nature only and is not intended to address the specific circumstances of any particular individual or entity; nor be necessarily comprehensive, complete, accurate or up to date; nor represent professional or legal advice.
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1 Introduction

The 2011 ITU-T held a technical session on home networks in 2011. The sessions on Damage to equipment in Japan and the US, Model testing and simulations and Need for special requirements documented field results, gave system analysis and test level proposals.

In 2016, in terms of single port 1.2/50 withstand voltages, levels of 2.5 kV (basic) and 6 kV (enhanced) are what many manufactures are using. How these levels are applied and their current capability is something that needs to be harmonised and standardised.

This document analyses the most likely surge events that impose the highest levels of Ethernet port stress and from that analysis defines recommended surge test circuits for a single twisted pair and the power feeding pairs.

Following this introductory clause 1, clause 2 takes the estimated field failure and non-failure levels to define an Ethernet common-mode surge test circuit used with 2.5 kV (basic) and 6 kV (enhanced) 1.2/50-8/20 generator charge levels. Clause 3 analyses surge coupling and the causes of differential-mode surge generation. Clause 4 runs circuit simulations of the clause 3 differential-mode surge event. Clause 5 takes the clause 4 results to define Ethernet differential-mode surge test circuits used with 2.5 kV (basic) and 6 kV (enhanced) 1.2/50-8/20 generator charge levels. A unique feature of the clause 5 power feed differential-mode surge test circuit is the comprehension that the equipment powering circuitry may be common to all the Power over Ethernet, PoE, ports.

2 Common mode surge current levels

The 2011 ITU-T technical sessions reported track vaporisation and 100 A 10/1000 rated fuses opening. From this it was deduced that the current \(i^2t\) causing this was in the region of 15 A\(^2\)s. The 1.2/50-8/20 output current waveform is dependent on the load resistance and finding the required external resistor for given waveform parameters is an iterative process. The technical sessions also established that the Ethernet port withstand voltage should be at least 6 kV. Figures 1 through 4 show the short-circuit peak current, \(i^2t\) charge and di/dt variation with external load resistances of 0 to 20 \(\Omega\) for a 6 kV charge voltage setting of the 1.2/50-8/20 generator.

![Figure 1 – 1.2/50-8/20 generator peak current versus external resistance value (6 kV charge voltage)](image)

Once the external series resistance exceeds the generator 2 \(\Omega\) effective resistance the peak current then depends inversely on the value of external resistance.
**Figure 2 – 1.2/50-8/20 generator current waveform $i^2t$ versus external resistance value (6 kV charge voltage)**

**Figure 3 – 1.2/50-8/20 generator current waveform charge versus external resistance value (6 kV charge voltage)**

**Figure 4 – 1.2/50-8/20 generator current front $di/dt$ versus external resistance value (6 kV charge voltage)**
In Figure 4, the variation of di/dt depends on two factors; the peak current and current waveshape front time. As the external series resistance increases the peak current falls (Figure 1), however as the resistance increases the front time decreases. The net result for front time di/dt is only a two to one change over the resistance change from 0 to 20 Ω.

From Figure 2, to produce a current surge waveform in the 15 A^2s region from a 1.2/50-8/20 generator, set to a 6 kV charge voltage, requires an external resistance of about 5 Ω (12 A^2s). In turn, the 5 Ω external resistor results in a current surge waveform having a peak current of 816 A (Figure 1), a charge of 22 mC (Figure 3) and a maximum waveform front di/dt of 460 A/µs (Figure 4). At a generator basic charge voltage setting of 2.5 kV, the current waveform values will ratio down to 340 A peak current, 6 A^2s i^2t, 9 mC charge and 190 A/µs di/dt.

2.1 Common mode generator resistance and circuit recommendation

A suitable value for the 1.2/50-8/20 generator series resistor for common mode Ethernet port surging is 5 Ω.

NOTE: The termination networks for untested Power over Ethernet, PoE, ports, using two or four twisted pair power feeds must be floating (not solidly earthed) as they are likely to be connected to the tested port surge voltage (see Figure 1 for an example). Any resistive discharge connection from an untested PoE port termination to the EUT reference bar must be at least 20*n MΩ, where n is the number of untested PoE ports.

**Figure 5 – Ethernet common mode surge test circuit**

All the tested port terminals are connected together as the first terminal to conduct current due to insulation breakdown or voltage limiting is generally unknown and the full surge current must be available at that terminal. Limiting the surge current by a separate higher value resistor in series with each terminal will reduce the terminal available surge current. If the terminal separate series resistance value is kept at 5 Ω and there is synchronous voltage limiting then the delivered surge current will be excessive with all terminals conducting current.

3 Common mode to differential surge conversion

The essay on *Voltages and currents in Ethernet cables due to lightning strokes* established that magnet induction can create high levels of voltage on the Ethernet cable, but not much current. The most damaging stress occurs when a surge current has an entry point and exit point to the equipment ports. Figure 6 shows the circuit considered. At the Equipment 1 Ethernet port a surge is coupled to one cable conductor by either insulation breakdown or the operation of an asynchronously operating voltage-limiter. At the Equipment 2 port either insulation breakdown or the operation of an asynchronously operating voltage-limiter provides the surge return path.
To generate the largest differential surge; the surge coupling and switching voltage limiter actions occur on different conductors.

![Diagram of twisted pair surge coupling and differential surge generation](image1)

**Figure 6 – Twisted pair surge coupling and differential surge generation**

As the surge has relatively low-frequency spectrum compared to the Ethernet signal, the Ethernet circuit can be simplified to the components of port circuit resistance, $R_1$ & $R_2$, and cable conductor resistance, $r$, after the transformer core has saturated, see Figure 7.

![Diagram of Ethernet twisted pair circuit resistances](image2)

**Figure 7 – Ethernet twisted pair circuit resistances**

## 4 Ethernet circuit differential surge emulation

Figure 8 shows the LTSpice circuit used for emulation. A 1.2/50-8/20 generator charged to the basic voltage level of 2.5 kV produces the surge. Using a basic voltage level of 2.5 kV is logical as the maximum differential surge will increase with common-mode surge voltage. The series resistor $R_4$ limits the maximum current. Resistor $R_4$ has a value of 5 Ω, as at the enhanced voltage level of 6 kV this produces the field verified $i^2t$ value of 10 A²s. To maximise the current in the ports the cable resistance, $r$, is assumed to be very low and can be neglected. Only the equipment port resistances, shown as $R_5$ and $R_6$ in the circuit, are included in the emulation circuit and they are assumed to be both of the same value.
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Figure 8 – LTSpice emulation of Ethernet differential surge conditions

The emulation was run for port resistance values, \( R_5 \) and \( R_6 \), ranging from 1 \( \Omega \) to 50 \( \Omega \) and the peak currents recorded. Figure 9 shows the variation of the equipment port peak current with port resistance value.

![Figure 9 - Port peak current vs port resistance](image)

Figure 9 shows the prospective current is 170 A peak. Typically the port resistance will be in the range of 1 \( \Omega \) to 5 \( \Omega \), making the peak port voltage range from 170 V to 620 V after core saturation.

Resistance values above 5 \( \Omega \) will be the result of substantial conductor resistance \( r \) and would not represent a maximum stress condition. For example a 25 \( \Omega \) conductor resistance and a 3 \( \Omega \) port resistance would result in a peak current of 60 A. The port peak voltage would be 180 V and the cable plus port peak voltage would be 1.68 kV.

5 Differential mode test circuit

The emulation tested two equipment ports simultaneously. A test circuit that tests a single port is needed. The two port test emulation used a generator set to 2.5 kV, having an effective source resistance of 2 \( \Omega \) (from 1.2/50-8/20 generator) plus the external resistance of 5 \( \Omega \) derived in clause 2. The dual port emulation can be redrawn as shown in Figure 10. Figure 10 splits the 5 \( \Omega \) resistor into two 10 \( \Omega \) resistors, each feeding a separate equipment port.
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One of the port feeds can be replaced by a shunt 10 Ω load to maintain the current waveshape giving the differential surge test circuit of Figure 11. The prospective port current is half of the common-mode prospective current with the same waveshape.

Figure 10 – Separating port surge feeds

Figure 11 – Differential surge test circuit

Figure 12 shows the basic level peak port current and front di/dt versus the port resistance. The front di/dt is an important factor as it controls the Ethernet transformer secondary peak let through current before the transformer core saturation. The prospective 100 A/µs front di/dt of Figure 11 aligns with the GR-1089-CORE Ethernet differential surge test value using a <2/>10, 800 V, 100 A generator, see Ethernet differential surge testing – di/dt.

Figure 12 – Figure 10 peak port current and front di/dt for 2.5 kV charging voltage
5.1 Differential mode generator resistance and circuit recommendations

A suitable value for the 1.2/50-8/20 generator series and shunt resistors (Figure 11) for differential mode Ethernet port surging is 10 Ω. The following figures show the test circuits for twisted-pair differential surging, power feed differential surging and a suggested termination circuit for untested PoE ports.

**Figure 13 – Ethernet twisted pair differential mode surge test circuit**

In Figure 13 all four switches, SW(1-2) to SW(7-8), are single-pole change-over break before make. The switch contact arm is shown in red to clearly indicate the arm position. Figure 13 shows the test configuration for port terminal pair 1-2 with the generator output connected to terminal 1 via switch SW(1-2). The test configuration for a given terminal pair is with that terminal pair switch connecting the switched terminal to the generator series resistor R1, while all the other three terminal pair switches connect their terminals to the EUT reference bar.

**Figure 14 – Ethernet power feed differential mode surge test circuit**

In multiple output power sourcing equipment and powered equipment using several power feeds, the applied surge to one PoE feed terminal set is likely to propagate to the other PoE ports via common powering circuitry. Figure 15 shows a suggested termination network for the untested PoE ports. The components and their values should correspond to the established components used in IEEE 802.3 designs. Diodes D1 through D4 and D6 through D9 form polarity correction bridges that feed the avalanche breakdown diodes D5 and D10 and capacitors C1 and C2. Typical emulation components used are: Schottky rectifier bridge diodes type B1100/B, avalanche breakdown diode type SMAJ58A and decoupling capacitor 100 nF, 100 V.

NOTE: The termination networks for the untested Power over Ethernet, PoE, ports, using two or four twisted pair power feeds must be floating (not solidly earthed) as the common power source is likely to be connected to the tested port surge voltage. Any resistive discharge connection from an untested PoE port termination to the EUT reference bar must be at least 20* n MΩ, where n is the number of untested PoE ports.
Key
C1, C2 = 100 nF, 100 V
D5, D10 = SMAJ58A or equivalent 400 W avalanche breakdown diodes
D1 to D4, D6 to D9 = B1100/B Schottky rectifier diodes or equivalent 1 A, 100 V diodes

Figure 15 – Example of termination network for an untested Ethernet PoE port