Durability of Connecting Hardware under Electrical Load for Power-over-Ethernet Applications

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Durability of Connecting Hardware under Electrical Load for Power-over-Ethernet Applications

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International Electrotechnical Commission
TECHNICAL COMMITTEE No. 48: ELECTROMECHANICAL COMPONENTS AND MECHANICAL STRUCTURES FOR ELECTRONIC EQUIPMENT

EC Cabling News Technical Note April 2007
PoE = POWER – over –ETHERNET

PoE enables network devices to receive power over the same cable that supplies data and eliminates the need in additional power cables and transformers and AC outlets.

As the result:
the network connecting hardware (RJ45 and ARJ45) are exposed to effects of the power discontinuation
## Transmission classes, Connector categories and Interfaces

<table>
<thead>
<tr>
<th>ISO/IEC 11801</th>
<th>Connector category</th>
<th>Freq. max. Character.</th>
<th>Application</th>
<th>Connecting Hardware Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class C</td>
<td>3</td>
<td>16 MHz</td>
<td>IEEE 802.5 TokenRing</td>
<td>RJ 45</td>
</tr>
<tr>
<td>Class D</td>
<td>5e</td>
<td>100 MHz</td>
<td>10 to 1000baseT Ethernet</td>
<td>RJ45</td>
</tr>
<tr>
<td>Class E</td>
<td>6</td>
<td>250 MHz</td>
<td>100-1000 baseT</td>
<td>RJ45</td>
</tr>
<tr>
<td>Class Ea augmented</td>
<td>6a</td>
<td>500 MHz</td>
<td>10 Gigabit</td>
<td>RJ45, ARJ45</td>
</tr>
<tr>
<td>Class F</td>
<td>7</td>
<td>600 MHz</td>
<td>1G over single pair 10 Gigabit</td>
<td>GG45, ARJ45</td>
</tr>
<tr>
<td>Class Fa augmented</td>
<td>7a</td>
<td>1000 MHz</td>
<td>10 Gigabit over 2 pairs</td>
<td>ARJ45, Tera</td>
</tr>
<tr>
<td>NA</td>
<td>NA</td>
<td>5000 MHz</td>
<td></td>
<td>ARJ45</td>
</tr>
</tbody>
</table>
STANDARD CONNECTOR INTERFACES for NETWORKING

GG45 or ARJ45 HD 12-CONTACTS

ARJ45 HS 8-CONTACTS, 1000 MHz + Category 7A

RJ45 8-CONTACTS, Up to 500 MHz Cat. 3 to 6A

Tera Connector
Alternative interface
PHYSICAL PHENOMENA
due to
ELECTRICAL CONTACT SEPARATION

• Effects caused by mechanical abrasion and environmental exposure
• Effects caused by electrical discharge

<table>
<thead>
<tr>
<th>SPARK</th>
<th>CORONA DISCHARGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast, single event,</td>
<td>Relatively slow, time dependent</td>
</tr>
<tr>
<td>Time independent</td>
<td>Multiple events, shallow craters or pitted surface,</td>
</tr>
<tr>
<td>Large distinct crater</td>
<td>erosion</td>
</tr>
</tbody>
</table>

Combination of all
Effects and Acceptance criteria

**EFFECTS**

Short term
- Physical/mechanical damage
- Electrical Interface Degradation

Long term
- Physical/mechanical damage
- Corrosion
- Electrical Interface Degradation

**MAJOR ACCEPTANCE CRITERION**

LOW LEVEL CONTACT Resistance

**LLCR (bulk)**
Low Level Contact Resistance (LLCR-bulk)

consists of four components

Plug Conductor Resistance
Plug Blade/Conductor Contact Resistance
Plug Blade/Jack Wire Contact Resistance
Jack Wire Resistance
**Connector Durability under Electrical Load**

Table 1. Some factors affecting the connecting hardware durability

<table>
<thead>
<tr>
<th>Test Matrix Variable Options.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable</strong></td>
<td><strong>Item</strong></td>
</tr>
<tr>
<td>Connector type</td>
<td>IEC 60603 interface</td>
</tr>
<tr>
<td>Connector manufacturer</td>
<td>Various</td>
</tr>
<tr>
<td>Speed of separation</td>
<td>Cycle/Hour</td>
</tr>
<tr>
<td>Cable length</td>
<td>m</td>
</tr>
<tr>
<td>Cable type</td>
<td>Shielded or unshielded</td>
</tr>
<tr>
<td>Number of contacts energized simultaneously</td>
<td>0, 1 or 8</td>
</tr>
<tr>
<td>Test circuit</td>
<td>A, B, C</td>
</tr>
<tr>
<td>Polarity</td>
<td>+/- Plug</td>
</tr>
<tr>
<td>Plating and finish</td>
<td>Thickness and porosity</td>
</tr>
</tbody>
</table>
Bel Stewart Connectors

Power Cycling of Connectors

- **POWER OFF**
- **POWER ON**
- **POWER ON/OFF**

Discharge !!
Twisted Pair Cables used in this study

*Category 5e (100 MHz) unshielded twisted pair, stranded*

*Category 7 and 6A shielded twisted pair cables, stranded with pairs shielded*
EXAMPLE of JACK Contacts

Bel Stewart Connectors
NOMINAL CONTACT AREA in RJ45 and ARJ45 CONNECTORS

Jack-Plug prior to mating

Jack-Plug Initial contact

Jack-Plug Final mating position

Final mating position typically within 0.024’ (0.6 mm) +/- 0.012” (0.3 mm) from a nominal position and 0.030” (0.75 mm) from the initial contact.

Nominal contact area is a final contact position in reference to nominal position.
Connector Durability under Electrical Load

NOMINAL CONTACT AREA in RJ45 and ARJ45 CONNECTORS

Contact A

Contact B

Wiping Zone

Nominal contact area

Connect-/ disconnect area

Typical damage location
Connecting Hardware Contacts

A) Fresh unused
B) After mechanical cycling without electrical load
C) Crater caused by a spark
D) Multiple craters due to discharges
Typical effect of Electrical Discharge in connectors

Connector Wiping Zone

SPARK CRATER located outside of nominal contact zone
### Connector Durability under Electrical Load

Table 2. Selected parameters of the test set up and procedures

<table>
<thead>
<tr>
<th>Test No</th>
<th>Connector type</th>
<th>Speed of separation, cycle/hour</th>
<th>Cable length, m</th>
<th>Patch cord cable type</th>
<th>Contacts energized simultaneously</th>
<th>Power contact, W</th>
<th>Test Circuit</th>
<th>Cycle</th>
<th>Polarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1A</td>
<td>RJ45</td>
<td>300</td>
<td>2</td>
<td>5e unsh</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Test 2A</td>
<td>60603-7-7</td>
<td>300</td>
<td>2</td>
<td>7 shielded</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Test 3A</td>
<td>RJ45</td>
<td>300</td>
<td>2</td>
<td>5e unsh</td>
<td>1</td>
<td>20</td>
<td>A</td>
<td>Unmate</td>
<td>+PLUG</td>
</tr>
<tr>
<td>Test 4A</td>
<td>RJ45</td>
<td>5e unsh</td>
<td>2</td>
<td>12.6</td>
<td>B</td>
<td>both</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 5A</td>
<td>RJ45</td>
<td>5e unsh</td>
<td>4</td>
<td>12</td>
<td>C</td>
<td>both</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 6A</td>
<td>RJ45</td>
<td>5e unsh</td>
<td>8</td>
<td>12</td>
<td>D</td>
<td>Unmate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 7A</td>
<td>RJ45</td>
<td>450</td>
<td>2</td>
<td>5e unsh</td>
<td>1</td>
<td>20</td>
<td>A</td>
<td>Unmate</td>
<td>-PLUG</td>
</tr>
<tr>
<td>Test 8A</td>
<td>RJ45</td>
<td>720</td>
<td>2</td>
<td>5e unsh</td>
<td>8</td>
<td>20</td>
<td>A</td>
<td>Unmate</td>
<td>-PLUG</td>
</tr>
<tr>
<td>Test 9A</td>
<td>RJ45</td>
<td>450</td>
<td>10</td>
<td>5e unsh</td>
<td>8</td>
<td>20</td>
<td>E</td>
<td>Unmate</td>
<td>-PLUG</td>
</tr>
<tr>
<td>Test 10A</td>
<td>RJ45</td>
<td>450</td>
<td>10</td>
<td>6 unsh</td>
<td>8</td>
<td>20</td>
<td>C</td>
<td>Unmate</td>
<td>-PLUG</td>
</tr>
<tr>
<td>Test 11A</td>
<td>60603-7-7</td>
<td>450</td>
<td>10</td>
<td>7 shielded</td>
<td>8</td>
<td>20</td>
<td>E</td>
<td>Unmate</td>
<td>-PLUG</td>
</tr>
<tr>
<td>Test 12A</td>
<td>RJ45</td>
<td>720</td>
<td>10</td>
<td>5e unsh</td>
<td>8</td>
<td>20</td>
<td>F</td>
<td>Unmate</td>
<td>+PLUG</td>
</tr>
<tr>
<td>Test 13A</td>
<td>60603-7-7</td>
<td>450</td>
<td>10</td>
<td>7 shielded</td>
<td>8</td>
<td>20</td>
<td>F</td>
<td>Unmate</td>
<td>-PLUG</td>
</tr>
<tr>
<td>Test 14A</td>
<td>60603-7-7</td>
<td>720</td>
<td>100</td>
<td>7 shielded</td>
<td>8</td>
<td>20</td>
<td>F</td>
<td>Unmate</td>
<td>-PLUG</td>
</tr>
<tr>
<td>Test 15A</td>
<td>RJ45</td>
<td>720</td>
<td>100</td>
<td>6 unsh</td>
<td>8</td>
<td>20</td>
<td>F</td>
<td>Unmate</td>
<td>-PLUG</td>
</tr>
</tbody>
</table>
Connector Durability under Electrical Load

Identify the effects of mechanical operations

Tests 1A and 2A

RJ45 fresh Contact
After 750 mechanical Cycles no el. load

ARJ45 fresh contact

ARJ45 after 750 cycles no el.load
Tests 3A
Objective of this test was to identify parameters of the expected LLCR changes and variations in the LLCR during the unmating cycles only. The power was 20 W per contact. The LLCR was measured initially and after each 80 cycles, using a separate measuring plug. A total of 800 cycles were performed.
Overview of IEC TR: Connector Durability under Electrical Load

Figure 12. Test results of tests 1A and 3A. (Data for “No power contact before test” and “Power contact before test” represent a single measurement for each contact)
Test 4A: Comparison of different RJ45’s with proposed SC25 WG3 requirement

Proposed by SC25 WG3 during the development of the ISO/IEC 11801 2nd Ed: assumed extra voltage of 50% over 48V and the supposed worst case scenario, that when the contacts of the jack do not open simultaneously, the power of 12.6 W has to be covered by one pair only.
The charging power was present during mating and unmating.
Disconnect zone

Wiping area

Nominal contact area

Test 4A. 23 test specimens manufactured by Chinese, European and US suppliers, Shielded and Unshielded

Overview of IEC TR: Connector Durability under Electrical Load

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LOCATION of EROSION TYPICALLY OUTSIDE OF NOMINAL CONTACT ZONE (WIPING ZONE)

PLUG and UNPLUG MOVEMENT

Typical Erosion Location

Nominal Contact Area

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Overview of IEC TR: Connector Durability under Electrical Load

Test 5A: Resistive test setup simulating PoE power stress

This test is to imitate the conditions of IEEE PoE. The feeding power is split up to both wires of a pair (e.g. to 4,5 and 7,8). 48V, power 12W, resulting in a current of 250mA. Power was present during mating and unmating.

The approximate value for $R$ is 184 Ohm

3 test samples: representing 3 manufacturers (Swiss, US and Asian)
Test 5A results:

Test with resistive load resulted in very little damage to contacts and negligible change in LLCR - irrespective of the connector manufacturer.
Overview of IEC TR: Connector Durability under Electrical Load

Test 6A: Mating and unmating with PoE hardware
An actual IEEE 802.3af PoE hardware was used in this test supporting the complete functionality of IEEE 802.3af. A resistive load was attached to the 12V output to generate 12W (R \( \sim \) 12 Ohm).

Test 6A results:
Power interruption using PoE equipment did not cause any failures or significant damage
Overview of IEC TR: Connector Durability under Electrical Load

Test 7A and 8A. Effect of Speed of Contact Separation

Results: no failures, no effects attributable to difference in contact separation speed
Overview of IEC TR: Connector Durability under Electrical Load

Tests 9A, 10A and 11A. Effect of the patch cord length

The tests were conducted with shielded and unshielded patch cords: 2m, 10 m and 100 m long (see table 2) . No differences in discharge effects were observed. No failures
Overview of IEC TR: Connector Durability under Electrical Load

Test 12A: effects of polarity

Damage was small in comparison to jacks. Two possible factors:

a) jack contact experiences simultaneously a mechanical stress (bending) and electrical discharge leading to greater observed damage

b) that the thermal mass of plug contact is greater in the discharge area
Category 7 and 7A connecting hardware 1000 MHz

ARJ45
Overview of IEC TR: Connector Durability under Electrical Load

ARJ45 Category 7
Bottom contacts

ARJ45 Category 7
Top contacts

Discharge effects in the area peripheral to contact area

Very little or no visible discharge effects
Overview of IEC TR: Connector Durability under Electrical Load

Change in Bulk Low Level Contact Resistance combined for all groups for ARJ45 HD connectors
Overview of IEC TR: Connector Durability under Electrical Load

**Tests 14A and 15A. 100-meter long cable test**

During these tests the connecting hardware was mated for 750 cycles using 100-meter long patch cord cables with electrical load. After that the jacks were placed in a climatic chamber for 21 days under the following conditions:

- 8 hours @ +25 °C
- 8 hours @ +65 °C
- 8 hours @ -10 °C

ARJ45 and RJ45 jacks were not mated. After the exposure the jacks were cycled 3 times with a test plug and LLCR was remeasured.

*There was no degradation in the LLCR exceeding the specified limits.*
Simulation of unmating under power. 100m channel

Connecting hardware: Connecting hardware is simulated as a conductance with a step response.

For reasons of simulation the network is transformed to an asymmetric network.

Equivalent diagram.

Figure 1. Equivalent diagram of circuit for unmating under load.

ISO/IEC JTC 1/SC 25/WG 3Kna023_CHW_POEP
Simulation of unmating under power. 100m channel

Figure 3: Voltage over contact during break.

Voltage across contacts during unmating
Experimental evaluation of unmating under power

Mechanism for mating-unmating of connecting hardware
Experimental evaluation of unmating under power
The tested connector with a contact carrying 420mA did not exhibit any spark erosion after 750 cycles.
Observations and Conclusions

- Unmating a connection while transmitting power can cause damage to contacts.

- Proper design of the modular connectors should assure that the zone of breaking contact is separate from the zone where contact between plug and jack is made during normal operation. This results in certain immunity to the effects of unmating under the electrical load.

- The reduction in the separation between a nominal contact zone and a disconnect zone, could lead to an upper limit of breaking power for modular connectors.

- The voltage waveforms across contacts obtained by simulation and the experiments were very similar.
Thank you for your time and attention

ANY QUESTIONS?