IEC/TR 62652

Edition 1.0 2010-03

TECHNICAL REPORT

colour inside

Effects of engaging and separating under electrical load on connector interfaces in cabling used to support IEEE 802.3af (power-over-ethernet) applications

IEC/TR 62652:2010(E)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE U

ICS 13.220.10

ISBN 2-8318-1087-3

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

EFFECTS OF ENGAGING AND SEPARATING UNDER ELECTRICAL LOAD ON CONNECTOR INTERFACES IN CABLING USED TO SUPPORT IEEE 802.3af (POWER-OVER-ETHERNET) APPLICATIONS

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This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The text of this standard is based on the following documents:

DTR	Report on voting
48B/2076/DTR	48B/2146/RVC

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INTRODUCTION

The ISO/IEC/JTC1/SC25 subcommittee requested IEC SC 48B to prepare an engaging and separating under electrical load test method to be referenced in their standards. This test method standard was published as IEC 60512-9-3:2006. The experts of SC 48B/WG5 were concerned about the effect of engaging/separating under electrical load on the IEC 60603-7 series connector interfaces that would be typically used in the IEEE 802.3af (PoE) applications. The experts developed a set of tests to evaluate the effects, the results of which are reported in this Technical Report.

NOTE "Engaging" and "Separating" are terms used in most IEC TC 48 publications to describe the physical mating or un-mating of connectors.

IEC 60050-581:1978, 581-08-08[1] defines the terms as follows:

engaging and separating force
connector mating and unmating force (deprecated)
The force required to engage fully or separate a pair of mating components including the effect of a coupling, locking or similar device.

The IEC 60603-7 series of standards use the terms mating and un-mating throughout. To avoid confusion in reading this Technical Report and also the IEC 60603-7 series of standards, it is important to know that the term "engaging" is equivalent to "mating" and the term "separating" is equivalent to "un-mating".

1 IEC 60050-581:1978, *International Electrotechnical Vocabulary – Chapter 581: Electromechanical components for electronic equipment*

EFFECTS OF ENGAGING AND SEPARATING UNDER ELECTRICAL LOAD ON CONNECTOR INTERFACES IN CABLING USED TO SUPPORT IEEE 802.3af (POWER-OVER-ETHERNET) APPLICATIONS

1 Scope

This Technical Report is intended to provide information on the effects of engaging and separating under electrical load on the connector interfaces in cabling, used to support IEEE 802.3af (Power-over-Ethernet (PoE)) applications.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60512-9-3:2006, *Connectors for electronic equipment – Tests and measurements – Part 9-3: Endurance tests – Test 9c: Mechanical operation (engaging/separating) with electrical load*

IEC 60603-7, *Connectors for electronic equipment – Part 7: Detail specification for 8-way, unshielded, free and fixed connectors*

IEC 60603-7-7, *Connectors for electronic equipment – Part 7-7: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 600 MHz*

IEC 61076-3-110, *Connectors for electronic equipment – Product requirements – Part 3-110: Detail specification for shielded, free and fixed connectors for data transmission with frequencies up to 1 000 MHz*

IEC 61156 (all parts), *Multicore and symmetrical pair/quad cables for digital communications*

ISO/IEC 11801:2002, *Information technology – Generic cabling for customer premises*
Amendment 1 (2008)

IEEE 802.3af, *"Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications – Data Terminal Equipment (DTE) Power Via Media Dependent Interface (MDI),"*

3 Abbreviations

For the purposes of this document the following abbreviations and special terms apply.

IEEE	The Institute of Electrical and Electronics Engineers
LLCR	Low-Level Contact Resistance
S/FTP	Acronym for a twisted pair cable with overall braid screened cable with foil screened balanced elements
U/UTP	Acronym for a twisted pair cable with no overall screen and unscreened balanced elements

4 General

This Technical Report summarizes information on the effects of engaging and separating under electrical load on the connecting hardware in cabling used to support IEEE 802.3af (Power-over-Ethernet (PoE)) applications. It is intended to make the industry aware of possible problems utilizing modular connectors in applications with increasing power levels and to encourage further investigation of the effects of the connector engaging under electrical load.

This report also includes information regarding test procedures and test results. It is not the intention of this report to recommend any test procedure or specify requirements (to be utilized in order to evaluate the connecting hardware) for connectors in cabling used to support IEEE 802.3af applications.

The tests were conducted using fixed and free connectors made by US, European and Asian-Pacific suppliers. The evaluation utilized several test procedures and took place at test facilities located in the USA and Switzerland. The bulk low level contact resistance was used as a criterion in measuring the effects of engaging cycles under the electrical load on connector durability. In some cases the electrical load was applied for the separating cycles only, in other cases the electrical load was used in both engaging and separating. The electrical load power exceeded the corresponding requirements of the IEEE 802.3af standard.

5 Telecommunications industry information

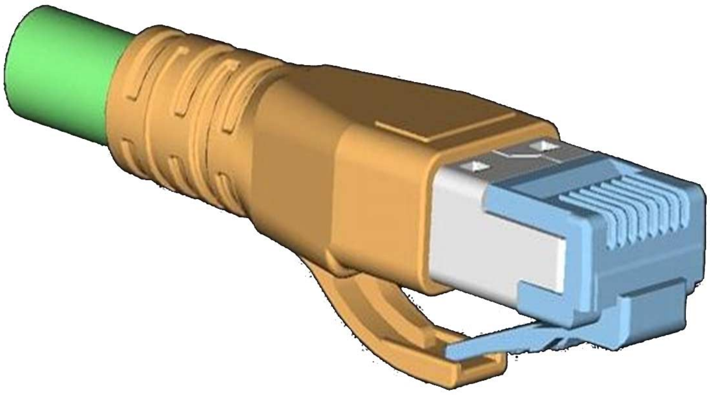
With the advent of generic cabling used in the telecommunication industry, connectors are now used for a multitude of applications. In the past the great majority of such applications all were of a low power level: 4 W or less.

The development of the IEEE 802.3af (Power over Ethernet (PoE)) standard changed the situation. This application requires transmitting power of up to 15 W over the connectors with a nominal voltage of 48 V_{dc}. And already new IEEE projects are under way to increase the transmitted power level up to 40 W.

Different telecommunication connectors subject to the ISO/IEC standards can be used in IEEE 802.3af applications. Some of the connectors used in this study are illustrated in Figures 1 and 2. Figure 1 shows a connector according to IEC 60603-7 which is typically used for applications up to 500 MHz. Figure 2 illustrates a connector according to IEC 60603-7-7 or IEC 61076-3-110 which is typically used for applications up to 1 000 MHz.

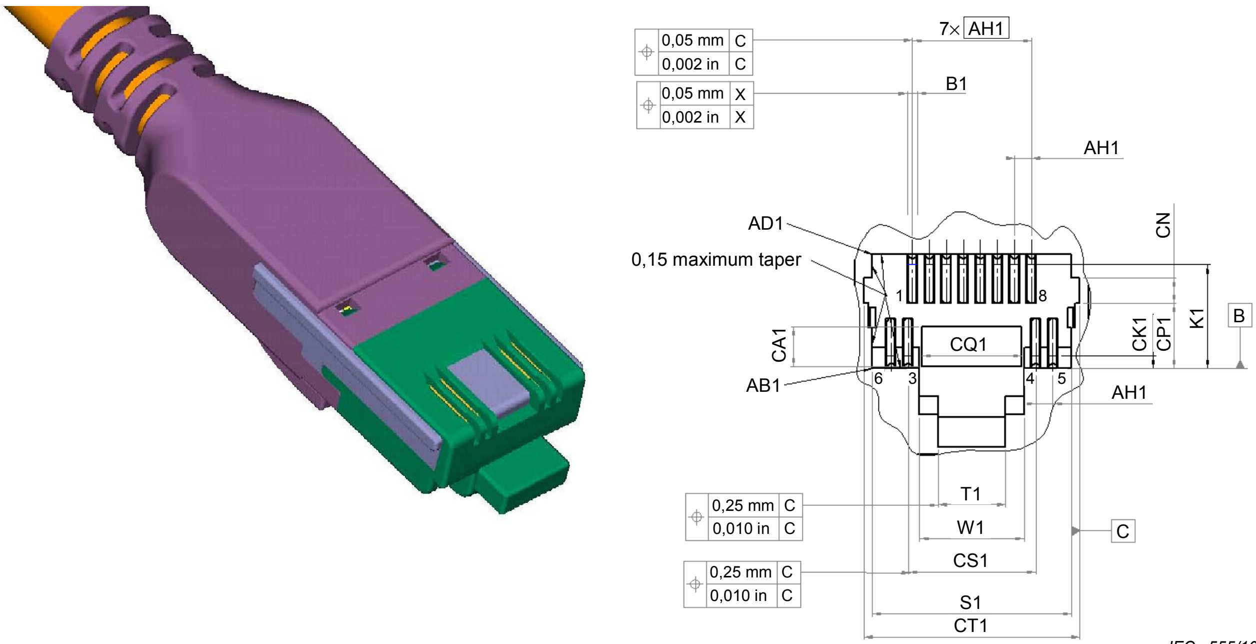
While transmitting some power over engaged connectors is within the specification for continuous current, the problem starts when the plug is removed / disconnected under electrical load. The breaking of a live contact produces discharges that may damage the surfaces on the connector contacts.

Different factors that could affect the connector interfaces were evaluated, including: power levels from 10 W to 20 W, cable length from 2 m to 100 m, the electrical load polarity, and speed of disconnect. The report includes observations based on the visual inspection prior and after multiple engaging cycles and the temperature and humidity conditioning. The report contains a proposal for additional future testing.



IEC 554/10

Figure 1 – Illustration of a typical shielded 8-way connector according IEC 60603-7



IEC 555/10

Figure 2 – Illustration of an IEC 60603-7-7 or IEC 61076-3-110 connector

6 Technical information

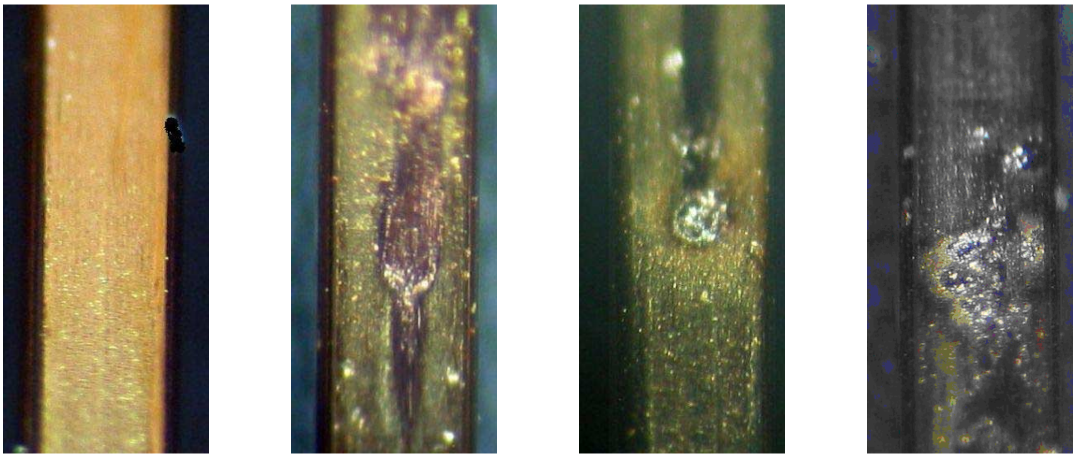
6.1 Electrical discharges

The process of connector engaging and separating causes mechanical damage to the surface of the interface. Such damage could be accelerated or accentuated by the electrical potential between a plug and jack if the electrical load is present during the engaging cycle. In general, there are two such phenomena: corona discharge and spark discharge.

The corona discharge is caused by ionized gas in the presence of an electrical field with a high potential gradient. It is a time-dependent process, which may cause erosion, pitted surface and multiple but shallow craters. There are two distinct types of corona – positive and negative. For IEC 60603-7 type connectors in a IEEE 802.3af environment corona discharge may not be relevant, since there are no long term, high potential gradients present.

Another type of discharge is spark. The spark discharge is to be considered a single and irregular event. Due its high speed it is considered for this work to be time-independent. The damage caused by a spark is usually limited to a singe crater. However, it is not possible to differentiate with certainty if a particular crater was caused by corona or spark.

The effects of the discharges are accompanied by changes in the interface appearance caused by mechanical operations. Connecting hardware contacts are shown in Figure 3.



A B C D

IEC 556/10

Key

A Fresh unused

B Mechanical operations without electrical load

C Crater caused by a spark

D Multiple craters

Figure 3 – Connecting hardware contacts

6.2 Surface plating. long and short term effects

The connector contacts made of copper alloys are protected from the environmental damage by plating. Typical plating consists of nickel plating on the copper alloy base metal, typically 2,5 µm to 3,5 µm, with a noble metal (gold or palladium-nickel) plating on top of the nickel. Surface damage that did not expose the copper alloy is not considered significant. However, when the copper alloy base metal is exposed, it is premature to conclude that the damage affects the connector electrical function.

Such damage can cause short term effects such as loss of mechanical or electrical functionality, as well as long term effects such as corrosion, that also lead to the loss of electrical functionality.

For this reason the study included environmental tests that are often used as accelerated life tests. Also the evaluation of the long-term effects is recommended in future tests proposed later in this Technical Report.

6.3 IEEE 802.3af – Power-over-Ethernet environment (PoE)

PoE is a system designed to provide data as well as power from a central device to a remote device within an environment defined by the generic cabling standard ISO/IEC 11801:2002. The central device, normally located in a floor distributor, is called PSE (Power Sourcing Equipment). It is either integrated into the data switch or hub as an endspan PSE, see Figure 4, or it is a separate device, usually between data switch and patch panel, called midspan PSE, see Figure 5. The remote device, i.e. the equipment the user wants to use, is called the PD (Powered Device)

The PSE is able to power up to 15,4 W into the cabling of which 13 W arrive at the PD in the worst case. The nominal voltage is 48 V_{dc} with current of 350 mA divided on two wires of one pair. There are two possibilities to transmit the power. Alternative A, see Figure 4, uses a phantom circuit to transmit the power on the same pairs used for signaling (1,2 and 3,6). This alternative A is utilized in the 1 Gbs transmission where all 4 pairs are used. Alternative B, see Figure 5, uses the extra two pairs (4,5 and 7,8) for power. The PDs are designed in such a way as to be able to receive power according to alternative A or B.

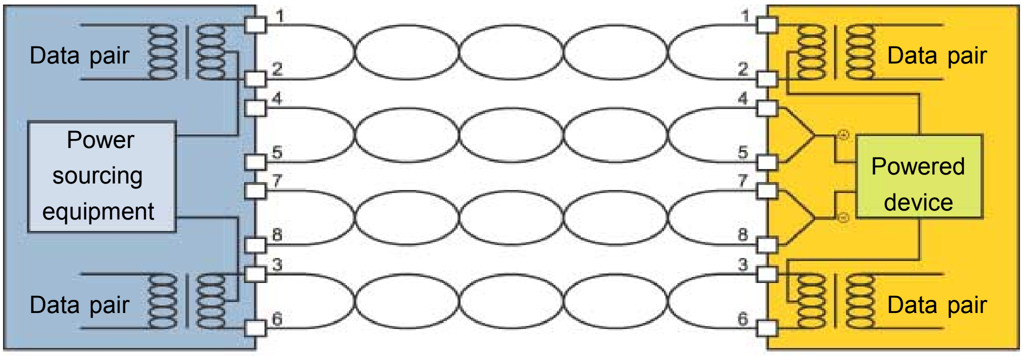


Figure 4 – Endspan PSE – Alternative A according to IEEE 802.3af

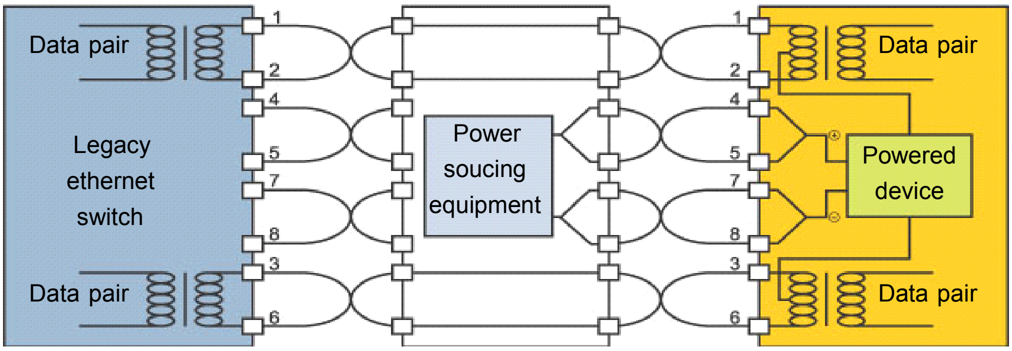


Figure 5 – Midspan PSE – Alternative B according to IEEE 802.3af

In order to ensure operational safety, every PoE channel features an automatic detection logic, which switches the power on only after a PoE capable PD is detected. The same routine will turn off the power as soon as the PD is removed from the channel.

Therefore the engaging operation does not stress the connector, because the power is only switched on after the connection is made, see Figure 7 for an illustration of a typical contact engaging cycle. On the other hand, the separating may cause a problem depending on the speed of the disconnect detection and how the power shutdown is initiated.

6.4 Factors affecting the connector durability and definition of a nominal contact zone

The energy of the discharge may be affected by a number of factors:

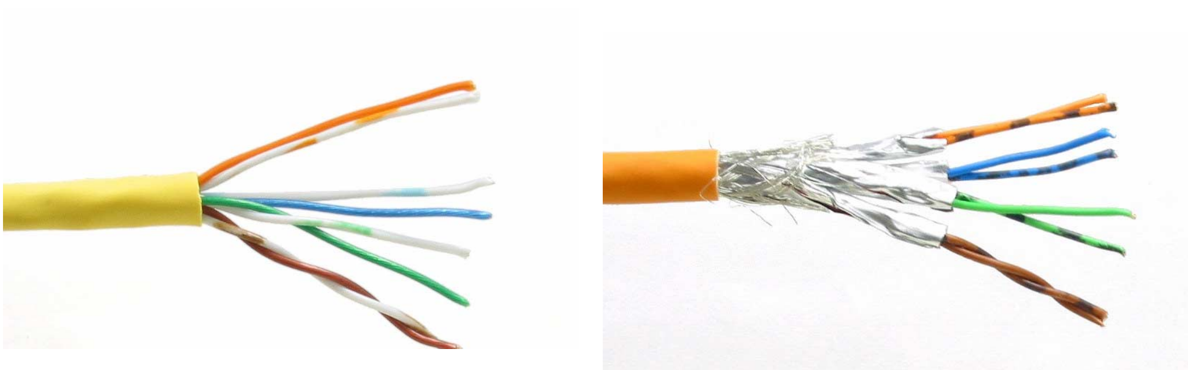
- nominal voltage and current (switching power);
- speed of separation;
- form or shape of electrodes;
- impedance of the load and source;
- cable length and structure;
- polarity.

The tests dealing with attempted qualitative evaluation of the effects of the factors listed above are shown in Table 1.

Table 1 – Some factors affecting the connecting hardware durability

Test matrix variable options	
Variable	**Item**
Connector type	IEC 60603-7 interface
Connector manufacturer	Various
Speed of separation	Cycle/hour
Cable length	m
Cable type	Shielded or unshielded
Number of contacts energized simultaneously	0, 1 or 8
Test circuit	A, B, C
Polarity	± plug
Plating and finish	Thickness and porosity

Figure 6 shows the two types of cables used in this study.



100 MHz U/UTP cable according IEC 61156

600 MHz S/FTP cable according to IEC 61156

IEC 559/10

Figure 6 – Cables used in the study

Figure 7 – Illustration of contact engaging cycle

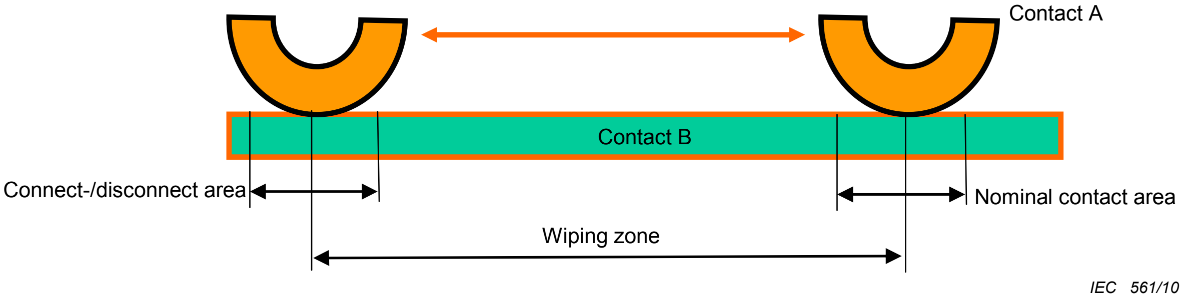


Figure 8 – Illustration of a nominal contact area concept

Damage to the connecting hardware contact surfaces would interfere with the electrical contact between A and B. In order to understand the study results it is important to understand the concept of a nominal contact area, as shown in Figure 8. During the engaging operation, the point of contact between A and B moves along the surface of the contacts from a point of first contact (the connect/disconnect area) to the point of final rest (the nominal contact area). These two areas are separated by the wiping zone.

6.5 Acceptance criteria

The low level contact resistance (bulk) (LLCR) was adopted as an evaluation criterion for the connector durability valuation. The advantage of this measurement is its ability to address several possible areas where degradation can take place, even though not all of them may be visually inspected.

Figure 9 shows the components of the LLCR that may be affected by long or short effects of the electrical disconnect.

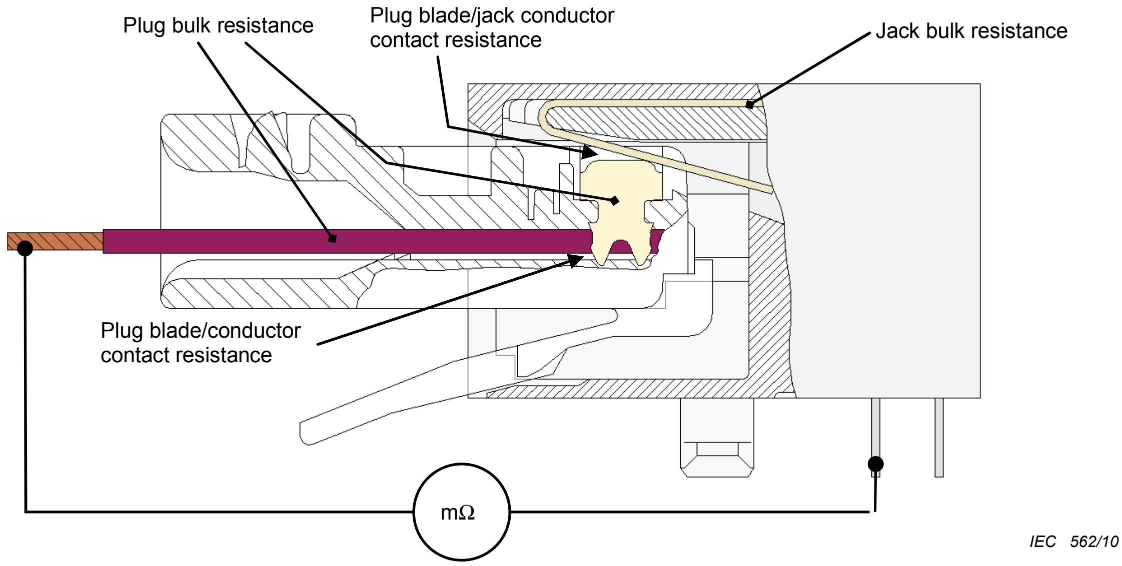


Figure 9 – Illustration of a low level contact resistance (bulk) test

7 Test procedures, test set-up description and results

7.1 General

IEC 60512-9-3 provides some guidance to the testing. However, it does not provide specific test parameters, but refers the reader to “detail specifications”, (typically connecting hardware standards), for the required testing parameters, such as: open voltage, current, type of load, etc. Since there are no detail specifications published yet, one shall define these specifics according to the intended connector applications.

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

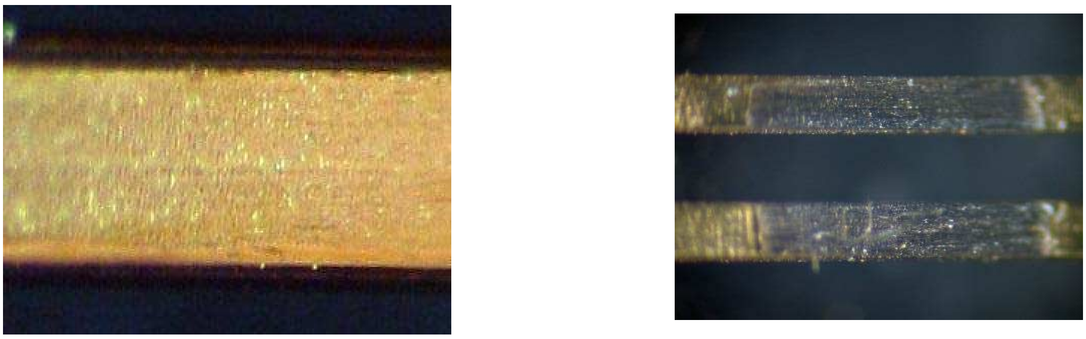
Test No	Connector type	Speed of separation, cycle/hour	Cable length m	Cord cable type	No. of energized contacts	Power contact W	Test circuit	Cycle	Polarity
1A	IEC 60603 -7	300	2	100 MHz U/UTP	0	NA	NA	NA	NA
2A	IEC 60603 -7-7	300	2	600 MHz S/FTP	0	NA	NA	NA	NA
3A	IEC 60603 -7	300	2	100 MHz U/UTP	1	20	A	Engage	+PLUG
4A	IEC 60603 -7			100 MHz U/UTP	2	12,6	B	both	
5A	IEC 60603 -7			100 MHz U/UTP	4	12	C	both	
6A	IEC 60603 -7			100 MHz U/UTP	8	12	D	Separate	
7A	IEC 60603 -7	450	2	100 MHz U/UTP	1	20	A	Separate	–PLUG
8A	IEC 60603 -7	720	2	100 MHz U/UTP	8	20	A	Separate	–PLUG
9A	IEC 60603 -7	450	10	100 MHz U/UTP	8	20	E	Separate	–PLUG

Test No	Connector type	Speed of separation, cycle/hour	Cable length m	Cord cable type	No. of energized contacts	Power contact W	Test circuit	Cycle	Polarity
10A	IEC 60603 -7	450	10	250 MHz U/UTP	8	20	C	Separate	–PLUG
11A	IEC 60603 -7-7	450	10	600 MHz S/FTP	8	20	E	Separate	–PLUG
12A	IEC 60603 -7	720	10	100 MHz U/UTP	8	20	F	Separate	+PLUG
13A	IEC 60603 -7-7	450	10	600 MHz S/FTP	8	20	F	Separate	–PLUG
14A	IEC 60603 -7-7	720	100	600 MHz S/FTP	8	20	F	Separate	–PLUG
15A	IEC 60603 -7	720	100	250 MHz U/UTP	8	20	F	Separate	–PLUG

Some details of the conducted testing are assembled in Table 2. Additional explanations and details can be found elsewhere in this report.

7.2 Tests 1A and 2A – Evaluation of the mechanical damage

The purpose of these tests was to identify change in surface appearance created by mechanical operations. The testing showed clearly visible traces identifying the wiping zones. Examples of the observations are shown in Figures 3 and 10.



A (one contact)

B (two contacts)

IEC 563/10

Key

A fresh contacts

B contacts after 750 cycles of mechanincal insertion without electrical load

Figure 10 – IEC 60603-7-7 connector contacts

7.3 Tests 3A

This test was performed using a test circuit A shown schematically in Figure 11. The objective of this test was to identify parameters of the expected LLCR changes and variations in the LLCR during the separating 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.

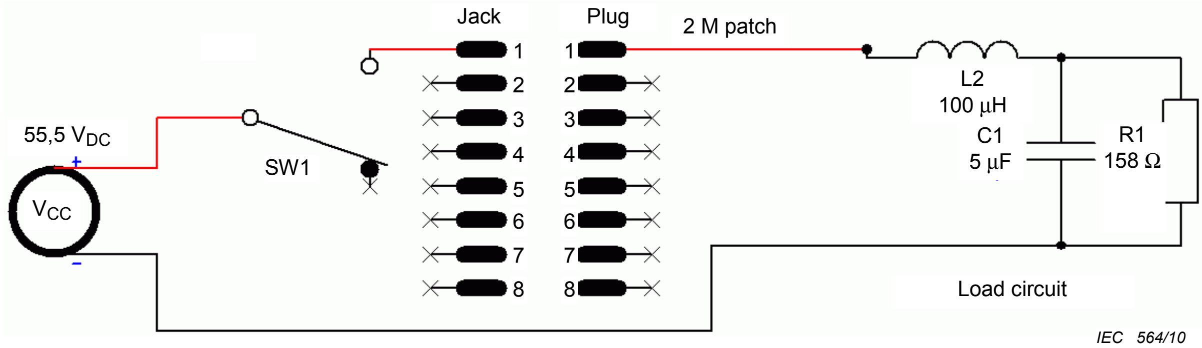
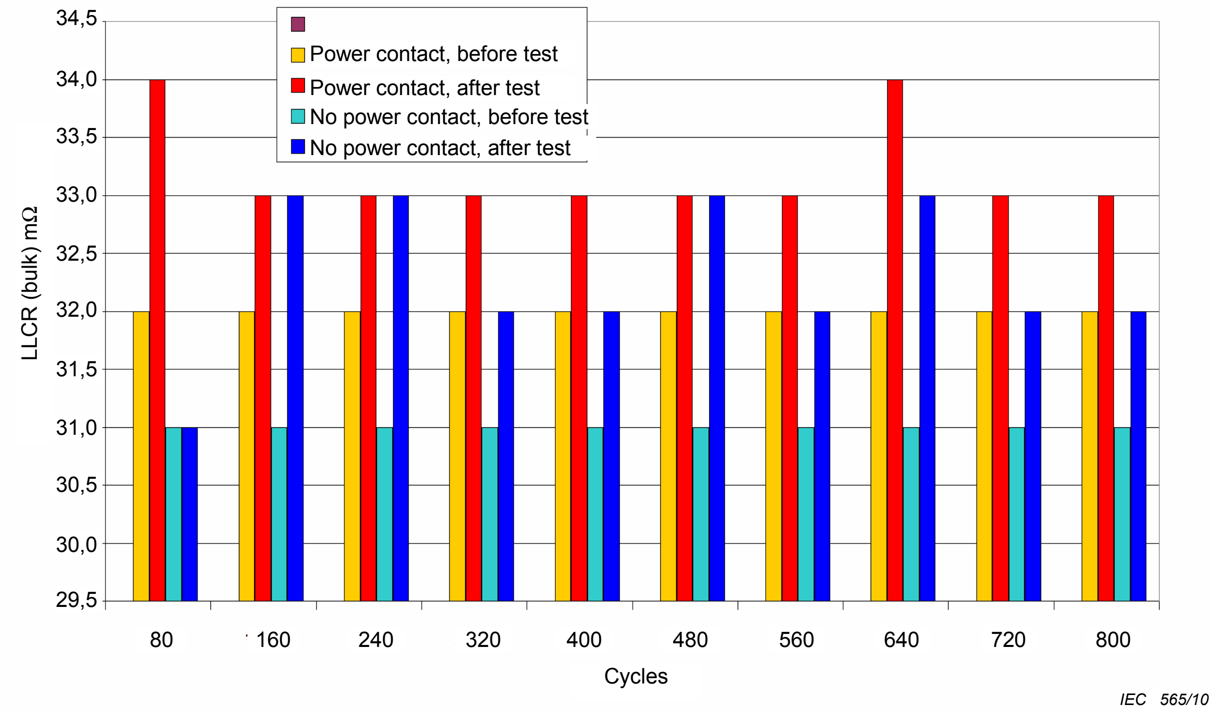


Figure 11 – Test circuit A

The test results of tests 1A and 3A are shown in Figure 12. No significant changes were observed as a result of electrical loading or mechanical insertions. There was slightly more pronounced change in the LLCR for contacts under power after the first 80 cycles and 640 cycles.



Data for “No power contact before test” and “Power contact before test” represent a single measurement for each contact.

Figure 12 – Test results of tests 1A and 3A

7.4 Test 4A – Comparison of different IEC 60603-7 connectors

7.4.1 General

The requirements for this test were proposed by experts[2] during the development of the second edition of ISO/IEC 11801 when the IEEE PoE requirements were not yet finalized. The basis of this requirement is an assumed extra voltage of 50 % over the IEEE voltage of 48 V and the supposed worst case scenario, that when the contacts of the jack do not open simultaneously, the whole breaking power of 12,6 W has to be covered by one pair only.

The charging power was present during engaging and separating. The test circuit is shown schematically in Figure 13.

The ISO/IEC 11801:2002 does not contain a specification other than that the matter will be considered for future study as the experts did not reach an agreement.

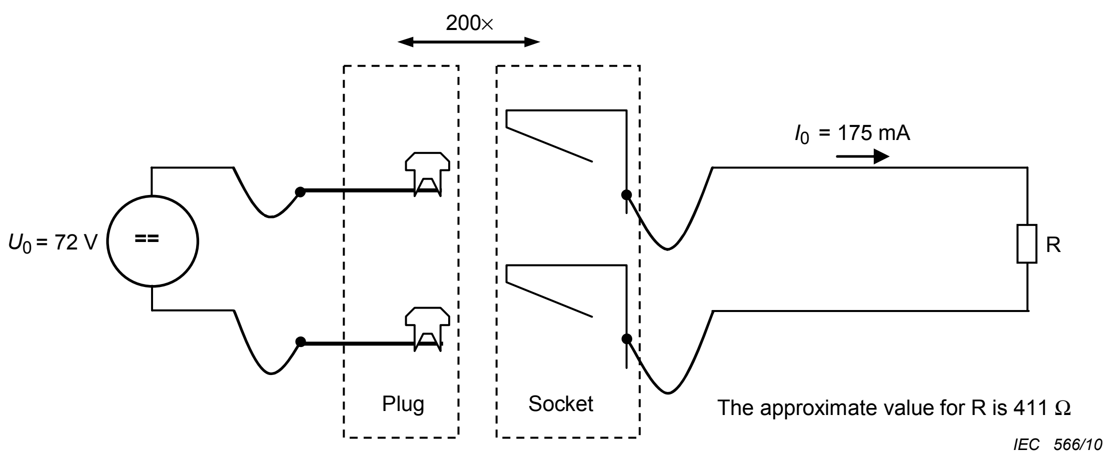


Figure 13 – Test circuit B

7.4.2 Tests – Visual inspection of contacts

LLCR change before and after engaging under load.

DUT: 21 Cat6 RJ45 connections (plug and jack) of 15 different vendors.

7.4.3 Results and observations to test 4A

The visual inspection showed heavy damage on all investigated products. The area damaged by the burn marks was in most cases in a different location than the area used for the contact between plug and jack. An example of this behaviour is shown in Figure 14.

The longer the wiping area, i.e. the separation between the disconnect area (with burn marks) and the nominal contact area, the better the expected contact quality.

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2 While preparing the second edition of ISO/IEC 11801 the requirements for this test were proposed by ISO/IEC/SC25/WG3 experts.

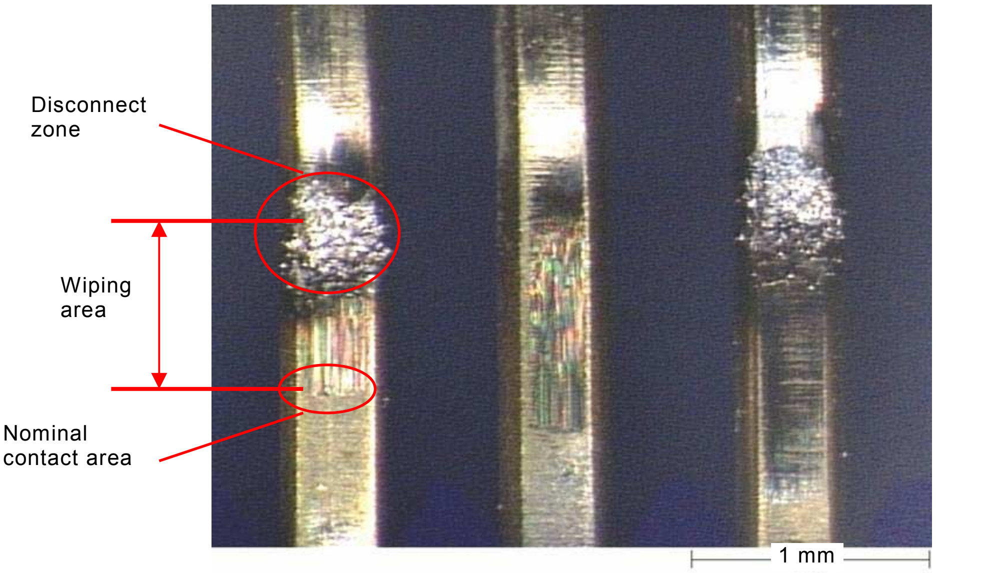


Figure 14 – Damage due to electrical discharges

The results of the increase of LLCR are shown in Figure 15. While most of the samples maintain a good contact quality, V7 exhibits an uncontrolled increase of resistance. The uncommon contact design of V7 which is optimized for transmission performance in such a way, that the disconnect area and the nominal contact area are not separated enough and the damage of the disconnect area reaches into the nominal contact area. V4, V16 and V23 show some increase in resistance that may be due to contaminations of the contact area with oxides from the burn areas.

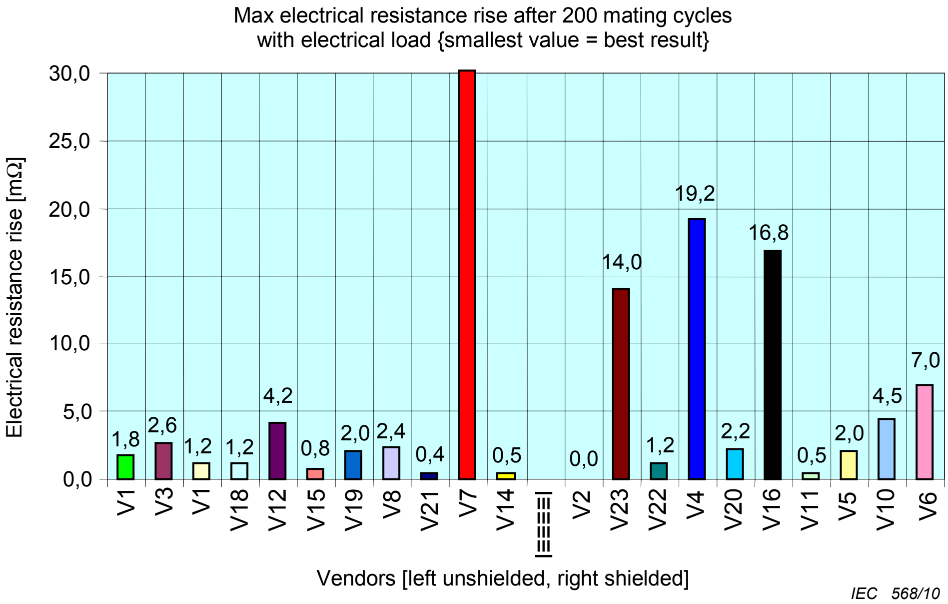


Figure 15 – Test 4A – Changes in LLCR

7.5 Test 5A – Resistive test setup simulating PoE power stress

7.5.1 General

The background of this test is to try to imitate the conditions of IEEE 802.3af as near as possible in a test set-up. The feeding power is split up to both wires of a pair (e.g. to 4,5 and 7,8). The voltage was 48 V and the breaking power 12 W, resulting in a current of 250 mA.

The charging power was present during engaging and separating. The test circuit is shown schematically in Figure 16.

7.5.2 Test setup

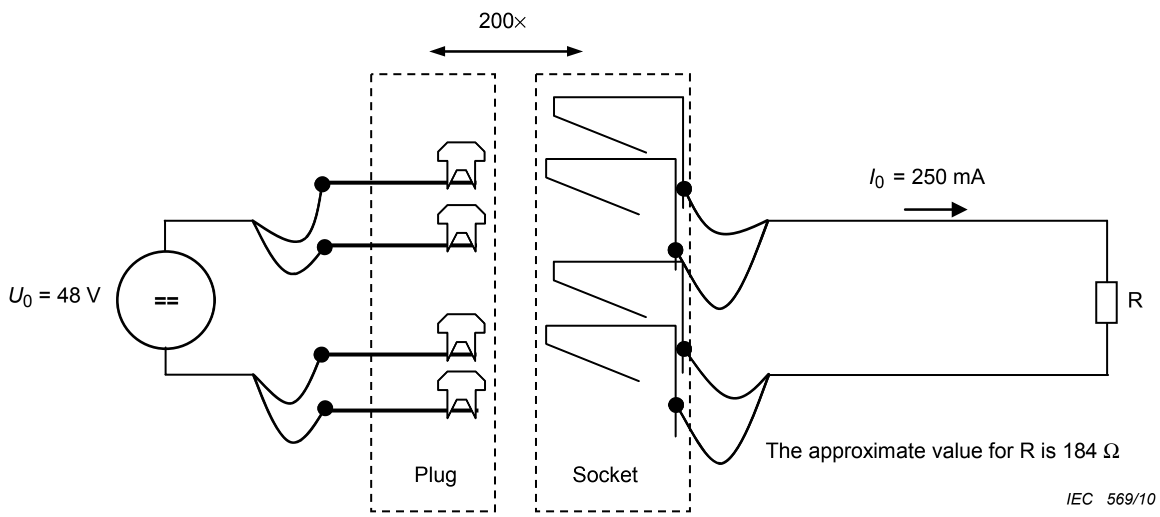


Figure 16 – Test circuit C

DUT: 1 PCB jack from a Chinese manufacturer, 1 PCB jack from a manufacturer from the USA and one Cat 6 jack from a Swiss manufacturer.

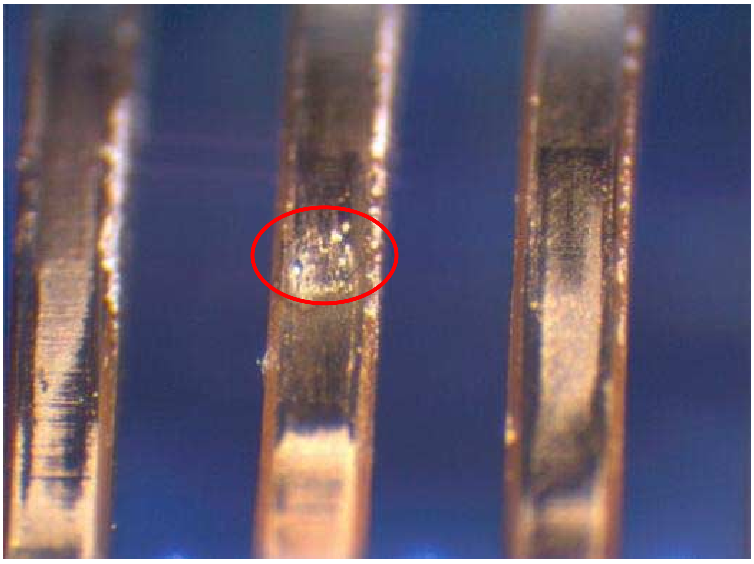
7.5.3 Tests – Visal inspection of contacts

LLCR change before and after engaging under load.

7.5.4 Results and observations to test 5A

The visual inspection shows slight damage on all investigated products. Similar to the results of test 4A the area damaged by the burn marks is in a different location than the area used for the contact between plug and jack. A typical example of this behaviour is shown in Figure 17.

The overall damage to the contacts is much lighter than the damage in test 4A, even though the breaking power was about the same. Only one of the used contacts actually shows visual burn marks, but some of the other contacts must have taken over some of the energy as well to account for the much lighter damage.

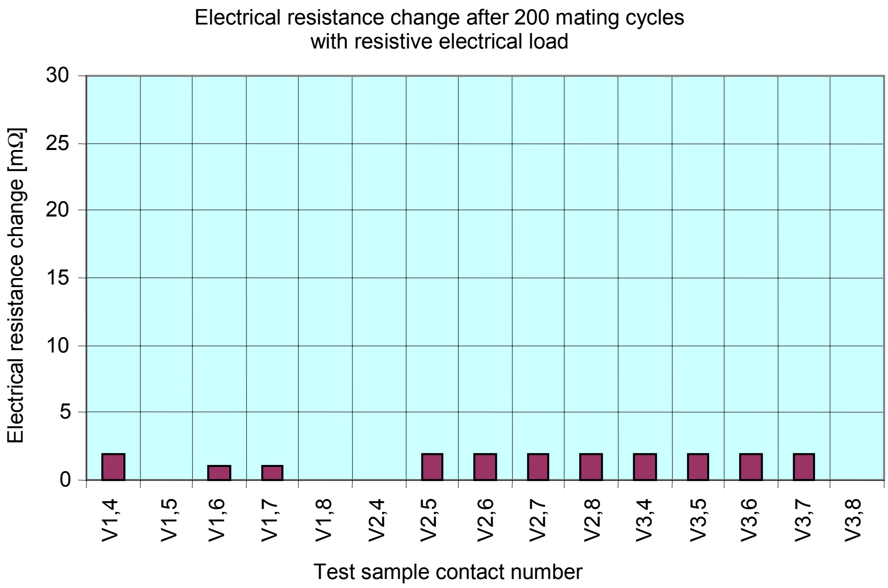


IEC 570/10

Figure 17 – Test 5A observations

The results of the increase of LLCR are shown in Figure 18.

There is no significant change of resistance due to this test.



IEC 571/10

Figure 18 – Test 5A results show little change in LLCR

7.6 Test 6A – Engaging and separating with IEEE 802.3af hardware

7.6.1 PoE hardware

An actual IEEE 802.3af PoE hardware was used in this test. In order to control the transmitted power we used a PoE splitter. This equipment has a built-in DC-DC converter to power legacy equipment not able to use 48 V directly. A resistive load was attached to the 12 V output to generate 12 W of power consumption (approximate value of R = 12 Ω). A PoE injector was used as a power source. This is a midspan device supporting the complete functionality of IEEE 802.3af.

The data transmission channel was not used during the test. The test circuit is shown schematically in Figure 19.

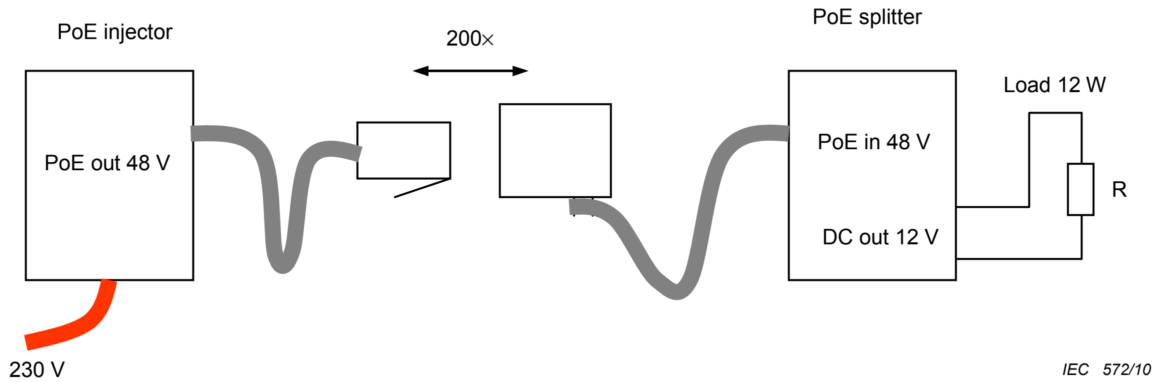


Figure 19 – Test circuit D

7.6.2 Tests – Visual inspection of contacts

LLCR change before and after engaging under load

DUT: 1 PCB jack from a Chinese manufacturer, 1 PCB jack from a manufacturer from the USA and one Cat 6 jack from a Swiss manufacturer.

7.6.3 Results – Test 6A

The visual inspection shows no apparent damage due to the separating under load on all investigated products. The results of the increase of LLCR are shown in Figure 20. There was no significant change of resistance due to this test.

The IEEE 802.3af application clearly stressed the connection less than a purely resistive load. Whether this was due to the automatic power shut down features of IEEE 802.3af or due to the input impedance of the powered equipment is not clear yet.

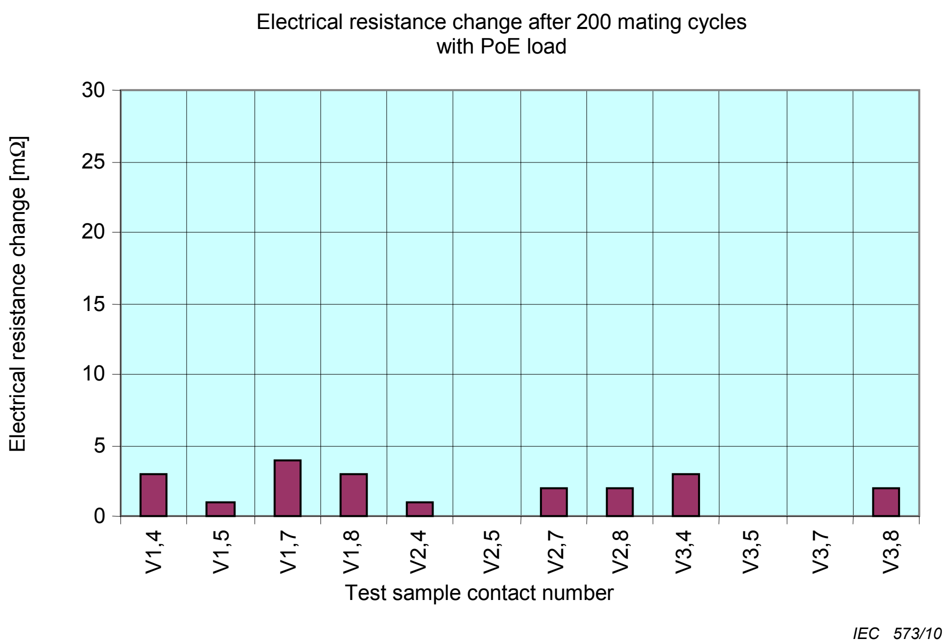


Figure 20 – Test results test 6A

7.7 Test 7A and 8A – Effect of speed of contact separation

The test circuit is shown in Figure 21. The test parameters are shown in Table 1. The test parameters of 7A are similar to that of the test 8A. The most notable exception was the speed of separation measured in cycles /hour.

The test results are shown in Figure 22.

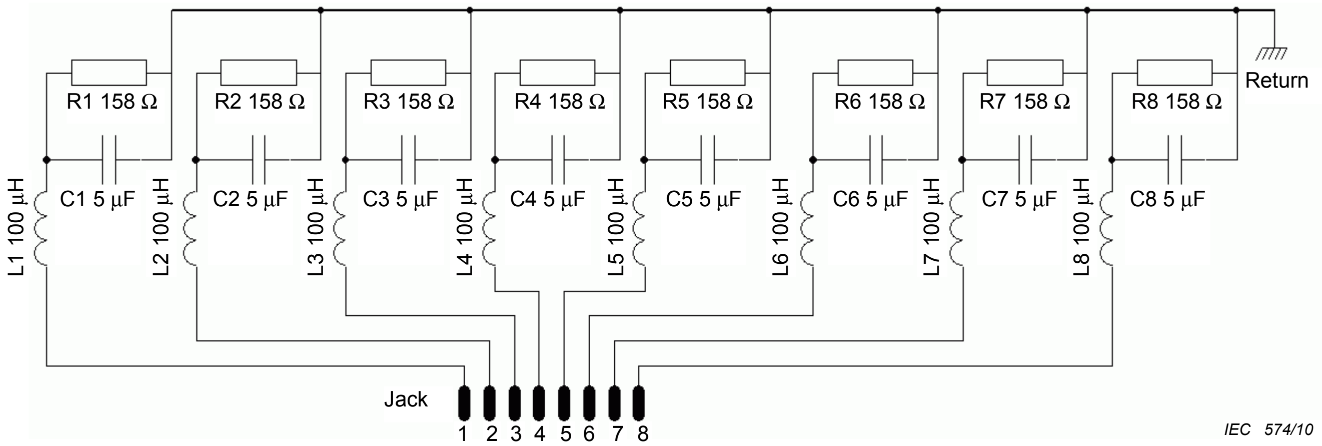


Figure 21 – Test circuit E

Test 7A and 8A observation: there was no effect on the changes in LLCR depending upon the contact speed separation within tested speed limits. Figure 22 shows a diagram of an LLCR (bulk) change in mΩ, tested with 2 m cord cable, 450 cycles/h versus 720 cycles/h.

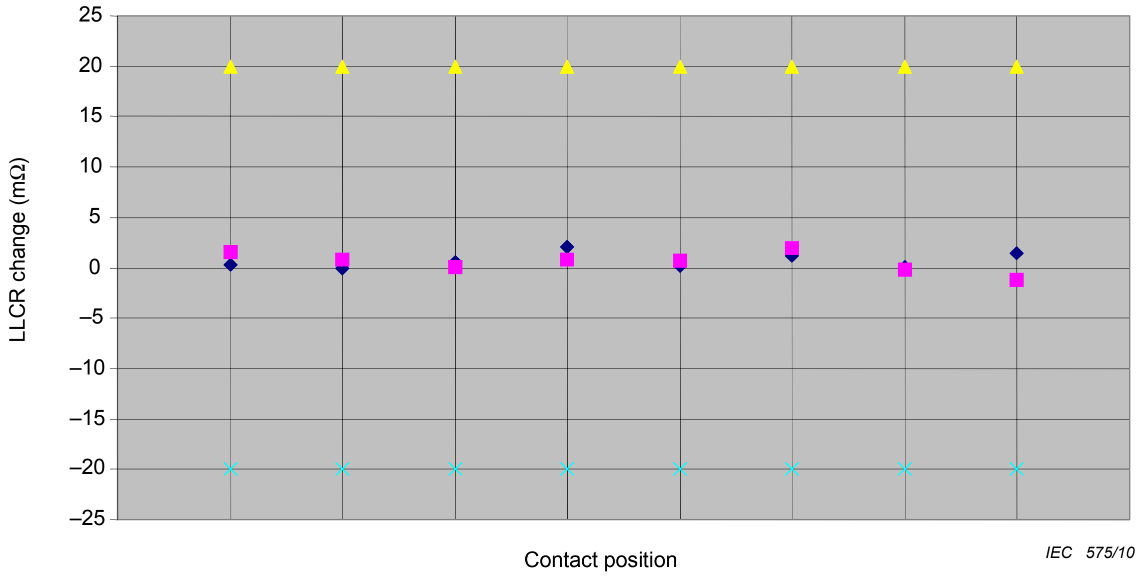


Figure 22 – LLCR (bulk) change

7.8 Tests 9A, 10A and 11A – Effect of the cord length

The tests described as 7A and 8A using 2 m cord cables were repeated in tests 9A to 11A using 10 m long cables between jack and load circuit (see Figure 23). The test 9A used

100 MHz U/UTP cord cables, test 10A used 250 MHz U/UTP cables, and in test 11A a 600 MHz S/FTP cable was used.

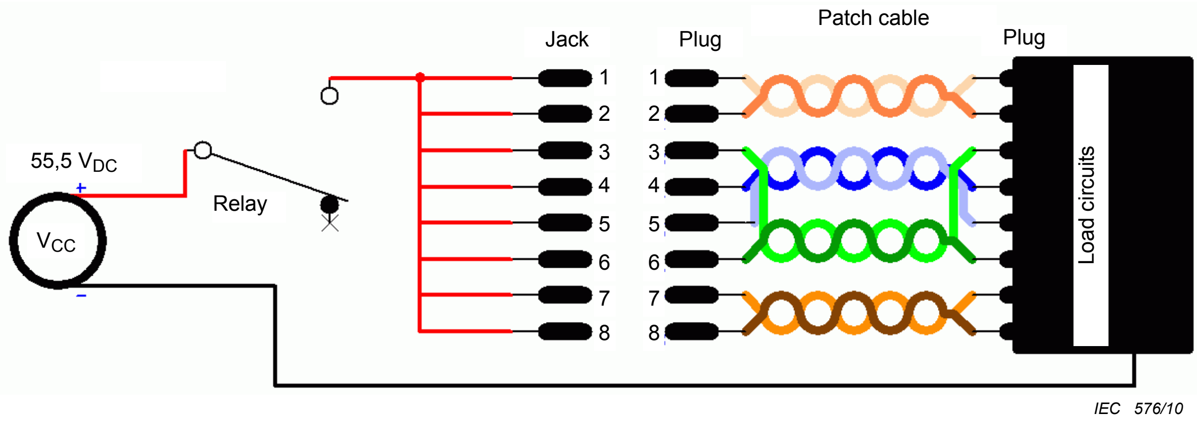


Figure 23 – Test circuit F

There was no noticeable difference in the LLCR test results depending upon the cable length change from 2 m to 10 m as shown in Figure 27.

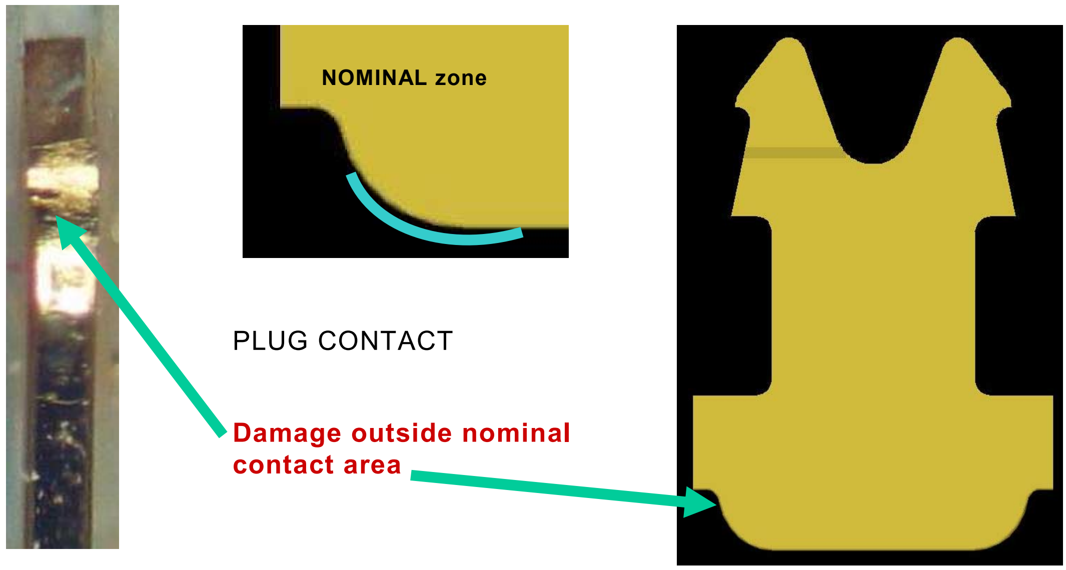
7.9 Test 12A – Effect of polarity

During the previous tests it was observed that the damage to the plug was less noticeable than that observed on the fixed connector contacts. During the testing the polarity of the applied load was changed from the plug connected to a negative output of power supply to the positive.

The observations are illustrated in Figure 24. It can be seen that the damage is outside a nominal contact zone. Again it was observed that the damage was small in comparison to some observed on jacks. The researchers attributed that to two possible factors:

a) that the 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.



IEC 577/10

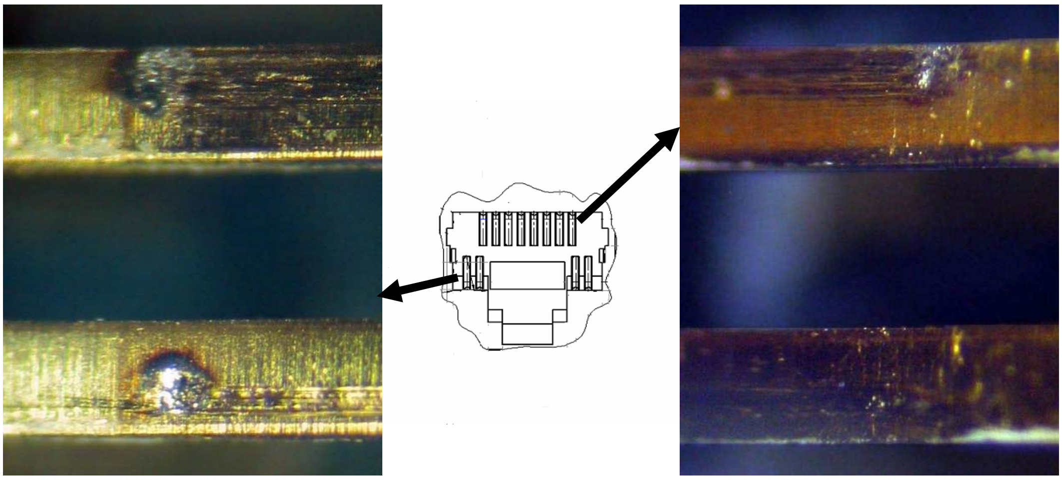
Figure 24 – Test 12A – Observed minor damage to the plug connector surface

It was interesting to notice that the jack contacts suffered similar effects to other tests regardless of the polarity changes.

7.10 Test 13 A – Investigation of IEC 60603-7-7 or IEC 61076-3-110 connecting hardware

The connecting hardware was tested using a 10 m long 600 MHz S/FTP cable, with the plug connected to a negative output of a power supply. Unlike the traditional IEC 60603-7 connector, the IEC 60603-7-7 interface exhibits two sets of contacts: identified as top and bottom contacts in the illustrations.

While the discharge effects were located in the area peripheral to the nominal contact zone, the effects were more noticeable in the "bottom" contacts, and were practically negligible in the "top" contacts. Figure 25 shows the discharge effects for the IEC 60603-7-7 connector and Figure 26 shows the LLCR test results after 750 insertions and exposure to the temperature humidity test.



A B

Key

IEC 578/10

A bottom contacts show more pronounced effects
B very little or no visible discharge effects on the top contacts

Figure 25 – Discharge effects for the IEC 60603-7-7 connector

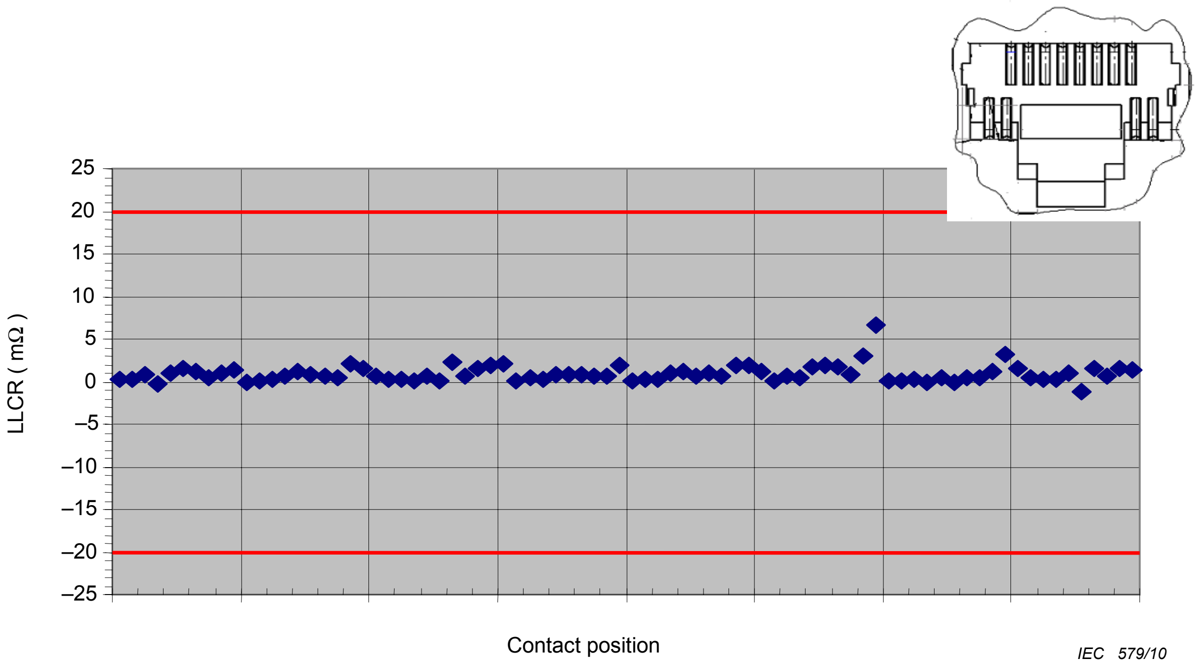


Figure 26 – Test results test 13A

7.11 Tests 14A and 15 A. 100 m long cable test

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

- 8 h at +25 °C;

- 8 h at +65 °C;
- 8 h at –10 °C.

The IEC 60603-7-7 and IEC 60603-7 jacks were not engaged. After the exposure the jacks were cycled 3 times with a test plug and LLCR was re-measured.

There was no degradation in the LLCR exceeding the specified limits.

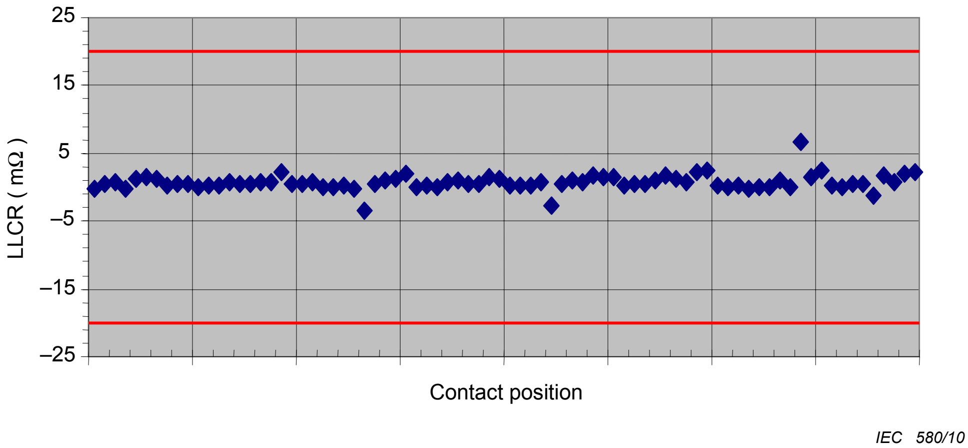


Figure 27 – Change in the LLCR due to electrical and mechanical discharge for IEC 60603-7 connectors including 2 m, 10 m, and 100 m cables combined

8 Conclusions

Separating a connection while transmitting power of the level used in IEEE 802.3af (PoE) can cause damage to the connector contacts. Such damage may depend on the power source and the load conditions. Traditionally the design of the modular connectors described in the IEC 60603-7 series of standards assures that the zone of breaking contact (with damage) is separate from the zone where contact between plug and jack is made during normal operation (the nominal contact area). This results in certain immunity to the effects of separating under the electrical load. It may be expected, that the greater the breaking power, the greater the damaged area on the contacts. 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 numerical value of such a limit is not clear yet.

The separation between a disconnect zone and a nominal contact zone is defined by the design of the contacts of plug and jack. It is possible that there are designs where the separation between disconnect zone and a nominal contact zone is so small that damage due to separating under power could become a problem.

9 Future work

Future work should focus on the evaluation of long-term effects due to electrical discharges in the connecting hardware interface. Such discharges, as was shown in this Technical Report lead to surface changes and possible exposure of base metal. The long term environmental exposure may result in corrosive damage to the underlying base metal or primary plating (Ni). The testing of such damage is usually accomplished by an exposure to the mixed flowing gases in combination with multiple insertion cycles.

Additional testing should focus on the temperature cycling of the parts (after the electrical discharges) comprising of the alternative contact designs. As was found in this work the separation between a nominal contact zone and a disconnect zone in the traditional modular connector designs was a prime reason for the tested connectors showing the immunity to the effects of the electrical discharges. However, with proliferation of higher frequency connecting hardware up to 500 MHz and 1 000 MHz, the contact designs deviate significantly from more traditional designs and may be affected by electrical discharges.

Furthermore, the effects of different source and load conditions on the damage of the contacts should be investigated in more detail.

Bibliography

IEC 60603-7 (all parts), *Connectors for electronic equipment – Part 7: Detail specification for 8-way, unshielded, free and fixed connectors*

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch