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PRE-STANDARD

Multicore and symmetrical pair/quad cables for digital communications – Part 1-4: Symmetrical pair/quad cables with transmission characteristics up to 1 000 MHz – Conductor heating of bundled data grade cables for limited power transmission based on IEEE 802.3

IEC/PAS 61156-1-4:2010(E)

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colour inside

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IEC-PAS 61156-1-4 has been processed by subcommittee 46C: Wires and symmetric cables, of IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document
Draft PAS	**Report on voting**
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MULTICORE AND SYMMETRICAL PAIR/QUAD CABLES FOR DIGITAL COMMUNICATIONS –

Part 1-4: Symmetrical pair/quad cables with transmission characteristics up to 1 000 MHz – Conductor heating of bundled data grade cables for limited power transmission based on IEEE 802.3

1 Scope

This PAS is a technical supplement to IEC 61156-1, edition 3 (2007): *Multicore and symmetrical pair/quad cables for digital communications – Part 1: Generic specification*.

This PAS, covering exclusively four-pair data grade cables, is intended to provide a test method for the determination of the maximum attained conductor temperatures which occur due to the deployment of the IEEE protocol for PoE /PoEP.

It gives as well the required background information about the thermodynamic behaviour of such bundled cables, if they are located in areas with restricted heat dissipation, a reality which occurs in every installation situation. However, only the basic principles are given, as the rigorous application and solution of these problems fall into the relevant cabling standards.

NOTE 1 The restriction to four-pair data grade cables is very important, as the heating of a multiple pair cable, especially if it has a protective screen, is much worse, since the ratio of the heat generation within the cross-section versus the overall circumferential surface to dissipate the heat is dramatically decreased, thus yielding substantially higher conductor temperatures. Additionally, the screen acts as a near perfect IR–reflector, thus increasing additionally only the excess heat within the cable.

This restriction is of importance considering the installed base, where individual four-pair cables in a loose bundle arrangement may need to replace multiple pair cables.

Hence, the main objective is

a) the indication of a suitable measuring method to assess the heating gradient across bundled data grade cables subject to d.c. power transmission, using for the incident and return conductors the common mode circuits of either two or four pairs;

b) to provide, toward this end, the worst case assessment of the conductor and cable heating in bundled cable configurations, where the densest hexagonal packing configuration is required. This assessment of the heating is anticipated to be carried out under the extremely lenient condition of freely suspended cable bundles in an air-conditioned environment free of any air draft, the heat dissipation thus being achieved by undisturbed convection into the surrounding environment;

c) to provide some explanatory background information on the heat dissipation of heated conductors, insulated conductors, pair and cables, both screened or unscreened;

d) to provide means to assess the installed base of data grade cables with a view to their compliance with the requirements of either PoE or PoEP, if required in a comparative way, but based on the resistance assessment of at least one short cable length withdrawn from the installed base by replacement;

e) to indicate the basic physical assessment proceedure, based upon the testing of a cable bundle according to item b). A comparable heating trial on the same cable bundle, but under restricted heat dissipation conditions, yields then some indication of how to assess the maximum occurring temperatures under these conditions;

f) towards this end, the densest hexagonal packing configuration has to be simplified, using an equivalence in order to allow a consecutive evaluation of the heating under any heat dissipation restriction using a layered structure of the cables and the interstitial air spaces within the bundled structure.

For this purpose a test method is provided:

– to allow the evaluation of the heating of the conductors of cable bundles where all (or a certain percentage of the cables) are exposed to powering. Additionally is considered the case that either two of four pairs in a cable are used for d.c. power transmission;

– to measure the temperature of $\left(1+\sum_{n=1}^{N} 6\cdot n\right)$ cables in hexagonal densest packing structure, in order to allow the assessment of the temperature gradient and the heat insulating properties of the cables. The densest packing of cables represents the worst case situation [1];

– to provide a means to assess the performance potential of an installed base of data grade cables for power transmission. Evidently such a process has to take into account the specified d.c. resistance for categorized cables. If an experimental assessment of the installed cables is not feasible, then a normalizing procedure to IACS could be envisioned, though the specified cable d.c. resistances are substantially below 100 % IACS;

– to allow the assessment of the d.c. current transmission performance potential of the newly developed cables (these cables may be made based on the most recent design principles);

– to indicate a comparative test for a cable under 2- or 4-pair heating conditions and under free and restricted heat dissipation conditions, as encountered for instance with frame-wall, insulating material ducts etc.;

– to give the mathematical approach for this procedure;

– to allow also the extension of the results of two heating trials to any cable bundle size, i.e. also to higher bundle sizes, provided the heat insulation conditions to which the cable bundle is exposed to are known.

NOTE 2 The scope of this PAS exclusively covers the cable performances. The variable heat insulating properties of the cables resulting out of the installation practices for channels (for instance feeding bundled cables through insulating materials) is outside the scope of this PAS. This has to be initiated and be taken care of in ISO/IEC JTC1/SC25 WG3 in a suitable technical report or installation guide. This is the reason that here only general guidelines are given.

The test method described lends itself also to cable testing if higher currents than those resulting out of the basic specified d.c. resistances and the specified currents for the IEEE 802.3 PoE / PoEP protocol are required. This would eventually allow the transmission of higher powers at the same maximum ambient temperature of 60 °C, without exceeding the maximum permissible conductor temperatures in the cable. This may be applicable to higher performing cable categories in cases where the user really needs the transmission of higher power levels than anticipated in the IEEE 802.3 PoE / PoEP protocol.

In these cases, a verification of their conductor heating properties has to be assessed, and the cable performance has to be guaranteed by the manufacturer.

The PAS is written in a general way, thus covering not only horizontal cables. Stranded cord cables will have to be evaluated as well, and this very carefully, as they are so far installed in the equipment rooms in higher cable count bundles as well. This PAS establishes some basic guidelines to deal with these problems.

The heating in this PAS is the result of the resistance which is specified in IEC 61156-5 and IEC 61156-6 as 19 [ohm / 100 m] and 29 [ohm / 100 m].

1 Later in this document, a method is given to determine the equivalent diameters for bundles of densest packing, having approximately the same dissipation properties with respect to convection and radiation. This may be interesting for modelling purposes, in case a statistical current loading situation may have to be evaluated, especially in cases where the convection is severely restrained due to surrounding insulation material or any other means to prevent the targeted heat dissipation by radiation and convection.

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 61156-1:2007, *Multicore and symmetrical pair/quad cables for digital communications – Part 1: Generic specification*

IEC 61156-5:2009, *Multicore and symmetrical pair/quad cables for digital communications – Part 5: Symmetrical pair/quad cables with transmission characteristics up to 1 000 MHz – Horizontal floor wiring – Sectional specification*

IEC 61156-6:2010, *Multicore and symmetrical pair/quad cables for digital communications – Part 6: Symmetrical pair/quad cables with transmission characteristics up to 1 000 MHz – Work area wiring – Sectional specification*

IEEE 802.3af-2003, IEEE *Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications – Amendment: Data Terminal Equipment (DTE) Power via Media Dependent Interface (MDI)*

IEEE 802.3at-2009 Part 3: *Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications – Amendment 3: Data Terminal Equipment (DTE) Power via the Media Dependent Interface (MDI) Enhancements*

3 Terms, definitions, symbols, units and abbreviated terms

3.1 Terms and definitions

Open thermodynamic systems - In this PAS, thermodynamic open systems are considered.

Such systems differ from the usually considered systems in the classic thermodynamics, which have generally a constant mass flow going in and out over the system borders. In the present case, the systems have a constant mass flow equal to zero and an energy transfer over the system borders, i.e. an energy influx and/or outflux. This energy influx/outflux may be based on electrical energy going into the system and being transformed therein into heat or on any other kind of heat transfer, be it by radiation, conduction or convection, or any combination thereof.

Two-dimensional systems - In this PAS, a two-dimensional thermodynamic system is understood as a cable or cable bundle which is homogeneous in longitudinal direction, heated by an electric energy influx, dissipating and/or absorbing energy over the system borders in radial direction. The dissipated and/or absorbed energy may be transferred by radiation, conduction and convection or any combination of the latter.

Hence the cross-sectional system borders of a two-dimensional system are subject to a radial energy flow, which is only in case of a thermal equilibrium constant and equal to the sum of the internally produced heat and energy influx minus the energy outflux by radiation, conduction and convection.

Excess energy	-	is the sum of the internally produced heat and energy influx minus the energy outflux under thermal equilibrium conditions. It is this excess heat which is the culprit for the heat increase of the conductors.
Concatenation of systems	-	concatenations of thermodynamic systems are only understood in this PAS as concatenations in any of the radial directions, while all the concatenated systems have the same longitudinal dimension.
Longitudinal open systems	-	such systems are understood here as systems which in the main dimension – here the cable length – are homogeneous with respect to the electrical energy conversion into heat within the systems.
Electrical energy influx	-	is the electrical energy influx over the open thermodynamic system borders at one or both ends of their longitudinal extensions (this allows the very unlikely testing under a powering of the pairs from either one or both sides open)
Internally generated heat	-	is the internally generated heat by the electric influx corresponding to $I^2 \cdot R \cdot t$ [Watt·sec/ length] and is length homogeneous, i.e. constant over the length.
Radial energy in – or outflux	-	is the energy either picked up over the radial borders of the system or increments thereof or the radial outflux of energy out of the system or increments thereof. Both the influx and the outflux can occur for bundled cables by radiation, conduction and convection or any combination thereof.

NOTE As a result of the above definitions, any cable is considered to heat up homogeneously over its length in the described bundled systems, and this independently of reaching the thermal equilibrium. If the above-system definitions are not met, then the cable heats up inhomogeneously over its length – dependent upon the locally varying dissipation conditions length –resulting in a length distributed resistance increase. This may happen under installation conditions, when the heat dissipation is restricted locally over the length of the cable bundles. This may easily yield local conductor temperatures which substantially exceed the maximum specified temperature of 60 °C.

As this aspect has to be considered more in detail in the appropriate installation guidelines, it is outside the scope of this report.

This report will however adress the subject of restricted heat dissipation as a guide to developing the appropriate installation guidelines.

3.2 Symbols, units and abbreviated terms

N	number of cables in the bundle [-]
n	number of cable layers around the centre conductor [-]
R_{Ri}	round trip loss of a pair in the cable [Ω/100 m]
R_B	resistance of the concatenated quad conductors of a cable for one- or two-pair heating at 20 °C [Ω/l_B] or [$2\cdot\Omega/l_B$] depending upon one- or two-pair heating
l_B	length of the cable bundle [m]
i	summation counter for one- and two-pair heating [-]
m	indicator for 2-pair (m = 2) or 4-pair (m=4) heating [-]
$R_{B\,T}$	resistance of the entire concatenated bundle at the temperature T in [Ω/l_B] or [$2\cdot\Omega/l_B$]
$R_{B\,m}$	measured resistance of the entire concatenated bundle under heating condition, but after having reached thermal equilibrium [Ω/l_B] or [$2\cdot\Omega/l_B$]
α	temperature coefficient of the resistance [-]
T	temperature under heating and thermal equilibrium conditions [°C]

T_R	reference temperature of 20 °C or the measured temperature of the air conditioned room. In the latter case, the resistance at room temperature has to be measured precisely [°C]
$U_{Test\ min.}$	minimum voltage which has to be precisely measured by the used volt-meter [V]
I_{Test}	constant current applied to the conductors [A]
Q	generated heat in the conductor at any time t [W·sec/m]
Cond.	suffix to describe the heat generated in one of the conductors forming the “common mode” lead for powering
R (t)	conductor loop resistance at the time t
t	time elapsed during which the conductor is exposed to the current. This time has to be sufficiently long to reach thermal equilibrium
$Q_{EX\ t \rightarrow \infty}$	excess heat remaining in the conductor under thermal equilibrium [W·sec/m]
$Q_{GE\ t \rightarrow \infty}$	generated heat in the conductor at thermal equilibrium [W·sec/m]
$Q_{t \rightarrow \infty}$	dissipated heat from the conductor after reaching thermal equilibrium [W·sec/m]
$Q_{Radiation\ t\ \infty}$	heat dissipated by radiation at thermal equilibrium
$Q_{Conduction\ t\ \infty}$	heat dissipated by conduction at thermal equilibrium
$Q_{Convection\ t\ \infty}$	heat dissipated by convection at thermal equilibrium
- / +	the preceding superscripts to indicate the heat dissipated (-) and absorbed (+) from the outer and inner cable or cable layers, respectively
ΔT	temperature difference between T and T_R [°C]
R (T_R)	specified or measured d.c. loop resistance of the conductors at 20 °C per m
$U_{M\ t \rightarrow \infty}$	voltage measured across the conductors under thermal equilibrium
ρ (T)	specific resistance at a temperature of T [$\Omega \cdot mm^2/m$]
ρ 20 °C	specific resistance at a temperature of 20 °C [$\Omega \cdot mm^2/m$]
r_0	corresponds to the radius of a single cable
r	outer radius of the cable jacket
$r_{C\ n}$	outer equivalent radius of the n^{th} cable layer
$r_{A\ n}$	outer equivalent radius of the n^{th} air layer
q	amount of heat in a general way
F	surface area through with the heat is conducted
k	heat transfer coefficient
k_O	heat transfer coefficient at a temperature T_R
κ	coefficient of the temperature dependence of the heat transfer
k_A	heat transfer coefficient of air
T_i	temperature at the inner surface of a layer
T_a	temperature at the outer surface of a layer
R_a	outer radius of a layer
R_i	inner radius of a layer
$Q_{A\ n}$	heat transferred through the n^{th} air layer
$\Phi_{A\ n}$	logarithmic mean of the inner and outer transfer surfaces of the n^{th} air layer
$Q_{C\ n}$	heat transferred through the n^{th} cable layer
$\Phi_{C\ n}$	logarithmic mean of the inner and outer transfer surfaces of the n^{th} cable layer

$Q(n)$	total heat generated in the n^{th} cable layer
$Q(0)$	heat generated in the centre cable
$T(n)$	logarithmic mean temperature of the helical conductors within the cable jackets
$T_{Ambient}$	ambient temperature the cable bundle is exposed to
Φ_{C0}	dissipating surface of the centre cable
$Q(N)$	heat transferred to the environment through the multiple layers

4 The testing of bundled cables

4.1 General comments

Any standard and code considering the "ampacity" of conductors refers to the conductor surface temperature. This results from the historical fact that sometimes conductors are also used for the power transmission at high frequencies. In this case, the heating of the conductor surface is affected by the mode of transmission.

Some concepts to correlate the attenuation to the d. c. resistance could be used, however in this case, for all practical purposes, they are not applicable, as here the 4-pair data grade cables are used as quads for the d.c. transmission, yielding either six or three "twisted conductor" combinations for the power transmission over one or two pairs. It is for all practical purposes beyond the scope of any cable standards to specify the attenuations of these "twisted conductor" configurations, to be able to derive there from any d.c. resistance at a zero frequency. Furthermore, it has to be realized that:

a) the impedance variations as well as the impedance roughness scatter so widely for different cable designs of the same data transmission performance that such an approach is not more than impractical;

b) the impedance roughness has an impact on the attenuation;
c) there are no methods available to measure the common mode impedance and attenuation between the twisted conductors used for the power transmission, and these would be the only ones required to make an honest assessment of the d.c. resistance.

Hence, this PAS strictly refers to the conductor temperature as the current transfer within the IEEE PoE / PoEP protocols covers only d.c. currents over the common mode circuits of either 2 or 4 pairs. In this case, the conductor temperature is based on the specified cable d.c. resistances and is assumed to be uniform across the cross-section, though there is in reality a very minor temperature gradient occurring due to the heat dissipation through the insulation. However, this effect is absolutely negligible due to the very good heat conductivity within the conductor. In fact, this effect is so small that it escapes any measurement accessibility.

As a result, in this PAS, the conductor surface temperature is equated to the conductor temperature.

This temperature is of outmost importance for the suitability of the insulation material at the interface, in order to avoid an overheating and a consecutive degradation of the insulation. Otherwise the health and safety issues cannot be guaranteed, as a melt down and the potential danger of self-ignition may otherwise occur.

The PAS is written in a general way, thus covering not only horizontal cables. The testing of stranded cord cables is covered as well, as they are installed in and close to the equipment rooms in higher cable count bundles as well.

4.2 The bundling of cables

To determine the maximum permissible heating of the data grade cables under simultaneous PoE / PoEP deployment, the consideration of the worst case conditions prevailing has to be