Dr.– Ing. J.– H. (Jo) Walling
Consultant
Cables – Standards – Machinery

Procedure to assess the heating of bundled data grade cables

Note: This is not a procedure to be rolled into a standard, as it is intended exclusively towards the assessment the capability of existing and future cables and cabling systems for power transmission. Once this assessment has been made the results will have to be reflected in the relevant codes, and this test method becomes obsolete.

0. Scope

The present proposal for a test method pursues several objectives:

a.) To provide a normalized test method which allows the assessment of the performance potential of the installed base of premises cabling, consisting basically of channels based on Category 5/5e.
b.) To provide a test method which allows the assessment of the performance potential of the newly developed premises cables and cabling classes. They use cables with substantially increased conductor diameters to cope with the more stringent attenuation requirements.
c.) To use the results of the obtained results to validate a Mathcad program simulating in a simplified model the temperature raise of the cables.
d.) To optionally heat the cables from the inside out, i.e. to heat first the center cable alone, then the center cable and the first layer, then add the second and finally the third layer.

1. Introduction

Any standard and code considering the “ampacity” of conductors, refers to the conductor surface temperature. This results out of the fact that some conductors are used at higher frequencies. It is also this temperature which is predominantly important for the suitability of the insulation material at the interface. However, here we refer only to conductor temperature as the current transfer within the PoE or PoEP projects covers DC currents (even AC currents of 60 Hz could be considered in the case conductor heating to be equivalent to a DC current) over the common mode circuits. Additionally we refer exclusively to four pair data grade cables.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

1.1 Background

1.1.1 The installed base

In order to be able to compare any heating test to the behavior of the installed base, they have to be carried our necessarily on the same type of cable, primarily with respect to its conductor diameters, but also with respect to it design regarding the heat transfer properties of its insulation and jacket.

The latter can be assessed only using very extensive test series, such that it is advisable to use a model and compare the obtained results to it.

This obviously implies that the conductors for all tests have to be identical.

In practice this is not possible. As a result it is proposed to use for the heating trial a current which is, with respect to the actual copper conductor diameter comparable to a standardized diameter, reflecting the traditional Category 5 / 5e cables.

Hence, under these constraints the minimal requirement for any heating trial test series, with the objective to obtain comparable test results within the limits imposed by the design, is to use tests which have equal and comparable heat generation with respect to their actual conductor diameters.

As PoE is to be deployed over the installed base, it is mandatory to consider a reference to something comparable to a basic Category 5/5e cable, as this represents the majority of the entire installed base.

However, in the standards there are only specified maximum conductor resistance values (19,0 Ω and 29,0 Ω per 100 m of cable for solid and stranded conductors, respectively).

This leaves a precise resistance definition very vague and for our purposes unpractical.

Hence it is proposed to use a standardized base diameter for a reference conductor and standardized copper resistance reference.

However, a normalization of the resistance of each pair within the cable is from a testing point of view impractical, as the pairs would need to have slightly different length. This would entail major errors at the ends of the cables with respect to the heat dissipation.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

1.1.1 The new installed higher performing cabling systems

The conductors of Category 6 and higher data grade cables of different manufacturers span a wide range of diameters.

In fact, the diameters of categorized cables increased such that some have easily 20 % ÷ 25 % (and more) reduced resistance compared to the Category 5e cables.

As a result such cables can inherently carry higher currents under similar conditions as applicable to the installed base of Cat. 5 / 5e cables.

For the testing of these cables to the full anticipated currents, the normalization to a Cat. 5 / 5e conductor diameter should not be applied. Hence the heating trial has to be carried out only with the currents anticipated for PoE and PoEP.

1.2 The heat dissipation in a conductor, cable and cable bundle

The simulation of any heating of a cable has to be reduced to the simplified case of a single heat source, in order to keep the mathematical effort within reasonable limits. This has been done in a program already presented to IEC SC46C WG7.

It is obvious that the heat dissipation changes slightly with increasing insulation and jacket thickness.

Hence, if we "normalize" our heating tests to a specified diameter and a specified resistance, we obtain results which are very slightly off those obtained with the exact diameter and proportionally reduced or increased insulation or jacket thickness. However, these differences are relatively minor, a fact which can be verified using the above mentioned program. Incidentally, this is also true for foam or foam skin constructions.

Hence we can safely ignore the effect of these minor changes which necessarily will result out of the design change to a cable with the reference conductor resistance and diameter, while having at least the same impedance.

The last described option in Section 0.d. allows also to assess the insulation capacity of the cables in layers, and will thus allow a more reasonable down-rating of the permissible current or a reduction of the permissible maximum ambient temperature to remain within the temperature approval range, which is based upon the conductor temperature.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

1.3 The temperature measurement

To measure the conductor temperature poses a problem. To measure the resistance of one conductor as a means to determine the temperature may be objectionable. The use of thermocouples or resistance temperature probes in a cable bundle would yield only a point measurement.

Furthermore these thermocouples or probes will have to be very small and the problem of introducing them up to the conductor surface is very difficult, if not impossible without destroying the integrity of the cable.

To measure the jacket surface temperature in a cable bundle does not allow a direct conclusion on the conductor temperature, hence the measurement of the jacket surface temperature has to be discarded

As a result it is proposed to use the pairs of some cable to assess the conductor temperature, and measure first their resistance at room–temperature and then follow the voltage across the pairs connected to a constant current source. The schematic to connect the pairs for measuring the temperature is shown in Fig. 1.

In the Fig. 1 it is assumed that the pair # 1 and the pair # 4 have the shortest and longest twist lay, respectively, while the pair # 2 and pair # 3 have the intermediate twist lays.

In this way we have at least two "pairs" of conductors with the same resistance, which helps to get faster to an equilibrium of the temperature across the entire cables used for the temperature measurement.

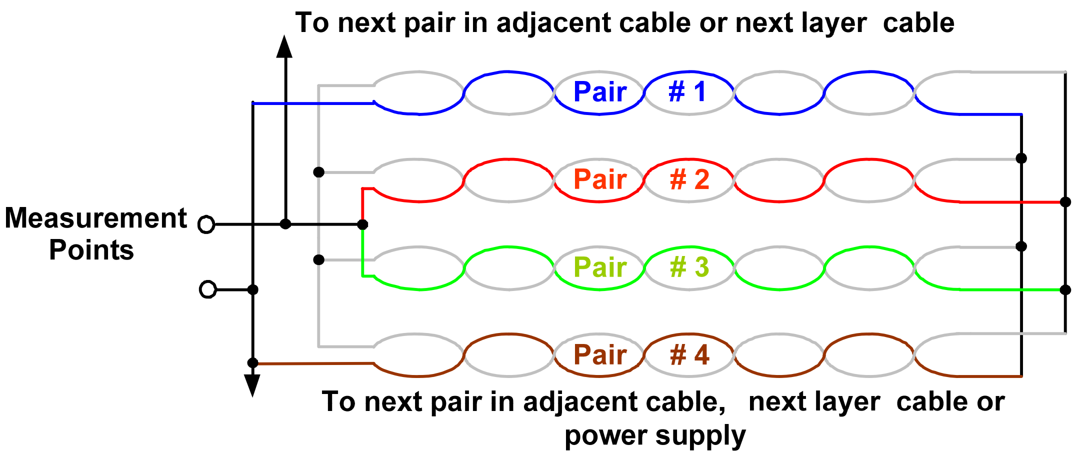

Fig.1: Connections on both ends of the center cable to obtain two slightly different "pair" resistances, which can then be measured using the voltage across all pairs.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

2. The resistance normalization

The entire Section 2 refers only to "normalized conductor diameter" measurements to assess the performance of the installed base.

The first step is to normalize the average resistance of the conductors in each cable to be tested to the nominal resistance of a 0,5 mm conductor.

2.1. The reference resistance

For the International Annealed Copper Standard at 20 °C we have:

$$IACS = 0{,}15328 \qquad \left[\frac{\Omega \cdot gram}{m}\right] \tag{1}$$

Hence we have for the resistivity, using the copper density of 8,89×10^{-3} [gr/mm^3]:

$$\rho = 0{,}0172418 \qquad \left[\frac{\Omega \cdot mm^2}{m}\right] \tag{2}$$

We have furthermore for the temperature coefficient of the resistance increase:

$$\alpha = 0{,}00393 \qquad \left[\frac{1}{^oC}\right] \tag{3}$$

Using these normalizing values we can now calculate the reference resistance for a 0.5 mm diameter copper conductor with a length of 1 m at 20 °C. We get:

$$R_{Ref.} = R_{1m;\,20\,^oC;\,0{,}5\,dia} = 8{,}781177 \cdot 10^{-2} \qquad \left[\frac{\Omega}{m}\right] \tag{4}$$

The Eq (4) indicates our reference resistance to which all our trial have to be normalized.

2.2. The normalization based upon heat generation

For the generated heat L of the reference conductor we have:

$$L_{Ref.} = I^2_{Ref.} \cdot R_{Ref.} \qquad \left[\frac{W}{m}\right] \tag{5}$$

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

There are two reference currents to be verified, i.e. the actually standardized current for PoE of 0,175 A and the preliminary targeted current for PoEP of 0,420 A both for a 0,5 mm conductors.

Hence these values represent our reference current values for calculating the heat generated, $L_{1Ref.}$ and $L_{2 Ref.}$.

Therefore, if the average resistance of the cable under test is R_{Cond} then the correspondingly generated heat is:

$$L_{Cond.} = I^2_{Cond.} \cdot R_{Cond.} \qquad \left[\frac{W}{m}\right] \tag{6}$$

The condition for the normalization is:

$$L_{Ref.} = L_{Cond.} \qquad \left[\frac{W}{m}\right] \tag{7}$$

Hence we get:

$$I_{Cond.} = I_{Ref.} \cdot \sqrt{\frac{R_{Ref.}}{R_{Cond.}}} = \left| \begin{matrix} 0{,}05185783 \\ 0{,}12445881 \end{matrix} \right| \cdot \frac{1}{\sqrt{R_{Cond.}}} \qquad [A] \tag{8}$$

Here the values in between the vertical lines (|…|) represent the values for 0,175 and 0,420 A, respectively.

PoE and PoEP are running and/or are anticipated to run the current over the common mode circuit. Therefore the pairs of the cables are connected together at their ends. Thus the current goes truly in all the cables surrounding the center cable through the common mode circuit, with the exception of the cables used for measuring the temperature, which are slightly differently connected, see Fig. 1, in order to minimize the resistance differences, and to avoid to the maximum extent non uniform longitudinal heating in the different pairs, which would affect the measurement accuracy. This is important, especially if we use cables with a cross–web which would act like as heat barrier between the different pairs. As it is not possible to harmonize the resistance across all four pairs, the pairs with the shortest and longest twist lays as well as both pairs the two intermediate twist lays should be combined. In the Fig. 1 these are the blue and brown pairs and the green and red pairs respectively.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
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To make it very clear, if the conductors are greater than 0,5 mm in diameter, then the test current will have to be increased according to Eq (8), in order to assess the approximate real heat dissipation of a comparable cable design, having 0,5 mm diameter.

The main objective of the entire exercise is to establish the maximum current limit for the installed base, which consists even up to date basically of Category 5/5e cables. Clearly we are not interested in the potentially higher current carrying capacity of larger conductor diameters, as used in Category 6 (7) and Category 6_A (7_A) cables, though we could use them for the heating trial using the above "normalization".

3. The testing procedure

The testing comprises basically three steps, be it for each reference current or for each current in case that the resistance normalization is not desired. In the following those cables, used for the temperature measurement are simply referred to a measurement cables.

3.1 Assessment of average measurement cable resistance

The first step is to measure the average resistance at the measured ambient room temperature of the measurement cables. It is suggested to carry the trials out in an air conditioned room having limited access to maintain a constant temperature (limiting thus a major change in the convection conditions). This room temperature will have to be measured and recorded.

In case of resistance normalization this value is required to adjust the measured average resistance to a 20 ºC value.

Further down it is proposed to use cable bundles of maximum 36 around 1, i.e a total of 37 individual cables. These should have a minimum length of approximately 5 m each, depending on the available room, the power supply and the milli– or micro voltmeter available.

Obviously the length limitation is dictated by the maximum voltage range achievable with the constant current source required for testing.

On the other side the length selected depends on the resistance bridge used to the initial resistance measurement and finally on the available instrument to follow the voltage across the measurement cable pairs.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
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As the conductors are connected in series the resistance of the total length of the "common mode" conductor length in the center cable will have to be measured and referenced to the average resistance of 1 m of conductor (in the cable) at a temperature of 20 ºC:

$$R_{Cond.} = R_{measured} \frac{1}{\ell \cdot \left(1 + \alpha \cdot \left(t_{room} - 20\right)\right)} \qquad \left[\frac{\Omega}{m}\right] \qquad (9)$$

Where:

$R_{measured}$	-	is the measured resistance
ℓ	-	is the total "common mode" conductor length, contained in the cable
t_{room}	-	is the measured room temperature
α	-	is the temperature coefficient of resistance increase, see Eq (3)

3.2 The bundling of the cables for the heating trial

For the bundling of the cables 37 length of cables have to be prepared, each having the predetermined length. The measurement cables should be 1 cm longer than the rest of the cables in order to allow the rather complex connection according to Fig 1. The remaining cable connections are made according to Fig. 2.

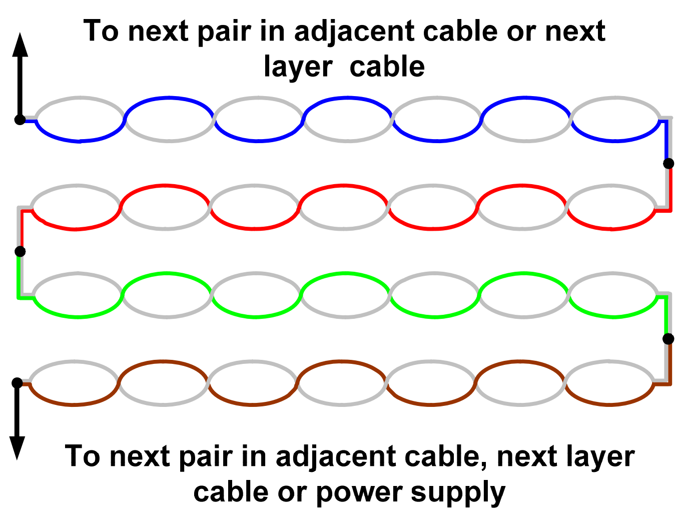

Fig. 2: End connections between the pairs of the peripheral cables around the center cable

33 cables will have to be stripped off their jacket on each end by approximately 8 mm. All the insulation of each conductor should then be stripped by 3 mm.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
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The four measurement cables shall be stripped off its jacket by 13 mm on each end. One conductor of each pair shall then be stripped by 3 mm from its insulation. The remaining conductors of the pairs shall then be back by 5 mm at one end and stripped as before. The insulation of remaining conductor shall then be stripped on each end by 5 mm.

The thus prepared cable ends can be further finalized by connecting the conductors pair-wise in series. This can be done on one end completely by twisting the conductors of each pair together. This twist is preferentially to be soldered and insulated it with a very short end of shrink tubing.

On the other side the conductors of each two pairs have to be chained and twisted with the exception of two pairs which serve to concatenate the cables in series. Their conductors should be simply twisted together to concatenate them later on after assembling the entire bundle.

Four measurement cables shall be prepared, one for the center of the bundle and one located in each layer of the bundle, in order to determine the temperature gradient across the layers, starting with the center cable.

To simplify the task of bundling the cables it is recommended to use a small plastic plate (a lay-plate) with 36 concentrically arranged holes around a center hole, see Fig. 3. The cables should be laid up parallel, i.e. without a lay.

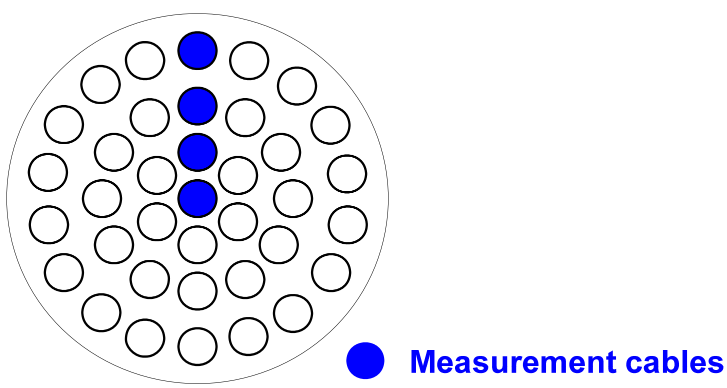

Fig. 3: Schematic of lay plate for a 1-6-12-18 cable bundle configuration with indication of the location of the measurement cables used to determine the temperature.

As a binder, it is recommended to use a smaller tex-count (~300 ÷ ~700 Tex) Kevlar or Twaron rowing. The main reason for this is the fact that this rowing does not tend to loosen when heated, as it has a negative expansion coefficient.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

To start, the measurement cables have to be fed through the “lay-plate” and then the remaining cables. This requires that the cable ends are prepared, but not yet concatenated. If the “lay-plate” is mounted in a fix position, approximately 30 cm of all cable ends should be pulled through and aligned with respect to their ends to start the wrapping with the poly-aramid rowing. The lay of the hand made wrapping should be approximately 1 to 5 cm. The bundle should be preferentially kept all time in a straight position, in order to avoid buckling, which otherwise would require a “stranding” of the cables.

3.3 The suspension of the bundled cables for the heating trial

The cable bundle should be suspended, in order to have it in a horizontal position, with an undisturbed convection to the surrounding air.

The completed bundle should be freely suspended in air using a suitable support structure or rack, such that there is a distance of approximately 20 cm between the support or rack and the cable bundle, as schematically shown in Fig. 4.

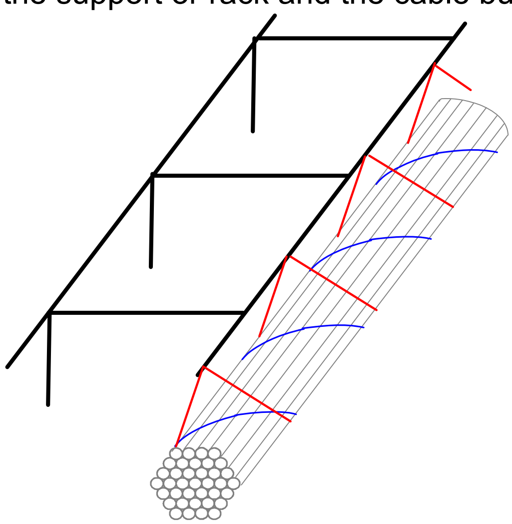

Fig. 4: Schematic of the suspension of the cable bundle

Only when the cable bundle is suspended, the remaining connections between the cable ends can be completed. The remaining cables should be connected in series including the measurement cables.

It is irrelevant where the power feeding ends are on the bundle. But it is preferable to have the power feeding ends in the outer layer of the cable bundle, opposite to the measurement cable in the outer layer, as there may be observed an end effect due to the feeding cables, which should be kept away from the measurement cables as much as possible.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
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However if the option described in the Scope under Section 0.d is followed, then it is preferable to use the measurement cables also a power feeding cables. Fig. 5 shows the required concatenation for heating additional layers from the inside towards the outside or from the outside towards the center.

Thus it is also feasible to simply heat any layer by itself and measure the resulting temperatures in the other layers, including the center cable.

If a small heavier gauge size lead is connected and soldered to the inlet and outlet, without affecting the concatenation of the pairs in between the cables, then the cut back to a lower or higher number of heated layers is easily feasible. In this case it is also feasible to heat only the outer layer for instance and measure the temperatures in the inner layers. This would yield a very good approximation for the required down rating in real installations.

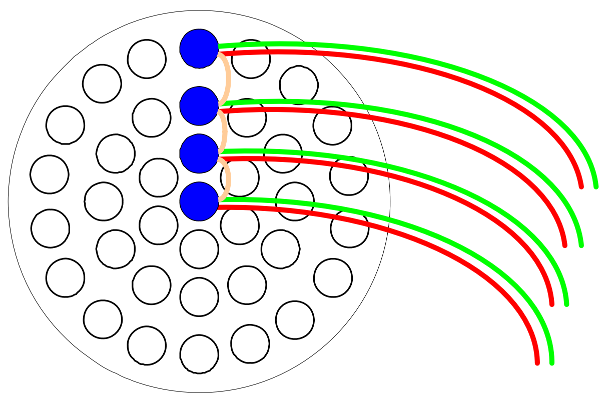

Fig. 5 : Concatenation of the cables for heating according to the option of Section 0. d.)

Once all the interconnections have been made, the power feeding circuit (s) should be tested for continuity.

Then the reference conductor pairs of the measurement cables should be connected to a high precision resistance meter or better a bridge, usually used for determining the conductivity, using flexible heavy gauge size leads. The measurement itself has to be made after a sufficient time to guarantee thermal equilibrium of the cable bundle with the surrounding room temperature (normally 24 hrs).

To minimize the end-effect, it is recommended to use an insulation foam spray, to cover all the cable ends, with the exception of the feeding leads and the measurement cable access points. Such thermal insulation foam sprays (poly-urethane based) are available in any hardware store. End caps on the cable ends are not recommended, as they fan out the cable ends.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

4. The heating trial

Before starting any heating trial the room temperature has to be measured, and then the resistance of the reference conductor "pairs" has to be measured.

For the heating trial a constant current source is required, matching the required cable bundle length. The author used in the past a double power supply from Hewlett Packard having 50 V DC each with a maximum current of 5 A. As an even number of conductor pairs in series is heated, the feeding ends are on the same end of the cable bundle. The connection to the power supply should be made with a heavier gauge size wire, which should be suspended such as to allow very good heat convection, such that they are not affected by any current heating, but remain at room temperature.

The current should be set to either the calculated value according to Eq (8) in case a normalization is required or the specified current for PoE or PoEP.

But before connecting the power, it has to be made sure, that the cable bundle is exposed sufficiently long to the surrounding room temperature to attain temperature equilibrium. Only then the room temperature and the resistance of the reference wire shall be measured.

Then the current to the conductors shall be switched on and it should be verified, that the current is on the targeted value.

It is recommended to wait for at least 24 hours for temperature equilibrium. Then the room temperature should be verified and the resistance of the reference wire should be determined by exactly measuring the current across all wires and the voltage drop across the reference "pairs" of the measurement cables.

5. The calculation of the conductor temperature of the measurement cables

The previously mentioned 24 hour stabilization temperature is required, as the reference wires of the measurement canles will have to reach the equilibrium temperature on all conductors of these cables.

We have then for the conductor temperature in the measurement cables under current load conditions:

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

$$t_{cond.} = \frac{1}{\alpha} \cdot \left(\frac{R_{Heated}}{R_{20}} - 1 \right) + 20$$

or: $\left[\frac{1}{^{o}C} \right]$ (10)

$$t_{cond.} = \frac{1}{\alpha} \cdot \left(\frac{R_{Heated}}{R_{measured}} - 1 \right) + t_{room}$$

Where:

$t_{Cond.}$	-	is the temperature of the reference wires of the measurement cables, equivalent to the heated conductor temperatures
R_{Heated}	-	is the measured resistance after the 24 hour heating period at start
R_{20}	-	is the calculated resistance at reference temperature of 20 ºC

The resistance of the heated wire "pairs" is then determined according to the Eq (11):

$$R_{Heated} = \frac{U_{4\,Pairs}}{I_{Cond.}} \quad [\,\Omega\,] \tag{11}$$

Where:

$U_{4\ Pairs}$	-	is the measured voltage across the reference "pairs", measured in mV or µV, depending on the length of the cable bundle and the resistance R_{20}
I_{Cond}	-	is the heating current according to Eq (8) re-measured

With Eq (11) we have now the conductor temperature for a 36 around 1 configuration of cables. The results may be normalized to a conductor diameter of 0,5 mm diameter, or refer directly to the actual conductor diameter. The Eq (11) has to be calculated for each measurement cables individually. Using Eq (10) consecutively allows then to determine the conductor temperature in each of the measurement cables, resulting in the gradient across the layers, starting with the center cable and going over the three layers of cables used in the trial.

This allows the extrapolation to a higher number of cable layers in the bundle, and allows as well a validation of the Mathcad model before applying it to a lower number of power loaded cables in the bundle.

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

6. Accknowledgement

I am grateful to Erik Bech who picked up a mistake in the original document and kindly pointed it out to me for correction. I am also indebt to him for his insisting to extend the test method to cover cables with slightly higher conductor diameter for assessing their usefulness to an eventual deployment of PoEP over cabling systems using these cables.

7. A note of precaution

So far basically horizontal cables have been considered. However, the cables used for equipment cords and patch cords are frequently bundled in high numbers in the equipment rooms. If these rooms are not air conditioned, then there may be a substantial problem, mainly due to the fat that these stranded cables have a substantially higher resistance. In this case these cables are heating up much higher than the horizontal cables.

The work area cords are normally less affected, as they are normally individualized, and as the ambient temperature is normally below 35 °C (above this temperature it is conjectured that the working force is leaving to jump into a swimming pool).

Both the types of cables mentioned above may be affected nevertheless by the deployment of "mitigation techniques" to cope with the alien cross-talk problem for the 10GBase-T protocol. In fact several manufactures as well as TIA recommend the utilization for UTP systems of shielded cords both in the work area and the equipment room. Frequently these cords have conductor diameters down to 0.32 mm, thus not even fulfilling the minimum requirement of a down grading of 50 % of the attenuation relative to the horizontal cable.

As a result these cables may heat up to a much higher extent than normally anticipated.

Jo Walling
Beaconsfield, Feb. 28, 2006

431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063 Fax: (514) 695-8220
Email : jo.walling@sympatico.ca