Finite element analysis of cables heating due to PoE/PoE+

Sandrine FRANCOIS
Nexans Research Center
170 avenue Jean Jaures
69353 Lyon cedex 07 – France
sandrine.francois@nexans.com

Patrick NAMY
SIMTEC
8 rue Duployé
38100 Grenoble - France
patrick.namy@simtecsolution.fr

Abstract

Power over Ethernet (PoE/PoE+) is a technology allowing to transmit data and power over the same data cable. The major concern for this technology is the degradation of data transmission performances due to the temperature increase in the cable.
To have a better quantitative and qualitative knowledge of the temperature field in the cables, Nexans has developed a 2D finite element thermal model thanks the software COMSOL Multiphysics^{TM}. In this model, the heat source is due to the joule effect, depending on the intensity level. This thermal model enables us to take into consideration several configurations of cable bundles and to optimize the temperature field thanks to cable design.

Keywords: PoE, category cables, LANmark^{TM} cables, Ethernet, cable bundle, heating, thermal modeling, finite elements.

1. PoE/PoE+

From PoE to PoE+

Power over Ethernet (PoE) has been used in certain networking applications for more than 5 years with great success. IP telephones, wireless LAN access points and Web cameras are among the most used PoE devices. The IEEE standard (IEEE 802.3af) [1] was developed for use with Category 3 and Category 5 cables and delivers 12.95W to the end equipment at a distance up to 100m.
There are many other pieces of networking gear that need up to 40W such as video IP phones, pan-tilt-zoom IP cameras, and point-of-sales and information kiosk. Other like laptop computers, even require up to 70W. Recognizing this, the IEEE started development of a follow-on standard – PoE plus (IEEE 802.3at) [2].

Cable heating

Data cables were not originally designed for transmitting power, so careful consideration must be taken while specifying cabling solutions. The most pressing concern is degradation of performance (higher insertion loss) from increase temperature in the cable. This can be an issue especially in high cable density area such as data centers. To this end, Nexans Research Center has measured and modelized the heating of cables for PoE and PoE+ applications.

2. Nexans thermal model

We have developed a model allowing to compute heating of a cable or a cable bundle depending of the DC current in it. Physical mechanisms taken into account are conduction (for internal heat transfer), convection and radiation (for external heat transfer with air).

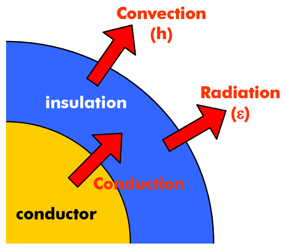

Figure 1 : Internal and external heat transfer in a cable

The model is a finite element model based on COMSOL Multiphysics^{TM}. A 2D stationary calculation is used to obtain temperature distribution on a cross-section for all category cables (UTP, FTP, STP, SFTP).

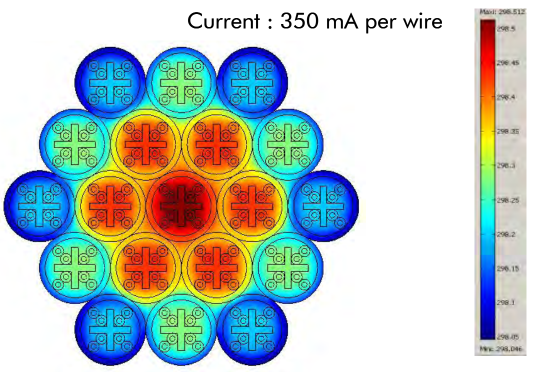

Figure 2: Temperature distribution within a 19-cable bundle - Cat6 FTP – PoE.

The resulting PDE reads:

$$\nabla.\left[-\frac{1}{\rho(T)}\nabla T\right]=Q \qquad \text{[Eq1]}$$

where the main parameters are thermal conductivities (copper, insulation, sheath, air, aluminum if screened), radiation and convection coefficients, ambient temperature (see Eq3). The heat source, Q, is the Joule effect in energized conductors, taken into account the temperature dependence of the copper resistivity:

$\rho(T) = \rho(T0).[1+\alpha.(T-T0)]$ with ($T0=20°C$, $\rho(T0)=1.7e\text{-}8\ \Omega.m$, $\alpha=3.93e\text{-}3$ [1/K]) [Eq2]

<u>Boundary conditions</u>:

$$-\vec{n}.J = h\left(T_{amb}-T\right)+\epsilon\sigma\left(T_{amb}^4-T^4\right) \qquad \text{[Eq3]}$$

where n is the outward normal unit vector, J the conductive flux, T the temperature, Tamb the ambient temperature, ε the emissivity and σ the Stefan constant.

Several meshes have been tested to check numerical solutions. The shown results are computed with 135000 Lagrange triangular quadratic elements, associated with more than 270000 DOF (typical for 61 cable bundle).

3. Experimental validation

The model has been validated by temperature measurements on different category cable bundles:

- bundles of 7 (1+6) Cat5e, Cat6, Cat7 LANmark^{TM} cables
- bundles of 19 (1+6+12)Cat5e, Cat6 LANmark^{TM} cables
- 1 bundle of 37 (1+6+12+18) Cat7 LANmark^{TM} cables

Experimental set-up

Copper resistivity varies with the temperature, according to [Eq2]. Measuring electrical voltage U between both ends of a cable, knowing injected direct current I, one deduces the electrical resistance R (U=R.I) and then the conductor temperature.

$$T = \left| T_{.0}+\frac{1}{\alpha}\cdot\left[\left[1+\alpha\cdot\left(T_{.init}-T_{.0}\right)\right]\cdot\frac{R}{R_{.init}}-1\right]\right.$$

$R_{.init}$ is the resistance at ambient temperature T_{init}.
$T_{.0}$ is the reference temperature (293K).

This temperature dependence is the basis of the temperature measurement inside cable bundles. Within a cable, pairs are connected in series. Within a bundle, cables are connected in series. Voltage measurement on each successive layers f cables inside the bundle allow to obtain conductors temperature for each layer. To complement this measure, sheath temperature is also measured using a contact probe. For 3m length bundles, we obtain a measurement precision of +/-3°C.

Figure 3: Experimental set-up

Comparison with modelling results

For all bundles characterized (up to 37 cables), modeling results and temperature measurements are in good concordance, within the measurement precision (+/-3°C).
Comparison between modelling results and temperature measurements for a 7 Cat5e FTP bundle are shown on Figure 4 (conductors temperature) and Figure 5 (sheath temperature. Calculated convection coefficient h is equal to 3 W/m^2/K for 7 Cat5e FTP bundle [3].

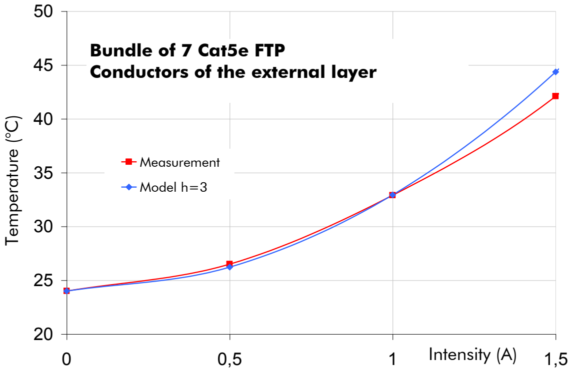

Figure 4: Modeling results and temperature measurements of the conductors of the external layer.

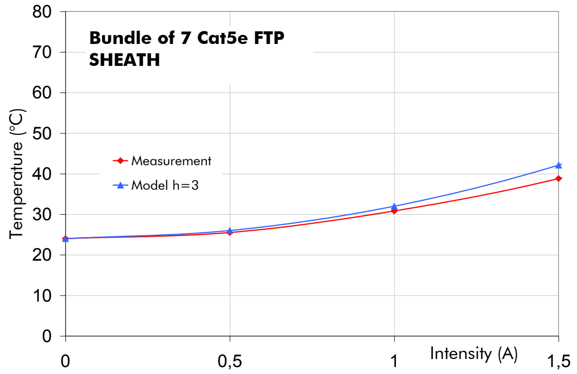

Figure 5: Modeling results and temperature measurements of the sheath of the external layer of cables.

Some comparisons have been made with temperature measurements provided by TIA for larger 100-cable bundles. Concordance obtained was also very good.

4. Temperature increase estimation for large bundles

Based on this good concordance between the modelling and experimental results, we can use the thermal model to estimate temperature increase in large category cable bundles.

The graph on Figure 6 shows the calculated temperature increase in category cable bundles for PoE (2 pairs energized, 0.175A per wire). Maximum temperature rise is obtained for category 5 UTP cables but is not high (around 2°C for a 169-cable bundle).

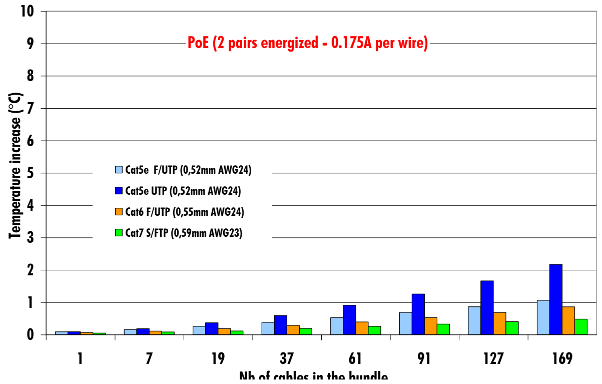

Figure 6: Calculated maximum temperature increase for PoE as a function of the number of cables in the bundle.

For PoE+ (see Figure 7) temperature rise is obviously higher: 9°C for a 169 category 5 UTP cable bundle.

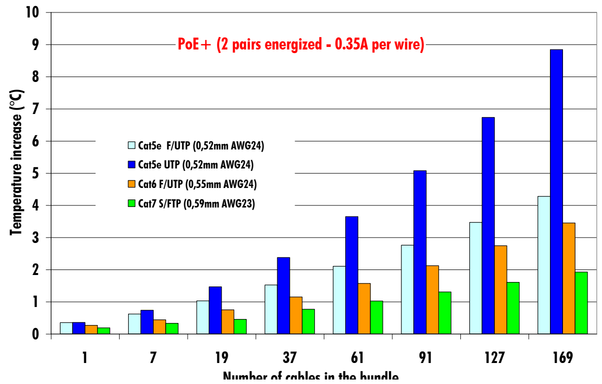

Figure 7: Calculated maximum temperature increase for PoE+ as a function of the number of cables in the bundle.

On Figure 8, one can see the comparison between AWG23 and AWG22 category 7 cables. The heating due to PoE+ for Cat7 cables is very low: below 2°C for a 169-cable bundle. The difference between AWG22 and AWG23 Cat7 cables is negligible: below 0.5°C for a 169-cable bundle.

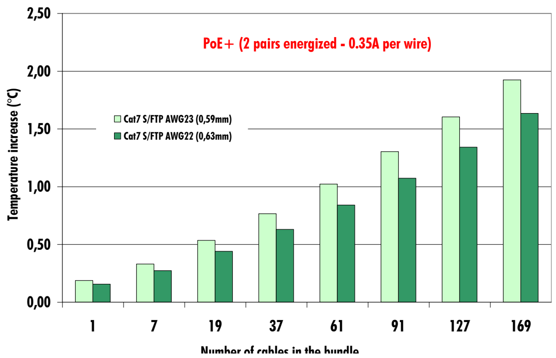

Figure 8: Calculated maximum temperature increase for Cat7 (AWG22 or AWG23) cable bundles.

Contribution to IEEE802.3at

One of the major concerns to overcome for this new standard PoE+ was the possibility of cables in bundles overheating when trying to deliver higher power.

Temperature rise affect cable performances: Insertion loss will be increased by about 4% per degree and a 10°C increase would require 0.35dB more in margin or a shorter link.

IEEE802.3at has worked on a specification to limit this increase to less than 15°C. Thanks to the thermal model developed by Nexans, it was possible to estimate the maximum current in each wire allowing not to reach this temperature increase even for large cable bundles (see **Tableau 1**).

Temperature rise	Maximum allowed current per pair
5°C	420mA
7.5°C	550mA
10°C	600mA
12.5°C	680mA
15°C	720mA

Tableau 1: Current capacity for a category 5 100-cable bundle.

Conclusion

Nexans has developed and validated a 2D finite element thermal model allowing to estimate the temperature of large category cable bundles for PoE and PoE+ technologies.

This thermal model has been very useful to overcome one of the major concern of the new standard POE+ dealing with the overheating of cables in bundles when trying to deliver higher power.

It is also very helpful to show the benefits of a better cabling, allowing for example to deliver higher power for the same temperature rise. High category cables lead to lower temperature increase, as well as screened cables (SFTP).

Next steps are now the 3D modeling of the cable with connectors (RJ45/GG45) and the development of a more general thermal model for data centers, including the free or forced convection phenomenon. Such consideration implies the use of the Navier-Stokes equations and their computation with the new CFD solver of the version 4.0a of COMSOL Multiphysics™.

References

[1] IEEE Std 802.3af™-2003, IEEE standard for information technology - Telecommunications and information exchange between systems – Local and metropolitan area networks- Specific requirements, Part 3, amendment 3: Data terminal Equipment (DTE) power via the media dependent interface (MDI) Enhancements

[2] IEEE standard 802.3at™ – 2009

[3] Convection heat transfer, Adrian Bejan, Wiley, 2004.