Transient validation method: a new approach

Introduction

One of the European PROFIT Project goals is the generation of transient thermal compact models for some IC-packages.
Hence it is necessary to create detailed models and to validate them by comparison with experimental data.
Package validation results are presented in PROFIT deliverables D4.3.1 and D4.3.2.

Validation for our models seems difficult especially at short times ($t < 100$ ms), because not only discrepancy between measured and simulated temperature profile is very high (percent error up to 50%, in some cases), but also deviations between time constant spectra and structure functions are still very big.

To solve these accuracy problems, we have tried to use another method to create simulation model. Before describing it, it's better to summarize the main features of previous method.

First validation method limits

First of all, geometric model is created.
Then to verify it, we did steady state simulation and we compared model results with experimental ones. So we fixed model properties using steady state experimental data, for each different boundary condition (i.e. for each DCP configuration).
In these conditions to obtain steady state experimental value by simulation model, we can change some package and boundaries parameters: thickness and material for Underfill between package and cold plate, ambient heat transfer coefficient, simplified geometric parameters, etc.

The problem is that when we started running transient simulations, we found out discrepancies between experimental and simulation profiles especially at short times, but we couldn't improve the model accuracy, because it was quite impossible to change simulation parameters without varying also steady state values.
Moreover this approach has not a physical meaning, but it's only a computing exercise.
To introduce another validation method, we have to change the way to approach the problem.

New validation method

Temperature profile depends on different parameters, considering the different time range. In particular the thermal response at short times (below 100 ms) should not depend too much on the "world outside" the package. It is quite reasonable to assume that the silicon itself and, at minor extent the die attach material, determines the temperature rise after few milliseconds, while, for higher time, materials surrounding the chip (epoxy moulding resin, substrate, slug, etc. depending on package structure) contribute the most in temperature change.
Finally after some hundreds of milliseconds ($t \geq 500$ msec) boundary conditions are the main parameters, like heat transfer coefficient value, interposer material, etc.
In other words, time constants, which are variable for each material, are responsible of temperature rise profile in different time ranges.

From these considerations, we created the package model and we started the validation process, without considering steady state results. We performed transient simulation, proceeding "step by step" in time; at each time interval, material properties of which time constant corresponded to the considered time range were the alone variable parameters.

This technique leads to a better agreement between experimental and simulation data, since all the modelled profiles (temperature rise, structure functions and time constant spectra) show the same trend than the measured ones.

Now we will present results for new validation. Comparison between measured, old and new simulation curves will be shown.
For this analysis we have chosen two packages: FLEXIWATT25 (ST Series 1) as example for power package, and LFBGA12x12, 168 (ST Series 2) representative of BGAs family.
DCP3 *(junction to case)* and DCP4 *(junction to ball)* configurations have been used for FLEXIWATT25 and for LFBGA12x12, 168 respectively; as a matter of fact they are the most representative configurations for these packages, because quite all package materials are involved in thermal dissipation. On the other hand, for example, for FLEXIWATT25 in DCP2 configuration, resin contribute is quite zero, because heat is dissipated quite only by the exposed slug. Same considerations can be done for BGA substrate in DCP3 configuration.

FLEXIWTT25 Transient Simulation

Figure 1 shows experimental die temperature profile, compared with both old and new simulation curves.

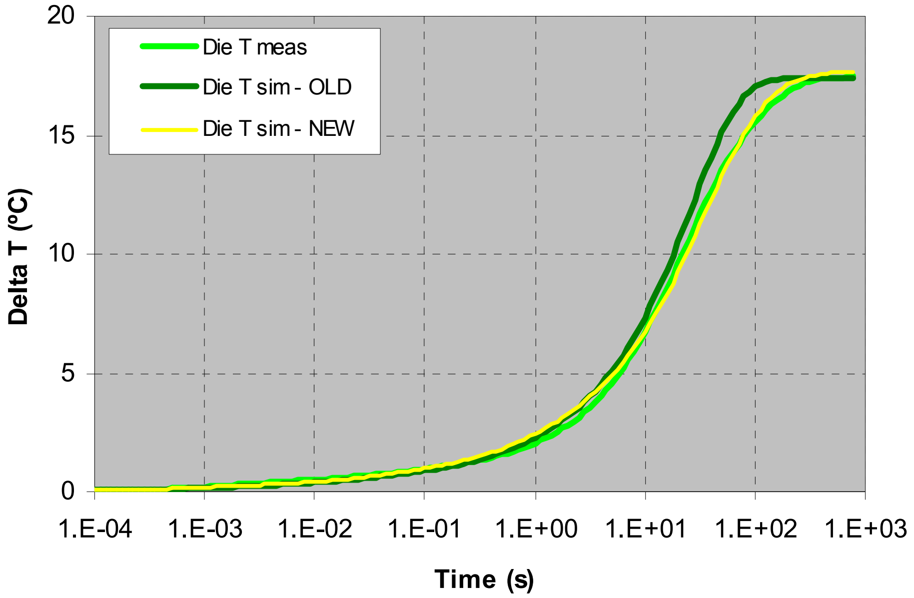

Fig. 1: FLEXIWATT25 – DCP3: Die Temperature Curves (P = 2 W)

Fit improvement gained by new simulation temperature profile is evident, almost qualitatively. For example we can see that after 10 s, previous simulation temperature rises too rapidly, reaching steady state too soon, about 400 s before measured profile.

Pictures above present absolute and relative error. In general new simulation error is less than the old simulation one; the same for the maximum percentage error (~ 20% *vs.* ~ 28%). Even if improvement is not too large, the point is that now simulated and measured temperature profiles show the same trend.

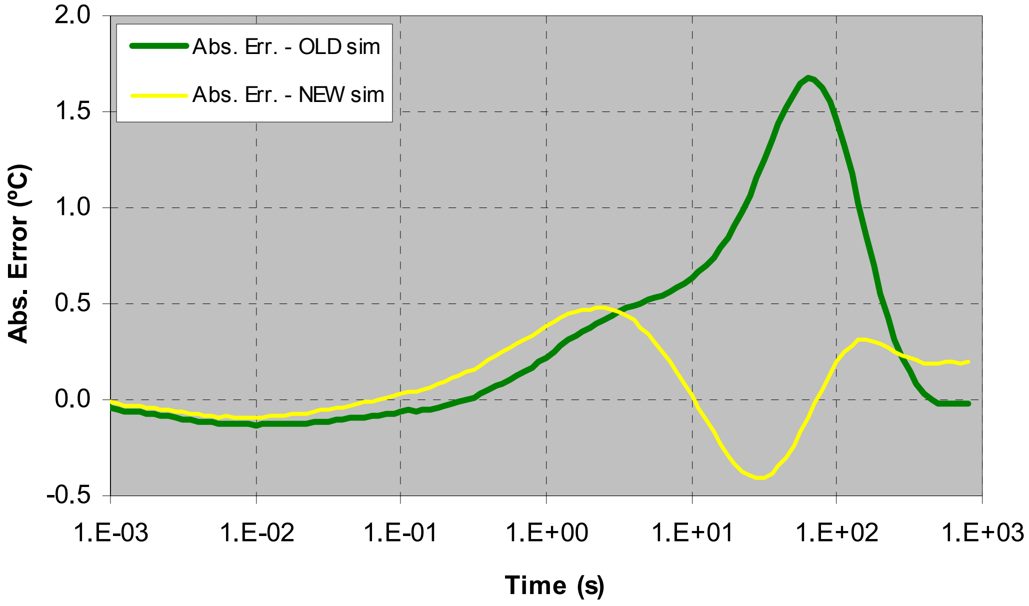

Fig. 2: FLEXIWATT25 – DCP3: Temperature Absolute Error

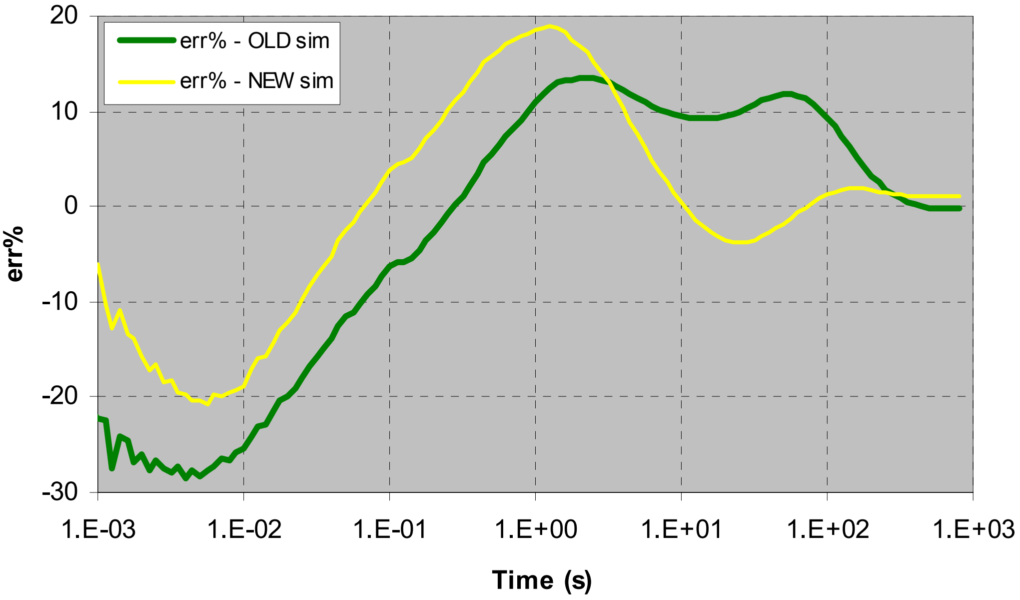

Fig. 3: FLEXIWATT25 – DCP3: Temperature % Error

To complete this analysis, we can see also time constant spectra and structure functions profiles (figure 4, 5).

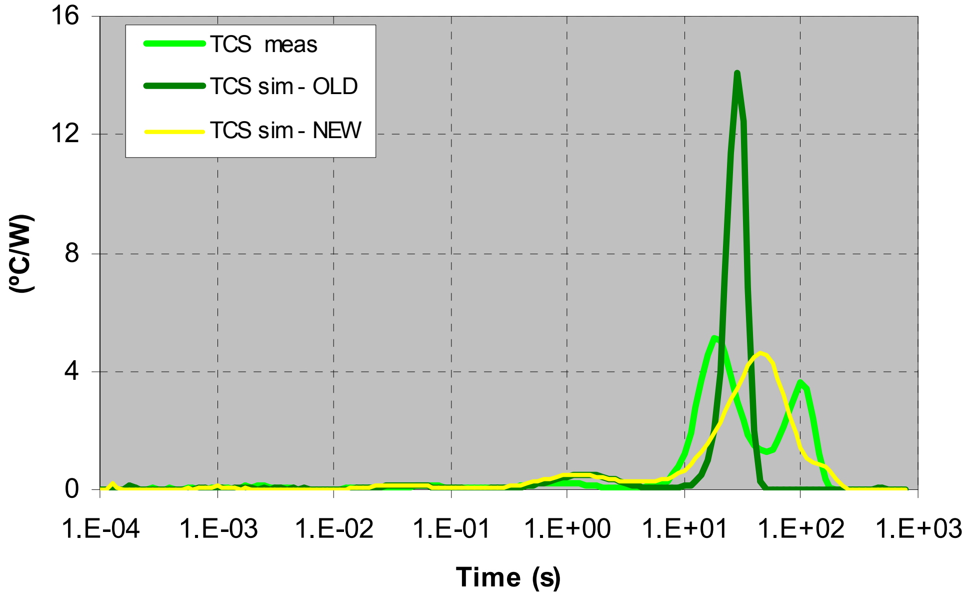

Fig. 4: FLEXIWATT25 – DCP3: Time Constant Spectra

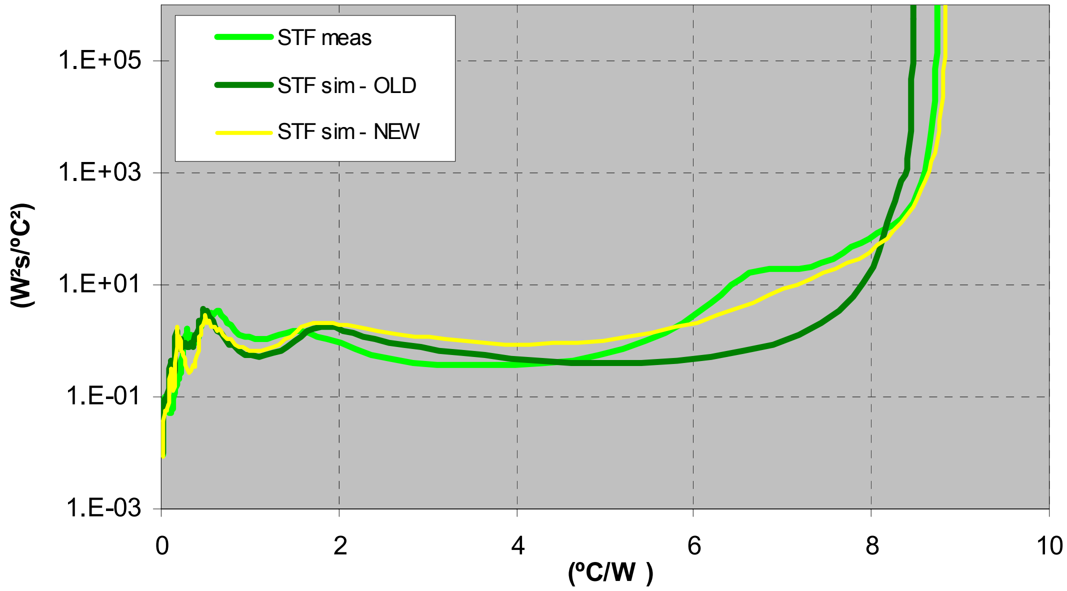

Fig. 5: FLEXIWATT25 – DCP3: Structure Functions

Expectation from time constant spectrum and structure function analysis is to identify possible changes to be introduced in the FEM model. This is reasonably within the capability

of structure function approach. Actually, the comparison between simulated and measured structure functions does not appear so straightforward. It is not possible to recognize a correlation between temperature errors and structure function mismatch. That is at least our limited understanding based on a relative short time practice with this methodology. We do not exclude that a more "skilled" eye could recommend some modification to FEM model educated by structure function inspection.
In any case, by graphs shown in figure 4 and 5, we can see new simulation curves fit experimental ones better than previous simulations, since they have similar trend.

LFBGA12x12, 168 Transient Simulation

All previous considerations, done for FLEXIWATT25, are valid also for LFBGA12x12, 168. In particular temperature rise founded out from old simulation presents same problem in time reaching steady state conditions, while curve got by new validation method shows good agreement with experimental data (see figure 6).

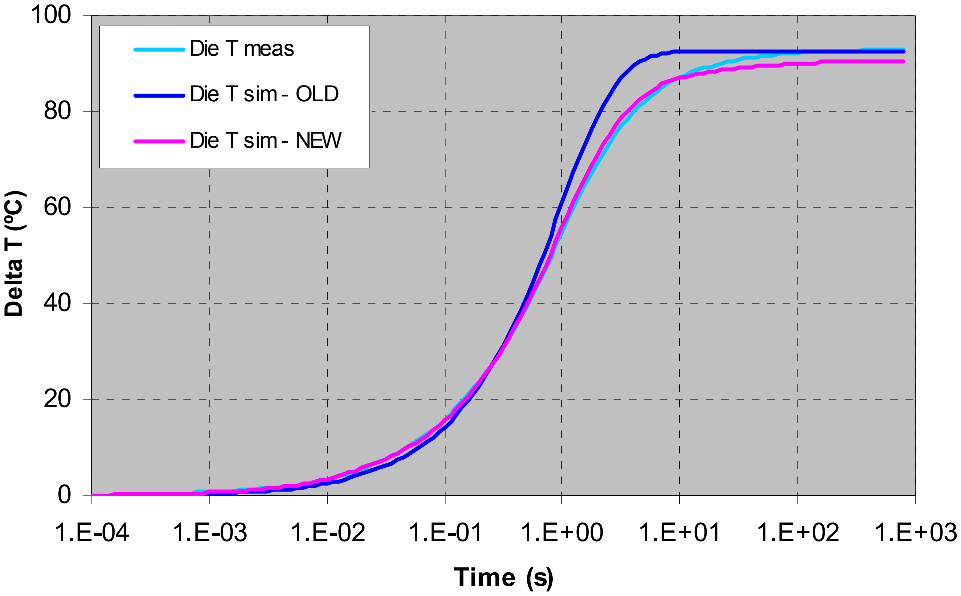

Fig. 6: LFBGA12x12, 168 – DCP4: Die Temperature Curves (P = 6 W)

New validation method reliability is confirmed by error calculations: new models always have smaller error than the previous ones. Moreover maximum relative error is ~ 15% at first time, but after 100 ms it's always less than 10%, that is better than our target.
Error profiles vs time are presented in figure 7 and 8.

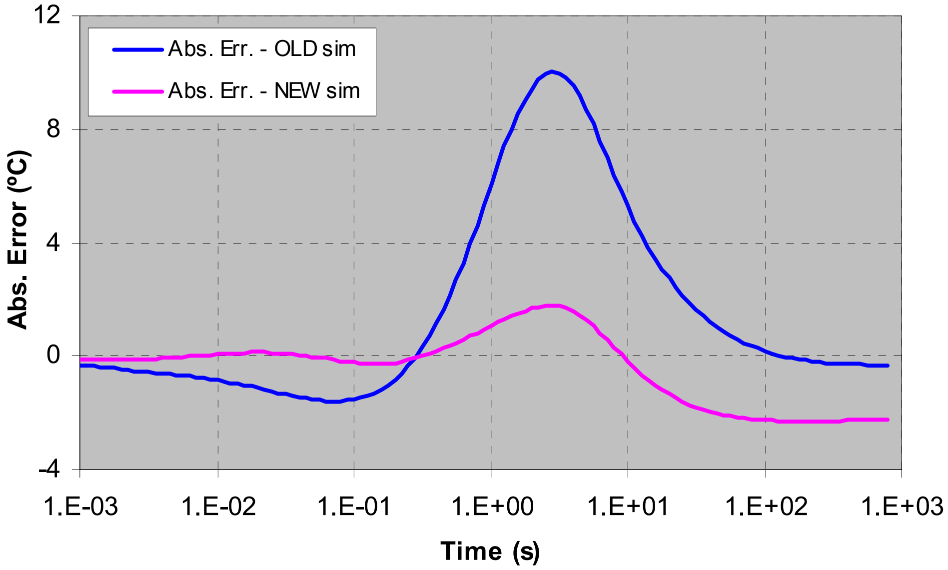

Fig. 7: LFBGA12x12, 168 – DCP4: Temperature Absolute Error

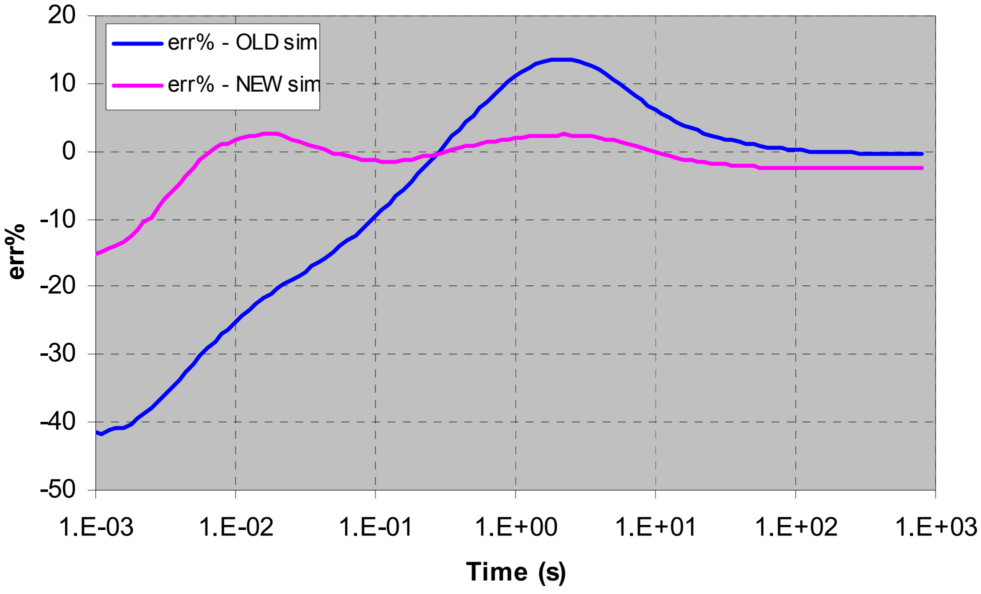

Fig. 8: LFBGA12x12, 168 – DCP4: Temperature % Error

Finally, time constant spectra and structure functions are plotted in picture 9 and 10. For these graphs we can do same observations than for FLEXIWATT25 study (see previous paragraph).

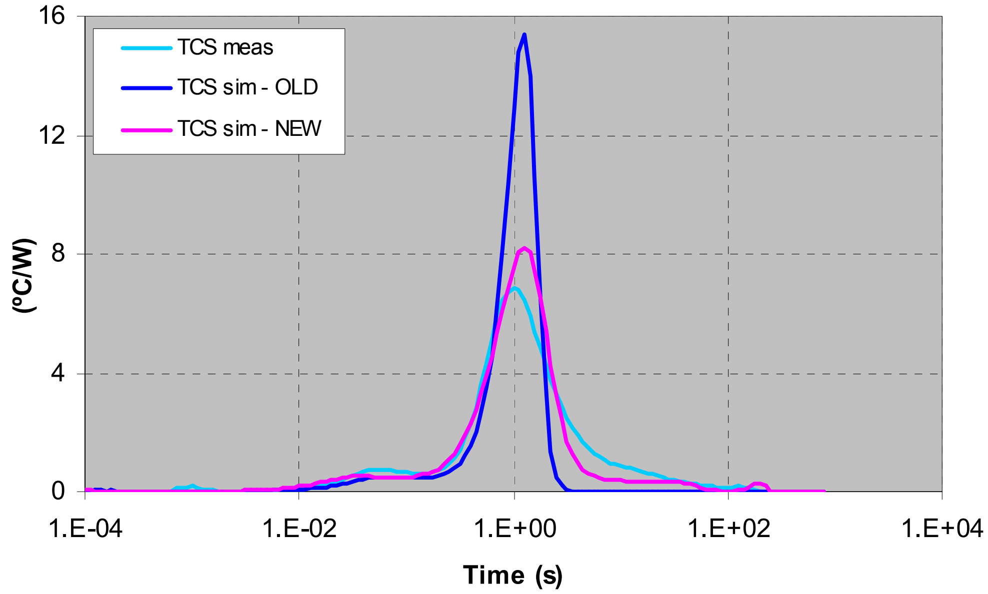

Fig. 9: LFBGA12x12, 168 – DCP4: Time Constant Spectra

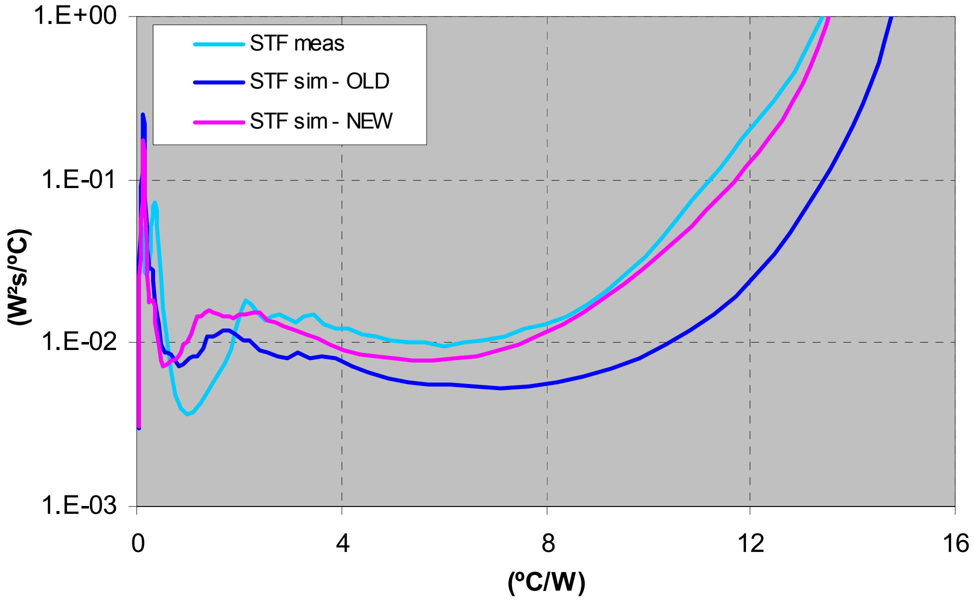

Fig. 10: LFBGA12x12, 168 – DCP4: Structure Functions

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