Designing for mK / µK
A challenge also for thermal solvers ?

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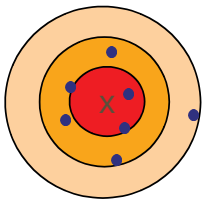
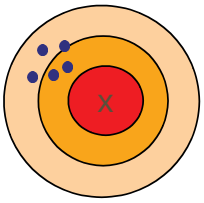
INTRODUCTION

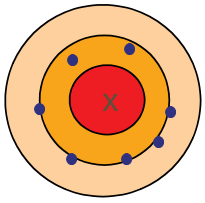
- **In some space programs *(e.g. GAIA, GOCE)* a high accuracy and precision are requested to numerical simulations, down to the levels of milli-Kelvin or even to micro-Kelvin (for temperatures and gradients).**



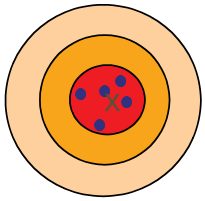
Not precise / not accurate



Precise / not accurate



Not precise / accurate



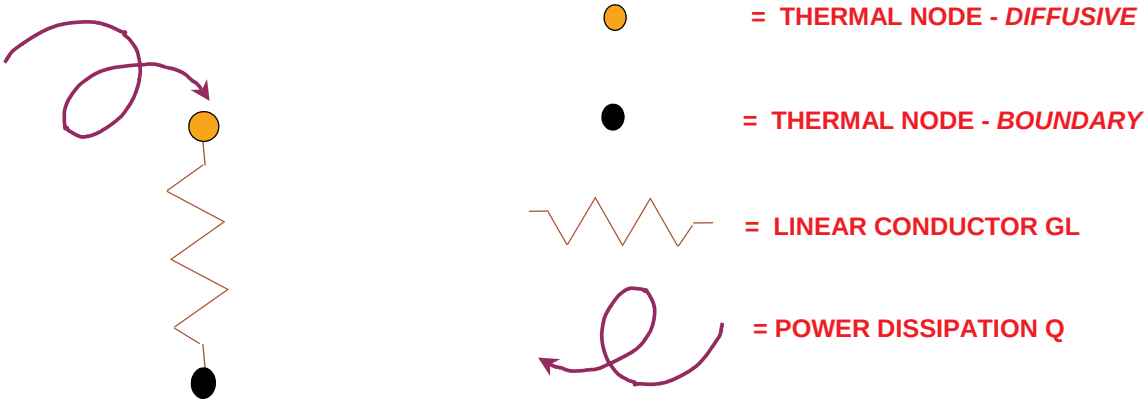
Precise / accurate

Accuracy -> average deviation **Precision -> standard deviation**

INTRODUCTION

- **Are the available solvers able to guarantee adequate results in front of these requirements ?**
- **To verify this, a simple 2-nodes model has been built to compare the ESATAN numerical solution with the analytical one.**
- **This very simple problem allows to assess the ESATAN numerical precision and accuracy and also to identify the parameters which affect them.**

2-NODES MODEL WITH IMPOSED THERMAL POWER



Thermal balance equation:

$$C * dT(t) / dt = Q(t) + GL \cdot [\ T_{boundary} - T(t)\ ]$$

with: $Q(t) = A \cdot (1 + \cos \omega \cdot t\ )$

2-NODES MODEL WITH IMPOSED THERMAL POWER (cont'd)

- **Analytical solution:**

$$T(t) = T_{boundary} + \left\{ \left[T_{t=0} - T_{boundary} \right] - \frac{A}{C}\left(\frac{1}{\alpha} + \frac{\alpha}{\alpha^2 + \omega^2} \right) \right\} \cdot \exp(-\alpha t) + \frac{A}{C \cdot \alpha} + \frac{A}{C} \cdot \frac{1}{\alpha^2 + \omega^2} \cdot \left(\alpha \cos \omega t + \omega \sin \omega t \right)$$

where: α = GL / C, ω = 2π / T

- **Several test cases have been made, each characterized by different values of parameters (linear conductor GL, specific heat, mass, boundary temperature, dissipated power)**

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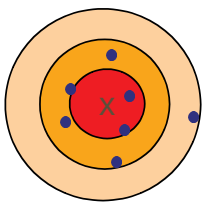
2-NODES MODEL WITH IMPOSED THERMAL POWER (cont'd)

- **For each test case several runs have been made to assess the effect of the ESATAN convergence control parameters.**
- **The difference ESATAN – analytical solution is the accuracy (actually the accuracy should be the average deviation of error for all runs with different values of control parameters, but in an analysis campaign such parameters are not explored estensively).**
- **The deviation of the accuracy with the convergence control parameters corresponds to the precision.**

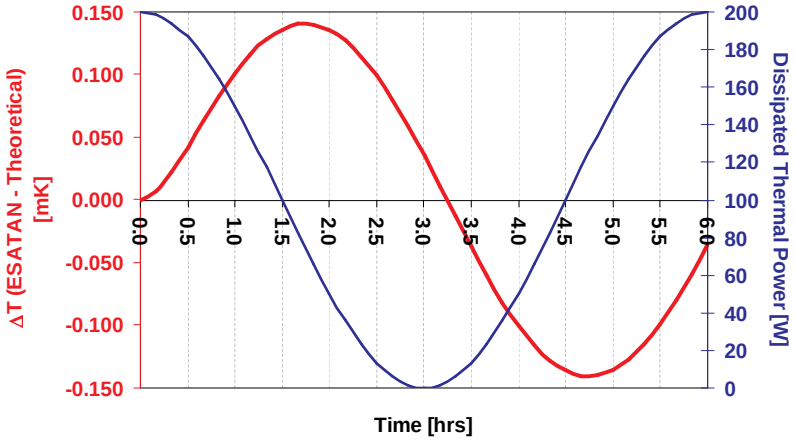


VERIFICATION OF ESATAN PERFORMANCES

Case with:

A = 100 W, m = 1 kg, c = 900 J/kg·K, Tb = T0 = 20 °C, GL = 1 W/K

Integration time step Δt = 0.01 s, Period T = 6 hrs



Time [s]	ESATAN Solution [°C]	Theoretical Solution [°C]	Difference [°C]
0	20.000000	20.000000	0.000000
1200	165.292930	165.292908	0.000022
2400	193.988628	193.988565	0.000063
3600	184.465538	184.465438	0.000100
4800	159.444963	159.444835	0.000128
6000	**127.631248**	**127.631107**	**0.000141**
7200	94.360541	94.360405	0.000136
8400	64.040898	64.040784	0.000114
9600	40.433468	40.433388	0.000080
10800	26.413110	26.413074	0.000036
12000	23.678121	23.678134	-0.000013
13200	32.560291	32.560351	-0.000060
14400	51.988800	51.988900	-0.000100
15600	79.620417	79.620545	-0.000128
16800	112.122395	112.122536	-0.000141
18000	145.574526	145.574662	-0.000136
19200	175.941990	175.942105	-0.000115
20400	199.562024	199.562104	-0.000080
21600	213.585703	213.585739	-0.000036

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VERIFICATION OF ESATAN PERFORMANCES (cont'd)

Maximum ΔT [mK] ESATAN - Analytical solution	Integration time step [s]	
Relaxation Constant	*0.01*	*0.1*
1.00E-10	0.141	1.403
1.00E-05	0.141	1.403
1.00E-03	0.141	1.403

From all the test cases:

- **No effect of RELXCA on solution accuracy can be appreciated for little models**
- **Very small time steps and RELXCA not compatible with ESATAN internal limit (one million steps maximum)**

CONCLUSIONS

- For this very simple linear model (no GR) the accuracy of ESATAN is of the order of 0.1 mK
- Accuracy can be somewhat reduced (not to μK levels) using very small time steps, but this is unfeasible with large models
- Accuracy for complex models can not be assessed, but it is reasonable to assume it is higher than mK
- With networks containing GR instead of GL, error is expected to increase as effect of non-linearity and necessary iterations within ESATAN

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CONCLUSIONS

OPEN POINTS:

- Is it possible to design a TCS with requirements in terms of mK / μK with the standard solvers ?
- Is it possible to improve the standard solvers accuracy ?
- Is it necessary to calculate also precision?
- Is it possible to achieve a TCS with requirements in terms of mK / μK with the classic procedure based on analysis (iterations design/analysis and subsequent tests) ?