Appendix G

ESATAN2SS tool
from ESATAN to Space State

Savino De Palo
(Thales Alenia Space, Italy)

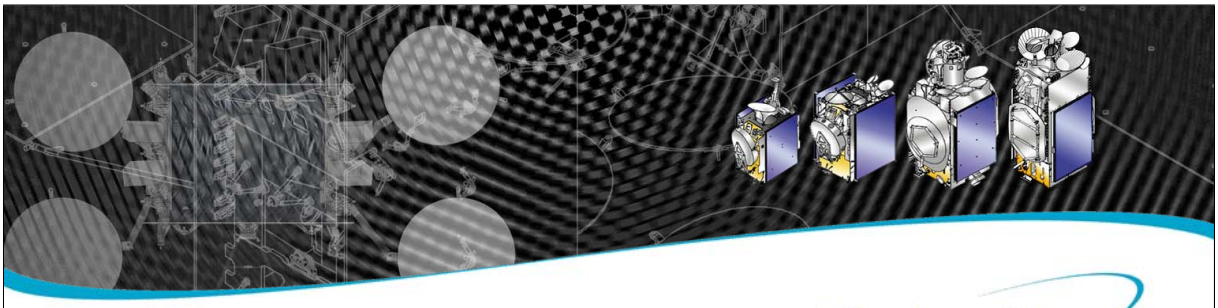
Donata Pietrafesa
(Sofiter System Engineering, Italy)

Abstract

ESATAN2SS tool, developed and working in MATLAB, is a fast means to compute Linear Time-Invariant (LTI) models directly from ESATAN TMMs: in other words it translates ESATAN (non-linear) thermal networks into (linear) Space State models by computing matrixes A, B, C, D.

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases}$$

Its main field of application is the design of control systems, such as the design of heaters with PID control laws, based on GOCE and HERSCHEL heritage.
To speed up the design of such systems it is useful to apply the (linear) Control System theory. For this purpose, it is usually required to have a model in the form of Space State (SS) or equivalent Laplace Transfer Functions (LTF). ESATAN2SS provides a simple and user-friendly way to derive the SS form by linearization of heat balance equations. In turn, the equivalent LTF can be derived with the simple formula $G(s) = C(sI - A)^{-1}B + D$.
The tool has been verified for several models: in all these cases the LTI models provides the same response as the original TMMs, showing that the ESATAN2SS linearisation correctly represents the thermal network. To make its utilization easier for first-time users, it is available in-house with simple run test cases documented as tutorials.
The navigation spacecraft Galileo is the first application of ESATAN2SS on a complex model, with significant analysis time savings. From now on, it is planned to use ESATAN2SS on all future applications where the use of Control System theory could have a positive impact both on design optimization and analysis time.



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ESATAN2SS

Savino De Palo – *TAS-I Turin*

Donata Pietrafesa – *SSE Turin*

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Introduction

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- What does it do?

ESATAN2SS → from ESATAN to State Space

ESATAN – TMM

$T = f(Q, GL, GR, C\ldots)$ →

State Space

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases}$$

A	state matrix
B	input matrix
C	output matrix
D	feedthrough matrix

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Introduction

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x (state vector)	→	Temperatures array for nodes with C≠0
u (input vector)	→	Temperature boundaries array + Heat Loads array (over all non-boundary nodes)
y (output vector)	→	Temperatures array (also for C=0)

Introduction

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- Why develop it ?
  - (linear) Control System theory → **Speed up** heaters active control systems design
- Why State Space form?
  - Control designer requires a model as → **State Space** / **Transfer Function**

SS → by linearization of heat balance equations

LTF → $G(s)=C(sI-A)^{-1}B+D$

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Introduction

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ESATAN2SS 2.6 main features:

- MATLAB script → Pre-parsed version


esatan2ss.p


esatan2sshelp.m

- Automatic recognition of Arithmetical Nodes → $T_{\text{NODES with C=0}} \notin x$
- No GUI → >>[A B C D] = ESATAN2SS ('MODELNAME')
- Tested only on Windows XP 32-bit with Matlab R2009b

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Esatan Data

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- Run ESATAN TMM (version 10.2 or later) → Steady State Conditions
- Perform CALL DMPTHM (see Esatan User Manual) → .csv files (to be moved) → ESATAN2SS working directory

- *MODELNAME.nl.csv* → Type, Number, Label, Model
- *MODELNAME.nd.csv* → *T, C, Q*
- *MODELNAME.gl.csv* → *GL*
- *MODELNAME.gr.csv* → *GR*
- *MODELNAME.gf.csv* → NOT REQUIRED

Input / Output options

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>>[A B C D] = ESATAN2SS ('MODELNAME')

Overall LTI SS model of Esatan Model *MODELNAME*

Sparse Matrices: A, B, C, D →

B =

(2,1)	2.0000
(3,1)	1.0000
(1,2)	0.2000
(2,2)	0.0500
(1,3)	0.2000
(2,4)	0.5000
(3,5)	0.5000

>>[A B C D Model] = ESATAN2SS ('MODELNAME')

.name	Esatan model name	.u0	full u_0 data
.date	file data damping date	.u0list	full u_0 list
.solver	Esatan version	.y0	full y_0 data
.x0	x_0 data	.y0list	full y_0 list
.x0list	x_0 list		

Input / Output options

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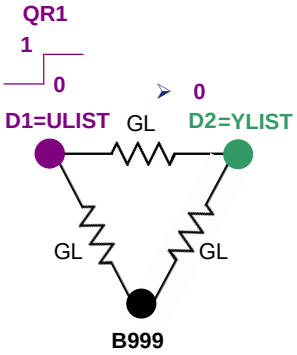
>>[A B C D] = ESATAN2SS ('MODELNAME', ULIST, YLIST)



ULIST: Cell Array defining the **Input** parameters (u variable)

- Boundary node (B type) → T_{NODE}
- Diffusive node (D type) → Q_{NODE}
- No arguments (i.e. ULIST={ }) → All Inputs

YLIST: Cell Array defining the **Output** parameters (y variable)

- Only diffusive nodes (D type)
- No arguments (i.e. YLIST={ }) → All Outputs

ULIST & YLIST → same format of *MODELNAME.nl.csv*

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Input / Output options

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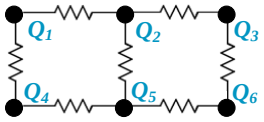
>>[A B C D] = ESATAN2SS ('MODELNAME', ULIST, YLIST, TUNIT, UFLAG, YFLAG)

TUNIT: Character defining **Temperature Unit**

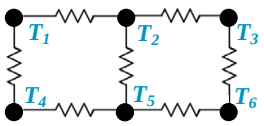
- 'C' → Celsius (default)
- 'K' → Kelvin

UFLAG: Boolean defining **Single Weighted Input** (default FALSE)



→ Q_{eq}

YFLAG: Boolean defining **Single Weighted Output** (default FALSE)



→ $T_{average}$

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Software Validation

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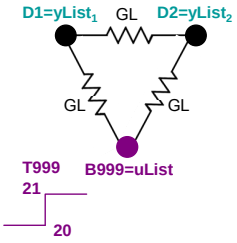
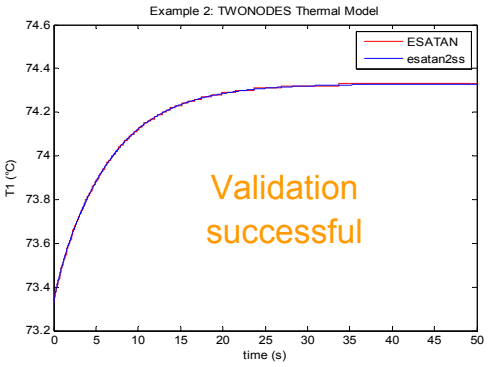
Software Validation Method:

- Matlab *step* function responses vs. ESATAN transients





Documented with validation / training cases:

- Linear and Non-linear models
- Model complexity increasing

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Galileo Experience

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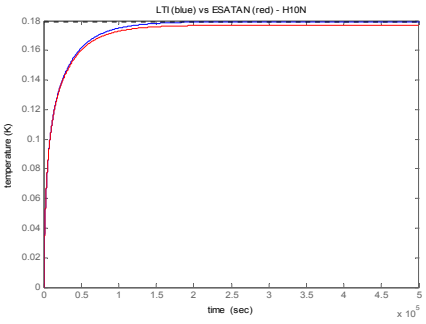
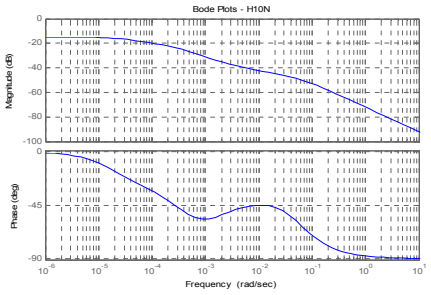
GALILEO heaters chains:

- Used to compute SS and then LTF
- Reduced TMM model (~400 nodes) due to RAM issues



- Gain differences up to 5%:
  - TMM non-linearity: *GL = f(T)*
  - False steady state conditions (< 0.01 °C)



Lessons Learnt

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To account for Heater Chains ON/OFF controlled → Q_{eq} before DMPTHM call

Esatan subroutine DMPTHM always dumps matrices in full form → Sparse form would save space

To avoid False Zero Output (in particular in the GR matrix) → Set FORMAT before DMPTHM call (i.e. FORMAT='E14.6')

Can handle large models (> 4000 nodes) → but Linux 64-bit machines to be tested

memory crash on 32-bit machines (SS matrices into full form)

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Conclusions

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Main features:

- **Fast** → computes LTI models directly from Esatan TMM
- **Verified** → available in house with simple run test cases
- **Time-saving** → complex models (e.g. Galileo)

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