Report on Simulation

Generated by MTT using :
(mtt -u -q -q Simulation rep pdf)

Tue Aug 19 15:30:27 BST 2003

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Part I

Simulation

Chapter 1

BigHeatedRod

1.1 BigHeatedRod_abg.tex *(-o)*

MTT command:

```
mtt -o BigHeatedRod abg tex
```

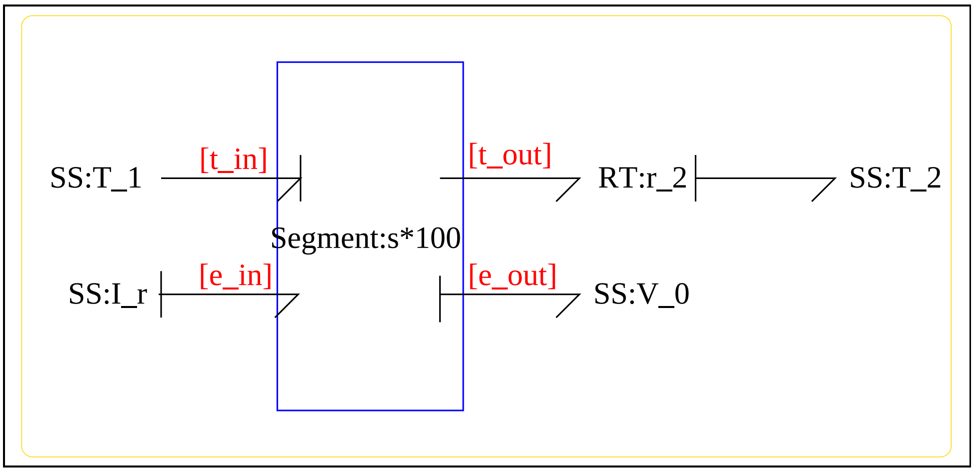

Figure 1.1: System **BigHeatedRod**: acausal bond graph

The acausal bond graph of system **BigHeatedRod** is displayed in Figure 1.1 (on page 9) and its label file is listed in Section 1.1.1 (on page 10). The subsystems are listed in Section 1.1.2 (on page 12).

1.1.1 Summary information

System BigHeatedRod::Thermal/Electrical model of Electric rod Introduces the idea of the ES component which transforms a relative-temperature/enthalpy pseudo bond (at the [e]port) into an absolute-temperature/enntropy energy bond (at the [s] port) and vice versa.

Interface information:

This component has no ALIAS declarations

Variable declarations:

area

delta_x

density

electrical_resistivity

mass

pi

rod_length

rod_radius

segments

thermal_capacity

thermal_resistivity

volume

Units declarations:

This component has no UNITs declarations

The label file: BigHeatedRod_lbl.txt

```
#SUMMARY BigHeatedRod: Thermal/Electrical model of Electric rod
#DESCRIPTION Introduces the idea of the ES component which
#DESCRIPTION transforms a relative-temperature/enthalpy pseudo bond
#DESCRIPTION (at the [e]port) into an absolute-temperature/enntropy
#DESCRIPTION energy bond (at the [s] port) and vice versa.

#PAR rod_length
#PAR rod_radius
#PAR electrical_resistivity
#PAR thermal_resistivity
#PAR thermal_capacity
#PAR segments
#PAR area
#PAR delta_x
#PAR volume
#PAR density
#PAR mass
#PAR pi

## Label file for system BigHeatedRod (BigHeatedRod_lbl.txt)

# ###############################################################
# ## Version control history
# ###############################################################
# ## $Id: BigHeatedRod_lbl.txt,v 1.2 2003/08/17 17:02:18 gawthrop Exp $
# ## $Log: BigHeatedRod_lbl.txt,v $
# ## Revision 1.2  2003/08/17 17:02:18  gawthrop
# ## Updated for new MTT
# ##
# ## Revision 1.1  2000/12/28 18:06:11  peterg
# ## To RCS
# ##
# ## Revision 1.1  1997/09/11 16:16:29  peterg
# ## Initial revision
# ##
# ###############################################################

## Each line should be of one of the following forms:
# a comment (ie starting with #)
```

```
# Component-name CR_name arg1,arg2,..argn
# blank



# Component type RT
r_2 lin flow,r_2

# Component type SS
I_r SS internal,external
T_1 SS t_0,internal
T_2 SS t_0,internal
V_0 SS internal,internal

# Component type Segment
s
```

1.1.2 Subsystems

- RT: Two port thermal resistance with T/Sdot bonds (1) No subsystems.
- Segment: Segment of HeatedRod (1)
  - CT: One-port thermal C component with T/Sdot bond (1)
  - RT: Two port thermal resistance with T/Sdot bonds (1)

1.1.3 CT

Component **CT** is a two port thermal resistor with true power bonds. Internally, it has a pseudo Bond Graph representation, and the corresponding thermal resistance just acts as an ordinary one-port **C** component.

Summary information

System CT::One-port thermal C component with T/Sdot bond CR and parameters as for a one-port C component Internally pseudo Example label file entry: c lin effort,c

Interface information:

Parameter $1 represents actual parameter **effort,c_t**

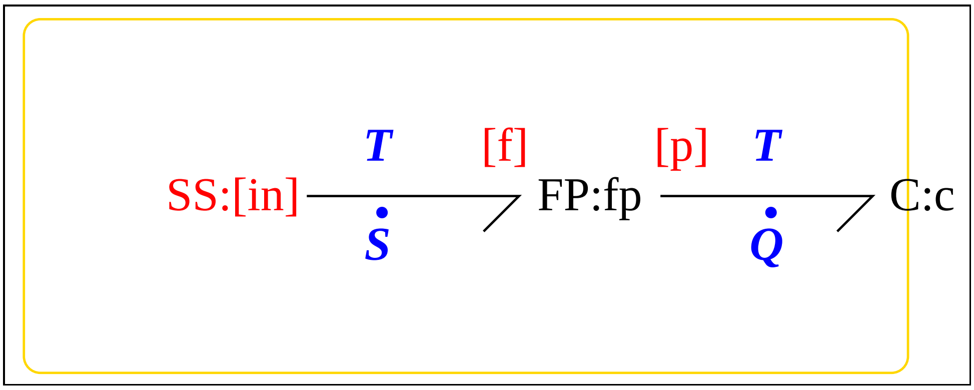

Figure 1.2: System **CT**: acausal bond graph

Parameter $a1 represents actual parameter **lin**

Port Thermal represents actual port **in**

Port out represents actual port **in**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: CT_lbl.txt

```
%SUMMARY CT: One-port thermal C component with T/Sdot bond
%DESCRIPTION CR and parameters as for a one-port C component
%DESCRIPTION Internally pseudo
%DESCRIPTION Example label file entry:
%DESCRIPTION % Component type CT
%DESCRIPTION  c lin effort,c

%Port aliases
%ALIAS Thermal|out in

%CR aliases
%ALIAS          $1 effort,c_t
```

```
%ALIAS          $a1 lin

%% Label file for system CT (CT_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: CT_lbl.txt,v 1.8 2001/07/05 08:42:43 gawthrop Exp $
% %% $Log: CT_lbl.txt,v $
% %% Revision 1.8  2001/07/05 08:42:43  gawthrop
% %% Updated to allow auto-generation of sensitivity version
% %%
% %% Revision 1.7  2001/07/03 22:59:10  gawthrop
% %% Fixed problems with argument passing for CRs
% %%
% %% Revision 1.6  2001/06/13 17:10:26  gawthrop
% %% Alias for the cr (ie ALIAS $1 lin)
% %%
% %% Revision 1.5  2001/06/11 15:09:18  gawthrop
% %% Removed spurious parameter
% %%
% %% Revision 1.4  1998/07/22 11:28:15  peterg
% %% Out as port alias
% %%
% %% Revision 1.3  1998/07/22 11:27:41  peterg
% %% Changed port name
% %%
% %% Revision 1.2  1998/06/29 10:12:58  peterg
% %% Converted to FP component
% %% Removed FP label
% %%
% %% Revision 1.1  1997/09/04  09:49:19  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%% Each line should be of one of the following forms:
% a comment (ie starting with %)
% Component-name CR_name arg1,arg2,..argn
% blank
```

```
% Component type C
c lin effort,c_t

% Component type FP
        fp

% Component type SS
[in] SS external,external
```

Subsystems

No subsystems.

1.1.4 RT

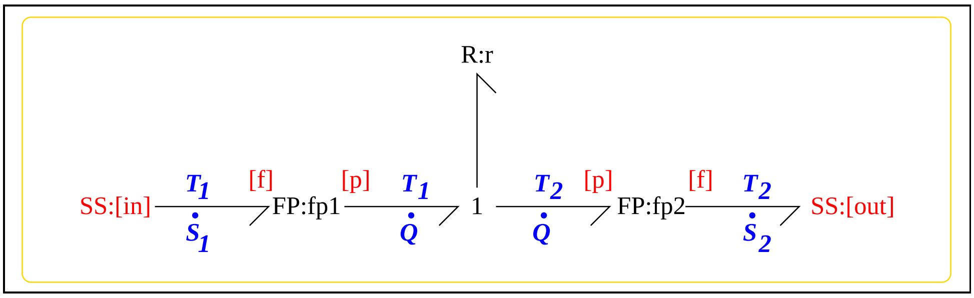

Figure 1.3: System **RT**: acausal bond graph

Component **RT** is a two port thermal resistor with true power bonds. Internally, it has a pseudo Bond Graph representation, and the corresponding thermal resistance just acts as an ordinary one-port **R** component.

Summary information

System RT::Two port thermal resistance with T/Sdot bonds Port [in]: T/Sdot power in Port [out]: T/Sdot power out CR and parameters as for a one-port R component Internally pseudo bond graph Example label file entry: r lin flow,r

Interface information:

Parameter $1 represents actual parameter **flow,r**

Parameter $a1 represents actual parameter **lin**

Port ThermalIn represents actual port **in**

Port ThermalOut represents actual port **out**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: RT_lbl.txt

```
%SUMMARY RT: Two port thermal resistance with T/Sdot bonds
%DESCRIPTION Port [in]: T/Sdot power in
%DESCRIPTION Port [out]: T/Sdot power out
%DESCRIPTION CR and parameters as for a one-port R component
%DESCRIPTION Internally pseudo bond graph
%DESCRIPTION Example label file entry:
%DESCRIPTION % Component type RT
%DESCRIPTION r lin flow,r

%ALIAS ThermalIn in
%ALIAS ThermalOut out

%ALIAS $1 flow,r
%ALIAS $a1 lin


%% Label file for system RT (RT_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: RT_lbl.txt,v 1.8 2001/07/05 08:42:41 gawthrop Exp $
% %% $Log: RT_lbl.txt,v $
% %% Revision 1.8  2001/07/05 08:42:41  gawthrop
% %% Updated to allow auto-generation of sensitivity version
% %%
```

```
% %% Revision 1.7  2001/07/03 22:59:10  gawthrop
% %% Fixed problems with argument passing for CRs
% %%
% %% Revision 1.6  2001/06/13 17:10:26  gawthrop
% %% Alias for the cr (ie ALIAS $1 lin)
% %%
% %% Revision 1.5  2001/06/11 19:51:08  gawthrop
% %% Zapped spurious $1 alias
% %%
% %% Revision 1.4  1998/07/22 11:31:42  peterg
% %% New port names
% %%
% %% Revision 1.3  1998/07/21 16:26:05  peterg
% %% Now has aliased parameters.
% %%
% %% Revision 1.2  1998/06/29 10:08:14  peterg
% %% Converted to FP component
% %% Removed lables from FP
% %%
% %% Revision 1.1  1997/09/04  09:48:47  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%% Each line should be of one of the following forms:
% a comment (ie starting with %)
% Component-name CR_name arg1,arg2,..argn
% blank


% Component type R
r lin flow,r

% Component type FP
        fp1
        fp2

% Component type SS
[in] SS external,external
[out] SS external,external
```

Subsystems

No subsystems.

1.1.5 Segment

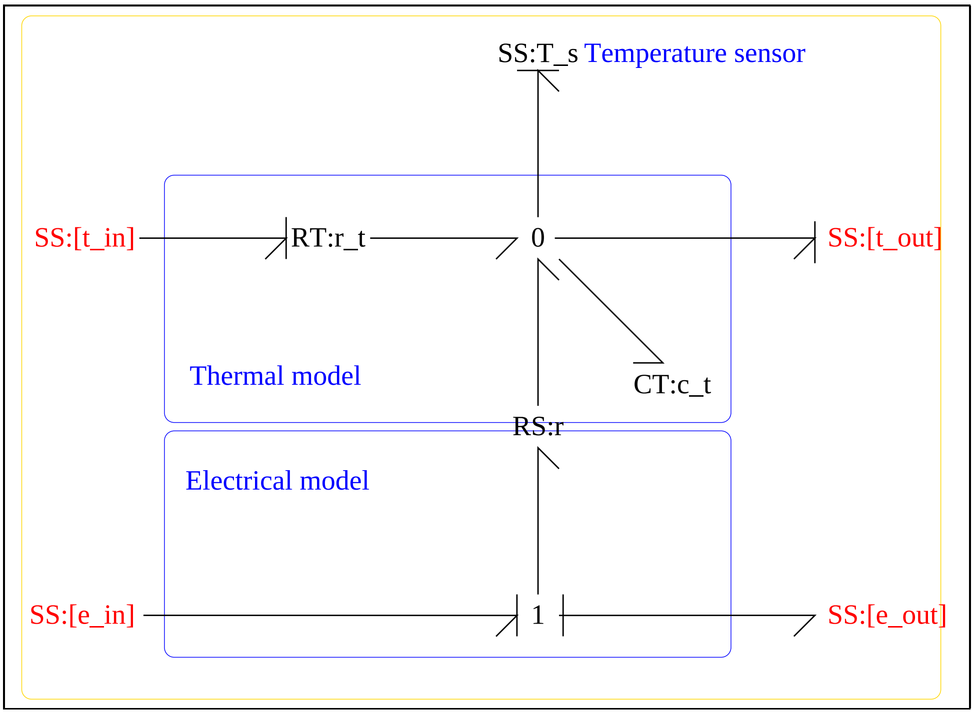

Figure 1.4: System **Segment**: acausal bond graph

The acausal bond graph of system **Segment** is displayed in Figure 1.4 (on page 18) and its label file is listed in Section 1.1.5 (on page 18). The subsystems are listed in Section 1.1.5 (on page 20).

Summary information

System Segment::Segment of HeatedRod Part of the HeatedRod example.

Interface information:

This component has no ALIAS declarations

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: Segment_lbl.txt

```
%SUMMARY Segment: Segment of HeatedRod
%DESCRIPTION Part of the HeatedRod example.
%% Label file for system Segment (Segment_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Segment_lbl.txt,v 1.3 2000/12/28 18:06:11 peterg Exp $
% %% $Log: Segment_lbl.txt,v $
% %% Revision 1.3  2000/12/28 18:06:11  peterg
% %% To RCS
% %%
% %% Revision 1.2  1998/08/10 12:29:48  peterg
% %% Added missing ports.
% %%
% %% Revision 1.1  1997/09/11 16:17:14  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%% Each line should be of one of the following forms:
% a comment (ie starting with %)
% Component-name CR_name arg1,arg2,..argn
% blank

% Component type CT
c_t lin effort,c_t

% Component type RS
r lin flow,r

% Component type RT
```

```
r_t lin flow,r_t

% Component type SS
T_s SS external,0
[t_in] SS external,internal
[t_out] SS internal,external
[e_in] SS external,internal
[e_out] SS external,internal
```

Subsystems

- CT: One-port thermal C component with T/Sdot bond (1) No subsystems.
- RT: Two port thermal resistance with T/Sdot bonds (1) No subsystems.

1.2 BigHeatedRod_numpar.txt *(-o)*

MTT command:

```
mtt -o BigHeatedRod numpar txt

# Numerical parameter file (BigHeatedRod_numpar.txt)
# Generated by MTT at Thu Sep  4 16:11:04 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: BigHeatedRod_numpar.txt,v 1.2 2003/08/17 17:02:24 gawthr
# %% $Log: BigHeatedRod_numpar.txt,v $
# %% Revision 1.2  2003/08/17 17:02:24  gawthrop
# %% Updated for new MTT
# %%
# %% Revision 1.1  2000/12/28 18:06:11  peterg
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


# Constants for copper
density = 8.96;
```

```
rod_length = 1.0;
rod_radius = 1e-3;
electrical_resistivity = 16.8*0.000000001;
thermal_resistivity = 1/390.0;
thermal_capacity = 380.0;

pi = 3.142;

segments = 100;
area = pi*rod_radius*rod_radius;
delta_x = rod_length/segments;
volume = area*delta_x;
mass = volume*density;

# Parameters
c_t =  thermal_capacity*mass;
r =  electrical_resistivity*delta_x/area;
r_t =  thermal_resistivity*delta_x/area;
r_2 =  r_t;
t_0 =  300; # Ambient
```

1.3 BigHeatedRod_input.txt *(-o)*

MTT command:

```
mtt -o BigHeatedRod input txt
```

```
# Numerical parameter file (BigHeatedRod_input.txt)
# Generated by MTT at Thu Sep  4 16:11:06 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: BigHeatedRod_input.txt,v 1.2 2003/08/17 17:02:12 gawthrop Exp
# %% $Log: BigHeatedRod_input.txt,v $
# %% Revision 1.2  2003/08/17 17:02:12  gawthrop
```

```
# %% Updated for new MTT
# %%
# %% Revision 1.1  2000/12/28 18:06:11  peterg
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Set the inputs
## Removed by MTT on Sun Aug 17 13:03:18 BST 2003: u(1) =
10.0*(t<5.0); # I_r
bigheatedrod__i_r = 10.0*(t<5.0); # I_r
```

1.4 BigHeatedRod_odeso.ps *(-o)*

MTT command:

```
mtt -o BigHeatedRod odeso ps
```

This representation is given as Figure 1.5 (on page 22).

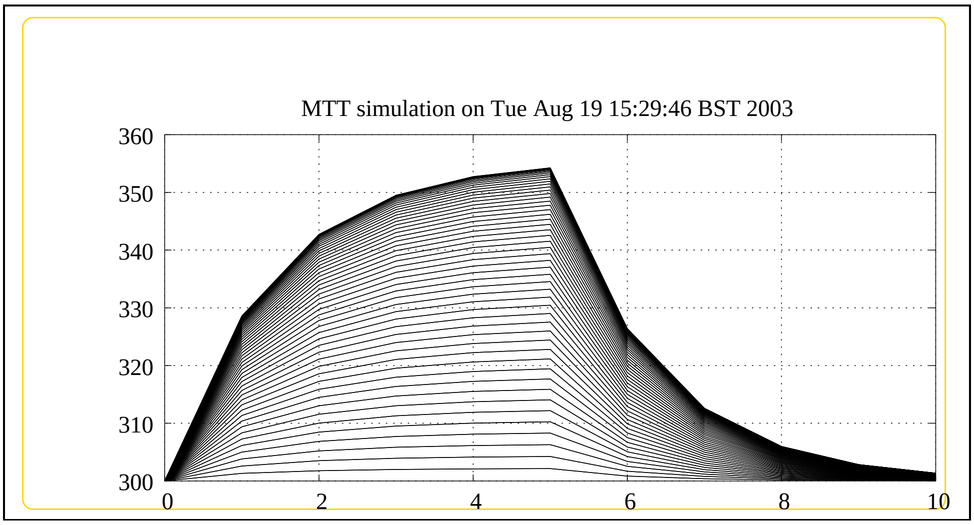

Figure 1.5: System **BigHeatedRod**, representation odeso (-o)

Chapter 2

ImplicitRC

2.1 ImplicitRC_abg.tex

MTT command:

```
mtt ImplicitRC abg tex
```

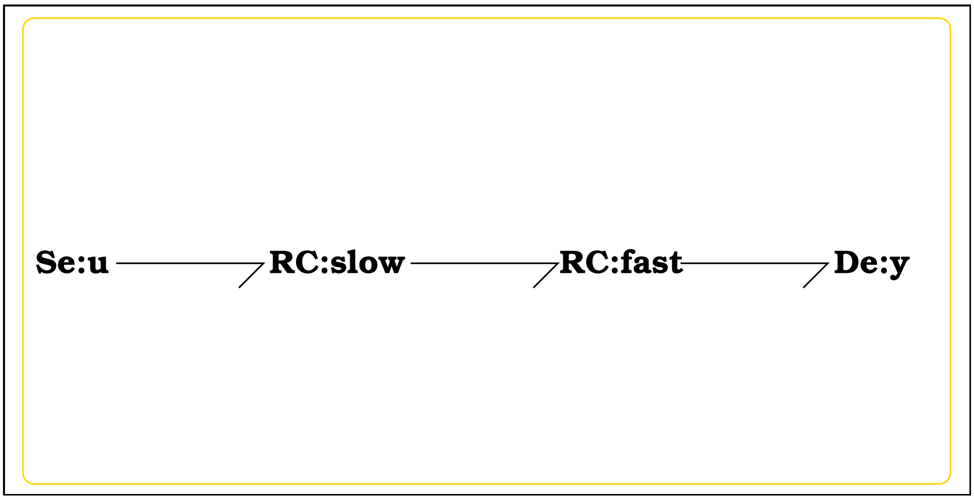

Figure 2.1: System **ImplicitRC**: acausal bond graph

This report describes the *implicit* integration methods available in MTT. They are introduced to provide simulation of systems within the following context:

1. The system may be stiff with a mixture of slow and fast (possibly due to approximating algebraic loops) subsystems.

2. The fast parts of the response are of no interest
3. A fixed sample interval is required – possibly for real-time simulation or control
4. The system is nonlinear.
5. The solution of nonlinear algebraic equations is to be avaided.

The following sections consider the linear and nonlinear versions respectively. The ideas are based on a standard textbook [1].

2.1.1 Implicit integration - the linear case

Consider the *linear* system:

$$\dot{x} = Ax + Bu \tag{2.1}$$

For the purposes of simulation, it can be discretised (with sample interval Δt) in at least two ways:

1. $\dot{x} \approx \frac{x_{i+1} - x_i}{\Delta t}$
2. $\dot{x} \approx \frac{x_i - x_{i-1}}{\Delta t}$

The former is gives rise to the *forward* Euler or *explicit* integration scheme:

$$x_{i+1} = x_i + \Delta t \left[A x_i + B_i u \right] \tag{2.2}$$

and the latter gives rise to the *backward* Euler or *implicit* integration scheme:

$$x_i = x_{i-1} + \Delta t \left[A x_i + B_i u \right] \tag{2.3}$$

which must be rewritten as:

$$x_i = \left[I - \Delta t A \right]^{-1} x_{i-1} + \Delta t B_i u \tag{2.4}$$

for the purposes of implementation.

The explicit method gives simple implementation whereas the implicit method requires matrix inversion. However, the explicit method is only stable if:

$$\Delta t < \frac{2}{|\lambda|} \tag{2.5}$$

[1] Press et al: *Numerical Recipes in C*, 2nd edition, 1992. Cambridge, Section 16.6

where λ is the *largest* eigenvalue of A. If this largest eigenvalue is real so $\lambda = \frac{1}{\tau}$ where τ is the *smallest* system time constant:

$$\Delta t < 2\tau \tag{2.6}$$

If the system is stiff, that is it contains at least one small time constant relative to the dominant time constants, Euler integration is not feasible due to the very small sample interval Δt required.

In contrast, the implicit method is stable.

Example

The acausal bond graph of system **ImplicitRC** is displayed in Figure 2.1 (on page 23) and its label file is listed in Section 2.1.3 (on page 26) The subsystems are listed in Section 2.1.4 (on page 27).

The system represents two simple RC circuits in series with differential equations as given in Section 2.3 (on page 35) and transfer function as given in Section 2.6 (on page 36).

For the purposes of this example the two time constants are 1 and $\varepsilon = 10^{-3}$ – this is a stiff system. All of the simulations use a sample interval of $\Delta t = 0.1$ ang the input is a unit step. Section 2.7 (on page 36) shows the exact (computed from the matrix exponential) solution, and Section sec:ImplicitRC$_o deso - cc.psshowsthesolutionbyimplicitintegration.$

The explicit solution is not shown, but was found to be unstable for $\Delta t > 0.002$ as predicted.

2.1.2 Implicit integration - the nonlinear case

Consider the *nonlinear* system:

$$\dot{x} = f(x,u) \tag{2.7}$$

and suppose it can be linearised about any state and input to give:

$$A(x,u) = \frac{\partial f(x,u)}{\partial x} \tag{2.8}$$

The corresponding *implicit* scheme is:

$$x_i = x_{i-1} + \Delta t\, f(x_i, u_i) \tag{2.9}$$

This is not easy to solve in general due to the set of non-linear equations that need to be solved. To avoid this, consider a further approximation:

$$f(x_i,u_i) \approx f(x_{i-1},u_i) + A(x_{i-1},u_i)(x_i - x_{i-1}) \tag{2.10}$$

This then gives the *semi-implicit* scheme

$$x_i = x_{i-1} + \Delta t \left[f(x_{i-1}, u_i) + A(x_{i-1}, u_i)(x_i - x_{i-1}) \right] \tag{2.11}$$

which can be rewritten as:

$$x_i = \left[I - \Delta t A(x_{i-1}, u_i) \right]^{-1} \Delta t \left[f(x_{i-1}, u_i) - A(x_{i-1}, u_i) x_{i-1} \right] \tag{2.12}$$

Because of the approximations invoved, Equation 2.12 is not guarenteed to be stable. Nevertheless, it should do a much better job than the corresponding *explicit* method for reasonably smooth systems. This method is chosen by setting

```
METHOD='Implicit'
```

in the MTT simpar.txt file.

A further approximation arises by setting $A(x_{i-1}, u_i) = A(x_0, u_0)$ ie computing it one only at the beginning of the simulation. This method is chosen by setting

```
METHOD='ImplicitL'
```

in the MTT simpar.txt file.

Both methods make use of the **smx** "state-matrix with state *x*" representation of MTT which is generated symbolically from the system bond graph.

2.1.3 Summary information

System ImplicitRC: ¡Detailed description here¿

Interface information:

This component has no ALIAS declarations

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ImplicitRC_lbl.txt

```
%SUMMARY ImplicitRC
%DESCRIPTION <Detailed description here>
%% Label file for system ImplicitRC (ImplicitRC_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ImplicitRC_lbl.txt,v 1.1 2000/12/28 18:06:50 peterg Exp $
% %% $Log: ImplicitRC_lbl.txt,v $
% %% Revision 1.1  2000/12/28 18:06:50  peterg
% %% To RCS
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%% Each line should be of one of the following forms:
% a comment (ie starting with %)
% Component-name CR_name arg1,arg2,..argn
% blank



% Component type RC
fast lin epsilon;1
slow lin 1;1

% Component type SS
u SS external
y SS external
```

2.1.4 Subsystems

- De Simple effort detector (1) No subsystems.

- RC A Simple two-port RC circuit (2) No subsystems.

- Se Simple effort source (1) No subsystems.

2.1.5 De

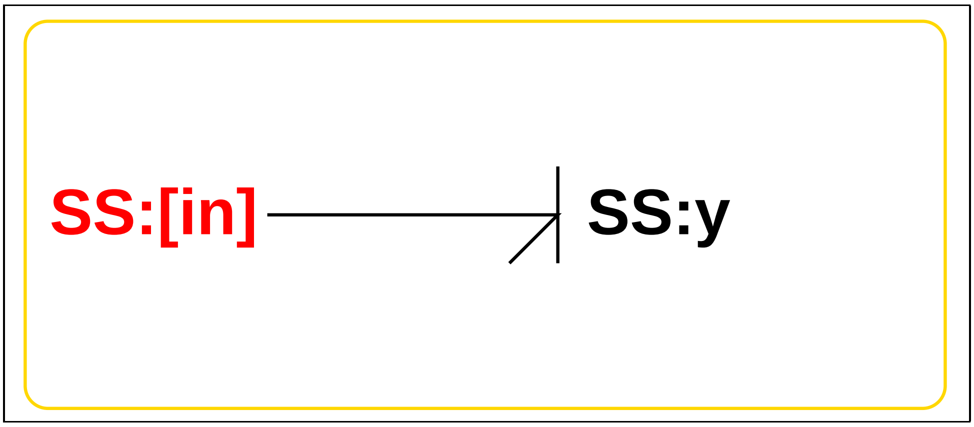

Figure 2.2: System **De**: acausal bond graph

The acausal bond graph of system **De** is displayed in Figure 2.2 (on page 28) and its label file is listed in Section 2.1.5 (on page 28). The subsystems are listed in Section 2.1.5 (on page 30).

Summary information

System De:Simple effort detector Simple effort detector constructed from SS with fixed causality

Interface information:

Parameter $1 represents actual parameter **external**

Port in represents actual port **in**

Port out represents actual port **in**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: De_lbl.txt

```
%% Label file for system De (De_lbl.txt)
%SUMMARY De Simple effort detector
%DESCRIPTION Simple effort detector constructed from SS with fixed causa

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: De_lbl.txt,v 1.4 2002/11/07 04:28:23 gawthrop Exp $
% %% $Log: De_lbl.txt,v $
% %% Revision 1.4  2002/11/07 04:28:23  gawthrop
% %% Now has argument - either internal or external
% %%
% %% Revision 1.3  1999/09/07 03:32:21  peterg
% %% Fixed alias bug
% %%
% %% Revision 1.2  1999/09/07 03:21:02  peterg
% %% Aliased to out as well as in
% %%
% %% Revision 1.1  1999/03/03 22:02:04  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS in|out in

% Argument aliases
%ALIAS $1 external

%% Each line should be of one of the following forms:
%       a comment (ie starting with %)
%       component-name cr_name arg1,arg2,..argn
%       blank

% ---- Component labels ----

% Component type SS
[in] SS external,external
```

```
y SS external,0
```

Subsystems

No subsystems.

2.1.6 RC

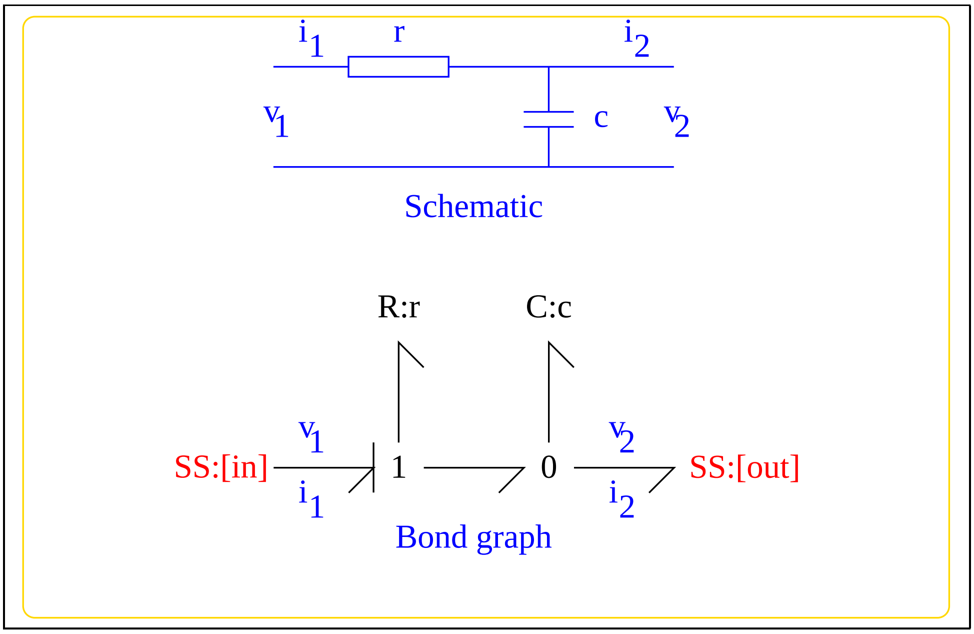

Figure 2.3: System **RC**: acausal bond graph

RC is a Simple two-port RC circuit. The two ports are [in] and [out] and the two parameters are c and r respectively

The acausal bond graph of system **RC** is displayed in Figure 2.3 (on page 30) and its label file is listed in Section 2.1.6 (on page 30). The subsystems are listed in Section 2.1.6 (on page 32).

Summary information

System RC:A Simple two-port RC circuit This simple example is used in the manual.

Interface information:

Parameter $1 represents actual parameter **c** – Capacitance

Parameter $2 represents actual parameter **r** – Resistance

Port in represents actual port **in** – The left-hand port

Port out represents actual port **out** – The right-hand port

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: RC_lbl.txt

```
%% Label file for system RC (RC_lbl.txt)
%SUMMARY RC A Simple two-port RC circuit
%DESCRIPTION This simple example is used in the manual.

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: RC_lbl.txt,v 1.4 2001/07/24 04:25:16 gawthrop Exp $
% %% $Log: RC_lbl.txt,v $
% %% Revision 1.4  2001/07/24 04:25:16  gawthrop
% %% Relabeled ports - easier for sensitivity to handle
% %%
% %% Revision 1.3  2000/09/14 15:13:02  peterg
% %% Changed port CRs to give SISO system when used in isolation
% %%
% %% Revision 1.2  1998/07/27 11:09:36  peterg
% %% Commented the aliases.
% %%
% %% Revision 1.1  1998/07/16 20:16:30  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% Port aliases
%ALIAS in in # The left-hand port
%ALIAS out out # The right-hand port

% Argument aliases
%ALIAS $1 c # Capacitance
%ALIAS $2 r # Resistance

%% Each line should be of one of the following forms:
%       a comment (ie starting with %)
%       component-name cr_name arg1,arg2,..argn
%       blank

% ---- Component labels ----

% Component type C
c lin effort,c

% Component type R
r lin flow,r

% Component type SS
[in] SS external,internal
[out] SS external,0
```

Subsystems

No subsystems.

2.1.7 Se

The acausal bond graph of system **Se** is displayed in Figure 2.4 (on page 33) and its label file is listed in Section 2.1.7 (on page 32). The subsystems are listed in Section 2.1.7 (on page 34).

Summary information

System Se:Simple effort source Simple effort source constructed from SS with fixed causality

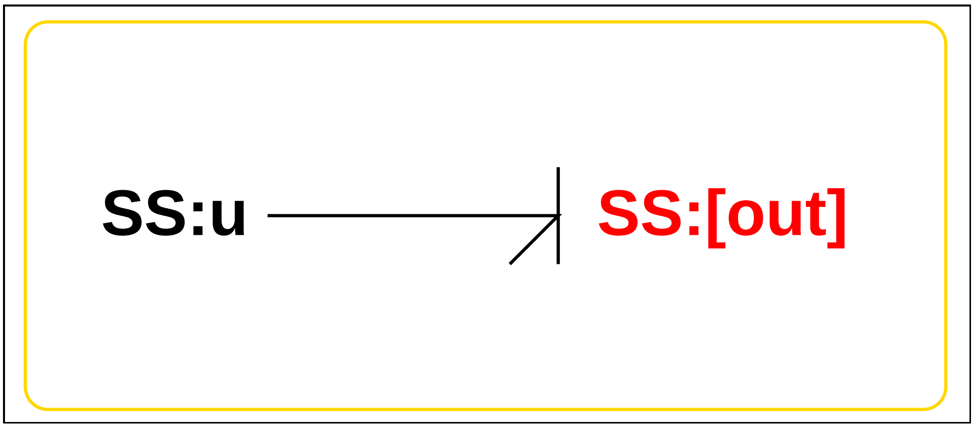

Figure 2.4: System **Se**: acausal bond graph

Interface information:

Parameter $1 represents actual parameter **e_s**

Port in represents actual port **out**

Port out represents actual port **out**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: Se_lbl.txt

```
%% Label file for system Se (Se_lbl.txt)
%SUMMARY Se Simple effort source
%DESCRIPTION Simple effort source constructed from SS with fixed causali


% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Se_lbl.txt,v 1.3 1999/08/05 07:31:39 peterg Exp $
% %% $Log: Se_lbl.txt,v $
```

```
% %% Revision 1.3  1999/08/05 07:31:39  peterg
% %% Added in alias
% %%
% %% Revision 1.2  1999/03/12 04:04:27  peterg
% %% Single argument - the effort value e_s
% %%
% %% Revision 1.1  1999/03/03 21:55:46  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS out|in out

% Argument aliases
%ALIAS $1 e_s

%% Each line should be of one of the following forms:
%       a comment (ie starting with %)
%       component-name cr_name arg1,arg2,..argn
%       blank

% ---- Component labels ----

% Component type SS
[out] SS external,external
u SS e_s,internal
```

Subsystems

No subsystems.

2.2 ImplicitRC_struc.tex

MTT command:

```
mtt ImplicitRC struc tex
```

List of inputs for system ImplicitRC			
	Component	System	Repetition
1	u	ImplicitRC__u__u	1

List of outputs for system ImplicitRC			
	Component	System	Repetition
1	y	ImplicitRC__y__y	1

List of states for system ImplicitRC			
	Component	System	Repetition
1	c	ImplicitRC__fast__c	1
2	c	ImplicitRC__slow__c	1

2.3 ImplicitRC_ode.tex

MTT command:

```
mtt ImplicitRC ode tex
```

$$\begin{aligned} \dot{x}_1 &= \frac{(\varepsilon x_2 - x_1)}{\varepsilon} \\ \dot{x}_2 &= \frac{(\varepsilon u_1 - 2\varepsilon x_2 + x_1)}{\varepsilon} \end{aligned} \tag{2.13}$$

$$y_1 = \frac{x_1}{\varepsilon} \tag{2.14}$$

2.4 ImplicitRC_sm.tex

MTT command:

```
mtt ImplicitRC sm tex
```

$$A = \begin{pmatrix} \frac{(-1)}{\varepsilon} & 1 \\ \frac{1}{\varepsilon} & -2 \end{pmatrix} \tag{2.15}$$

$$B = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \tag{2.16}$$

$$C = \begin{pmatrix} \frac{1}{\varepsilon} & 0 \end{pmatrix} \tag{2.17}$$

$$D = \begin{pmatrix} 0 \end{pmatrix} \tag{2.18}$$

2.5 ImplicitRC_sm.m

MTT command:

```
mtt ImplicitRC sm m
```

2.6 ImplicitRC_tf.tex

MTT command:

```
mtt ImplicitRC tf tex
```

$$G = \left(\frac{1}{(\varepsilon s^2 + 2\varepsilon s + s + 1)} \right) \tag{2.19}$$

2.7 ImplicitRC_sro.ps

MTT command:

```
mtt ImplicitRC sro ps
```

This representation is given as Figure 2.5 (on page 37).

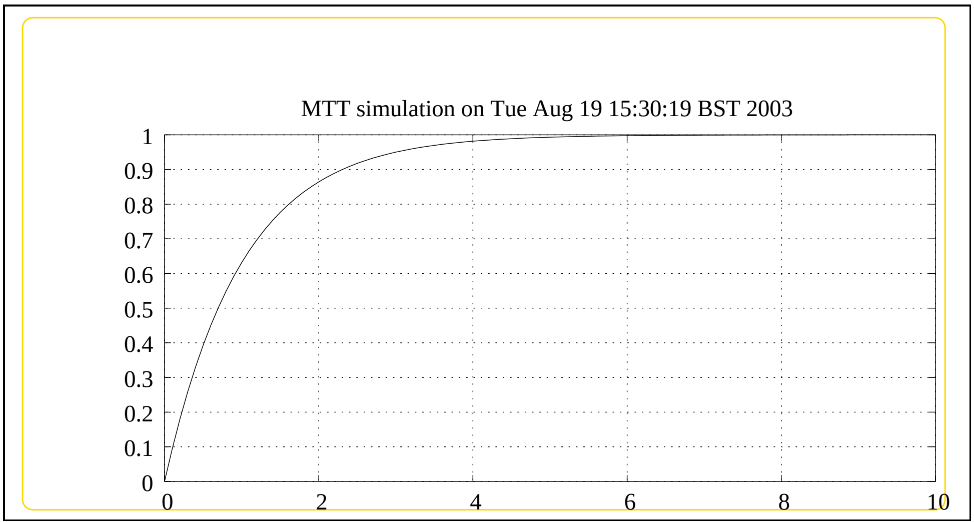

Figure 2.5: System **ImplicitRC**, representation sro (-noargs)

2.8 ImplicitRC_numpar.tex

MTT command:

```
mtt ImplicitRC numpar tex

# Numerical parameter file (ImplicitRC_numpar.txt)
# Generated by MTT at Wednesday June 24 09:21:23 BST 1998

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: ImplicitRC_numpar.txt,v 1.2 2003/08/17 17:02:56 gawthrop Exp $
# %% $Log: ImplicitRC_numpar.txt,v $
# %% Revision 1.2  2003/08/17 17:02:56  gawthrop
# %% Updated for new MTT
# %%
# %% Revision 1.1  2000/12/28 18:06:50  peterg
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Parameters
epsilon =  1e-3; # ImplicitRC
```

```
## Removed by MTT on Sun Aug 17 13:59:26 BST 2003: ## Removed by M
1.0;
## Removed by MTT on Sun Aug 17 13:59:26 BST 2003: r = 1.0;
```

2.9 ImplicitRC_simpar.tex

MTT command:

```
mtt ImplicitRC simpar tex
```

```
%% Simulation parameters for system ImplicitRC (ImplicitRC_simpar.

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ImplicitRC_simpar.txt,v 1.1 2000/12/28 18:06:50 peterg E
% %% $Log: ImplicitRC_simpar.txt,v $
% %% Revision 1.1  2000/12/28 18:06:50  peterg
% %% To RCS
% %%
% %% Revision 1.1  1998/08/12 13:29:02  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

LAST=10.0
DT=0.1
STEPFACTOR=1
```

2.10 ImplicitRC_odeso.ps

MTT command:

```
mtt ImplicitRC odeso ps
```

This representation is given as Figure 2.6 (on page 39).

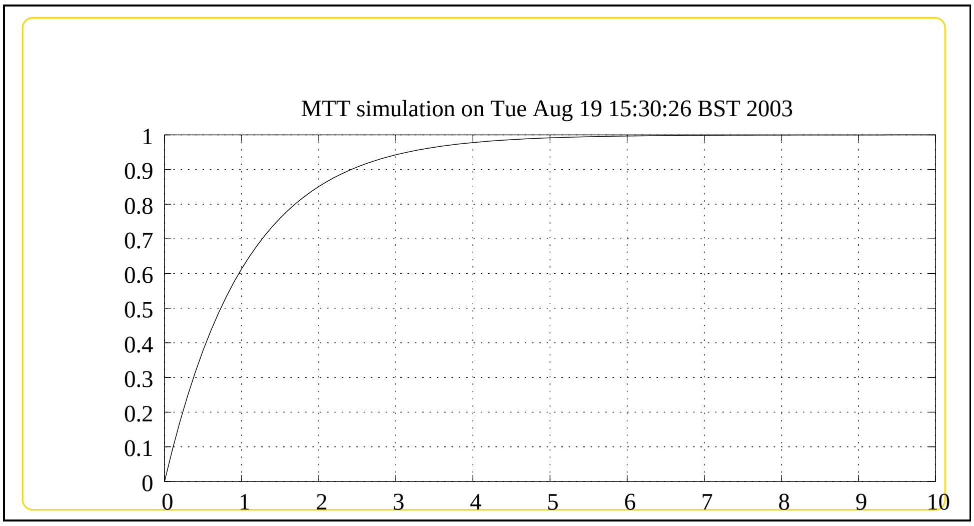

Figure 2.6: System **ImplicitRC**, representation odeso (-noargs)

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