Report on Mechanical

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Part I

Beams

Chapter 1

CantileverBeam

1.1 CantileverBeam_abg.tex

MTT command:

```
mtt CantileverBeam abg tex
```

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

This example represents the dynamics of a uniform beam with one fixed and one free end. The beam is approximated by 20 equal lumps using the Bernoulli-Euler approximation with damping. The input is the angular velocity of the fixed end, the output is the linear velocity of the free end.

The system parameters are given in Section **??** (on page **??**). Note that the numer of ban segments has been set to 21.

The system has 20 states (10 modes of vibration), 1 inputs and 1 outputs.

The first 5 vibration frequencies are given in Table 2.2 togtherr with the theoretical (based on the Bernoulli-Euler beam with the same values of EI and ρA.

1.1.1 Summary information

System CantileverBeam: ¡Detailed description here¿

Interface information:

This component has no ALIAS declarations

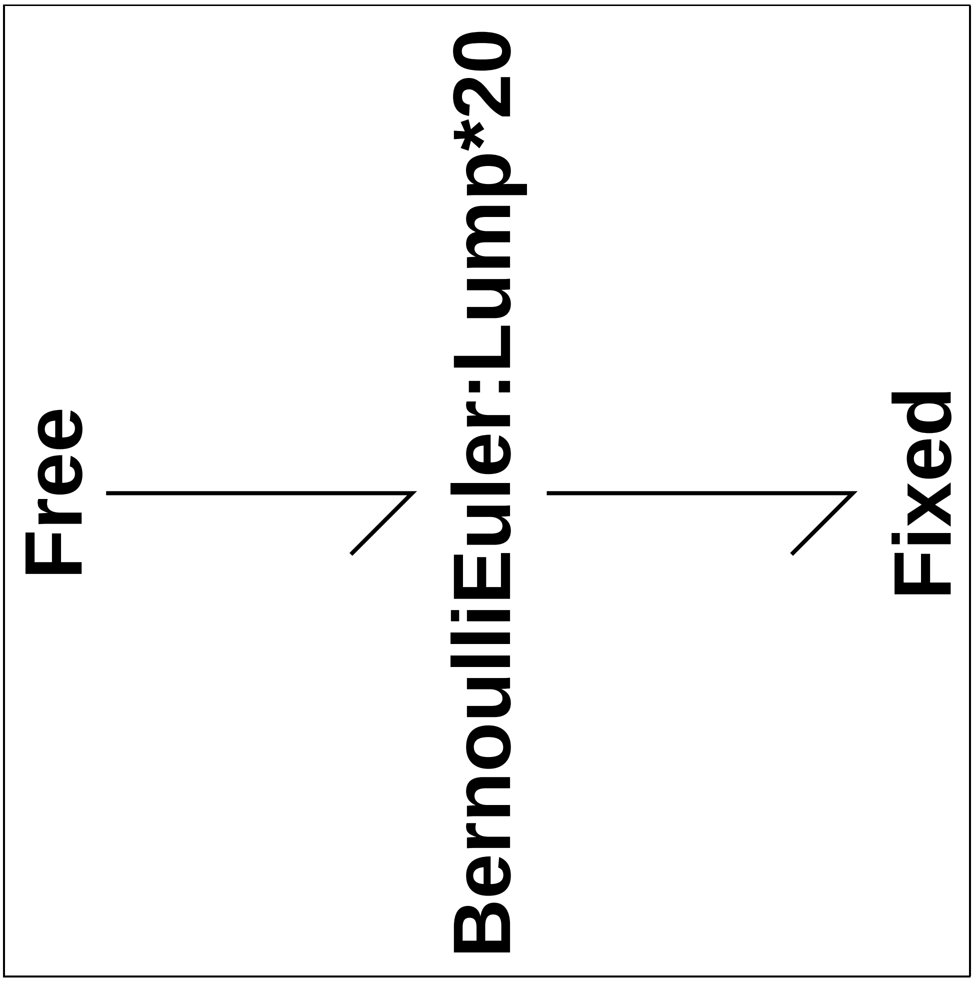

Figure 1.1: System **CantileverBeam**: acausal bond graph

Mode	Frequency	Theoretical frequency
1	76.14	76.14
2	477.11	484.50
3	1330.62	1334.55
4	2586.77	2617.19
5	4225.14	4323.77

Table 1.1: Mode frequencies (rad s^{-1})

Variable declarations:

Area

AreaMoment

BeamLength

BeamThickness

BeamWidth

Density

EI

Youngs

k

n

rhoA

Units declarations:

This component has no UNITs declarations

The label file: CantileverBeam_lbl.txt

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

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: CantileverBeam_lbl.txt,v 1.1 2000/08/01 12:11:27 peterg Exp $
% %% $Log: CantileverBeam_lbl.txt,v $
% %% Revision 1.1  2000/08/01 12:11:27  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%VAR n
%VAR BeamLength
%VAR BeamWidth
%VAR BeamThickness
%VAR Youngs
%VAR Density
%VAR Area
%VAR AreaMoment
%VAR EI
%VAR rhoA
%VAR k

% Port aliases

% Argument aliases

%% 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 BernoulliEuler
Lump
```

1.1.2 Subsystems

- BernoulliEuler (1) No subsystems.
- Fixed (1)
  - Sf Simple flow source (2)
- Free (1)
  - Df Simple flow detector (1)
  - Se Simple effort source (1)

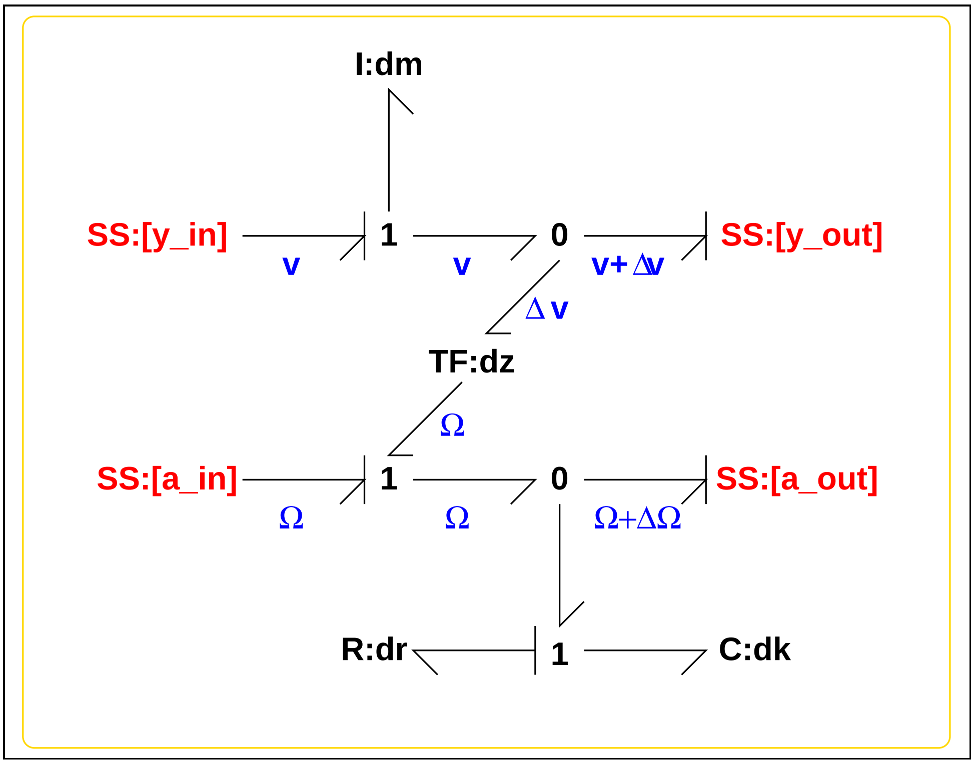

Figure 1.2: System **BernoulliEuler**: acausal bond graph

1.1.3 BernoulliEuler

The acausal bond graph of system **BernoulliEuler** is displayed in Figure 2.2 (on page 37) and its label file is listed in Section 2.1.3 (on page 38). The subsystems are listed in Section 2.1.3 (on page 40).

This component represents one lump of a lumped model of a uniform beam modelled using the the Bernoulli-Euler assumptions:

1. The shear forces can be neglected.

2. Rotational inertia can be neglected.

- The **I** component represents the inertial properties of the lump in the perpendicular direction. In particular the velocity of the lump v is:

$$\dot{v} = \frac{\Delta f}{\Delta m} \tag{1.1}$$

  where Δm is the lump mass and Δf is the net vertical force.

- The **C** component represents the angular stiffness of the lump. In particular the torque acting on the lump is:

$$\dot{\tau} = \Delta k \Delta \Omega \tag{1.2}$$

  where Δk is the lump (angular) stiffness and $\Delta\Omega$ is the net angular velocity.

- The **TF** component represents the relation between the angular domains

$$\begin{aligned} \tau &= \Delta x \Delta f \\ \Delta v &= \Delta x \Omega \end{aligned} \tag{1.3}$$

Summary information

System BernoulliEuler: ¡Detailed description here¿

Interface information:

Parameter $1 represents actual parameter **dk**

Parameter $2 represents actual parameter **dm**

Parameter $3 represents actual parameter **dz**

Parameter $4 represents actual parameter **dr**

Port in represents actual port **y_in,a_in**

Port out represents actual port **y_out,a_out**

Port theta_in represents actual port **a_in**

Port theta_out represents actual port **a_out**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: BernoulliEuler_lbl.txt

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

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: BernoulliEuler_lbl.txt,v 1.5 2000/12/27 16:34:35 peterg Exp $
% %% $Log: BernoulliEuler_lbl.txt,v $
% %% Revision 1.5  2000/12/27 16:34:35  peterg
% %% *** empty log message ***
% %%
% %% Revision 1.4  1999/10/13 07:01:58  peterg
% %% Added aliases:
% %%  a_in theta_in
% %%  a_out theta_out
% %%
% %% Revision 1.3  1999/09/02 03:07:16  peterg
% %% r_d --> dr
% %%
% %% Revision 1.2  1999/05/17 21:27:05  peterg
% %% Added damping
% %%
% %% Revision 1.1  1999/05/16 07:12:40  peterg
```

```
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS theta_in        a_in
%ALIAS theta_out a_out
%ALIAS in y_in,a_in
%ALIAS out y_out,a_out

% Argument aliases
%ALIAS $1 dk
%ALIAS $2 dm
%ALIAS $3 dz
%ALIAS $4 dr

%% 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 I
dm lin flow,dm

% Component type C
dk lin state,dk

% Component type R
dr lin flow,dr

% Component type SS
[y_in] SS external,external
[y_out] SS external,external
[a_in] SS external,external
[a_out] SS external,external

% Component type TF
dz lin effort,dz
```

Subsystems

No subsystems.

1.1.4 Df

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

The acausal bond graph of system **Df** is displayed in Figure 1.3 (on page 17) and its label file is listed in Section 1.1.4 (on page 17). The subsystems are listed in Section 1.1.4 (on page 19).

Summary information

System Df:Simple flow detector Simple flow detector constructed from SS with fixed causality

Interface information:

Parameter $1 represents actual parameter **external**

Port in represents actual port **port**

Port out represents actual port **port**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: Df_lbl.txt

```
%% Label file for system Df (Df_lbl.txt)
%SUMMARY Df Simple flow detector
%DESCRIPTION Simple flow detector constructed from SS with fixed c


% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Df_lbl.txt,v 1.4 2002/11/07 04:28:29 gawthrop Exp $
% %% $Log: Df_lbl.txt,v $
% %% Revision 1.4  2002/11/07 04:28:29  gawthrop
% %% Now has argument - either internal or external
% %%
% %% Revision 1.3  1999/09/07 03:31:47  peterg
% %% Fixed alias bug
% %%
% %% Revision 1.2  1999/09/07 03:20:34  peterg
% %% Aliased to out as well as in
% %%
% %% Revision 1.1  1999/03/03 22:05:16  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS in|out port

% 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
[port] SS external,external
y SS 0,external
```

Subsystems

No subsystems.

1.1.5 Fixed

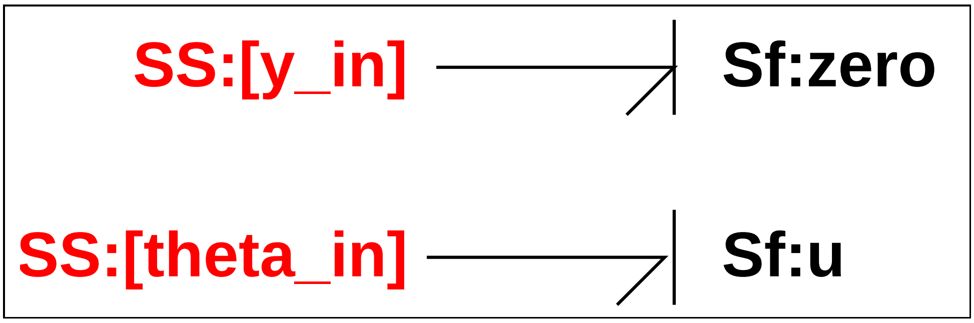

Figure 1.4: System **Fixed**: acausal bond graph

The acausal bond graph of system **Fixed** is displayed in Figure 1.4 (on page 19) and its label file is listed in Section 1.1.5 (on page 19). The subsystems are listed in Section 1.1.5 (on page 21).

Summary information

System Fixed: ¡Detailed description here¿

Interface information:

Port in represents actual port **y_in,theta_in**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: Fixed_lbl.txt

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

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Fixed_lbl.txt,v 1.1 1999/09/08 01:56:33 peterg Exp $
% %% $Log: Fixed_lbl.txt,v $
% %% Revision 1.1  1999/09/08 01:56:33  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS in y_in,theta_in

% Argument aliases

%% 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
[theta_in] SS external,external
[y_in] SS external,external

% Component type Sf
u SS external
zero SS 0
```

Subsystems

- Sf Simple flow source (2) No subsystems.

1.1.6 Free

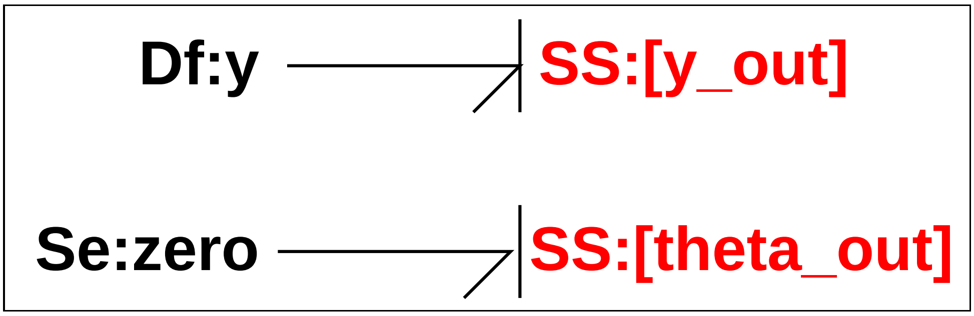

Figure 1.5: System **Free**: acausal bond graph

The acausal bond graph of system **Free** is displayed in Figure 1.5 (on page 21) and its label file is listed in Section 1.1.6 (on page 21). The subsystems are listed in Section 1.1.6 (on page 23).

Summary information

System Free: ¡Detailed description here¿

Interface information:

Port out represents actual port **y_out,theta_out**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: Free_lbl.txt

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

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Free_lbl.txt,v 1.1 1999/09/08 01:56:24 peterg Exp $
% %% $Log: Free_lbl.txt,v $
% %% Revision 1.1  1999/09/08 01:56:24  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS out y_out,theta_out

% Argument aliases

%% 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 Df
y SS external

% Component type SS
[theta_out] SS external,external
[y_out] SS external,external

% Component type Se
zero SS 0
```

Subsystems

- Df Simple flow detector (1) No subsystems.
- Se Simple effort source (1) No subsystems.

1.1.7 Se

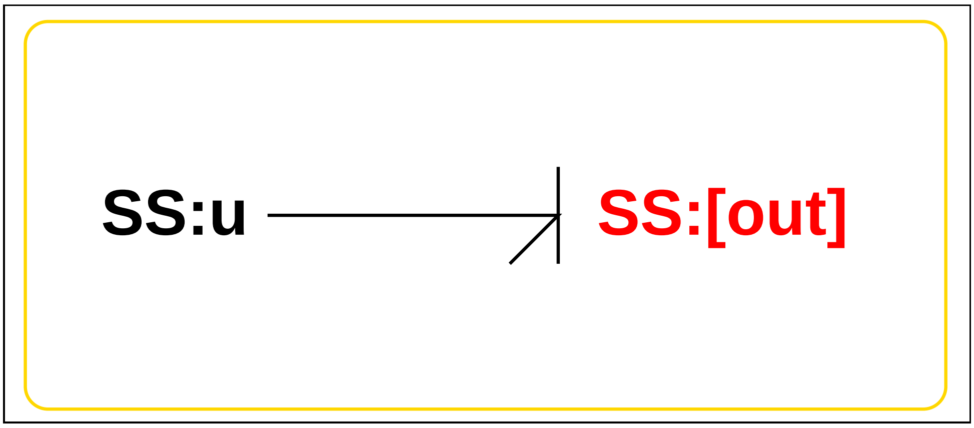

Figure 1.6: System **Se**: acausal bond graph

The acausal bond graph of system **Se** is displayed in Figure 5.6 (on page 84) and its label file is listed in Section 5.1.7 (on page 84). The subsystems are listed in Section 5.1.7 (on page 86).

Summary information

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

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 c


% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% 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.

1.1.8 Sf

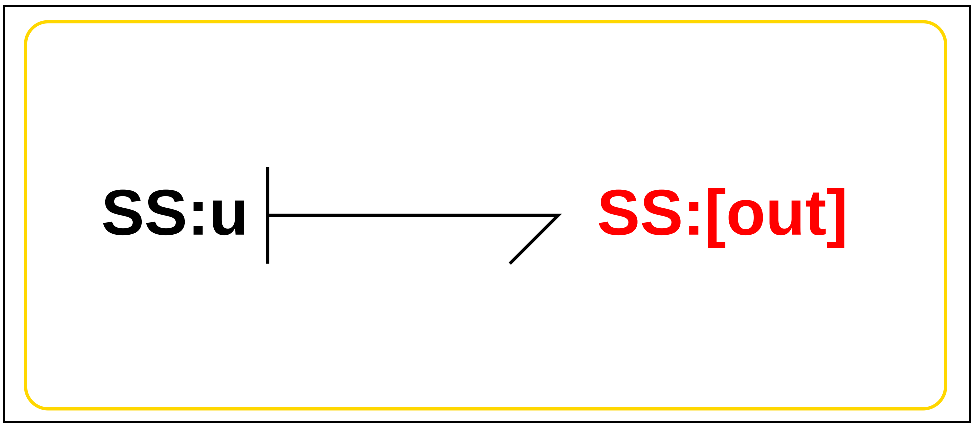

Figure 1.7: System **Sf**: acausal bond graph

The acausal bond graph of system **Sf** is displayed in Figure 5.7 (on page 86) and its label file is listed in Section 5.1.8 (on page 86). The subsystems are listed in Section 5.1.8 (on page 88).

Summary information

System Sf:Simple flow source Simple flow source constructed from SS with fixed causality

Interface information:

Parameter $1 represents actual parameter **f_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: Sf_lbl.txt

```
%% Label file for system Sf (Sf_lbl.txt)
%SUMMARY Sf Simple flow source
%DESCRIPTION  Simple flow source constructed from SS with fixed ca

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Sf_lbl.txt,v 1.3 1999/08/05 07:32:07 peterg Exp $
% %% $Log: Sf_lbl.txt,v $
% %% Revision 1.3  1999/08/05 07:32:07  peterg
% %% Added in alias
% %%
% %% Revision 1.2  1999/03/12 04:03:09  peterg
% %% Single argument - the value of the flow
% %%
% %% Revision 1.1  1999/03/03 21:50:15  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS out|in out

% Argument aliases
%ALIAS    $1 f_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 internal,f_s
```

Subsystems

No subsystems.

1.2 CantileverBeam_struc.tex

MTT command:

```
mtt CantileverBeam struc tex
```

List of inputs for system CantileverBeam			
	Component	System	Repetition
1	u	CantileverBeam__mttFixed__u__u	1

List of outputs for system CantileverBeam			
	Component	System	Repetition
1	y	CantileverBeam__mttFree__y__y	1

List of states for system CantileverBeam			
	Component	System	Repetition
1	dm	CantileverBeam_Lump_dm	1
2	dk	CantileverBeam_Lump_dk	1
3	dm	CantileverBeam_Lump_2_dm	2
4	dk	CantileverBeam_Lump_2_dk	2
5	dm	CantileverBeam_Lump_3_dm	3
6	dk	CantileverBeam_Lump_3_dk	3
7	dm	CantileverBeam_Lump_4_dm	4
8	dk	CantileverBeam_Lump_4_dk	4
9	dm	CantileverBeam_Lump_5_dm	5
10	dk	CantileverBeam_Lump_5_dk	5
11	dm	CantileverBeam_Lump_6_dm	6
12	dk	CantileverBeam_Lump_6_dk	6
13	dm	CantileverBeam_Lump_7_dm	7
14	dk	CantileverBeam_Lump_7_dk	7
15	dm	CantileverBeam_Lump_8_dm	8
16	dk	CantileverBeam_Lump_8_dk	8
17	dm	CantileverBeam_Lump_9_dm	9
18	dk	CantileverBeam_Lump_9_dk	9
19	dm	CantileverBeam_Lump_10_dm	10
20	dk	CantileverBeam_Lump_10_dk	10
21	dm	CantileverBeam_Lump_11_dm	11

List of states for system CantileverBeam (continued)			
	Component	System	Repetition
22	dk	CantileverBeam_Lump_11_dk	11
23	dm	CantileverBeam_Lump_12_dm	12
24	dk	CantileverBeam_Lump_12_dk	12
25	dm	CantileverBeam_Lump_13_dm	13
26	dk	CantileverBeam_Lump_13_dk	13
27	dm	CantileverBeam_Lump_14_dm	14
28	dk	CantileverBeam_Lump_14_dk	14
29	dm	CantileverBeam_Lump_15_dm	15
30	dk	CantileverBeam_Lump_15_dk	15
31	dm	CantileverBeam_Lump_16_dm	16
32	dk	CantileverBeam_Lump_16_dk	16
33	dm	CantileverBeam_Lump_17_dm	17
34	dk	CantileverBeam_Lump_17_dk	17
35	dm	CantileverBeam_Lump_18_dm	18
36	dk	CantileverBeam_Lump_18_dk	18
37	dm	CantileverBeam_Lump_19_dm	19
38	dk	CantileverBeam_Lump_19_dk	19
39	dm	CantileverBeam_Lump_20_dm	20
40	dk	CantileverBeam_Lump_20_dk	20

1.3 CantileverBeam_simpar.tex

MTT command:

```
mtt CantileverBeam simpar tex

# -*-octave-*- Put Emacs into octave-mode
# Simulation parameters for system CantileverBeam (CantileverBeam_simpar
# Generated by MTT on Mon Apr 19 06:32:42 BST 1999.
###############################################################
## Version control history
###############################################################
## $Id: CantileverBeam_simpar.txt,v 1.1 2000/12/28 17:58:27 peterg Exp $
## $Log: CantileverBeam_simpar.txt,v $
## Revision 1.1  2000/12/28 17:58:27  peterg
## To RCS
##
```

```
#################################################################


LAST         = 1.0;       # Last time in simulation
DT           = 0.001;        # Print interval
STEPFACTOR  = 1;          # Integration steps per print interval
WMIN         = 1;         # Minimum frequency = 10^WMIN
WMAX         = 4;          # Maximum frequency = 10^WMAX
WSTEPS       = 200;        # Number of frequency steps
INPUT        = 1;          # Index of the input
```

1.4 CantileverBeam_numpar.tex

MTT command:

```
mtt CantileverBeam numpar tex
```

```
# -*-octave-*- Put Emacs into octave-mode
# Numerical parameter file (CantileverBeam_numpar.txt)
# Generated by MTT at Mon Apr 19 06:24:08 BST 1999

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: CantileverBeam_numpar.txt,v 1.1 2000/12/28 17:58:27 pete
# %% $Log: CantileverBeam_numpar.txt,v $
# %% Revision 1.1  2000/12/28 17:58:27  peterg
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Parameters
N = 21;
BeamLength = 0.58;
BeamWidth = 0.05;
BeamThickness = 0.005;
Youngs = 68.94e9;
Density =  2712.8;
Area = BeamWidth*BeamThickness;
AreaMoment = (BeamWidth*BeamThickness^3)/12;
```

```
EI = Youngs*AreaMoment;
rhoA = Density*Area;

dz = BeamLength/N; # Incremental length
dm = rhoA*dz; # Incremental mass
dk = EI/dz; # Incremental stiffness
dr = 0; # Damping

K = sqrt(EI/rhoA)/BeamLength^2; # Normalising factor


# EI= 58.6957 # from Reza
# rhoA= 0.7989 # from Reza
```

1.5 CantileverBeam_lmfr.ps

MTT command:

```
mtt CantileverBeam lmfr ps
```

This representation is given as Figure 1.8 (on page 32).

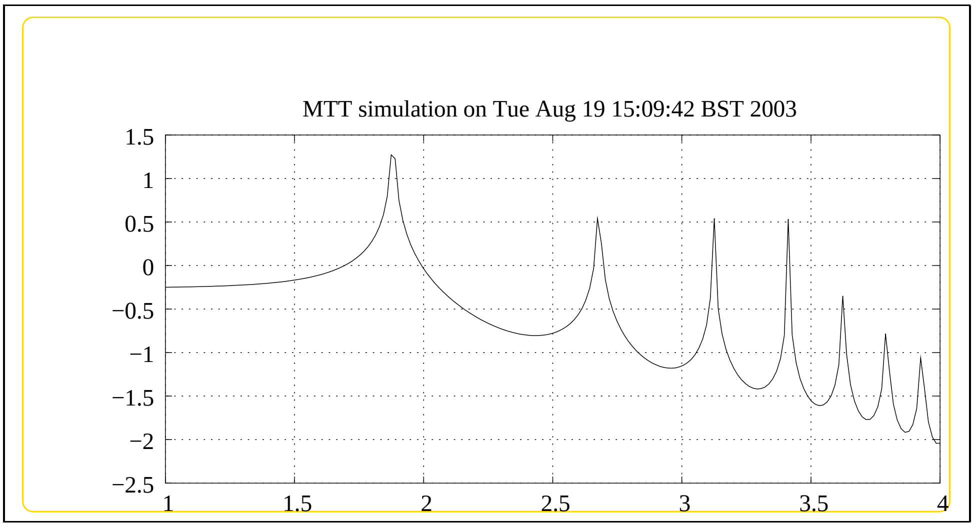

Figure 1.8: System **CantileverBeam**, representation lmfr (-noargs)

Chapter 2

PinnedBeam

2.1 PinnedBeam_abg.tex

MTT command:

```
mtt PinnedBeam abg tex
```

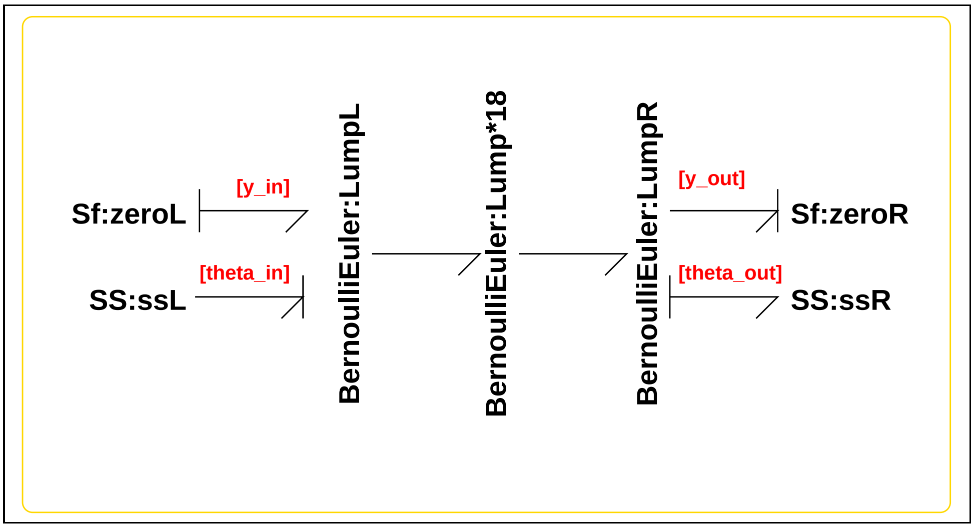

Figure 2.1: System **PinnedBeam**: acausal bond graph

The acausal bond graph of system **PinnedBeam** is displayed in Figure 2.1 (on page 33) and its label file is listed in Section 2.1.1 (on page 35). The subsystems are listed in Section 2.1.2 (on page 37).

This example represents the dynamics of a uniform beam with two pinned ends. The left-hand end is driven by a torque input and the corresponding collocated angular velocity is measured. The beam is approximated by 20 equal lumps using the Bernoulli-Euler. Because the two end lumps have different causality to the rest of the beam lumps, they are represented seperately. The system has 40 states (20 modes of vibration), 1 input and 1 output.

Name	Value
Beam Length, L	0.60 m
Beam Width w	0.05 m
Beam Thickness t_b	0.003
Young's Modulus E	68.94×10^9
Density ρ	2712.8
Derived quantities	
EI	7.76
ρA	0.40692

Table 2.1: Beam parameters

The beam was made of aluminium with physical dimensions and constants given in Table 2.1. The derived beam constants are given by the formulae:

$$\begin{aligned} EI &= E \times w \frac{1}{12} t_b^3 \\ \rho A &= \rho \times w t_b \end{aligned} \tag{2.1}$$

The system parameters are also given in Section **??** (on page **??**).

Index	f_r (theory)	f_r (model)	f_a (theory)	f_a (model)
1	19.05	19.01	29.72	31.28
2	76.24	75.57	96.50	100.80
3	171.58	168.29	200.73	208.20
4	304.76	294.89	344.13	350.88
5	476.34	452.25	524.98	525.23

Table 2.2: Resonant and anti-resonant frequencies (Hz)

Standard modal analysis give the theoretical system resonant frequencies f_r (based on the Bernoulli-Euler beam with the same values of EI and ρA). The system anti-resonances f_a correspond to those of the *inverse* system with reversed causality, that the driven pinned end is replaced by a clamped end; again modal analysis of the inverse system gives the system anti resonances. The model and theoretical values are compared in Table 2.2 for the first 5 modes. (This table was generated using the script MakeFreqTable.m)

2.1.1 Summary information

System PinnedBeam: ¡Detailed description here¿

Interface information:

This component has no ALIAS declarations

Variable declarations:

Area

AreaMoment

BeamLength

BeamThickness

BeamWidth

Density

EI

Lumps

Youngs

rhoA

Units declarations:

This component has no UNITs declarations

The label file: PinnedBeam_lbl.txt

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

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: PinnedBeam_lbl.txt,v 1.3 2003/06/11 16:02:52 gawthrop Exp $
% %% $Log: PinnedBeam_lbl.txt,v $
```

```
% %% Revision 1.3  2003/06/11 16:02:52  gawthrop
% %% Updated examples for latest MTT.
% %%
% %% Revision 1.2  2000/08/01 12:11:57  peterg
% %% Added %Vars
% %%
% %% Revision 1.1  1999/10/11 05:08:22  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


%VAR Lumps
%VAR BeamLength
%VAR BeamWidth
%VAR BeamThickness
%VAR Youngs
%VAR Density
%VAR Area
%VAR AreaMoment
%VAR EI
%VAR rhoA

% Port aliases

% Argument aliases

%% 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 BernoulliEuler
Lump
LumpL
LumpR

% Component type SS
ssL SS external,external
```

```
ssR SS 0,internal

% Component type Sf
zeroL  none 0
zeroR  none 0
```

2.1.2 Subsystems

- BernoulliEuler (3) No subsystems.
- Sf Simple flow source (2) No subsystems.

2.1.3 BernoulliEuler

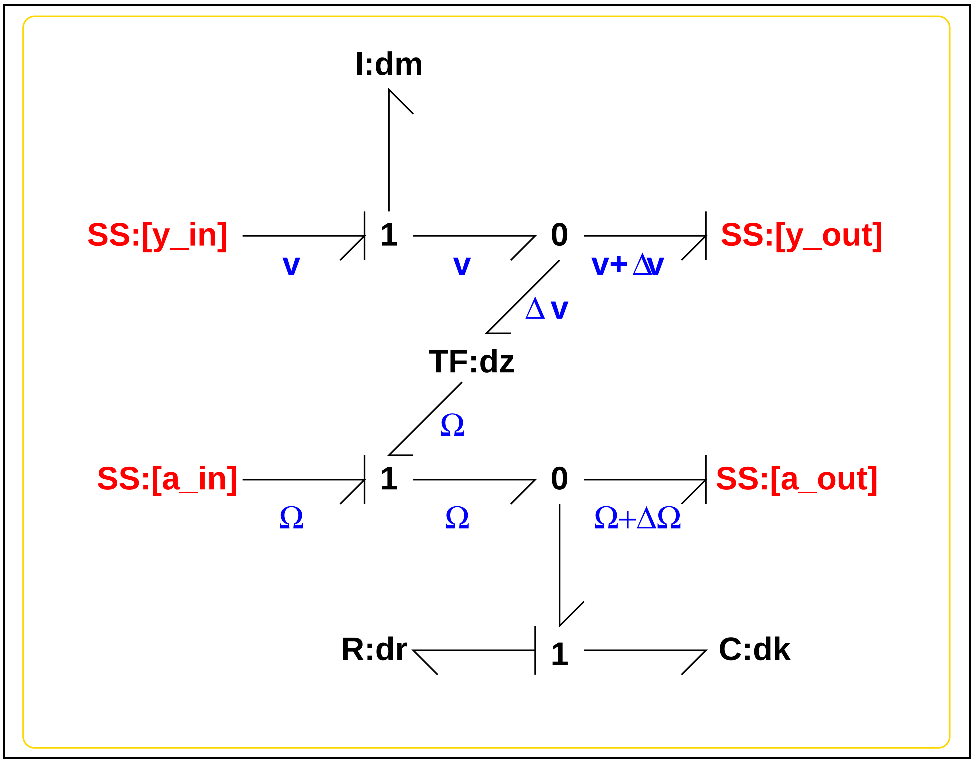

Figure 2.2: System **BernoulliEuler**: acausal bond graph

The acausal bond graph of system **BernoulliEuler** is displayed in Figure 2.2 (on page 37) and its label file is listed in Section 2.1.3 (on page 38). The subsystems are listed in Section 2.1.3 (on page 40).

This component represents one lump of a lumped model of a uniform beam modelled using the the Bernoulli-Euler assumptions:

1. The shear forces can be neglected.
2. Rotational inertia can be neglected.

- The **I** component represents the inertial properties of the lump in the perpendicular direction. In particular the velocity of the lump v is:

$$\dot{v} = \frac{\Delta f}{\Delta m} \tag{2.2}$$

  where Δm is the lump mass and Δf is the net vertical force.

- The **C** component represents the angular stiffness of the lump. In particular the torque acting on the lump is:

$$\dot{\tau} = \Delta k \Delta \Omega \tag{2.3}$$

  where Δk is the lump (angular) stiffness and $\Delta\Omega$ is the net angular velocity.

- The **TF** component represents the relation between the angular domains

$$\begin{aligned} \tau &= \Delta x \Delta f \\ \Delta v &= \Delta x \Omega \end{aligned} \tag{2.4}$$

Summary information

System BernoulliEuler: ¡Detailed description here¿

Interface information:

Parameter $1 represents actual parameter **dk**

Parameter $2 represents actual parameter **dm**

Parameter $3 represents actual parameter **dz**

Parameter $4 represents actual parameter **dr**

Port in represents actual port **y_in,a_in**

Port out represents actual port **y_out,a_out**

Port theta_in represents actual port **a_in**

Port theta_out represents actual port **a_out**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: BernoulliEuler_lbl.txt

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

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: BernoulliEuler_lbl.txt,v 1.5 2000/12/27 16:34:35 peterg Exp $
% %% $Log: BernoulliEuler_lbl.txt,v $
% %% Revision 1.5  2000/12/27 16:34:35  peterg
% %% *** empty log message ***
% %%
% %% Revision 1.4  1999/10/13 07:01:58  peterg
% %% Added aliases:
% %%  a_in theta_in
% %%  a_out theta_out
% %%
% %% Revision 1.3  1999/09/02 03:07:16  peterg
% %% r_d --> dr
% %%
% %% Revision 1.2  1999/05/17 21:27:05  peterg
% %% Added damping
% %%
% %% Revision 1.1  1999/05/16 07:12:40  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS theta_in        a_in
%ALIAS theta_out a_out
```

```
%ALIAS in y_in,a_in
%ALIAS out y_out,a_out

% Argument aliases
%ALIAS $1 dk
%ALIAS $2 dm
%ALIAS $3 dz
%ALIAS $4 dr

%% 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 I
dm lin flow,dm

% Component type C
dk lin state,dk

% Component type R
dr lin flow,dr

% Component type SS
[y_in] SS external,external
[y_out] SS external,external
[a_in] SS external,external
[a_out] SS external,external

% Component type TF
dz lin effort,dz
```

Subsystems

No subsystems.

2.1.4 Sf

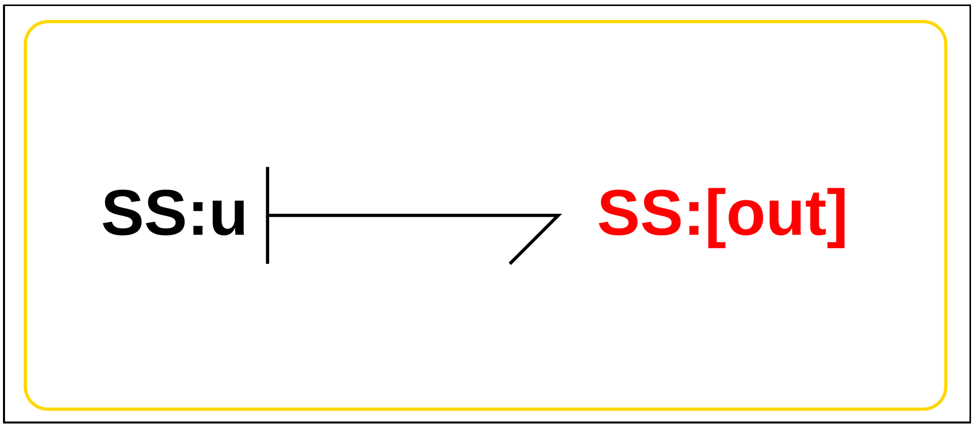

Figure 2.3: System **Sf**: acausal bond graph

The acausal bond graph of system **Sf** is displayed in Figure 5.7 (on page 86) and its label file is listed in Section 5.1.8 (on page 86). The subsystems are listed in Section 5.1.8 (on page 88).

Summary information

System Sf:Simple flow source Simple flow source constructed from SS with fixed causality

Interface information:

Parameter $1 represents actual parameter **f_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: Sf_lbl.txt

```
%% Label file for system Sf (Sf_lbl.txt)
%SUMMARY Sf Simple flow source
%DESCRIPTION  Simple flow source constructed from SS with fixed ca

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Sf_lbl.txt,v 1.3 1999/08/05 07:32:07 peterg Exp $
% %% $Log: Sf_lbl.txt,v $
% %% Revision 1.3  1999/08/05 07:32:07  peterg
% %% Added in alias
% %%
% %% Revision 1.2  1999/03/12 04:03:09  peterg
% %% Single argument - the value of the flow
% %%
% %% Revision 1.1  1999/03/03 21:50:15  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS out|in out

% Argument aliases
%ALIAS    $1 f_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 internal,f_s
```

Subsystems

No subsystems.

2.2 PinnedBeam_struc.tex

MTT command:

```
mtt PinnedBeam struc tex
```

List of inputs for system PinnedBeam			
	Component	System	Repetition
1	ssL	PinnedBeam__ssL	1

List of nonstates for system PinnedBeam			
	Component	System	Repetition
1	dm	PinnedBeam__LumpL__dm	1
2	dk	PinnedBeam__LumpR__dk	1

List of outputs for system PinnedBeam			
	Component	System	Repetition
1	ssL	PinnedBeam__ssL	1

List of states for system PinnedBeam			
	Component	System	Repetition
1	dm	PinnedBeam_Lump_dm	1
2	dk	PinnedBeam_Lump_dk	1
3	dm	PinnedBeam_Lump_2_dm	2
4	dk	PinnedBeam_Lump_2_dk	2
5	dm	PinnedBeam_Lump_3_dm	3
6	dk	PinnedBeam_Lump_3_dk	3
7	dm	PinnedBeam_Lump_4_dm	4
8	dk	PinnedBeam_Lump_4_dk	4
9	dm	PinnedBeam_Lump_5_dm	5
10	dk	PinnedBeam_Lump_5_dk	5
11	dm	PinnedBeam_Lump_6_dm	6
12	dk	PinnedBeam_Lump_6_dk	6
13	dm	PinnedBeam_Lump_7_dm	7
14	dk	PinnedBeam_Lump_7_dk	7
15	dm	PinnedBeam_Lump_8_dm	8
16	dk	PinnedBeam_Lump_8_dk	8
17	dm	PinnedBeam_Lump_9_dm	9
18	dk	PinnedBeam_Lump_9_dk	9
19	dm	PinnedBeam_Lump_10_dm	10
20	dk	PinnedBeam_Lump_10_dk	10
21	dm	PinnedBeam_Lump_11_dm	11
22	dk	PinnedBeam_Lump_11_dk	11
23	dm	PinnedBeam_Lump_12_dm	12
24	dk	PinnedBeam_Lump_12_dk	12
25	dm	PinnedBeam_Lump_13_dm	13
26	dk	PinnedBeam_Lump_13_dk	13

List of states for system PinnedBeam (continued)			
	Component	System	Repetition
27	dm	PinnedBeam__Lump__14__dm	14
28	dk	PinnedBeam__Lump__14__dk	14
29	dm	PinnedBeam__Lump__15__dm	15
30	dk	PinnedBeam__Lump__15__dk	15
31	dm	PinnedBeam__Lump__16__dm	16
32	dk	PinnedBeam__Lump__16__dk	16
33	dm	PinnedBeam__Lump__17__dm	17
34	dk	PinnedBeam__Lump__17__dk	17
35	dm	PinnedBeam__Lump__18__dm	18
36	dk	PinnedBeam__Lump__18__dk	18
37	dk	PinnedBeam__LumpL__dk	1
38	dm	PinnedBeam__LumpR__dm	1

2.3 PinnedBeam_simpar.tex

MTT command:

```
mtt PinnedBeam simpar tex

# -*-octave-*- Put Emacs into octave-mode
# Simulation parameters for system PinnedBeam (PinnedBeam_simpar.txt)
# Generated by MTT on Mon Apr 19 06:32:42 BST 1999.
###############################################################
## Version control history
###############################################################
## $Id: PinnedBeam_simpar.txt,v 1.1 2000/12/28 17:59:05 peterg Exp $
## $Log: PinnedBeam_simpar.txt,v $
## Revision 1.1  2000/12/28 17:59:05  peterg
## To RCS
##
###############################################################


LAST         = 1.0;       # Last time in simulation
DT           = 0.01;        # Print interval
STEPFACTOR  = 10;           # Integration steps per print interval
WMIN         = 1;         # Minimum frequency = 10^WMIN
```

```
WMAX        = 4;         # Maximum frequency = 10^WMAX
WSTEPS      = 200;       # Number of frequency steps
INPUT       = 1;         # Index of the input
```

2.4 PinnedBeam_numpar.tex

MTT command:

```
mtt PinnedBeam numpar tex
```

```
# -*-octave-*- Put Emacs into octave-mode
# Numerical parameter file (pPinnedBeam_numpar.txt)
# Generated by MTT at Mon Apr 19 06:24:08 BST 1999

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: PinnedBeam_numpar.txt,v 1.2 2003/06/11 16:03:06 gawthrop
# %% $Log: PinnedBeam_numpar.txt,v $
# %% Revision 1.2  2003/06/11 16:03:06  gawthrop
# %% Updated examples for latest MTT.
# %%
# %% Revision 1.1  2000/12/28 17:59:05  peterg
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

## Number of lumps
Lumps = 20; # Number of lumps

## Beam physical parameters
BeamLength = 0.60;
BeamWidth  = 0.05;
BeamThickness = 0.003;
Youngs = 68.94e9;
Density =  2712.8;
Area = BeamWidth*BeamThickness;
AreaMoment = (BeamWidth*BeamThickness^3)/12;
EI = Youngs*AreaMoment;
rhoA = Density*Area;
```

```
## Segments
dz = BeamLength/Lumps;          # Incremental length
dm = rhoA*dz; # Incremental mass
dk = EI/dz; # Incremental stiffness
dr = 0; # Damping
```

2.5 PinnedBeam_lmfr.ps

MTT command:

```
mtt PinnedBeam lmfr ps
```

This representation is given as Figure 2.4 (on page 47).

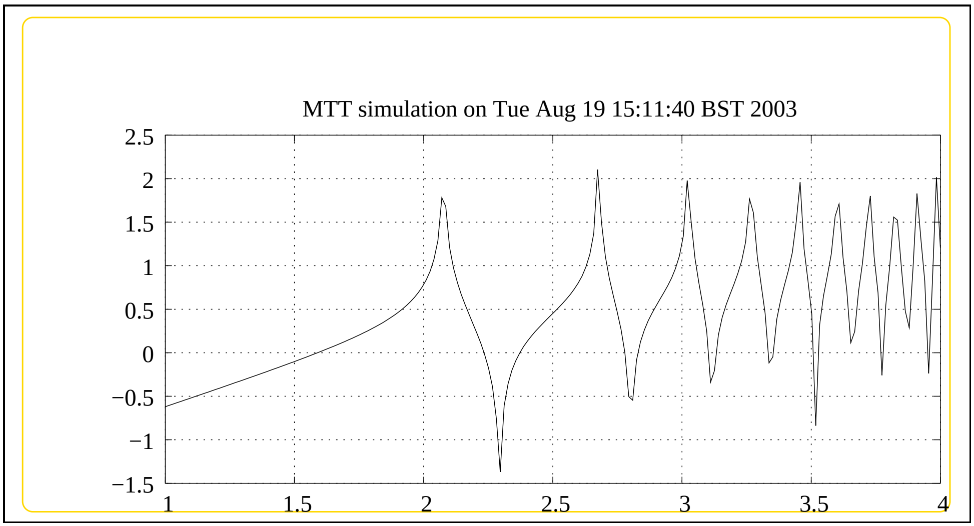

Figure 2.4: System **PinnedBeam**, representation lmfr (-noargs)

Part II

Mechanical-1D

Chapter 3

MacroMicro

3.1 MacroMicro_abg.tex

MTT command:

```
mtt MacroMicro abg tex
```

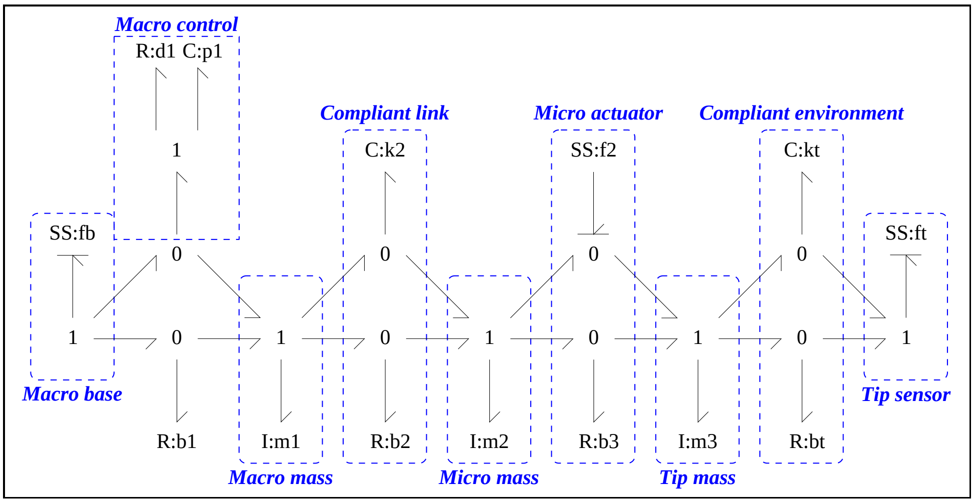

Figure 3.1: System **MacroMicro**: acausal bond graph

The acausal bond graph of system **MacroMicro** is displayed in Figure 3.1 (on page 51) and its label file is listed in Section 3.1.1 (on page 52). The subsystems are listed in Section 3.1.2 (on page 53).
This is a Bond Graph model of the macro-micro manipulation system discussed by Sharon in his thesis and BY Sharon, Hogan and Hardt in various papers.

3.1.1 Summary information

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: MacroMicro_lbl.txt

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

%Masses
m1 lin flow,m_1
m2 lin flow,m_2
m3 lin flow,m_3

%Springs
k2 lin state,k_2
kt lin state,k_t

%Dampers
b1 lin flow,b_1
b2 lin flow,b_2
b3 lin flow,b_3
bt lin flow,b_t

%Source/sensors
f2 SS external,internal
ft SS external,0
fb SS internal,0
```

```
%Control
p1 lin flow,p_1
d1 lin flow,d_1
```

3.1.2 Subsystems

No subsystems.

3.2 MacroMicro_cbg.ps

MTT command:

```
mtt MacroMicro cbg ps
```

This representation is given as Figure 3.2 (on page 53).

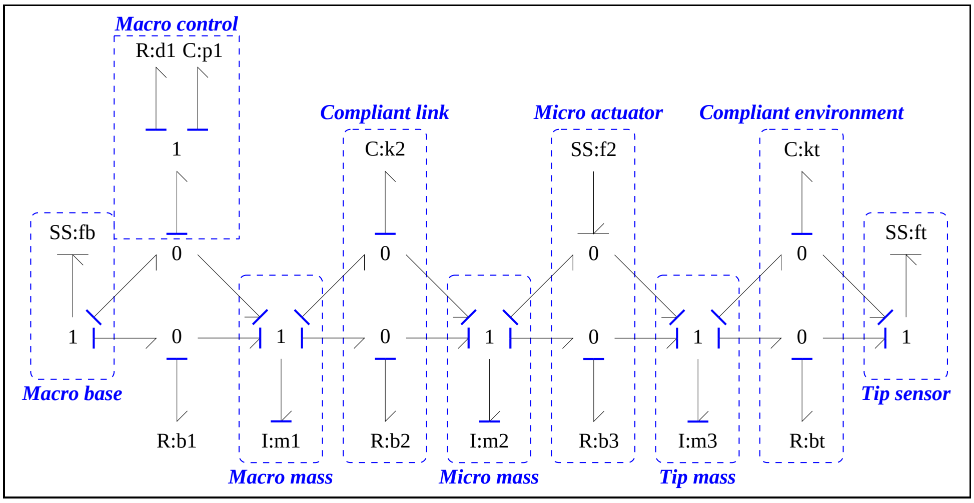

Figure 3.2: System **MacroMicro**, representation cbg (-noargs)

3.3 MacroMicro_struc.tex

MTT command:

```
mtt MacroMicro struc tex
```

List of inputs for system MacroMicro			
	Component	System	Repetition
1	f2	MacroMicro__f2	1

List of outputs for system MacroMicro			
	Component	System	Repetition
1	ft	MacroMicro__ft	1

List of states for system MacroMicro			
	Component	System	Repetition
1	m1	MacroMicro__m1	1
2	m2	MacroMicro__m2	1
3	m3	MacroMicro__m3	1
4	k2	MacroMicro__k2	1
5	kt	MacroMicro__kt	1
6	p1	MacroMicro__p1	1

3.4 MacroMicro_dae.tex

MTT command:

```
mtt MacroMicro dae tex
```

$$
\begin{aligned}
\dot{x}_1 &= \frac{(-b_1 m_2 x_1 p_1 + b_2 m_1 x_2 p_1 - b_2 m_2 x_1 p_1 - d_1 m_2 x_1 p_1 - k_2 m_1 m_2 x_4 p_1 + m_1 m_2 x_6)}{(m_1 m_2 p_1)} \\
\dot{x}_2 &= \frac{(-b_2 m_1 m_3 x_2 + b_2 m_2 m_3 x_1 + b_3 m_1 m_2 x_3 - b_3 m_1 m_3 x_2 + k_2 m_1 m_2 m_3 x_4 - m_1 m_2 m_3 u_1)}{(m_1 m_2 m_3)} \\
\dot{x}_3 &= \frac{(-b_3 m_2 x_3 + b_3 m_3 x_2 - b_t m_2 x_3 - k_t m_2 m_3 x_5 + m_2 m_3 u_1)}{(m_2 m_3)} \\
\dot{x}_4 &= \frac{(-m_1 x_2 + m_2 x_1)}{(m_1 m_2)} \\
\dot{x}_5 &= \frac{x_3}{m_3} \\
\dot{x}_6 &= \frac{(-x_1)}{m_1}
\end{aligned}
\tag{3.1}
$$

$$y_1 = \frac{(b_t x_3 + k_t m_3 x_5)}{m_3} \tag{3.2}$$

3.5 MacroMicro_dm.tex

MTT command:

```
mtt MacroMicro dm tex
```

$$A = \begin{pmatrix} \frac{(-(b_1+b_2+d_1))}{m_1} & \frac{b_2}{m_2} & 0 & -k_2 & 0 & \frac{1}{p_1} \\ \frac{b_2}{m_1} & \frac{(-(b_2+b_3))}{m_2} & \frac{b_3}{m_3} & k_2 & 0 & 0 \\ 0 & \frac{b_3}{m_2} & \frac{(-(b_3+b_t))}{m_3} & 0 & -k_t & 0 \\ \frac{1}{m_1} & \frac{(-1)}{m_2} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{m_3} & 0 & 0 & 0 \\ \frac{(-1)}{m_1} & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \tag{3.3}$$

$$B = \begin{pmatrix} 0 \\ -1 \\ 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{3.4}$$

$$C = \begin{pmatrix} 0 & 0 & \frac{b_t}{m_3} & 0 & k_t & 0 \end{pmatrix} \tag{3.5}$$

$$D = \begin{pmatrix} 0 \end{pmatrix} \tag{3.6}$$

3.6 MacroMicro_tf.tex

MTT command:

```
mtt MacroMicro tf tex
```

$$G = \left(\frac{}{(b_1 b_2 b_3 p_1 s^3 + b_1 b_2 b_t p_1 s^3 + b_1 b_2 k_t p_1 s^2 + b_1 b_2 m_3 p_1 s^4 + b_1 b_3 b_t p_1 s^3 + b_1 b_3 k_2 p_1 s^2 + b_1 b_3 k_t p_1 s^2 + b_1 b_3 m_2 p_1 s^4 + b_1 b_3 m_3 p_1 s^4 + b_1 b_t k_2 p_1 s} \right. \tag{3.7}$$

3.7 MacroMicro_numpar.txt

MTT command:

```
mtt MacroMicro numpar txt
```

```
m_1 = 0.0169; # m_1;
m_2 = 0.0169; # m_2;
b_1 = 0.13; # b_1;
b_2 = 0.013; # b_2;
k_2 = 24;         # k_2;
k_t = 150; # k_t;
b_t = 0.16; # b_t;
b_3 = 0.13; # b_3;
m_3 = 0.005; # m_3;
p_1 = 10; # p_1;
d_1 = 0.9; # d_1;
```

3.8 MacroMicro_lmfr.ps

MTT command:

```
mtt MacroMicro lmfr ps
```

This representation is given as Figure 3.3 (on page 57).

3.9 MacroMicro_sro.ps

MTT command:

```
mtt MacroMicro sro ps
```

This representation is given as Figure 3.4 (on page 57).

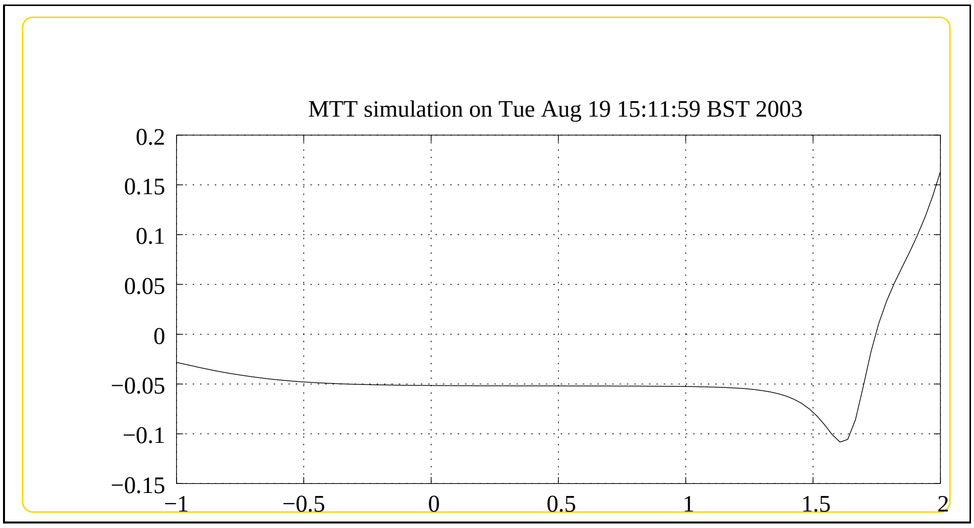

Figure 3.3: System **MacroMicro**, representation lmfr (-noargs)

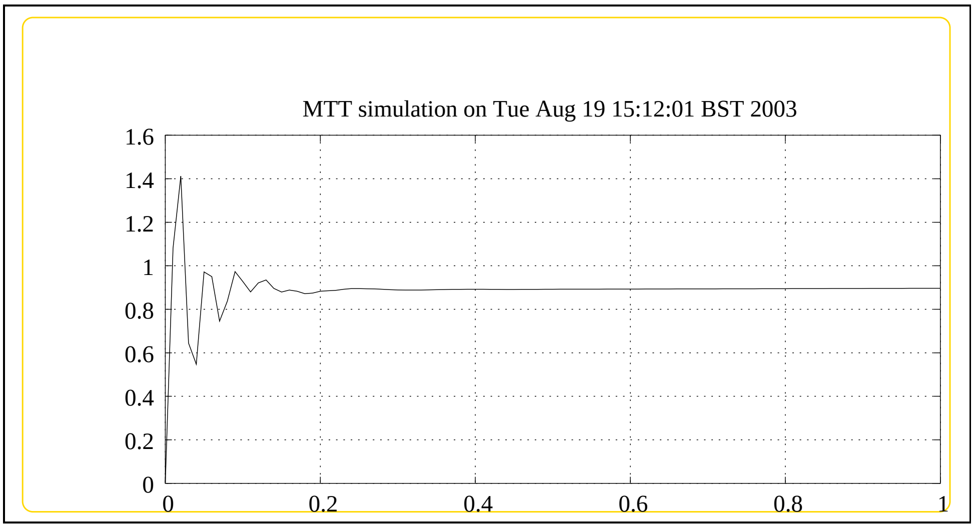

Figure 3.4: System **MacroMicro**, representation sro (-noargs)

Chapter 4

NonlinearMSD

4.1 NonlinearMSD_abg.tex

MTT command:

```
mtt NonlinearMSD abg tex
```

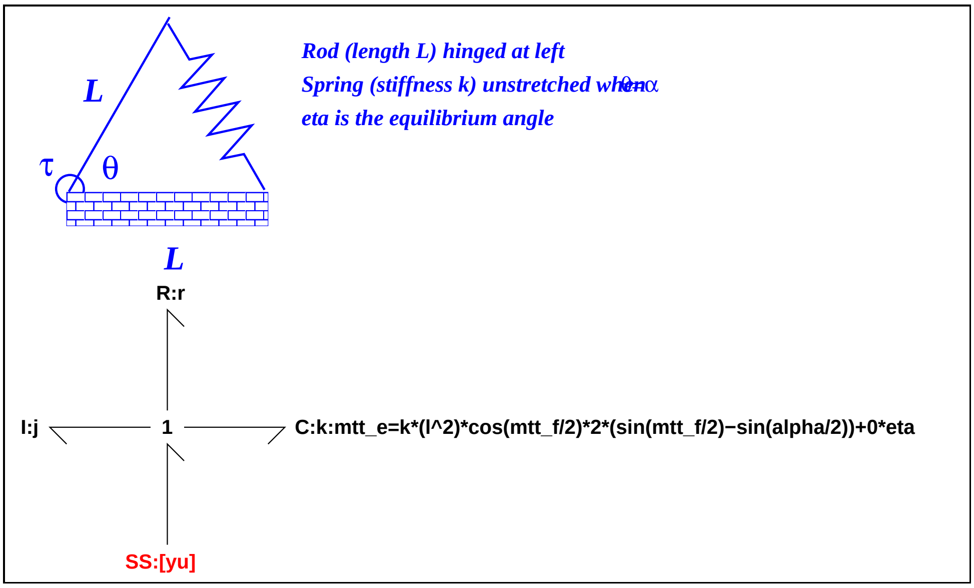

Figure 4.1: System **NonlinearMSD**: acausal bond graph

This example illustrates the use of **MTT** to *linaerise* a nonlinear system – a non-linear mass-spring-damper system called **NonlinearMSD**. The model is considered in Section 4.1.1 and linearisation in Section 4.1.2 (on page 60). Further work is suggested in Section 4.1.3 (on page 61).

4.1.1 Bond Graph model

The schematic diagram of the system **NonlinearMSD** is displayed in Figure 4.1. The system comprises

- a rigid foundation,
- a rod of length L hinged at the left-hand end and
- a linear spring of stiffness k attached to the rigid foundation a distance L from the hinge and to the free end of the rod.

The spring is unstretched when the rod makes an angle $\theta == \frac{pi}{3}$ with the foundation.
Using elementary geometry, the effectice angular spring generates a torque τ given by (4.1)

$$\tau = -2kl^2 \cos\frac{\theta}{2}(\sin\frac{\theta}{2} - \sin\frac{\alpha}{2}) \tag{4.1}$$

The acausal bond graph of system **NonlinearMSD** is also displayed in Figure 4.1 (on page 59). This shows the three bond graph components representing the friction **R**, the inertia **I** and the spring **C** components. The non-linear spring characteristic is given explicitly[1].
The (nonlinear) system ordinary differential equation is given by **MTT** in Section **??** (on page **??**). This is a special case of the general non-linear ordinary differential equation:

$$\begin{cases} \dot{x} = f(x,u) \\ y = g(x,u) \end{cases} \tag{4.2}$$

4.1.2 Linearisation

The first step in linearisation is to determine a set of (constant) states x_e and (constant) inputs u_e so that the system is in equilibrium - that is

$$\dot{x} = f(x_e, u_e) = 0 \tag{4.3}$$

In this case, choosing an angle $\theta = \eta$ and an input:

$$u_e = -\tau = 2kl^2 \cos\frac{\eta}{2}(\sin\frac{\eta}{2} - \sin\frac{\alpha}{2}) \tag{4.4}$$

[1] The additional 0*eta term has no effect - it merely introduced the variable η – the equilibrium angle – into the model

together with zero velocity gives an equilibrium.
With this choice The linearised system is given in terms of the *A*, *B*, *C* and *D* matrices appearing in the state equation:

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases} \tag{4.5}$$

MTT automatically generates these matrices – see Section **??** (on page **??**).

4.1.3 Further work

1. Derive the system ordinary differential equation appearing in Section **??** (on page **??**).

2. Explain how the input of (4.4) gives equilibrium for all η.

3. Explain how the elements of the *A*, *B*, *C* and *D* appearing Section **??** (on page **??**) arise from the ordinary differential equation of Section **??** (on page **??**) together with the input of (4.4).

4. Setting up parameters, inputs and initial state as in Sections **??** (on page **??**), **??** (on page **??**) and **??** (on page **??**), perform simulations as in Section **??** (on page **??**) - the figure shows the angular *velocity* $\dot{\theta}$.

5. Repeat the simulation with different perturbations by modifying the file "NonlinearMSD_input.tex" (see Section **??** (on page **??**))

   (a) note that for smaller perturbations, the graphs are of similar shape (scaled by the perturbation input)

   (b) note that for larger perturbations the graphs are quite different - this is a non-linear system.

6. Repeat the simulation with different equilibrium angles η by modifying the file "NonlinearMSD_numpar.tex" (see Section **??** (on page **??**)) appropriately. Note that when $\eta = \pi$, the linearised system is *unstable*.

7. The (2,1) element of the *A* matrix in Section **??** (on page **??**) is the *linearised* stiffness k_l. Plot this against η and explain the observation in item 6.

4.1.4 Summary information

System NonlinearMSD: Detailed description here

Interface information:

Parameter $1 represents actual parameter **alpha**

Parameter $2 represents actual parameter **eta**

Parameter $3 represents actual parameter **j**

Parameter $4 represents actual parameter **k**

Parameter $5 represents actual parameter **l**

Parameter $6 represents actual parameter **r**

Port yu represents actual port **yu**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: NonlinearMSD_lbl.txt

```
#SUMMARY NonlinearMSD
#DESCRIPTION Detailed description here

## System NonlinearMSD, representation lbl, language txt
## File NonlinearMSD_lbl.txt
## Generated by MTT on Tue Aug 19 15:12:03 BST 2003

  ######################################
  ##### Model Transformation Tools #####
  ######################################

  ###############################################################
  ## Version control history
  ###############################################################
  ## $Id: mtt_banner.sh,v 1.2 2001/07/03 22:59:10 gawthrop Exp $
  ## $Log: mtt_banner.sh,v $
  ## Revision 1.2  2001/07/03 22:59:10  gawthrop
```

```
  ## Fixed problems with argument passing for CRs
  ##
  ###############################################################

## Port aliases
#ALIAS yu yu

## Argument aliases
#ALIAS $1 alpha
#ALIAS $2 eta
#ALIAS $3 j
#ALIAS $4 k
#ALIAS $5 l
#ALIAS $6 r

## 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
k cr mtt_e=k*(l^2)*cos(mtt_f/2)*2*(sin(mtt_f/2)-sin(alpha/2))+0*eta

## Component type I
j lin flow,j

## Component type R
r lin flow,r

## Component type SS
[yu] SS external,external
```

4.1.5 Subsystems

No subsystems.

4.2 NonlinearMSD_sympar.tex

MTT command:

```
mtt NonlinearMSD sympar tex
```

Parameter	System
alpha	NonlinearMSD
eta	NonlinearMSD
j	NonlinearMSD
k	NonlinearMSD
l	NonlinearMSD
r	NonlinearMSD

Table 4.1: Parameters

4.3 NonlinearMSD_ode.tex

MTT command:

```
mtt NonlinearMSD ode tex
```

$$\begin{aligned} \dot{x}_1 &= \frac{x_2}{j} \\ \dot{x}_2 &= \frac{\left(2\cos\left(\frac{x_1}{2}\right)\sin\left(\frac{\alpha}{2}\right)jkl^2 - 2\cos\left(\frac{x_1}{2}\right)\sin\left(\frac{x_1}{2}\right)jkl^2 + ju_1 - x_2 r\right)}{j} \end{aligned} \tag{4.6}$$

$$y_1 = \frac{x_2}{j} \tag{4.7}$$

4.4 NonlinearMSD_sspar.tex

MTT command:

```
mtt NonlinearMSD sspar tex
```

```
% Steady-state parameter file (NonlinearMSD_sspar.r)
% Generated by MTT at Thu Mar  7 10:39:15 GMT 2002

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% % Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% % $Id: NonlinearMSD_sspar.r,v 1.1 2002/04/17 18:12:43 gawthrop Exp $
% % $Log: NonlinearMSD_sspar.r,v $
% % Revision 1.1  2002/04/17 18:12:43  gawthrop
% % Additional files for this example
% %
% % Revision 1.1  2000/12/28 09:32:04  peterg
% % Initial revision
% %
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


%% This one corresponds to the unstretched spring at theta = pi/3
%% Note that U is calculated to give equilibrium for all angles

alpha := pi/3;

% Steady-state states
MTTX1 :=  eta;     %Initial angle (corresponds to u=0)
MTTX2 :=  0;        %Initial anglular velocity
% Steady-state inputs
MTTU1 :=  k*(l^2)*cos(MTTX1/2)*2*(sin(MTTX1/2)-sin(alpha/2));
;;END;
```

4.5 NonlinearMSD_ss.tex

MTT command:

```
mtt NonlinearMSD ss tex
```

$$x = \begin{pmatrix} \eta \\ 0 \end{pmatrix} \tag{4.8}$$

$$u = \left(\cos\left(\frac{eta}{2}\right) k l^2 \left(2 \sin\left(\frac{eta}{2}\right) - 1\right)\right) \tag{4.9}$$

$$y = \begin{pmatrix} 0 \end{pmatrix} \tag{4.10}$$

$$\dot{x} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \tag{4.11}$$

4.6 NonlinearMSD_sm.tex

MTT command:

```
mtt NonlinearMSD sm tex
```

$$A = \begin{pmatrix} 0 & \frac{1}{j} \\ \frac{\left(kl^2\left(-2\cos\left(\frac{eta}{2}\right)^2+2\sin\left(\frac{eta}{2}\right)^2-\sin\left(\frac{eta}{2}\right)\right)\right)}{2} & \frac{(-r)}{j} \end{pmatrix} \tag{4.12}$$

$$B = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \tag{4.13}$$

$$C = \begin{pmatrix} 0 & \frac{1}{j} \end{pmatrix} \tag{4.14}$$

$$D = \begin{pmatrix} 0 \end{pmatrix} \tag{4.15}$$

4.7 NonlinearMSD_numpar.tex

MTT command:

```
mtt NonlinearMSD numpar tex
```

```
## -*-octave-*- Put Emacs into octave-mode ##

##
## System NonlinearMSD, representation numpar, language txt;
## File NonlinearMSD_numpar.txt;
```

```
## Generated by MTT on Thu Mar  7 14:03:19 GMT 2002;



alpha = pi/3; # Angle for unstretched string
eta = pi/3; #  Equilibrium angle
j = 1.0; # Inertia
k = 1.0; # Spring constant
l = 1.0; # Rod length
r = 1.0; # Rotational resistance
```

4.8 NonlinearMSD_state.tex

MTT command:

```
mtt NonlinearMSD state tex

## -*-octave-*- Put Emacs into octave-mode ##

##
## System NonlinearMSD, representation state, language txt;
## File NonlinearMSD_state.txt;
## Generated by MTT on Thu Mar  7 10:50:45 GMT 2002;



## Removed by MTT on Tue Jun 10 16:51:50 BST 2003: NonlinearMSD_j
= 0.0;  % Initial angular momentum
## Removed by MTT on Tue Jun 10 16:51:50 BST 2003: NonlinearMSD_k
= eta; % Initial angle
nonlinearmsd__j = 0.0; # Added by MTT on Tue Jun 10 16:51:52 BST 2003
nonlinearmsd__k = eta; # initial angle
```

4.9 NonlinearMSD_input.tex

MTT command:

```
mtt NonlinearMSD input tex

## -*-octave-*- Put Emacs into octave-mode ##
```

```
##
## System NonlinearMSD, representation input, language txt;
## File NonlinearMSD_input.txt;
## Generated by MTT on Thu Mar  7 10:50:46 GMT 2002;

## First term is the equilibrium input; last term is the perturbat
## Removed by MTT on Tue Jun 10 16:50:53 BST 2003: NonlinearMSD_yu
= k*(lˆ2)*cos(eta/2)*2*(sin(eta/2)-sin(alpha/2)) + 1e-2;

nonlinearmsd__yu = k*(lˆ2)*cos(eta/2)*2*(sin(eta/2)-sin(alpha/2))
```

4.10 NonlinearMSD_odeso.ps

MTT command:

```
mtt NonlinearMSD odeso ps
```

This representation is given as Figure 4.2 (on page 68).

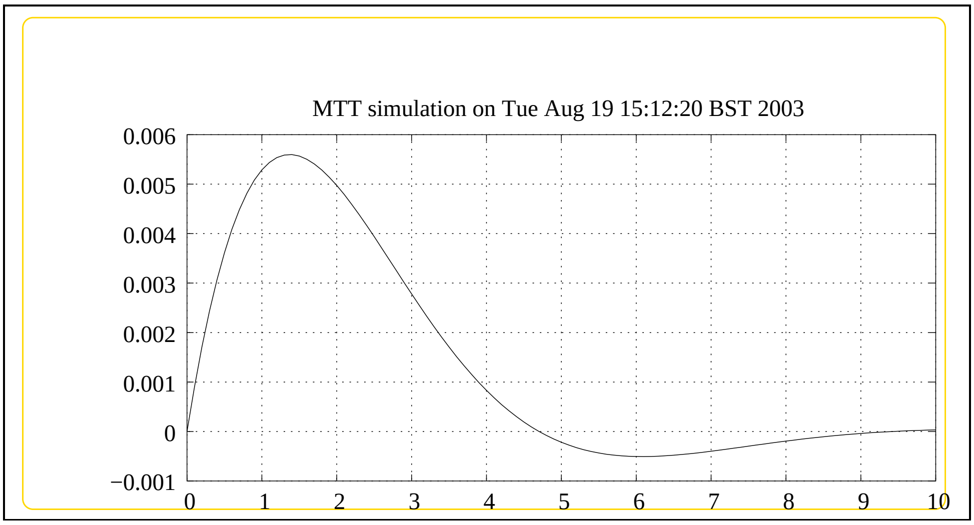

Figure 4.2: System **NonlinearMSD**, representation odeso (-noargs)

Part III

Mechanical-2D

Chapter 5

InvertedPendulumOnCart

5.1 InvertedPendulumOnCart_abg.tex

MTT command:

```
mtt InvertedPendulumOnCart abg tex
```

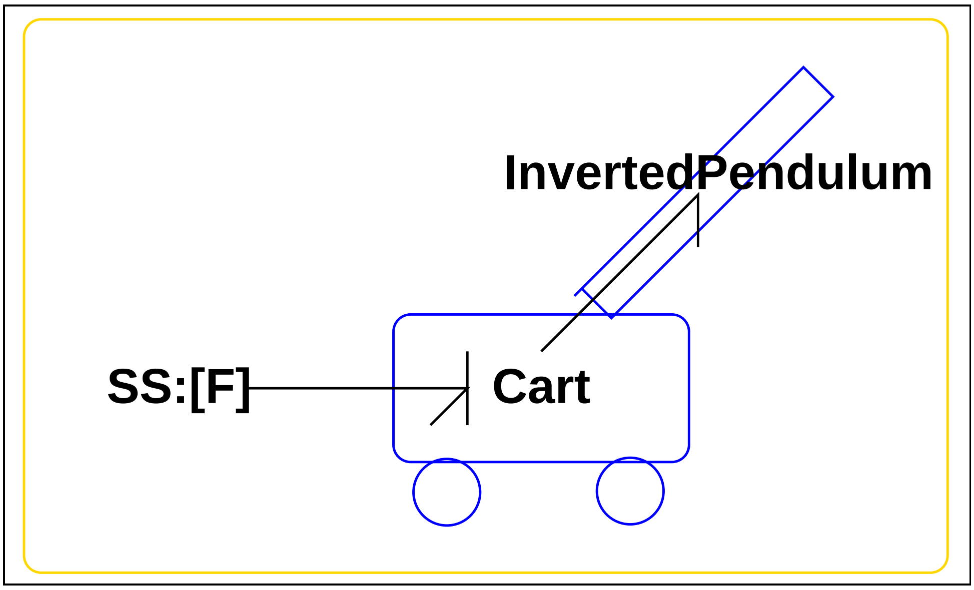

Figure 5.1: System **InvertedPendulumOnCart**: acausal bond graph

The acausal bond graph of system **InvertedPendulumOnCart** is displayed in Figure 5.1 (on page 71) and its label file is listed in Section 5.1.1 (on page 72). The subsystems are listed in Section 5.1.2 (on page 73).

This is a one input, two output nonlinear system comprising an inverted pendulum attached by a hinge to a cart constrained to move in the horizontal direction. The input is the horizontal force acting on the cart, and the two outputs are the horizontal position and the pendulum angle respectively.

5.1.1 Summary information

System InvertedPendulumOnCart: An Inverted Pendulum on a Cart

Interface information:

Port in represents actual port **F**

Variable declarations:

This component has no PAR declarations

Units declarations:

Port F has domain translational

Effort units N

Flow units m/s

The label file: InvertedPendulumOnCart_lbl.txt

```
%% Label file for system InvertedPendulumOnCart (InvertedPendulumO
%SUMMARY InvertedPendulumOnCart
%DESCRIPTION An Inverted Pendulum on a Cart

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: InvertedPendulumOnCart_lbl.txt,v 1.2 2001/04/11 09:44:26
% %% $Log: InvertedPendulumOnCart_lbl.txt,v $
% %% Revision 1.2  2001/04/11 09:44:26  gawthrop
% %% Fixed cc and c problems to do with pow(x,y) and integers
% %% mtt/lib/reduce/fix_c.r is included in rdae2dae and cse2smx_la
% %% -c, -cc and -oct options
% %%
% %% Revision 1.1  2000/12/28 18:00:45  peterg
```

```
% %% To RCS
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS in   F
%UNITS F    translational  N m/s

% Argument aliases

%% 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
[F]   SS  external,internal
```

5.1.2 Subsystems

- Cart (1)
  - De Simple effort detector (1)
  - INTF: flow integrator (1)
  - Sf Simple flow source (1)
- InvertedPendulum (1)
  - De Simple effort detector (1)
  - Se Simple effort source (3)
  - gRODa: rigid rod in two dimensions - with gravity and angle port (1)

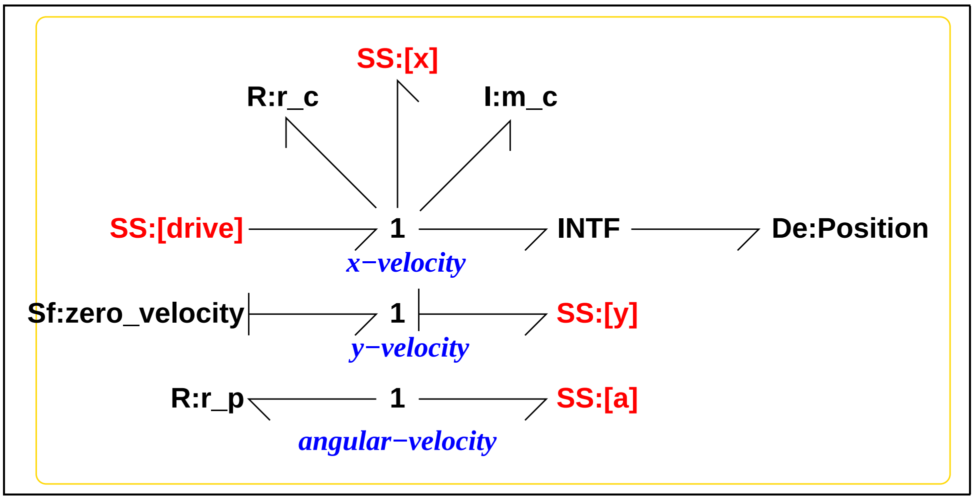

Figure 5.2: System **Cart**: acausal bond graph

5.1.3 Cart

The acausal bond graph of system **Cart** is displayed in Figure 5.2 (on page 74) and its label file is listed in Section 5.1.3 (on page 74). The subsystems are listed in Section 5.1.3 (on page 77).

Summary information

System Cart: Simple cart model

Interface information:

Parameter $1 represents actual parameter **m_c**

Port in represents actual port **drive**

Port out represents actual port **x,y,a**

Port pendulum represents actual port **x,y,a**

Variable declarations:

This component has no PAR declarations

Units declarations:

Port drive has domain translational

Effort units N

Flow units m/s

Port x has domain translational

Effort units N

Flow units m/s

Port y has domain translational

Effort units N

Flow units m/s

Port a has domain rotational

Effort units N*m

Flow units radian/s

The label file: Cart_lbl.txt

```
%% Label file for system Cart (Cart_lbl.txt)
%SUMMARY Cart
%DESCRIPTION Simple cart model

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Cart_lbl.txt,v 1.2 2001/04/11 09:44:26 gawthrop Exp $
% %% $Log: Cart_lbl.txt,v $
% %% Revision 1.2  2001/04/11 09:44:26  gawthrop
% %% Fixed cc and c problems to do with pow(x,y) and integers
% %% mtt/lib/reduce/fix_c.r is included in rdae2dae and cse2smx_lang for
% %% -c, -cc and -oct options
% %%
% %% Revision 1.1  2000/12/28 18:00:45  peterg
% %% To RCS
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% Port aliases
%ALIAS in drive
%ALIAS pendulum|out x,y,a
%UNITS  drive     translational N m/s
b%UNITS  x         translational N m/s
%UNITS  y         translational N m/s
%UNITS  a         rotational N*m radian/s


% Argument aliases
%ALIAS $1 m_c

%% 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 I
m_c lin flow,m_c

% Component type R
r_c lin flow,r_c
r_p lin flow,r_p

% Component type SS
[a] SS external,external
[drive] SS external,external
[x] SS external,external
[y] SS external,external

% Component type De
Position SS external

% Component type Sf
zero_velocity SS 0
```

Subsystems

- De Simple effort detector (1) No subsystems.
- INTF: flow integrator (1) No subsystems.
- Sf Simple flow source (1) No subsystems.

5.1.4 De

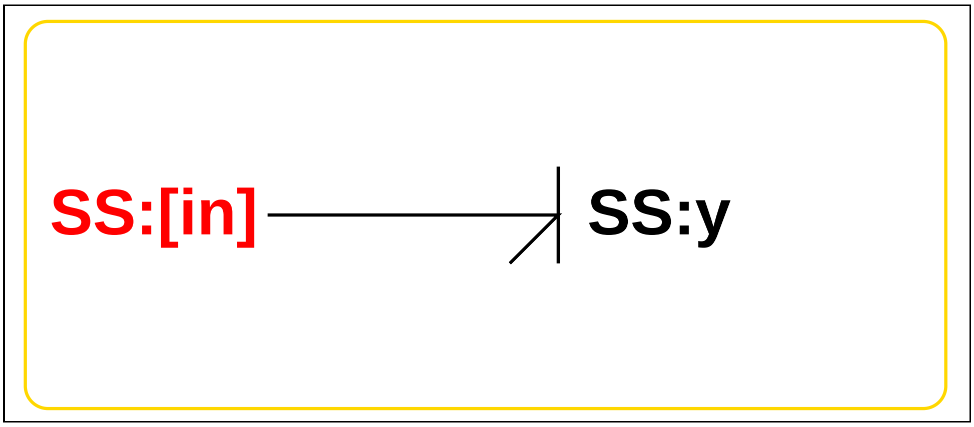

Figure 5.3: System **De**: acausal bond graph

The acausal bond graph of system **De** is displayed in Figure 5.3 (on page 77) and its label file is listed in Section 5.1.4 (on page 77). The subsystems are listed in Section 5.1.4 (on page 79).

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

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% 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.

5.1.5 INTF

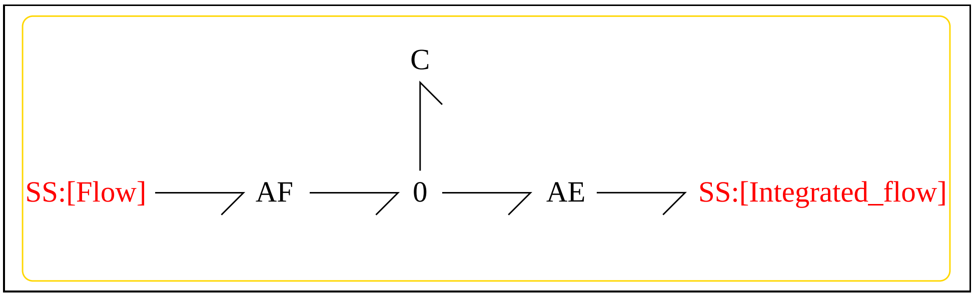

Figure 5.4: System **INTF**: acausal bond graph

The acausal bond graph of system **INTF** is displayed in Figure 10.3 (on page 173) and its label file is listed in Section 10.1.4 (on page 173). The subsystems are listed in Section 10.1.4 (on page 174).
INTF is a two-port component where the effort on port [out] is the integral of the flow on port [in].

Summary information

System INTF::flow integrator Port [in]: Flow to be integrated Port [out]: Effort = integral of flow on port [in]

Interface information:

Port in represents actual port **Flow**

Port out represents actual port **Integrated_flow**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: INTF_lbl.txt

```
%% Label file for system INTF (INTF_lbl.txt)
%SUMMARY INTF: flow integrator
%DESCRIPTION Port [in]: Flow to be integrated
%DESCRIPTION Port [out]: Effort = integral of flow on port [in]


% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: INTF_lbl.txt,v 1.3 1998/07/16 07:35:10 peterg Exp $
% %% $Log: INTF_lbl.txt,v $
% %% Revision 1.3  1998/07/16 07:35:10  peterg
% %% Aliased version
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS in Flow
%ALIAS out Integrated_flow

% Argument aliases

%% 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
[Flow] SS external,external
```

```
[Integrated_flow] SS external,external
```

Subsystems

No subsystems.

5.1.6 InvertedPendulum

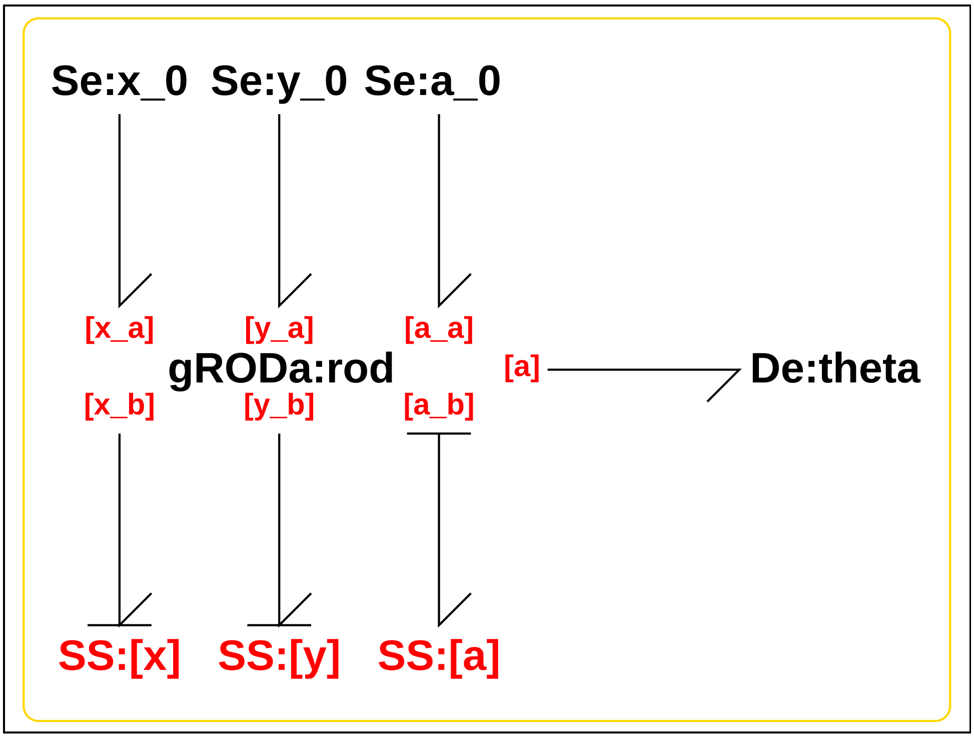

Figure 5.5: System **InvertedPendulum**: acausal bond graph

The acausal bond graph of system **InvertedPendulum** is displayed in Figure 5.5 (on page 81) and its label file is listed in Section 5.1.6 (on page 81). The subsystems are listed in Section 5.1.6 (on page 84).

Summary information

System InvertedPendulum: ¡Detailed description here¿

Interface information:

Port cart represents actual port **x,y,a**

Port in represents actual port **x,y,a**

Variable declarations:

This component has no PAR declarations

Units declarations:

Port x has domain translational

Effort units N

Flow units m/s

Port y has domain translational

Effort units N

Flow units m/s

Port a has domain rotational

Effort units N*m

Flow units radian/s

The label file: InvertedPendulum_lbl.txt

```
%% Label file for system InvertedPendulum (InvertedPendulum_lbl.tx
%SUMMARY InvertedPendulum
%DESCRIPTION <Detailed description here>

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: InvertedPendulum_lbl.txt,v 1.2 2001/04/11 09:44:26 gawth
% %% $Log: InvertedPendulum_lbl.txt,v $
% %% Revision 1.2  2001/04/11 09:44:26  gawthrop
% %% Fixed cc and c problems to do with pow(x,y) and integers
% %% mtt/lib/reduce/fix_c.r is included in rdae2dae and cse2smx_la
% %% -c, -cc and -oct options
% %%
% %% Revision 1.1  2000/12/28 18:00:45  peterg
```

```
% %% To RCS
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%UNITS  x        translational N m/s
%UNITS  y        translational N m/s
%UNITS  a        rotational N*m radian/s


%ALIAS in|cart x,y,a


% Argument aliases

%% 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 De
theta SS external

% Component type SS
[a] SS external,external
[x] SS external,external
[y] SS external,external

% Component type Se
a_0  SS 0
x_0      SS     0
y_0      SS     0

% Component type gRod
rod  none l;l;j_r;m_r;g
```

Subsystems

- De Simple effort detector (1) No subsystems.
- Se Simple effort source (3) No subsystems.
- gRODa: rigid rod in two dimensions - with gravity and angle port (1)
  - INTF: flow integrator (1)
  - Se Simple effort source (1)

5.1.7 Se

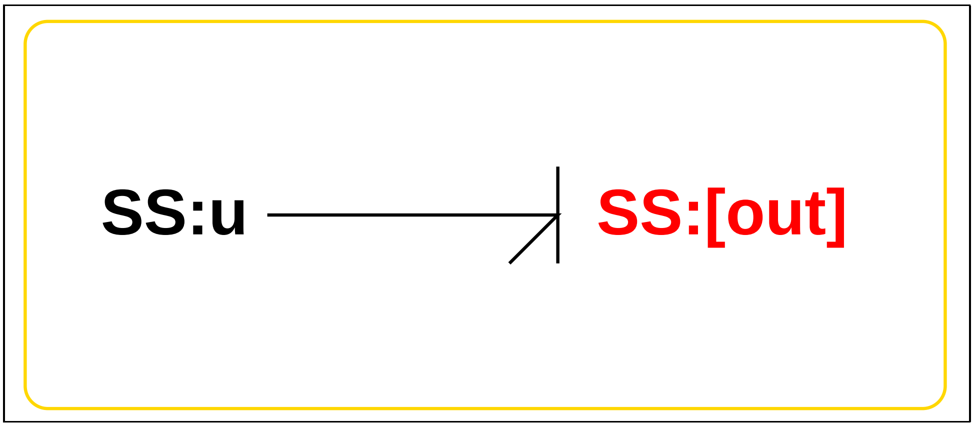

Figure 5.6: System **Se**: acausal bond graph

The acausal bond graph of system **Se** is displayed in Figure 5.6 (on page 84) and its label file is listed in Section 5.1.7 (on page 84). The subsystems are listed in Section 5.1.7 (on page 86).

Summary information

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

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.

5.1.8 Sf

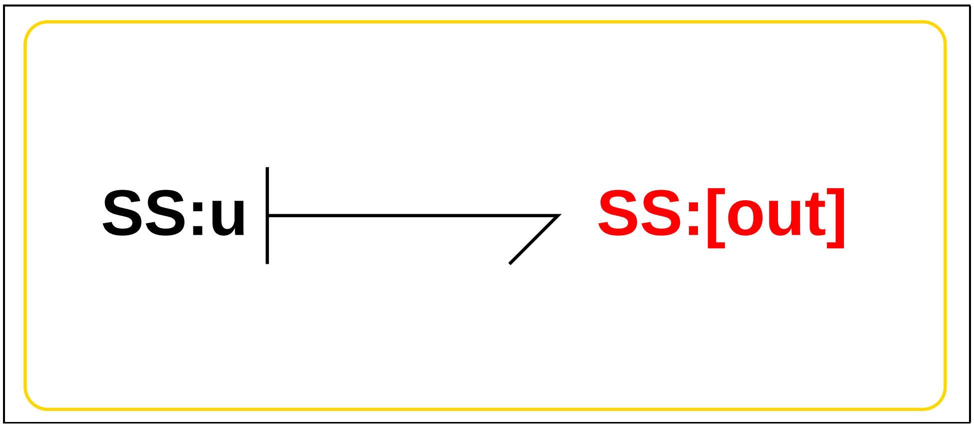

Figure 5.7: System **Sf**: acausal bond graph

The acausal bond graph of system **Sf** is displayed in Figure 5.7 (on page 86) and its label file is listed in Section 5.1.8 (on page 86). The subsystems are listed in Section 5.1.8 (on page 88).

Summary information

System Sf:Simple flow source Simple flow source constructed from SS with fixed causality

Interface information:

Parameter $1 represents actual parameter **f_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: Sf_lbl.txt

```
%% Label file for system Sf (Sf_lbl.txt)
%SUMMARY Sf Simple flow source
%DESCRIPTION  Simple flow source constructed from SS with fixed causalit

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Sf_lbl.txt,v 1.3 1999/08/05 07:32:07 peterg Exp $
% %% $Log: Sf_lbl.txt,v $
% %% Revision 1.3  1999/08/05 07:32:07  peterg
% %% Added in alias
% %%
% %% Revision 1.2  1999/03/12 04:03:09  peterg
% %% Single argument - the value of the flow
% %%
% %% Revision 1.1  1999/03/03 21:50:15  peterg
% %% Initial revision
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS out|in out

% Argument aliases
%ALIAS    $1 f_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 internal,f_s
```

Subsystems

No subsystems.

5.1.9 gRODa

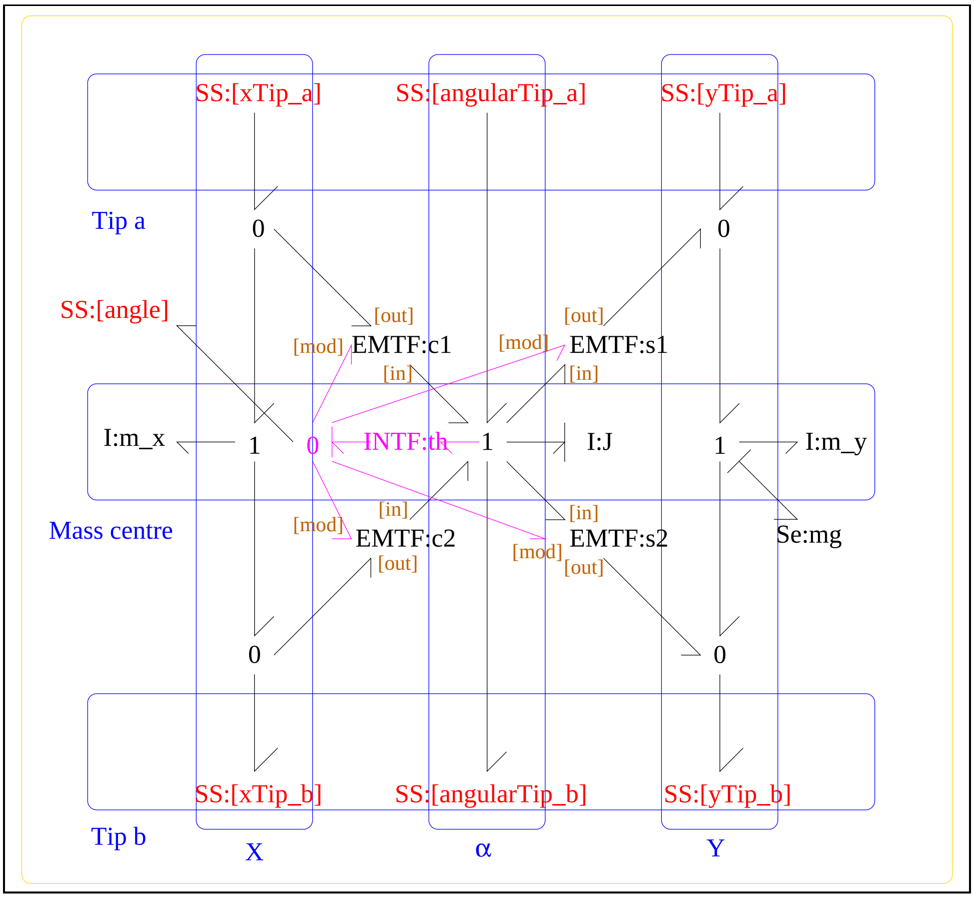

Figure 5.8: System **gRODa**: acausal bond graph

The acausal bond graph of system **gRODa** is displayed in Figure 5.8 (on page 88) and its label file is listed in Section 5.1.9 (on page 89). The subsystems are listed in Section 5.1.9 (on page 93).
gRODa is essentially as described in Figure 10.2 of "Metamodelling".

Summary information

System gRODa::rigid rod in two dimensions - with gravity and angle port
See Section 10.2 of "Metamodelling" Gravity term added at centre

Interface information:

Component INTF is in library **General/INTF** – The flow integration component.

Parameter $1 represents actual parameter **l_a** – length from end a to mass centre

Parameter $2 represents actual parameter **l_b** – length from end b to mass centre

Parameter $3 represents actual parameter **j_m** – inertia about mass centre

Parameter $4 represents actual parameter **m** – mass

Parameter $5 represents actual parameter **g** – gravity

Port Tip_a represents actual port **xTip_a,angularTip_a,yTip_a**

Port Tip_a represents actual port **xTip_a,angularTip_a,yTip_a**

Port Tip_b represents actual port **xTip_b,angularTip_b,yTip_b**

Port Tip_b represents actual port **xTip_b,angularTip_b,yTip_b**

Port a_a represents actual port **angularTip_a** – Torque/angular velocity at tip a

Port a_b represents actual port **angularTip_b** – Torque/angular velocity at tip b

Port a represents actual port **angle** – Angle port

Port alpha_a represents actual port **angularTip_a** – Torque/angular velocity at tip a

Port alpha_b represents actual port **angularTip_b** – Torque/angular velocity at tip b

Port angle represents actual port **angle** – Angle port

Port in represents actual port **xTip_a,angularTip_a,yTip_a**

Port in represents actual port **xTip_a,angularTip_a,yTip_a**

Port out represents actual port **xTip_b,angularTip_b,yTip_b**

Port out represents actual port **xTip_b,angularTip_b,yTip_b**

Port x_a represents actual port **xTip_a** – Force/velocity at tip a in x direction

Port x_b represents actual port **xTip_b** – Force/velocity at tip b in x direction

Port y_a represents actual port **yTip_a** – Force/velocity at tip a in y direction

Port y_b represents actual port **yTip_b** – Force/velocity at tip b in y direction

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: gRODa_lbl.txt

```
%SUMMARY gRODa: rigid rod in two dimensions - with gravity and ang
%DESCRIPTION See Section 10.2 of "Metamodelling"
%DESCRIPTION Gravity term added at centre

%ALIAS $1 l_a # length from end a to mass centre
%ALIAS $2 l_b # length from end b to mass centre
%ALIAS $3 j_m # inertia about mass centre
%ALIAS $4 m # mass
%ALIAS $5 g # gravity

%ALIAS in|Tip_a xTip_a,angularTip_a,yTip_a
%ALIAS out|Tip_b xTip_b,angularTip_b,yTip_b

%ALIAS in|Tip_a xTip_a,angularTip_a,yTip_a
%ALIAS out|Tip_b xTip_b,angularTip_b,yTip_b

%ALIAS x_a xTip_a # Force/velocity at tip a in x direction
```

```
%ALIAS y_a yTip_a # Force/velocity at tip a in y direction
%ALIAS alpha_a|a_a angularTip_a # Torque/angular velocity at tip a

%ALIAS x_b xTip_b # Force/velocity at tip b in x direction
%ALIAS y_b yTip_b # Force/velocity at tip b in y direction
%ALIAS alpha_b|a_b angularTip_b # Torque/angular velocity at tip b

%ALIAS angle|a angle # Angle port

%ALIAS INTF General/INTF # The flow integration component.

%% Label file for system gRODa (gRODa_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: gRODa_lbl.txt,v 1.2 2001/04/11 09:44:26 gawthrop Exp $
% %% $Log: gRODa_lbl.txt,v $
% %% Revision 1.2  2001/04/11 09:44:26  gawthrop
% %% Fixed cc and c problems to do with pow(x,y) and integers
% %% mtt/lib/reduce/fix_c.r is included in rdae2dae and cse2smx_lang for
% %% -c, -cc and -oct options
% %%
% %% Revision 1.1  1999/08/05 08:04:40  peterg
% %% Initial revision
% %%
% %% Revision 1.3  1998/11/30 10:47:53  peterg
% %% Added extra a_a and a_b aliases
% %%
% %% Revision 1.2  1998/11/25 13:55:42  peterg
% %% Added missig attribute field m*g,internal
% %%
% %% Revision 1.1  1998/11/25 10:48:34  peterg
% %% Initial revision
% %%
% %% Revision 1.5  1998/07/27 12:27:27  peterg
% %% Added vector port aliases
% %%
% %% Revision 1.4  1998/07/27 10:51:20  peterg
% %% Aliased INTF as well.
% %%
```

```
% %% Revision 1.3  1998/07/27 10:49:10  peterg
% %% Major revision to include aliases etc
% %%
% %% Revision 1.2  1997/08/15  09:43:06  peterg
% %% Now has lablelled (as opposed to numbered) ports.
% %%
% Revision 1.1  1996/11/07  10:57:17  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

%Inertias
J lin flow,j_m
m_x lin flow,m
m_y lin flow,m

%Integrate angular velocity to get angle
th

%Modulated transformers
s1 lsin flow,l_a
s2 lsin flow,l_b
c1 lcos flow,l_a
c2 lcos flow,l_b


% Component type Se
mg SS m*g


[angularTip_a] SS external,external
[angularTip_b] SS external,external
[xTip_a] SS external,external
[xTip_b] SS external,external
[yTip_a] SS external,external
[yTip_b] SS external,external
```

```
[angle] SS external,external
```

Subsystems

- INTF: flow integrator (1) No subsystems.
- Se Simple effort source (1) No subsystems.

5.2 InvertedPendulumOnCart_cbg.ps

MTT command:

```
mtt InvertedPendulumOnCart cbg ps
```

This representation is given as Figure 5.9 (on page 93).

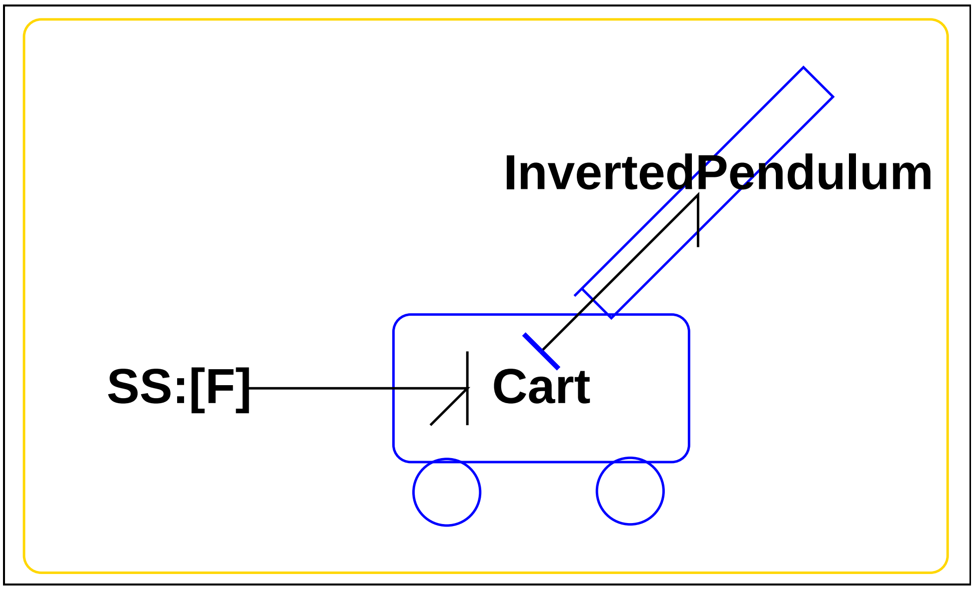

Figure 5.9: System **InvertedPendulumOnCart**, representation cbg (-noargs)

5.3 InvertedPendulumOnCart_struc.tex

MTT command:

```
mtt InvertedPendulumOnCart struc tex
```

List of inputs for system InvertedPendulumOnCart			
	Component	System	Repetition
1	F	InvertedPendulumOnCart__F	1

List of nonstates for system InvertedPendulumOnCart			
	Component	System	Repetition
1	m_x	InvertedPendulumOnCart__mttInvertedPendulum__rod__m_x	1
2	m_y	InvertedPendulumOnCart__mttInvertedPendulum__rod__m_y	1

List of outputs for system InvertedPendulumOnCart			
	Component	System	Repetition
1	y	InvertedPendulumOnCart__mttCart__Position__y	1
2	y	InvertedPendulumOnCart__mttInvertedPendulum__theta__y	1

List of states for system InvertedPendulumOnCart			
	Component	System	Repetition
1	m_c	InvertedPendulumOnCart__mttCart__m_c	1
2	mttC	InvertedPendulumOnCart__mttCart__mttINTF__mttC	1
3	J	InvertedPendulumOnCart__mttInvertedPendulum__rod__J	1
4	mttC	InvertedPendulumOnCart__mttInvertedPendulum__rod__th__mttC	1

5.4 InvertedPendulumOnCart_dae.tex

MTT command:

```
mtt InvertedPendulumOnCart dae tex
```

$$\begin{aligned}
\dot{x}_1 &= \frac{(m_c\dot{z}_1 + m_c u_1 - x_1 r_c)}{m_c} \\
\dot{x}_2 &= \frac{x_1}{m_c} \\
\dot{x}_3 &= \frac{(-\cos(x_4) j_r l \dot{z}_1 + \sin(x_4) g j_r l m_r + \sin(x_4) j_r l \dot{z}_2 - x_3 r_p)}{j_r} \\
\dot{x}_4 &= \frac{x_3}{j_r}
\end{aligned} \tag{5.1}$$

$$
\begin{aligned}
z_1 &= \frac{(m_r(\cos(x_4) l m_c x_3 - j_r x_1))}{(j_r m_c)} \\
z_2 &= \frac{(-\sin(x_4) l m_r x_3)}{j_r}
\end{aligned}
\tag{5.2}
$$

$$
\begin{aligned}
y_1 &= x_2 \\
y_2 &= x_4
\end{aligned}
\tag{5.3}
$$

Chapter 6

Pendulum

6.1 Pendulum_abg.tex

MTT command:

```
mtt Pendulum abg tex
```

The acausal bond graph of system **Pendulum** is displayed in Figure 6.1 (on page 98) and its label file is listed in Section 6.1.1 (on page 97). The subsystems are listed in Section 6.1.2 (on page 100).

This is a heirachical version of the example from Section 10.3 of “Metamodelling”. It uses two compound components: **ROD** and **GRAV**. **ROD** is essentially as described in Figure 10.2 **GRAV** represents gravity by a vertical accelleration as in Section 10.9 of ”Metamodelling”.

6.1.1 Summary information

System Pendulum::Pendulum example from Section 10.3 of ”Metamodelling” This is a heirachical version of the example from Section 10.3 of ”Metamodelling”. It uses two compound components: ROD and GRA ROD is essentially as described in Figure 10.2 GRAV represents gravity by a vertical accelleration as in Section 10.9 of ”Metamodelling”.

Interface information:

Component ACCEL is in library **Mechanical-2D/ACCEL** – Constant acceleration

Variable declarations:

This component has no PAR declarations

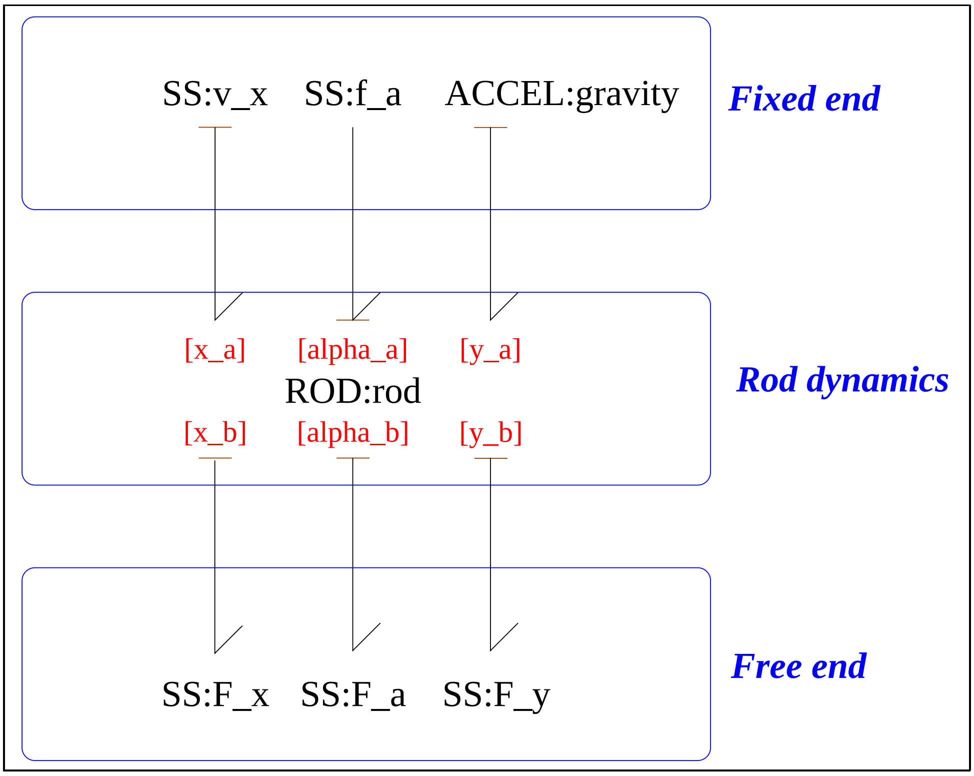

Figure 6.1: System **Pendulum**: acausal bond graph

Units declarations:

This component has no UNITs declarations

The label file: Pendulum_lbl.txt

```
%SUMMARY Pendulum: Pendulum example from Section 10.3 of "Metamodelling"
%DESCRIPTION This is a heirachical version of the
%DESCRIPTION example from Section 10.3 of "Metamodelling".
%DESCRIPTION It uses two compound components: ROD and GRA
%DESCRIPTION ROD is essentially as described in Figure 10.2
%DESCRIPTION GRAV represents gravity by a vertical accelleration
%DESCRIPTION as in Section 10.9 of "Metamodelling".

%ALIAS ACCEL Mechanical-2D/ACCEL # Constant acceleration
%% Label file for system pend (pend_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: Pendulum_lbl.txt,v 1.3 2000/12/28 18:01:28 peterg Exp $
% %% $Log: Pendulum_lbl.txt,v $
% %% Revision 1.3  2000/12/28 18:01:28  peterg
% %% To RCS
% %%
% %% Revision 1.2  1997/08/15  09:46:22  peterg
% %% New labeled ports version
% %%
% Revision 1.1  1996/11/09  18:44:58  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

%Rod parameters
rod none l;l;j;m
```

```
%Zero velocity sources
v_x SS     internal,0

%Zero force/torque sources
F_x SS    0,internal
F_y SS    0,internal
F_a SS    0,internal

%Torque at end
f_a SS external,external

%Gravity
gravity
```

6.1.2 Subsystems

- ACCEL: Provides a acceleration (useful for simulating gravity. (1) No subsystems.
- ROD: rigid rod in two dimensions (1)
  - INTF: flow integrator (1)

6.1.3 ACCEL

The acausal bond graph of system **ACCEL** is displayed in Figure 10.2 (on page 171) and its label file is listed in Section 10.1.3 (on page 171). The subsystems are listed in Section 10.1.3 (on page 173).

Summary information

System ACCEL::Provides a acceleration (useful for simulating gravity. Useful for simulating gravity as explaned in Section 10.9 of ”Metamodelling”.

Interface information:

Port in represents actual port **Acceleration**

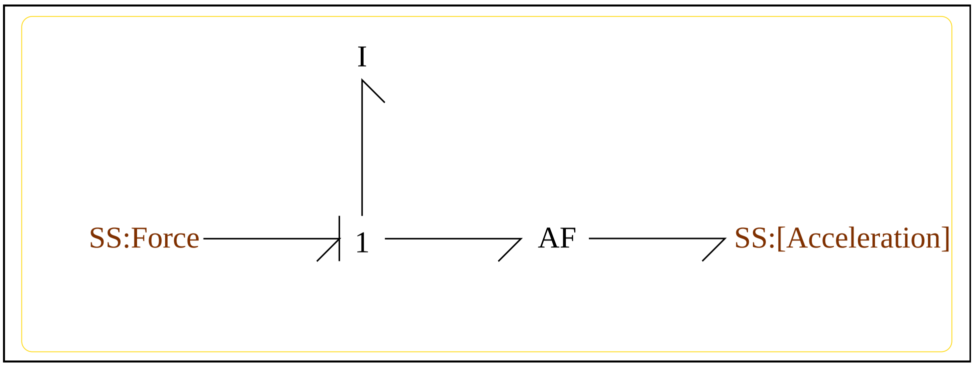

Figure 6.2: System **ACCEL**: acausal bond graph

Port out represents actual port **Acceleration**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ACCEL_lbl.txt

```
%SUMMARY ACCEL: Provides a acceleration (useful for simulating gravity.
%DESCRIPTION Useful for simulating gravity as explaned in Section 10.9
%DESCRIPTION of "Metamodelling".

%ALIAS in|out Acceleration

%% Label file for system ACCEL (ACCEL_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ACCEL_lbl.txt,v 1.4 1998/07/27 20:33:17 peterg Exp $
% %% $Log: ACCEL_lbl.txt,v $
% %% Revision 1.4  1998/07/27 20:33:17  peterg
% %% Aliases
% %%
```

```
% %% Revision 1.3  1998/07/27 06:50:41  peterg
% %% *** empty log message ***
% %%
% %% Revision 1.2  1998/07/27 06:49:57  peterg
% %% Added blank line at end
% %%
% %% Revision 1.1  1998/07/27 06:47:32  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

% SS components
Force SS external,internal
[Acceleration] SS external,external
```

Subsystems

No subsystems.

6.1.4 INTF

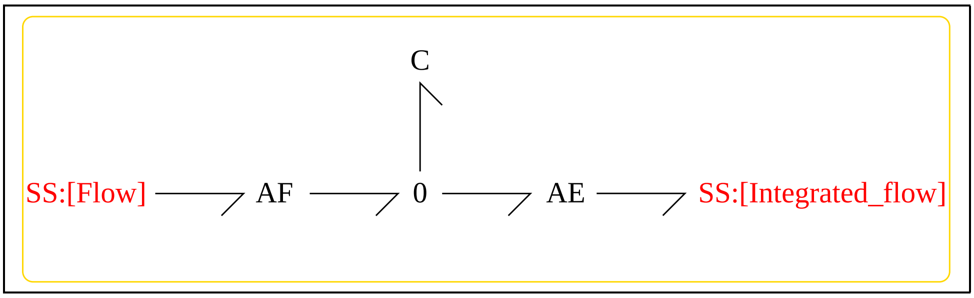

Figure 6.3: System **INTF**: acausal bond graph

The acausal bond graph of system **INTF** is displayed in Figure 10.3 (on page 173) and its label file is listed in Section 10.1.4 (on page 173). The subsystems are listed in Section 10.1.4 (on page 174).

INTF is a two-port component where the effort on port [out] is the integral of the flow on port [in].

Summary information

System INTF::flow integrator Port [in]: Flow to be integrated Port [out]: Effort = integral of flow on port [in]

Interface information:

Port in represents actual port **Flow**

Port out represents actual port **Integrated_flow**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: INTF_lbl.txt

```
%% Label file for system INTF (INTF_lbl.txt)
%SUMMARY INTF: flow integrator
%DESCRIPTION Port [in]: Flow to be integrated
%DESCRIPTION Port [out]: Effort = integral of flow on port [in]


% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: INTF_lbl.txt,v 1.3 1998/07/16 07:35:10 peterg Exp $
% %% $Log: INTF_lbl.txt,v $
% %% Revision 1.3  1998/07/16 07:35:10  peterg
% %% Aliased version
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% Port aliases
%ALIAS in Flow
%ALIAS out Integrated_flow

% Argument aliases

%% 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
[Flow] SS external,external
[Integrated_flow] SS external,external
```

Subsystems

No subsystems.

6.1.5 ROD

The acausal bond graph of system **ROD** is displayed in Figure 10.4 (on page 175) and its label file is listed in Section 10.1.5 (on page 175). The subsystems are listed in Section 10.1.5 (on page 178).
ROD is essentially as described in Figure 10.2 of “Metamodelling”.

Summary information

System ROD::rigid rod in two dimensions See Section 10.2 of ”Metamodelling”

Interface information:

Component INTF is in library **General/INTF** – The flow integration component.

Parameter $1 represents actual parameter **l_a** – length from end a to mass centre

Parameter $2 represents actual parameter **l_b** – length from end b to mass centre

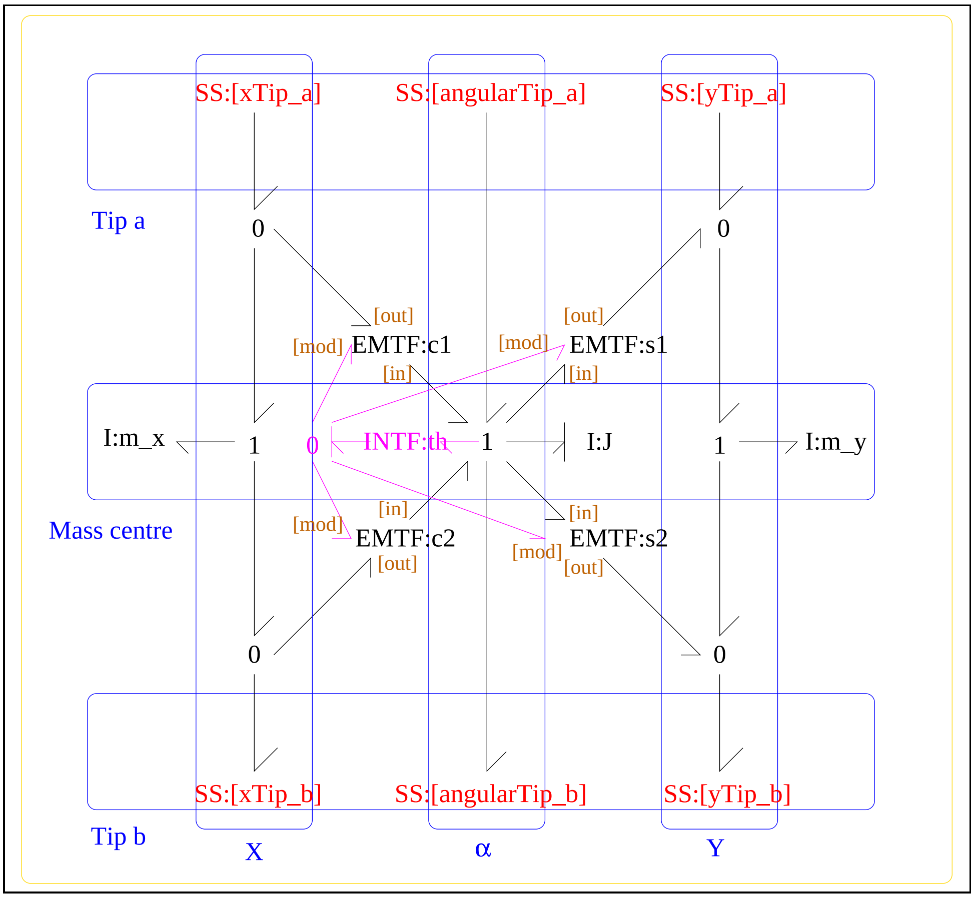

Figure 6.4: System **ROD**: acausal bond graph

Parameter $3 represents actual parameter **j_m** – inertia about mass centre

Parameter $4 represents actual parameter **m** – mass

Port Tip_a represents actual port **xTip_a,angularTip_a,yTip_a**

Port Tip_b represents actual port **xTip_b,angularTip_b,yTip_b**

Port alpha_a represents actual port **angularTip_a** – Torque/angular velocity at tip a

Port alpha_b represents actual port **angularTip_b** – Torque/angular velocity at tip b

Port in represents actual port **xTip_a,angularTip_a,yTip_a**

Port out represents actual port **xTip_b,angularTip_b,yTip_b**

Port x_a represents actual port **xTip_a** – Force/velocity at tip a in x direction

Port x_b represents actual port **xTip_b** – Force/velocity at tip b in x direction

Port y_a represents actual port **yTip_a** – Force/velocity at tip a in y direction

Port y_b represents actual port **yTip_b** – Force/velocity at tip b in y direction

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ROD_lbl.txt

```
%SUMMARY ROD: rigid rod in two dimensions
%DESCRIPTION See Section 10.2 of "Metamodelling"

%ALIAS $1 l_a # length from end a to mass centre
%ALIAS $2 l_b # length from end b to mass centre
%ALIAS $3 j_m # inertia about mass centre
%ALIAS $4 m # mass

%ALIAS in|Tip_a xTip_a,angularTip_a,yTip_a
```

```
%ALIAS out|Tip_b xTip_b,angularTip_b,yTip_b

%ALIAS x_a xTip_a # Force/velocity at tip a in x direction
%ALIAS y_a yTip_a # Force/velocity at tip a in y direction
%ALIAS alpha_a angularTip_a # Torque/angular velocity at tip a

%ALIAS x_b xTip_b # Force/velocity at tip b in x direction
%ALIAS y_b yTip_b # Force/velocity at tip b in y direction
%ALIAS alpha_b angularTip_b # Torque/angular velocity at tip b

%ALIAS INTF General/INTF # The flow integration component.

%% Label file for system ROD (ROD_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ROD_lbl.txt,v 1.5 1998/07/27 12:27:27 peterg Exp $
% %% $Log: ROD_lbl.txt,v $
% %% Revision 1.5  1998/07/27 12:27:27  peterg
% %% Added vector port aliases
% %%
% %% Revision 1.4  1998/07/27 10:51:20  peterg
% %% Aliased INTF as well.
% %%
% %% Revision 1.3  1998/07/27 10:49:10  peterg
% %% Major revision to include aliases etc
% %%
% %% Revision 1.2  1997/08/15  09:43:06  peterg
% %% Now has lablelled (as opposed to numbered) ports.
% %%
% Revision 1.1  1996/11/07  10:57:17  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
```

```
%Inertias
J lin flow,j_m
m_x lin flow,m
m_y lin flow,m

%Integrate angular velocity to get angle
th

%Modulated transformers
s1 lsin flow,l_a
s2 lsin flow,l_b
c1 lcos flow,l_a
c2 lcos flow,l_b

% Component type SS
[angularTip_a] SS external,external
[angularTip_b] SS external,external
[xTip_a] SS external,external
[xTip_b] SS external,external
[yTip_a] SS external,external
[yTip_b] SS external,external
```

Subsystems

- INTF: flow integrator (1) No subsystems.

6.2 Pendulum_struc.tex

MTT command:

```
mtt Pendulum struc tex
```

List of inputs for system Pendulum			
	Component	System	Repetition
1	f_a	Pendulum__f_a	1
2	Force	Pendulum__gravity__Force	1

List of nonstates for system Pendulum			
	Component	System	Repetition
1	m_x	Pendulum__rod__m_x	1
2	m_y	Pendulum__rod__m_y	1

List of outputs for system Pendulum			
	Component	System	Repetition
1	f_a	Pendulum__f_a	1

List of states for system Pendulum			
	Component	System	Repetition
1	J	Pendulum__rod__J	1
2	mttC	Pendulum__rod__th__mttC	1
3	mttI	Pendulum__gravity__mttI	1

List of states for system Pendulum (continued)			
	Component	System	Repetition

6.3 Pendulum_dae.tex

MTT command:

```
mtt Pendulum dae tex
```

$$\begin{aligned} \dot{x}_1 &= \cos(x_2) l \dot{z}_1 - \sin(x_2) l \dot{z}_2 + u_1 \\ \dot{x}_2 &= \frac{x_1}{j} \\ \dot{x}_3 &= u_2 \end{aligned} \tag{6.1}$$

$$\begin{aligned} z_1 &= \frac{(-\cos(x_2) l m x_1)}{j} \\ z_2 &= \frac{(m(\sin(x_2) l x_1 + j x_3))}{j} \end{aligned} \tag{6.2}$$

$$y_1 = \frac{x_1}{j} \tag{6.3}$$

6.4 Pendulum_cse.tex

MTT command:

```
mtt Pendulum cse tex
```

$$\dot{\chi}_1 = \frac{(j(-\sin(x_2) l m u_2 + u_1))}{(j + l^2 m)} \tag{6.4}$$

$$\dot{\chi}_2 = \frac{x_1}{j} \tag{6.5}$$

$$\dot{\chi}_3 = u_2 \tag{6.6}$$

$$y_1 = \frac{x_1}{j} \tag{6.7}$$

$$E = \begin{pmatrix} \frac{(j+l^2m)}{j} & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{6.8}$$

6.5 Pendulum_ode.tex

MTT command:

```
mtt Pendulum ode tex
```

$$\begin{aligned} \dot{x}_1 &= \frac{\left(j^2(-\sin(x_2)lmu_2 + u_1)\right)}{(j^2 + 2jl^2m + l^4m^2)} \\ \dot{x}_2 &= \frac{x_1}{j} \\ \dot{x}_3 &= u_2 \end{aligned} \tag{6.9}$$

$$y_1 = \frac{x_1}{j} \tag{6.10}$$

6.6 Pendulum_input.txt

MTT command:

```
mtt Pendulum input txt
```

```
# -*-octave-*- Put Emacs into octave-mode’
# Numerical parameter file (Pendulum_input.txt)
# Generated by MTT at Fri Aug 15 09:02:02 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: Pendulum_input.txt,v 1.3 2003/06/11 16:04:21 gawthrop Exp $
# %% $Log: Pendulum_input.txt,v $
```

```
# %% Revision 1.3  2003/06/11 16:04:21  gawthrop
# %% Updated examples for latest MTT.
# %%
# %% Revision 1.2  1998/07/27 11:27:05  peterg
# %% Reformatted
# %%
# Revision 1.1  1997/08/15  08:04:01  peterg
# Initial revision
#
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Set the inputs
## Removed by MTT on Tue Jun 10 17:17:50 BST 2003: u(1) =
0.0; # no torque at joint
## Removed by MTT on Tue Jun 10 17:17:50 BST 2003: u(2) =
9.81; # g
pendulum__f_a = 0.0; # No joint torque
pendulum__gravity__force = 9.81; # g
```

6.7 Pendulum_numpar.txt

MTT command:

```
mtt Pendulum numpar txt
```

```
# -*-octave-*- Put Emacs into octave-mode
# Numerical parameter file (Pendulum_numpar.txt)
# Generated by MTT at Mon Jul 27 12:38:25 BST 1998

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: Pendulum_numpar.txt,v 1.1 1998/07/27 11:40:30 peterg Exp
# %% $Log: Pendulum_numpar.txt,v $
# %% Revision 1.1  1998/07/27 11:40:30  peterg
# %% Initial revision
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Parameters
```

```
l =  1.0; # Pendulum
m =  1.0; # Pendulum
j =  m*l*l/12.0; # Pendulum
```

6.8 Pendulum_odeso.ps

MTT command:

```
mtt Pendulum odeso ps
```

This representation is given as Figure 6.5 (on page 113).

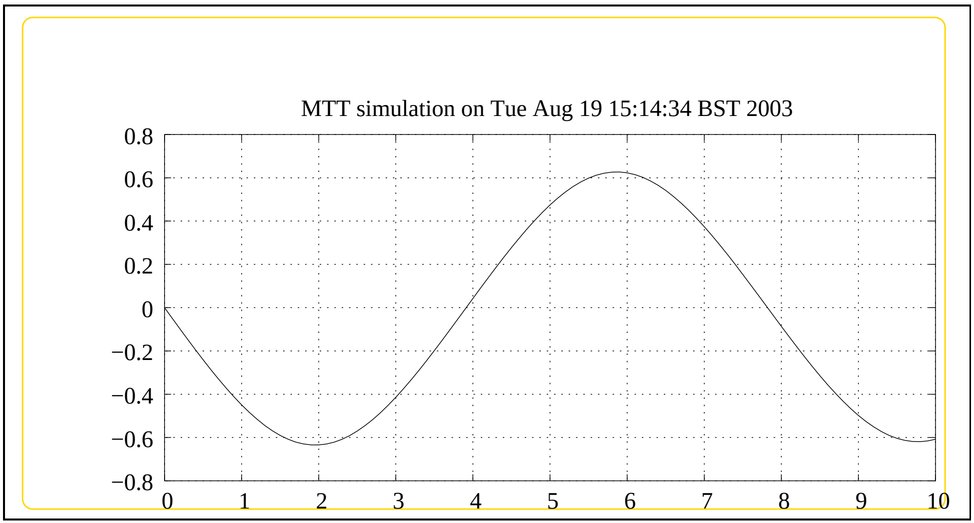

Figure 6.5: System **Pendulum**, representation odeso (-noargs)

Chapter 7

TwoLink

7.1 TwoLink_abg.tex

MTT command:

```
mtt TwoLink abg tex
```

The acausal bond graph of system **TwoLink** is displayed in Figure 7.1 (on page 116) and its label file is listed in Section 7.1.1 (on page 115). The subsystems are listed in Section 7.1.2 (on page 118).

This is a heirachical version of the example from Section 10.5 of ”Metamodelling”. It uses the compound components: **ROD**. **ROD** is essentially as described in Figure 10.2. There is no gravity included in this model.

This system has a number of dynamic elements (those corresponding to translation motion) in derivative causality, thus the system is represnted as a Differential-Algebraic Equation (Section **??** (on page **??**)). Hovever, this is of contrained-state form and therfore can be written as a set of constrained-state equations (Section **??** (on page **??**)). The corresponding ordinary differential equation is complicated due to the trig functions involved in inverting the E matrix.

As well as the standard representation the “robot-form” equations appear in Section **??** (on page **??**).

7.1.1 Summary information

System TwoLink::two-link manipulator from Section 10.5 of ”Metamodelling” This is a heirachical version of the example from Section 10.5 of ”Metamodelling”. It uses two compound components: ROD and GRA ROD is essentially as described in Figure 10.2 GRAV represents gravity by a vertical accelleration as in Section 10.9 of ”Metamodelling”

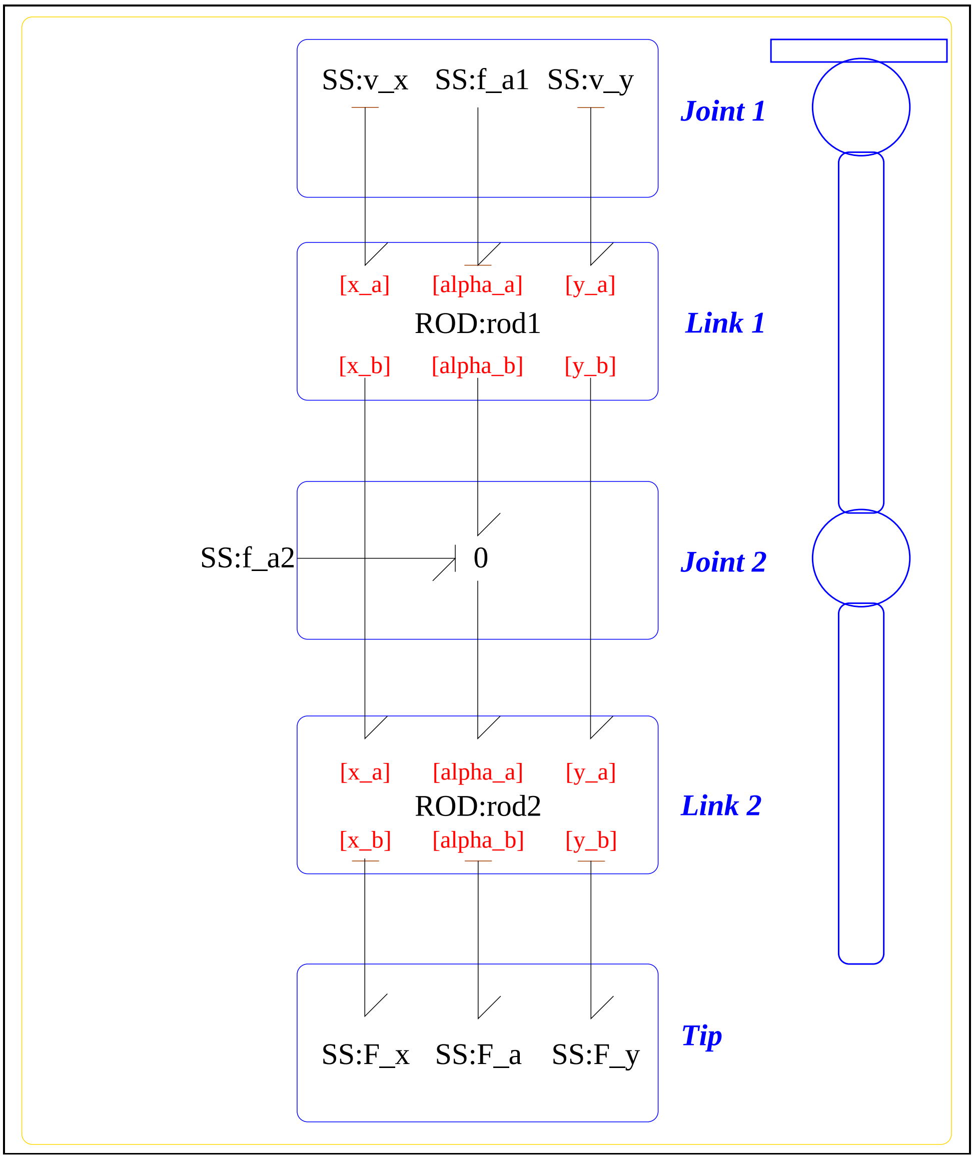

Figure 7.1: System **TwoLink**: acausal bond graph

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: TwoLink_lbl.txt

```
%SUMMARY TwoLink: two-link manipulator from Section 10.5 of "Metamodelli
%DESCRIPTION This is a heirachical version of the
%DESCRIPTION example from Section 10.5 of "Metamodelling".
%DESCRIPTION It uses two compound components: ROD and GRA
%DESCRIPTION ROD is essentially as described in Figure 10.2
%DESCRIPTION GRAV represents gravity by a vertical accelleration
%DESCRIPTION as in Section 10.9 of "Metamodelling"


%% Label (TwoLink_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: TwoLink_lbl.txt,v 1.2 2000/05/19 14:30:03 peterg Exp $
% %% $Log: TwoLink_lbl.txt,v $
% %% Revision 1.2  2000/05/19 14:30:03  peterg
% %% New SS labels
% %%
% %% Revision 1.1  1998/07/27 10:45:22  peterg
% %% Initial revision
% %%
% %% Revision 1.2  1996/12/05  12:39:49  peterg
% %% Documentation
% %%
% %% Revision 1.1  1996/12/05 12:17:15  peterg
% %% Initial revision
% %%
```

```
% %% Revision 1.1  1996/11/14  10:48:42  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

%Rod parameters - uniform rods
rod1 none l_1;l_1;j_1;m_1
rod2 none l_2;l_2;j_2;m_2

%Zero velocity sources
v_x SS     internal,0
v_y SS     internal,0


%Zero force/torque sources
F_x SS    0,internal
F_a SS    0,internal
F_y SS    0,internal


%Torque/velocity at joints
f_a1 SS  external,external
f_a2 SS  external,external
```

7.1.2 Subsystems

- ROD: rigid rod in two dimensions (2)
  - INTF: flow integrator (1)

7.1.3 INTF

The acausal bond graph of system **INTF** is displayed in Figure 10.3 (on page 173) and its label file is listed in Section 10.1.4 (on page 173). The subsystems

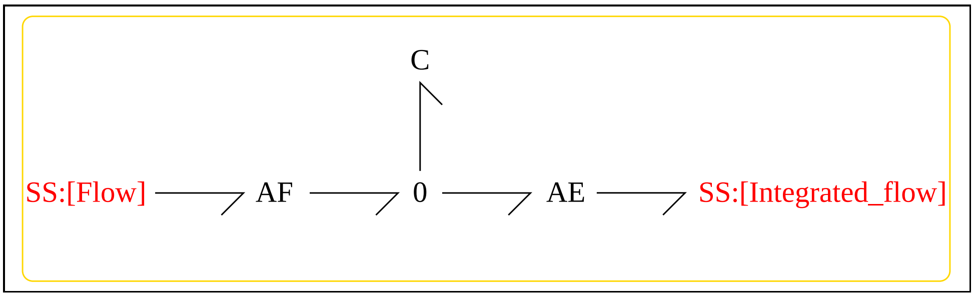

Figure 7.2: System **INTF**: acausal bond graph

are listed in Section 10.1.4 (on page 174).
INTF is a two-port component where the effort on port [out] is the integral of the flow on port [in].

Summary information

System INTF::flow integrator Port [in]: Flow to be integrated Port [out]: Effort = integral of flow on port [in]

Interface information:

Port in represents actual port **Flow**

Port out represents actual port **Integrated_flow**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: INTF_lbl.txt

```
%% Label file for system INTF (INTF_lbl.txt)
%SUMMARY INTF: flow integrator
%DESCRIPTION Port [in]: Flow to be integrated
%DESCRIPTION Port [out]: Effort = integral of flow on port [in]
```

```
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: INTF_lbl.txt,v 1.3 1998/07/16 07:35:10 peterg Exp $
% %% $Log: INTF_lbl.txt,v $
% %% Revision 1.3  1998/07/16 07:35:10  peterg
% %% Aliased version
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS in Flow
%ALIAS out Integrated_flow

% Argument aliases

%% 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
[Flow] SS external,external
[Integrated_flow] SS external,external
```

Subsystems

No subsystems.

7.1.4 ROD

The acausal bond graph of system **ROD** is displayed in Figure 10.4 (on page 175) and its label file is listed in Section 10.1.5 (on page 175). The subsystems are listed in Section 10.1.5 (on page 178).

ROD is essentially as described in Figure 10.2 of "Metamodelling".

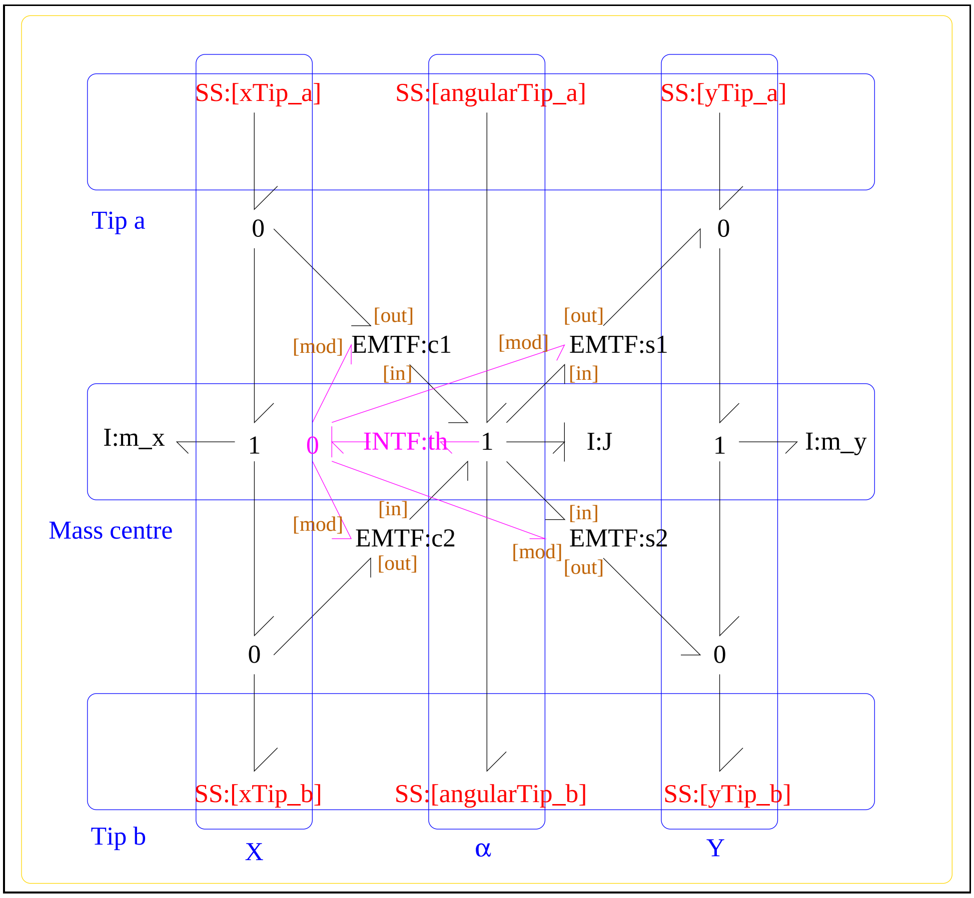

Figure 7.3: System **ROD**: acausal bond graph

Summary information

System ROD::rigid rod in two dimensions See Section 10.2 of ”Metamodelling”

Interface information:

Component INTF is in library **General/INTF** – The flow integration component.

Parameter $1 represents actual parameter **l_a** – length from end a to mass centre

Parameter $2 represents actual parameter **l_b** – length from end b to mass centre

Parameter $3 represents actual parameter **j_m** – inertia about mass centre

Parameter $4 represents actual parameter **m** – mass

Port Tip_a represents actual port **xTip_a,angularTip_a,yTip_a**

Port Tip_b represents actual port **xTip_b,angularTip_b,yTip_b**

Port alpha_a represents actual port **angularTip_a** – Torque/angular velocity at tip a

Port alpha_b represents actual port **angularTip_b** – Torque/angular velocity at tip b

Port in represents actual port **xTip_a,angularTip_a,yTip_a**

Port out represents actual port **xTip_b,angularTip_b,yTip_b**

Port x_a represents actual port **xTip_a** – Force/velocity at tip a in x direction

Port x_b represents actual port **xTip_b** – Force/velocity at tip b in x direction

Port y_a represents actual port **yTip_a** – Force/velocity at tip a in y direction

Port y_b represents actual port **yTip_b** – Force/velocity at tip b in y direction

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ROD_lbl.txt

```
%SUMMARY ROD: rigid rod in two dimensions
%DESCRIPTION See Section 10.2 of "Metamodelling"

%ALIAS $1 l_a # length from end a to mass centre
%ALIAS $2 l_b # length from end b to mass centre
%ALIAS $3 j_m # inertia about mass centre
%ALIAS $4 m # mass

%ALIAS in|Tip_a xTip_a,angularTip_a,yTip_a
%ALIAS out|Tip_b xTip_b,angularTip_b,yTip_b

%ALIAS x_a xTip_a # Force/velocity at tip a in x direction
%ALIAS y_a yTip_a # Force/velocity at tip a in y direction
%ALIAS alpha_a angularTip_a # Torque/angular velocity at tip a

%ALIAS x_b xTip_b # Force/velocity at tip b in x direction
%ALIAS y_b yTip_b # Force/velocity at tip b in y direction
%ALIAS alpha_b angularTip_b # Torque/angular velocity at tip b

%ALIAS INTF General/INTF # The flow integration component.

%% Label file for system ROD (ROD_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ROD_lbl.txt,v 1.5 1998/07/27 12:27:27 peterg Exp $
% %% $Log: ROD_lbl.txt,v $
% %% Revision 1.5  1998/07/27 12:27:27  peterg
% %% Added vector port aliases
% %%
% %% Revision 1.4  1998/07/27 10:51:20  peterg
% %% Aliased INTF as well.
% %%
% %% Revision 1.3  1998/07/27 10:49:10  peterg
% %% Major revision to include aliases etc
% %%
% %% Revision 1.2  1997/08/15  09:43:06  peterg
% %% Now has lablelled (as opposed to numbered) ports.
```

```
% %%
% Revision 1.1  1996/11/07  10:57:17  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

%Inertias
J lin flow,j_m
m_x lin flow,m
m_y lin flow,m

%Integrate angular velocity to get angle
th

%Modulated transformers
s1 lsin flow,l_a
s2 lsin flow,l_b
c1 lcos flow,l_a
c2 lcos flow,l_b

% Component type SS
[angularTip_a] SS external,external
[angularTip_b] SS external,external
[xTip_a] SS external,external
[xTip_b] SS external,external
[yTip_a] SS external,external
[yTip_b] SS external,external
```

Subsystems

- INTF: flow integrator (1) No subsystems.

7.2 TwoLink_struc.tex

MTT command:

```
mtt TwoLink struc tex
```

List of inputs for system TwoLink			
	Component	System	Repetition
1	f_a1	TwoLink__f_a1	1
2	f_a2	TwoLink__f_a2	1

List of nonstates for system TwoLink			
	Component	System	Repetition
1	m_x	TwoLink__rod1__m_x	1
2	m_y	TwoLink__rod1__m_y	1
3	m_x	TwoLink__rod2__m_x	1
4	m_y	TwoLink__rod2__m_y	1

List of outputs for system TwoLink			
	Component	System	Repetition
1	f_a1	TwoLink__f_a1	1
2	f_a2	TwoLink__f_a2	1

List of states for system TwoLink			
	Component	System	Repetition
1	J	TwoLink__rod1__J	1
2	mttC	TwoLink__rod1__th__mttC	1
3	J	TwoLink__rod2__J	1
4	mttC	TwoLink__rod2__th__mttC	1

7.3 TwoLink_sympar.tex

MTT command:

```
mtt TwoLink sympar tex
```

Parameter	System
j_1	TwoLink
j_2	TwoLink
l_1	TwoLink
l_2	TwoLink
m_1	TwoLink
m_2	TwoLink

Table 7.1: Parameters

7.4 TwoLink_dae.tex

MTT command:

```
mtt TwoLink dae tex
```

$$\begin{aligned}
\dot{x}_1 &= \cos(x_2) l_1 \dot{z}_1 + 2\cos(x_2) l_1 \dot{z}_3 - \sin(x_2) l_1 \dot{z}_2 - 2\sin(x_2) l_1 \dot{z}_4 + u_1 - u_2 \\
\dot{x}_2 &= \frac{x_1}{j_1} \\
\dot{x}_3 &= \cos(x_4) l_2 \dot{z}_3 - \sin(x_4) l_2 \dot{z}_4 + u_2 \\
\dot{x}_4 &= \frac{x_3}{j_2}
\end{aligned} \tag{7.1}$$

$$\begin{aligned}
z_1 &= \frac{(-\cos(x_2) l_1 m_1 x_1)}{j_1} \\
z_2 &= \frac{(\sin(x_2) l_1 m_1 x_1)}{j_1} \\
z_3 &= \frac{(m_2(-2\cos(x_2) j_2 l_1 x_1 - \cos(x_4) j_1 l_2 x_3))}{(j_1 j_2)} \\
z_4 &= \frac{(m_2(2\sin(x_2) j_2 l_1 x_1 + \sin(x_4) j_1 l_2 x_3))}{(j_1 j_2)}
\end{aligned} \tag{7.2}$$

$$\begin{aligned}
y_1 &= \frac{x_1}{j_1} \\
y_2 &= \frac{(j_1 x_3 - j_2 x_1)}{(j_1 j_2)}
\end{aligned} \tag{7.3}$$

7.5 TwoLink_cse.tex

MTT command:

```
mtt TwoLink cse tex
```

$$\dot{\chi}_1 = \frac{\left(2\cos\left(x_2 - x_4\right) j_1^2 j_2^2 l_1 l_2 m_2 u_2 + 2\sin\left(2x_2 - 2x_4\right) j_2^2 l_1^2 l_2^2 m_2^2 x_1^2 + 2\sin\left(x_2 - x_4\right) j_1^2 j_2 l_1 l_2 m_2 x_3^2 + 2\sin\left(x_2 - x_4 \right.\right.}{\left(j_1 j_2^2 \left(2\cos\left(2x_2 - 2x_4\right) l_1^2 l_2^2 m_2^2 - j_1 j_2 - j_1 l_2^2 m_2 - j_2 l_1^2 m_1 - 4 j_2 l_1^2 m_2 \right.\right.} \tag{7.4}$$

$$\dot{\chi}_2 = \frac{x_1}{j_1} \tag{7.5}$$

$$\dot{\chi}_3 = \frac{\left(2\cos\left(x_2 - x_4\right) j_1^2 j_2^2 l_1 l_2 m_2 u_1 - 2\cos\left(x_2 - x_4\right) j_1^2 j_2^2 l_1 l_2 m_2 u_2 - 2\sin\left(2x_2 - 2x_4\right) j_1^2 l_1^2 l_2^2 m_2^2 x_3^2 - 2\sin\left(x_2 - x \right.\right.}{\left(j_1^2 j_2 \left(2\cos\left(2x_2 - 2x_4\right) l_1^2 l_2^2 m_2^2 - j_1 j_2 - j_1 \right.\right.} \tag{7.6}$$

$$\dot{\chi}_4 = \frac{x_3}{j_2} \tag{7.7}$$

$$y_1 = \frac{x_1}{j_1} \tag{7.8}$$

$$y_2 = \frac{\left(j_1 x_3 - j_2 x_1\right)}{\left(j_1 j_2\right)} \tag{7.9}$$

$$E = \begin{pmatrix} \frac{\left(j_1 + l_1^2 m_1 + 4 l_1^2 m_2\right)}{j_1} & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{\left(j_2 + l_2^2 m_2\right)}{j_2} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{7.10}$$

7.6 TwoLink_input.txt

MTT command:

```
mtt TwoLink input txt
```

```
# Numerical parameter file (TwoLink_input.txt)
# Generated by MTT at Fri Jun 13 16:56:09 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: TwoLink_input.txt,v 1.2 2003/06/11 16:04:56 gawthrop Exp
# %% $Log: TwoLink_input.txt,v $
# %% Revision 1.2  2003/06/11 16:04:56  gawthrop
# %% Updated examples for latest MTT.
# %%
# %% Revision 1.1  1998/07/27 10:44:59  peterg
# %% Initial revision
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Set the inputs
## Removed by MTT on Tue Jun 10 17:24:08 BST 2003: u(1) =
(t<1.0); # Torque on Joint 1
## Removed by MTT on Tue Jun 10 17:24:08 BST 2003: u(2) =
-(t>10.0)&&(t<11.0); # Torque on Joint 2
## Removed by MTT on Tue Jun 10 17:24:08 BST 2003: u(3) =
0.0; # Gravity
twolink__f_a1 = (t<1.0); # Torque on Joint 1
twolink__f_a2 = -(t>10.0)&&(t<11.0); # Torque on Joint 2
```

7.7 TwoLink_numpar.txt

MTT command:

```
mtt TwoLink numpar txt
```

```
# Numerical parameter file (TwoLink_numpar.txt)
# Generated by MTT at Mon Jan 19 13:53:15 GMT 1998

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
```

```
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: TwoLink_numpar.txt,v 1.1 1998/07/27 10:45:44 peterg Exp $
# %% $Log: TwoLink_numpar.txt,v $
# %% Revision 1.1  1998/07/27 10:45:44  peterg
# %% Initial revision
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Parameters
j_1 =  1.0; # Parameter j_1 for TwoLink
j_2 =  1.0; # Parameter j_2 for TwoLink
l_1 =  1.0; # Parameter l_1 for TwoLink
l_2 =  1.0; # Parameter l_2 for TwoLink
m_1 =  1.0; # Parameter m_1 for TwoLink
m_2 =  1.0; # Parameter m_2 for TwoLink
```

7.8 TwoLink_odeso.ps *(-ieuler)*

MTT command:

```
mtt -i euler TwoLink odeso ps
```

This representation is given as Figure 7.4 (on page 130).

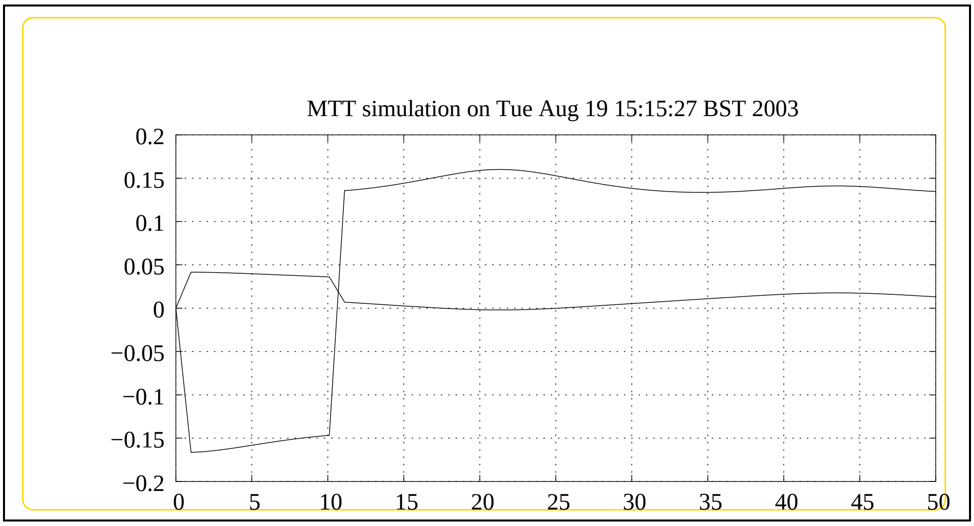

Figure 7.4: System **TwoLink**, representation odeso (-ieuler)

Chapter 8

TwoLinkxyc

8.1 TwoLinkxyc_abg.tex

MTT command:

```
mtt TwoLinkxyc abg tex
```

The acausal bond graph of system **TwoLinkxyc** is displayed in Figure 8.1 (on page 132) and its label file is listed in Section 8.1.1 (on page 131). The subsystems are listed in Section 8.1.2 (on page 134).
This system is identical to **twolink** except that the two colocated **SS** components act at the tip in the *x* and *y* directions instead of at the two joints.
It uses two compound components: **ROD** and **GRAV**. **ROD** is essentially as described in Figure 10.2 of ”Metamodelling” and **GRAV** represents gravity by a vertical acceleration as in Section 10.9 of ”Metamodelling”

8.1.1 Summary information

System TwoLinkxyc::two-link manipulator with collocated tip source-sensors. This is related to a heirachical version of the example from Section 10.5 of ”Metamodelling”. It uses two compound components: ROD and GRA ROD is essentially as described in Figure 10.2 GRAV represents gravity by a vertical accelleration as in Section 10.9 of ”Metamodelling” except that the collocated source-sensors act at the tip rather than at the joints.

Interface information:

This component has no ALIAS declarations

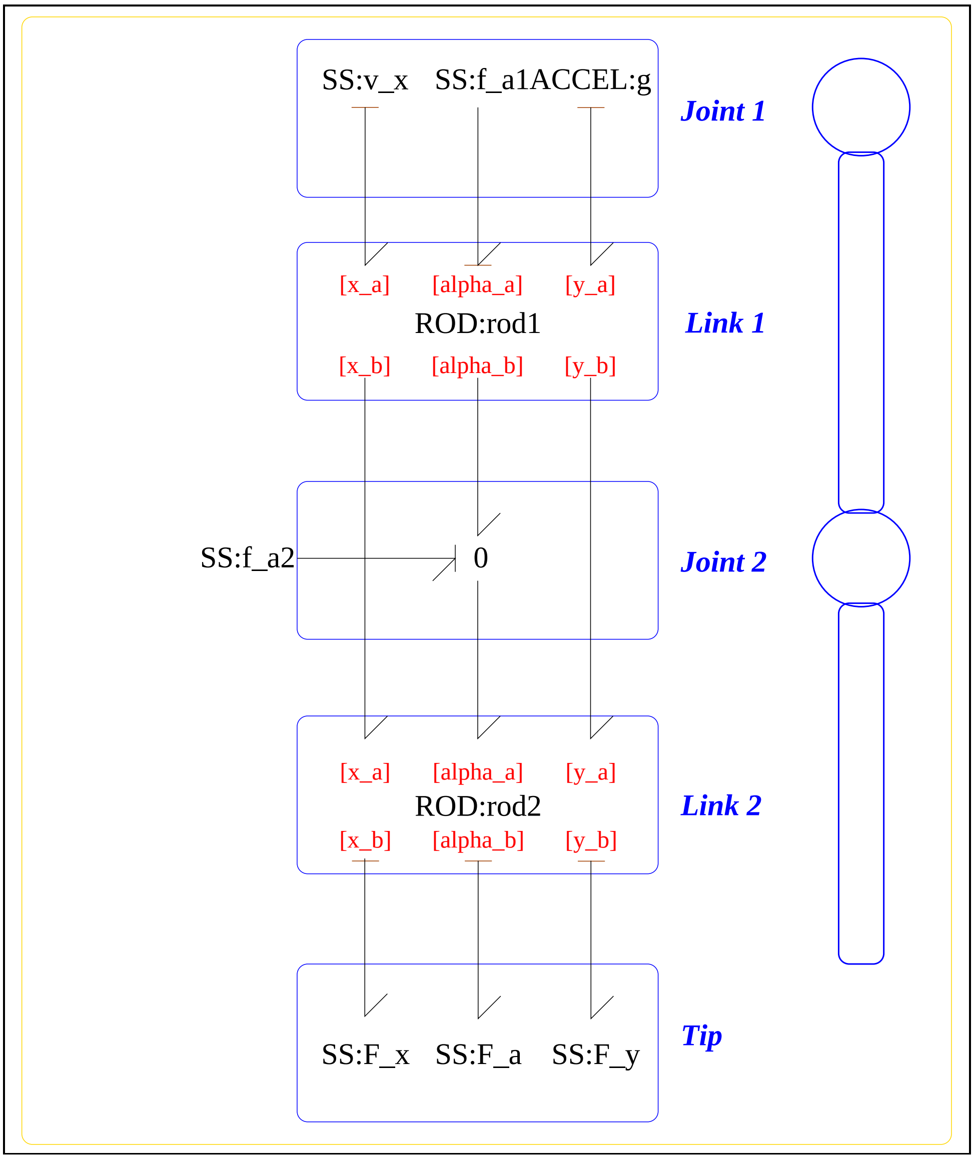

Figure 8.1: System **TwoLinkxyc**: acausal bond graph

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: TwoLinkxyc_lbl.txt

```
%SUMMARY TwoLinkxyc: two-link manipulator with collocated tip source-ser
%DESCRIPTION This is related to a heirachical version of the
%DESCRIPTION example from Section 10.5 of "Metamodelling".
%DESCRIPTION It uses two compound components: ROD and GRA
%DESCRIPTION ROD is essentially as described in Figure 10.2
%DESCRIPTION GRAV represents gravity by a vertical accelleration
%DESCRIPTION as in Section 10.9 of "Metamodelling"
%DESCRIPTION except that the  collocated  source-sensors act at the
%DESCRIPTION tip rather than at the joints.

%% Label (TwoLinkxyc_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: TwoLinkxyc_lbl.txt,v 1.2 2000/12/28 18:02:44 peterg Exp $
% %% $Log: TwoLinkxyc_lbl.txt,v $
% %% Revision 1.2  2000/12/28 18:02:44  peterg
% %% To RCS
% %%
% %% Revision 1.1  1998/01/06  15:56:31  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

%Rod parameters - identical rods
rod1 none l;l;j;m;mg
```

```
rod2 none l;l;j;m;mg

%Zero velocity sources
v_x SS     internal,0


%Zero force/torque sources
F_a SS    0,internal


%Torque at joints
f_a1 SS 0,internal
f_a2 SS 0,internal

%Forces at tip
F_x SS external,external
F_y SS external,external


%Gravity
g
```

8.1.2 Subsystems

- ACCEL: Provides a acceleration (useful for simulating gravity. (1) No subsystems.
- ROD: rigid rod in two dimensions (2)
  - INTF: flow integrator (1)

8.1.3 ACCEL

The acausal bond graph of system **ACCEL** is displayed in Figure 10.2 (on page 171) and its label file is listed in Section 10.1.3 (on page 171). The subsystems are listed in Section 10.1.3 (on page 173).

Summary information

System ACCEL::Provides a acceleration (useful for simulating gravity.
Useful for simulating gravity as explaned in Section 10.9 of ”Metamodelling”.

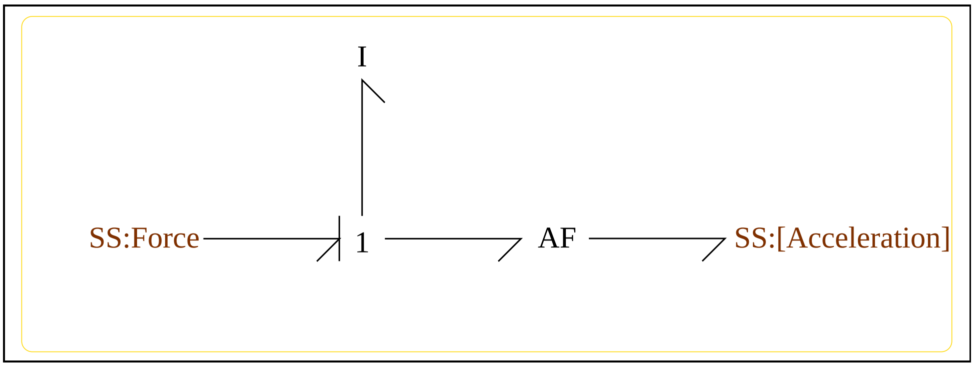

Figure 8.2: System **ACCEL**: acausal bond graph

Interface information:

Port in represents actual port **Acceleration**

Port out represents actual port **Acceleration**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ACCEL_lbl.txt

```
%SUMMARY ACCEL: Provides a acceleration (useful for simulating gravity.
%DESCRIPTION Useful for simulating gravity as explaned in Section 10.9
%DESCRIPTION of "Metamodelling".

%ALIAS in|out Acceleration

%% Label file for system ACCEL (ACCEL_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ACCEL_lbl.txt,v 1.4 1998/07/27 20:33:17 peterg Exp $
% %% $Log: ACCEL_lbl.txt,v $
```

```
% %% Revision 1.4  1998/07/27 20:33:17  peterg
% %% Aliases
% %%
% %% Revision 1.3  1998/07/27 06:50:41  peterg
% %% *** empty log message ***
% %%
% %% Revision 1.2  1998/07/27 06:49:57  peterg
% %% Added blank line at end
% %%
% %% Revision 1.1  1998/07/27 06:47:32  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

% SS components
Force SS external,internal
[Acceleration] SS external,external
```

Subsystems

No subsystems.

8.1.4 INTF

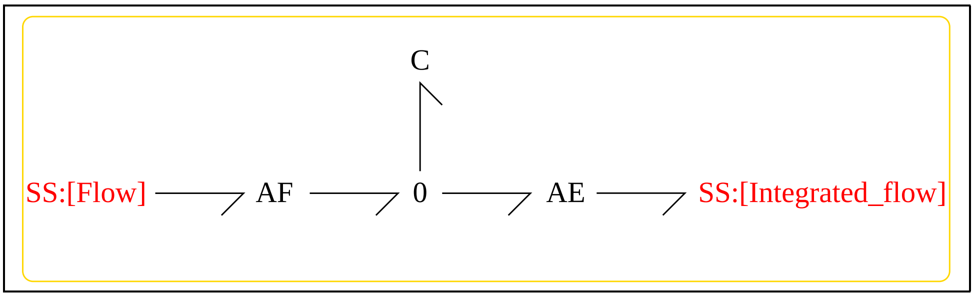

Figure 8.3: System **INTF**: acausal bond graph

The acausal bond graph of system **INTF** is displayed in Figure 10.3 (on page 173) and its label file is listed in Section 10.1.4 (on page 173). The subsystems are listed in Section 10.1.4 (on page 174).

INTF is a two-port component where the effort on port [out] is the integral of the flow on port [in].

Summary information

System INTF::flow integrator Port [in]: Flow to be integrated Port [out]: Effort = integral of flow on port [in]

Interface information:

Port in represents actual port **Flow**

Port out represents actual port **Integrated_flow**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: INTF_lbl.txt

```
%% Label file for system INTF (INTF_lbl.txt)
%SUMMARY INTF: flow integrator
%DESCRIPTION Port [in]: Flow to be integrated
%DESCRIPTION Port [out]: Effort = integral of flow on port [in]


% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: INTF_lbl.txt,v 1.3 1998/07/16 07:35:10 peterg Exp $
% %% $Log: INTF_lbl.txt,v $
% %% Revision 1.3  1998/07/16 07:35:10  peterg
% %% Aliased version
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% Port aliases
%ALIAS in Flow
%ALIAS out Integrated_flow

% Argument aliases

%% 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
[Flow] SS external,external
[Integrated_flow] SS external,external
```

Subsystems

No subsystems.

8.1.5 ROD

The acausal bond graph of system **ROD** is displayed in Figure 10.4 (on page 175) and its label file is listed in Section 10.1.5 (on page 175). The subsystems are listed in Section 10.1.5 (on page 178).
ROD is essentially as described in Figure 10.2 of “Metamodelling”.

Summary information

System ROD::rigid rod in two dimensions See Section 10.2 of ”Metamodelling”

Interface information:

Component INTF is in library **General/INTF** – The flow integration component.

Parameter $1 represents actual parameter **l_a** – length from end a to mass centre

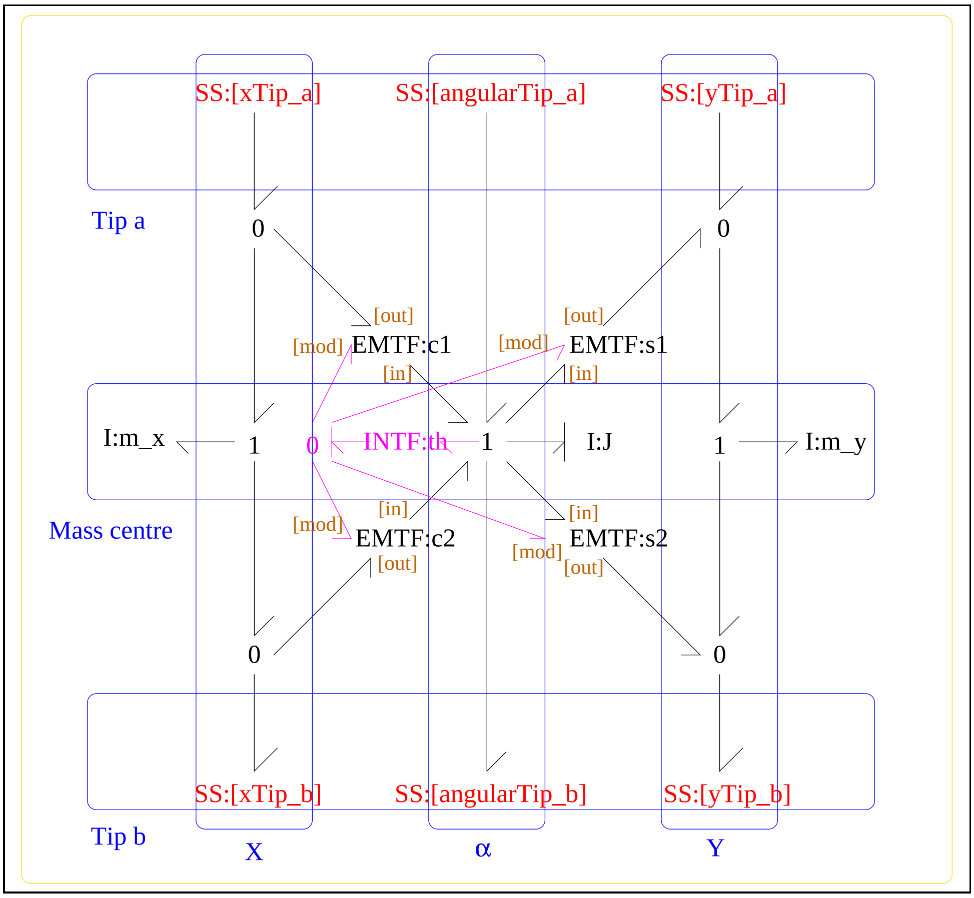

Figure 8.4: System **ROD**: acausal bond graph

Parameter $2 represents actual parameter **l_b** – length from end b to mass centre

Parameter $3 represents actual parameter **j_m** – inertia about mass centre

Parameter $4 represents actual parameter **m** – mass

Port Tip_a represents actual port **xTip_a,angularTip_a,yTip_a**

Port Tip_b represents actual port **xTip_b,angularTip_b,yTip_b**

Port alpha_a represents actual port **angularTip_a** – Torque/angular velocity at tip a

Port alpha_b represents actual port **angularTip_b** – Torque/angular velocity at tip b

Port in represents actual port **xTip_a,angularTip_a,yTip_a**

Port out represents actual port **xTip_b,angularTip_b,yTip_b**

Port x_a represents actual port **xTip_a** – Force/velocity at tip a in x direction

Port x_b represents actual port **xTip_b** – Force/velocity at tip b in x direction

Port y_a represents actual port **yTip_a** – Force/velocity at tip a in y direction

Port y_b represents actual port **yTip_b** – Force/velocity at tip b in y direction

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ROD_lbl.txt

```
%SUMMARY ROD: rigid rod in two dimensions
%DESCRIPTION See Section 10.2 of "Metamodelling"

%ALIAS $1 l_a # length from end a to mass centre
%ALIAS $2 l_b # length from end b to mass centre
%ALIAS $3 j_m # inertia about mass centre
%ALIAS $4 m # mass
```

```
%ALIAS in|Tip_a xTip_a,angularTip_a,yTip_a
%ALIAS out|Tip_b xTip_b,angularTip_b,yTip_b

%ALIAS x_a xTip_a # Force/velocity at tip a in x direction
%ALIAS y_a yTip_a # Force/velocity at tip a in y direction
%ALIAS alpha_a angularTip_a # Torque/angular velocity at tip a

%ALIAS x_b xTip_b # Force/velocity at tip b in x direction
%ALIAS y_b yTip_b # Force/velocity at tip b in y direction
%ALIAS alpha_b angularTip_b # Torque/angular velocity at tip b

%ALIAS INTF General/INTF # The flow integration component.

%% Label file for system ROD (ROD_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ROD_lbl.txt,v 1.5 1998/07/27 12:27:27 peterg Exp $
% %% $Log: ROD_lbl.txt,v $
% %% Revision 1.5  1998/07/27 12:27:27  peterg
% %% Added vector port aliases
% %%
% %% Revision 1.4  1998/07/27 10:51:20  peterg
% %% Aliased INTF as well.
% %%
% %% Revision 1.3  1998/07/27 10:49:10  peterg
% %% Major revision to include aliases etc
% %%
% %% Revision 1.2  1997/08/15  09:43:06  peterg
% %% Now has lablelled (as opposed to numbered) ports.
% %%
% Revision 1.1  1996/11/07  10:57:17  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

%Inertias
J lin flow,j_m
m_x lin flow,m
m_y lin flow,m

%Integrate angular velocity to get angle
th

%Modulated transformers
s1 lsin flow,l_a
s2 lsin flow,l_b
c1 lcos flow,l_a
c2 lcos flow,l_b

% Component type SS
[angularTip_a] SS external,external
[angularTip_b] SS external,external
[xTip_a] SS external,external
[xTip_b] SS external,external
[yTip_a] SS external,external
[yTip_b] SS external,external
```

Subsystems

- INTF: flow integrator (1) No subsystems.

8.2 TwoLinkxyc_struc.tex

MTT command:

```
mtt TwoLinkxyc struc tex
```

List of inputs for system TwoLinkxyc			
	Component	System	Repetition
1	F_x	TwoLinkxyc__F_x	1
2	F_y	TwoLinkxyc__F_y	1

List of inputs for system TwoLinkxyc (continued)			
	Component	System	Repetition
3	Force	TwoLinkxyc__g__Force	1

List of nonstates for system TwoLinkxyc			
	Component	System	Repetition
1	m_x	TwoLinkxyc__rod1__m_x	1
2	m_y	TwoLinkxyc__rod1__m_y	1
3	m_x	TwoLinkxyc__rod2__m_x	1
4	m_y	TwoLinkxyc__rod2__m_y	1

List of outputs for system TwoLinkxyc			
	Component	System	Repetition
1	F_x	TwoLinkxyc__F_x	1
2	F_y	TwoLinkxyc__F_y	1

List of states for system TwoLinkxyc			
	Component	System	Repetition
1	J	TwoLinkxyc__rod1__J	1
2	mttC	TwoLinkxyc__rod1__th__mttC	1
3	J	TwoLinkxyc__rod2__J	1
4	mttC	TwoLinkxyc__rod2__th__mttC	1
5	mttI	TwoLinkxyc__g__mttI	1

8.3 TwoLinkxyc_dae.tex

MTT command:

```
mtt TwoLinkxyc dae tex
```

$$\begin{aligned}
\dot{x}_1 &= l(\cos(x_2)\dot{z}_1 + 2\cos(x_2)\dot{z}_3 + 2\cos(x_2)u_1 - \sin(x_2)\dot{z}_2 - 2\sin(x_2)\dot{z}_4 - 2\sin(x_2)u_2) \\
\dot{x}_2 &= \frac{x_1}{j} \\
\dot{x}_3 &= l(\cos(x_4)\dot{z}_3 + 2\cos(x_4)u_1 - \sin(x_4)\dot{z}_4 - 2\sin(x_4)u_2) \\
\dot{x}_4 &= \frac{x_3}{j} \\
\dot{x}_5 &= u_3
\end{aligned} \tag{8.1}$$

$$
\begin{aligned}
z_1 &= \frac{(-\cos(x_2)lmx_1)}{j}\\
z_2 &= \frac{(m(\sin(x_2)lx_1 + jx_5))}{j}\\
z_3 &= \frac{(lm(-2\cos(x_2)x_1 - \cos(x_4)x_3))}{j}\\
z_4 &= \frac{(m(2\sin(x_2)lx_1 + \sin(x_4)lx_3 + jx_5))}{j}
\end{aligned} \tag{8.2}
$$

$$
\begin{aligned}
y_1 &= \frac{(-2l(\cos(x_2)x_1 + \cos(x_4)x_3))}{j}\\
y_2 &= \frac{(2\sin(x_2)lx_1 + 2\sin(x_4)lx_3 + jx_5)}{j}
\end{aligned} \tag{8.3}
$$

8.4 TwoLinkxyc_cse.tex

MTT command:

```
mtt TwoLinkxyc cse tex
```

$$
\dot{\chi}_1 = \frac{\left(l\left(2\cos(x_2 - 2x_4)j^2l^2mu_1 - 2\cos(x_2)j^3u_1 + 2\sin(2x_2 - 2x_4)l^3m^2x_1^2 + \sin(x_2 - 2x_4)j^2l^2m^2u_3\right.\right.}{(j(2\cos} \tag{8.4}
$$

$$
\dot{\chi}_2 = \frac{x_1}{j} \tag{8.5}
$$

$$
\dot{\chi}_3 = \frac{\left(l\left(2\cos(2x_2 - x_4)j^2l^2mu_1 - 2\cos(x_4)j^3u_1 - 8\cos(x_4)j^2l^2mu_1 - 2\sin(2x_2 - 2x_4)l^3m^2x_3^2 - 3\sin\right.\right.}{} \tag{8.6}
$$

$$
\dot{\chi}_4 = \frac{x_3}{j} \tag{8.7}
$$

$$
\dot{\chi}_5 = u_3 \tag{8.8}
$$

$$y_1 = \frac{(-2l(\cos(x_2)x_1 + \cos(x_4)x_3))}{j} \tag{8.9}$$

$$y_2 = \frac{(2\sin(x_2)lx_1 + 2\sin(x_4)lx_3 + jx_5)}{j} \tag{8.10}$$

$$E = \begin{pmatrix} \frac{(j+5l^2m)}{j} & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & \frac{(j+l^2m)}{j} & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \tag{8.11}$$

8.5 TwoLinkxyc_input.txt

MTT command:

```
mtt TwoLinkxyc input txt
```

```
# Numerical parameter file (TwoLinkxyc_input.txt)
# Generated by MTT at Fri Jun 13 16:56:09 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: TwoLinkxyc_input.txt,v 1.2 2003/06/11 16:05:44 gawthrop Exp $
# %% $Log: TwoLinkxyc_input.txt,v $
# %% Revision 1.2  2003/06/11 16:05:44  gawthrop
# %% Updated examples for latest MTT.
# %%
# %% Revision 1.1  2000/12/28 18:02:44  peterg
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Set the inputs
## Removed by MTT on Wed Jun 11 14:02:21 BST 2003: u(1) =
(t<1.0);
```

```
## Removed by MTT on Wed Jun 11 14:02:21 BST 2003: u(2) =
0.0; #
## Removed by MTT on Wed Jun 11 14:02:21 BST 2003: u(3) =
0.0; # gravity
twolinkxyc__f_x = (t<1.0);
twolinkxyc__f_y = 0.0;
twolinkxyc__g__force = 0.0;
```

8.6 TwoLinkxyc_numpar.txt

MTT command:

```
mtt TwoLinkxyc numpar txt
```

```
# Numerical parameter file (TwoLinkxyc_numpar.txt)
# Generated by MTT at Fri Jun 13 16:39:41 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: TwoLinkxyc_numpar.txt,v 1.3 2003/06/11 16:06:01 gawthrop
# %% $Log: TwoLinkxyc_numpar.txt,v $
# %% Revision 1.3  2003/06/11 16:06:01  gawthrop
# %% Updated examples for latest MTT.
# %%
# %% Revision 1.2  2000/05/20 15:44:26  peterg
# %% Split from old numpar file
# %%
# %% Revision 1.1  2000/05/20 15:43:27  peterg
# %% Initial revision
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Parameters
l =  1.0; # Default value
m =  1.0; # Default value
j =  m*l*l/12.0; # Uniform rod
mg = m*9.81;
```

8.7 TwoLinkxyc_odeso.ps *(-ieuler)*

MTT command:

```
mtt -i euler TwoLinkxyc odeso ps
```

This representation is given as Figure 8.5 (on page 147).

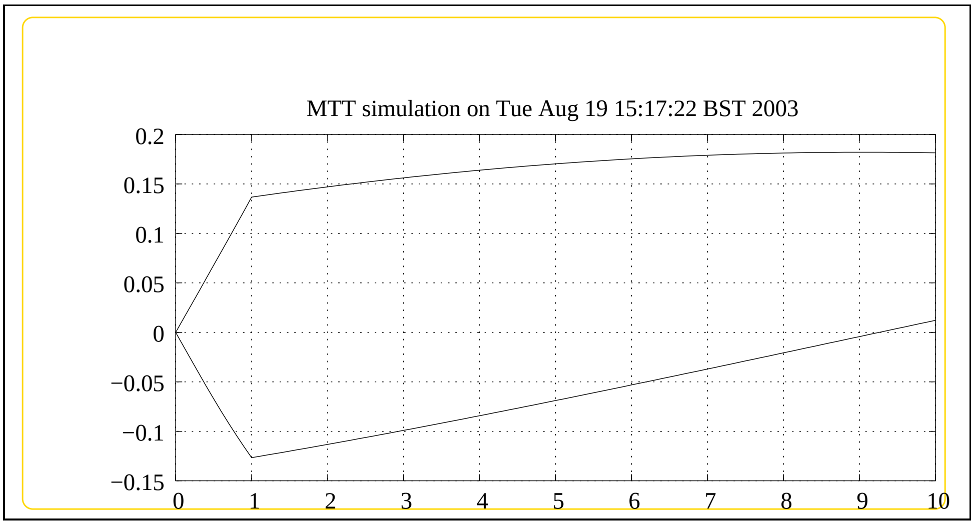

Figure 8.5: System **TwoLinkxyc**, representation odeso (-ieuler)

Chapter 9

TwoLinkxyn

9.1 TwoLinkxyn_abg.tex

MTT command:

```
mtt TwoLinkxyn abg tex
```

The acausal bond graph of system **TwoLinkxyn** is displayed in Figure 9.1 (on page 150) and its label file is listed in Section 9.1.1 (on page 149). The subsystems are listed in Section 9.1.2 (on page 152).
This system is identical to **twolink** except that there are now two non-collocated input-output pairs: The torque input to joint 1 – x velocity of the tip and the torque input to joint 2 – y velocity of the tip.
It uses two compound components: **ROD** and **GRAV**. **ROD** is essentially as described in Figure 10.2 of ”Metamodelling” and **GRAV** represents gravity by a vertical acceleration as in Section 10.9 of ”Metamodelling”

9.1.1 Summary information

System TwoLinkxyn::two-link manipulator with collocated tip source-sensors. This is related to a heirachical version of the example from Section 10.5 of ”Metamodelling”. It uses two compound components: ROD and GRA ROD is essentially as described in Figure 10.2 GRAV represents gravity by a vertical accelleration as in Section 10.9 of ”Metamodelling” except that the source sensors are not collocated: sources at the joints, sensors at the xy motion of the tip.

Interface information:

This component has no ALIAS declarations

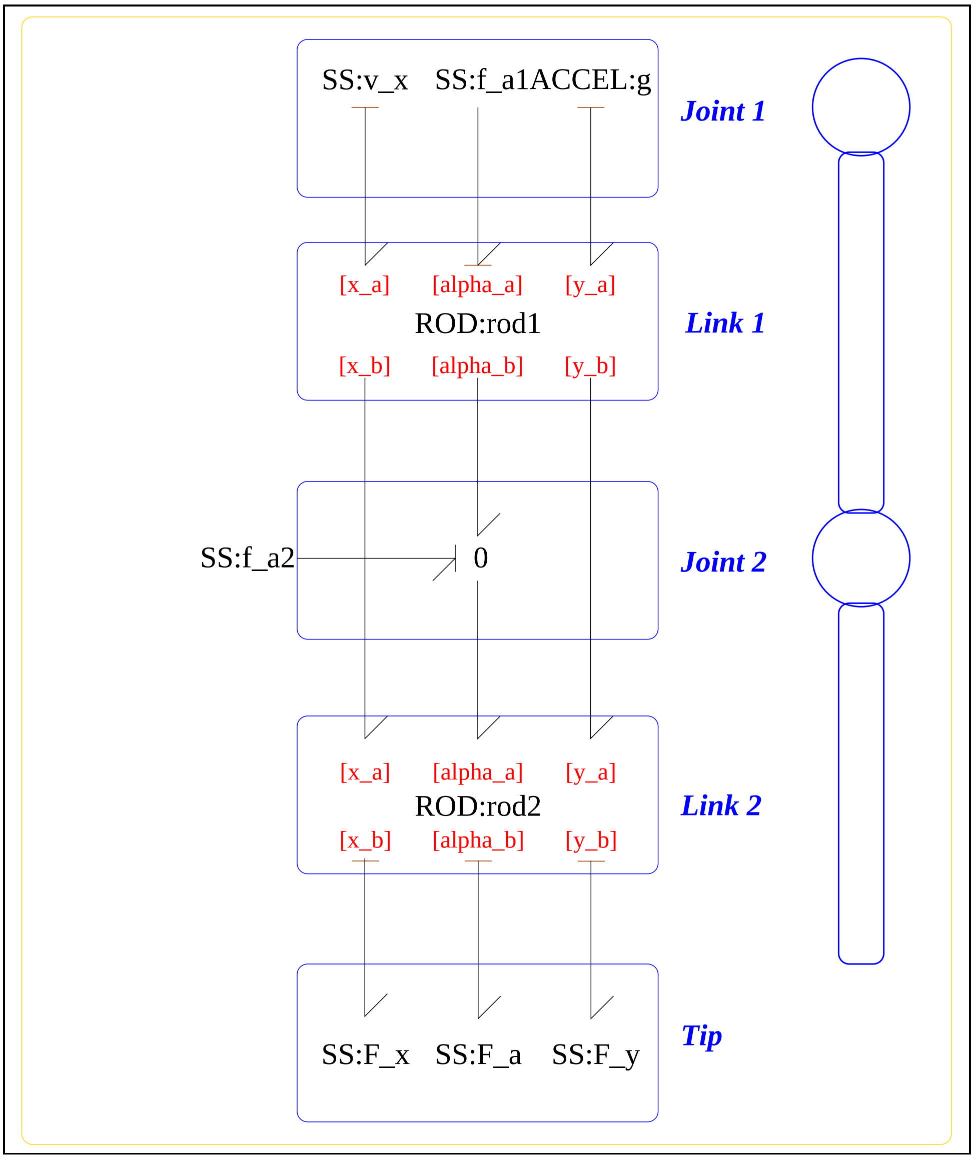

Figure 9.1: System **TwoLinkxyn**: acausal bond graph

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: TwoLinkxyn_lbl.txt

```
%SUMMARY TwoLinkxyn: two-link manipulator with collocated tip source-ser
%DESCRIPTION This is related to a heirachical version of the
%DESCRIPTION example from Section 10.5 of "Metamodelling".
%DESCRIPTION It uses two compound components: ROD and GRA
%DESCRIPTION ROD is essentially as described in Figure 10.2
%DESCRIPTION GRAV represents gravity by a vertical accelleration
%DESCRIPTION as in Section 10.9 of "Metamodelling"
%DESCRIPTION except that the source sensors are not collocated:
%DESCRIPTION sources at the joints, sensors at the xy motion of the tip.

%% Label (TwoLinkxyn_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: TwoLinkxyn_lbl.txt,v 1.2 2000/12/28 18:03:12 peterg Exp $
% %% $Log: TwoLinkxyn_lbl.txt,v $
% %% Revision 1.2  2000/12/28 18:03:12  peterg
% %% To RCS
% %%
% %% Revision 1.1  1998/01/06  17:37:55  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

%Rod parameters - identical rods
rod1 none l;l;j;m;mg
```

```
rod2 none l;l;j;m;mg

%Zero velocity sources
v_x SS     internal,0


%Zero force/torque sources
F_a SS    0,internal


%Torque at joints
f_a1 SS external,internal
f_a2 SS external,internal

%Forces at tip
F_x SS 0,external
F_y SS 0,external


%Gravity
g
```

9.1.2 Subsystems

- ACCEL: Provides a acceleration (useful for simulating gravity. (1) No subsystems.
- ROD: rigid rod in two dimensions (2)
  - INTF: flow integrator (1)

9.1.3 ACCEL

The acausal bond graph of system **ACCEL** is displayed in Figure 10.2 (on page 171) and its label file is listed in Section 10.1.3 (on page 171). The subsystems are listed in Section 10.1.3 (on page 173).

Summary information

System ACCEL::Provides a acceleration (useful for simulating gravity.
Useful for simulating gravity as explaned in Section 10.9 of ”Metamodelling”.

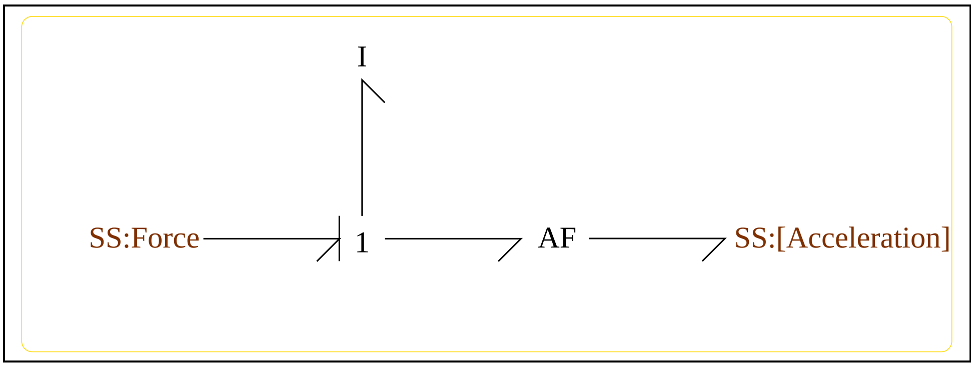

Figure 9.2: System **ACCEL**: acausal bond graph

Interface information:

Port in represents actual port **Acceleration**

Port out represents actual port **Acceleration**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ACCEL_lbl.txt

```
%SUMMARY ACCEL: Provides a acceleration (useful for simulating gravity.
%DESCRIPTION Useful for simulating gravity as explaned in Section 10.9
%DESCRIPTION of "Metamodelling".

%ALIAS in|out Acceleration

%% Label file for system ACCEL (ACCEL_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ACCEL_lbl.txt,v 1.4 1998/07/27 20:33:17 peterg Exp $
% %% $Log: ACCEL_lbl.txt,v $
```

```
% %% Revision 1.4  1998/07/27 20:33:17  peterg
% %% Aliases
% %%
% %% Revision 1.3  1998/07/27 06:50:41  peterg
% %% *** empty log message ***
% %%
% %% Revision 1.2  1998/07/27 06:49:57  peterg
% %% Added blank line at end
% %%
% %% Revision 1.1  1998/07/27 06:47:32  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

% SS components
Force SS external,internal
[Acceleration] SS external,external
```

Subsystems

No subsystems.

9.1.4 INTF

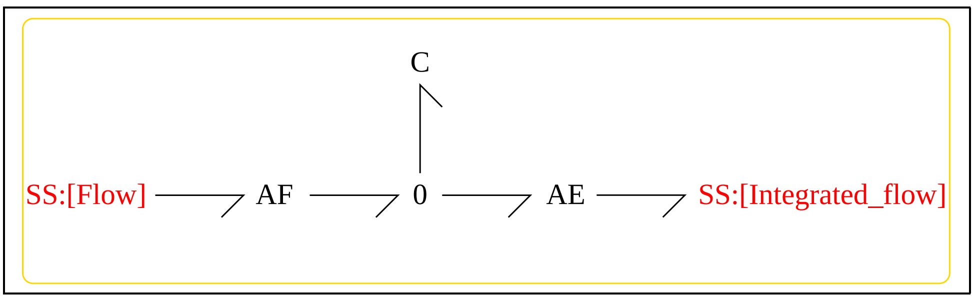

Figure 9.3: System **INTF**: acausal bond graph

The acausal bond graph of system **INTF** is displayed in Figure 10.3 (on page 173) and its label file is listed in Section 10.1.4 (on page 173). The subsystems are listed in Section 10.1.4 (on page 174).

INTF is a two-port component where the effort on port [out] is the integral of the flow on port [in].

Summary information

System INTF::flow integrator Port [in]: Flow to be integrated Port [out]: Effort = integral of flow on port [in]

Interface information:

Port in represents actual port **Flow**

Port out represents actual port **Integrated_flow**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: INTF_lbl.txt

```
%% Label file for system INTF (INTF_lbl.txt)
%SUMMARY INTF: flow integrator
%DESCRIPTION Port [in]: Flow to be integrated
%DESCRIPTION Port [out]: Effort = integral of flow on port [in]


% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: INTF_lbl.txt,v 1.3 1998/07/16 07:35:10 peterg Exp $
% %% $Log: INTF_lbl.txt,v $
% %% Revision 1.3  1998/07/16 07:35:10  peterg
% %% Aliased version
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% Port aliases
%ALIAS in Flow
%ALIAS out Integrated_flow

% Argument aliases

%% 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
[Flow] SS external,external
[Integrated_flow] SS external,external
```

Subsystems

No subsystems.

9.1.5 ROD

The acausal bond graph of system **ROD** is displayed in Figure 10.4 (on page 175) and its label file is listed in Section 10.1.5 (on page 175). The subsystems are listed in Section 10.1.5 (on page 178).

ROD is essentially as described in Figure 10.2 of “Metamodelling”.

Summary information

System ROD::rigid rod in two dimensions See Section 10.2 of ”Metamodelling”

Interface information:

Component INTF is in library **General/INTF** – The flow integration component.

Parameter $1 represents actual parameter **l_a** – length from end a to mass centre

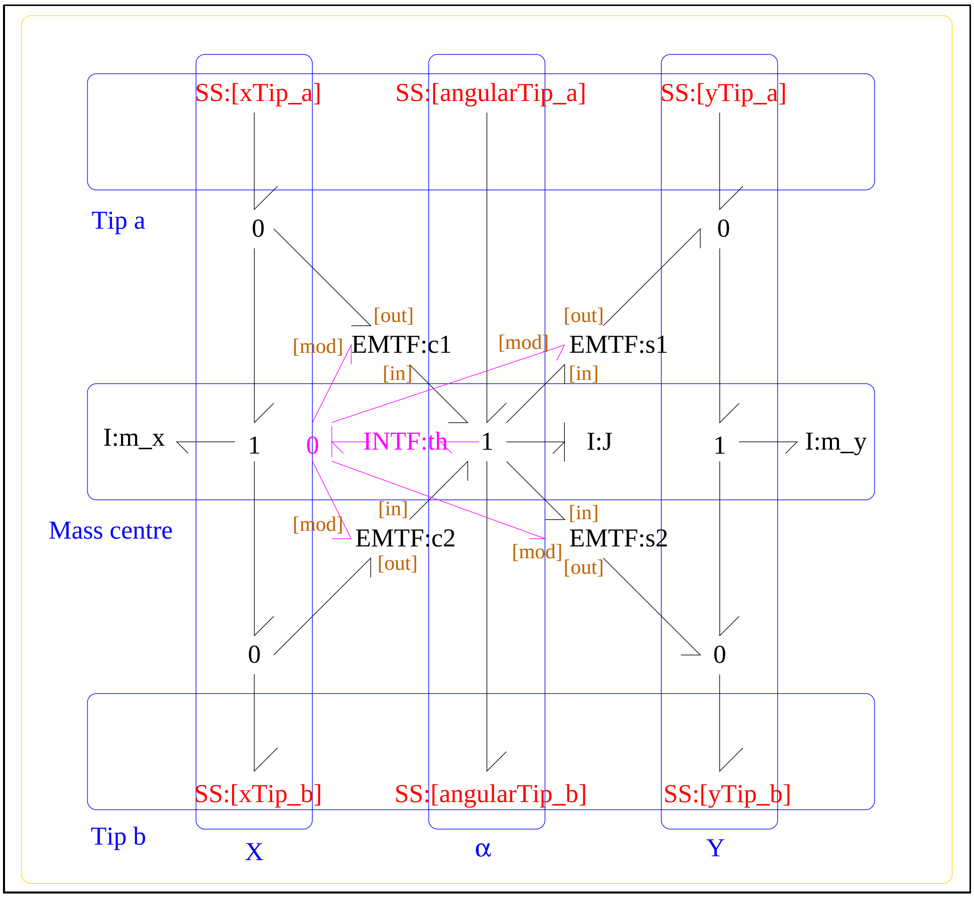

Figure 9.4: System **ROD**: acausal bond graph

Parameter $2 represents actual parameter **l_b** – length from end b to mass centre

Parameter $3 represents actual parameter **j_m** – inertia about mass centre

Parameter $4 represents actual parameter **m** – mass

Port Tip_a represents actual port **xTip_a,angularTip_a,yTip_a**

Port Tip_b represents actual port **xTip_b,angularTip_b,yTip_b**

Port alpha_a represents actual port **angularTip_a** – Torque/angular velocity at tip a

Port alpha_b represents actual port **angularTip_b** – Torque/angular velocity at tip b

Port in represents actual port **xTip_a,angularTip_a,yTip_a**

Port out represents actual port **xTip_b,angularTip_b,yTip_b**

Port x_a represents actual port **xTip_a** – Force/velocity at tip a in x direction

Port x_b represents actual port **xTip_b** – Force/velocity at tip b in x direction

Port y_a represents actual port **yTip_a** – Force/velocity at tip a in y direction

Port y_b represents actual port **yTip_b** – Force/velocity at tip b in y direction

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ROD_lbl.txt

```
%SUMMARY ROD: rigid rod in two dimensions
%DESCRIPTION See Section 10.2 of "Metamodelling"

%ALIAS $1 l_a # length from end a to mass centre
%ALIAS $2 l_b # length from end b to mass centre
%ALIAS $3 j_m # inertia about mass centre
%ALIAS $4 m # mass
```

```
%ALIAS in|Tip_a xTip_a,angularTip_a,yTip_a
%ALIAS out|Tip_b xTip_b,angularTip_b,yTip_b

%ALIAS x_a xTip_a # Force/velocity at tip a in x direction
%ALIAS y_a yTip_a # Force/velocity at tip a in y direction
%ALIAS alpha_a angularTip_a # Torque/angular velocity at tip a

%ALIAS x_b xTip_b # Force/velocity at tip b in x direction
%ALIAS y_b yTip_b # Force/velocity at tip b in y direction
%ALIAS alpha_b angularTip_b # Torque/angular velocity at tip b

%ALIAS INTF General/INTF # The flow integration component.

%% Label file for system ROD (ROD_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ROD_lbl.txt,v 1.5 1998/07/27 12:27:27 peterg Exp $
% %% $Log: ROD_lbl.txt,v $
% %% Revision 1.5  1998/07/27 12:27:27  peterg
% %% Added vector port aliases
% %%
% %% Revision 1.4  1998/07/27 10:51:20  peterg
% %% Aliased INTF as well.
% %%
% %% Revision 1.3  1998/07/27 10:49:10  peterg
% %% Major revision to include aliases etc
% %%
% %% Revision 1.2  1997/08/15  09:43:06  peterg
% %% Now has lablelled (as opposed to numbered) ports.
% %%
% Revision 1.1  1996/11/07  10:57:17  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

%Inertias
J lin flow,j_m
m_x lin flow,m
m_y lin flow,m

%Integrate angular velocity to get angle
th

%Modulated transformers
s1 lsin flow,l_a
s2 lsin flow,l_b
c1 lcos flow,l_a
c2 lcos flow,l_b

% Component type SS
[angularTip_a] SS external,external
[angularTip_b] SS external,external
[xTip_a] SS external,external
[xTip_b] SS external,external
[yTip_a] SS external,external
[yTip_b] SS external,external
```

Subsystems

- INTF: flow integrator (1) No subsystems.

9.2 TwoLinkxyn_struc.tex

MTT command:

```
mtt TwoLinkxyn struc tex
```

List of inputs for system TwoLinkxyn			
	Component	System	Repetition
1	f_a1	TwoLinkxyn__f_a1	1
2	f_a2	TwoLinkxyn__f_a2	1

List of inputs for system TwoLinkxyn (continued)			
	Component	System	Repetition
3	Force	TwoLinkxyn__g__Force	1

List of nonstates for system TwoLinkxyn			
	Component	System	Repetition
1	m_x	TwoLinkxyn__rod1__m_x	1
2	m_y	TwoLinkxyn__rod1__m_y	1
3	m_x	TwoLinkxyn__rod2__m_x	1
4	m_y	TwoLinkxyn__rod2__m_y	1

List of outputs for system TwoLinkxyn			
	Component	System	Repetition
1	F_x	TwoLinkxyn__F_x	1
2	F_y	TwoLinkxyn__F_y	1

List of states for system TwoLinkxyn			
	Component	System	Repetition
1	J	TwoLinkxyn__rod1__J	1
2	mttC	TwoLinkxyn__rod1__th__mttC	1
3	J	TwoLinkxyn__rod2__J	1
4	mttC	TwoLinkxyn__rod2__th__mttC	1
5	mttI	TwoLinkxyn__g__mttI	1

9.3 TwoLinkxyn_dae.tex

MTT command:

```
mtt TwoLinkxyn dae tex
```

$$\begin{aligned}
\dot{x}_1 &= \cos(x_2) l \dot{z}_1 + 2\cos(x_2) l \dot{z}_3 - \sin(x_2) l \dot{z}_2 - 2\sin(x_2) l \dot{z}_4 + u_1 - u_2 \\
\dot{x}_2 &= \frac{x_1}{j} \\
\dot{x}_3 &= \cos(x_4) l \dot{z}_3 - \sin(x_4) l \dot{z}_4 + u_2 \\
\dot{x}_4 &= \frac{x_3}{j} \\
\dot{x}_5 &= u_3
\end{aligned} \tag{9.1}$$

$$
\begin{aligned}
z_1 &= \frac{(-\cos(x_2) l m x_1)}{j} \\
z_2 &= \frac{(m(\sin(x_2) l x_1 + j x_5))}{j} \\
z_3 &= \frac{(lm(-2\cos(x_2) x_1 - \cos(x_4) x_3))}{j} \\
z_4 &= \frac{(m(2\sin(x_2) l x_1 + \sin(x_4) l x_3 + j x_5))}{j}
\end{aligned} \tag{9.2}
$$

$$
\begin{aligned}
y_1 &= \frac{(-2l(\cos(x_2) x_1 + \cos(x_4) x_3))}{j} \\
y_2 &= \frac{(2\sin(x_2) l x_1 + 2\sin(x_4) l x_3 + j x_5)}{j}
\end{aligned} \tag{9.3}
$$

9.4 TwoLinkxyn_cse.tex

MTT command:

```
mtt TwoLinkxyn cse tex
```

$$
\dot{\chi}_1 = \frac{\left(2\cos(x_2 - x_4) j^2 l^2 m u_2 + 2\sin(2x_2 - 2x_4) l^4 m^2 x_1^2 + \sin(x_2 - 2x_4) j^2 l^3 m^2 u_3 + 2\sin(x_2 - x_4) j l^2\right.}{(j(2\cos(2x_2 - 2x_4)} \tag{9.4}
$$

$$
\dot{\chi}_2 = \frac{x_1}{j} \tag{9.5}
$$

$$
\dot{\chi}_3 = \frac{\left(2\cos(x_2 - x_4) j^2 l^2 m u_1 - 2\cos(x_2 - x_4) j^2 l^2 m u_2 - 2\sin(2x_2 - 2x_4) l^4 m^2 x_3^2 - 3\sin(2x_2 - x_4) j^2\right.}{(j(2\cos(2x_2 -} \tag{9.6}
$$

$$
\dot{\chi}_4 = \frac{x_3}{j} \tag{9.7}
$$

$$
\dot{\chi}_5 = u_3 \tag{9.8}
$$

$$y_1 = \frac{(-2l(\cos(x_2)x_1 + \cos(x_4)x_3))}{j} \tag{9.9}$$

$$y_2 = \frac{(2\sin(x_2)lx_1 + 2\sin(x_4)lx_3 + jx_5)}{j} \tag{9.10}$$

$$E = \begin{pmatrix} \frac{(j+5l^2m)}{j} & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & \frac{(j+l^2m)}{j} & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \tag{9.11}$$

9.5 TwoLinkxyn_input.txt

MTT command:

```
mtt TwoLinkxyn input txt
```

```
# Numerical parameter file (TwoLinkxyn_input.txt)
# Generated by MTT at Fri Jun 13 16:56:09 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: TwoLinkxyn_input.txt,v 1.2 2003/06/11 16:07:04 gawthrop Exp $
# %% $Log: TwoLinkxyn_input.txt,v $
# %% Revision 1.2  2003/06/11 16:07:04  gawthrop
# %% Updated examples for latest MTT.
# %%
# %% Revision 1.1  2000/12/28 18:03:12  peterg
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Set the inputs
## Removed by MTT on Wed Jun 11 14:14:40 BST 2003: u(1) =
(t<1.0);
```

```
## Removed by MTT on Wed Jun 11 14:14:40 BST 2003: u(2) =
0.0; #
## Removed by MTT on Wed Jun 11 14:14:40 BST 2003: u(3) =
0.0; # gravity
twolinkxyn__f_a1 = (t<1.0);
twolinkxyn__f_a2 = 0.0;
twolinkxyn__g__force = 0.0;
```

9.6 TwoLinkxyn_numpar.txt

MTT command:

```
mtt TwoLinkxyn numpar txt
```

```
# Numerical parameter file (TwoLinkxyn_numpar.txt)
# Generated by MTT at Fri Jun 13 16:39:41 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: TwoLinkxyn_numpar.txt,v 1.2 2003/06/11 16:07:17 gawthrop
# %% $Log: TwoLinkxyn_numpar.txt,v $
# %% Revision 1.2  2003/06/11 16:07:17  gawthrop
# %% Updated examples for latest MTT.
# %%
# %% Revision 1.1  2000/05/20 15:50:31  peterg
# %% Initial revision
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Parameters
l =  1.0; # Default value
m =  1.0; # Default value
j =  m*l*l/12.0; # Uniform rod
mg = m*9.81;
```

9.7 TwoLinkxyn_odeso.ps *(-ieuler)*

MTT command:

```
mtt -i euler TwoLinkxyn odeso ps
```

This representation is given as Figure 9.5 (on page 165).

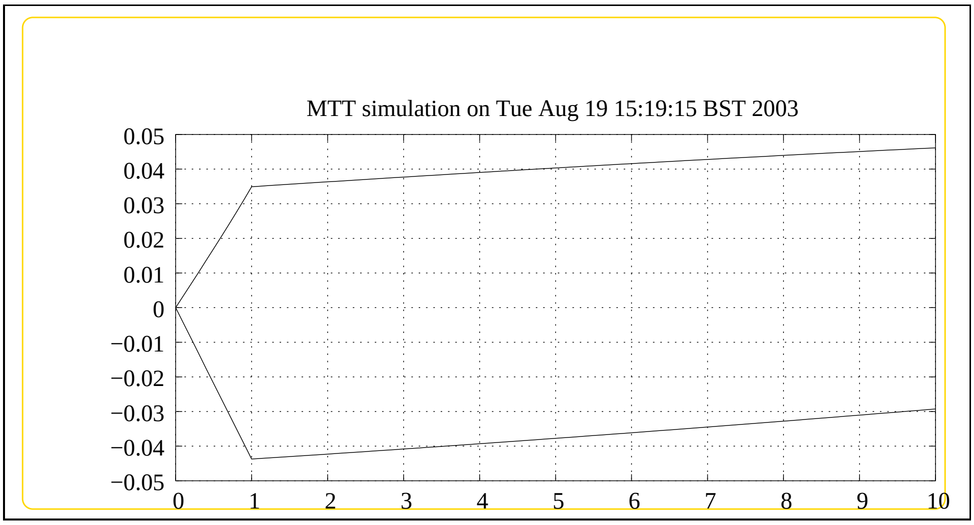

Figure 9.5: System **TwoLinkxyn**, representation odeso (-ieuler)

Chapter 10

gTwoLink

10.1 gTwoLink_abg.tex

MTT command:

```
mtt gTwoLink abg tex
```

The acausal bond graph of system **gTwoLink** is displayed in Figure 10.1 (on page 168) and its label file is listed in Section 10.1.1 (on page 167). The subsystems are listed in Section 10.1.2 (on page 170).

This is a heirachical version of the example from Section 10.5 of ”Metamodelling”. It uses the compound components: **ROD**. **ROD** is essentially as described in Figure 10.2. Gravity is included as discussed in ”Metamodelling” by accelerating the manipulator vertically using the **ACCEL** component.

This system has a number of dynamic elements (those corresponding to translation motion) in derivative causality, thus the system is represnted as a Differential-Algebraic Equation (Section **??** (on page **??**)). Hovever, this is of contrained-state form and therfore can be written as a set of constrained-state equations (Section **??** (on page **??**)). The corresponding ordinary differential equation is complicated due to the trig functions involved in inverting the E matrix.

As well as the standard representation the “robot-form” equations appear in Section **??** (on page **??**).

10.1.1 Summary information

System gTwoLink::two-link manipulator from Section 10.5 of ”Metamodelling” This is a heirachical version of the example from Section 10.5 of ”Metamodelling”. It uses two compound components: ROD and GRA

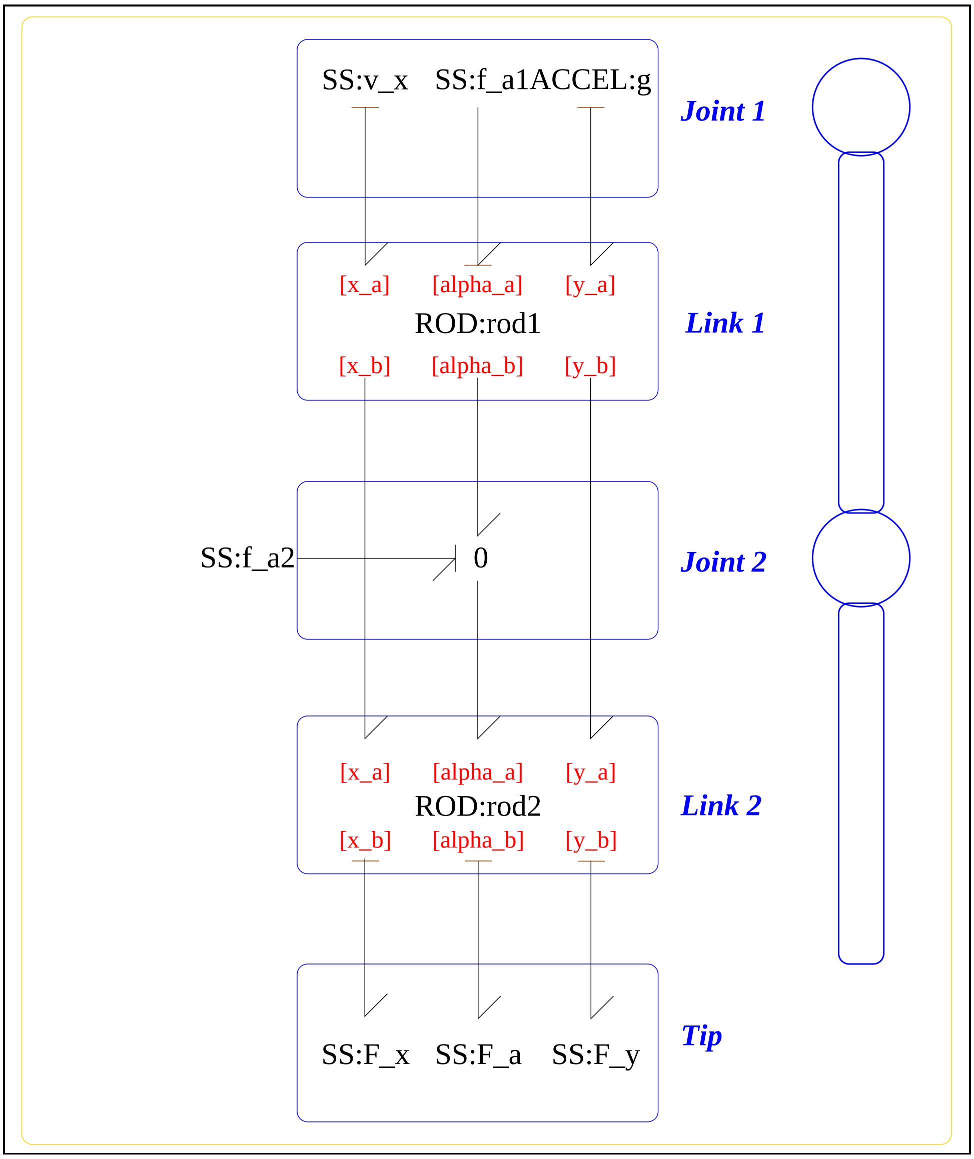

Figure 10.1: System **gTwoLink**: acausal bond graph

ROD is essentially as described in Figure 10.2 GRAV represents gravity by a vertical accelleration as in Section 10.9 of "Metamodelling"

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: gTwoLink_lbl.txt

```
%SUMMARY gTwoLink: two-link manipulator from Section 10.5 of "Metamodell
%DESCRIPTION This is a heirachical version of the
%DESCRIPTION example from Section 10.5 of "Metamodelling".
%DESCRIPTION It uses two compound components: ROD and GRA
%DESCRIPTION ROD is essentially as described in Figure 10.2
%DESCRIPTION GRAV represents gravity by a vertical accelleration
%DESCRIPTION as in Section 10.9 of "Metamodelling"


%% Label (gTwoLink_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: gTwoLink_lbl.txt,v 1.1 2000/12/28 18:03:41 peterg Exp $
% %% $Log: gTwoLink_lbl.txt,v $
% %% Revision 1.1  2000/12/28 18:03:41  peterg
% %% To RCS
% %%
% %% Revision 1.2  1996/12/05  12:39:49  peterg
% %% Documentation
% %%
% %% Revision 1.1  1996/12/05 12:17:15  peterg
% %% Initial revision
```

```
% %%
% %% Revision 1.1  1996/11/14  10:48:42  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

%Rod parameters - identical rods
rod1 none l;l;j;m;mg
rod2 none l;l;j;m;mg

%Zero velocity sources
v_x SS     internal,0


%Zero force/torque sources
F_x SS    0,internal
F_a SS    0,internal
F_y SS    0,internal


%Torque at joints
f_a1 SS external,external
f_a2 SS external,external

%Gravity
g
```

10.1.2 Subsystems

- ACCEL: Provides a acceleration (useful for simulating gravity. (1) No subsystems.
- ROD: rigid rod in two dimensions (2)
  - INTF: flow integrator (1)

10.1.3 ACCEL

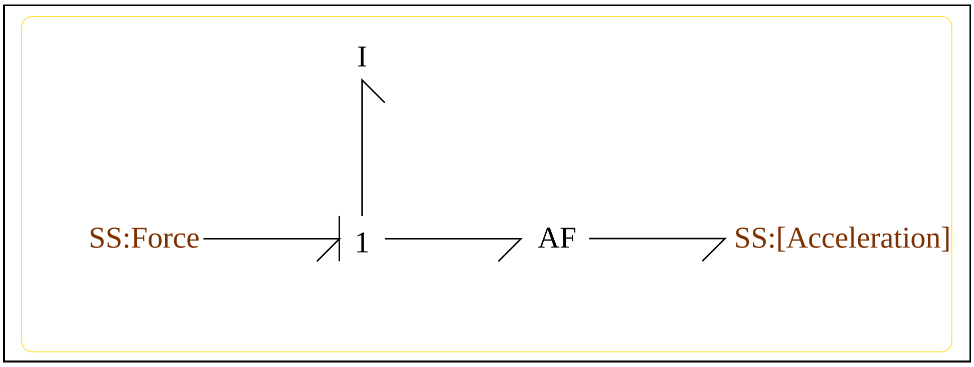

Figure 10.2: System **ACCEL**: acausal bond graph

The acausal bond graph of system **ACCEL** is displayed in Figure 10.2 (on page 171) and its label file is listed in Section 10.1.3 (on page 171). The subsystems are listed in Section 10.1.3 (on page 173).

Summary information

System ACCEL::Provides a acceleration (useful for simulating gravity. Useful for simulating gravity as explaned in Section 10.9 of ”Metamodelling”.

Interface information:

Port in represents actual port **Acceleration**

Port out represents actual port **Acceleration**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ACCEL_lbl.txt

```
%SUMMARY ACCEL: Provides a acceleration (useful for simulating gra
%DESCRIPTION Useful for simulating gravity as explaned in Section
%DESCRIPTION of "Metamodelling".

%ALIAS in|out Acceleration

%% Label file for system ACCEL (ACCEL_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ACCEL_lbl.txt,v 1.4 1998/07/27 20:33:17 peterg Exp $
% %% $Log: ACCEL_lbl.txt,v $
% %% Revision 1.4  1998/07/27 20:33:17  peterg
% %% Aliases
% %%
% %% Revision 1.3  1998/07/27 06:50:41  peterg
% %% *** empty log message ***
% %%
% %% Revision 1.2  1998/07/27 06:49:57  peterg
% %% Added blank line at end
% %%
% %% Revision 1.1  1998/07/27 06:47:32  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

% SS components
Force SS external,internal
[Acceleration] SS external,external
```

Subsystems

No subsystems.

10.1.4 INTF

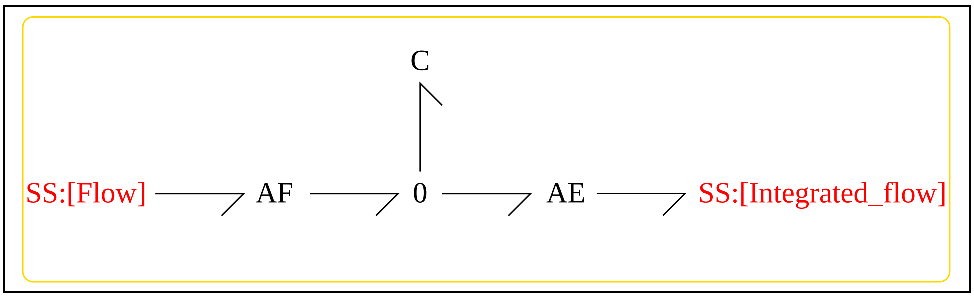

Figure 10.3: System **INTF**: acausal bond graph

The acausal bond graph of system **INTF** is displayed in Figure 10.3 (on page 173) and its label file is listed in Section 10.1.4 (on page 173). The subsystems are listed in Section 10.1.4 (on page 174).
INTF is a two-port component where the effort on port [out] is the integral of the flow on port [in].

Summary information

System INTF::flow integrator Port [in]: Flow to be integrated Port [out]: Effort = integral of flow on port [in]

Interface information:

Port in represents actual port **Flow**

Port out represents actual port **Integrated_flow**

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: INTF_lbl.txt

```
%% Label file for system INTF (INTF_lbl.txt)
%SUMMARY INTF: flow integrator
%DESCRIPTION Port [in]: Flow to be integrated
%DESCRIPTION Port [out]: Effort = integral of flow on port [in]


% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: INTF_lbl.txt,v 1.3 1998/07/16 07:35:10 peterg Exp $
% %% $Log: INTF_lbl.txt,v $
% %% Revision 1.3  1998/07/16 07:35:10  peterg
% %% Aliased version
% %%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Port aliases
%ALIAS in Flow
%ALIAS out Integrated_flow

% Argument aliases

%% 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
[Flow] SS external,external
[Integrated_flow] SS external,external
```

Subsystems

No subsystems.

10.1.5 ROD

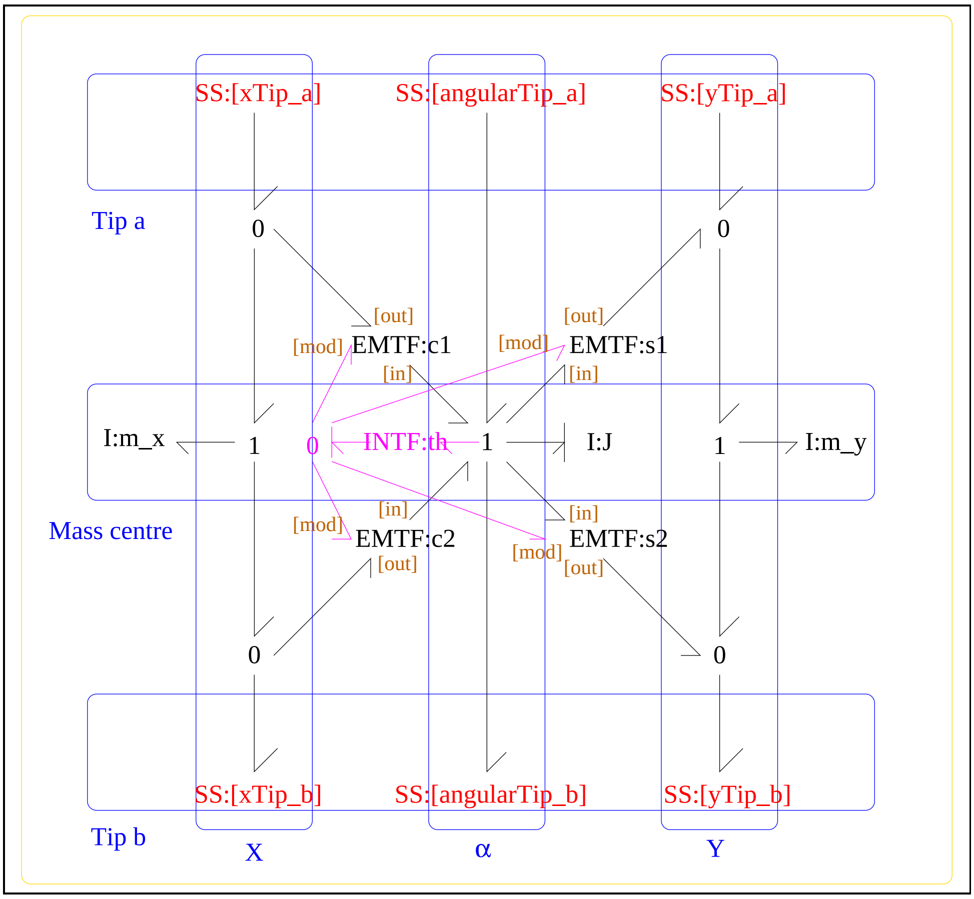

Figure 10.4: System **ROD**: acausal bond graph

The acausal bond graph of system **ROD** is displayed in Figure 10.4 (on page 175) and its label file is listed in Section 10.1.5 (on page 175). The subsystems are listed in Section 10.1.5 (on page 178).

ROD is essentially as described in Figure 10.2 of “Metamodelling”.

Summary information

System ROD::rigid rod in two dimensions See Section 10.2 of ”Metamodelling”

Interface information:

Component INTF is in library **General/INTF** – The flow integration component.

Parameter $1 represents actual parameter **l_a** – length from end a to mass centre

Parameter $2 represents actual parameter **l_b** – length from end b to mass centre

Parameter $3 represents actual parameter **j_m** – inertia about mass centre

Parameter $4 represents actual parameter **m** – mass

Port Tip_a represents actual port **xTip_a,angularTip_a,yTip_a**

Port Tip_b represents actual port **xTip_b,angularTip_b,yTip_b**

Port alpha_a represents actual port **angularTip_a** – Torque/angular velocity at tip a

Port alpha_b represents actual port **angularTip_b** – Torque/angular velocity at tip b

Port in represents actual port **xTip_a,angularTip_a,yTip_a**

Port out represents actual port **xTip_b,angularTip_b,yTip_b**

Port x_a represents actual port **xTip_a** – Force/velocity at tip a in x direction

Port x_b represents actual port **xTip_b** – Force/velocity at tip b in x direction

Port y_a represents actual port **yTip_a** – Force/velocity at tip a in y direction

Port y_b represents actual port **yTip_b** – Force/velocity at tip b in y direction

Variable declarations:

This component has no PAR declarations

Units declarations:

This component has no UNITs declarations

The label file: ROD_lbl.txt

```
%SUMMARY ROD: rigid rod in two dimensions
%DESCRIPTION See Section 10.2 of "Metamodelling"

%ALIAS $1 l_a # length from end a to mass centre
%ALIAS $2 l_b # length from end b to mass centre
%ALIAS $3 j_m # inertia about mass centre
%ALIAS $4 m # mass

%ALIAS in|Tip_a xTip_a,angularTip_a,yTip_a
%ALIAS out|Tip_b xTip_b,angularTip_b,yTip_b

%ALIAS x_a xTip_a # Force/velocity at tip a in x direction
%ALIAS y_a yTip_a # Force/velocity at tip a in y direction
%ALIAS alpha_a angularTip_a # Torque/angular velocity at tip a

%ALIAS x_b xTip_b # Force/velocity at tip b in x direction
%ALIAS y_b yTip_b # Force/velocity at tip b in y direction
%ALIAS alpha_b angularTip_b # Torque/angular velocity at tip b

%ALIAS INTF General/INTF # The flow integration component.

%% Label file for system ROD (ROD_lbl.txt)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% Version control history
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %% $Id: ROD_lbl.txt,v 1.5 1998/07/27 12:27:27 peterg Exp $
% %% $Log: ROD_lbl.txt,v $
% %% Revision 1.5  1998/07/27 12:27:27  peterg
% %% Added vector port aliases
% %%
% %% Revision 1.4  1998/07/27 10:51:20  peterg
% %% Aliased INTF as well.
% %%
% %% Revision 1.3  1998/07/27 10:49:10  peterg
% %% Major revision to include aliases etc
% %%
% %% Revision 1.2  1997/08/15  09:43:06  peterg
% %% Now has lablelled (as opposed to numbered) ports.
```

```
% %%
% Revision 1.1  1996/11/07  10:57:17  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

%Inertias
J lin flow,j_m
m_x lin flow,m
m_y lin flow,m

%Integrate angular velocity to get angle
th

%Modulated transformers
s1 lsin flow,l_a
s2 lsin flow,l_b
c1 lcos flow,l_a
c2 lcos flow,l_b

% Component type SS
[angularTip_a] SS external,external
[angularTip_b] SS external,external
[xTip_a] SS external,external
[xTip_b] SS external,external
[yTip_a] SS external,external
[yTip_b] SS external,external
```

Subsystems

- INTF: flow integrator (1) No subsystems.

10.2 gTwoLink_struc.tex

MTT command:

```
mtt gTwoLink struc tex
```

List of inputs for system gTwoLink			
	Component	System	Repetition
1	f_a1	gTwoLink__f_a1	1
2	f_a2	gTwoLink__f_a2	1
3	Force	gTwoLink__g__Force	1

List of nonstates for system gTwoLink			
	Component	System	Repetition
1	m_x	gTwoLink__rod1__m_x	1
2	m_y	gTwoLink__rod1__m_y	1
3	m_x	gTwoLink__rod2__m_x	1
4	m_y	gTwoLink__rod2__m_y	1

List of outputs for system gTwoLink			
	Component	System	Repetition
1	f_a1	gTwoLink__f_a1	1
2	f_a2	gTwoLink__f_a2	1

List of states for system gTwoLink			
	Component	System	Repetition
1	J	gTwoLink__rod1__J	1
2	mttC	gTwoLink__rod1__th__mttC	1
3	J	gTwoLink__rod2__J	1
4	mttC	gTwoLink__rod2__th__mttC	1
5	mttI	gTwoLink__g__mttI	1

10.3 gTwoLink_sympar.tex

MTT command:

```
mtt gTwoLink sympar tex
```

Parameter	System
j	gTwoLink
l	gTwoLink
m	gTwoLink
mg	gTwoLink

Table 10.1: Parameters

10.4 gTwoLink_dae.tex

MTT command:

```
mtt gTwoLink dae tex
```

$$
\begin{aligned}
\dot{x}_1 &= \cos(x_2) l \dot{z}_1 + 2\cos(x_2) l \dot{z}_3 - \sin(x_2) l \dot{z}_2 - 2\sin(x_2) l \dot{z}_4 + u_1 - u_2 \\
\dot{x}_2 &= \frac{x_1}{j} \\
\dot{x}_3 &= \cos(x_4) l \dot{z}_3 - \sin(x_4) l \dot{z}_4 + u_2 \\
\dot{x}_4 &= \frac{x_3}{j} \\
\dot{x}_5 &= u_3
\end{aligned}
\tag{10.1}
$$

$$
\begin{aligned}
z_1 &= \frac{(-\cos(x_2) l m x_1)}{j} \\
z_2 &= \frac{(m(\sin(x_2) l x_1 + j x_5))}{j} \\
z_3 &= \frac{(l m(-2\cos(x_2) x_1 - \cos(x_4) x_3))}{j} \\
z_4 &= \frac{(m(2\sin(x_2) l x_1 + \sin(x_4) l x_3 + j x_5))}{j}
\end{aligned}
\tag{10.2}
$$

$$
\begin{aligned}
y_1 &= \frac{x_1}{j} \\
y_2 &= \frac{(-x_1 + x_3)}{j}
\end{aligned}
\tag{10.3}
$$

10.5 gTwoLink_cse.tex

MTT command:

```
mtt gTwoLink cse tex
```

$$\dot{\chi}_1 = \frac{\left(2\cos\left(x_2 - x_4\right) j^2 l^2 m u_2 + 2\sin\left(2x_2 - 2x_4\right) l^4 m^2 x_1^2 + \sin\left(x_2 - 2x_4\right) j^2 l^3 m^2 u_3 + 2\sin\left(x_2 - x_4\right) j l^2 m x_3^2 + 2\,\mathrm{s}\ldots\right.}{\left(j(2\cos\left(2x_2 - 2x_4\right) l^4 m^2 - j\ldots\right.} \tag{10.4}$$

$$\dot{\chi}_2 = \frac{x_1}{j} \tag{10.5}$$

$$\dot{\chi}_3 = \frac{\left(2\cos\left(x_2 - x_4\right) j^2 l^2 m u_1 - 2\cos\left(x_2 - x_4\right) j^2 l^2 m u_2 - 2\sin\left(2x_2 - 2x_4\right) l^4 m^2 x_3^2 - 3\sin\left(2x_2 - x_4\right) j^2 l^3 m^2 u_3 - \ldots\right.}{\left(j(2\cos\left(2x_2 - 2x_4\right) l^4 m\ldots\right.} \tag{10.6}$$

$$\dot{\chi}_4 = \frac{x_3}{j} \tag{10.7}$$

$$\dot{\chi}_5 = u_3 \tag{10.8}$$

$$y_1 = \frac{x_1}{j} \tag{10.9}$$

$$y_2 = \frac{\left(-x_1 + x_3\right)}{j} \tag{10.10}$$

$$E = \begin{pmatrix} \frac{\left(j+5l^2 m\right)}{j} & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & \frac{\left(j+l^2 m\right)}{j} & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \tag{10.11}$$

10.6 gTwoLink_input.txt

MTT command:

```
mtt gTwoLink input txt
```

```
# Numerical parameter file (gTwoLink_input.txt)
# Generated by MTT at Fri Jun 13 16:56:09 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: gTwoLink_input.txt,v 1.2 2003/06/11 16:08:46 gawthrop Ex
# %% $Log: gTwoLink_input.txt,v $
# %% Revision 1.2  2003/06/11 16:08:46  gawthrop
# %% Updated examples for latest MTT.
# %%
# %% Revision 1.1  2000/12/28 18:03:41  peterg
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Set the inputs
## Removed by MTT on Wed Jun 11 14:23:00 BST 2003: u(1) =
(t<1.0);
## Removed by MTT on Wed Jun 11 14:23:00 BST 2003: u(2) =
0.0; #
## Removed by MTT on Wed Jun 11 14:23:00 BST 2003: u(3) =
0.0; # gravity
gtwolink__f_a1 = (t<1.0);
gtwolink__f_a2 = 0.0;
gtwolink__g__force = 0.0;
```

10.7 gTwoLink_numpar.txt

MTT command:

```
mtt gTwoLink numpar txt
```

```
# Numerical parameter file (gTwoLink_numpar.txt)
# Generated by MTT at Fri Jun 13 16:39:41 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: gTwoLink_numpar.txt,v 1.2 2003/06/11 16:08:57 gawthrop Exp $
# %% $Log: gTwoLink_numpar.txt,v $
# %% Revision 1.2  2003/06/11 16:08:57  gawthrop
# %% Updated examples for latest MTT.
# %%
# %% Revision 1.1  2000/12/28 18:03:41  peterg
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Parameters
l =  1.0; # Default value
m =  1.0; # Default value
j =  m*l*l/12.0; # Uniform rod

mg = m*9.81;
```

10.8 gTwoLink_odeso.ps *(-ieuler)*

MTT command:

```
mtt -i euler gTwoLink odeso ps
```

This representation is given as Figure 10.5 (on page 184).

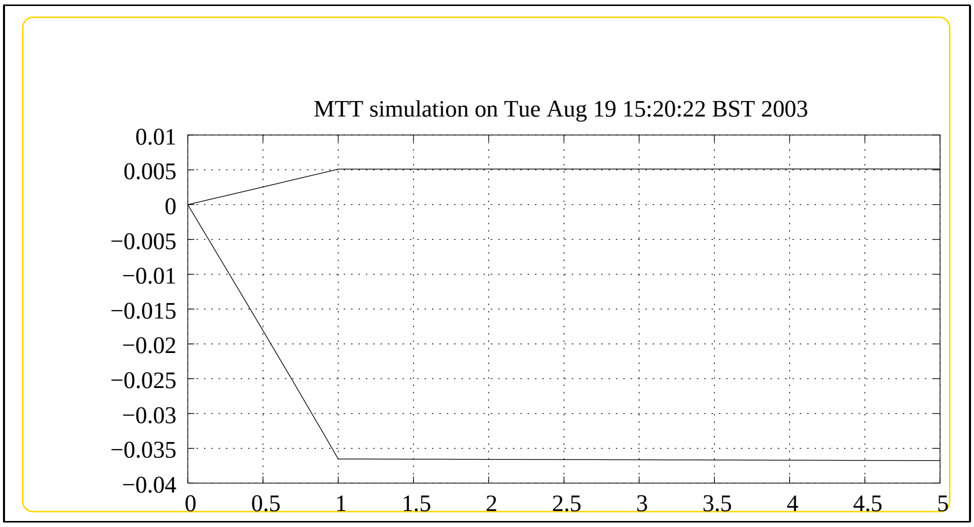

Figure 10.5: System **gTwoLink**, representation odeso (-ieuler)

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