# Python for Control purposes

## Requirements

- Linux machine. For better performances in RT a kernel with preempt-rt patch can be useful, but not mandatory (better latencies in RT!)
- Python 2.7
  - numpy
  - scipy
  - slycot
  - control toolbox (R. Murray)
  - python-qt4 and python-qt4-dev
- pyControlDistro.tgz

## Install the SUPSI control packages

Open a shell and then run

- tar xvfz pyControlDistro.tgz
- Follow the README file to install all the SUPSI packages

## Install gEDAschem

gEDA schem is a open source tool which can be used to draw electronics schemes. It has been modified my adding some blocks required for control purposes (input, output, linear systems, non linear blocks etc.

The followin ackages are required for gEDA package:

- geda
- geda-doc
- geda-gattrib
- geda-gnetlist
- geda-gschem
- geda-gsymcheck
- geda-symbols
- geda-utils

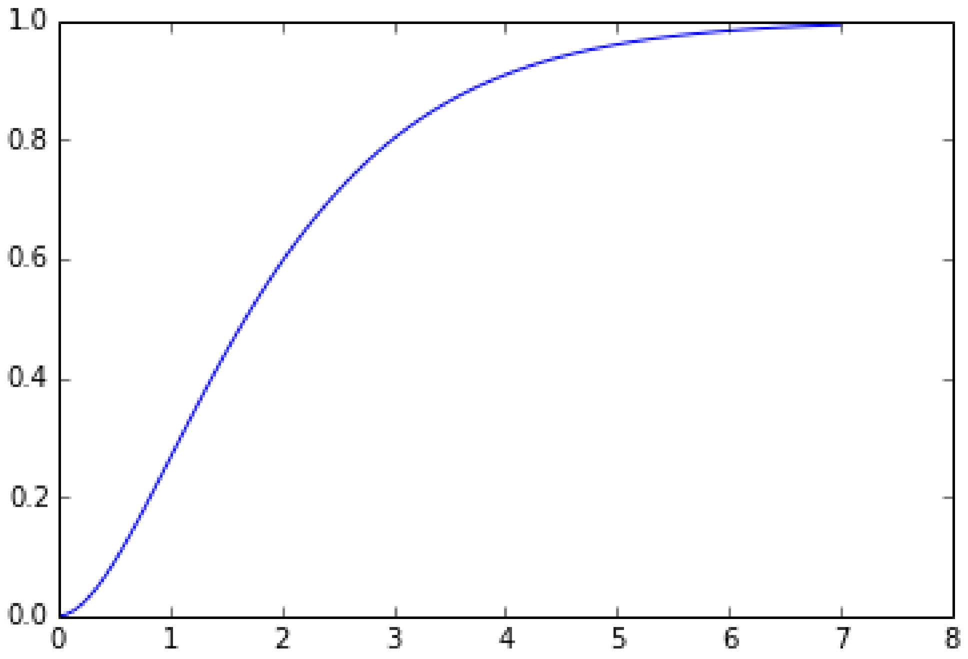
## Hardware

In SUPSI we made the choice to use the CAN bus as general system for our plants in laboratory. In particular we have different plants based on Maxon motors. COMEDI clock are also provided to access a great number of acquisition cards.

## Design of a simulation system

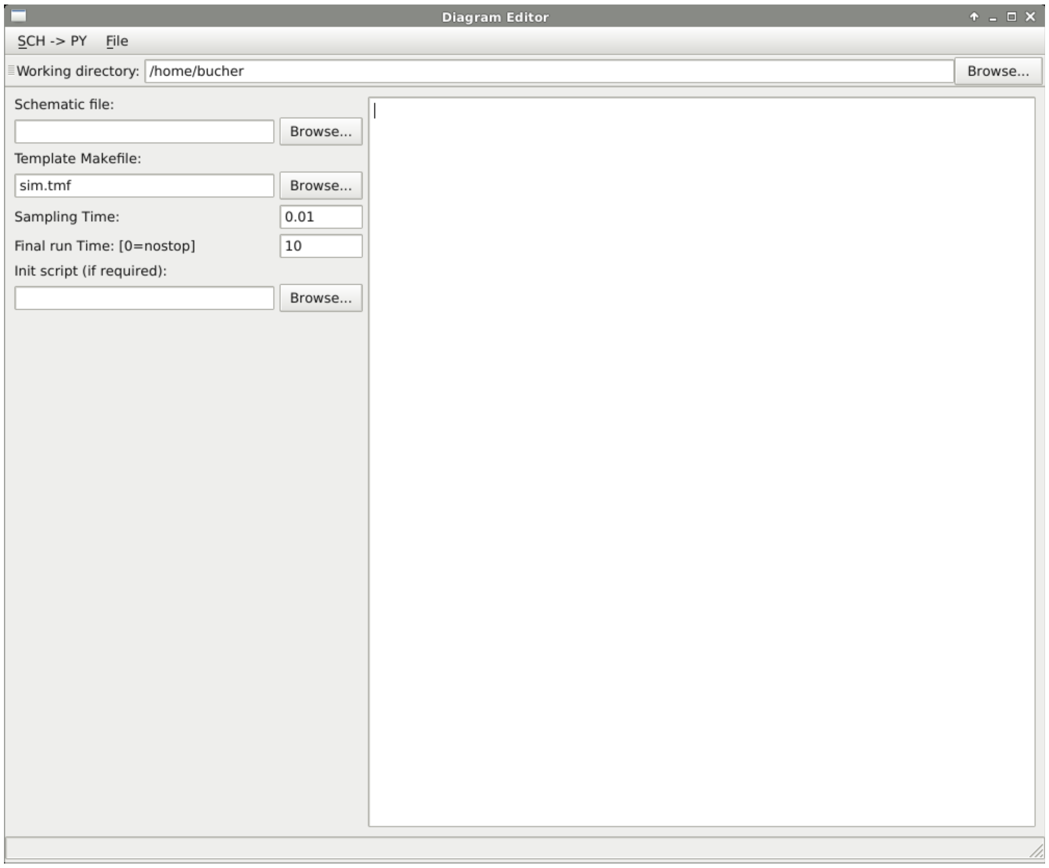
Using the toolbox from Richard Murray we can create some systems using a python script

```
from control import *

g = tf([1],[1,2,0])
print g

    1
---------
s^2 + 2 s

gtot = feedback(g,1)
print gtot

      1
-------------
s^2 + 2 s + 1

y,t=step(gtot)
plot(t,y)
```



## The pyCodeGenCenter application

This is a Qt application allowing to perform different tasks



Working directory: /home/bucher
Schematic file:
Template Makefile: sim.tmf
Sampling Time: 0.01
Final run Time: [0=nostop] 10
Init script (if required):

Under the menu “SCH → PY” we have the following choices

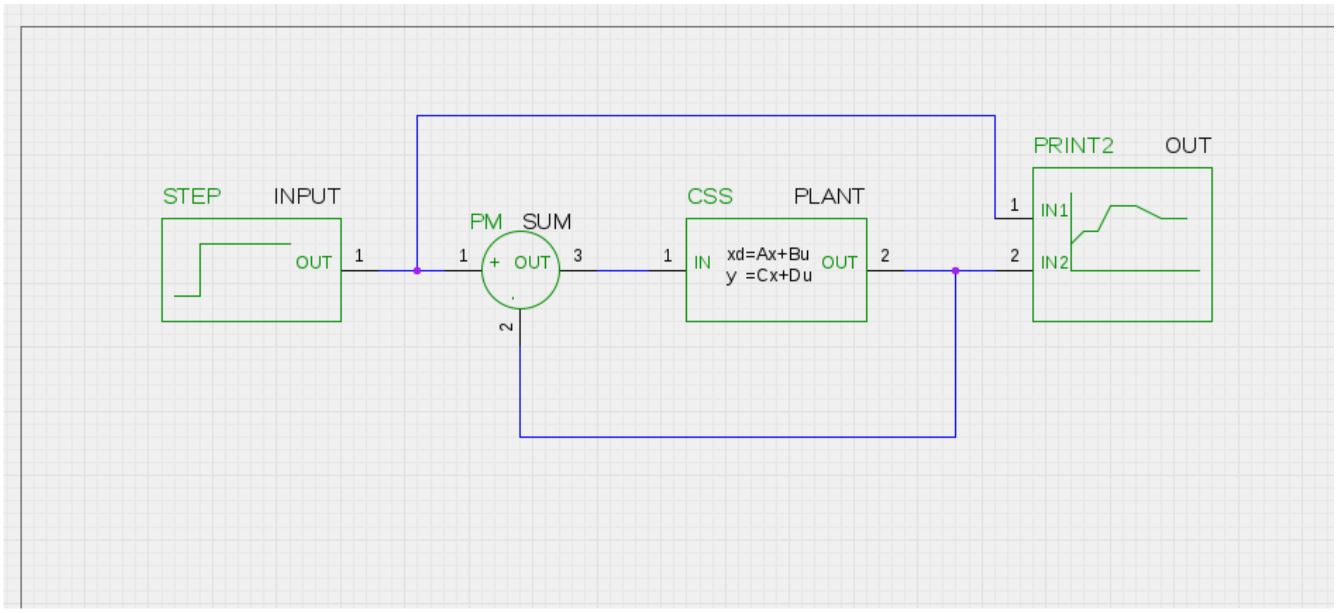
1. open geda schem: open the gEDA schem application (if a sch is defined it will be open)
2. open geda attrib: allows changing the parameters of the block diagram using the pyAttrib application
3. Code generation: generate the code starting from the schematic and the python initialisation script
4. run: launch the generated executable (using the pySim application)
5. stop: stop the “run” and if possible, plot the results

Under the menu “File” we have the following choices

1. Open CGF file: Open a predefined configuration for the pyCodegen application (extension “.cgf”)
2. Save CGF file: Save the defined configuration
3. Open  python script: Open a python script into the editor window
4. Save python script: Save the editor window as python script

## Creating a block diagra

Open the gEDA editor using the menu “gEDA schem”. It is possible to use the control blocks to create a block diagram as shown in the next figure



It is important to chenge the names of the blocks (for example B?) by clicking on it with the mouse.

In particular we can change

- I? to INPUT
- B? to SUM
- B? to PLANT
- O? to OUT

as showed in the previous figure.

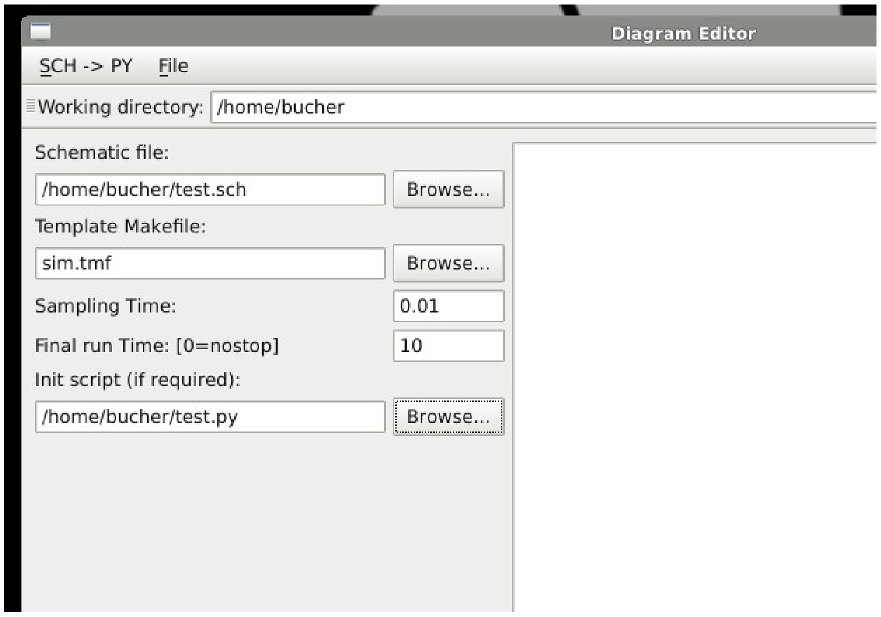
This block diagram can be saved for example under the name “test.sch”.

## Generating the code

Before launching the code generation we have to provide the name of the block diagram (“test.sch”), the name of the template Makefile with the corrected instructions to generate the executable (sim.tmf, or rt.tmf for rt code generation) and, if required, the name of python script containig the initialisation of the blocks. We can modify the sampling time and the final time (0 is no stop).

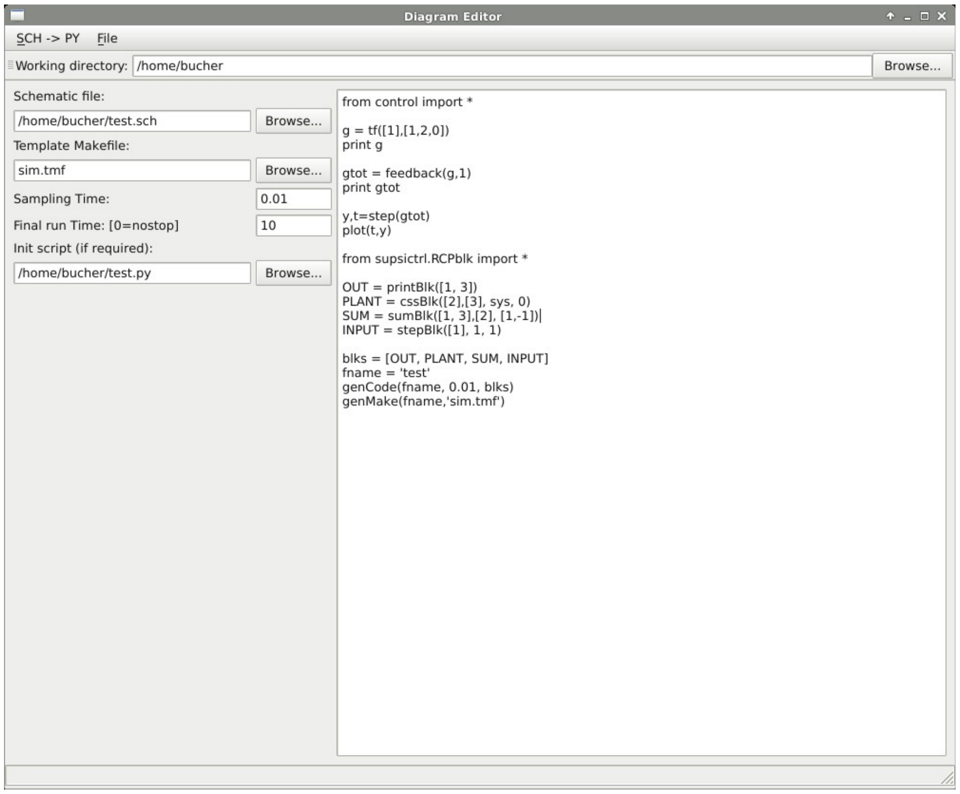
Our script in this case only create the PLANT transfer function

```
from control import *

g = tf([1],[1,2,0])
print g

    1
---------
s^2 + 2 s
```



Working directory: /home/bucher
Schematic file: /home/bucher/test.sch
Template Makefile: sim.tmf
Sampling Time: 0.01
Final run Time: [0=nostop] 10
Init script (if required): /home/bucher/test.py

Now we are ready to launch the command “Code Generation” (translate the block diagram first into RCPBlocks, and then generate C-code from the block sequence). This command fills the editor window with a python script performing the initialisation and the required commands for code generation.

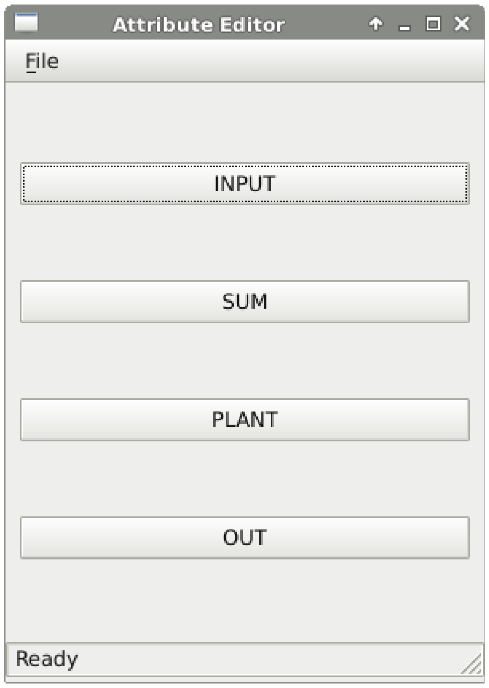


Working directory: /home/bucher
Schematic file: /home/bucher/test.sch
Template Makefile: sim.tmf
Sampling Time: 0.01
Final run Time: [0=nostop] 10
Init script (if required): /home/bucher/test.py

```
from control import *

g = tf([1],[1,2,0])
print g

gtot = feedback(g,1)
print gtot

y,t=step(gtot)
plot(t,y)

from supsictrl.RCPblk import *

OUT = printBlk([1, 3])
PLANT = cssBlk([2],[3], sys, 0)
SUM = sumBlk([1, 3],[2], [1,-1])
INPUT = stepBlk([1], 1, 1)

blks = [OUT, PLANT, SUM, INPUT]
fname = 'test'
genCode(fname, 0.01, blks)
genMake(fname,'sim.tmf')
```

## Modify the blocks Parameters

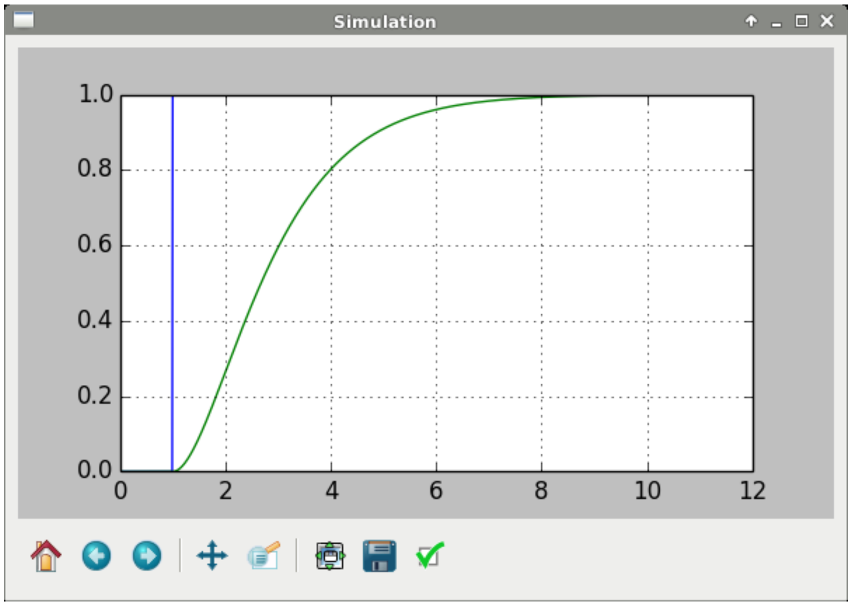
Before generating the code there is the possibility to modify the blocks parameters using the menu "SCH->PY, pyAttrib". A window is open allowing to change the parameters of each block.



Con l'utilizzo del menu "gEDA attrib" si apre il file "test.sch" e si modifica gli attributi dei blocchi, in particolare il nome del systema nel blocco CSS da "sys" a "g"

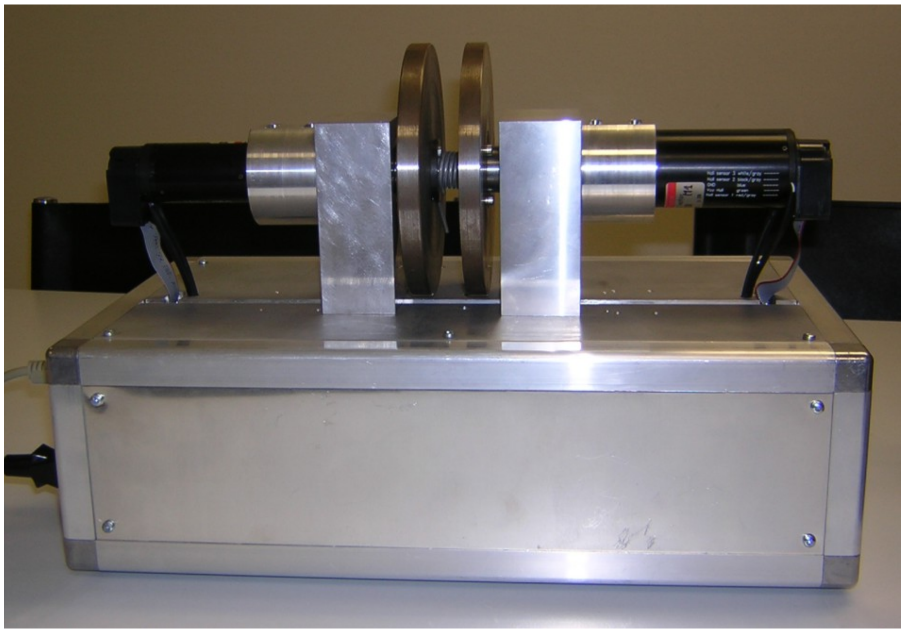
## Launch the simulation

From menu "SCH->PY" we can now launch the simulation ("->Run") which is performed using the utility "pySim"



## A RT system

### *The plant*



This plant is used in SUPSI to teach State feedback control of MIMO systems. The idea is to move the disk on the right using the motor on the left. The two disks are connected through a spring.

### *Control of the plant*

The design of the controller is perfomed using the Control System Toolbox from Richard Murray and additional functions developed at SUPSI (saved as “disks.py”).

```
 from supsictrl.yottalab import *
from scipy import zeros
import numpy as np
import scipy as sp
import matplotlib.pyplot as plt
import matplotlib.image as mpimg
from control import *
from control.matlab import *


# Plant
img = mpimg.imread('disks.jpg')
```

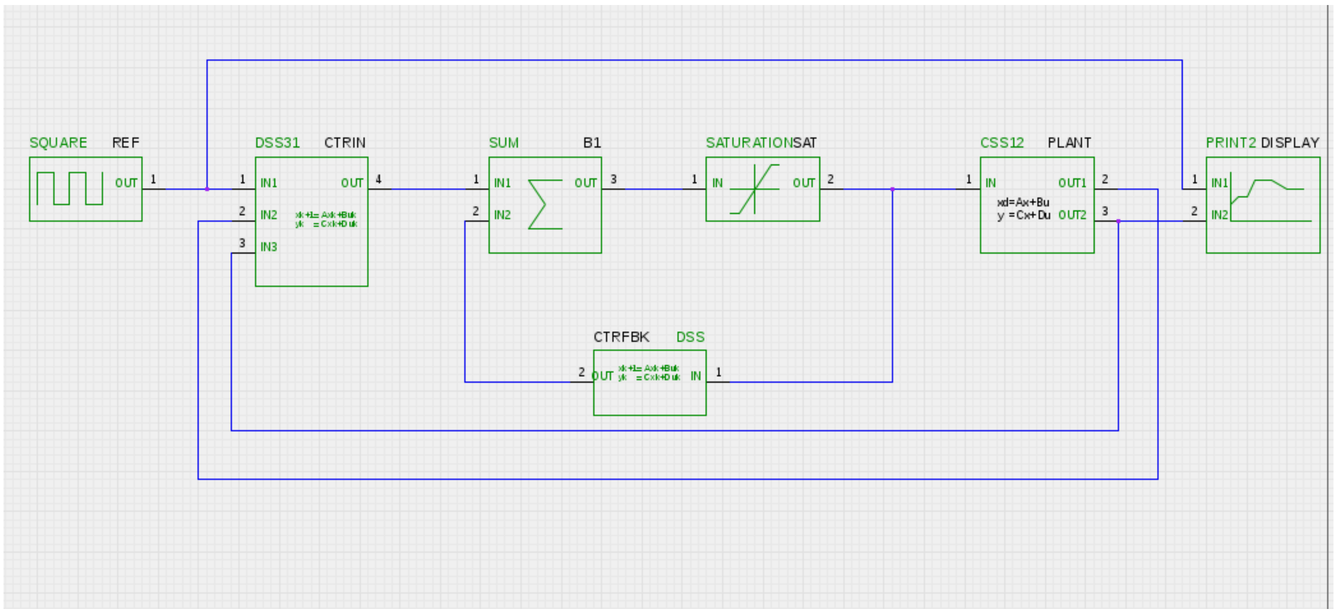
```
plt.imshow(img)
show()

# Motore 1
jm1 = 0.0000085  # inerzia [kg*m2]
kt1 = 0.0000382  # constante di coppia [Nm/mA] per la centralina al posto di [Nm/A]

# Volano motore 1
rho_ac = 7900  # densita alluminio [g/m3]
rv1 = 0.065    # raggio [m]
hv1 = 0.01     # spessore [m]
mv1 = ((rho_ac*(rv1**2))*np.pi)*hv1   # massa [kg]
jv1 = (mv1*(rv1**2))/2   # inerzia [kg*m2]
theta1 = jv1+jm1   # inerzia totale [kg*m2]

# Motore 2
jm2 = 0.000003   # inerzia [kg*m2]
kt2 = 0.0000205  # constante di coppia [Nm/mA] per la centralina al posto di [Nm/A]

# Volano motore 2
rho_ac = 7900   # densita acciao [kg/m3]
rv2 = 0.065     # raggio [m]
hv2 = 0.01      # spessore [m]
mv2 = ((rho_ac*(rv2**2))*np.pi)*hv2   # massa [kg]
jv2 = (mv2*(rv2**2))/2              # inerzia [kg*m2]
theta2 = jv2+jm2                   # inerzia totale [km*m2]

# Molla                    (frequenza d''oscillazione di 2 Hz)
d = 0.0027836   # attrito molla (smorzamento)
c = 0.4797954
d1 = 0.0002953
d2 = 0.0004001

# Plant in SS form
```

```
A = [[0, 1, 0, 0], \
    [-c/theta1, -(d1+d)/theta1, -c/theta1, -d/theta1], \
    [0, 0, 0, 1], \
    [-c/theta2, -d/theta2, -c/theta2, -(d2+d)/theta2]]

B = [[0], \
    [kt1/theta1], \
    [0], \
    [0]]

C = [[1,0,0,0],[0,0, 1, 0]]
C2 = [0,0,1,0]
D = [[0],[0]]
D2 = [0]

ts = 10e-3

gss1 = ss(A,B,C,D)
gss = ss(A,B,C2,D2)
gz = c2d(gss,ts,'zoh')

# Control design
wn = 10
xi1 = np.sqrt(2)/2
xi2 = 0.85

cl_p1 = [1,2*xi1*wn,wn**2]
cl_p2 = [1,2*xi2*wn,wn**2]
cl_p3 = [1,wn]
cl_poly1 = sp.polymul(cl_p1,cl_p2)
cl_poly = sp.polymul(cl_poly1,cl_p3)
cl_poles = sp.roots(cl_poly)   # Desired continous poles
cl_polesd = sp.exp(cl_poles*ts)  # Desired discrete poles
```

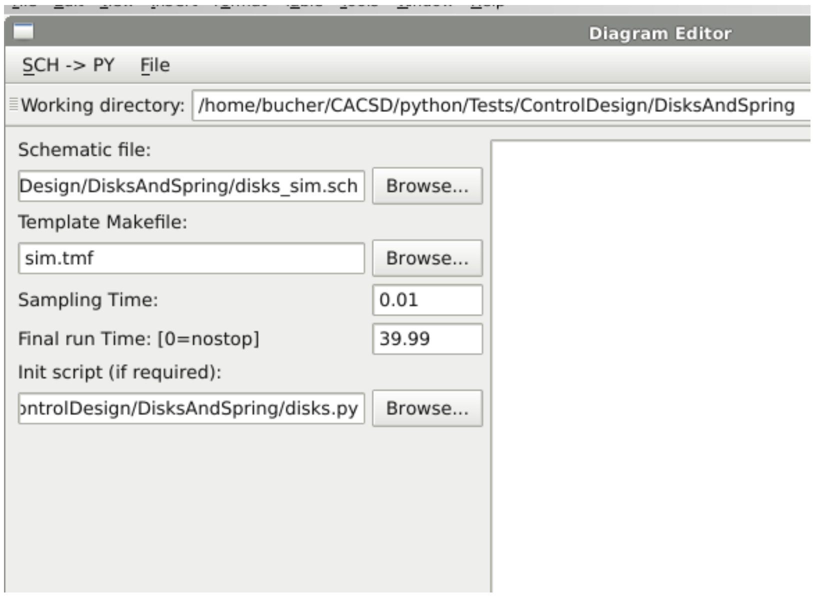
```
# Add discrete integrator for steady state zero error
Phi_f = np.vstack((gz.A,-gz.C*ts))
Phi_f = np.hstack((Phi_f,[[0],[0],[0],[0],[1]]))
G_f = np.vstack((gz.B,zeros((1,1))))

# Pole placement
k = placep(Phi_f,G_f,cl_polesd)

# Observer design - reduced order observer
poli_o = 5*cl_poles[0:2]
poli_oz = sp.exp(poli_o*ts)

disks = ss(A,B,C,D)
disksz = StateSpace(gz.A,gz.B,C,D,ts)
T = [[0,1,0,0],[0,0,0,1]]
r_obs = red_obs(disksz ,T, poli_oz)

# Controller and observer in the same matrix -  Compact form
contr_I = comp_form_i(disksz,r_obs,k,ts,[0,1])

# Implement anti windup
[gss_in,gss_out] = set_aw(contr_I,[0.1,0.1,0.1])
```

## *Simulation*

This is the gEDA block diagram for simulation



and this is the pyCodegenCenter window for the simulation



Working directory: /home/bucher/CACSD/python/Tests/ControlDesign/DisksAndSpring

Schematic file: Design/DisksAndSpring/disks_sim.sch

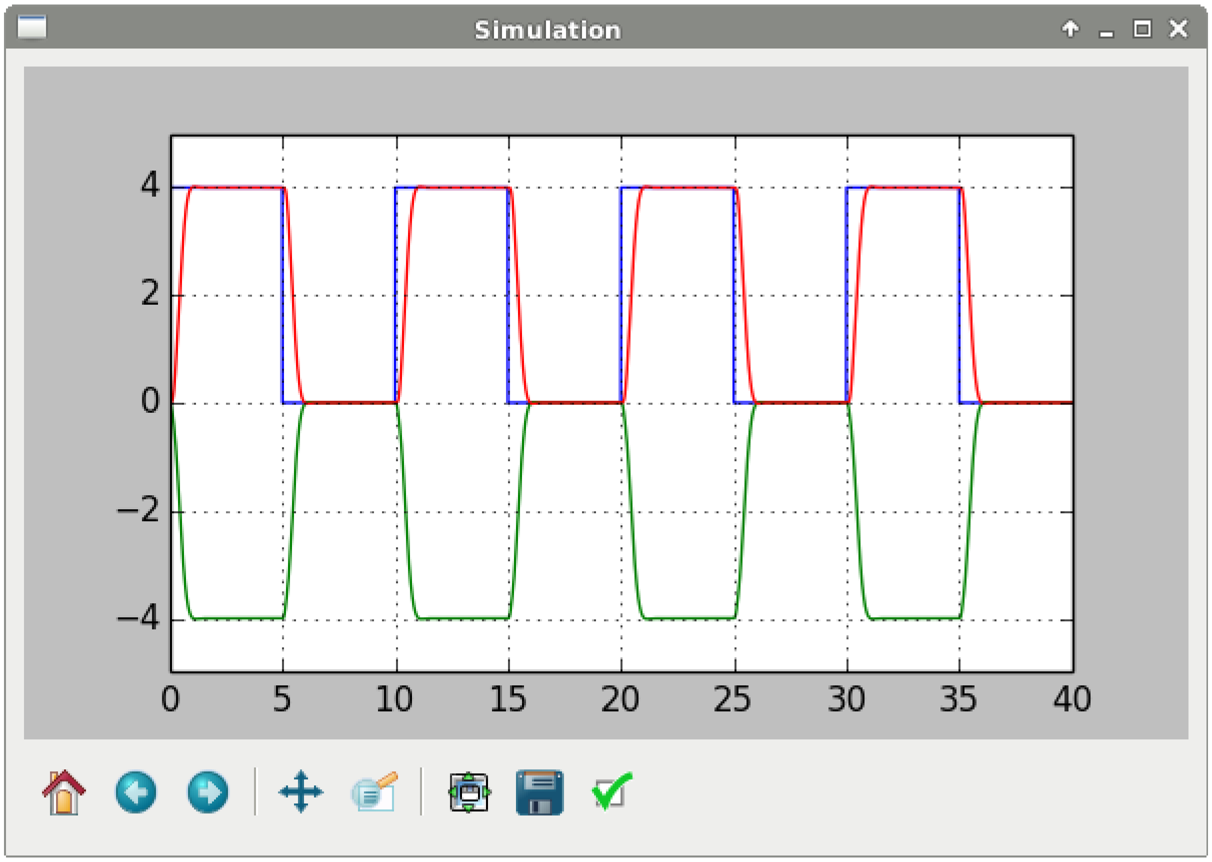
Template Makefile: sim.tmf

Sampling Time: 0.01

Final run Time: [0=nostop] 39.99

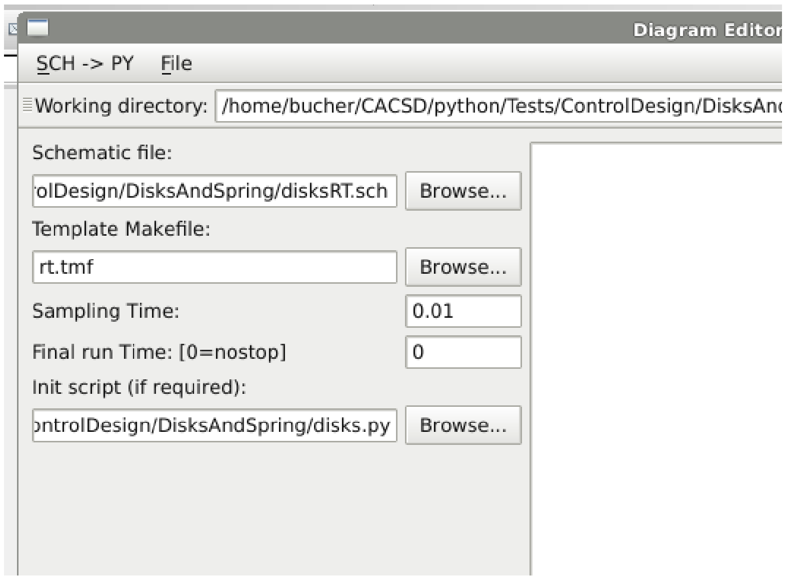
Init script (if required): ›ntrolDesign/DisksAndSpring/disks.py

The next figure shows the result of the simulation



## *RT executable*

In order to obtain the RT executable we have to change the block diagram and the template makefile (“rt.tmf”).



Working directory: /home/bucher/CACSD/python/Tests/ControlDesign/DisksAn

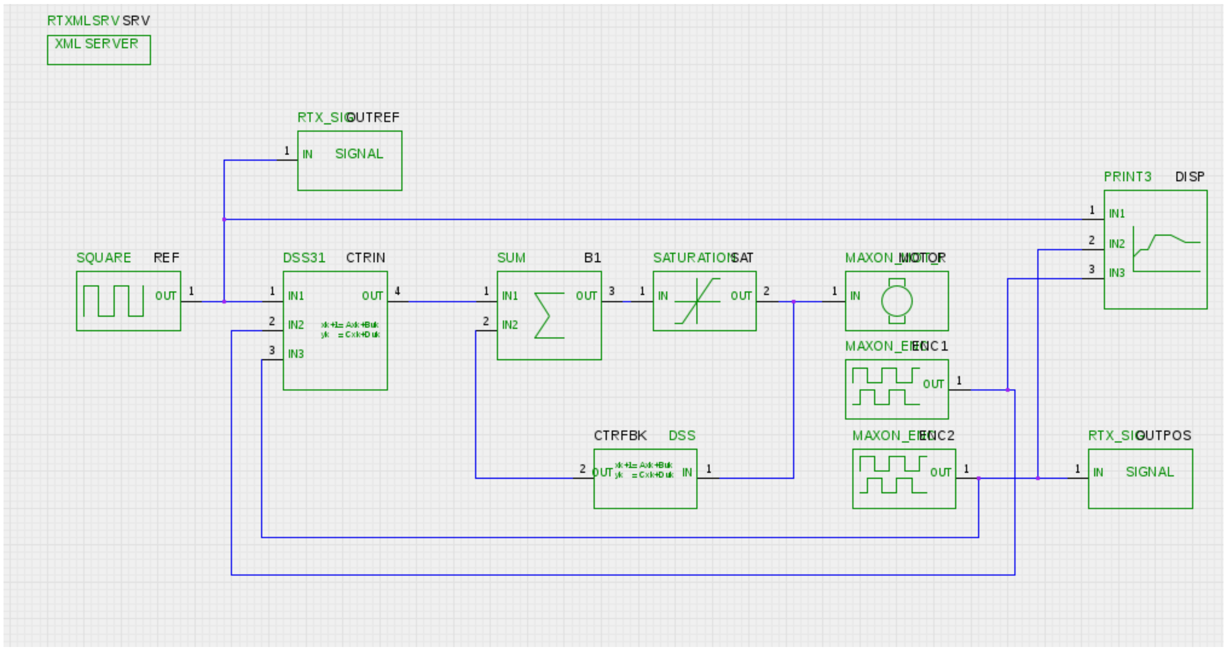
Schematic file: olDesign/DisksAndSpring/disksRT.sch

Template Makefile: rt.tmf

Sampling Time: 0.01

Final run Time: [0=nostop] 0

Init script (if required): ontrolDesign/DisksAndSpring/disks.py



## About code generation

The translation of the gEDA schematic into C-code is performed in two steps:

1. The gEDA schem is translated into a pspice netlist using the provide gEDA netlist application.
2. The netlist is translated into a RCPblk block, a python class provided by supsictrl.RCPblk using a a function defined in the same library

The RCPblk class is described as following

```
class RCPblk:
    def __init__(self, *args):
        if len(args) == 8:
            (fcn,pin,pout,nx,uy,realPar,intPar,str) = args
        elif len(args) == 7:
            (fcn,pin,pout,nx,uy,realPar,intPar) = args
            str=''
        else:
            raise ValueError("Needs 6 or 7 arguments; received %i." % len(args))

        self.fcn = fcn
        self.pin = mat(pin)
        self.pout = mat(pout)
        self.nx = array(nx)
        self.uy = array(uy)
        self.realPar = array(realPar)
        self.intPar = array(intPar)
        self.str = str

    def __str__(self):
        """String representation of the Block"""
        str =  "Function           : " + self.fcn.__str__() + "\n"
        str += "Input ports        : " + self.pin.__str__() + "\n"
        str += "Outputs ports      : " + self.pout.__str__() + "\n"
        str += "Nr. of states      : " + self.nx.__str__() + "\n"
        str += "Relation u->y      : " + self.uy.__str__() + "\n"
        str += "Real parameters    : " + self.realPar.__str__() + "\n"
        str += "Integer parameters : " + self.intPar.__str__() + "\n"
        str += "String Parameter   : " + self.str.__str__() + "\n"
        return str
```

The fields contain all the information nedded to generate the C-Code

- fcn is the name of the function to be called to execute the code associated with the block
- pin is a vector containing the input port identifiers
- pout is a vector containing the output port identifiers
- nx is a vector containg the number of continous and discrete states of the block
- uy is a int value (0 or 1) definig if there is a direct feedforward between input and output
- realPar is a vector containing the real parameters of the block
- intPar is a vector containing the integer parameters of the block
- str is a string parameters

Starting from the blocks list, the function “genCode” first analyze the topology of the schema tin order to find the right sequence of blocks. This first operation fails if algebric loops are found. Otherwise the function continues defining 3 functions:

- Initialization function
- ISR functions
- Terminating function

The generated code can be easily integrated into a RT environment. A “main” for the Linux preempt-rt system is provided. The compiling and link operations are handled by the Template Makefile (provided are “sim.tmf” and “rt.tmf”). For each block, a function is programmed under “Codegen/devices” and the object code is stored into the “libpyblk.a” library.