Design and simulation of switched mode power supplies with ScicosLab/Scicos

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Scopes

How to use digital control technology to improve switched mode power supplies replacing classic analog PID controllers. Validate the controller using ScicosLab/Scicos simulations for DSP implementation using automatic code generators.

Outline:

- *Mathematical models*
- *Controller design*
- *Simulation*
- *Code generation.*

Switched mode power supply

A power supply is an electronic circuit capable to realize a "perfect" (stabilized and controlled) voltage/current source from a generic "imperfect" (not stabilized) primary power source. Latest generation integrated circuits need very stabilized and precise sources with narrow tolerances (1% or better).

There are two typologies of power supplies :

- ***Linear power supplies (dissipative).***
- ***Switch-mode power supplies (conservative).***

Main characteristics:

*- **linear** = bulky (size and weight), average efficiency of 50%, electronic circuits working in linear regime, low ripple;*

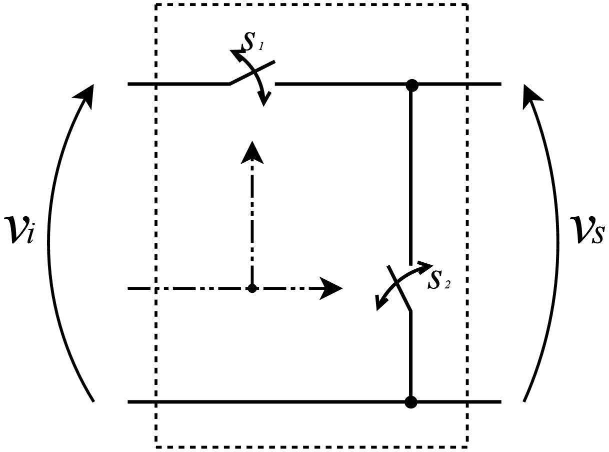
*- **switch mode** = compact (reduced size and weight), high efficiency (80% or better), non linear circuits (switches), ripple not negligible.*

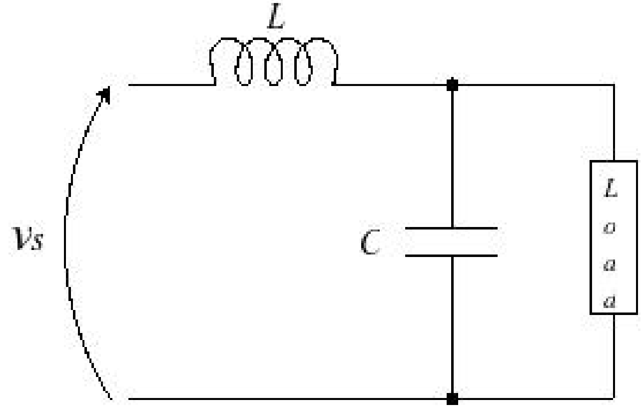
Switched mode power supplies

Usually SMPS are positioned between a non-stabilized voltage source and a load that needs precise and stabilized voltage or current.

SMPS are composed of two stages:

- *The chopper*
- *The filter*





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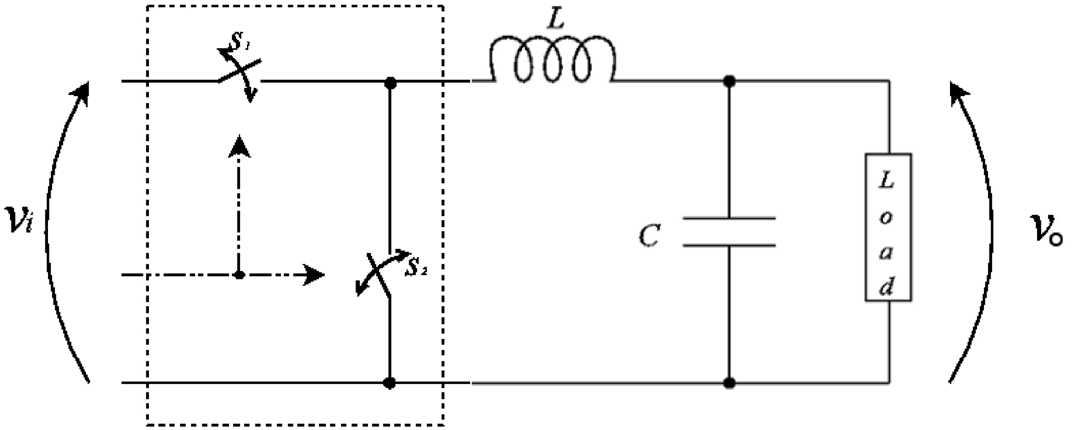

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The average voltage output is proportional to the open/close ratio (duty-cycle) of the switches.

Technical requirements:

- *commutation frequency of the switches;*
- *maximum voltage output ripple;*
- *maximum inductor current ripple;*
- *precision of the output voltage.*

The specifications allow the dimensioning of the energy storage components (inductors and capacitors) and the stresses on the active devices (switches).

Linearisation techniques

We need to find a linear model of the non-linear system working around a fixed operating point "good enough" for designing the linear controller.

We have used two methods:

- ***Equivalent circuits***
- ***State space averaging***

- ***Equivalent circuits linearisation***

Starting with the topological characteristics of the power circuit, the non-linear elements are replaced by linear equivalents (with values computed around the operating point).

From the new circuits a transfer function is computed.

We have decided not to use this method because it is difficult to implement it in a fully automatic way.

- ***State space averaging***

For each configuration of the active switches present in the circuit, we can write a state space linear representation. The final state space equations are a weighted average of the previously computed state space representations.

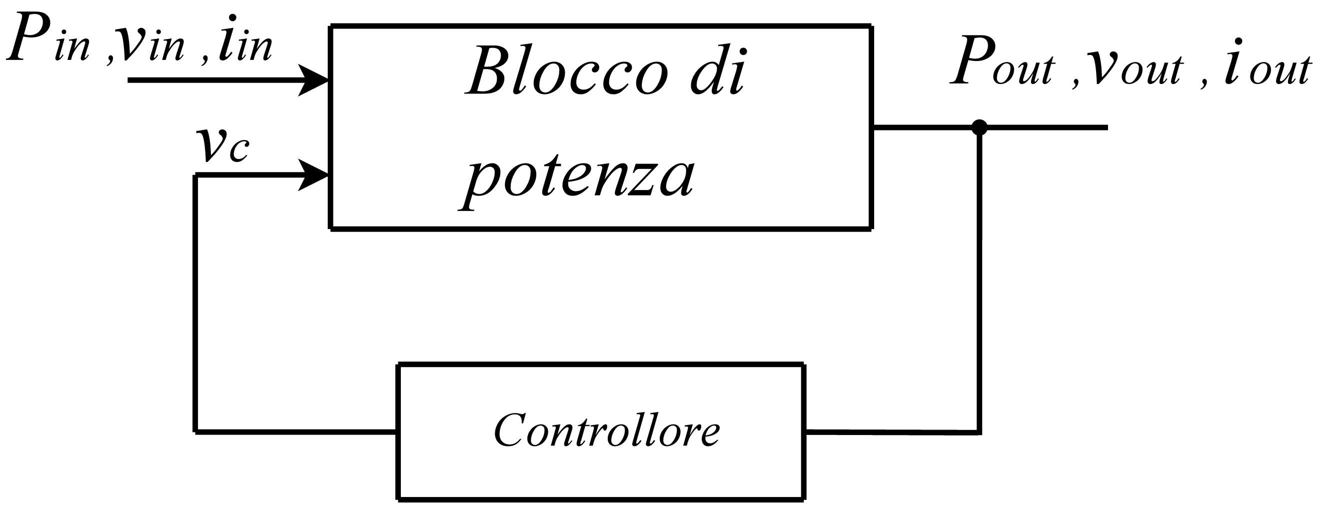
Usually there are only two configurations of the switches, therefore the average is computed directly from the duty cycle.

$$t_{on} \quad \begin{cases} \dot{x}'(t) = A_1 x(t) + B_1 u(t) \\ v_o'(t) = C_1 x(t) \end{cases} \qquad t_{off} \quad \begin{cases} \dot{x}''(t) = A_2 x(t) + B_2 u(t) \\ v_o''(t) = C_2 x(t) \end{cases}$$

$$\begin{cases} \dot{x}(t) = [A_1 D + A_2(1-D)]\,x(t) + [B_1 D + B_2(1-D)]\,u(t) \\ v_o(t) = [C_1 D + C_2(1-D)]\,x(t) \end{cases}$$

The controller

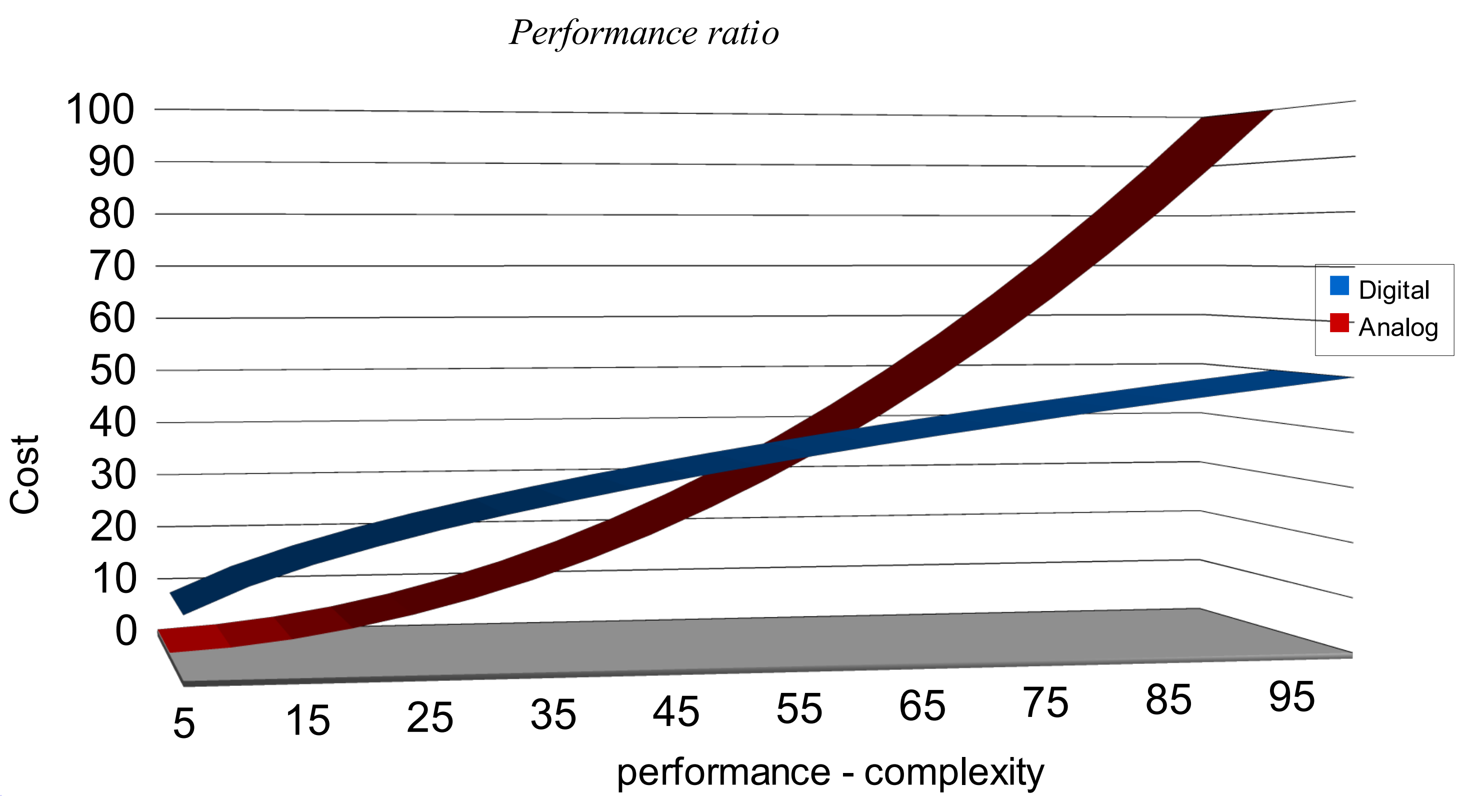
The controller is a device that supplies some inputs to the plant in order to "control" its outputs



Today, most of the controllers for SMPS are realized using simple, continuous time PIDs.

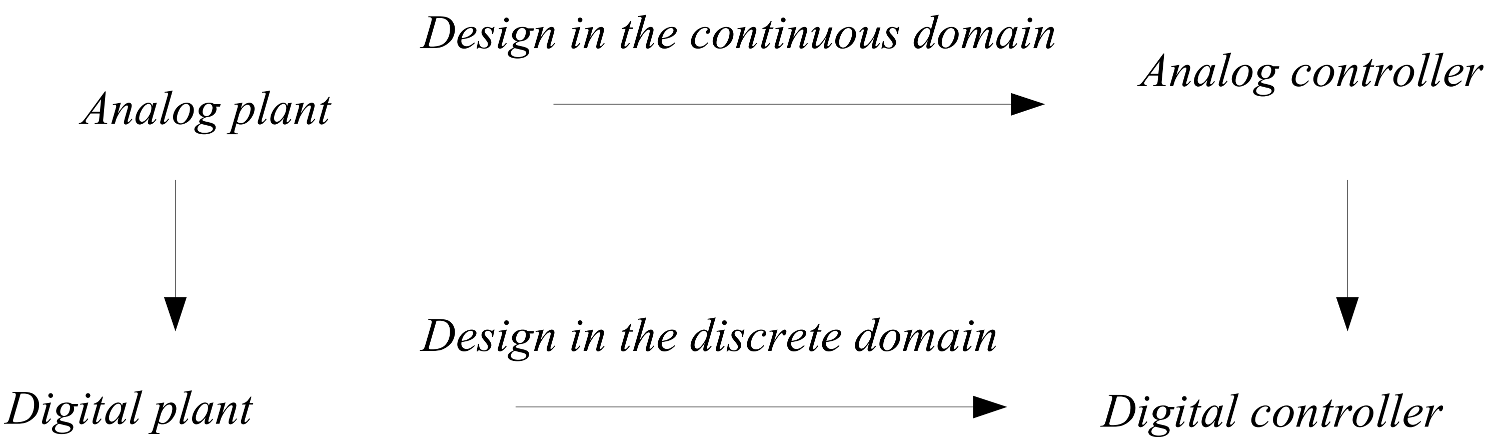
Analog vs digital controllers

Digital controllers win for high complexity applications, but the break even point is moving to the left.



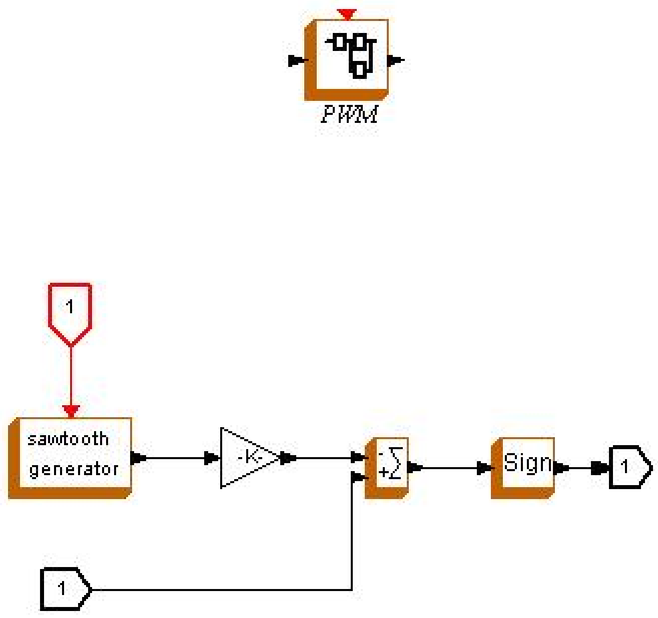
Design of digital controller

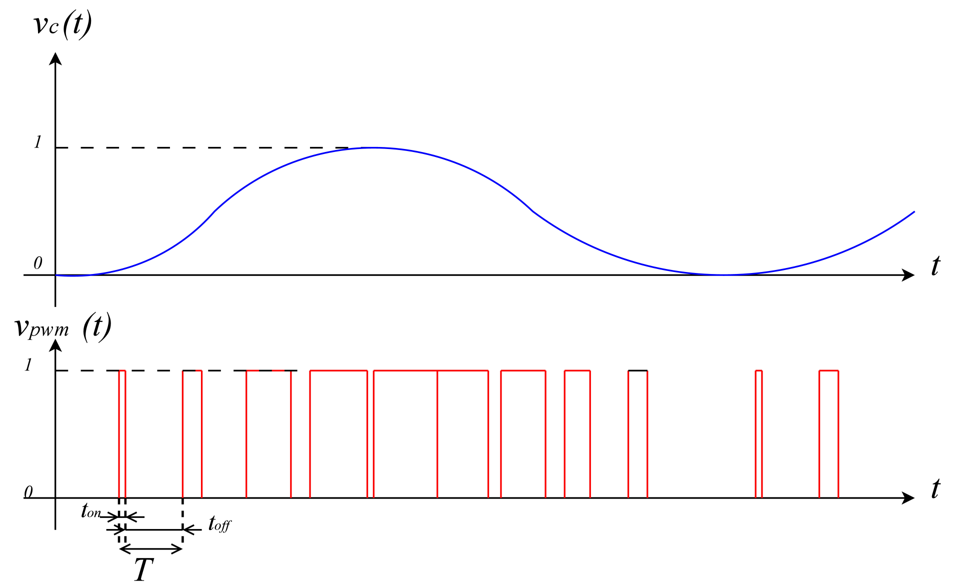
There are two ways to design a digital controller:



Switches need an on/off command signal. The PWM (pulse with modulator) transforms a linear signal into a square wave of fixed frequency and variable duty cycle.

PWM

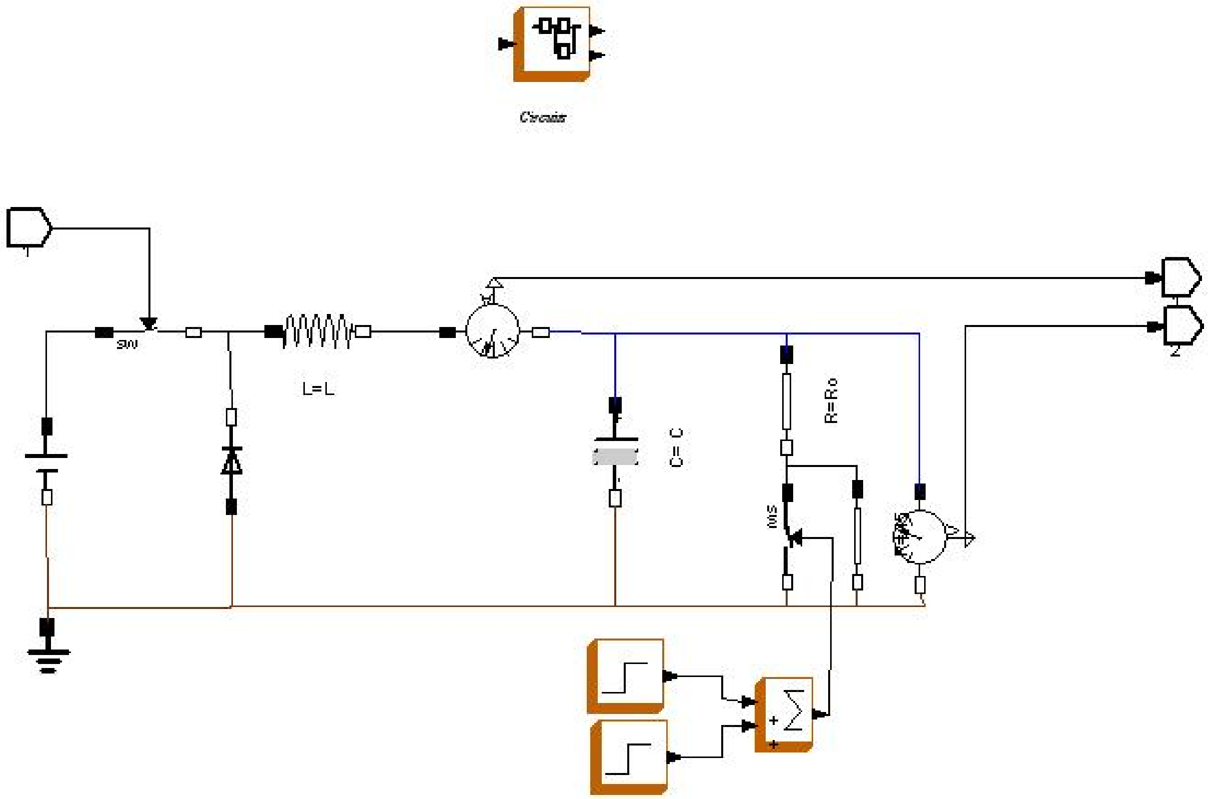




The PWM (pulse with modulator) transforms a linear signal into a square wave of fixed frequency and variable duty cycle.

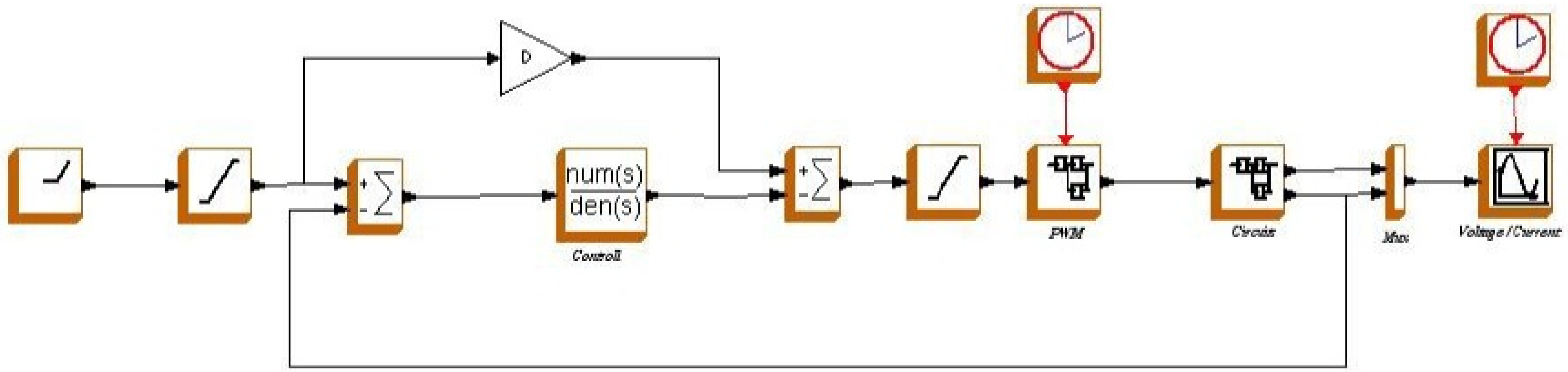
Digital controller design

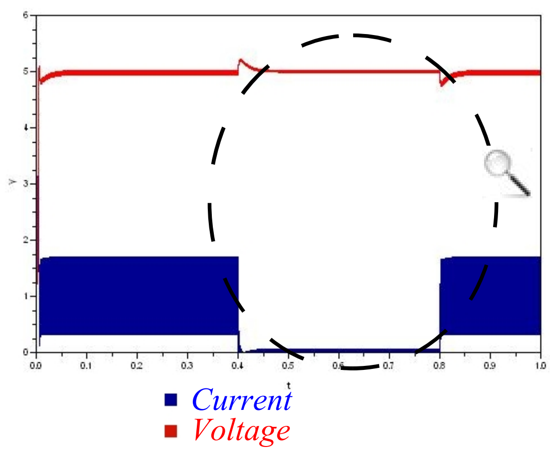
Scicos diagram of a buck power converter

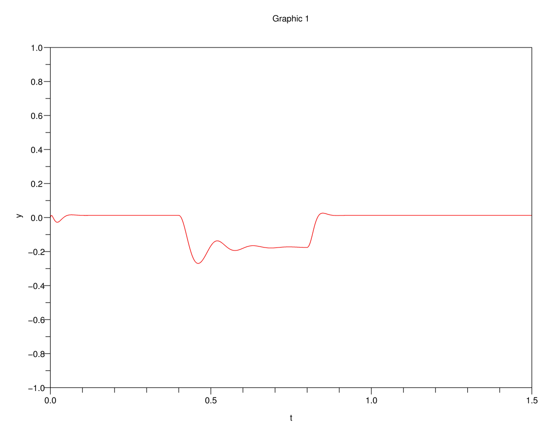


Controller design in the analog domain

1. Feed-forward + Feedback

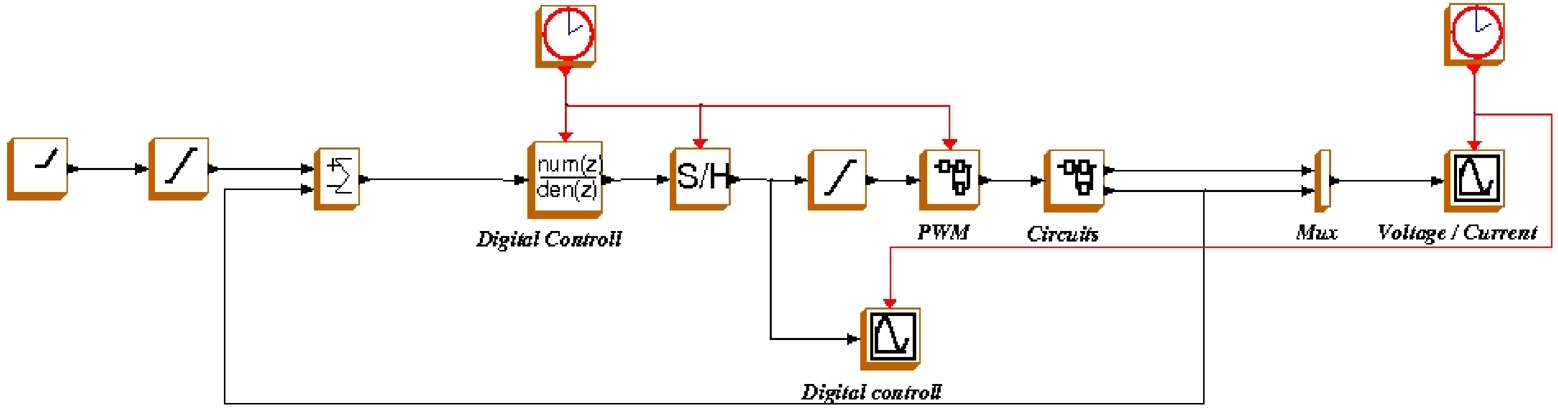




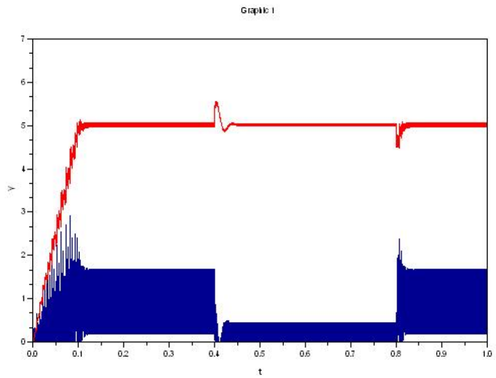


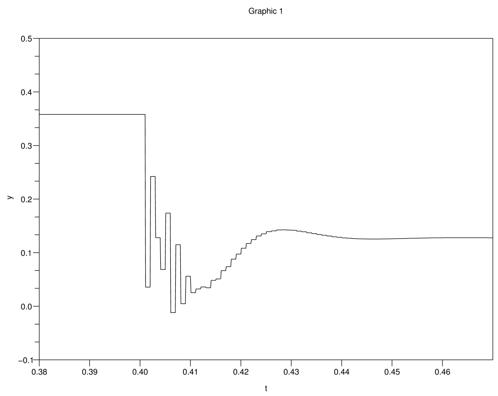
Controller design in the analog domain

2. Feedback plus integrator



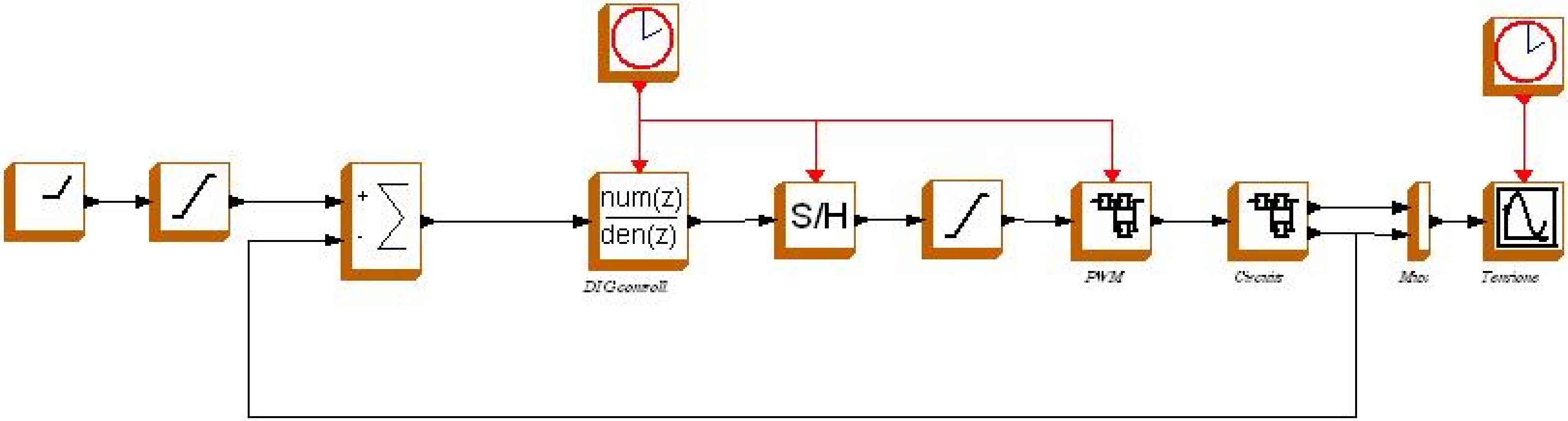
Voltage
Current





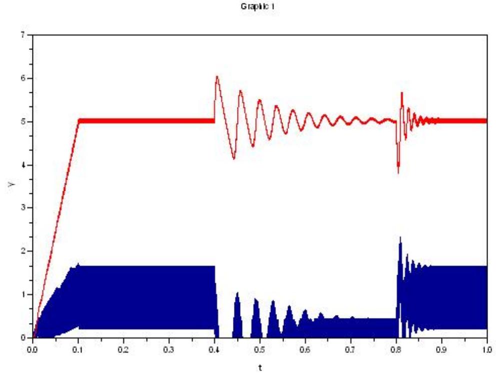
Controller design in the discrete domain

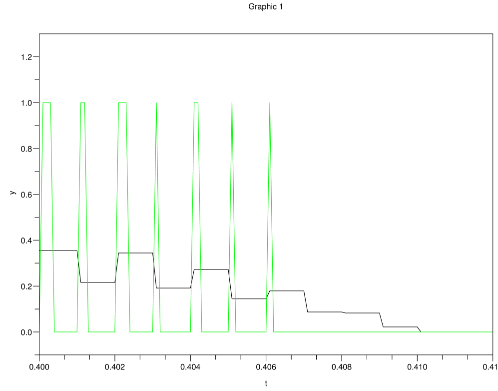
- *Pole-placement (deadbeat)*



Voltage

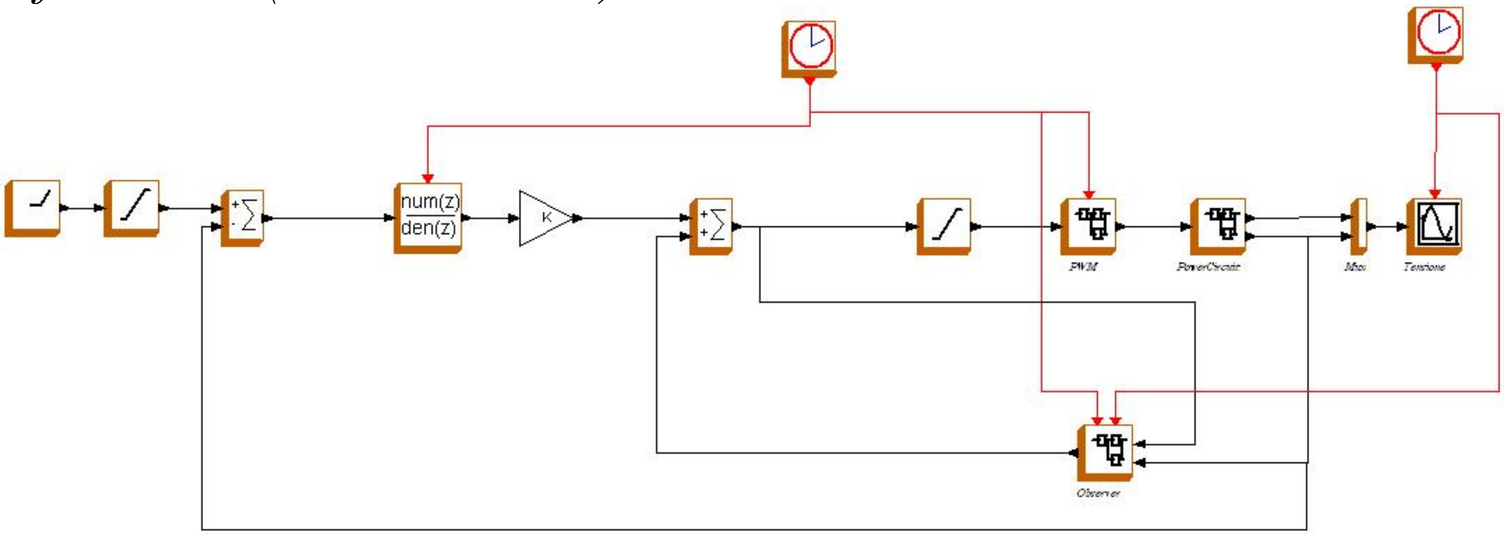
Current





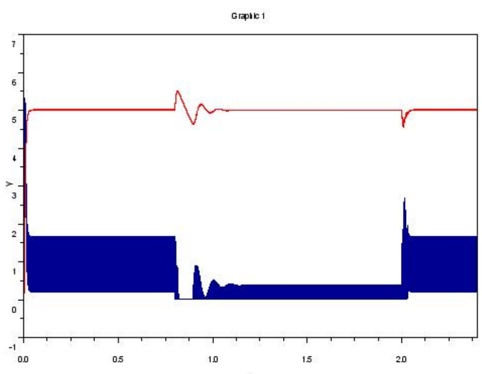
Controller design in the discrete domain

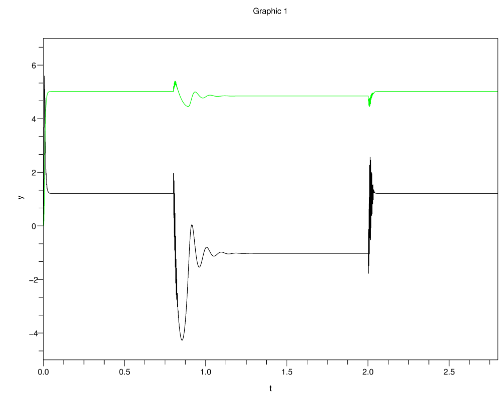
- *State feedback (with observer)*



Voltage

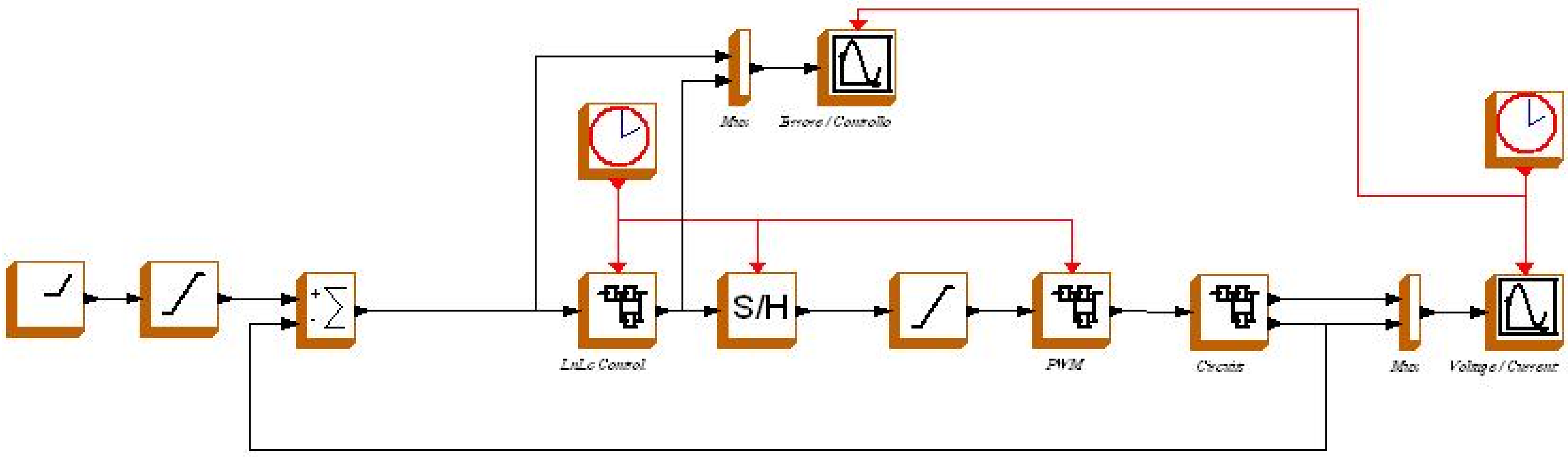
Current





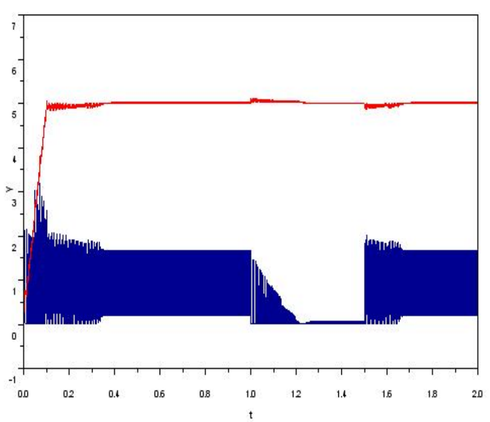
Controller design in the discrete domain

- *Non linear controller (LnLc method)*



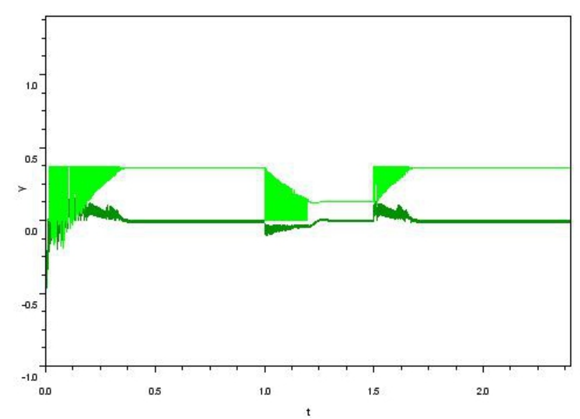
Voltage

Current



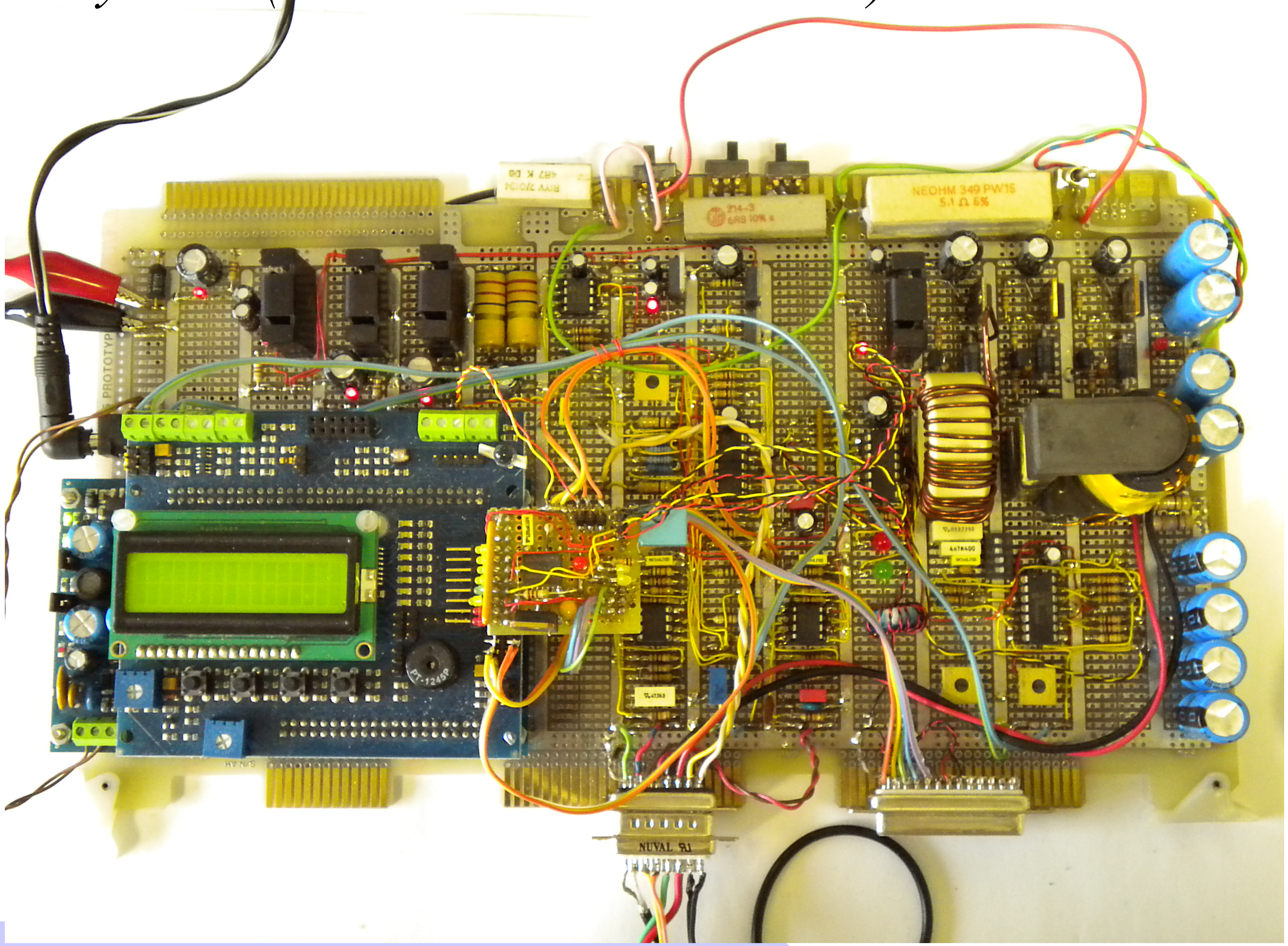
Error

Command

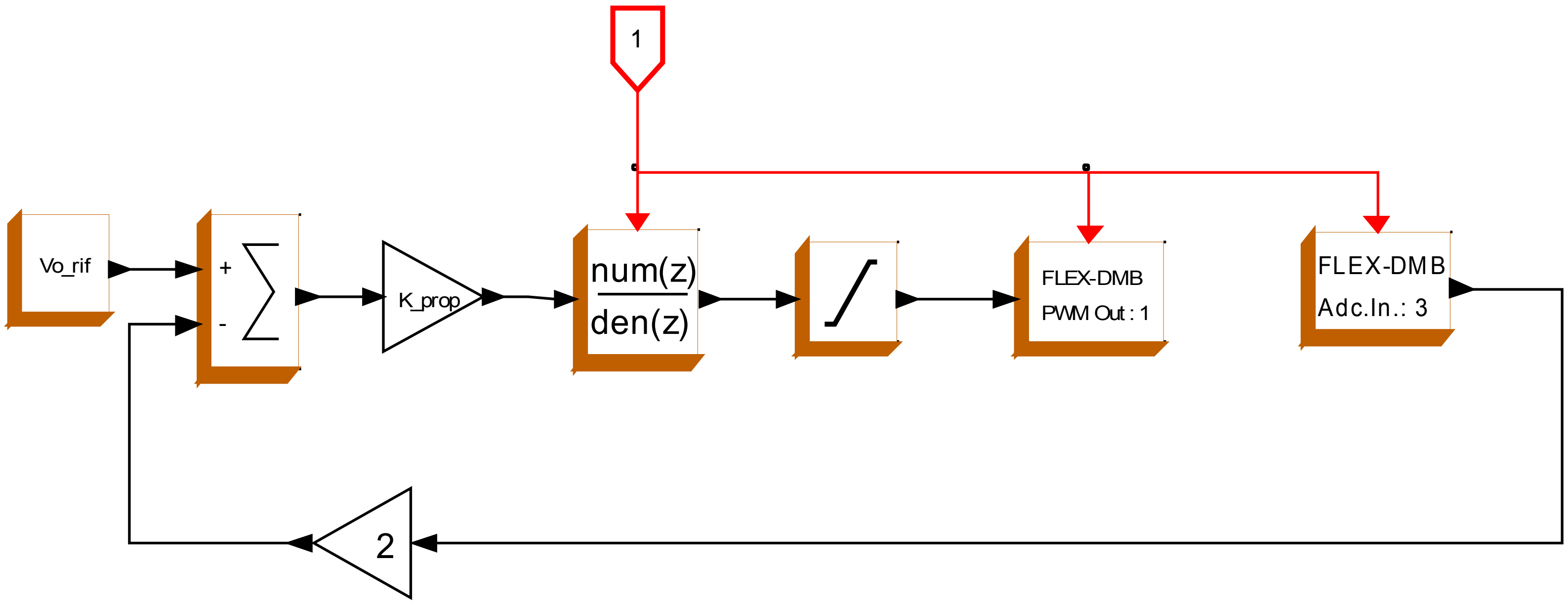


Code generation

We have verified the design using this prototype "main board" and a FLEX development systems (FLEX Full + DemoBoard)



Code generation



flex_dead_5V

flex_int_5V

Conclusions

We have shown several designing techniques for analog and digital (discrete) controllers

We have developed models and complete simulations using ScicosLab and Scicos.

We have used the code generation capabilities of Scicos-FLEX

Future developments

- *Better models of active and passive components*
- *Development of an automatic tool for the militarization of the power section (state space linear approximation)*
- *Development of SMPS specific code generator*
- *Prototype development*