Hardware in the loop for Electronic Throttle System Identification and Control

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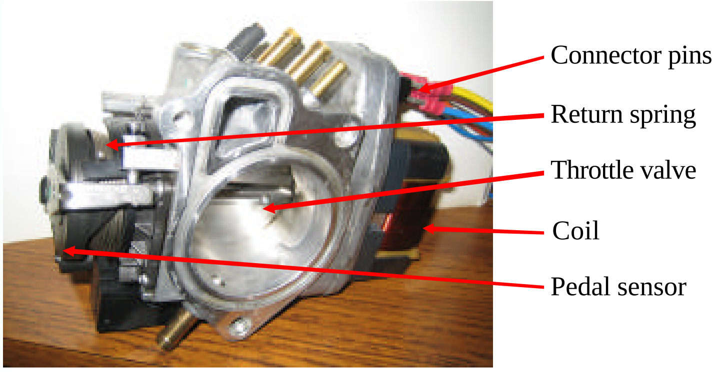
ACTC

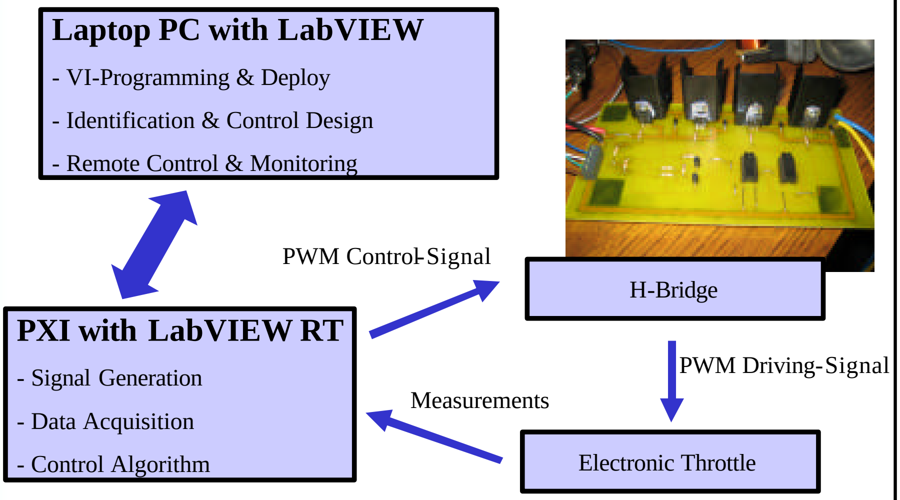
Electronic Throttle Body



Pedal and Throttle positions decoupling results in:

- Lower fuel consumption
- Better engine torque control
- Different engine response available (normal, snow, mountains)

System Overview



Laptop PC with LabVIEW
- VI-Programming & Deploy
- Identification & Control Design
- Remote Control & Monitoring

PXI with LabVIEW RT
- Signal Generation
- Data Acquisition
- Control Algorithm

PWM Control-Signal

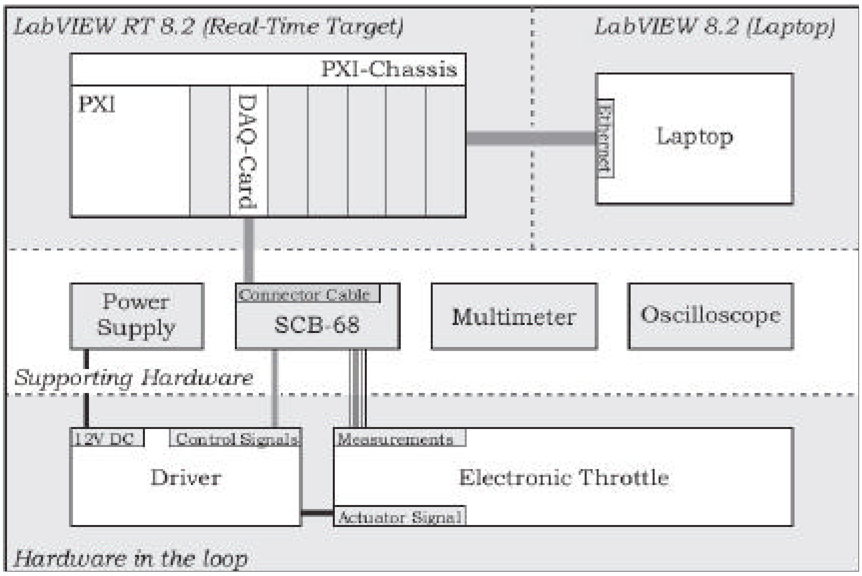
H-Bridge

PWM Driving-Signal

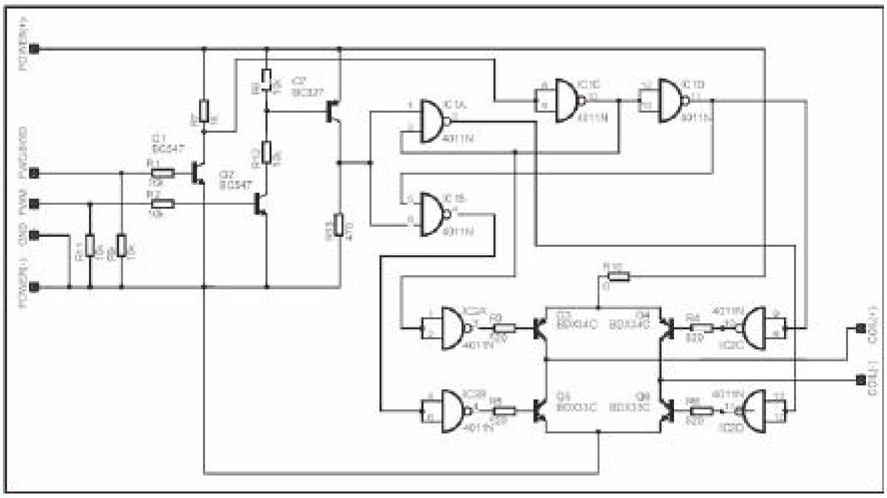
Measurements

Electronic Throttle

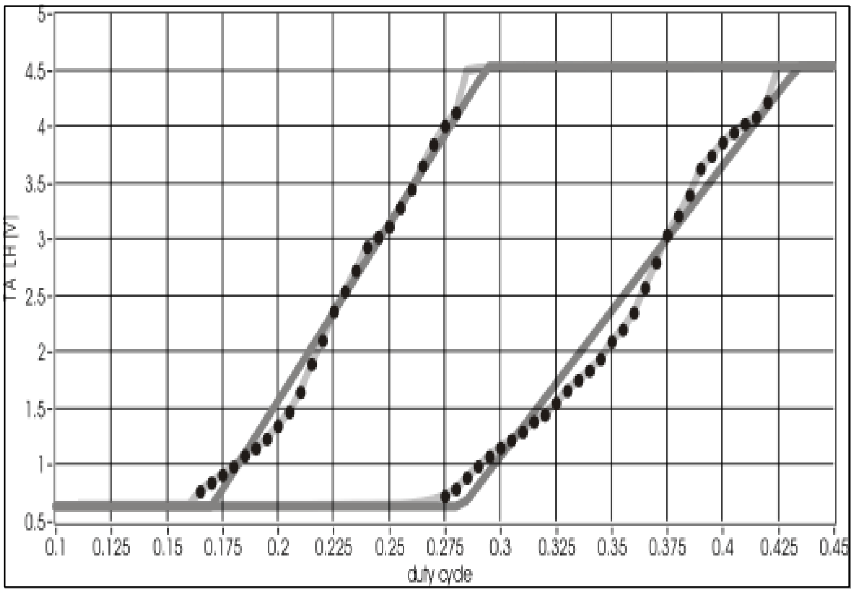
Hardware Connections



Driver (Power Amplifier)

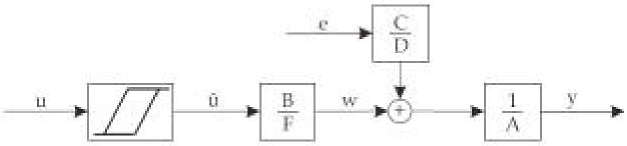


Steady State Characteristic



System model structure

- The following Hammerstein model structure will be used for modelling



  - Results will be compared with the pure linear model
- The above model structure suggests that the steady-state characteristic is a part of the system located before the linear dynamics

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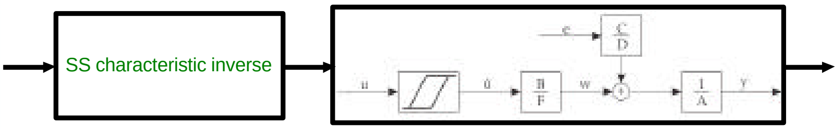
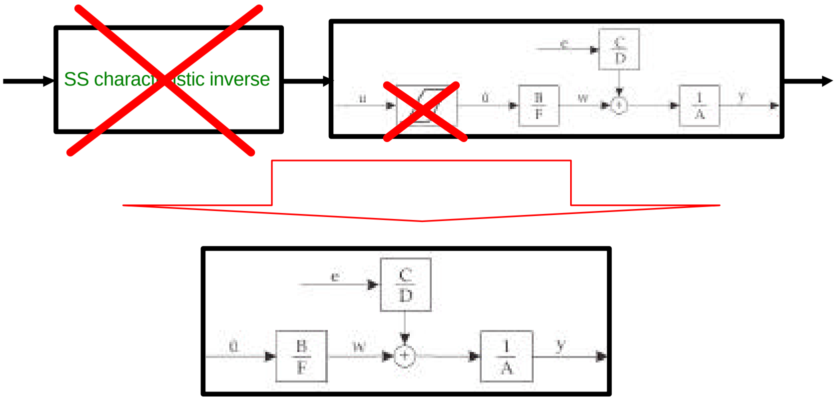
System model structure

- The assumption may not be in line with reality
  - Steady-state response and dynamics may not be separable
  - Dynamics may be non-linear
- Let’s assume that our assumptions are sufficiently accurate
  - Remove the steady-state behaviour by using a pseudo-inverse of the steady-state characteristic



System model structure

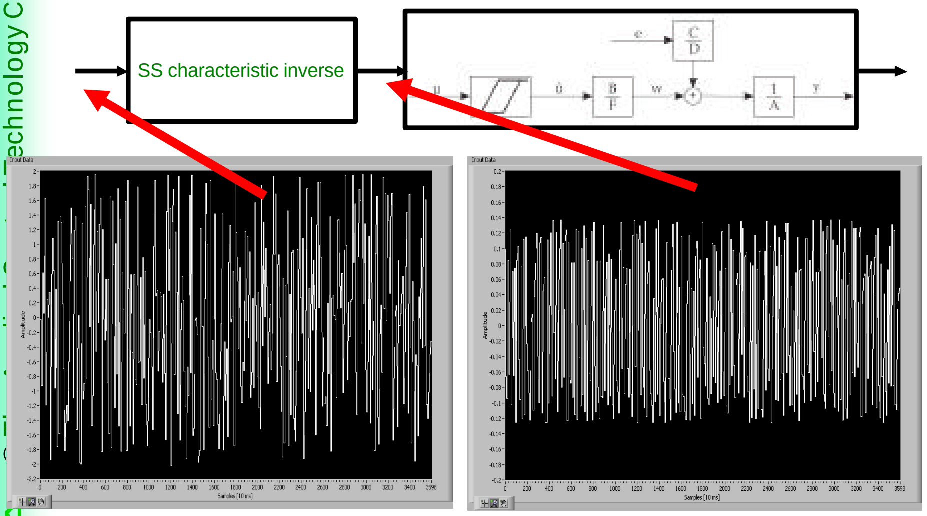
- Assuming that the static non-linearity is cancelled out by the pseudo-inverse the remaining model of the system is linear:



Identification Experiment

- Inverse of the input characteristic scales the input to the ‘virtual linear system’ with the similar input-output range
  - This range is about 0.63 … 4.53 [V]
- The random signal is generated and passed through the inverse of the steady-state characteristic
  - Signal that is obtained on the SS Characteristic output is a Duty Cycle signal that is sent to the power amplifier and the Electronic Throttle’s coil

Identification Experiment

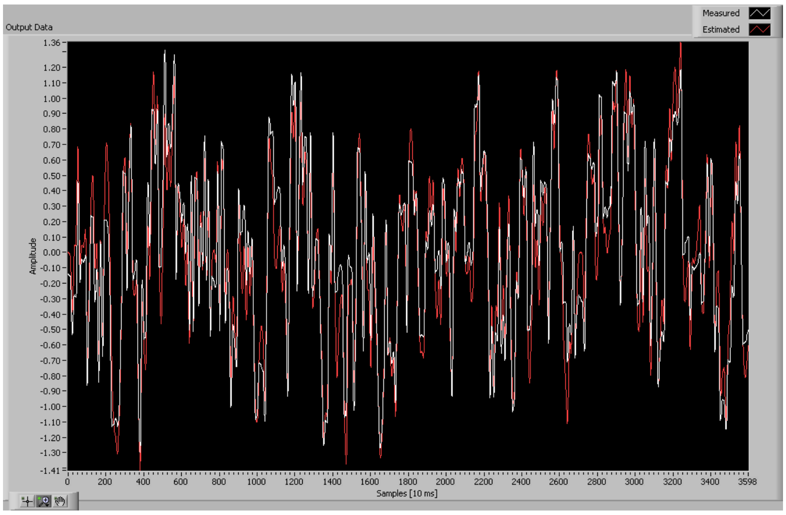


Input for Hammerstein model identification

Input for Linear model identification

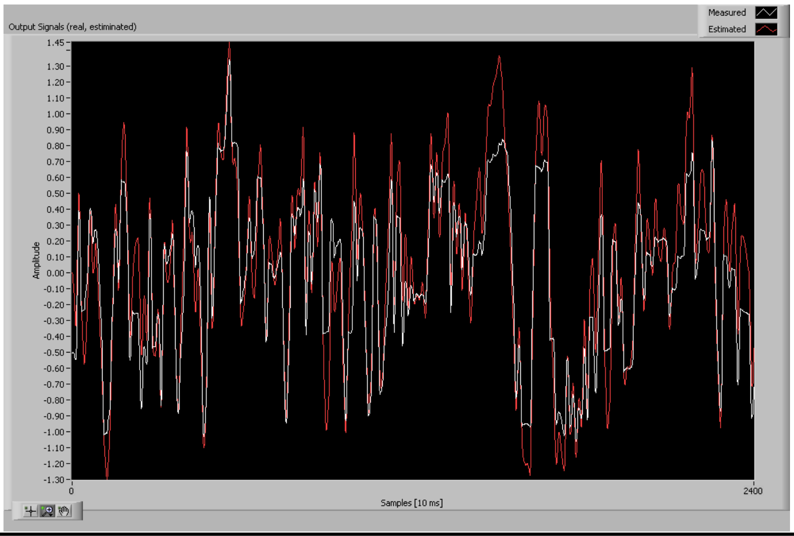
Identification Experiment

Hammerstein model identification: Identification Data



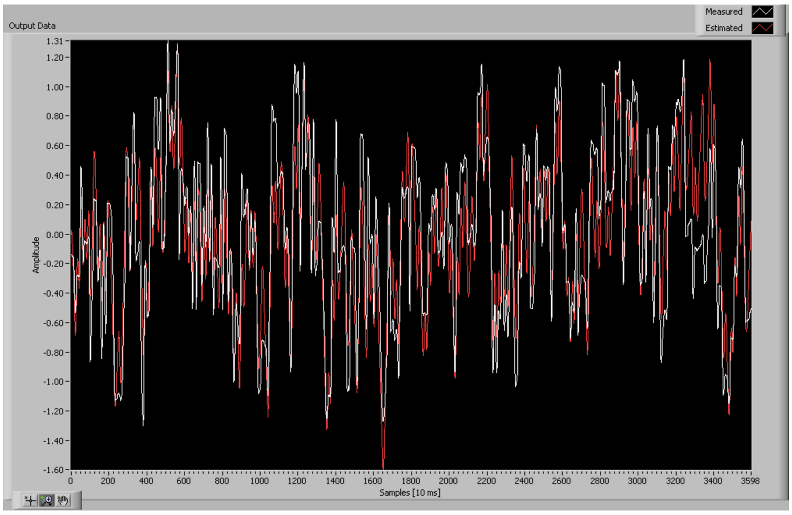
Identification Experiment

Hammerstein model identification: Validation Data



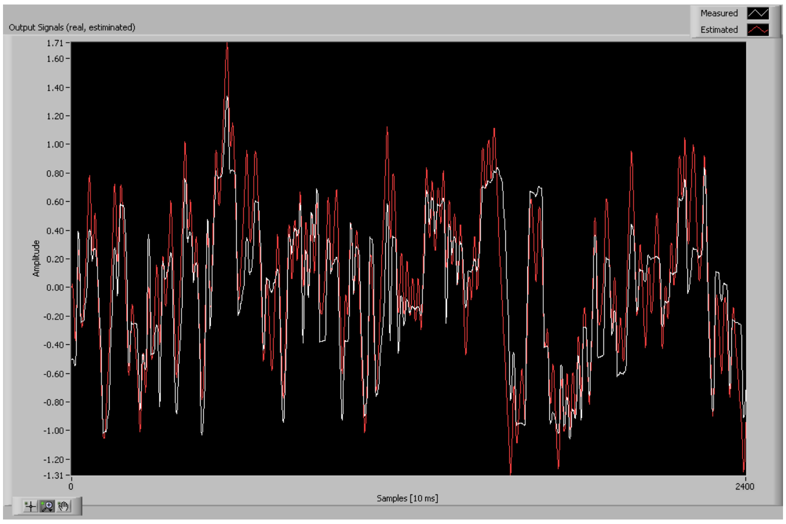
Identification Experiment

Linear model identification: Identification Data

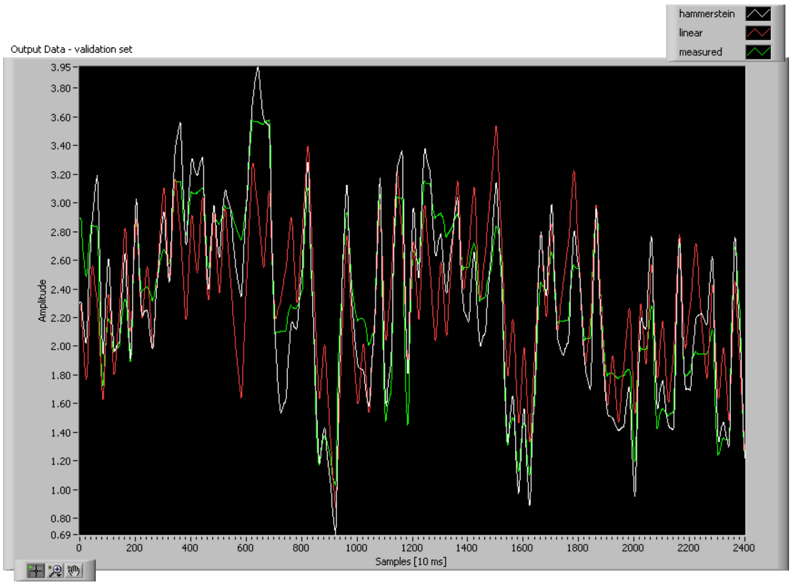


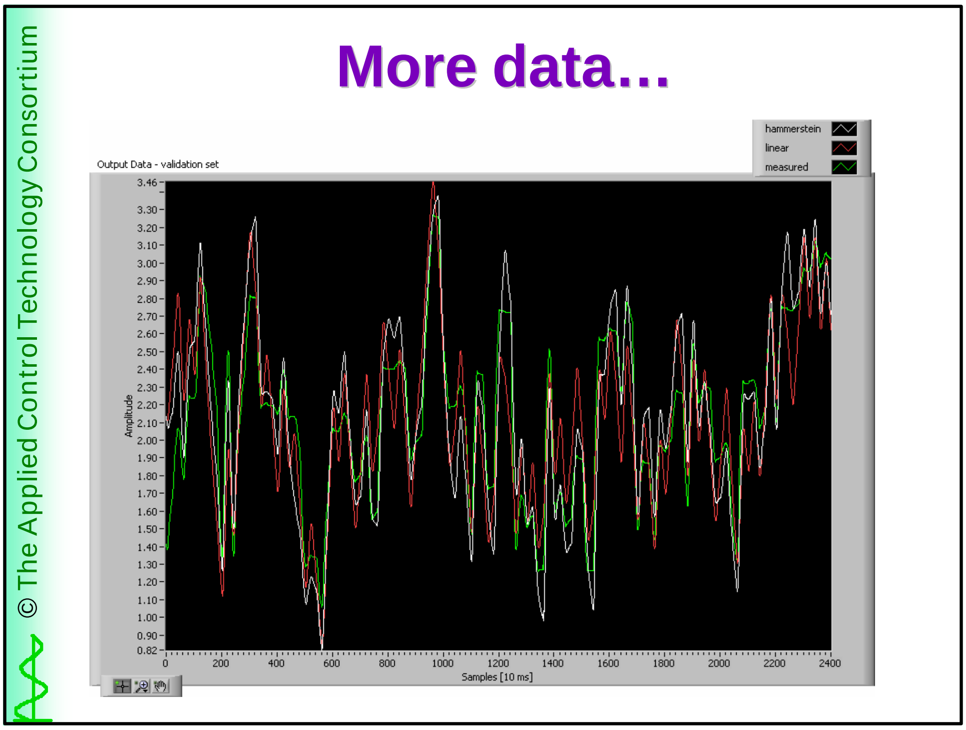
Identification Experiment

Linear model identification: Validation Data



More data…





More data…

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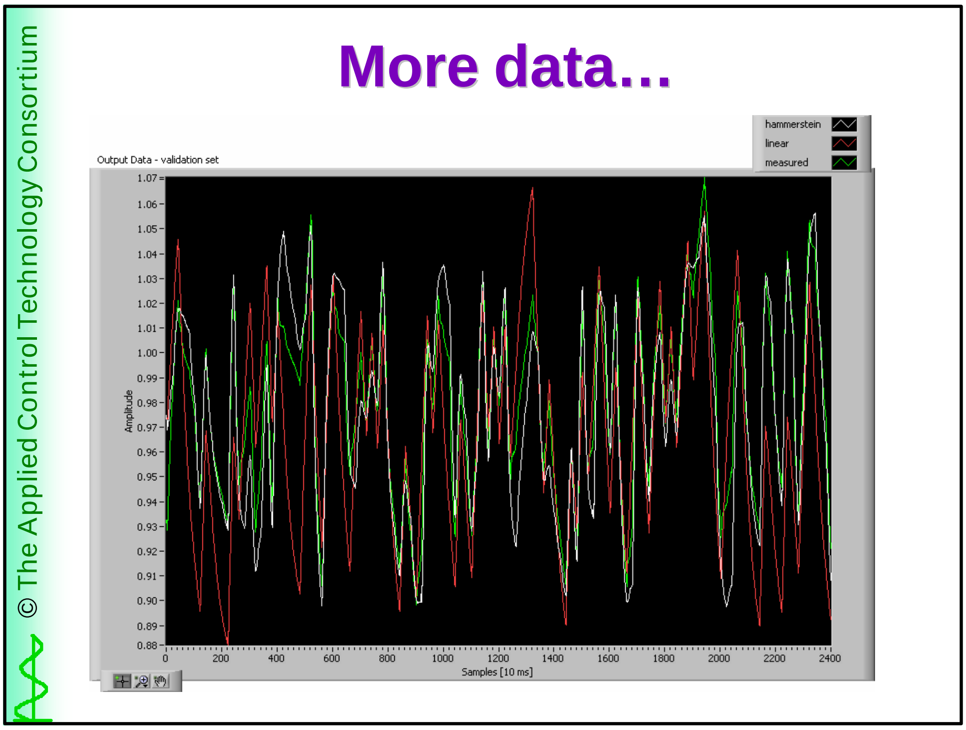

More data…

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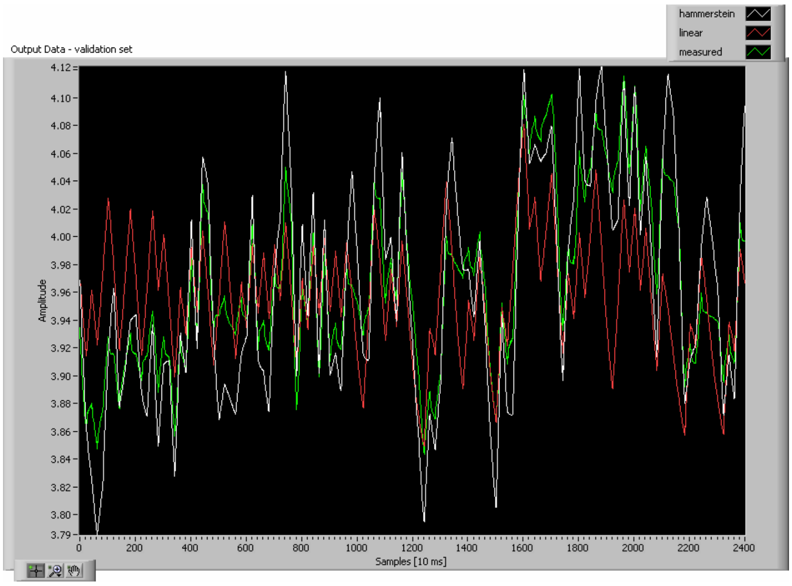
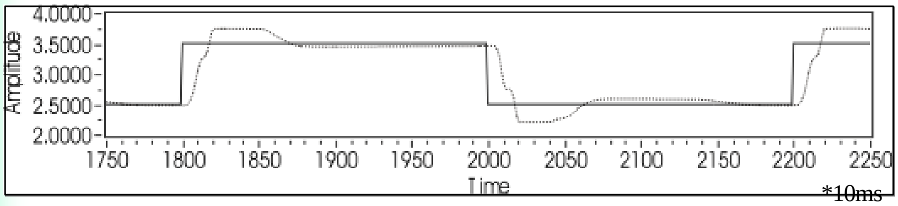
More data…

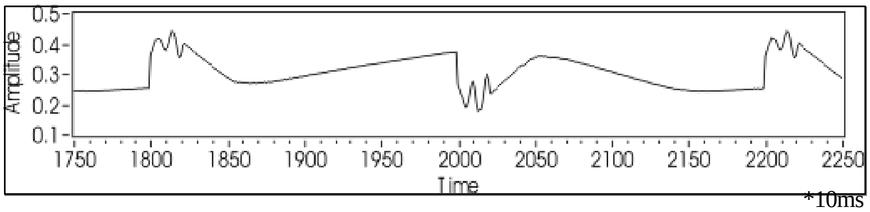


Controller: Hand-tuned - PID



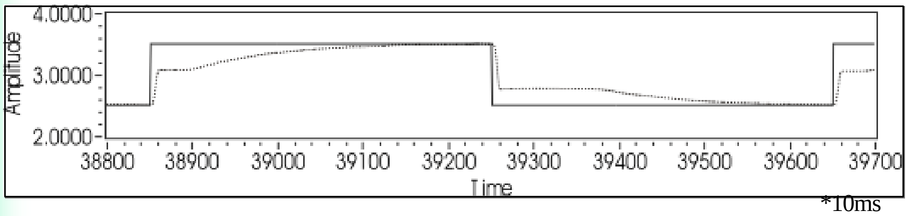
*10ms

Duty cycle

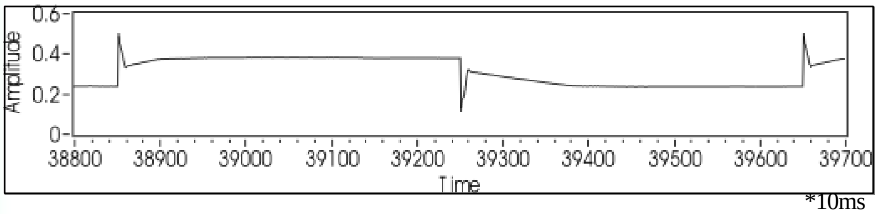


*10ms

Controller: PID from IMC tuning based on linear model

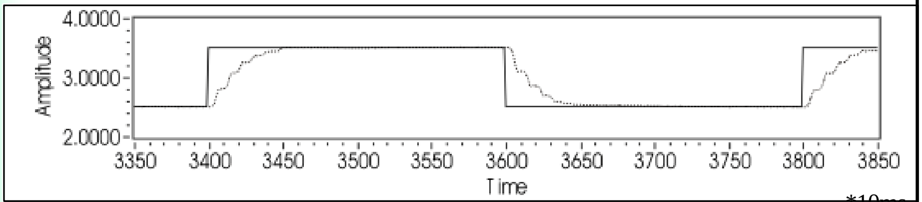


*10ms

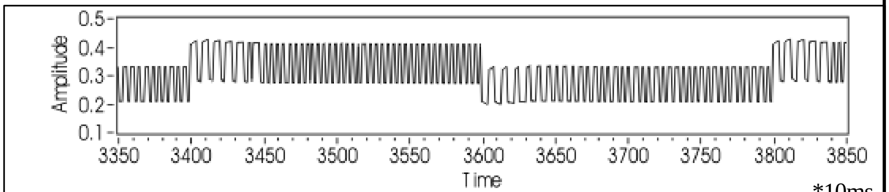


*10ms

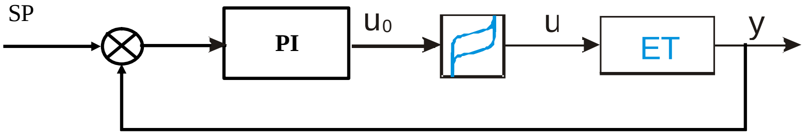
Controller: Hammerstein – PI from Z-N tuning



*10ms

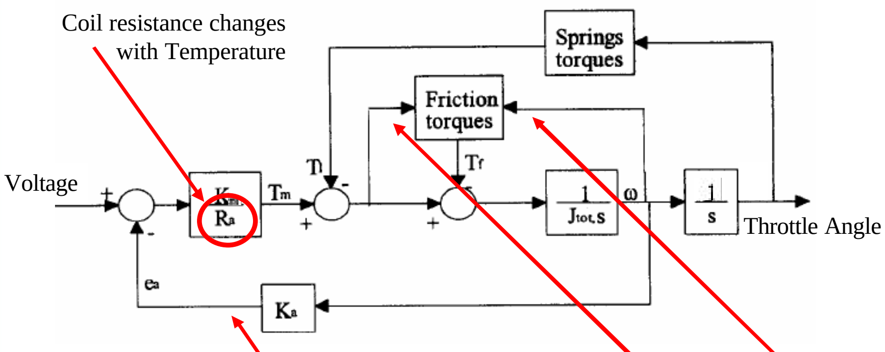


*10ms



Physical Model

Coil resistance changes
with Temperature

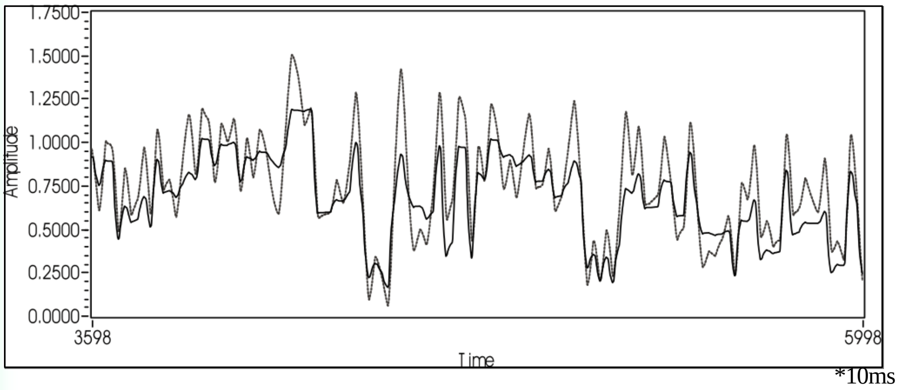


- Neglected electric dynamics
- Back electromotive force
- Spring torque

-Friction torques (stiction/Coulomb friction)

R.Scattolini et al.: „Modeling and Identification of an electromechanical Internal Combustion Engine Throttle Body. Control Eng. Practice, Vol. 5, No.9, pp. 1253-1259, 1997.

Physical Model Identification Result



Mean squared error of scaled data:
0.057

- Note: Hammerstein model was 0.026

Problems with EKF identification

- The discretisation of the system with discontinuities causes numerical problems (e.g. Coulomb friction – substituted by tanh())
- The model contains 6 unknown parameters – simultaneous identification depends on initial conditions
- Overall, poor knowledge of the initial system parameters which caused problems
- Unmodelled nonlinearities, observable in the steady state characteristic, might affect these results

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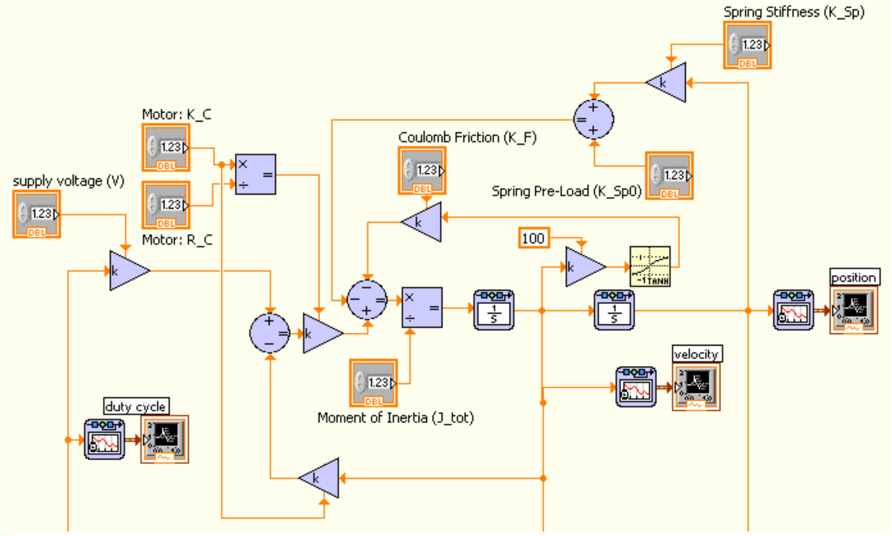
Simulation model



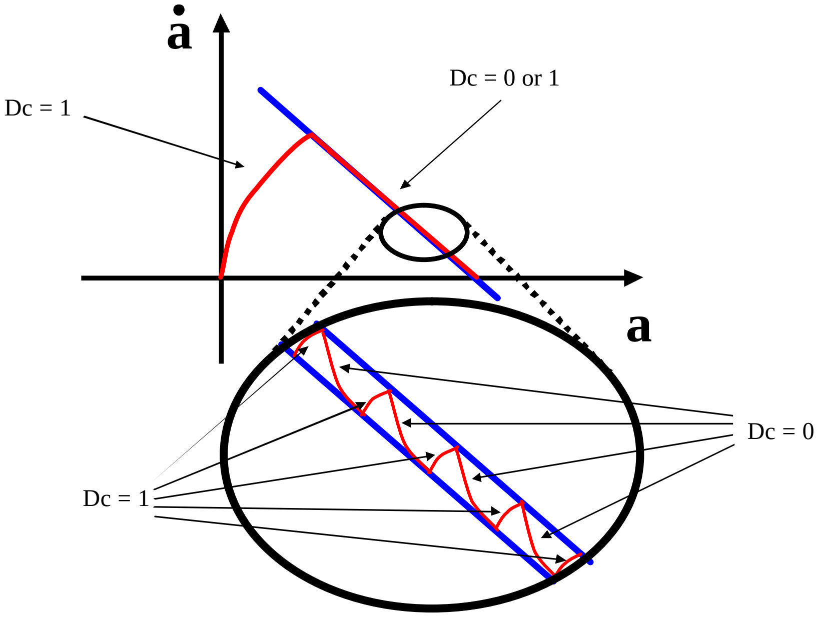
Alternative Control Technique

- PID control performance was not good enough: poor speed of response
  - This was the case for PID controller designed based on:
    - Manual tuning
    - Linear model based tuning
    - Non-Linear model based tuning
- The best result was obtained for Hammerstein model
  - But with significant amount of control activity

Alternative Control Technique

- Since the throttle is controlled through PWM modulation, the control signal is discontinuous and fast-switching
- This suggests that Sliding Mode control technique might be considered
- We’ll use system simulation to investigate properties of that control technique

Sliding Mode Control



Sliding Mode Control

- The approach used here is by far simpler than the formal Sliding Mode Control technique
    - Based on relay control
    - Depending on the current being on/off the throttle angle rate will increase or decrease
- The sliding manifold will need to be adjusted for these rates to give stable response
- The controller will be very simple with only 1 tuning parameter

Sliding Mode Control

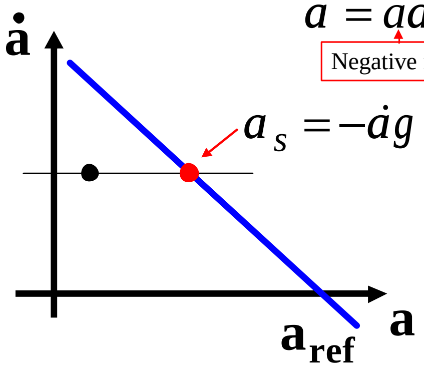
- We’ll use the model identified with the EKF

$$\dot{a} = aa + b \quad \Rightarrow \quad b = -aa_{ref}$$

Negative number

Positive number

$$g = -\frac{1}{a}$$



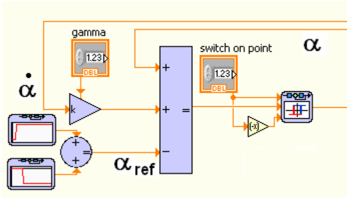
$$a_s = -\dot{a}g + a_{ref}$$

$$a - a_s = \dot{a}g - a_{ref} + a < 0$$

Need to increase speed (increase control)

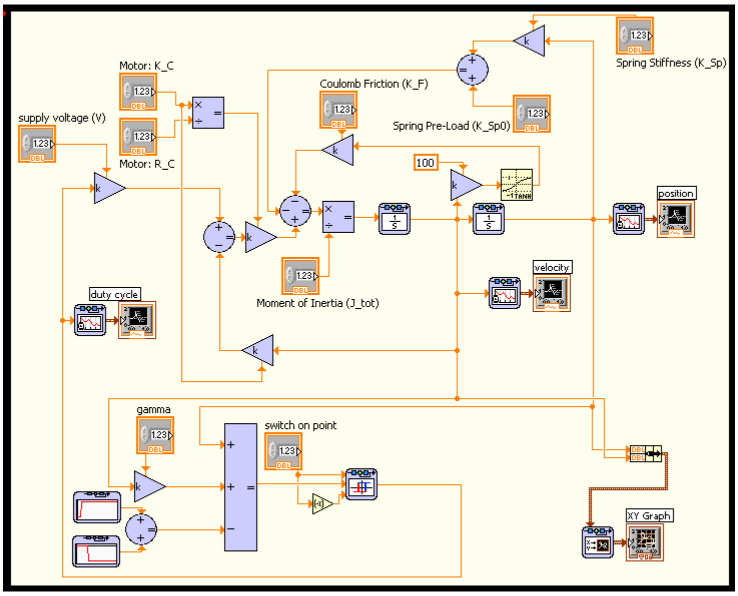
Sliding Mode Control

- The controller is implemented below:

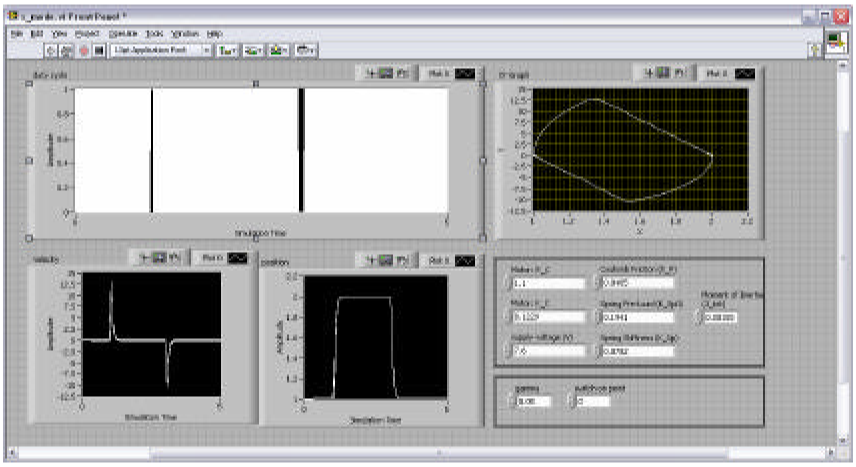


- The relay detects if control needs to be set to max. value or minimum value (0)
  - It is also possible to introduce a hysteresis to reduce switching frequency

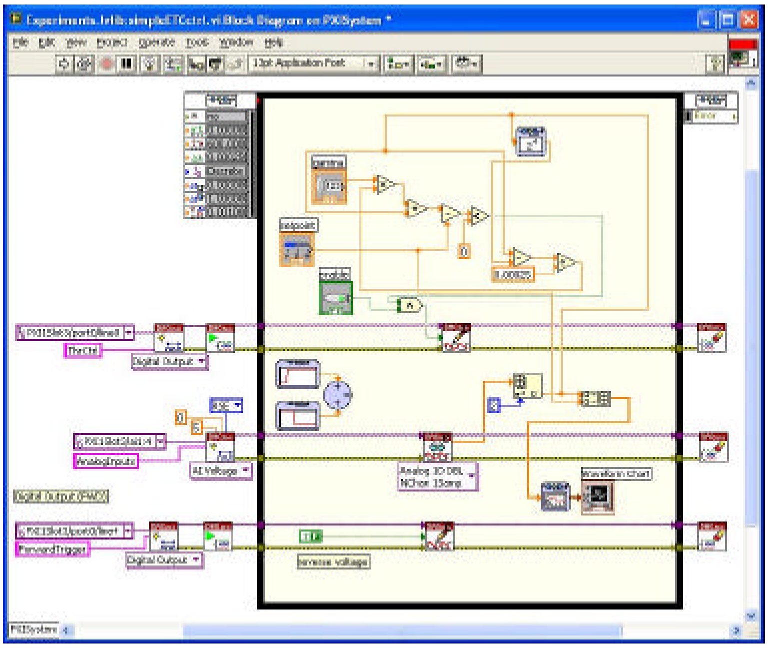
System simulation: diagram



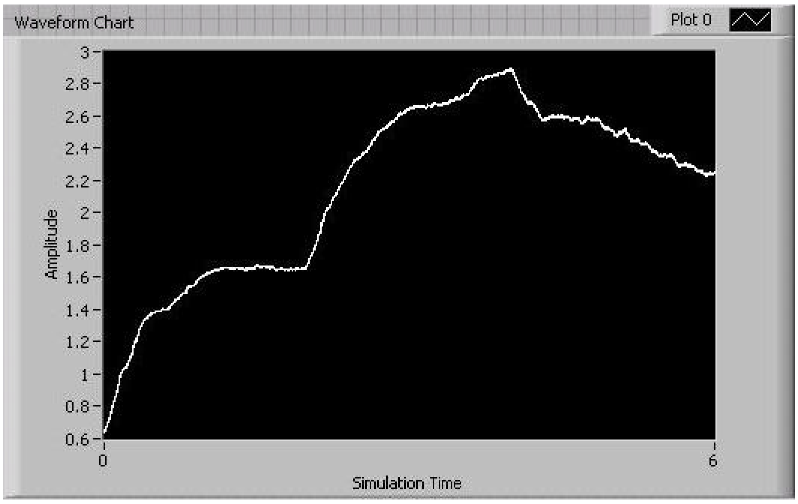
System simulation: front panel



Hardware results

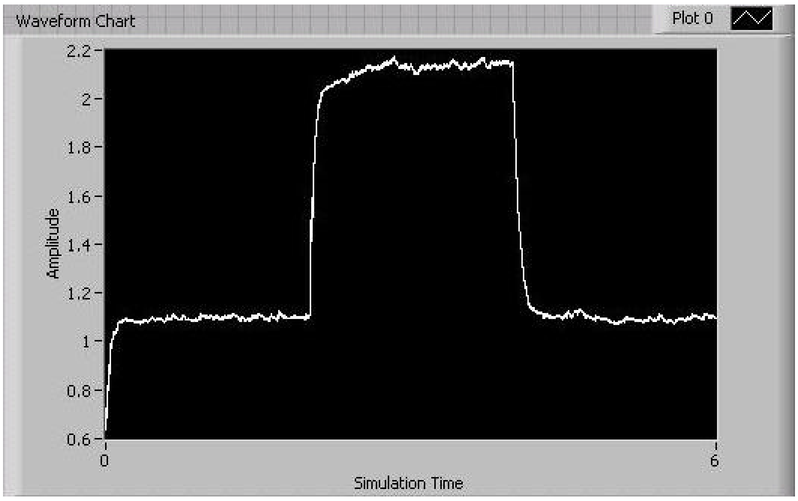


Hardware results



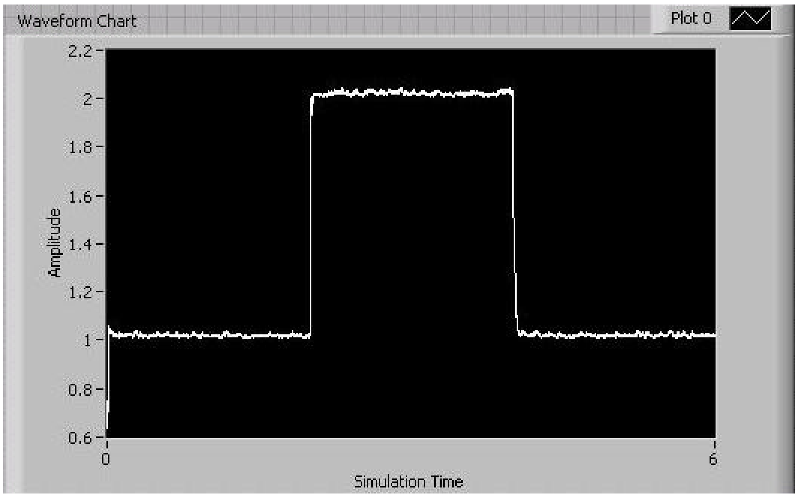
Gamma = 0.5

Hardware results



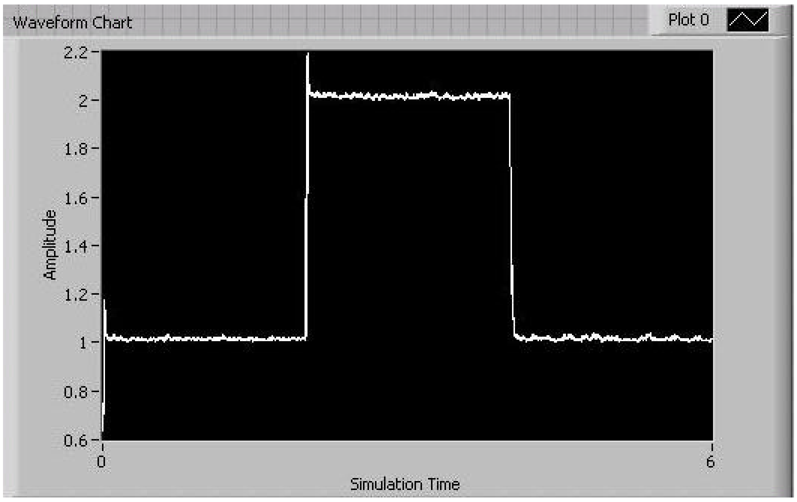
Gamma = 0.05

Hardware results



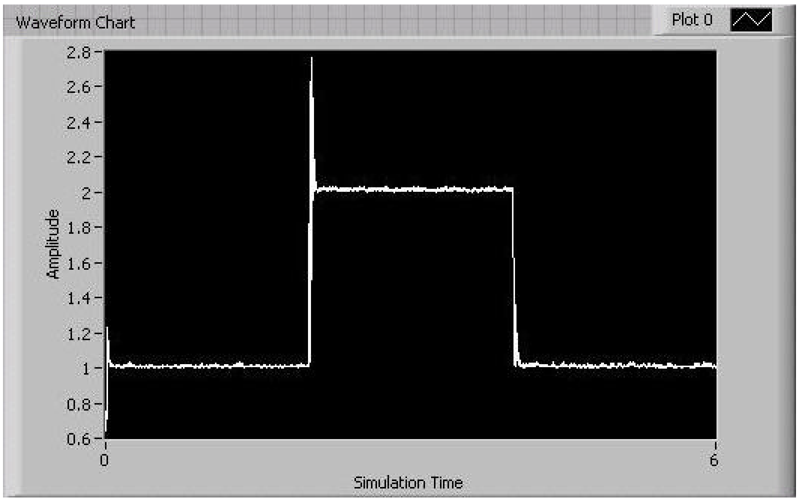
Gamma = 0.01

Hardware results



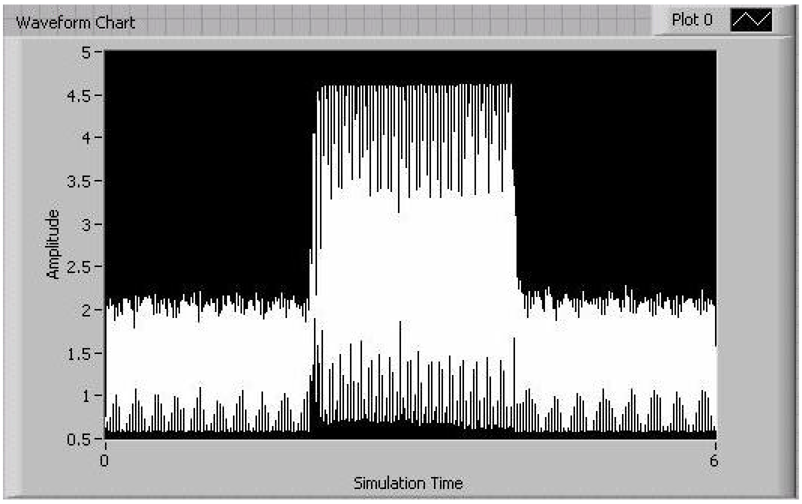
Gamma = 0.008

Hardware results



Gamma = 0.005

Hardware results



Gamma = 0.0005

Thank you!