FPGA Implementation of Multiple Controllers for a Magnetic Suspension System

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Outline

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- System Block Diagram
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Motivation

- System modeling and dynamics → nonlinear
- Previous controllers → xPC target box and Motorola ColdFire microcontroller

Magnetic suspension system

- Field Programmable Gate Array (FPGA) → Advantages
- In this project, FPGA is used to implement controllers for the magnetic suspension system

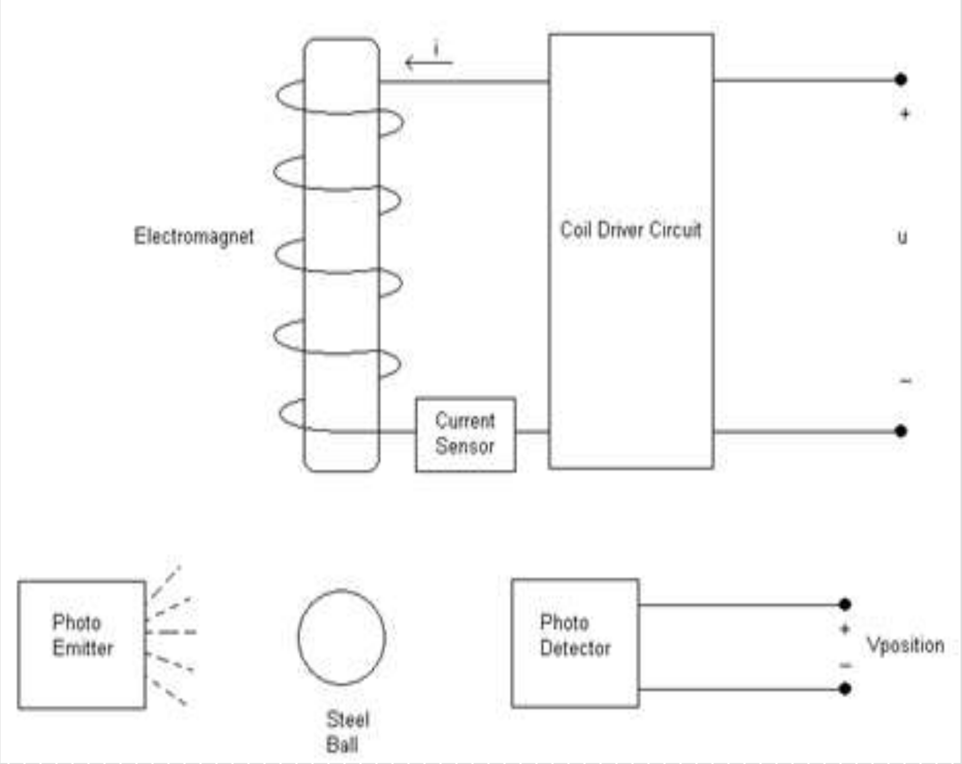
Spartan3E FPGA board

Project Goals

- Design and implement a stand-alone system which includes FPGA, ADC, DAC, and Conditioning Circuitry
- Utilize Xilinx System Generator simulation to determine computation precision of FPGA implementation
- Design the system using VHDL
- Compare FPGA implementation results with those from other platforms such as xPC target and microcontrollers

System Modeling and Dynamics

- Diagram of magnetic suspension system [1]



- Plant Model [1]

$$\dot{x}_1 = x_2 \qquad \dot{x}_2 = g - \frac{k}{m}\left(\frac{f(u)}{x_1}\right)^2$$

X_1 : Displacement of the steel ball
X_2 : Velocity of the steel ball
k : Force constant
u : Control voltage
m : The mass of the steel ball

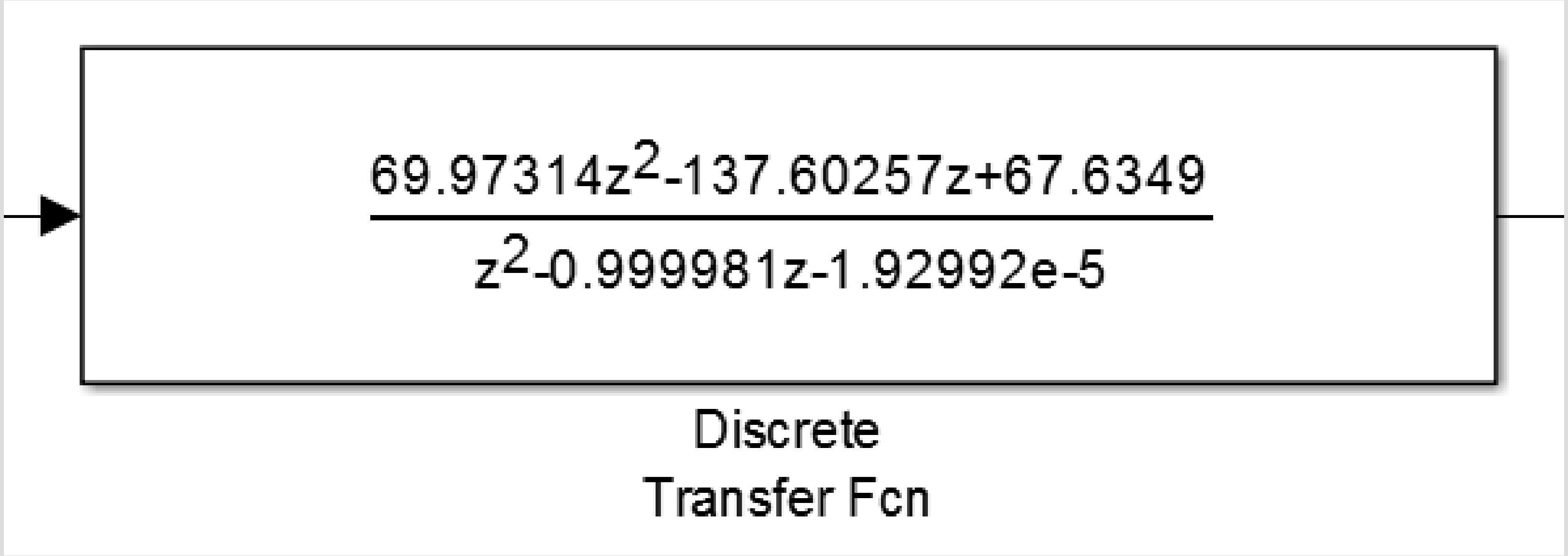
- Transfer functions of plant model [2]

$$H(s) = \frac{7.67}{\frac{s^2}{961} - 1}$$

Ts = 0.001 s

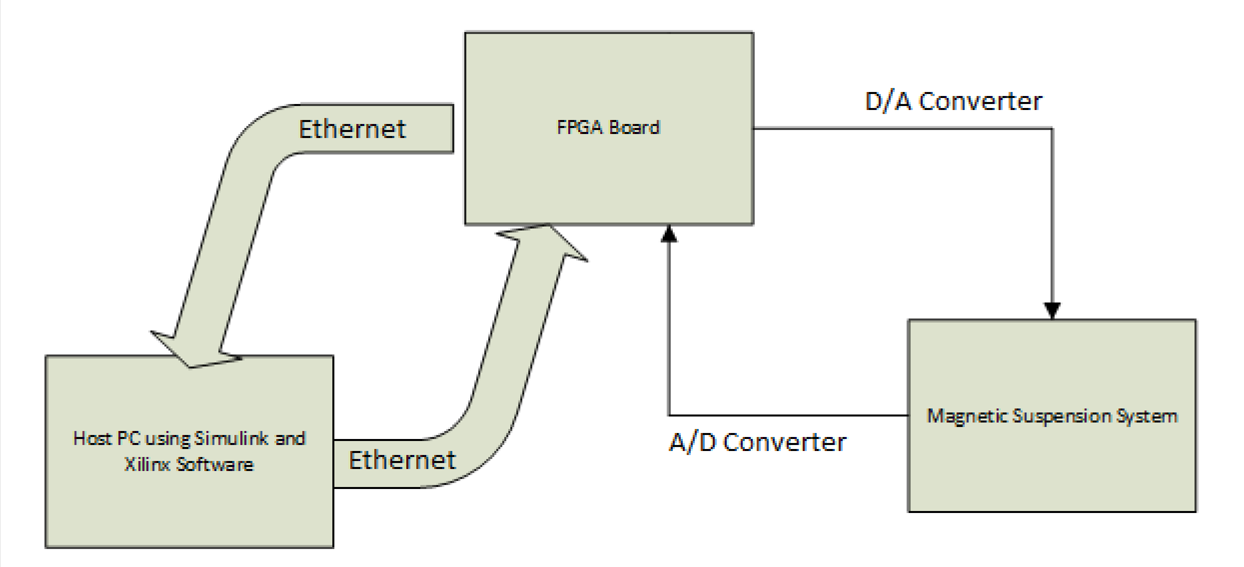
$$H(z) = \frac{6.6343e^{-4}\, z + 6.6343e^{-4}}{z^2 - 2.001\, z + 1}$$

Dunlap’s Controller [2]

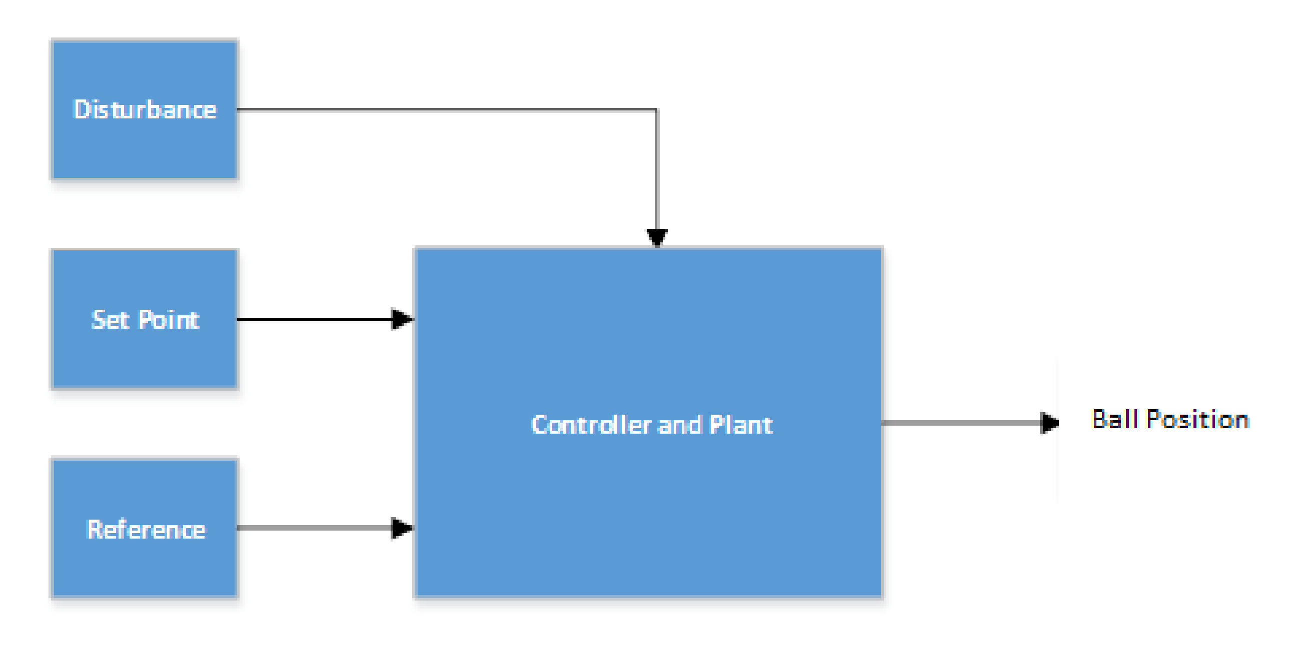


System Block Diagrams

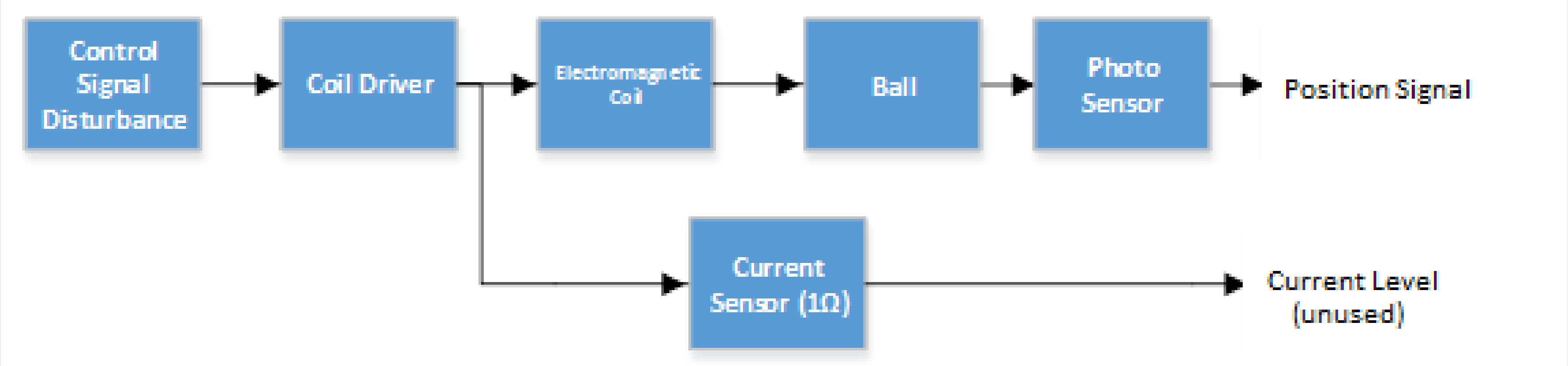
- High-Level Functional Diagram



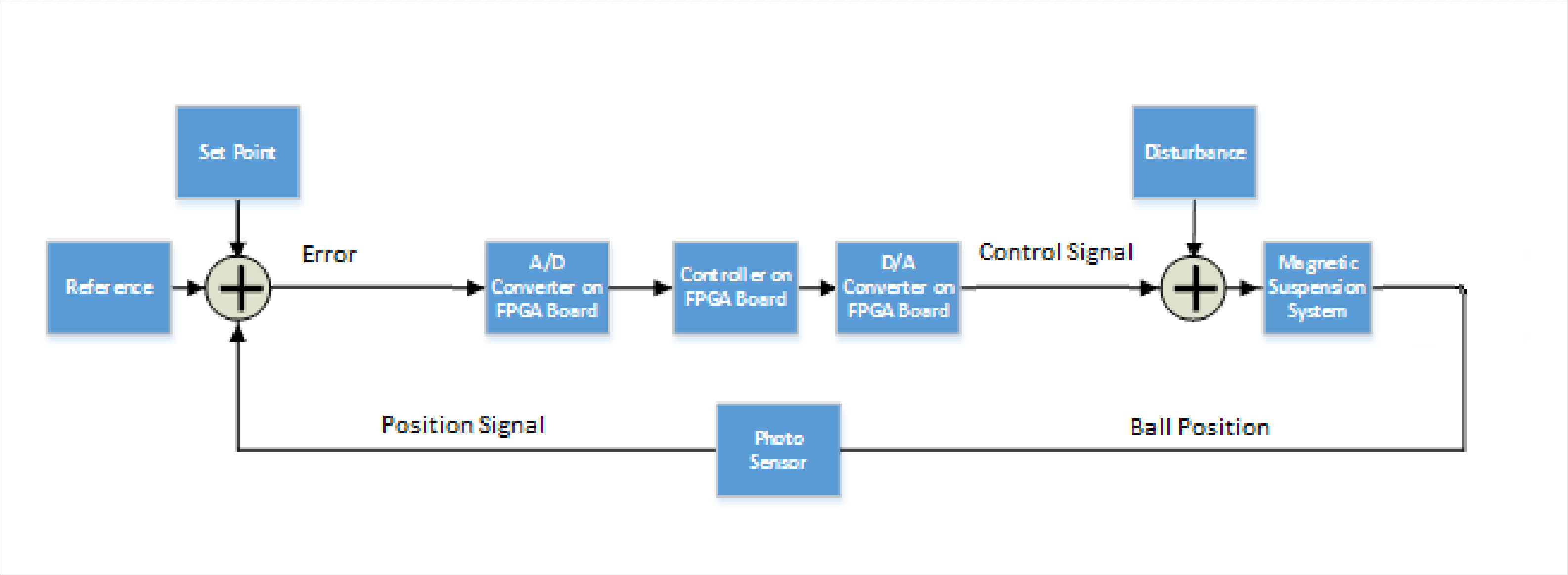
Overall System Block Diagram



Magnetic Suspension System



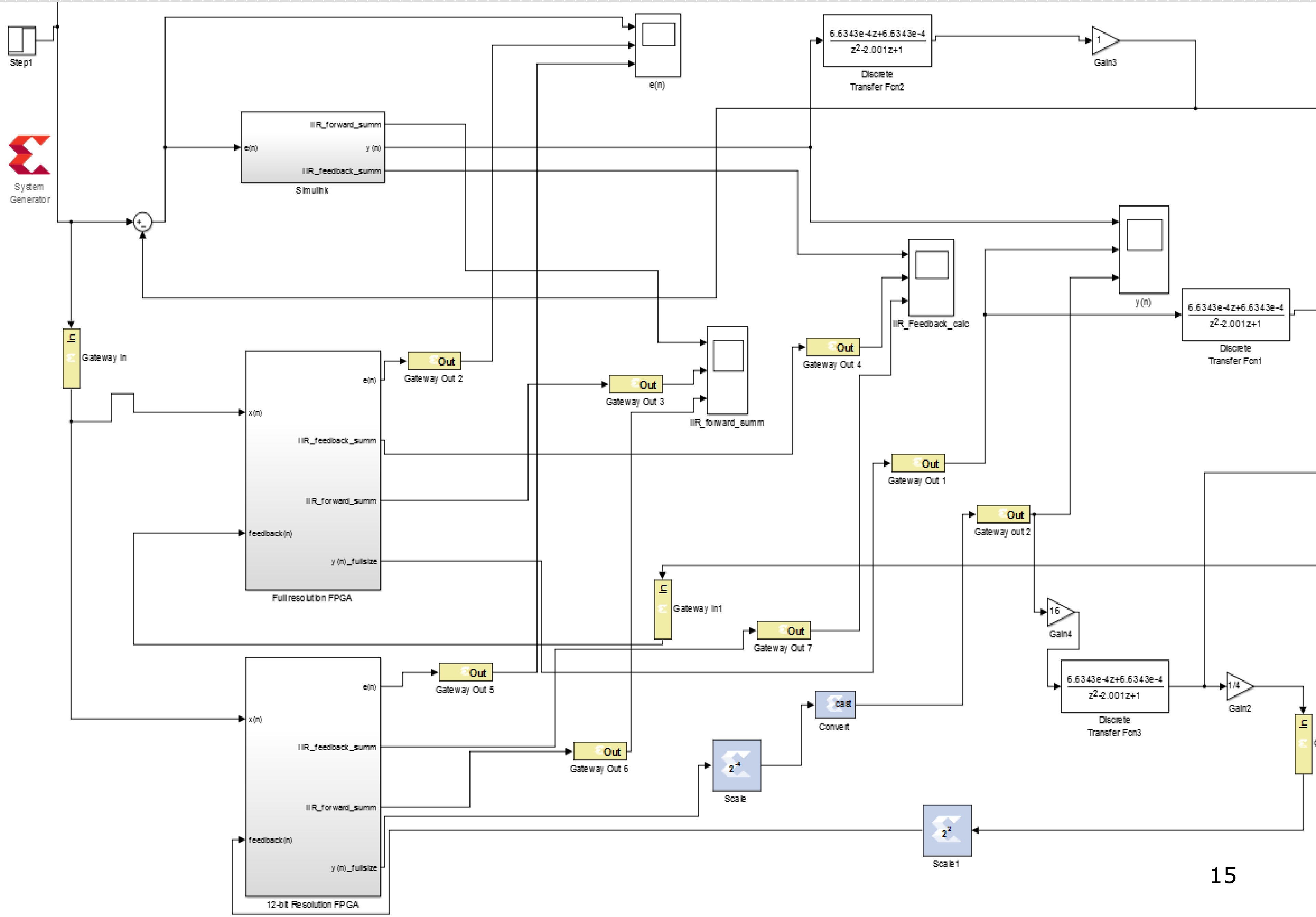
Control Block Diagram



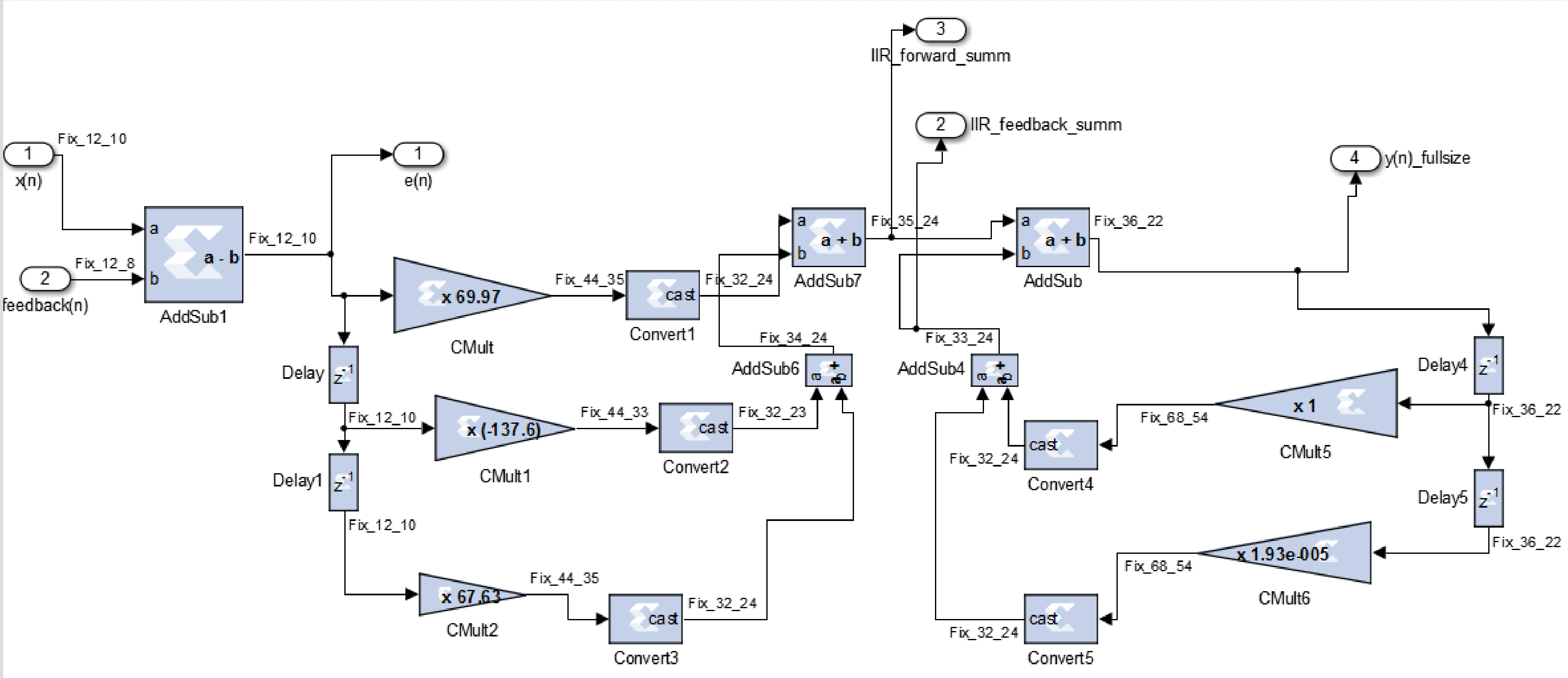
Design and Simulation

- Simulink and Xilinx System Generator

Simulink, Full-length FPGA, Reduced-length FPGA Modules



Details of reduced-length FPGA design module



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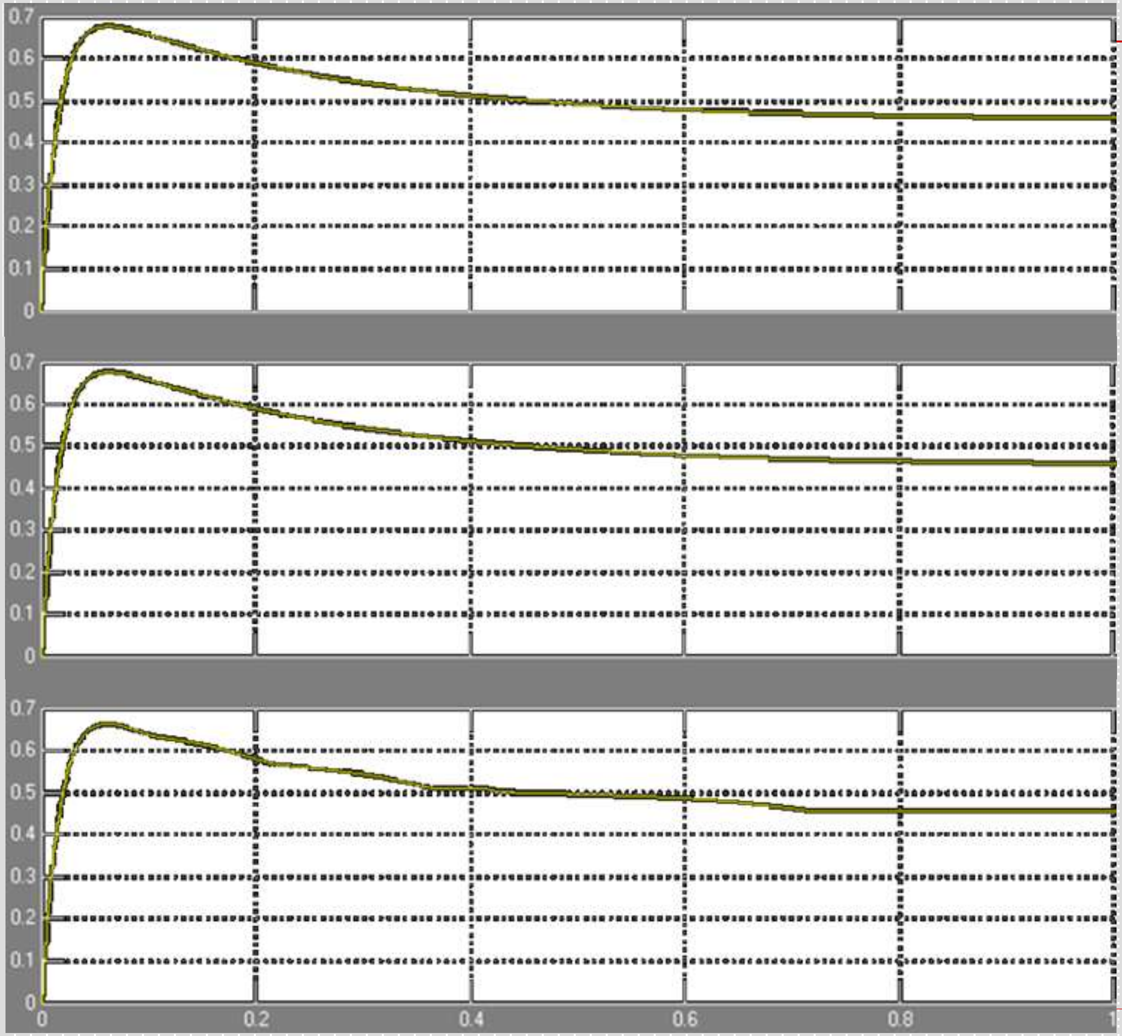
Simulation Results



Simulink module

Full-length FPGA design module

Reduced-length FPGA design module

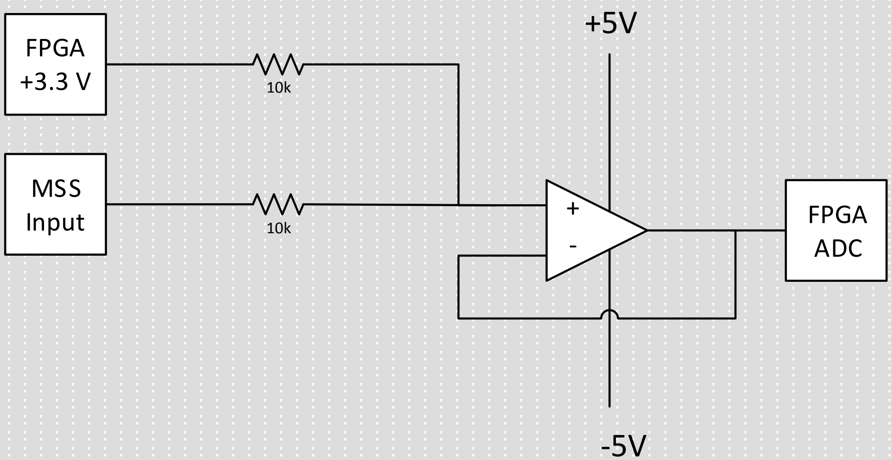
Testing and Conditioning Circuitry

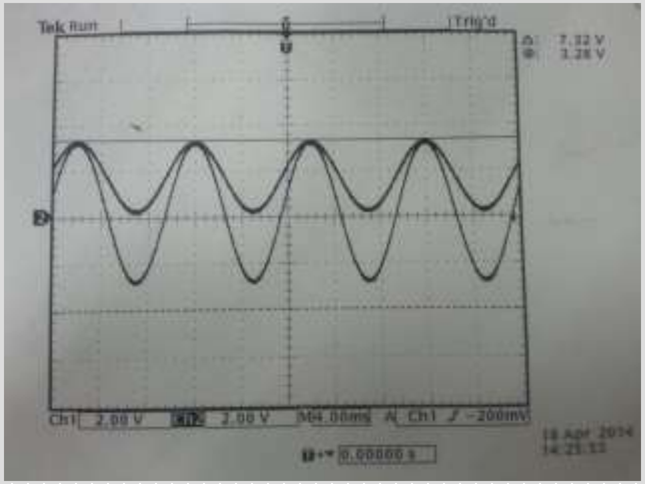
- Tested Voltage Ranges of Multiple Controllers

- Dunlap's Controller→ [-3V to +3V]
- Boline's #1 Controller → [-2V to +2V]
- Boline's #2 Controller → [-3V to +3V]

- Desired Worst Case Range → [-3V to +3V]

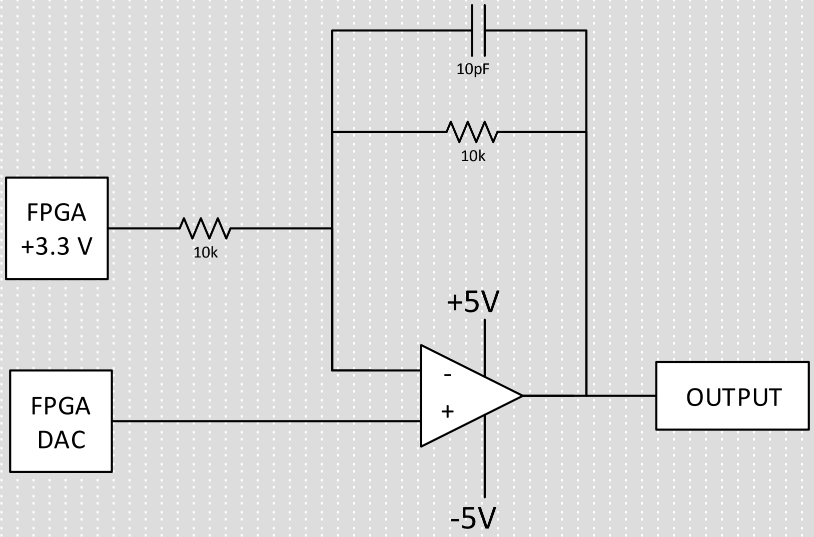
Circuit #1 → Bipolar to Unipolar

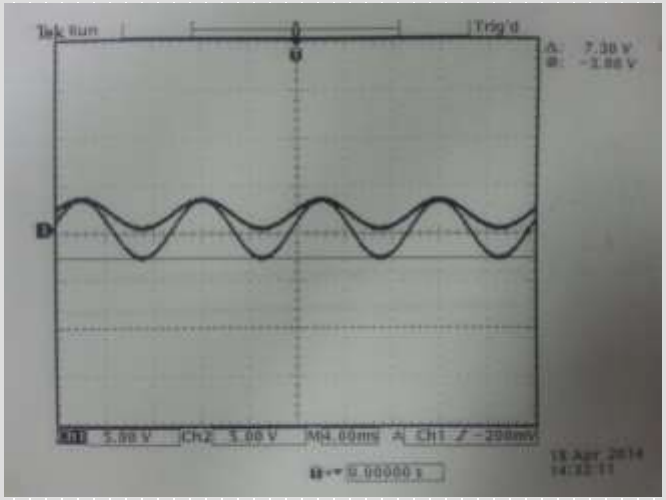




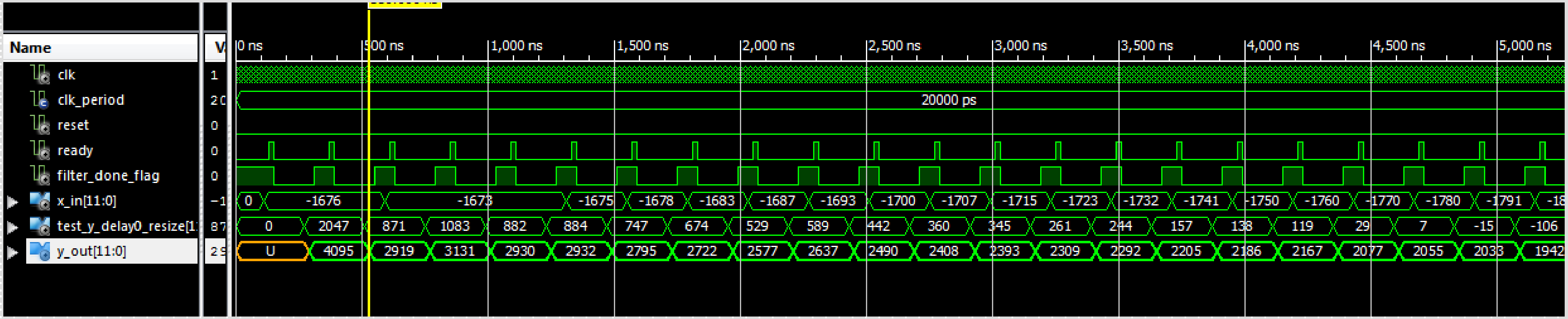
Conditioning Circuitry

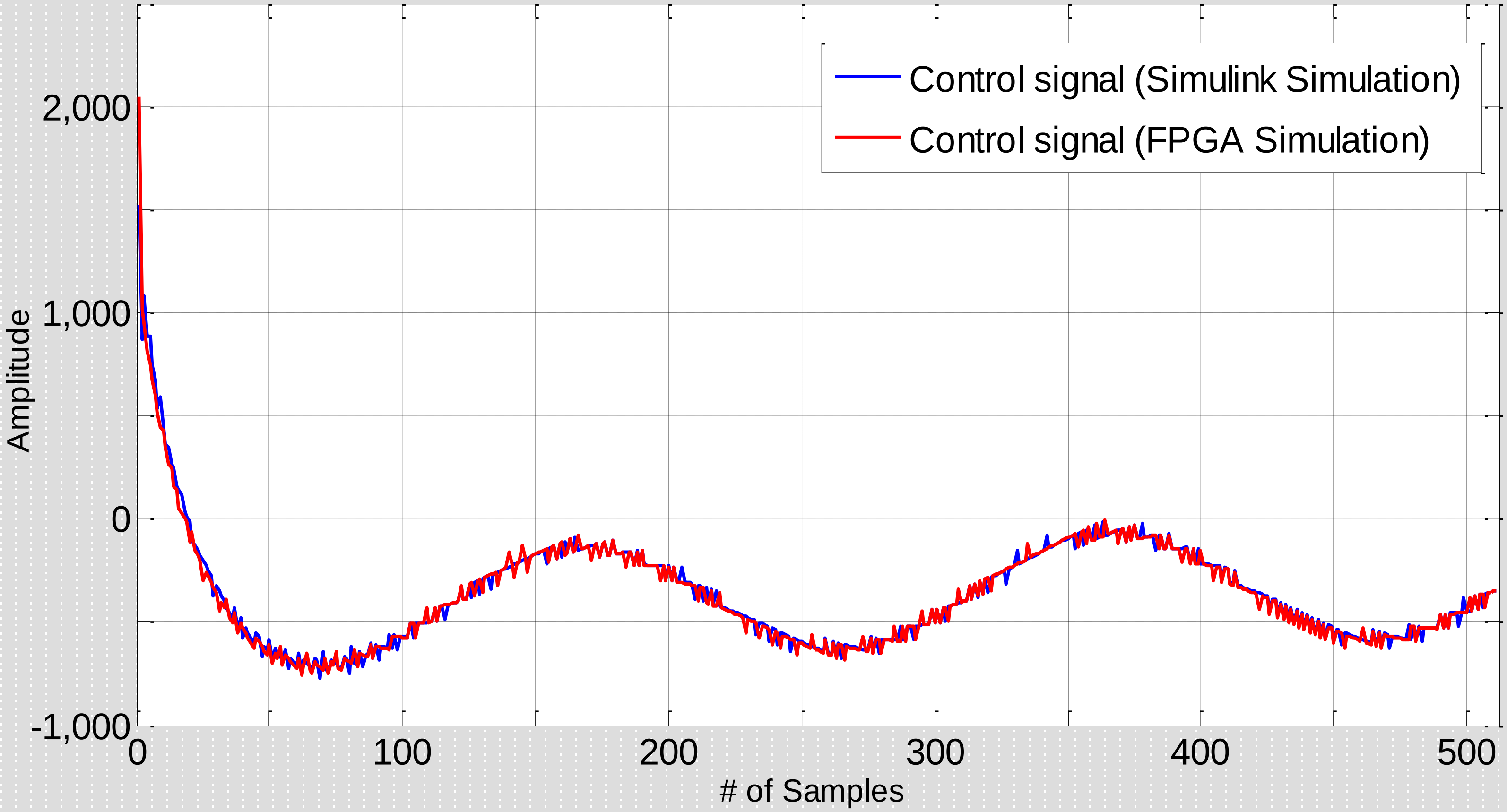
- Circuit #2 → Unipolar to Bipolar



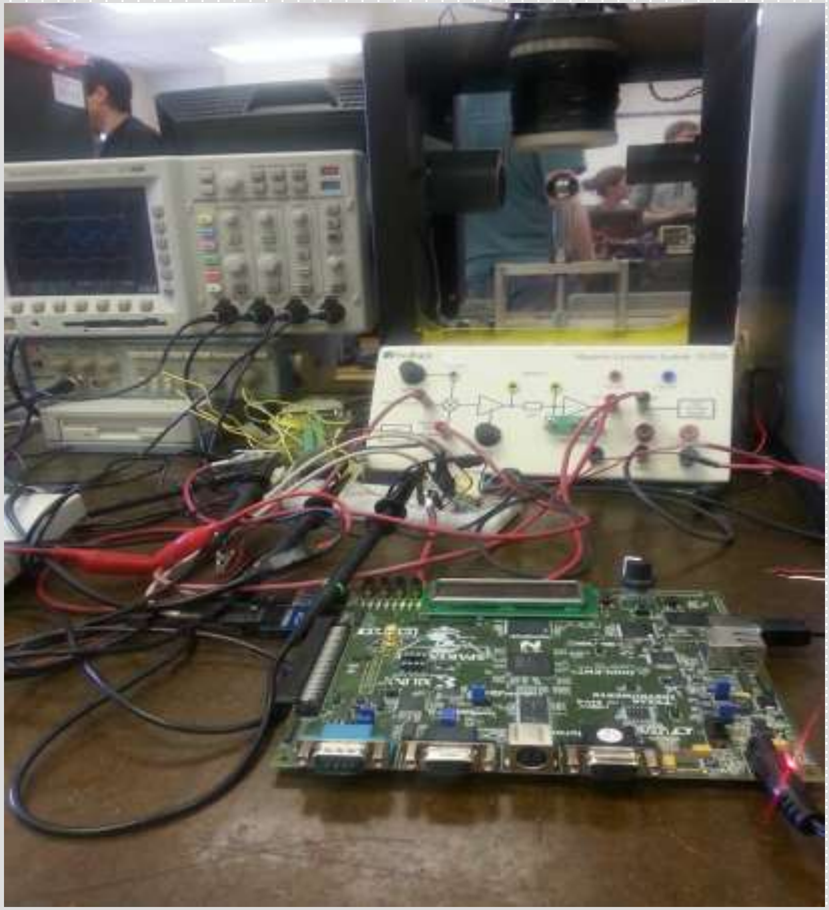


VHDL Simulation Results

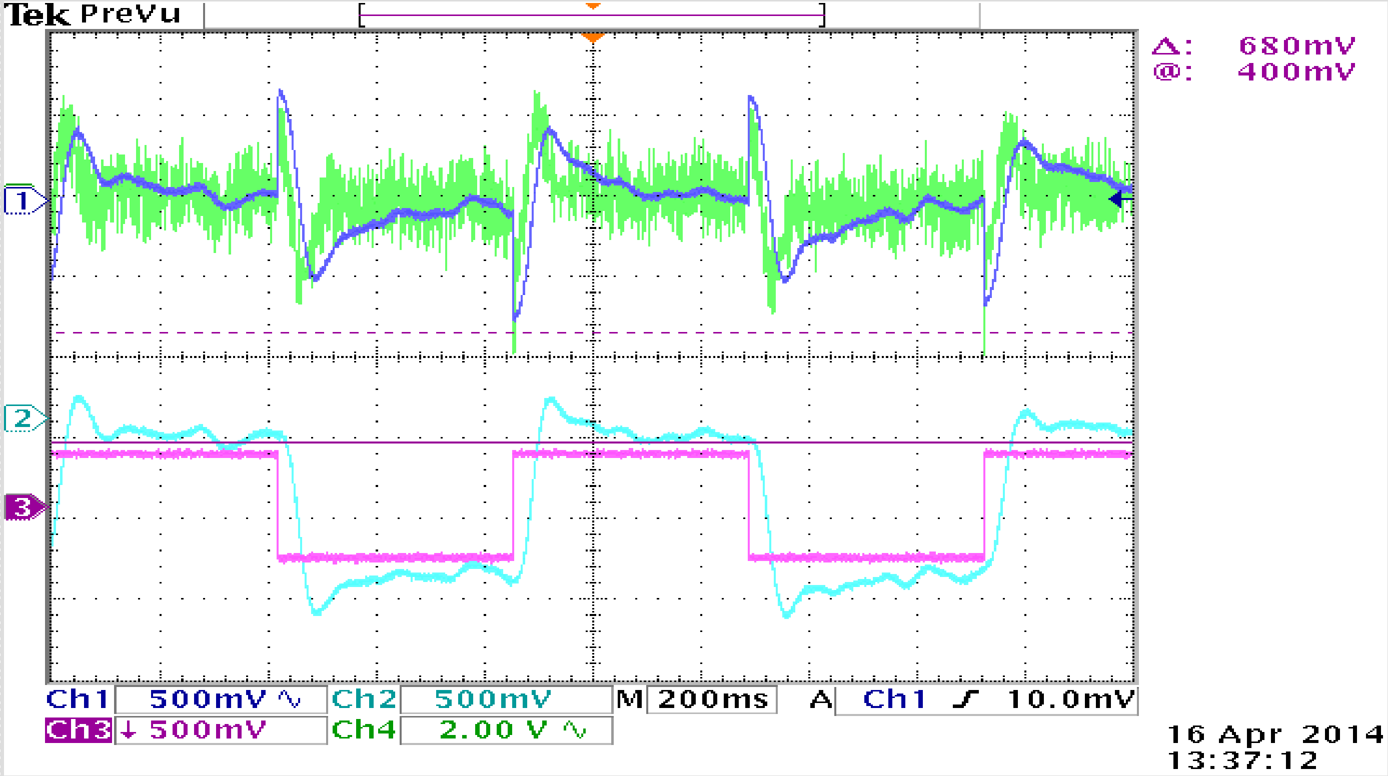



Control signal (Simulink Simulation)
Control signal (FPGA Simulation)
2,000
1,000
0
-1,000
Amplitude
0
100
200
300
400
500
# of Samples

System Setup



Hardware Implementation Results



Comparative Results

Using square wave input → 0.5Hz and 0.25V Amplitude

	Overshoot	Settling Time	Steady State Error
xPC Target Box	24%	0.41 sec	Zero
FPGA	TBD	TBD	TBD

Conclusion

- FPGA-based controller for magnetic suspension system has been designed
- Xilinx system generator proven to be efficient design tool of adjusting finite word-length for FPGA implementation
- VHDL design for the controller is completed
- For the comparative study, more measurements, testing and analysis are needed
- This project proved FPGA is viable solution for control application

References

[1] Jose A. Lopez and Winfred K.N. Anakwa, "Identification and Control of a Magnetic Suspension System using Simulink and dSPACE Tools", Proceedings of the ASEE Illinois/Indiana 2003 Sectional Conference, March 27, 2004, Peoria, Illinois, U.S.A.

[2] Jon Dunlap, "Design of Disturbance Rejection Controllers for a Magnetic Suspension System", Bradley University Department of Electrical and Computer Engineering, May 8, 2006, Peoria, Illinois, U.S.A

[3] Gary Boline and Andrew Michalets, "Magnetic Suspension System Control Using Position and Current Feedback", Bradley University Department of Electrical and Computer Engineering, May 17, 2007, Peoria, Illinois, U.S.A

[4] B.A. Francis and W.M. Wonham, "The Internal Model Principle of Control Theory," *Automatica*. Vol. 12, pp 457-465, 1976.

Questions?

Thank you