FPGA Implementation of Multiple Controllers for a Magnetic Suspension System

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Motivation

- System modeling and dynamics of magnetic suspension system are interesting and challenging due to the nonlinear nature of the system.
- A linear plant model has been studied, different controllers have been designed and implemented on various hardware platforms including xPC target box and Motorola ColdFire microcontroller using Simulink and real-time workshop[1,2].
- Field Programmable Gate Array(FPGA) has been widely used in embedded applications. It has advantages in design flexibility and functional enhancement.
- In this project, FPGA is used to implement controllers for magnetic suspension system.

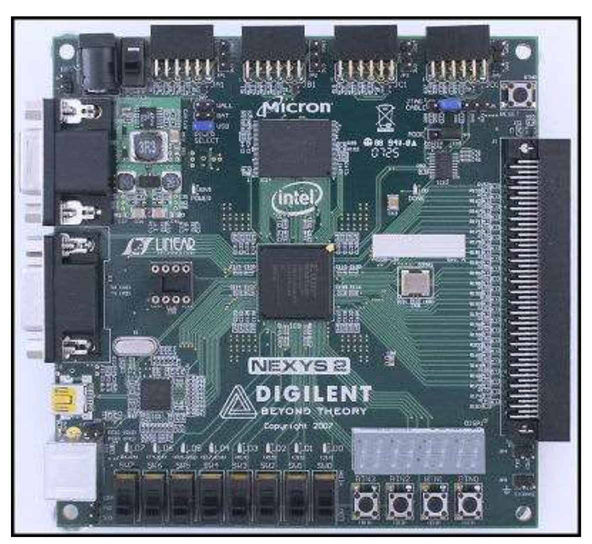

Fig 1. Spartan3E FPGA board

Fig 2. Magnetic suspension system

Project Goals

The project aims to design and implement a stand-alone system to demonstrate various controllers for magnetic suspension system. Details are described below.

- The system includes Xilinx Spartan3E FPGA, digital- to-analog (D/A) converter, analog-to-digital(A/D) converter and conditioning circuitry.
- Design and simulate controllers using *Xilinx system generator*, a design tool for FPGA fixed-point implementation.
- Study finite word-length effect and determine appropriate precisions for FPGA implementation.
- Program controllers in VHDL and compare FPGA implementation results with those from xPC Target Box and Motorola ColdFire microcontroller in terms of steady-state error, overshoot, and settling time.

System modeling and dynamics of magnetic suspension system[1]

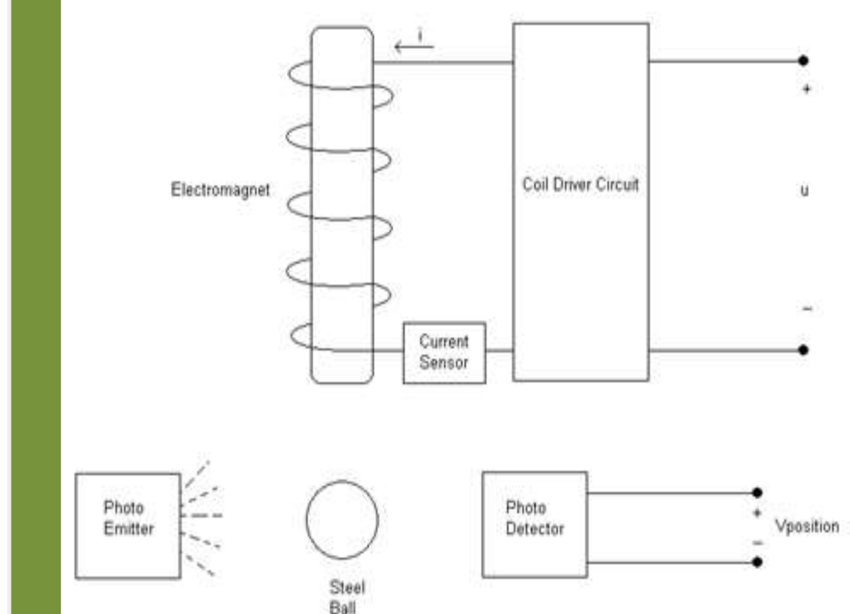

Fig 3. Diagram of Magnetic suspension system [1]

$$\dot{x}_1 = x_2$$

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

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

Linear Plant Model [1]

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

Ts = 0.001 s

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

Transfer functions of plant model

Design and Simulation using Simulink and Xilinx System Generator

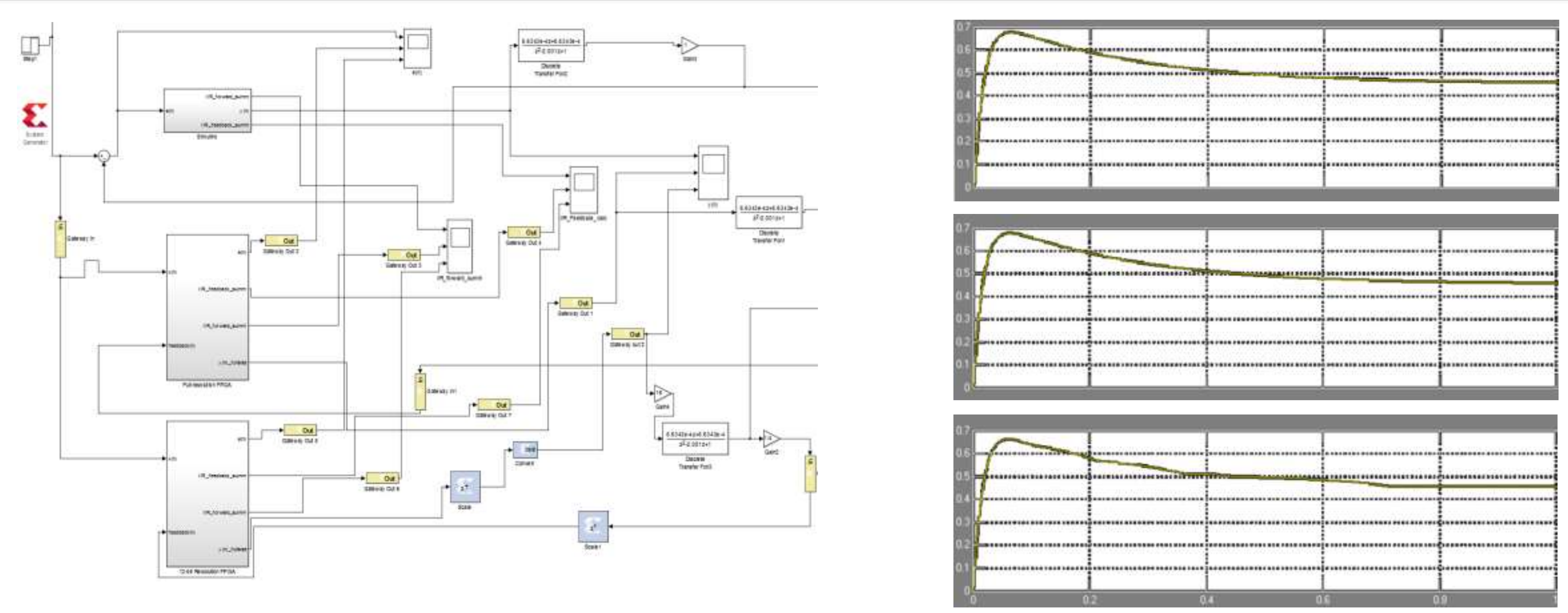

Fig 4. (From top to down) Simulink module , Full-length FPGA design module and reduced-length FPGA design module

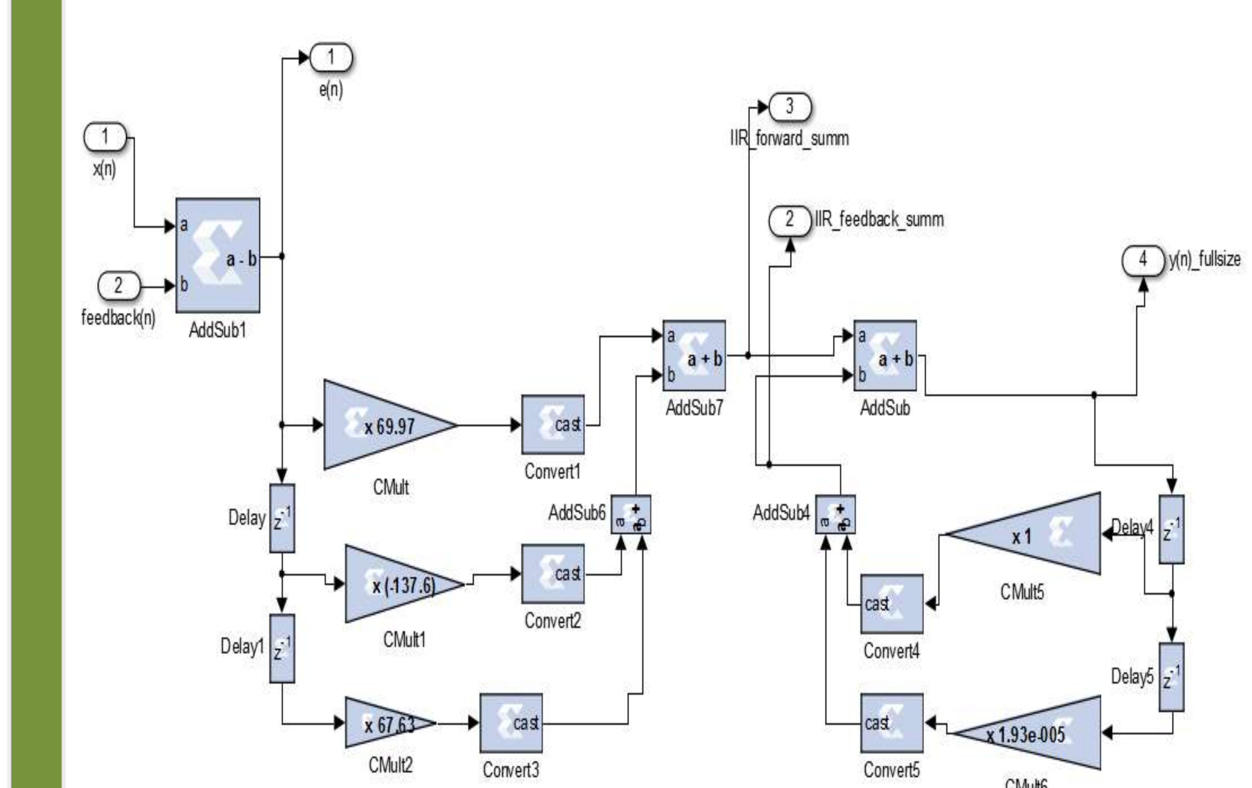

Fig 5. Details of reduced-length FPGA design module

Conditioning circuitry is built to interface unipolar D/A and A/D converters

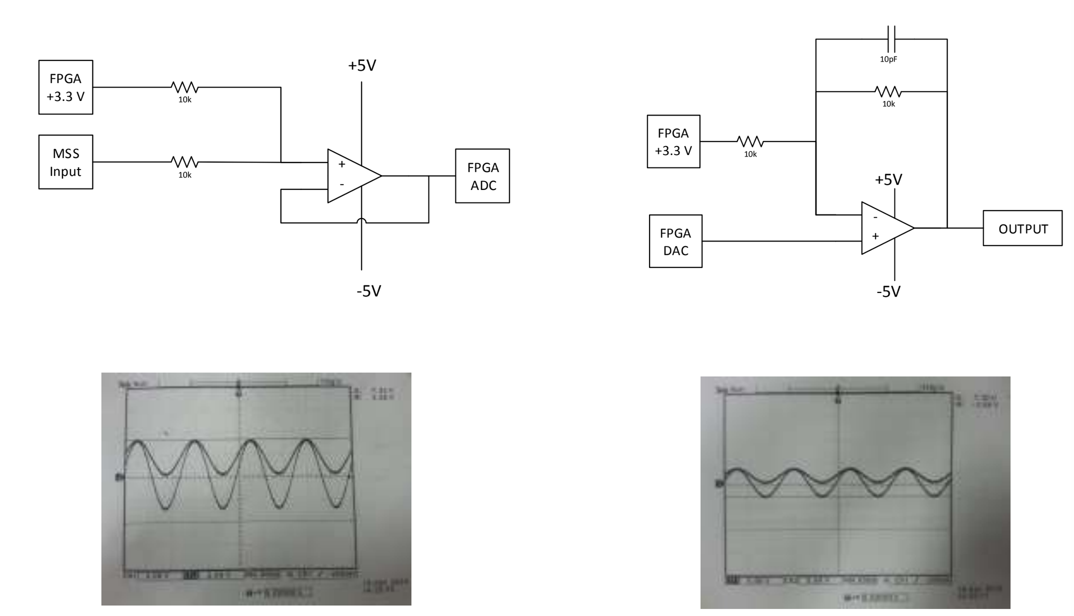

Fig 6. Conditioning Circuitry

Simulation results from the controller design using VHDL

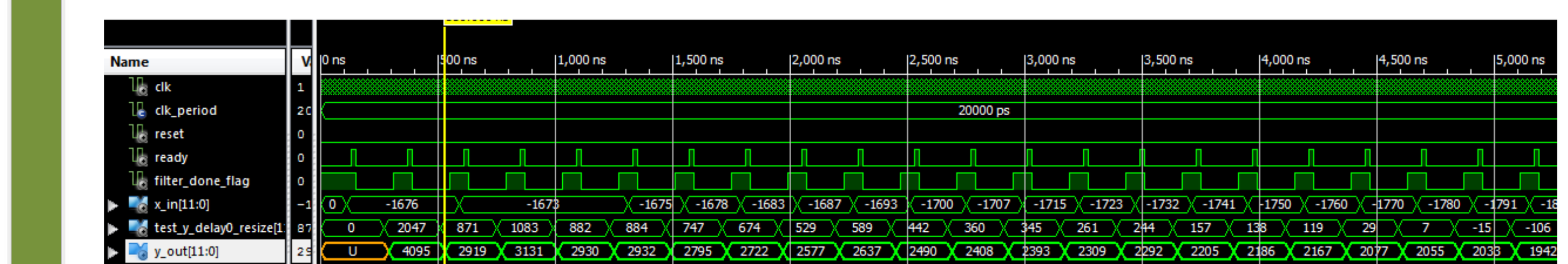

Fig 7. VHDL simulation results (see above)

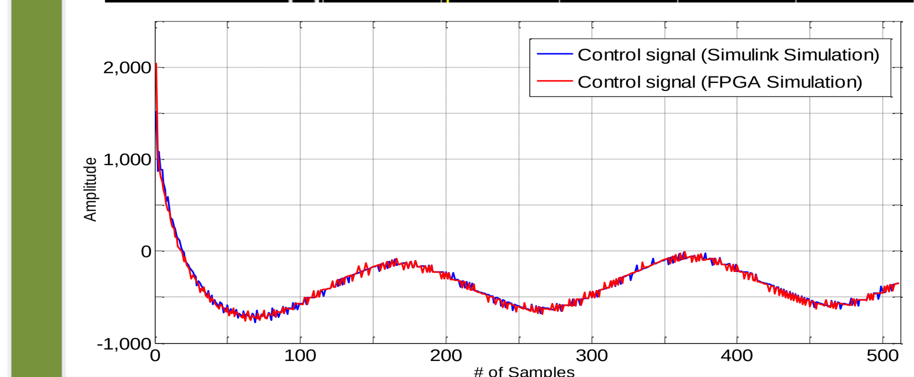

Fig 8. Comparison of the control signals from Simulink (in BLUE) and VHDL (in RED)

System Block Diagram

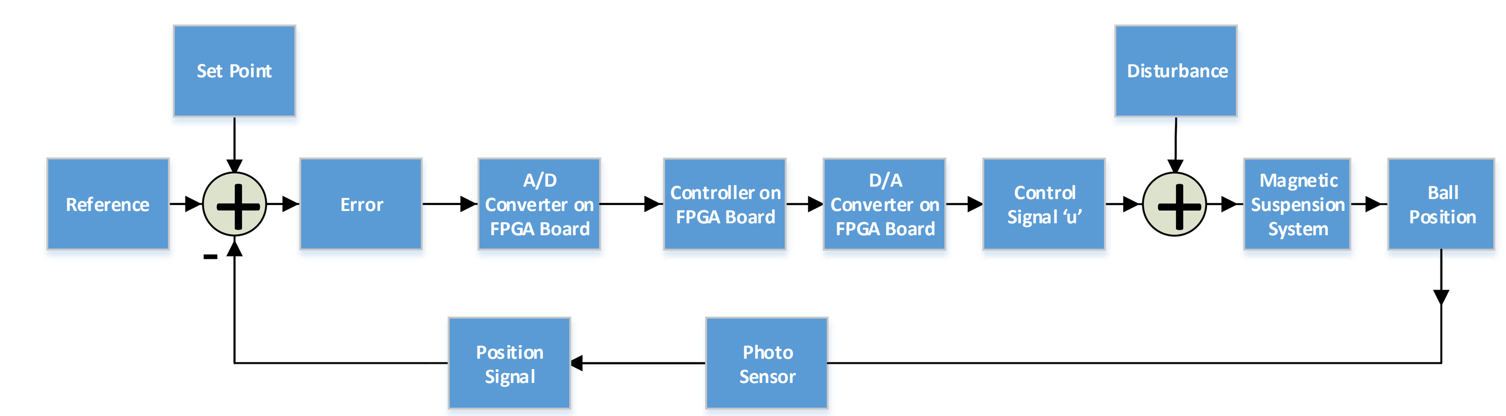

Fig 9. System block diagram

System Setup and Hardware Implementation Results

Fig 10. System Setup

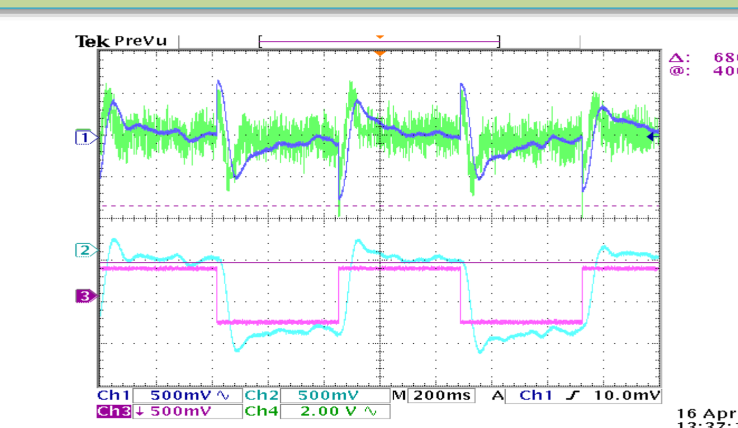

Fig 11. Top: Error signal and control signal
Bottom: Reference signal and position signal

Conclusion

In this project, an FPGA-based controller for magnetic suspension system has been successfully implemented using Xilinx tools. Further comparative analysis and measurements are needed. Nevertheless, this study shows that FPGA is a viable solution for control application. System generator has been proven to be an efficient design tool of adjusting finite word-length for digital designs.

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", Senior project report, Department of Electrical and Computer Engineering, May 2006, Peoria, Illinois, U.S.A.