EE-344 | Electronics Design Lab

Group 21 : Project Report

Digitally Programmable Analog Computer for Non-linear Dynamical Systems

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Contents

1 Abstract

Hardware-in-the-loop (HIL) simulation, or HWIL, is a technique that is used in the development and test of complex real-time embedded systems. HIL simulation provides an effective platform by adding the complexity of the plant under control to the test platform. The complexity of the plant under control is included in test and development by adding a mathematical representation of all related dynamic systems. HIL simulations find uses in various disciplines such as Power Systems, Automotive systems, Robotics etc. Emerging microscopic robots require the use of powerful mathematical models to simulate the physical world. Problems such as fluid dynamics and optimal control, once considered super-computing workloads, are now needed in autonomous mobile robots. These problems are phrased as nonlinear differential equations.

In this project we tackle the important problem class of solving non-linear/linear differential equations using a digitally programmable analog computer that has the traits of both an analog computer and digital computer. Digital computing offers ease of use and flexible programming while analog computing enables fast real time processing. For calculus functions such as integration, unlike digital computing, analog computing does not suffer from step size limitations. Hence, we use a hybrid analog-digital computer architecture to solve differential equations that draws on the strengths of each model of computation and avoids their weaknesses.

2 Objectives

- In this project we tackle the important problem class of solving non-linear/linear differential equations using a digitally programmable analog computer that has the traits of both an analog computer and digital computer.
- Develop a system that can solve a non-linear dynamical system described by:

$$\frac{dx_i}{dt} = f_i(x_1, x_2, x_3, x_4, x_5) + \phi_{1,2,3}$$

  where $f_i()$ can be non-linear and ϕ_i represents the forcing function.

3 Technical Design

3.1 Possible Solutions and Design Alternatives

- **Amount of analog computation :**
  The amount of analog computing can differ over different designs. One can include summations of the different terms or even the computation of terms involving multiplication in analog processing. But doing so will requiring an increase in the output channels of the DAC and will also increase the time required to complete one loop. Hence our analog computation will only include integration of the signal.
- **Input of forcing functions :**
  The forcing function can be introduced in the loop at two positions, at the input of ADC or at the output of DAC we can sum with appropriate signals and provide to integrator. If it's at the ADC input, it can be sampled at the same time as the state variables. If it's at the DAC output it frees up the ADC channels making more number of state variables possible but one also need to account for the corresponding time delay for the processing and insert a suitable delay using analog methods. Hence, we choose to implement forcing functions at the ADC input with additional digitally programmable forcing functions in the processor as per the user discretion.

4 System Overview

4.1 Specifications

- The system is able to solve non-linear differential equations having upto 8 state variables and 4 external analog forcing functions
- Apart from external analog forcing functions, digitally generated forcing functions can also be incorporated

- The power system generates all the DC supply voltages (±5V and 3.3V) required by the ADC, DAC, processor and op-amps from 230V, 50Hz AC supply
- The equations are programmed into the processor using an mini-USB interface which is also used to supply power to microprocessor

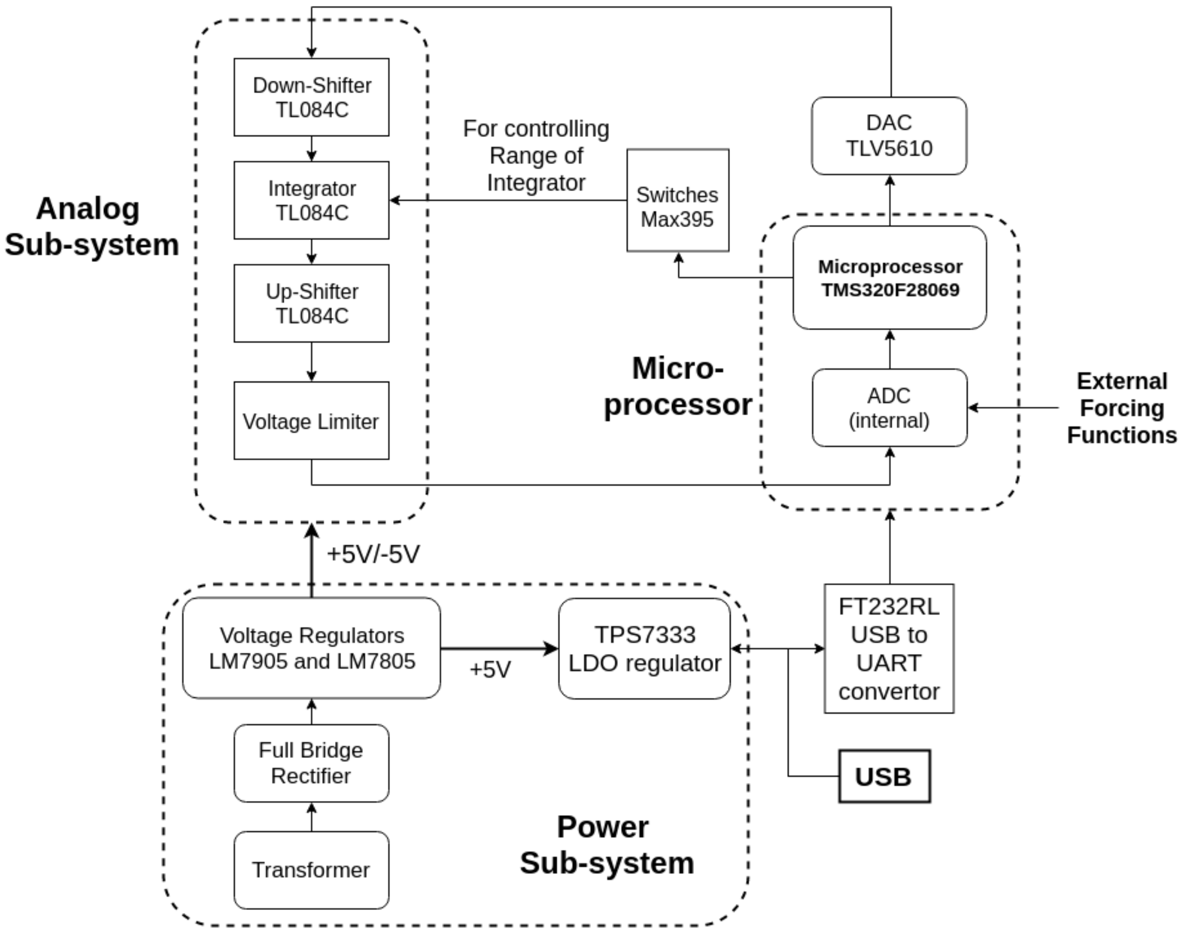

Figure 1: System level block diagram

4.2 Details of the subsystems

4.2.1 Analog Sub-system

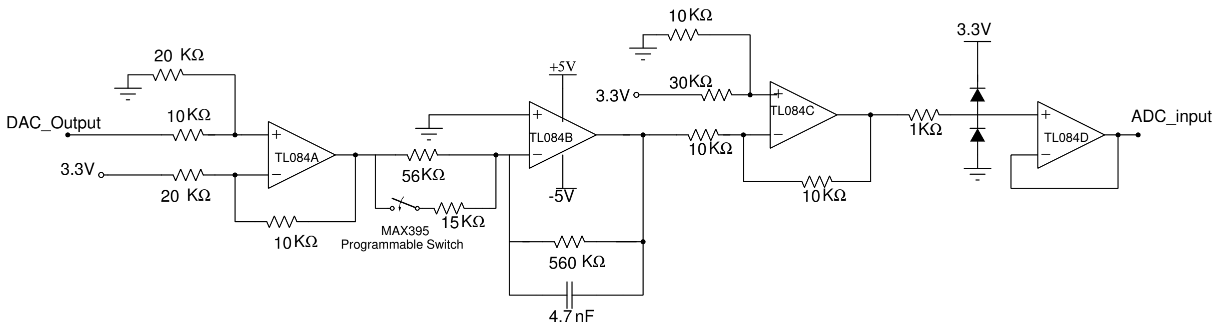

Figure 2: Analog Subsystem

As mentioned before, we will be using analog sub-system only for integration operation. Since the ADC and DAC used in the circuit are unipolar there was a need to design a level-up and level-down shifter. We also built a limiter circuit inorder to ensure that the input to ADC is between 0 and 3.3V.

4.2.2 Digital Subsystem

The microprocessor is used to calculate the differential function which can be linear/non-linear. It can also be used to control the range of analog integrator by controlling switch IC, MAX395.

4.2.3 Power Subsystem

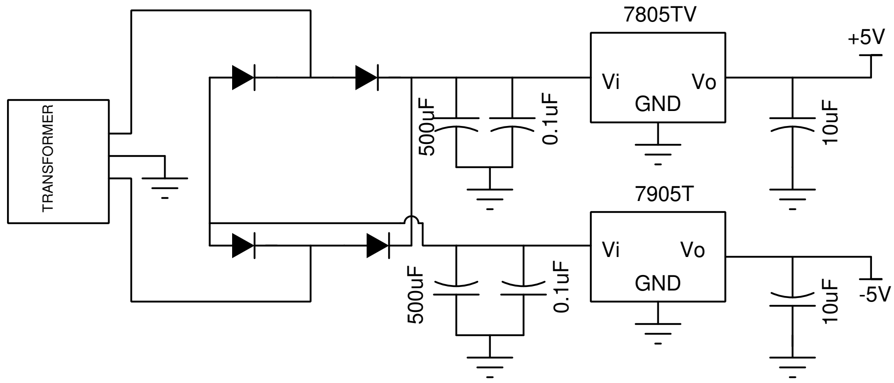

Figure 3: Power Subsystem

It is used to supply rail voltages(+/-5V) to the Opamps in the analog subsystem and 3.3V to the processor. There's also an option of powering the processor via USB only. The power circuit can convert the voltage from power socket to $\pm$5V, 3.3V.

4.3 Board

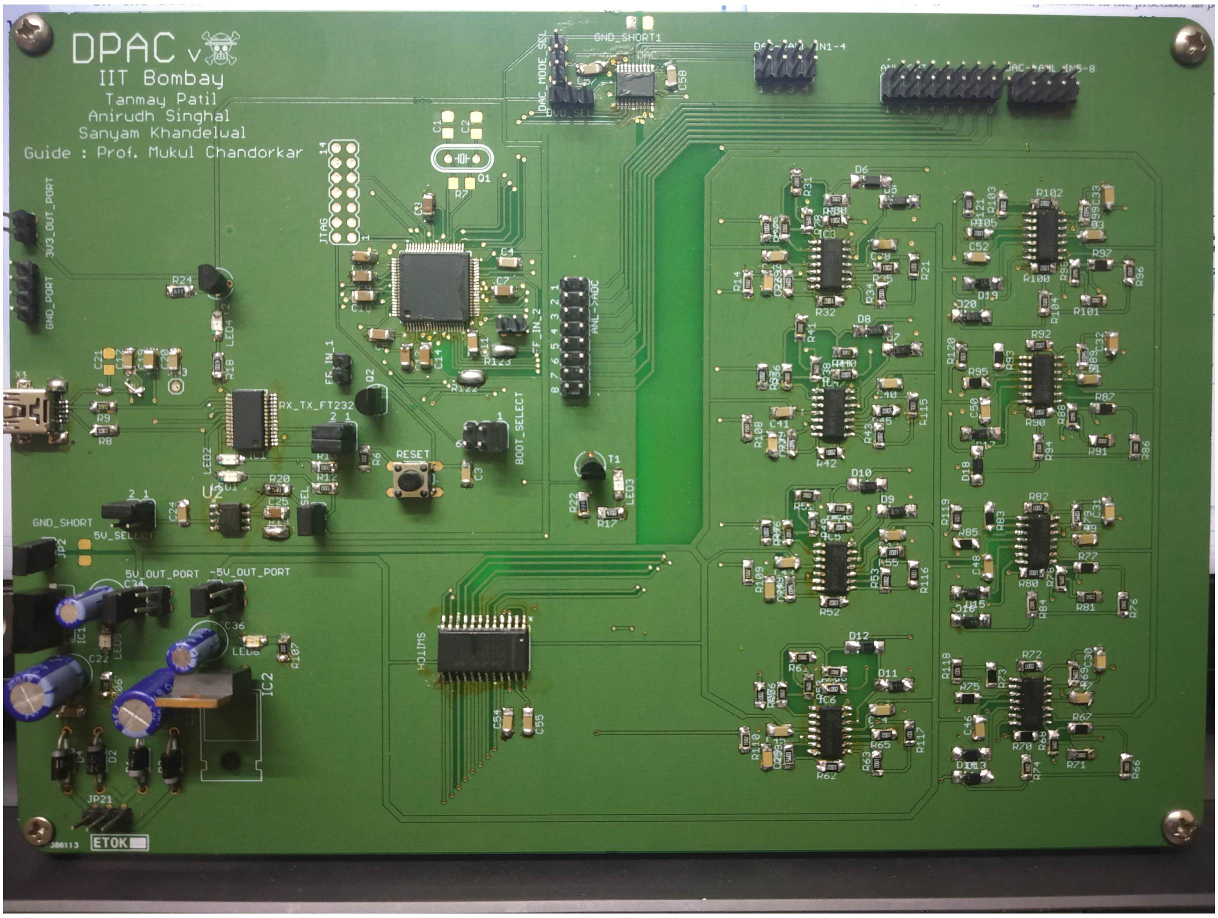

Figure 4: DPACv2.0

5 Results

5.1 First Order Linear System

$$\frac{dx}{dt} = -x + sin(2\pi * 600t)$$

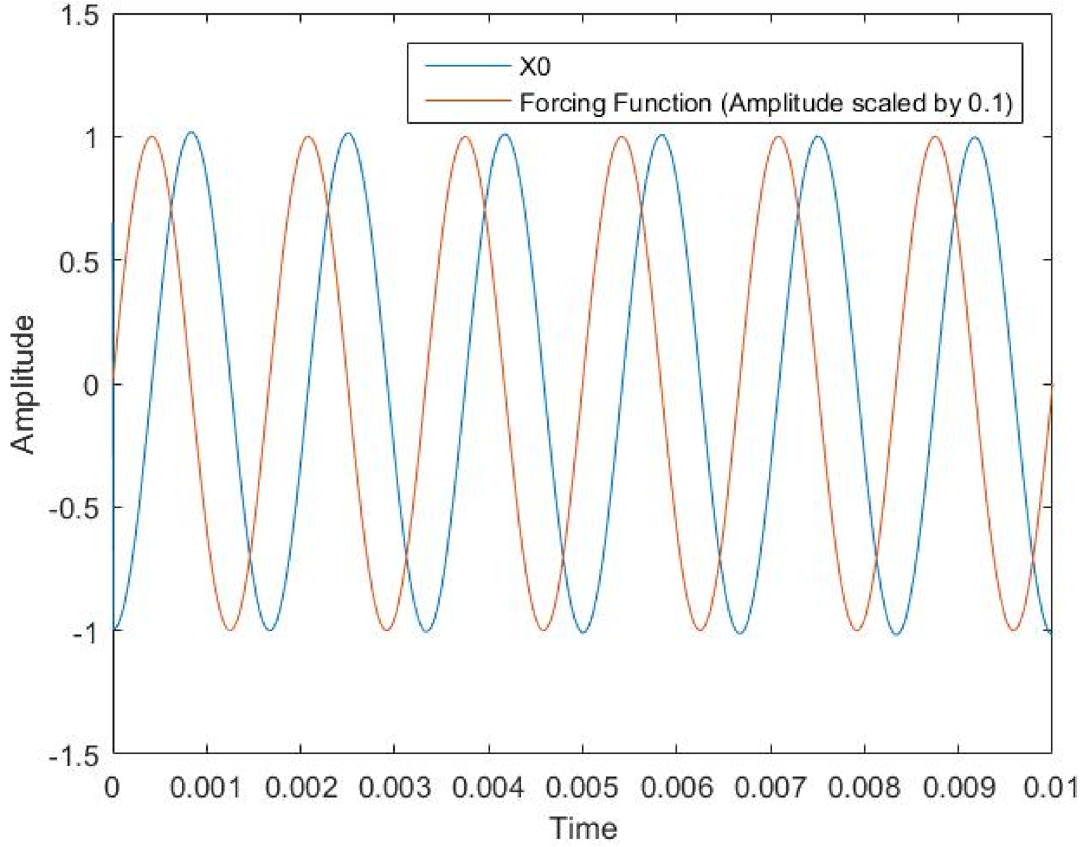

Figure 5: Simulation for first order Linear System

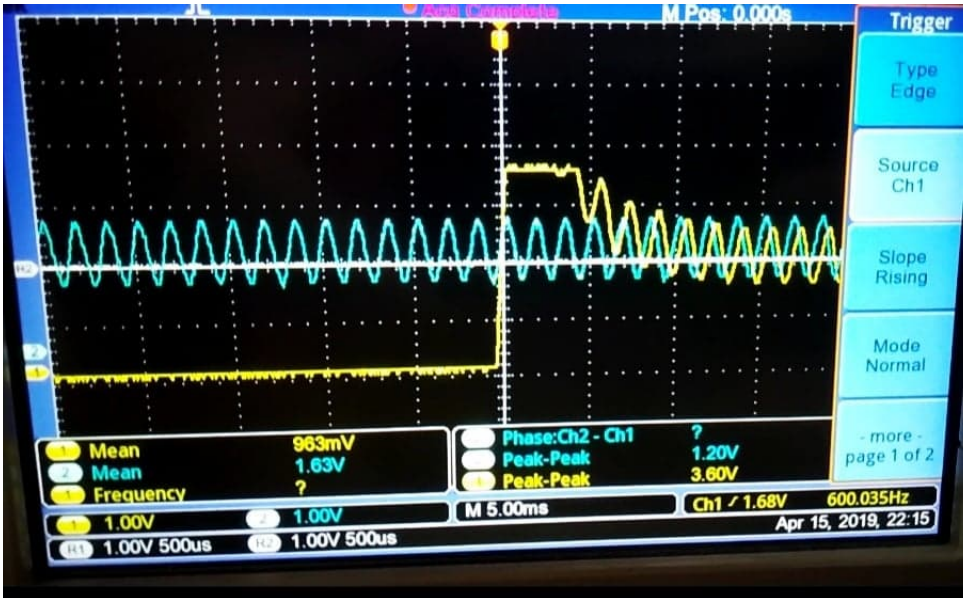

Figure 6: Transient Response obtained when solved using DPAC

5.2 Second Order Linear System

$$\dot{X} = 2\pi f_0(AX + u)$$

Where,

$$A : \begin{bmatrix} -2 & -1 \\ 1 & 0 \end{bmatrix}$$

$$\text{u} : [0.5\sin(2\pi f_0 t)]^T$$

$$f_0 = 800Hz$$

$$R = 2; L = C = 0$$

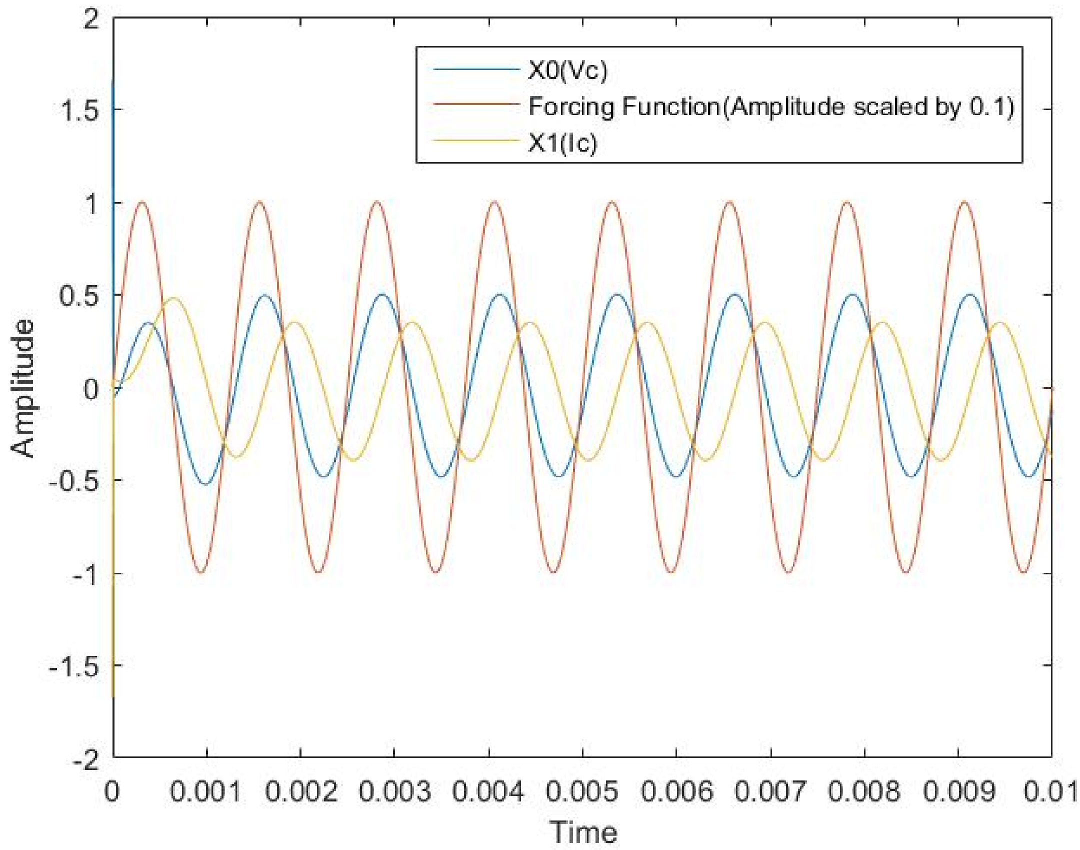

Figure 7: Simulation for second order Linear System(RLC circuit)

Figure 8: Current and Forcing Function, with Current set as zero initially

Figure 9: Voltage and Current steady state response

5.3 Second Order Non-Linear System

$$\frac{dx_0}{dt} = -2\pi f_0 x_0 x_1 + sin(2\pi f_0)$$
$$\frac{dx_1}{dt} = x_0$$
$$f_0 = 800Hz$$

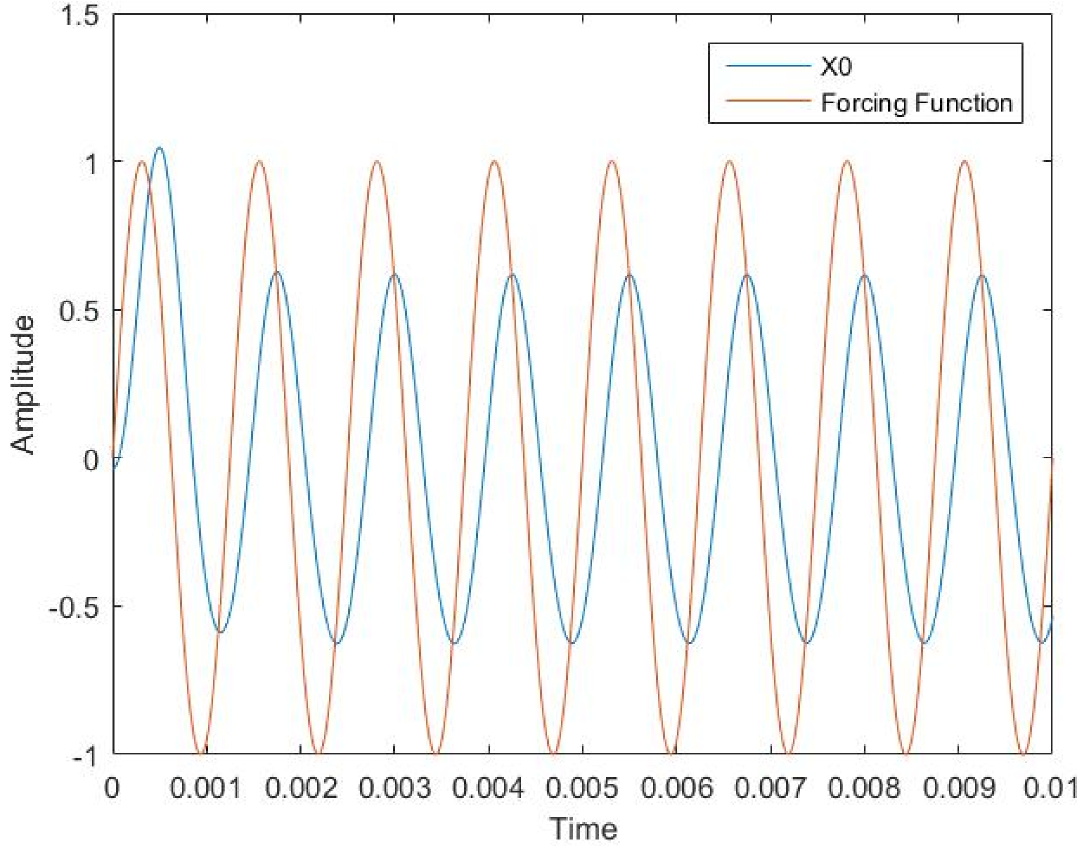

Figure 10: Simulation for second order Non-Linear System

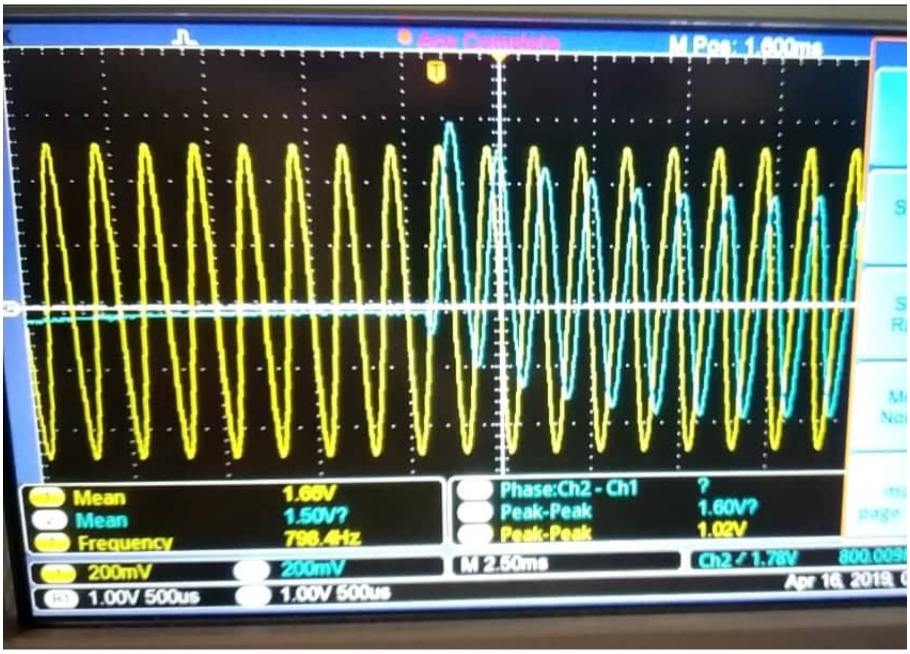

Figure 11: Results obtained using DPAC

5.4 Damped Oscillations

$$\frac{dx_0}{dt} = x_1$$
$$\frac{dx_1}{dt} = -x_0 - \frac{x_1}{2}$$

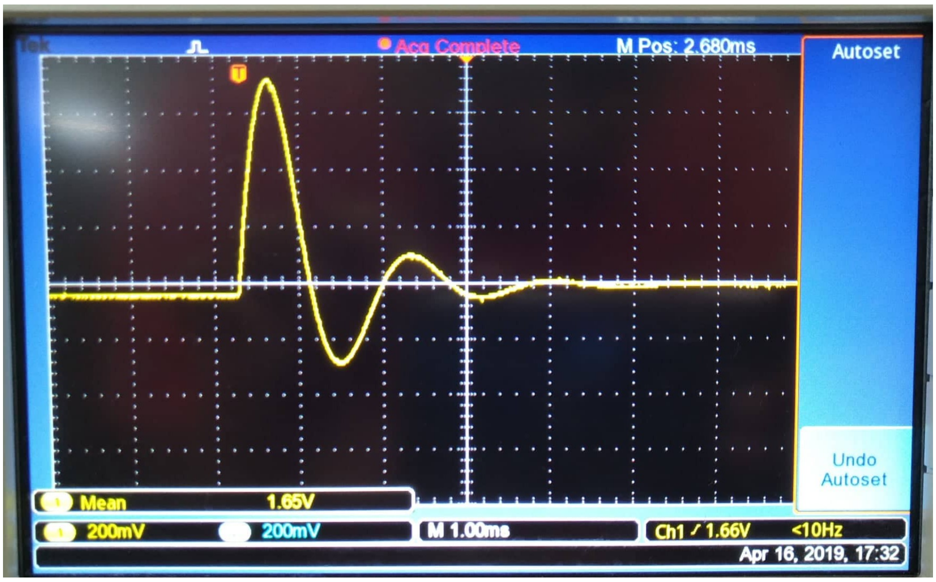

Figure 12: Result Obtained via DPAC