Reprogrammable Analog Ordinary Differential Equation Solver

Project

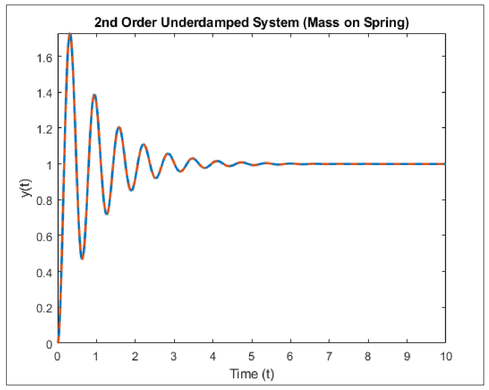
Problem Description and Motivation

Solving high-order differential equations digitally can be slow and computationally intensive especially in real-time systems.

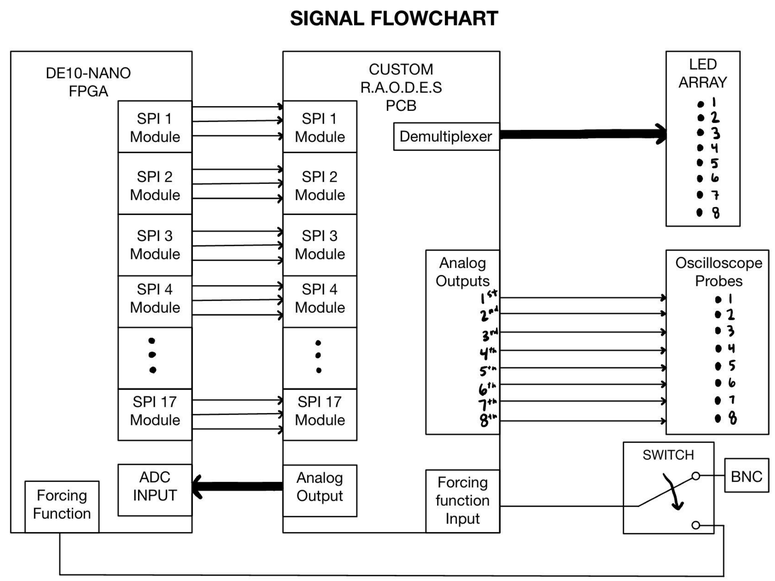
We built a real time reprogrammable analog computer that solves up to 8th-order linear ODEs using op-amp circuits and digitally controlled resistors, with synchronized configuration via FPGA.

Why It Matters

Our system provides fast, hardware-based solutions ideal for real-time simulation.

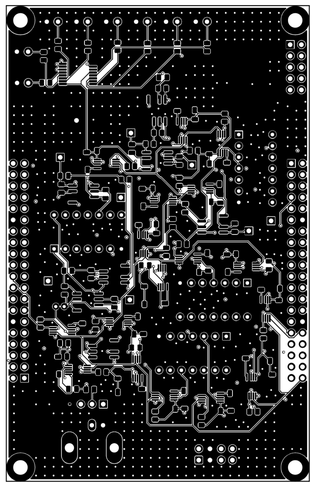


System



Methods

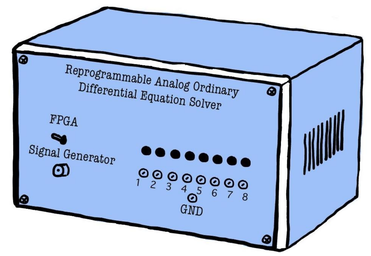
- We used op-amp circuits for integrators, adders, and scalers, with 17 digital potentiometers setting coefficients. An FPGA (DE10-Nano) controlled all 17 SPI channels in parallel for synchronized updates, chosen for its high GPIO count.
- A custom PCB was designed to match the FPGA's footprint, using surface-mount ICs to keep the layout compact—through-hole components would have made it significantly larger.
- We simulated the full circuit in EveryCircuit (SPICE) to validate behavior before hardware implementation.



Final PCB Design

Conclusion

- Our analog solver matched results from MATLAB and SPICE, validating accuracy for 3rd–5th order ODEs. Higher-order verification (up to 8th) is harder to confirm due to simulation limits but appears consistent.
- We achieved real-time, reprogrammable ODE solving with FPGA-driven SPI control. The project also taught us advanced surface-mount PCB design, enabling a compact board footprint.
- Next steps:
  - Confirm full 8th-order accuracy
  - Explore non-linear/time-varying systems
  - Implement Practical User Interface
  - Miniaturize for embedded/educational tools



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