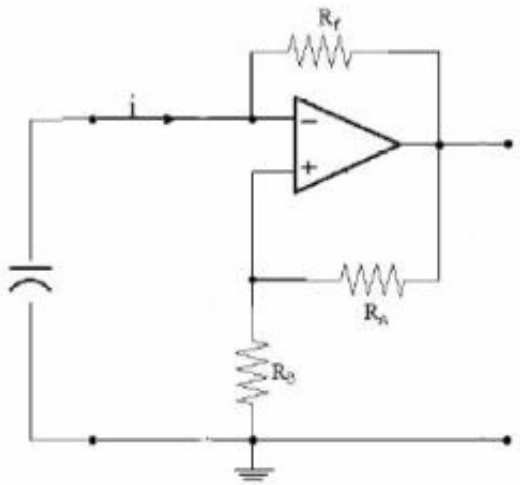
EE100 Summer 2007: WRAP UP
"Alls well that ends well"

The circuit shown here is a square-wave generator that you will build in lab. Circuits like these highlight the goal(s) of this class:
1. To help you learn basic concepts of electrical engineering and apply them to study useful circuits.
2. Build such circuits in lab. This will help you understand the practical limitations of circuit theory and hence make you think about the important differences between the academic world and the real world.
3. Interface such analog circuits to a microcontroller.



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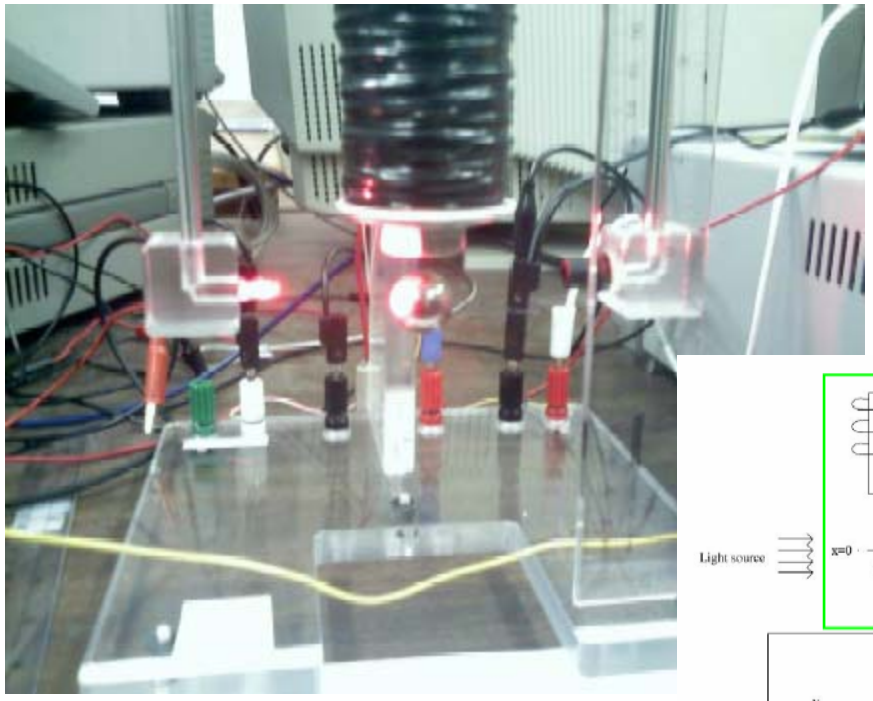
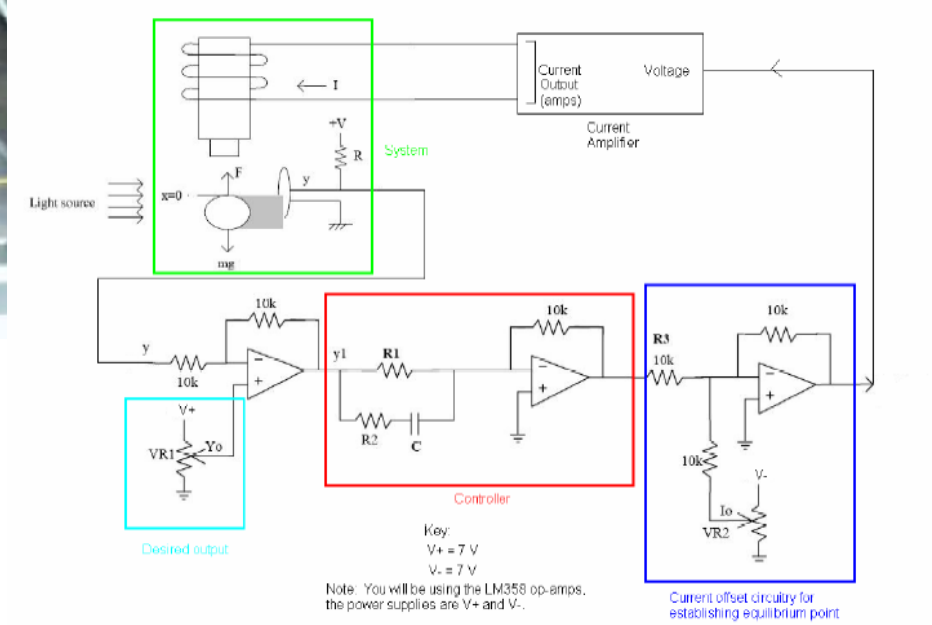
Outline

- Examples of systems:
  - Magnetic Levitation: EECS 128
  - Autonomous R/C cars: EECS 192
  - Digital Systems Design: EECS150, EECS152
- Courses you can take after EECS100/EECS42-43
- Sample Research Applications:
  - Reconfigurable Radio: FPGA SOCs
  - Introduction to Chaos using Chua's circuit
    - What is Chaos?
    - Chaos in Nature
    - Hallmarks of Chaos
      - Non-periodic behavior in time domain
      - Sensitive dependence on initial conditions
    - Proving the existence of Chaos
    - Easy Chaos: Chua's circuit
    - Building and working with Chua's circuit
      - References
      - Simulating Chua's circuit: MultiSim
      - Turning your PC into an oscilloscope: Osqoop
      - Chua's circuit for high school students
      - Interesting MATLAB experiments
- Questions

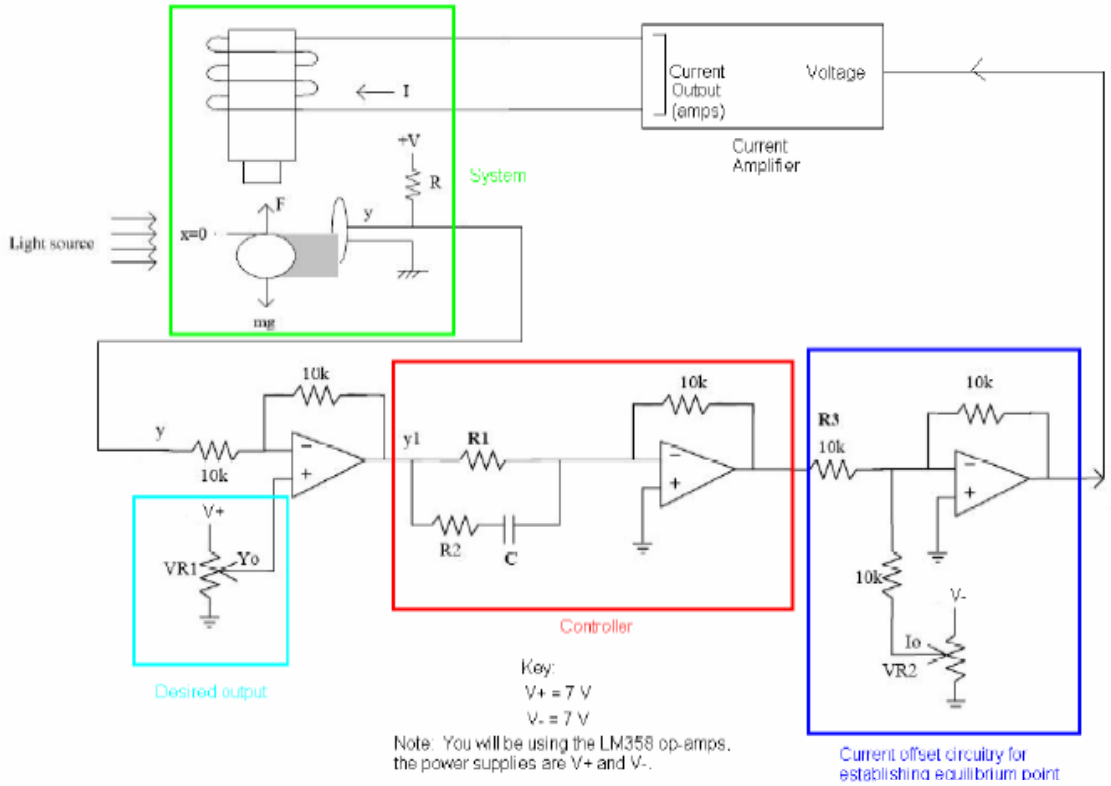
Examples of Systems: EECS 128





http://inst.eecs.berkeley.edu/~ee128

Examples of Systems: EECS 128



To find f(I,x): Find out the value of I that renders 0 N at x=0 position. Then, take force readings about x=0 and I=Io. [2] That is:

$$m\frac{d^2x}{dt^2} = f(I,x) - mg$$
$$= f(Io,0) + K_i i + K_x x - mg$$
$$= K_i i + K_x x$$

Thus, the linearized model of your system is:

$$\frac{d^2x}{dt^2} = \frac{K_x}{m}x + \frac{K_i}{m}i$$
$$y = ax$$

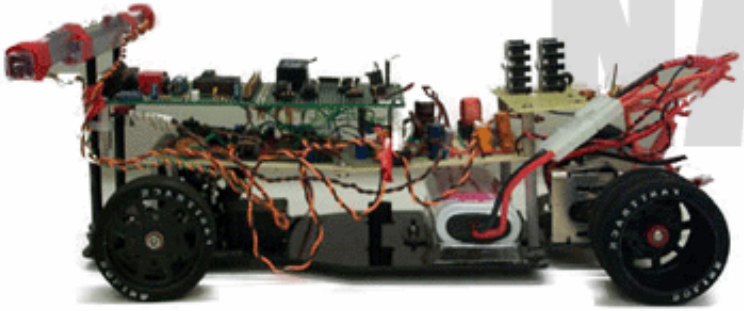
Linearize!

$$m\frac{d^2x}{dt^2} = f(I,x) - mg$$
$$y = h(x)$$

where: x: ball position in meters
m: mass of the ball (kg)
g: gravitational constant (m/s^2)
I: current in amperes (A)
$f(I,x)$: magnetic fornce (N) as a nonlinear function of x and I
$y(x)$: output voltage (V) as a nonlinear function of the ball position

Examples of Systems: EECS 192

Welcome to the Mechatronics Design Lab for Spring 2007.



EECS 192

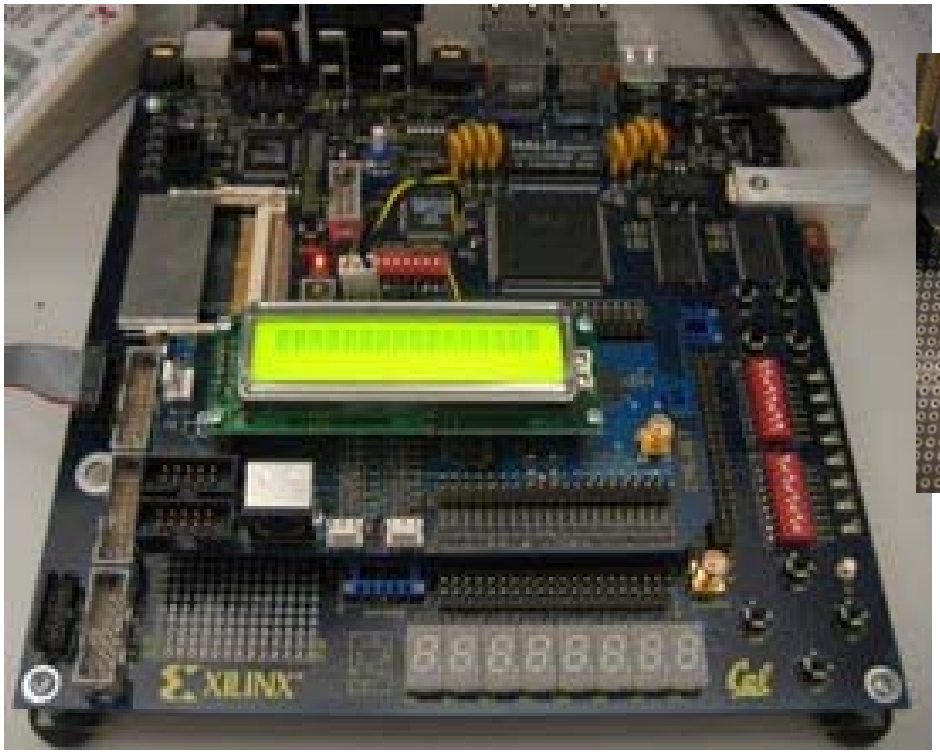
The Mechatronics Design Lab is a design project course focusing on application of theoretical principles in electrical engineering and computer science to control of mechatronic systems incorporating sensors, actuators and intelligence. This course gives you a chance to use your knowledge of (or learn about) power electronics, filtering and signal processing, control, electromechanics, microcontrollers, and real-time embedded software in designing a racing robot.

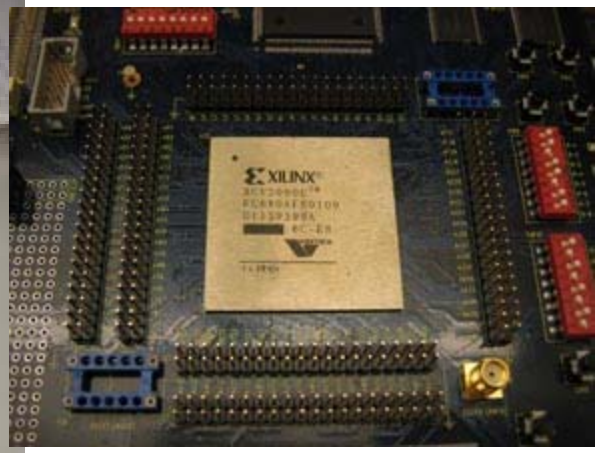
NATCAR

The class project is to design racing robots which can follow an embedded wire over a curving and self-crossing path at speeds greater than 3 meters per second.

http://inst.eecs.berkeley.edu/~ee192

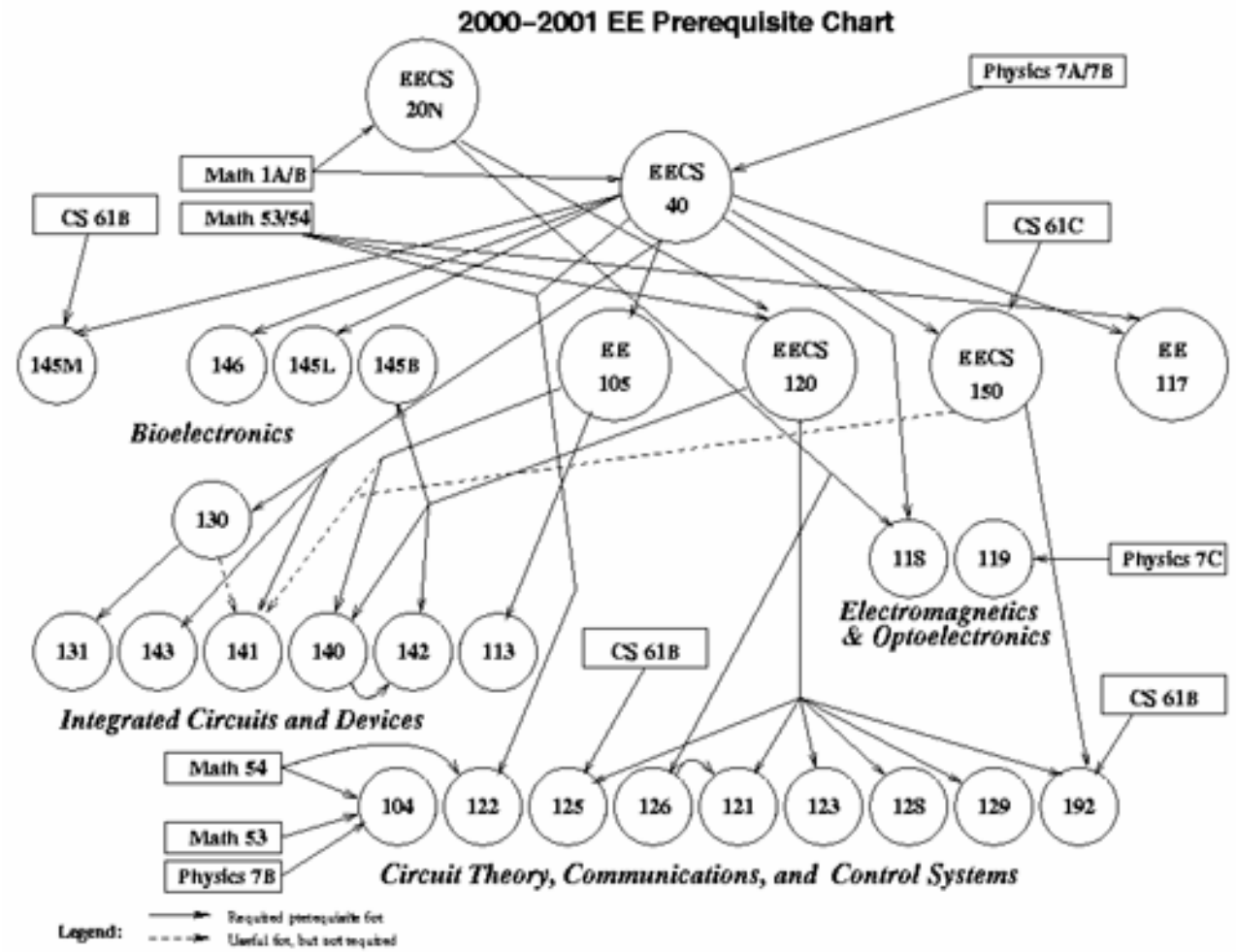
Examples of Systems: EECS 150/152





http://inst.eecs.berkeley.edu/~cs150

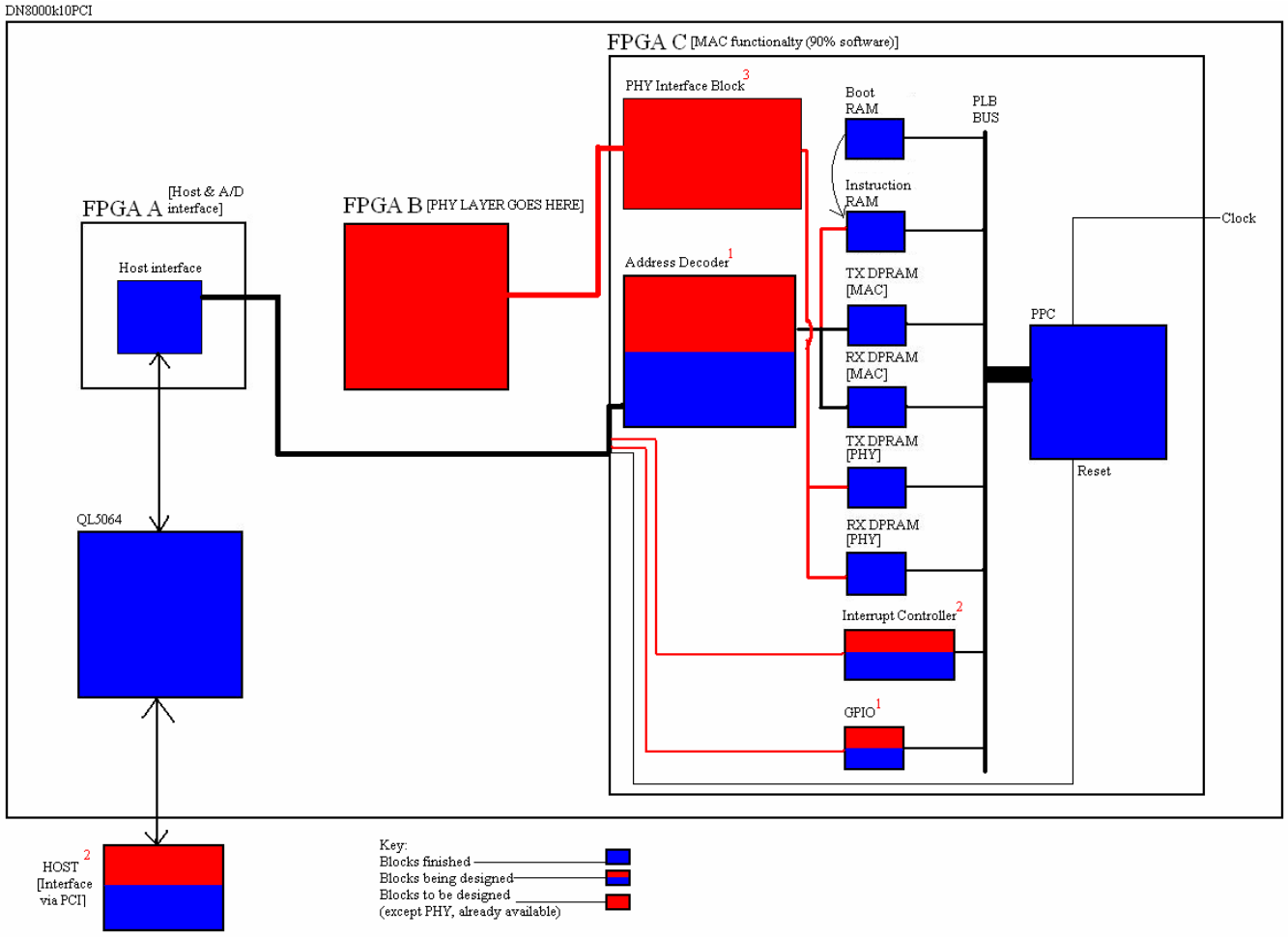
Courses you can take after EECS100



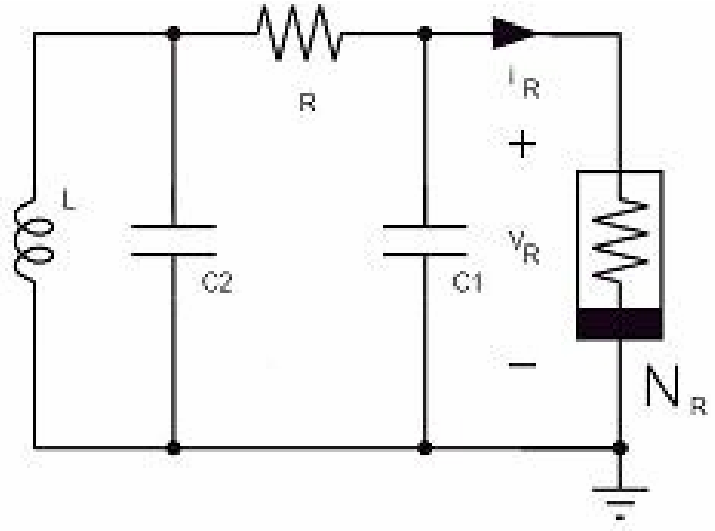
http://hkn.eecs.berkeley.edu/student/onlineexams.shtml

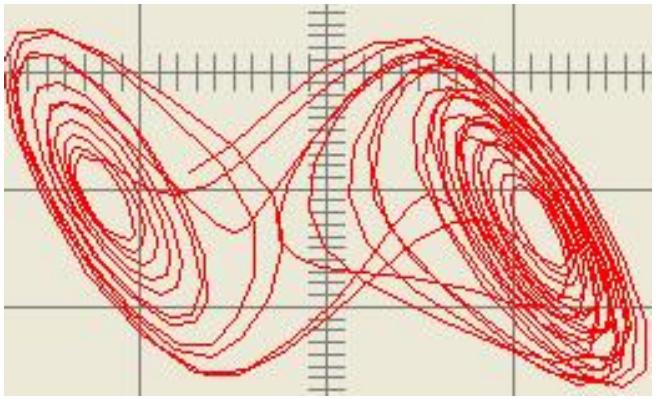
Sample Research Applications

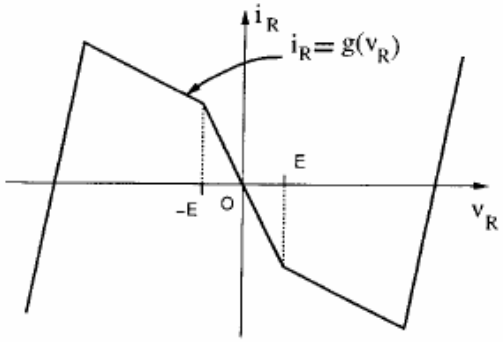
Field Programmable Gate Array (FPGA) System-On-Chip (SOC) Design for a 802.11 a/g/p/n Reconfigurable-Radio



Introduction to Chaos using Chua's circuit





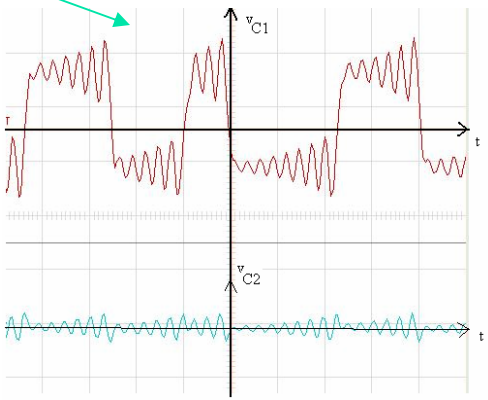


Introduction to Chaos: What is Chaos?

- There is **NO universal agreed-upon definition of Chaos**
- Loosely speaking, a Chaotic system is a deterministic system that exhibits random behavior. Example - Chua's circuit:

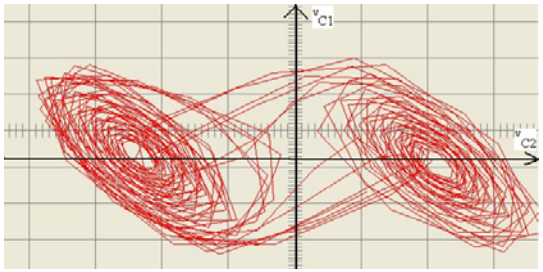
Set of ordinary **differential equations** with a **simple nonlinearity** BUT the **system behavior is complex**:

$$C_1\frac{dv_{C_1}}{dt} = G(v_{C_2} - v_{C_1}) - g(v_{C_1})$$
$$C_2\frac{dv_{C_2}}{dt} = G(v_{C_1} - v_{C_2}) + i_L$$
$$L\frac{di_L}{dt} = -v_{C_2}$$
$$g(v_R) = m_0 v_R + \frac{1}{2}(m_1 - m_0)\left[|v_R + B_p| - |v_R - B_p|\right]$$



Time domain

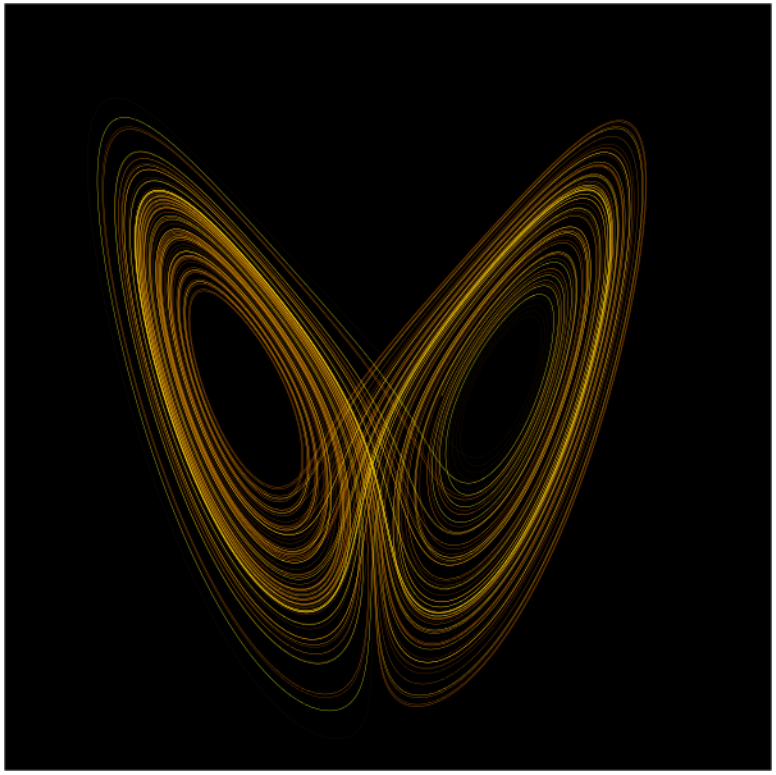
Phase space



Chaos in Nature

- Weather

(Reference: "Deterministic Nonperiodic Flow". Lorenz, Edward N. *Journal of Atmospheric Sciences*. pp. 130 – 141, 1963)



A plot of the Lorenz attractor for r = 28, σ = 10, b = 8/3
(Reference: Chaos Theory, Wikipedia Entry. Online at: http://en.wikipedia.org/wiki/Chaos_theory)

Chaos in Nature

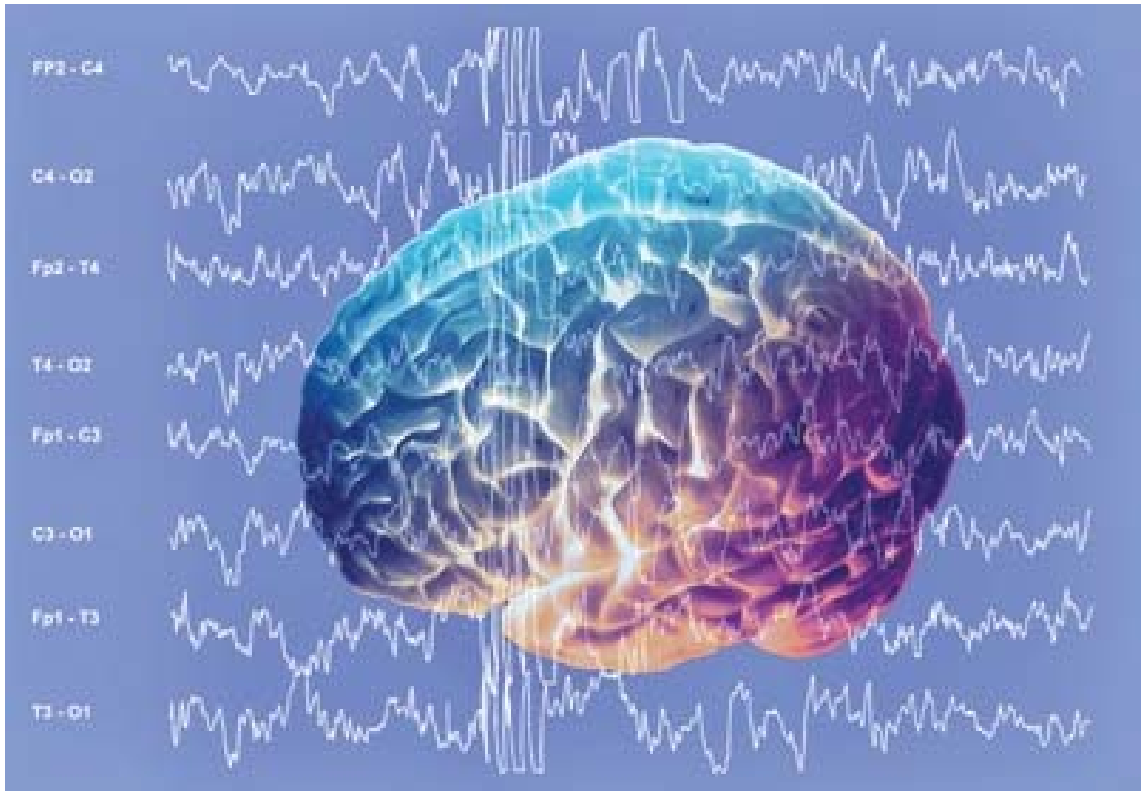
- Trajectory of planetary orbits:
  (Reference: "The role of chaotic resonances in the Solar System". Murray, N. and Holman M. *Nature.* pp. 773 – 780, vol. 410, 12 April 2001)
  - Irregulary shaped satellites like Hyperion (moon of Saturn) tumble chaotically.
  - Chaos in the orbits of giant planets (Jupiter, Saturn and Uranus) – the location of these planets cannot be predicted on a time scale longer than a few tens of millions of years.
  - Quote from the paper above:

"The worried reader
may find some comfort in that the
accompanying analytic theory
predicts that no planet will be ejected
before the Sun dies."

Chaos in Nature

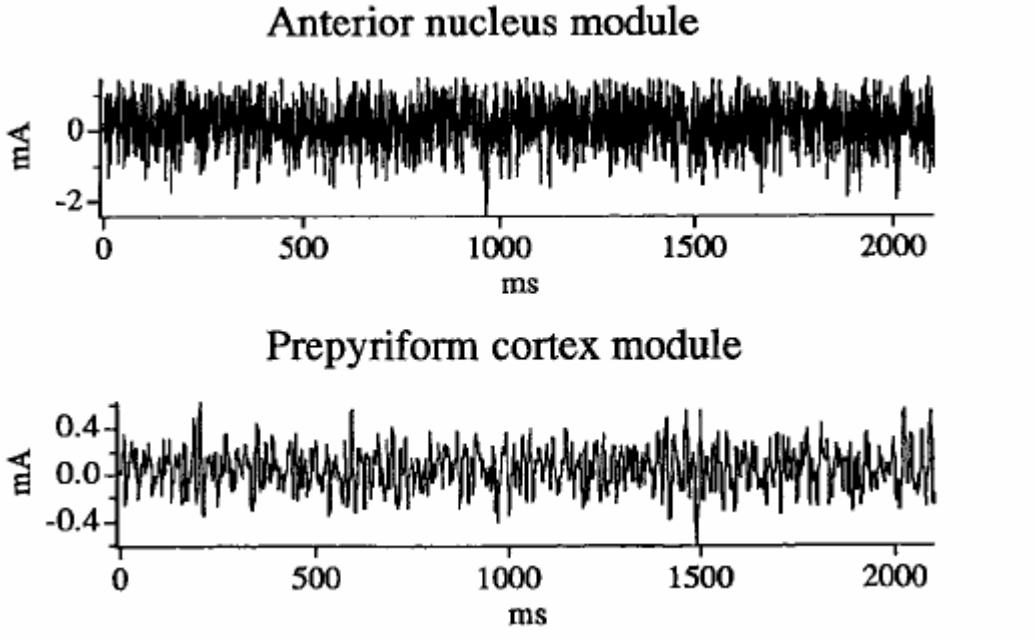
- Brain waves

(Reference: Rhythms of the Brain. Buzsaki, Gyorgy. *Oxford University Press*. 2006)



Hallmarks of Chaos

- **Non-periodic behavior in the time domain**

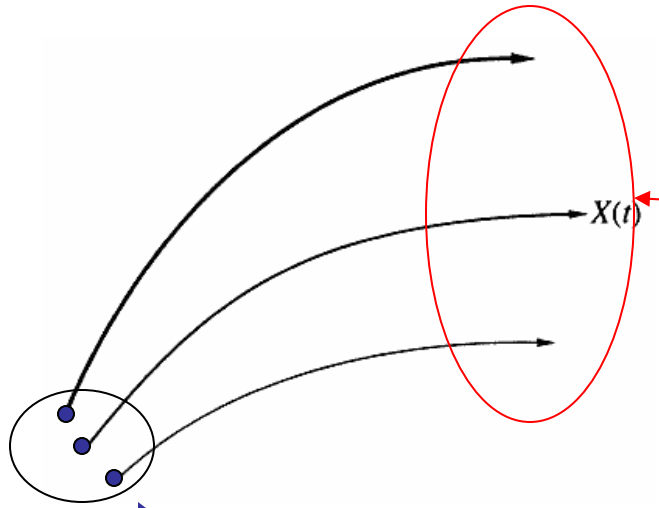


Time series data from neural nodes implanted in rat cortex

Reference: "Taming Chaos: Stabilization of Aperiodic Attractors by Noise". Freeman, W. et. al. *IEEE Trans. On Circuits and Systems – I: Fundamental Theory and Applications.* Vol. 44, No. 10, Oct. 1997

Hallmarks of Chaos

- **Sensitive dependence on initial conditions**



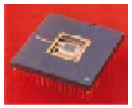
Eventually, the paths diverge (mathematically quantified by the Lyapunov exponent)

Three initial conditions x_{10}, x_{20} and x_{30} (they are arbitrarily close to each other)

Reference: http://www.keldysh.ru/departments/dpt_17/eng/ndeng.html

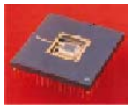
Proving the existence of Chaos

- Mathematically very challenging:
  - Lorenz's system was proved to be chaotic nearly **30 YEARS** after Lorenz's observations:
    - The Lorenz Attractor Exists. Tucker, Warwick. **Ph.D. Thesis**, 1998. University of Uppsala.
- One way to prove chaotic behavior: define a **homeomorphism** to the **Cantor set** using a **Smale horseshoe**



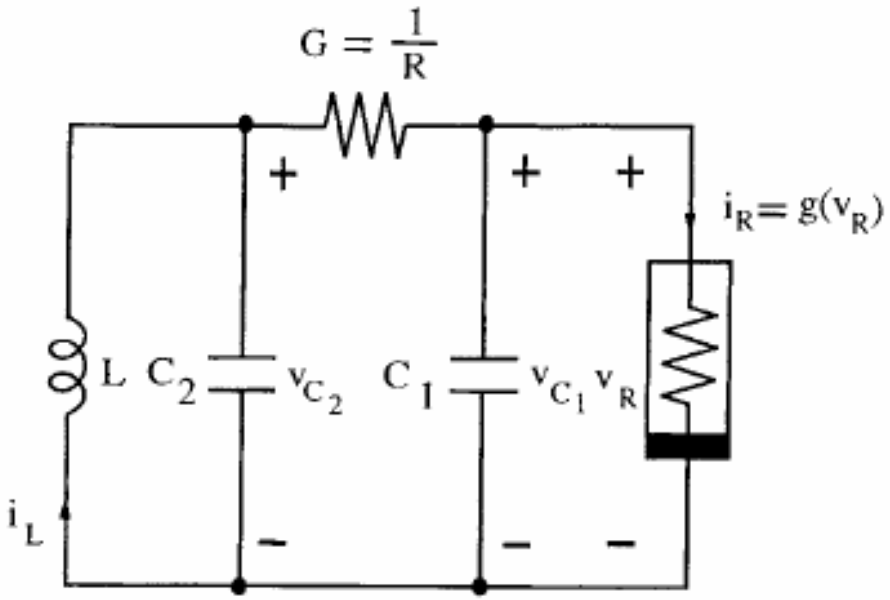
Proving the existence of Chaos

- But for the purposes of EE100:
  - Central concept: **Poincare-Bendixson Theorem**
    - In a nutshell, the consequence of the theorem is that a continuous time autonomous dynamical system CANNOT be chaotic in the plane (2-dimensions).



Easy Chaos: Chua's circuit

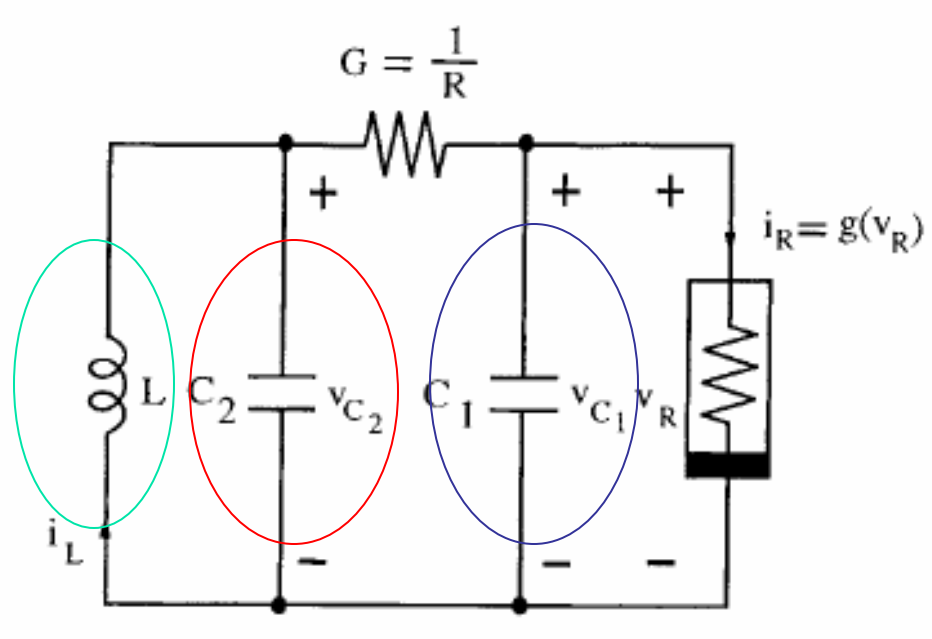
- Designed using **systematic nonlinear circuit techniques** by Leon O. Chua in 1983



Excellent Reference:
"The Genesis of Chua's circuit". Chua, Leon O. *Archiv fur Elektronik und Uebertragungstechnik,* July 1992, vol. 46, (no. 4): 250-257.

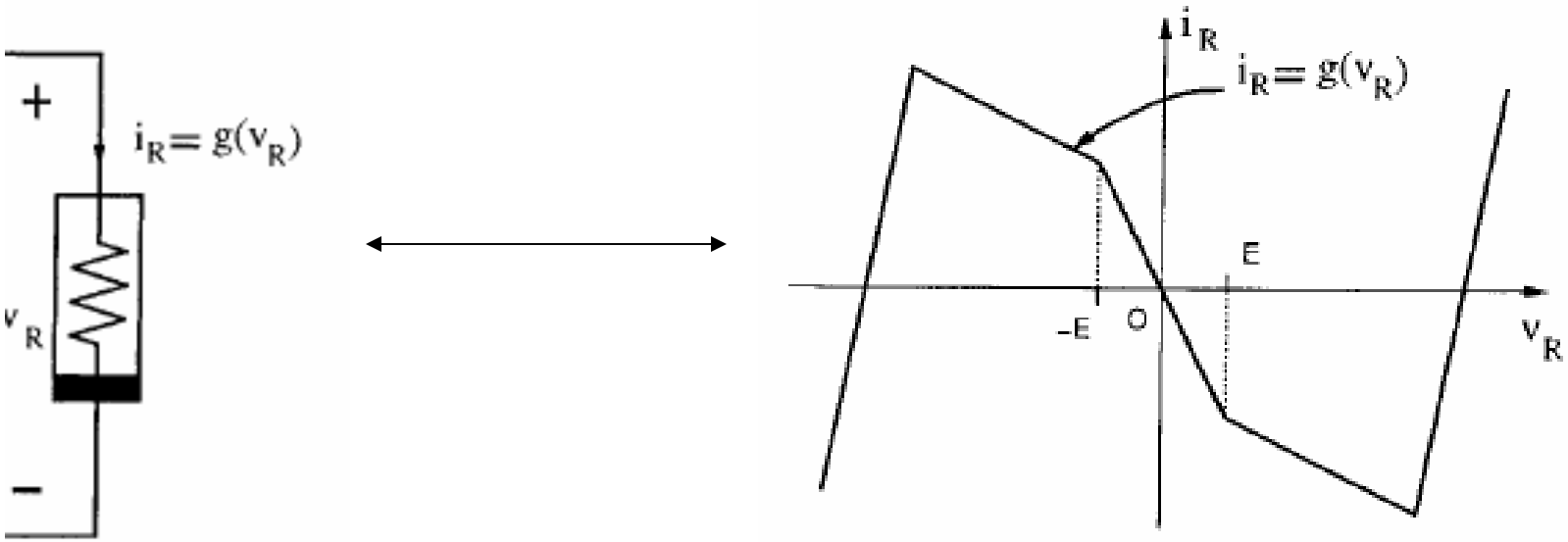
Easy Chaos: Chua's circuit

- **A consequence** of the **Poincare-Bendixson theorem** - we need **three independent energy storage elements**. Hence:



Easy Chaos: Chua's circuit

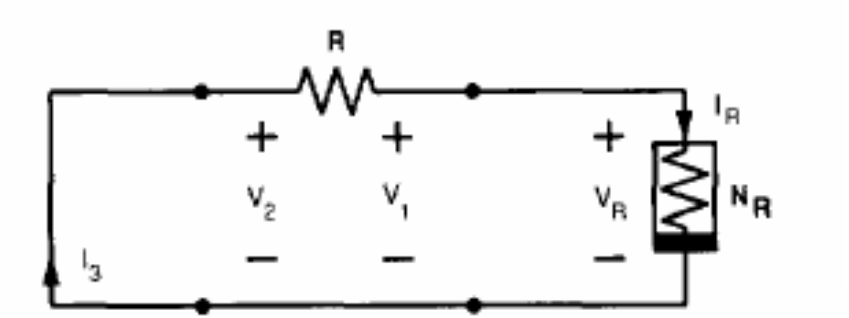
- Nonlinearity "designed" by Leon so that a proof of Chaos is "easy". For details, please refer to "The Genesis of Chua's Circuit" paper.



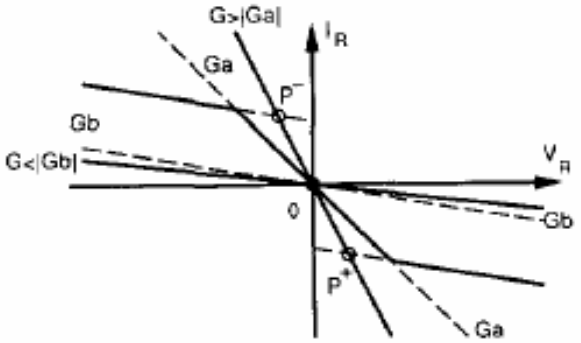
- **KEY: We need at least two unstable equilibrium points – one to provide stretching dynamics and the other to provide folding.**

Easy Chaos: Chua's circuit

- Existence of these equilibrium points can be seen from **DC load line**:



DC Load line



(a)

Reference: "Three Steps to Chaos – Part II: A Chua's Circuit Primer". Kennedy, Michael P. *IEEE Trans. On Circuits and Systems – I: Fundamental Theory and Applications.* Vol. 40, No. 10, Oct. 1993

- We will see how we can obtain this nonlinearity later using op-amps

Easy Chaos: Chua's circuit

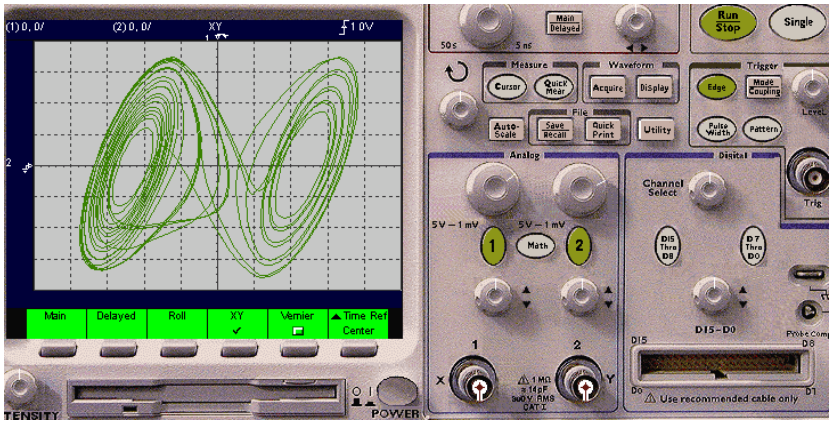
- Some properties of Chua's circuit:
  - Chua's circuit is the **simplest** possible electronic circuit that can exhibit chaotic behavior. Reference: "The double scroll family, Parts I and II". Chua et. al. *IEEE Trans. On Circuits and Systems*. Vol. CAS-33, no. 11, pp. 1073-1118, 1986.
- Applications of Chua's circuit:
  - Music:
    - "Reading Complexity in Chua's Oscillator through Music. Part I: A New Way of Understanding Chaos". Bilotta, Eleonara et. al. *International Journal of Bifurcation and Chaos*. Vol. 15, No. 2, pp. 253 – 282. 2005.
  - Communications:
    - "Chaotic Digital Encoding: An Approach to Secure Communication". Frey, D.R. *IEEE Trans. On Circuits and Systems II: Analog and Digital Signal Processing*. Vol. 40, #10, pp. 660 – 666. Oct. 1993.

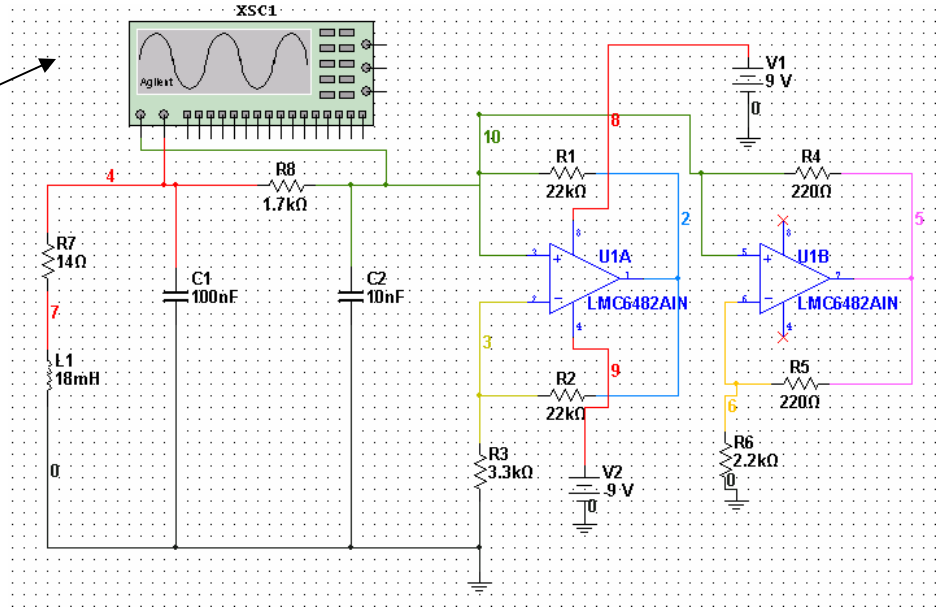
Building and working with Chua's circuit

- Now, we will see how **easy it is** to build Chua's circuit with **readily available components**!
- References
  - NOEL – Chaos in Chua's Circuit homepage http://nonlinear.eecs.berkeley.edu/chaos/chaos.html
  - Chaos Wiki: http://robotlab.itk.ppke.hu/~wiki/mediawiki-1.9.3/index.php/Main_Page
  - "Chua's Circuit for High School Students". Gandhi, Gaurav., Muthuswamy, Bharathwaj and Roska, Tamas. *To appear in the International Journal of Bifurcation and Chaos in Dec.* 2007

Building and working with Chua's circuit

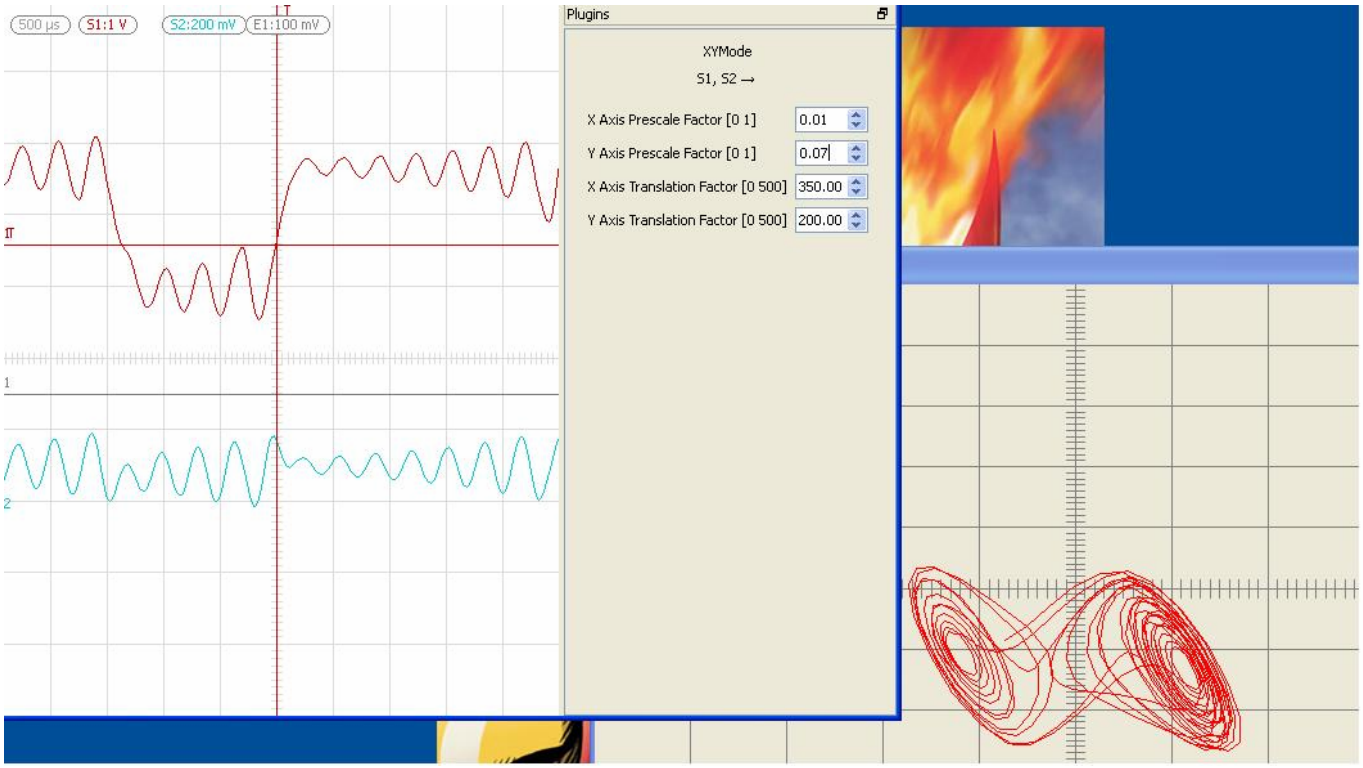
- Lecture demo - **Simulating Chua's circuit: MultiSim**





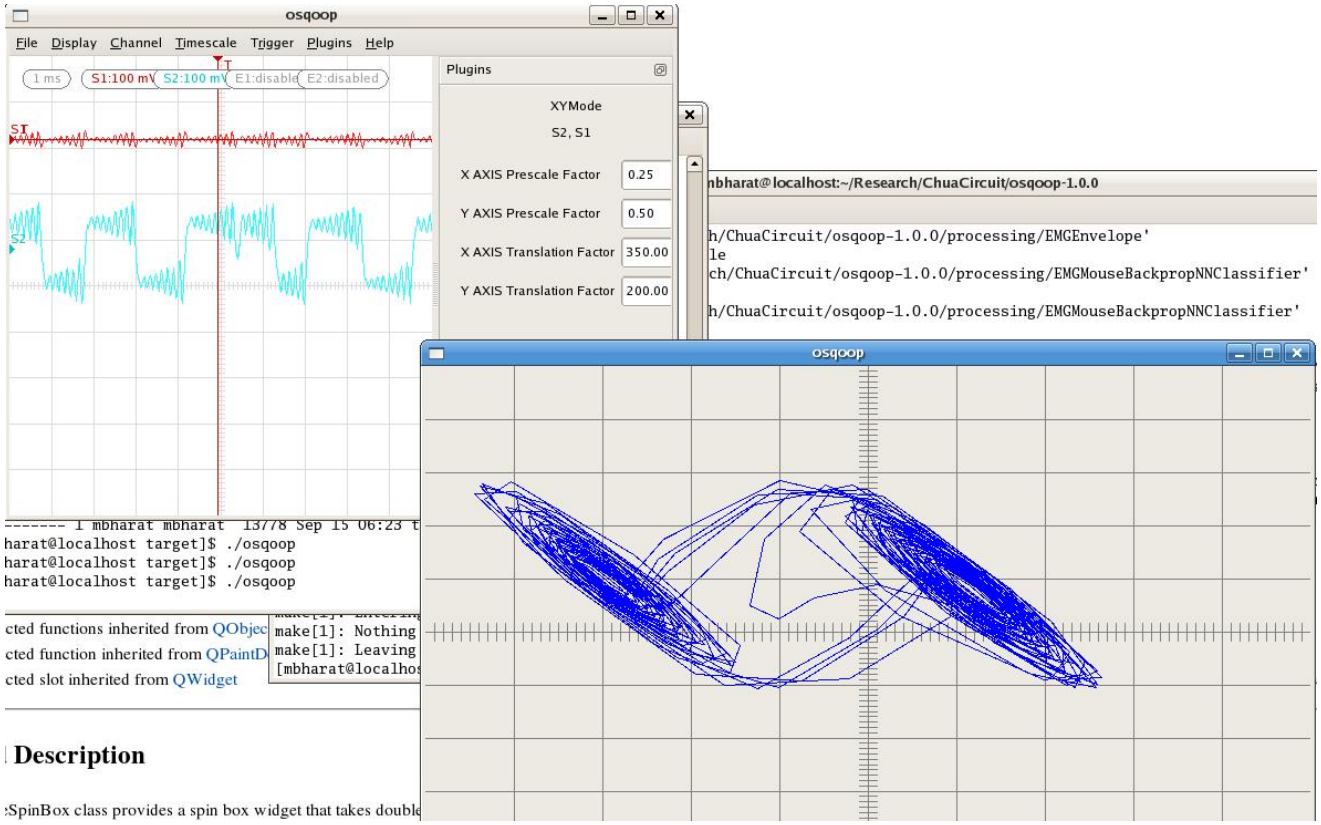
Building and working with Chua's circuit

- Lecture Demo - **Turning your PC into an oscilloscope: osqoop**



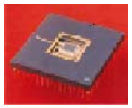
Building and working with Chua's circuit

- Lecture Demo - **Chua's circuit for high school students**



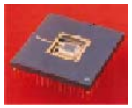
Building and working with Chua's circuit

- **Chua's circuit for high school students. Debugging Tips:**
  - **Checking the functionality of the nonlinear resistor**
  - **Tuning the circuit**

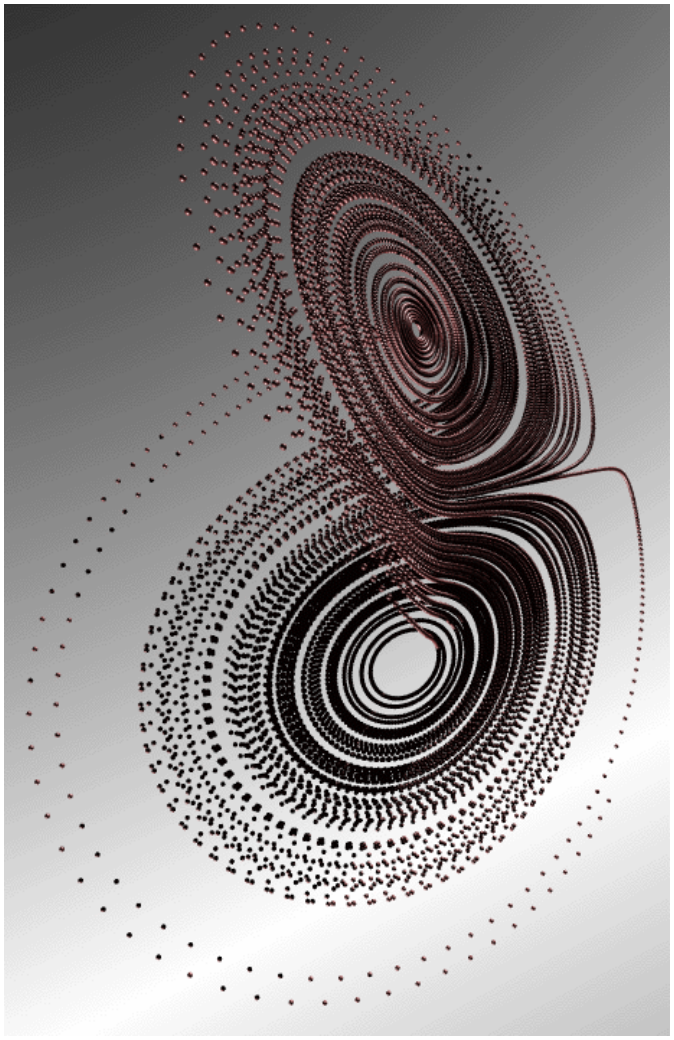


Building and working with Chua's circuit

- Lecture Demo - **Interesting MATLAB experiments** using Chua's circuit:
  - Sample data from Sound card
    - Compute Fourier Transform
    - Compute autocorrelation coefficient. Compare this to autocorrelation coefficient of white noise.



Questions…



Reference:
http://mathstat.helsinki.fi/mathphys/paolo_files/lorenz11.gif