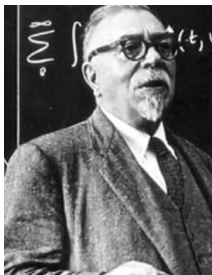


# Wiener's ideas and construction of modern high-tech systems

*Leonov G.A., Kondratyeva N.V., Kuznetsov N.V.,  
Kuznetsova O.A., Seledzhi S.M., Solovyeva E.P., Vagaytsev  
V.I., Yuldashev M.V., Yuldashev R.V., Zaretskiy A.M.*

# Wiener's ideas



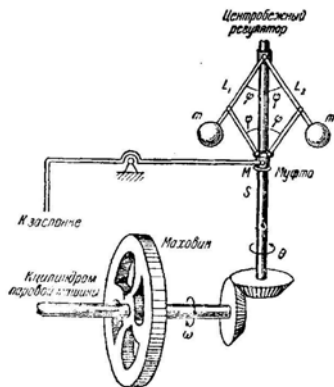
N. Wiener: first mathematician develops a model, then engineer realizes it



Wiener's ideas were suggested forward by I.A. Vyshnegradskiy (analysis of the Watt's governor using a mathematical model)

Wiener thesis: "Model  $\rightarrow$  Analysis (Research)  $\rightarrow$  Synthesis  $\rightarrow$  Realization"

# Watt's centrifugal governor. Vyshnegradskiy's research



I.A. Vyshnegradskiy "On Regulators of direct action" (1876)

Vyshnegradskiy's results:

- ▶ **Analysis:** no governor without friction
- ▶ **Realization:** cataract invention (physical realization of friction in the governor)

Result: nontrivial inventions and results are impossible without mathematics

# Aircraft "cloning" (B-29 and Tu-4)



B-29 (USA)



Tu-4 (USSR)

- ▶ Tu-4 is an exact clone of B-29 (hole for cans in the dashboard and ashtray were also cloned)
- ▶ Inches were used as a basic metric unit during aircraft design, then inches were converted to the millimeters
- ▶ A thicker and heavier sheet aluminium was used (1/16 in sheet aluminium were unavailable in USSR)

Result: either exact cloning, or full analysis and research;  
cloning distorts the tactical and technical characteristics

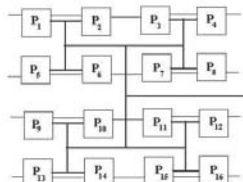
# PLL systems

- ▶ **Invention methods:** until certain time, PLL were invented at the engineering intuition level
- ▶ **Problem:** in the end, this approach led to a deadlock
  - ▶ Ian A. Young, PLL based clocking circuit in a microprocessor i486DX2-50 (1992) (In "Turbo" (2x CPU speed) mode stable operation is not guaranteed by manufacturer)
- ▶ **Solution:** usage of mathematical methods of investigation

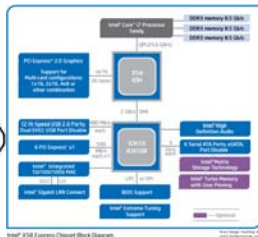
Mathematical model construction and mathematical methods of investigation (high-frequency analysis) allowed to obtain qualitatively new results in PLL design

Result: qualitatively new and nontrivial results obtaining is impossible without mathematics

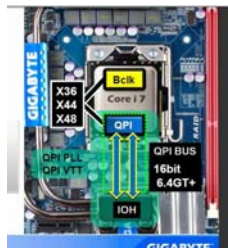
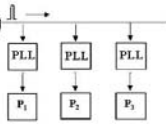
# PLL in Computer architectures: Synchronization, Elimination of Clock Skew, Frequencies synthesis



©

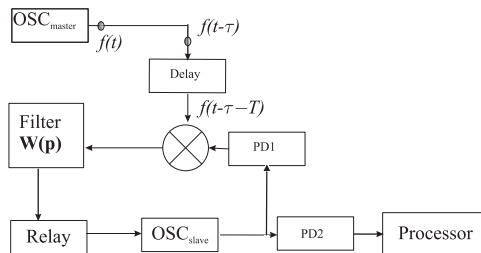


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# Block diagram of stable PLL

Mathematics allows to construct stable model (block diagram) using "Delay" element



PD1, PD2 –  
programmable dividers  
Delay – time-delay element  
Relay – correcting block  
(sign)  
Filter –  $W(p) = \frac{\beta}{p+\alpha}$

Result: desired result is obtained by means of mathematics

# Control theory: mathematical methods of phase synchronization



The theory of phase synchronization was developed in the second half of the last century on the basis of three applied theories:

- ▶ at the level of mechanical, electromechanical, or electronic model
- ▶ at the level of phase relations
- ▶ at the level of mathematical equations

Mathematical model and its research are primary, physical realization is secondary

Result: invention of effective and nontrivial devices lies in the borders of mathematics

# Hidden oscillations

Design and implementation of control systems without mathematical models may lead to unexpected results, like hidden oscillations (basin of attraction of which does not contain neighborhoods of equilibria) existence of which is not obvious for engineers

Hidden oscillations can arise in:

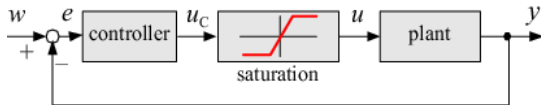
- ▶ control systems (pilot-induced oscillations, windup)
- ▶ PLL (semi-stable cycles)
- ▶ electrical circuits (hidden attractors in Chua's circuit)

Result: hidden oscillations can lead to unwanted effects and disasters

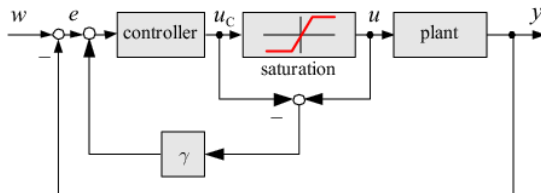
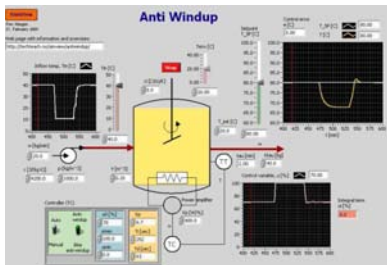
# Hidden oscillations in real life: control systems

## Problem: pilot-induced oscillation and windup

- ▶ F-22 Raptor (Boeing) crashed in 1992
- ▶ JAS 39 Gripen (SAAB) crashed in 1993



## Solution: anti-windup system



# Hidden oscillations in real life: PLL

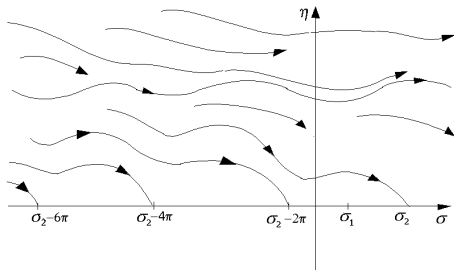
Existence of hidden oscillations in PLL was not obvious for engineers until a certain time, they didn't use mathematics during PLL design

Gubar' N.A. (1961),  
*J. Appl. Math. Mech*, 25,  
pp. 1519–1535.

First discovered semi-stable  
cycles in PLL

$$\dot{z} = \alpha z - (1 - a\alpha)(\sin(\sigma) - \gamma),$$

$$\dot{\sigma} = z - a(\sin(\sigma) - \gamma)$$

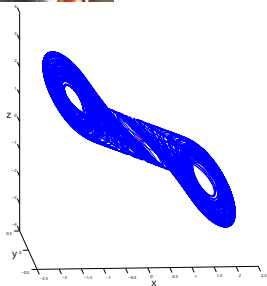
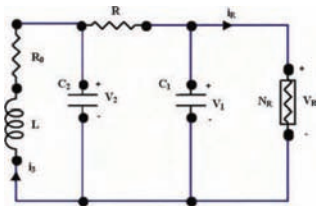


Result: first hidden oscillations (semi-stable cycles) in PLL was discovered by means of mathematics

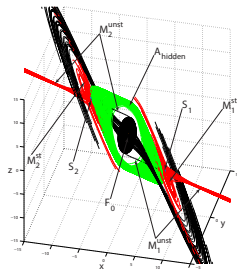
# Hidden oscillations in real life: Chua's circuit



1983 — now: L.O. Chua,  
T. Matsumoto, G.Chen  
and others — classical  
excitation of attractors  
from unstable equilibria

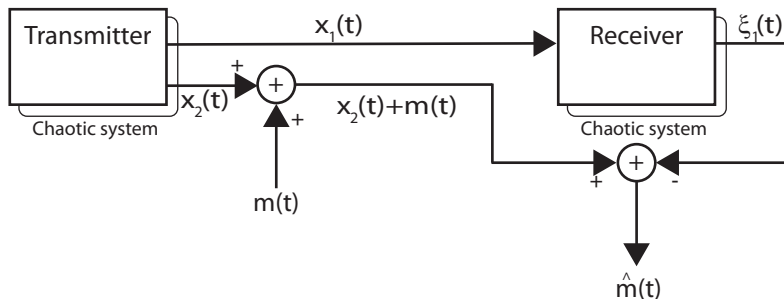


Engineering approach: classical  
attractor



Mathematical approach:  
hidden attractor

# Secured communication based on chaos



$m(t)$  — private message

$x_1(t)$  — synchronizing signal

$h(t) = x_2(t) + m(t)$  — hyperchaotic signal

$\hat{m}(t) = h(t) - \xi_1(t)$  — retrieved message

Hidden oscillations can lead to unexpected results, engineering approach doesn't guarantee detection of hidden regimes

Result: mathematics allows to detect hidden oscillating modes

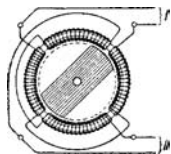
# Tesla's inventions

In 1888 an outstanding inventor Nikola Tesla discovered a rotating magnetic field generated by alternate current in stationary windings of stator of electrical machines. Till now this phenomenon is a base of constructing electrical machines of alternate current.



Tesla's contribution to the development of electrical engineering is enormous. He created:

- ▶ model of the alternator;
- ▶ two-phase induction motor;
- ▶ multiphase electric machines;
- ▶ the transmission system by means of a multiphase AC;



Totally there are about 300 patents, but inventions are much more.

# First mathematical model

Italian mathematician F. Tricomi first applied the strict methods for analysis of dynamics of synchronous machines. He considered the simplest model of a synchronous machine

$$\ddot{\theta} + \alpha\dot{\theta} + \beta \sin \theta = \gamma$$

is more known as the equation of the pendulum under a constant force.

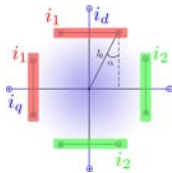
Tricomi conducted a global qualitative research of this equation, proved the existence of nontrivial global bifurcation and obtained estimates of the bifurcation parameters. Research of Francesco Tricomi allowed:

- ▶ to examine the dynamics of synchronous machines qualitatively;
- ▶ to improve the stability of synchronous machines.

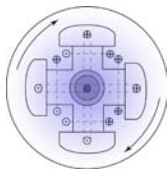


# “First model, then the realization”

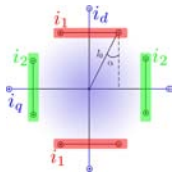
Let consider four-pole rotor of synchronous machine. In this model in a excitation system several types of commutations, namely several different manners of connection of exciting windings to a constant voltage source can be considered.



«Serial»  
commutation



Four-pole rotor  
scheme



«Parallel»  
commutation

$i_1, i_2$  – excitation currents  $i_q, i_d$  – damper currents

The models with different types of commutations proposed by mathematicians allow to optimize construction of electrical machines. This makes it possible to increase productivity of electrical machines.

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