Nonlinear Control for Performance: Frequency domain approach

Dates and time

13-04-2026 (Lecture 1, Marcel Heertjes)
20-04-2026 (Lecture 2, Marcel Heertjes)
11-05-2026 (Lecture 3, Hassan HosseinNia)
18-05-2026 (Lecture 4, Hassan HosseinNia)
From 13:45 – 16:00

Course location

Cursus- en vergadercentrum Domstad, Utrecht

ECTS

3 ECTS if the homework is completed successfully.
1 ECTS for auditing the course

Lecturers

Prof.dr.ir Marcel Heertjes, ASML and TU/e
Dr. Hassan HosseinNia, TUD

Objective

Upon completing this course, students will be equipped to analyze and design nonlinear control systems, focusing on variable gains, reset control, and hybrid integrator gain systems.

While linear motion control systems have thrived in industry due to their compatibility with frequency-domain analysis—particularly in handling disturbances and system uncertainties—nonlinear control has traditionally emphasized stability alone. However, achieving high performance in nonlinear systems requires advanced methods for quantitative performance analysis.

This course introduces frequency-domain techniques tailored to nonlinear control systems, enabling designs that can outperform traditional linear controllers. Practical examples from industry include variable-gain motion control in wafer scanners, optical drives, hard-disk actuators, and precision positioning systems, demonstrating the real-world effectiveness of these methods.

Contents

We will cover the following topics:

1. **Day 1, Lecture 1:** Amplitude-based nonlinear control: variable-gain systems
    a. What are variable-gain systems?
    b. Frequency-domain design & stability analysis
    c. Convergence and nonlinear Bode plots
    d. Examples/Assignment
2. **Day 2, Lecture2:** Phase-based nonlinear control: hybrid integrator-gain systems (HIGS)
    a. What are hybrid integrator-gain systems?
    b. Describing function analysis

    c. HIGS-PID control design, loop shaping and tuning
    d. LMI-based stability analysis
    e. Examples/Assignment
3. **Day 3, Lecture 3:** Constant Gain Lead Phase Control I
    a. What is complex order control
    b. Constant gain Lead phase control (CgLp)
    c. Approximation of CgLp using Reset
    d. High order describing function open loop
    e. Examples/Assignment
4. **Day 4, Lecture 4:** Constant Gain Lead Phase Control II
    a. High order describing function closed loop/ Loopshaping
    b. Tuning higher-order harmonics
    c. Example/Assignment

Prerequisites

A solid understanding of basic mathematics, linear control theory, and frequency-domain motion control tuning (including PID control design and loop shaping) is required. Familiarity with nonlinear control theory—particularly the stability of nonlinear systems and describing function analysis—will enhance your ability to follow the course more effectively.

Homework assignments

Homework will be assigned during every lecture.