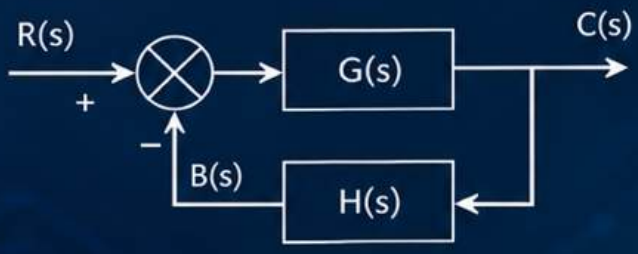
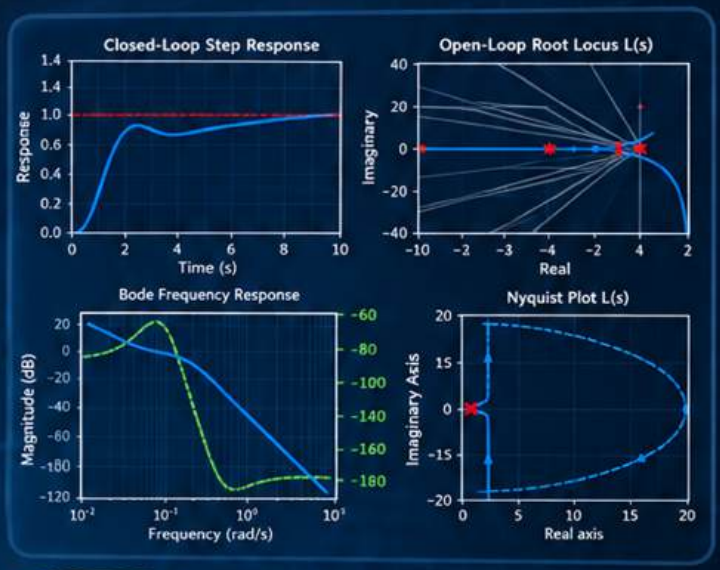
Python *for* CONTROL SYSTEMS

Guide for Analysis and Design of Continuous-Time LTI Systems






```
import numpy as np
import matplotlib.pyplot as plt
import control as ct
import ipywidgets as widgets
from ipywidgets import interact,
   FloatSlider, VBox, HBox, Output
from IPython.display import display
```



Dr. Leela A M

Python for Control Systems

Guide for Analysis and Design of Continuous-Time LTI systems

First Edition

Author
Dr. Leela A M



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Dedication

I dedicate my first book with deep gratitude to my parents, Smt. Girijamma A. M. and late Dr. Mari Gowda A. S., who laid the foundation for who I am today.

Preface

While teaching Digital Control System Lab using MATLAB in a class at BITs Pilani WILP, a student asked if any open source simulator available for Control System. I had a knowledge of Python basic library packages (NumPy, Matplotlib etc.) and previously had experience in simulating Signals and Systems using Python,and had conducted a course on the same at Sapthagiri College of Engineering under VTU.

This made me take up the decision of writing a book for Control system analysis & design using python. Though necessary library packages are available in Python libraries and other platforms like GitHub, Conda-Forge, PyPI etc., if a beginner wants to use for Control systems, referring these resources and developing the required programs is time consuming. I wondered if I could develop a library of ready-to-use foundation scripts—acting as modular frameworks and reusable templates—that handle core setup and recurring logic, allowing users to rapidly build, customize, and deploy application-specific packages across multiple projects. I have made a small effort in building foundational programs required for analysis in time & frequency domains & the book is restricted to Continuous-time LTI systems only. Each chapter starts with a small theoretical background with necessary mathematical expressions

Acknowledgement

Writing this book has been a wonderful journey, and I am deeply grateful to everyone who supported me along the way.

First, I would like to express my sincere thanks to my publisher, Iterative International Publishers (IIP), especially to Dr. Nanjesh Bennur, Founder and Managing Director of IIP Publisher, and his team for providing expert guidance, and bringing this book to life.

My gratitude also goes to my reviewer, Dr Harish Kumar J R, Associate Professor BITS Pilani WILP, whose thoughtful feedback, attention to detail, and constructive suggestions greatly improved the quality of this work.

I am forever grateful to my family—daughters Dr Kshamaa H G, Varshaa H G and Son-In-Law Dr Padmanabha T S—for their endless love, patience, and encouragement. Your unwavering support kept me motivated every step of the way.

Finally, a warm thank you to my extended family and dear friends. Thank you for always checking in on me, offering continuous encouragement, and celebrating every small milestone with me.This book would not have been possible without all of you.

Overview of Chapters

All programs developed, run and demonstrated with results on Python Anaconda Jupyter Notebook IDE. How to download and install Anaconda and thereby launch Jupyter notebook can be found at my video recording on YouTube[[4]]

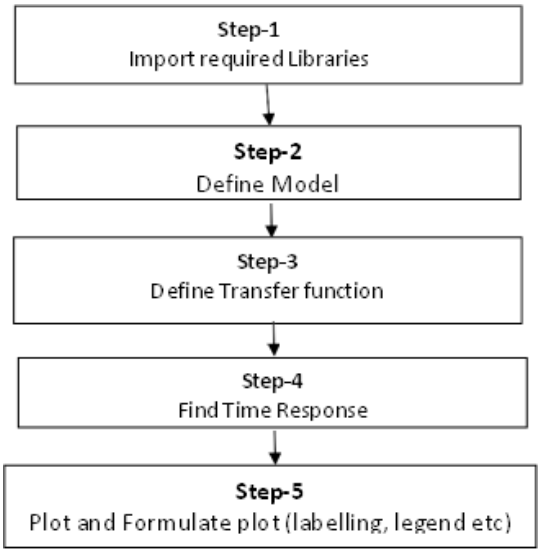
Chapter 1: Transfer Functions in Python

The basic building block for analysis and design of any system is its mathematical model. In control system studies the model takes the form of Transfer Function. Transfer function relates input and output of a system in the Laplace ('s') domain. This chapter describes how Numpy and Control libraries are used to build the transfer function model. Four methods are described with Python code. In addition, simplification blocks when 2 or more blocks are in cascade/ parallel and simplification of feedback loops demonstrated. Control system models involving time delay also illustrated.

Complete Python program and the results presented in Jupyter Notebook 1.

Chapter 2: Time Response Analysis

The program structure follows the following steps:



The Python code/code blocks explained in detail for time response of first and second order systems with single set of parameters and multiple sets of parameters. The program flow and steps are followed in the remaining chapters 3 through chapter 6. Any modification or addition made in any step/s explained in detail in the respective chapters.

Development of Interactive plot explained in detail for the first order system with the aid of mind map and flow chart. Understanding the program control and every command with ipywidgets in this chapter for interactive plots will help in developing interactive plots for any other problem.

Complete Python programs for each case along with results given in Jupyter Notebook 2.

Chapter 3: Root Locus

This chapter describes how the various functions/commands from Python control system library are used for: 1. Generating pole-zero plot. 2. Generating Root Locus plot. 3.To find the gain at critical stability(K_Critical). 4. To get the closed loop poles for a specified gain. 5.Interactive Root Locus a simple version. 6.Interactive Root Locus with ipywidget slider.

In section 3.5 the root locus generated using matplotlib.use( ) pops up a figure window with root locus plot. By clicking on the plot gives the coordinates of that point (location of closed loop poles), gain and damping factor at that location.

Section 3.6 illustrates in detail the program for generating the interactive root locus with a slider for gain variation.

All programs and results can be found in Jupyter Notebook 3

Chapter 4: Bode Plots

The chapter starts with an introduction to Bode plots and relation ship between Phase margin and time response like, %overshoot and damping ratio. Program developed for plotting the Bode plots, getting the Gain and Phase margins along with the respective crossover frequencies. Also getting the %OS and ξ.

Program for interactive Bode plots along with step response developed with dropdown menus for natural frequency (ω_n), damping ratio(ξ) and gain(K). One can vary these parameters and observe the changes in frequency domain specifications along with time domain specifications and get a feel for their inter

relationship. While using this program for higher order systems, care must be taken to use the transfer function for the second order approximation for the higher order system.

Jupyter Notebook 4 lists the complete program for each case described in this chapter.

Chapter 5: Nyquist Plots

N=ct.nyquist_plot(sys) is the Python control system command for getting the Nyquist plot for the system described by the transfer function 'sys'. To get complete information extraction from the Nyquist plot requires: 1. Axes preparation, 2. Extracting number of encirclements, 3. Identifying the net encirclements and, 4. Assess the stability status. Print all these as legend in the figure window of the plot. All the above are described in detail in this chapter. The detailed program with results for examples from the text [5] available in Jupyter Notebook 5.

Chapter 6: Design of PID Controller

This chapter introduces PID controller and the effect of P, I and D controllers on system performance specifications in both transient and steady state. The controller transfer function chosen in the form:

$$G_c(s)=K_p+\frac{K_i}{s}+K_d s$$

Interactive plot generated using the similar method described in the previous chapters with sliders for Kp, Ki and Kd. For demonstration of the effect of controller gain adjustment , a system with poor transient and steady state performance is chosen. The gains are adjusted for the required performance specifications. The complete program is in Jupyter Notebook 6.

Markdown (.md) files of the programs can be found in [7].

Video explanations of the programs can be found in [6].

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About the Author



Dr. Leela A M is an accomplished academician and researcher who currently serves as a Guest Faculty at BITS Pilani WILP. With a professional career deeply rooted in Electrical and Electronics Engineering, she earned her B.E. in Electrical Power from Mysore University, M.E. in Electrical Machines from Bharathiar University, Coimbatore and Ph.D from Jain University, Bangalore. Over an illustrious teaching career spanning 37+ years, she has taught a number of subjects spanning Electrical and Electronics Engineering and served in multiple academic and leadership roles, at prominent institutions such as AIT Chikmagalur, Sapthagiri College of Engineering, and Acharya Institute of Technology Bangaluru.Blending traditional teaching with modern digital education, Dr. Leela is also an active online content creator. She runs a popular technical YouTube channel covering Signals and Systems, Python, and Digital Signal Processing (DSP). Demonstrating her versatile interests, she also hosts a creative hobby YouTube channel and a popular Kannada podcast on Spotify, narrating moral-driven short stories from the Panchatantra, Jataka tales, and Sarvagna's vachanas.

The book illustrates various Python programs developed for both time and frequency domain analysis of control systems. Each analysis technique includes interactive plots giving an active learning experience for the user.

The book is reviewed by Dr. Harish Kumar J R, Associate Professor BITS Pilani WILP, who has taught Control Systems and Digital control systems along with simulation lab for the same using MATLAB. The review focused on the content coverage, practical orientation and pedagogical strength. The suggested areas for improvements are implemented to the best possible extent.

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