

## FREQUENCY RESPONSE ANALYSIS

Elke Laubwald and Mark Readman, control systems principles.co.uk

**ABSTRACT:** This is one of a series of white papers on systems modelling, analysis and control, prepared by Control Systems Principles.co.uk to give insights into important principles and processes in control. In control systems there are a number of generic systems and methods which are encountered in all areas of industry and technology. These white papers aim to explain these important systems and methods in straightforward terms. The white papers describe what makes a particular type of system/method important, how it works and then demonstrates how to control or use it. The demonstrations are performed using models of real systems developed by our senior partner Peter Wellstead and manufactured by TQ Education and Training Ltd in their CE range of equipment. This white paper describes the popular and important technique of frequency response analysis and uses the CE2000 control and simulation tool to show how frequency response analysis works and how to implement it.

### 1. What is a Frequency Response and why is it Important?

When we want to use or control a real system we must know how it behaves when different signals are applied to it. This will give a measure of the dynamic response of the system. One way to find the response of a system is to apply a test signal to the input and look at the output to see how it responds. Many test signals are possible, but a simple and useful test signal is the sine wave. This is because the output of a system with a sine wave input is also a sine wave, but with a different amplitude and phase. By measuring the output amplitude and phase of a system over a range of frequencies of the input sine wave, a particular version of the dynamic response is built – this is called the frequency response.



Figure 1. Linear transfer function with sinewave input.

If a system has transfer function  $G(s)$ , then the output response at a particular frequency  $\omega = 2\pi f$  is given by the gain and phase of the frequency response  $G(j\omega)$  at that frequency  $\omega$ . For the system shown in Figure 1 the input and output signals (after initial transients have gone) are:

$$u(t) = U \sin(\omega t), \quad y(t) = Y \sin(\omega t + \phi) \quad (1)$$

The corresponding gain and phase are given by:

$$\text{Gain at } \omega = |G(j\omega)| = \frac{Y}{U}, \quad \text{Phase at } \omega = \angle G(j\omega) = \phi \quad (2)$$

By measuring the gain and phase over a range of frequencies, the full frequency response of the system can be plotted.

Figure 2 shows typical frequency response measurements plotted in two ways – the first is a diagram of the imaginary part (Im on Figure 2a) of the frequency response  $G(j\omega)$ , against the Real part (Re on the Figure 2a) of the frequency response  $G(j\omega)$ . The second diagram, Figure 2b, shows a plot of the logarithm of the frequency response gain ( $\log|G(j\omega)|$  on Figure 2b) and the phase ( $\angle G(j\omega)$  on Figure 2b). The two figures are referred to as, respectively, the Nyquist plot and Bode plot. These are alternative ways of presenting the measurements that are named in acknowledgement of two great engineer/mathematicians who laid the foundations for frequency domain control systems analysis.

# Frequency Response Analysis Control Systems Principles

**Jingquan Cheng**



## **Frequency Response Analysis Control Systems Principles:**

**Control Systems**□**GATE, PSUS AND ES Examination** Satish K Karna, Test Prep for Control Systems GATE PSUS AND ES Examination     An Introduction to Control Systems K. Warwick,1996-01-01 This significantly revised edition presents a broad introduction to Control Systems and balances new modern methods with the more classical It is an excellent text for use as a first course in Control Systems by undergraduate students in all branches of engineering and applied mathematics The book contains A comprehensive coverage of automatic control integrating digital and computer control techniques and their implementations the practical issues and problems in Control System design the three term PID controller the most widely used controller in industry today numerous in chapter worked examples and end of chapter exercises This second edition also includes an introductory guide to some more recent developments namely fuzzy logic control and neural networks     *Principles of Adaptive Optics* Robert K. Tyson,Benjamin West Frazier,2022-02-27 *Principles of Adaptive Optics* describes the foundations principles and applications of adaptive optics AO and its enabling technologies This leading textbook addresses the fundamentals of AO at the core of astronomy high energy lasers biomedical imaging and optical communications Key Features Numerous examples to explain and support the underlying principles Hundreds of new references to support the topics that are addressed End of chapter questions and exercises A complete system design example threaded through each chapter as new material is introduced     Control System Theory Uday A. Bakshi,2020-12-01 The book is written for an undergraduate course on the theory of Feedback Control Systems It provides comprehensive explanation of theory and practice of control system engineering It elaborates various aspects of time domain and frequency domain analysis and design of control systems Each chapter starts with the background of the topic Then it gives the conceptual knowledge about the topic dividing it in various sections and subsections Each chapter provides the detailed explanation of the topic practical examples and variety of solved problems The explanations are given using very simple and lucid language All the chapters are arranged in a specific sequence which helps to build the understanding of the subject in a logical fashion The book starts with explaining the various types of control systems Then it explains how to obtain the mathematical models of various types of systems such as electrical mechanical thermal and liquid level systems Then the book includes good coverage of the block diagram and signal flow graph methods of representing the various systems and the reduction methods to obtain simple system from the analysis point of view The book further illustrates the steady state and transient analysis of control systems The book covers the fundamental knowledge of controllers used in practice to optimize the performance of the systems The book emphasizes the detailed analysis of second order systems as these systems are common in practice and higher order systems can be approximated as second order systems The book teaches the concept of stability and time domain stability analysis using Routh Hurwitz method and root locus method It further explains the fundamentals of frequency domain analysis of the systems including co relation between time domain and frequency

domain The book gives very simple techniques for stability analysis of the systems in the frequency domain using Bode plot Polar plot and Nyquist plot methods It also explores the concepts of compensation and design of the control systems in time domain and frequency domain The classical approach loses the importance of initial conditions in the systems Thus the book provides the detailed explanation of modern approach of analysis which is the state variable analysis of the systems including methods of finding the state transition matrix solution of state equation and the concepts of controllability and observability The book also introduces the concept of discrete time systems including digital and sample data systems z transform difference equations state space representation pulse transfer functions and stability of linear discrete time systems The variety of solved examples is the feature of this book which helps to inculcate the knowledge of the design and analysis of the control systems in the students The book explains the philosophy of the subject which makes the understanding of the concepts very clear and makes the subject more interesting Control System Principles and Design Ernest O.

Doebelin,1985-06-26 Designed for graduate and upper level undergraduate engineering students this is an introduction to control systems their functions and their current role in engineering design Organized from a design rather than an analysis viewpoint it shows students how to carry out practical engineering design on all types of control systems Covers basic analysis operating and design techniques as well as hardware software implementation Includes case studies *Principles of Adaptive Optics* Robert Tyson,2010-09-14 Since the publication of the second edition of Principles of Adaptive Optics the developments and applications in this area have increased tremendously Observatories are now producing outstanding science through adaptive optics technology components such as micromachined deformable mirrors and very low noise detectors are revolutionizing the f **Control System** Dr.P. Linga Reddy,, Dr.Jarupula Somlal,2019-08-22 This text book on control systems is designed for undergraduate students pursuing courses in Electrical and Electronics Engineering Electronics and Communication Engineering TeleCommunication Engineering Electronics and Instrumentation Engineering and Mechanical Engineering This book is suitable for self study and also useful for AMIE and IETE students The material given in this book covers syllabus of following Universities NIT s IIT s JNTUH JNTUK and its affiliated colleges Andhra University Sri Venkateswara University Kakatiya University a d Deemed Universities etc It is written in a student friendly and readable manner which explains all basic fundamentals and concepts of control systems in a clearly understandable form It is a balanced survey of theory aimed to provide the students with an in depth insight into system behaviour and control of continuous time control systems All the solved and unsolved problems in this book are classroom tested designed to illustrate the topics in a clear and thorough way KEY FEATURES Includes several fully worked out examples to help students master the concepts involved Provides short questions with answers at the end of each chapter to help students prepare for exams confidently Offers fill in the blanks and objective type questions with answers at the end of each chapter to quiz students on key learning points Gives chapter end review questions and problems to assist students in reinforcing their knowledge

Questions that are appearing in Competitive Technical Examinations will also be included whenever necessary

*Process Control: Concepts Dynamics And Applications* S. K. Singh, 2007-12 This book is a comprehensive introduction to the vast and important field of control systems The text introduces the theory of automatic control and its applications to the chemical process industries with emphasis on topics that are of use to the process control engineers and specialists It also covers the advanced control strategies and its practical implementation with an excellent balance of theoretical concepts and engineering practice

**Control Systems** Sonveer Singh, Sanjay Agrawal, 2022-11-11 In modern era a control system plays a vital role in human life A control system is an interconnection of components forming a system configuration in which quantity of interest is maintained or altered in accordance with a desired manner This book covers various aspects of control systems like reduction techniques of multiple systems time response analysis of the three orders of control systems and steady state error of different systems While delving into the finer details of the subject the book explains different components of control system like actuators sensors etc As the learners progress with these components the book explains the stability of control system which affects its performance of control system The root locus techniques of different systems and their frequency response analysis has been explained in a simple manner The book has also dealt with stability in frequency domain review of state variable techniques and also introduces design to the learner This book is designed for undergraduate engineering students of different branches in the field of control system This book strictly follows the syllabus of various universities without sacrificing the basic principles and depth of the subject

Flight Dynamics Principles Michael V. Cook, 2012-10-03 The study of flight dynamics requires a thorough understanding of the theory of the stability and control of aircraft an appreciation of flight control systems and a grounding in the theory of automatic control *Flight Dynamics Principles* is a student focused text and provides easy access to all three topics in an integrated modern systems context Written for those coming to the subject for the first time the book provides a secure foundation from which to move on to more advanced topics such as non linear flight dynamics flight simulation handling qualities and advanced flight control Additional examples to illustrate the application of computational procedures using tools such as MATLAB MathCad and Program CC Improved compatibility with and more expansive coverage of the North American notational style Expanded coverage of lateral directional static stability manoeuvrability command augmentation and flight in turbulence An additional coursework study on flight control design for an unmanned air vehicle UAV

Flight Control System Manuals: Suppl. Addendum Northrop Aircraft, Inc, 1952

*System Assurances* Prashant Johri, Adarsh Anand, Juri Vain, Jagvinder Singh, Mohammad Tabrez Quasim, 2022-02-16 *System Assurances* Modeling and Management updates on system assurance and performance methods using advanced analytics and understanding of software reliability growth modeling from today's debugging team's point of view along with information on preventive and predictive maintenance and the efficient use of testing resources The book presents the rapidly growing application areas of systems and software modeling including

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Clarence W. de Silva, 2005-06-27 Every so often a reference book appears that stands apart from all others destined to become the definitive work in its field The Vibration and Shock Handbook is just such a reference From its ambitious scope to its impressive list of contributors this handbook delivers all of the techniques tools instrumentation and data needed to model analyze monitor modify and control vibration shock noise and acoustics Providing convenient thorough up to date and authoritative coverage the editor summarizes important and complex concepts and results into snapshot windows to make quick access to this critical information even easier The Handbook's nine sections encompass fundamentals and analytical techniques computer techniques tools and signal analysis shock and vibration methodologies instrumentation and testing vibration suppression damping and control monitoring and diagnosis seismic vibration and related regulatory issues system design application and control implementation and acoustics and noise suppression The book also features an extensive glossary and convenient cross referencing plus references at the end of each chapter Brimming with illustrations equations examples and case studies the Vibration and Shock Handbook is the most extensive practical and comprehensive reference in the field It is a must have for anyone beginner or expert who is serious about investigating and controlling vibration and acoustics **Applied Mechanics Reviews**, 1969 **The Principles of Astronomical Telescope Design** Jingquan

Cheng, 2010-03-14 This book presents a complete summary of the author's twenty five years of experience in telescope design It provides a general introduction to every aspect of telescope design It also discusses the theory behind telescope design in depth which makes it a good reference book for professionals It covers Radio Infrared Optical X Ray and Gamma Ray wavelengths Originally published in Chinese *Undergraduate Announcement* University of Michigan--Dearborn, 1995

**Principles of Feedback Control: Advanced control topics** George Biernson, 1988 **Control System Engineering** Uday A. Bakshi, Varsha U. Bakshi, 2020-11-01 The book is written for an undergraduate course on the Feedback Control Systems It provides comprehensive explanation of theory and practice of control system engineering It elaborates various aspects of time domain and frequency domain analysis and design of control systems Each chapter starts with the background of the topic Then it gives the conceptual knowledge about the topic dividing it in various sections and subsections Each chapter provides the detailed explanation of the topic practical examples and variety of solved problems The explanations are given using very simple and lucid language All the chapters are arranged in a specific sequence which helps to build the understanding of the subject in a logical fashion The book starts with explaining the various types of

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**Scientific and Technical Aerospace Reports** ,1990      *Announcement* University of Michigan. College of Engineering,1962

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