

Preface

Resonance is one of the fundamental phenomena exhibited by nonlinear systems and is important in physics, engineering and biology. It refers to a realization of a maximum response of a dynamical system. In an oscillating system, the response is primarily due to the ability of the system to store and transfer energy received from an external forcing source into an internal oscillating mode. Resonance can be deterministic or stochastic and can be realized in microscopic and macroscopic systems. Both single and coupled systems can display resonance behaviour. It is beneficial in many applications and also leads to instability and disasters in certain systems.

Resonance can be induced in dynamical systems by means of external forces. Different kinds of external forces give rise to distinct types of resonances. An enhanced maximum response of a system at a frequency due to an external periodic force is termed a *forced resonance* or simply a resonance. Some of the other fascinating types of resonances are (1) stochastic resonance—induced by a weak noise at the frequency of the applied periodic force, (2) vibrational resonance—induced by a high-frequency force at the low-frequency of the external force, (3) coherence resonance—induced by an external noise in the absence of any external periodic force, (4) ghost resonance—induced by a multi-frequency force at a frequency absent in the external force, (5) parametric resonance—induced by a periodic variation of a parameter of the system, (6) autoresonance—induced by an external force with time-dependent frequency and (7) chaotic resonance due to a perturbation of chaotic nature. Among these types, the resonance due to an additive force with a single frequency and parametric resonance occur both in linear and nonlinear systems. Other resonances take place only in nonlinear systems. In addition to the above resonances, in certain systems the amplitude of the response is found to be either zero or minimum at one or more frequencies or at certain values of a control parameter. This phenomenon is termed *antiresonance*. Salient features of the above-mentioned resonances and antiresonance have been investigated in mathematical model equations of physically interesting systems and in real experimental systems. Theoretical procedures and statistical measures are developed to identify and explore the various features of resonances.

In the near future, the features of resonances are expected to lead to advanced technological applications. For example, many macro, micro and nanoscale oscillators and devices working in resonant modes as filters, nonlinear mixers, sensors, atomic scale imaging and amplifiers are found to give rise to higher efficiency and greatly improved performance.

This book presents basic aspects and salient features of the above-mentioned various nonlinear resonances and antiresonance. Particularly, for each resonance, it covers theoretical concepts, illustration, case studies, mechanism, characterization, numerical simulation, experimental realization, quantum analogue, applications and significant progresses made over the years. It is self-contained, mathematical derivations show all the main steps, and the techniques involved in numerical simulation are clearly described so that a reader is able to reproduce the results presented. This is written in a simple language and prototype and paradigmatic model equations are used to illustrate the mechanisms of resonances and describe the theoretical procedures. This is primarily developed as a text at the postgraduate level and also as a reference book for researchers working and/or interested in the dynamics of resonances.

This book is structured into 14 chapters and 3 appendices. The book begins with a detailed introduction to the phenomenon of a forced resonance in Chap. 1. Through a theoretical treatment, the occurrence of resonance in certain physically interesting nonlinear systems driven by a single deterministic periodic external force is discussed. Some notable applications of forced resonances are mentioned. Chapter 2 presents theory, characterization and applications of stochastic resonance, and a quantum analogue of stochastic resonance is pointed out. Chapter 3 is devoted to the theoretical analysis of the biharmonic force induced vibrational resonance in monostable nonlinear systems. Resonance with nonsinusoidal periodic forces, the effect of noise and the role of asymmetry of a potential on resonance are discussed. The features of both stochastic and vibrational resonances in multistable and excitable systems are presented in Chap. 4. Occurrences of both stochastic and vibrational resonances in spatially periodic potential (pendulum) system and in a modified Chua's circuit model equation with periodic characteristic curve of Chua's diode are analysed in Chap. 5. The role of the number of equilibrium points on resonances is explored. Furthermore, the characteristic differences between these two types of resonances are enumerated.

Chapter 6 mainly deals with vibrational resonances in the Duffing oscillator with time-delayed feedback. Notable examples of time-delay in different branches of science are enumerated. The role of constant single time-delay, multiple time-delay, integrative time-delay, distributed time-delay and state-dependent time-delay and the influence of strength of time-delayed feedback are analysed. Next, Chap. 7 reports on the resonance enhanced signal propagation in unidirectionally coupled nonlinear systems. Particularly, the influence of forced, vibrational and stochastic resonances on signal propagation is explored. Chapter 8 covers experimental observation of vibrational resonance in single Chua's circuit, overdamped bistable system, vertical cavity surface emitting laser system, an excitable electronic circuit and unidirectionally coupled Chua's circuits. In the next chapter, ghost-stochastic

resonance induced by noise and ghost-vibrational resonance due to a high-frequency force are covered. Both single and coupled systems are taken for analysis. The phenomenon of parametric resonance is dealt in Chap. 10. Particularly, its occurrence in certain linear and nonlinear systems, analog circuit simulation results and its certain signatures in quantum systems are presented.

Chapter 11 is devoted to autoresonance. The role of limiting phase trajectories on autoresonance is examined. The features of autoresonance in optical waveguides and four-wave mixing are elucidated. Its quantum analogue is shown to be ladder climbing of energy with time. Coherence resonance and chaotic resonance are treated in Chap. 12. Theory of coherence resonance is presented with reference to a two-state noise driven system. Resonance-like behaviour induced by certain kinds of chaotic perturbations and Gaussian white noise is analysed. The response of linear and nonlinear systems to time-varying frequency of the driving external force and monotonic increase of a parameter with time are discussed in the next chapter. Such perturbations are shown to give rise to a slow passage of trajectories through resonance and resonance tongues. The role of initial conditions on the maximum response is discussed. The final chapter is primarily concerned with the identification and analysis of antiresonance in both single and coupled oscillators. Analog circuit simulation results are also presented. Finally, equilibrium point analysis, analytical expression for the roots of a cubic equation and description of analog circuit construction for an ordinary differential equation are presented in the appendices.

We are indebted to J. Kurths, K. Thamilmaran, V. Chinnathambi, V.M. Gandhimathi, S. Jeyakumari, V. Ravichandran, S. Arathi, C. Jeevarathinam, R. Jothimurugan, J.M. Casado, M. Coccolo, A. Daza, J. Seoane, G. Litak, J. Used, A. Wagemakers, J.H. Yang, S. Zambrano, K. Abirami and S. Rajamani for many years of collaboration without which it would not have been possible to write this book. One of us (S.R) thanks P. Philominathan, T. Arivudainambi, A. Venkatesan and K. Murali for their suggestions and encouragement. All the analog circuit simulation studies presented in this book are prepared in collaboration with K. Thamilmaran and R. Jothimurugan. It is a great pleasure to thank them. Finally, we extend our thanks to our family members for their great support, cooperation and encouragement during the course of preparation of this work.

Tiruchirapalli, Tamil Nadu, India
Móstoles, Madrid, Spain
July 2015

S. Rajasekar
Miguel A.F. Sanjuan

<http://www.springer.com/978-3-319-24884-4>

Nonlinear Resonances

Rajasekar, S.; Vallejo, J.C.

2016, XVII, 409 p. 242 illus., 226 illus. in color.,

Hardcover

ISBN: 978-3-319-24884-4