Preface

In the second edition of the monograph published originally in 1997, I preserved the spirit of the first edition whereby the focus was on *analytic* and detailed analysis the fundamental concepts associated with beam–wave interaction in various radiation sources and accelerators. While the general framework of the material remained the same, each chapter has been improved and expanded. In the following paragraphs, I present the updated structure of the various chapters, skipping the introductory chapter – Chap. 1.

Chapter 2 is dedicated to the basic electromagnetic theory. After discussing *Maxwell equations* in general, I present simple homogeneous solutions corresponding to the TEM, TM, TE, and hybrid modes. When the current density is present, it is useful to employ Green's function method for solution of the electromagnetic field. Its formal description is accompanied by two examples which illustrate the Cerenkov radiation in free space and in a waveguide. The coherent process is also examined. Several finite length effects are considered, as well as edge effects. Scattered waves phenomena are also discussed.

Chapter 3: All topics considered throughout the text rely on *classical mechanics* and the basics are briefly discussed. Some of the methods of electrons generation are considered followed by some principles of beam transport – including limiting laws. Basic measures of beam quality are introduced. Space–charge waves are investigated, as well as a few instabilities that may develop when these waves are excited. Various radiation phenomena associated with accelerated charges conclude this chapter.

Chapter 4: In this chapter, I consider the fundamentals of beam–wave interaction in a *distributed* slow-wave structure. A dielectric loaded waveguide was chosen as the basic model in the first sections because it enables to illustrate the essence of the interaction without the complications associated with complex boundary conditions. Pierce's theory for the traveling wave amplifier extended to the relativistic regime is formulated and I present the operation of an oscillator in the context of finite length effects. While the dynamics of the beam in all these topics was considered in the framework of the hydrodynamic approximation, I gradually elevate the level of description of particles dynamics by using the macroparticle approach, namely, by representing the ensemble by a large number of clusters of electrons. This formalism enables to examine the interaction in phase-space either in the linear regime of operation or close to saturation. It also facilitates investigation of tapered structures and analysis of the interaction of prebunched beams in tapered structures. Further extension of the macroparticle approach to include the effect of reflections enables to describe the operation of an amplifier and an oscillator and obviously the transition from the former to the latter. A discussion on the interaction with hybrid modes concludes this chapter.

Chapter 5: In this chapter I present various characteristics of *periodic structures* with emphasis on those aspects relevant to interaction with electrons. Both closed and open periodic structures are considered. Smith–Purcell effect is analyzed as a particular case of a Green's function calculation for an open structure and a simple scattering problem is also considered. Planar and cylindrical Bragg waveguides are analyzed, paving the way to optical acceleration structures. Two dimensional periodic structures and some applications are considered. This chapter concludes with three examples of a transient solution in periodic structures.

Chapter 6: *Quasi-periodic structures* are the focus of this chapter. They are essential whenever it is required to maintain an interacting bunch in resonance with the wave if high efficiency is a must. Nonadiabatic change of geometry dictates a wide spatial spectrum, in which case the formulation of the interaction in terms of a single wave with a varying amplitude and phase is inadequate and I present an alternative approach. This is applicable to extraction sections in TWTs, klystron, or gyrotrons, or for evaluating roughness effect on beam quality in the case of advanced light sources. The chapter concludes with a discussion on a photoinjector.

Chapter 7: This chapter deals with the principles of *free electron laser*. Starting with the spontaneous emission as an electron traverses an ideal wiggler, I investigate coherent interaction in the low-gain and high-gain Compton regime. As in the TWT case, the macroparticle approach is introduced and I conclude the chapter with a brief overview of the various alternative schemes of free electron lasers and a special section dedicated to X-ray sources.

Chapter 8: One of the important systems where beam–wave interaction in periodic structures plays a crucial role is the *particle accelerator*. In the first part of this chapter I discuss some basics of linear acceleration. In the second part, I discuss various advanced acceleration concepts including, for example, acceleration in plasma by either laser or electrons wake, as well as acceleration at optical wavelengths.

Whenever possible I have referred the reader to experimental results although this was definitely not my main goal because of two reasons: first, as stated initially, my focus was to describe fundamental concepts and the models that can be represented by analytic or quasi-analytic expressions to readers. Second, the progress in the advanced acceleration physics is so rapid that by the time the monograph would be actually printed, some of the experimental results would become history. Nevertheless, I have definitely addressed the reader to the relevant reference whenever conceptually new ideas are supported by experiments.

Many new exercises were added in all chapters and a small fraction of the new material was formulated as exercises relying on the formulation in the specific chapter. Most of the exercises are not trivial and they fit to an advanced graduate course.

Now, to a few words of gratitude. Two mentors have influenced my research activity as reflected in this monograph: Professor John A. Nation of Cornell University during more than a decade of collaboration and Professor David Schieber of the Technion during almost three decades of discussions and deliberations. They both deserve my deepest gratitude. Three other individuals have impacted my decisions at some key junctions: the late Professor Norman M. Kroll of UCSD to whom I owe the encouragement to pursue the PASER concept at its early stages. To Professor Ilan Ben Zvi I am in debt for diffusing my hesitations as a theoretician to actually making an experiment and eventually performing the PASER experiment at Brookhaven National Laboratory. Last but definitely not least, Professor Maury Tigner of Cornell University. During a few discussions, he brought me to think seriously about energy recovery in optical accelerators which I believe will be an essential concept in the future.

Based on the first edition of the book, several mini-courses have been delivered out of which I wish to express my gratitude for the opportunity to Professor Koji Takata who organized the mini-course at KEK (Japan). To Mr. Guobin Fan the Director of the Institute of Applied Electronics, China Academy of Engineering Physics, Mianyang, Sichuan (China), and Dr. Zhuo Xu his deputy. They gathered a bunch of researchers from all over the country to this 1 week mini-course.

A couple of years ago after the first edition of this monograph was already out-of-print and even the copies available at Amazon were sold out, people from all over the world started to contact me directly for available exemplars. At this point I forwarded Dr. Chris Caron, the Topical Editor of Springer-Verlag, part of these letters with the suggestion to print out a few hundreds of exemplars. After a while, he had written to me with the suggestion to write a new edition. I was quite embarrassed because, on the one hand, when I finished the first edition I promised myself never to repeat the mistake of writing another book. On the other hand, it is difficult to ignore the readers. Naturally, after almost 15 years I had only the LaTeX version of the manuscript while the drawings were gone. To make a long story short, the commitment of Mrs Lesley Price and Mrs Hanna Bismut to assist had convinced me to commit to the laborious project. The first has agreed to convert the LaTeX to MS Word while the second agreed to redo all the drawings, as well as to make the new ones – about two hundreds overall. They both deserve my sincere appreciation, without their help, I would have never completed the project. Obviously, Dr. Caron deserves the credit for his initiative, without him, this edition would have never materialized.

Throughout the years, many students took courses that rely on the original text and their valuable questions lead to this revised version. In fact, part of these students, those whom I directly supervised during their graduate studies, had an important impact on several topics added in this edition. Four of them I wish to mention in the chronological order of their contributions: Dr. Samer Banna, Dr. Assaf Lahav, Dr. Amit Mizrahi, and Mr. Vadim Karagodsky. To all I thank for the dedication and diligence manifested during our collaboration that is only partially reflected in this edition.

Once the draft was completed, I have asked two colleagues to review the book and spell out their criticism. Dr. Eric Colby (SLAC) and Dr. Wayne D. Kimura (STI) did a wonderful job and their numerous suggestions have improved significantly the monograph. Their willingness to help, as well as the precious time they dedicated to the laborious task, is highly appreciated. Last but not least there are the members of the editorial board of the series "Particle Acceleration and Detection", in which this book is published: their input and suggestions were greatly appreciated.

Throughout the past 20 years and more, several agencies have directly supported my research activity as reflected in this manuscript. I am listing them in chronologic order: Rothschild Foundation, United States Department of Energy, United States Air Force, Bi-National United States – Israel Foundation, Israel Science Foundation, and the Kidron Foundation. Among these, four individuals from the US DoE deserve personal appreciation for their support throughout the years: Dr. David Sutter, Dr. Gerald Peters, Dr. Bruce Strauss, and Dr. L.K. Lin.

Finally, I wish to express my deepest gratitude for the support I was fortunate to get from my parents Genia and Izu, my wife Tal, and my three children Michal, Roy, and Yuval.

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