

Preface

This book is an outgrowth of lecture notes developed for a course in the applications of crystal acoustics at Johns Hopkins University. The course serves the needs of engineers and scientists working in the area of defense electronics, primarily in radar, electro-optics, and electronic warfare systems. Students generally are quite knowledgeable in system requirements, but lack the theory of device physics. The course and this book attempt to fill this gap.

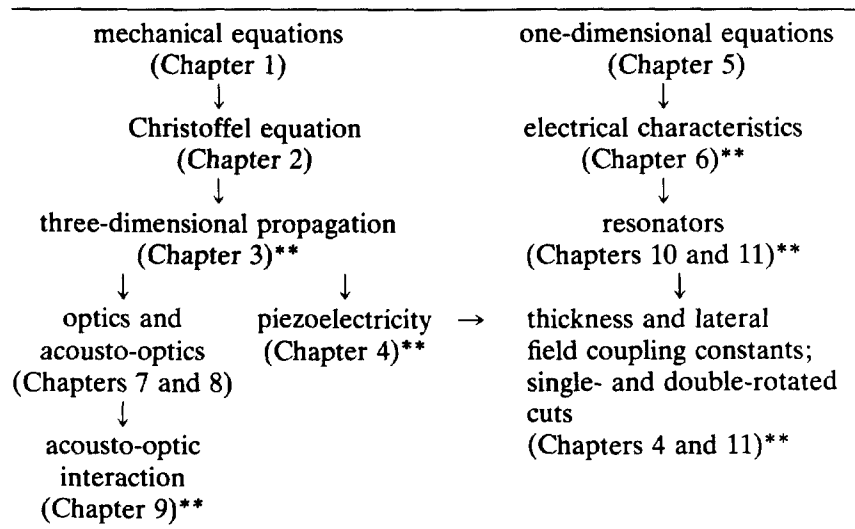
Approximately the first half of the book is dedicated to a discussion of the theory of crystal acoustics, with the latter half consisting of applications to the important areas of acousto-optics and crystal resonators. Organization in this form allows the applications section to reflect the theory in a set of “symmetric” analogues in which knowledge of one half promotes the learning of the other. Examples of these relations are:

I. Crystal Acoustics (Chapters 1–6)	↔	Crystal Optics (Chapter 7)
II. Wideband Operation (Chapter 6)	↔	Narrowband Operation (Chapter 10 and 11)
III. Thickness Excitation (Chapters 4,5, and 10)	↔	Lateral Field Excitation (Chapters 10 and 11)
IV. Electro-optic Effect (Chapter 7)	↔	Photoelastic Effect (Chapters 7–9)

To illustrate this principle further, the theory of crystal optics can be developed by using the same formalism as crystal acoustics. Whereas in acoustics there are three possible modes, with three orthogonal polarizations, in the optic case there are two polarizations: one is a pure shear direction called the ordinary mode; the second is a quasishear direction called the extraordinary mode. Understanding the structure of the acoustic

modes provides important insights into the optic case. Likewise, knowledge of wideband low- Q operation leads naturally to narrowband (high- Q resonator) operation, thickness excitation to lateral field excitation, and electro-optic perturbation to the photoelastic effect. The narrowband-wideband analogue is especially interesting. It is certainly not intuitively obvious that the *same* crystal can operate in both low- Q (delay line) and high- Q (resonator) configurations, depending on the boundary conditions. The same attribute (high piezoelectric coupling) that optimizes performance in the low- Q environment also enhances resonator performance in certain applications.

The theory section is further organized into two basic sections. The first four chapters deal with the solution of the three-dimensional wave equation without boundary conditions, and Chapters 5 and 6 consider the solution of the one-dimensional wave equation with boundaries in the propagation direction. These two basic approaches are continued in the application section, as illustrated in the following table.



**Indicates computer program listing.

In this light, the book forms a "closed-loop system," with the application sections reinforcing concepts developed in the theory section. It is intended for self-study as well as formal classroom training. A program that emphasizes applications to acousto-optics would include Chapters 1 to 4 and 6 to 9, and a resonator study would include Chapters 1 through 6, 10, and 11.

The computer programs reflect the dual approach. They are thus divided into two categories:

1. Solution of the Christoffel equation for arbitrary acoustic propagation direction (three-dimensional equation without boundaries);
2. Solution of the electrical impedance of acoustic devices (one-dimensional equation with boundaries).

The first group of programs includes:

1. Determination of the phase velocity and inverse velocity (slowness) as functions of propagation direction, i.e., the acoustic eigenvalue (Chapter 3).
2. Determination of properties of acoustic waves as functions of propagation direction; these include
 - power flow angle (Chapter 3),
 - energy velocity (Chapter 3),
 - deviation from pure mode direction (Chapter 3).
3. Determination of the effects of piezoelectricity on the propagation of acoustic waves (Chapter 4).
4. Determination of the electromechanical coupling constant as a function of crystal orientation (Chapter 4).
5. Determination of the effective photoelastic constant for arbitrary direction of acoustic and optic beams and acoustic and optic polarizations (Chapter 9). These programs are based on rotation matrices developed by Dr. Rob Bonney.
6. Determination of the coupling constant for lateral field excitation modes for arbitrary direction of electric and piezoelectric plate orientations (Chapter 11).

The second group of programs includes:

1. Determination of the electrical impedance for an infinite-length single-port delay line structure with metal loading, i.e., the Mason model (Chapter 6).
2. Determination of the electrical impedance for a finite-length single-port structure showing acoustic standing waves (Chapter 6)
3. Determination of motional elements of the equivalent circuit of acoustic resonator with and without metalization (Chapter 11).
4. Determination of electrical characteristics of composite resonator structure, including film bulk and high overtone acoustic resonators (Chapter 11).

The programs are written in True BASIC language (version 2.0) with listing of the eigenvalue and Mason model programs included in detail in Chapters 3 and 6. The other programs are formed by modifying these base

programs as explained in the text. These programs are meant to be used! They provide a valuable learning tool that complements the theory and adds a level of excitement and discovery to a theory that, admittedly, tends to be at times a bit dry. All of the figures in the text that involve physical parameters were drawn with these programs on a HP plotter. The field of crystal acoustics and its applications is still evolving; the best (and probably only) way to test new device structures is through computer simulation. This is especially true of the relatively complex configurations of coupling constants of doubly rotated piezoelectric crystals and interactions of acoustic and electric fields with optic beams of arbitrary direction and polarization. Typically, 20% of class time is spent working with specific computer-aided designs. All of the programs are available on disk in several languages. TrueBasic was chosen because it includes full matrix operations and uses a code that closely follows the text equations. Execution time per calculation varies with the program and computer, but the average time is less than .5 s/pt on an IBM AT running at 6 MHz.

Even a modest project of this sort does not materialize overnight in a vacuum. It evolves over a number of years with the help and support of many talented people working together. Coming from a fabrication background, I am deeply indebted to my former colleagues at Litton Amecom who patiently taught me the theory of acousto-optics. Special thanks to Dr. Michael Price, Dr. Rob Bonney, Dr. Otis Zehl, Mr. Zigmund Turski, Mr. Pradeep Wahi, and Mr. Jerry Long. I have also benefited greatly from discussions with my colleagues at Westinghouse, including Dr. Harry Salvo, Dr. Robert Moore, Dr. David Blackwell, Dr. Dickron Mergerian, Mr. Michael Driscoll, Mr. Irwin Abramowitz, Mr. Paul Smith, Mr. Dana Bailey, and Mr. Steven Brown. Many of the illustrations were expertly drawn by Lisa Carter of Brimrose Corporation.

Unfortunately, a book of this nature cannot be written without a certain level of mathematical sophistication. I have assumed that the reader is familiar with electromagnetic theory at the undergraduate level. I have, however, attempted to work out all the complex algebra in as much detail as possible consistent with space limitations; I regret any oversights that make the developments difficult to follow. To quote from Professor J. Gordon: "What we find difficult about mathematics is the formal symbolic presentation of the subject by pedagogues with a taste for dogma, sadism and incomprehensible squiggles." I have tried to minimize the sadism, and I sincerely hope that the reader will find that most of the "squiggles" are not completely incomprehensible.

*Lanham, MD
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