Chapter 1
Introduction

1.1 Photonics Revolution and Power Electronics

At the beginning of the new millennium, the invention of high-intensity and blue light-emitting diodes (LEDs) started a revolution in lighting technology. Their unique properties are leading to the replacement of all other light sources in general illumination devices by LEDs. The characteristics of the new LEDs are a high efficiency of electrical energy conversion into light, high reliability, long life, compact size, low cost, color variety, environmental friendliness, ability to be manufactured by very-well-developed semiconductor technologies, etc.

A similar revolution is occurring for laser engineering and technology. Diode lasers are not only replacing other laser types in well-known technologies but also creating new applications. The rapid progress in fiber optics further accelerated the advancement of industrial laser technologies. Optical fibers helped to increase the power delivered by a laser beam for up to several tens of kilowatts, making lighting technologies preferable for industrial applications.

Laser diode (LD) radiation characteristics depend primarily on the electric power provided to the LD by an electrical power source, i.e., a laser diode driver (LDD). As mentioned in the Preface, LEDs and LDs require power sources with the characteristic of a constant current source and, in some cases, constant power source. There has not been enough attention and coverage given to current and power sources in the contemporary technical literature. One of the goals of this book is to address that deficiency.

Whereas the maximum power of LED fixtures is limited to several hundred watts, laser-system power had reached several tens of kilowatts. Due to this difference, the conversion topologies and constructions of LDDs significantly differ from LED drivers. LDDs can be created using a variety of electrical conversion topologies. However, the reliability, efficiency, size, LDD cost, and ultimately the success or failure of the LDD project all depend primarily on the correct choice of the conversion topology. This book presents the effective and reliable conversion topologies for LDDs.

Mid- and high-power LDs are very expensive devices. The conversion topologies offered in the book have an inherent current limit. This feature provides the LD protection from any AC line instabilities or LDD malfunctioning. Unlike LEDs, LDs are widely used in the pulsed mode and thus require pulsed LDDs. Another goal of this book is to familiarize readers with the effective pulsed LDDs.

The book also covers some other important aspects of power electronics design, such as soft switching in high-frequency (HF) switched-mode converters, advantageous usage of parasitic elements of electrical circuit components, paralleling conversion modules to increase power in industrial LDDs, etc.

1.2 Audience

This book focuses on the powering of LD systems. It was written for two categories of professionals: (a) power-electronics design engineers involved in the development of LDDs and power supplies (PSs) for electrical components of laser systems, and (b) professionals who build and/or operate laser systems.

Companies or organizations that build or use LD systems have two alternatives when it comes to system creation. The first is to develop specific LDDs and PSs. This case requires a significant investment of finances and time, and it requires power-electronics-engineering resources experienced in the development of current and power sources (which is not always possible). The second alternative is to assemble the system from commercially available components. In many cases, companies prefer the latter.

LDDs and PSs for LD subsystems are very important parts of LD systems that directly affect the system's general reliability and the expected lifetime of the most expensive part of the system, i.e., the LD assembly. System developers and users should understand how to choose the appropriate power sources, which often involves compiling a list of questions for vendors and knowing the limitations of the standard PSs on the market. These topics are also discussed in the book.

The issue specific to LDs is their dangerous sensitivity to the slightest current overloads in comparison to the other laser types. There is a joke among laser specialists that "all LD system users can be divided into two groups: those who already burned down an expensive LD and those who will eventually." I hope that this book will help readers avoid belonging to either of these groups.

1.3 Equation Derivation, Numerical Calculations, and Units

The engineering math software MathCad 15[2] was used to derive the equations that describe electrical circuit operation and to numerically calculate these circuit examples. These formulas and examples can be copied from the book and pasted into MathCad software for use with variations for calculations of your circuits. Most graphics were also plotted using MathCad.

To interpret the formulas in the book correctly, it is necessary to mention several MathCad specifics:

- To define a variable definition, use the symbol :=. A variable can be set either numerically or symbolically. For example,

$$x := 2; \quad y := x^2 - 1.$$

- To evaluate an expression with previously defined variables, the standard evaluation symbol = is used. Following the previous expressions,

$$y = 3.$$

- To block the evaluation of an expression that has some undefined variables but is required to derive the following equations, the "Disable Equation" operator is used. The small black box next to the equation indicates that evaluation is turned off:

$$\frac{dI_{load}}{T_3 - T_2} := \frac{V_{dc}}{L_f} \blacksquare.$$

Numerical calculation of circuit parameters helps clarify circuit behavior and limitations. Variables are defined in the Initial Data section of the MathCad program, and the evaluation results are in the Calculation section. There are numerical examples for most of the circuits discussed in this book.

All of the examples of numerical calculation of circuits use units defined by the International Unit System (SI):

- Current in amperes (A),
- Voltage in volts (V),
- Power in watts (W),
- Energy in joules (J),
- Charge in coulombs (C),
- Resistance in ohms (ohm),
- Capacitance in farads (F),
- Inductance in henrys (H),
- Frequency in hertz (Hz),
- Time in seconds (s), and
- Temperature in degrees Celsius (°C).

1.4 Schematic Plotting and Circuit Computer Simulation

Schematic plotting and circuit computer simulation were performed with the simulation software LTspice IV by Linear Technology Inc.[3] For clarity, excessive details in schematics, such as the parameters of the component and those of the voltage and current sources, as well as the simulation directives, are omitted. These parameters should be added to make circuits workable in LTspice IV (see the Appendix). If you are interested in obtaining the files with calculations and simulations of circuits highlighted in this book, you can order them directly from the author.

1.5 Power-Supply Development

There is an absurd saying, "The easiest things are curing people and governing the state—everyone knows how to do it." Similarly, some electronics engineers and managers think that PS design is a trivial task. In the author's professional experience, people who are not specialists in power electronics, such as digital-electronic engineers, have sometimes been assigned to develop PSs, even for mass production, and the results have always been negative.

To a non-power-electronics engineer, it may seem that PS design and prototyping may commence after referring to books and online sources about power-conversion technology and finding some seemingly suitable schematics. In addition to the aid of a "developer," there is also modern computer simulation software. A working schema can be obtained in a short amount of time without a detailed understanding of circuit operation and mathematical calculations of circuit components. After assembling the prototype and varying the circuit component values, it may be possible to produce a device that fulfills a specified task.

This device might be suited for laboratory experimentation, but it would be hardly possible to manufacture it on the industrial scale due to the inconsistencies of this "development" for the requirements of the PS specification and certification compliance by such agencies as the FCC, UL, CE, VDE, etc. It will also be difficult to achieve a highly reliable performance.

A developed PS often cannot be placed in a given enclosure because its efficiency is too low and the temperature of the components is too high. Large heatsinks are needed to reduce the temperature to an acceptable level. The selected topology may be very "noisy," and the "designer" cannot identify the sources of noise and how to reduce them.

It should be clear that without preliminary consideration of the thermal and EMI problems, the design should not be attempted. A designer should consider a different topology to combat these problems. What if the PS spec requires a manufacturing warranty for two or even five years? The designer must now factor in PS long-term reliability. Which components could fulfill the warranty period? Again, it is necessary to dig into the literature and look for answers. The list of emerging issues and challenges is very long, including ensuring PS safety, protecting against power surges in the AC mains, preventing load failure when the PS malfunctions, etc.

It is possible to consider all of these issues, to find ways of solving them, and learn how to design reliable PSs. However, digital-design engineers would need to abandon their specialty for several years and completely immerse themselves in power-conversion technology, namely the design of PSs. Qualified experts in digital design who are not passionate about power electronics would do better to focus on their field. (The exception is a PS with microprocessor control. All a digital designer must do is develop the microprocessor control and nothing more.)

Readers who are adamant about becoming a power-electronics engineer will benefit from the useful rules and tips contained in this book. However, this one text is not enough to become a professional power-electronics designer. There are many other good books devoted to the subject matter, which can be found online.[4] Beginners should start with those light on mathematics; the calculation of converters is rather simple and is based on well-known mathematical formulations of electric-circuits laws.