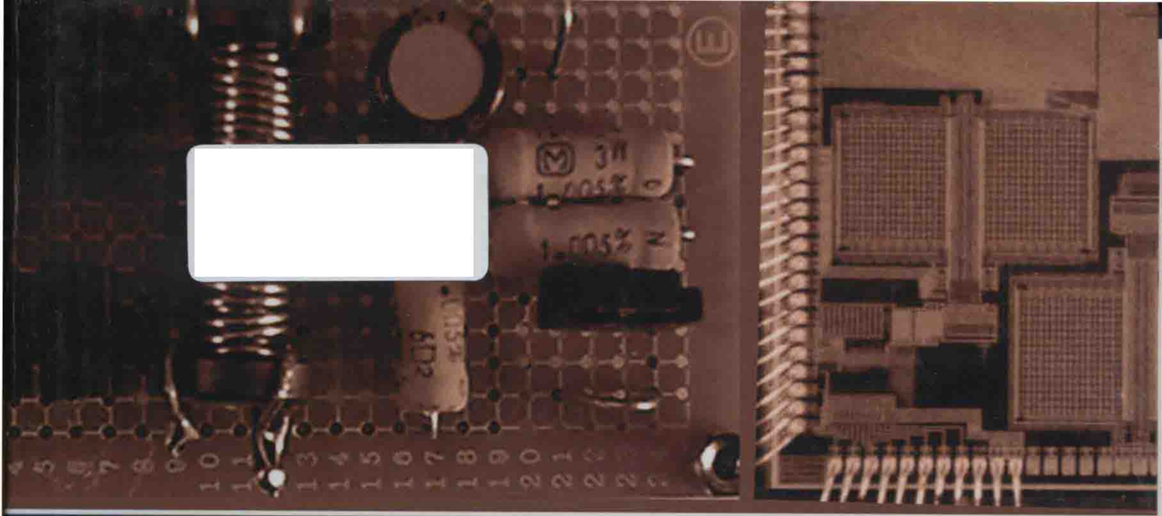

Handbook of Power Management Circuits

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Haruo Kobayashi
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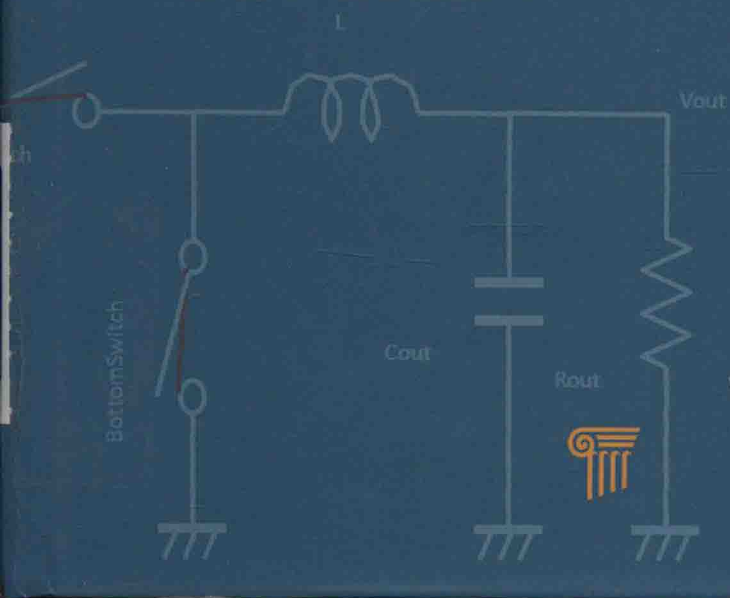

$$Vout = \frac{Ton}{Ton + Toff} Vin = \frac{Ton}{T} Vin$$

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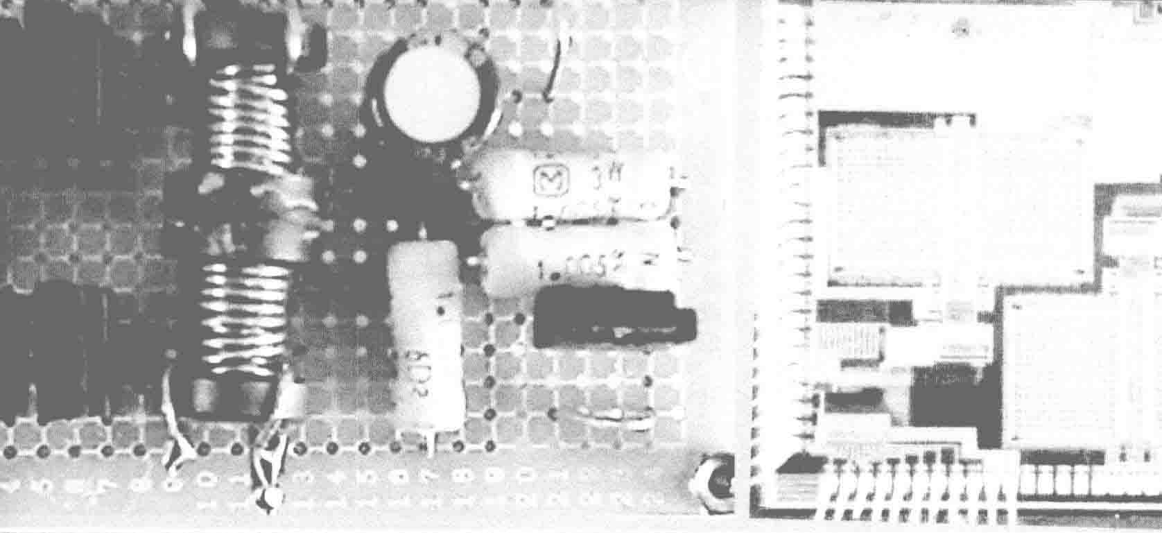

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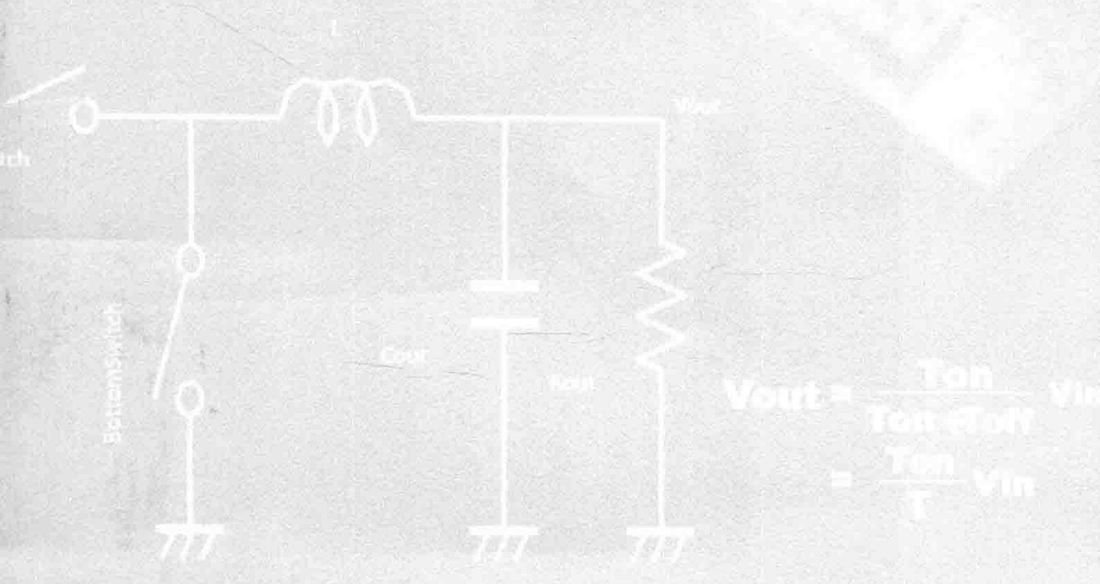

Preface

Electronics and electrical engineering may be only one part of physics. However, during the last 100 years, they have advanced rapidly and changed our lives drastically. Their roles can be classified into the following categories: (i) information and signal processing, (ii) information storage, (iii) communication, and (iv) energy and power. In this book, we focus on the fourth category—energy and power, or power electronics—which is becoming more and more important to make the earth green.

The book is intended for tutorials on power supply circuits for engineers and graduate students in circuit design fields as well as power electronics, and it covers a wide range of power supply circuits. The authors of all chapters have been engaged in research and development of their contents, and hence each chapter has its own originality, reflecting the authors' experiences. It is noteworthy that the power supply circuits as well as power amplifier circuits are different from analog, mixed-signal, and RF-integrated circuit design, and even circuit designers who have good background of analog, mixed-signal, and RF circuit design often get puzzled when they start to get involved in power supply circuits. In the 1997 IEEE International Solid-State Circuits Conference, there was a panel discussion session entitled "RF Designers are from Mars, Analog Designers are from Venus." Here I would like to add the following statement "Power Supply Designers are from Mercury and Power Amplifier Designers are from Jupiter."

This handbook is organized in two parts. In Part I, basics of power supply circuit have been reviewed systematically. In Chapter 1, basics of power supply circuit are introduced. The first hurdle to understand the DC–DC converter is the circuit behavior of an inductor. For example, current can be made to flow from lower- to higher-voltage nodes through the inductor, and thanks to the inductor, the DC–DC converter efficiency can theoretically be 100% in ideal conditions.

In Chapter 2, a buck converter—the most important DC–DC converter—for low-voltage applications is described elaborately.

First, buck, boost, and buck–boost DC–DC converters are introduced. Then two operation modes, that are, continuous current mode (CCM) and discontinuous current mode (DCM) are explained. Then their operating principle, circuit analysis with transfer function, closed-loop operation, design consideration such as error amplifier design, are discussed. An example of power supplies in a computer system is also discussed.

In Chapter 3, isolated DC–DC converters with a transformer (isolation of large voltage and current conversion, minimizing voltage and current stresses, multiple outputs, flyback converter, forward converter, push–pull converter, half-bridge converter, full-bridge converter of various types) are explained. These are used for handling relatively large power, and even beginners can understand them by a careful read, although they may find them difficult to understand at first.

Chapter 4 covers modeling and analysis of switching converters, such as state–space average model, averaged device model, and CCM and DCM models as well as transfer function. In Chapter 5, control schemes of switching converters are described, such as a self-oscillating hysteretic PWM control and a current mode control as well as a voltage mode PWM control, including some content based on the authors' research.

Chapter 6 describes passive components (inductor, transformers, and capacitors) and explains the fundamental physics behind inductors and transformers. It then introduces capacitors for switching converters, such as aluminum electrolytic capacitor, tantalum electrolytic capacitor, film capacitor, and ceramic capacitor as well as characteristics and applications of various capacitors.

In Part II, several selected topics are introduced individually. In Chapter 7, on-chip voltage converters are explained for large-scale integration (LSI) designer, such as voltage-reference circuit (bandgap reference circuit, or BGR), voltage-down converters, and voltage-up converters. On-chip voltage converters are very important for low-power operation in large-scale integrations (VLSIs).

Chapter 8 describes applications of DC–DC AC–DC switching converters and some of them are recent research results of the author: non-inverted buck–boost DC–DC converter with dual delta-sigma modulators and non-isolated AC–DC direct converter.

In Chapter 9, single-inductor multi-output DC–DC converters are introduced. The single-inductor multi-output DC–DC converters are attractive for small size but their control is difficult. Their several configurations and control methods are also described.

Chapter 10 shows a small, low-power boost regulator optimized for energy-harvesting applications. Recently, interests of energy-harvesting applications are booming up and an example of boost-converter design for this purpose is introduced. Chapter 11 introduces wireless power delivery for 3D system integration and for non-contact wafer-level test focusing on the author's experience and interest. Chapter 12 shows high-power GaN–HEMT amplifier for cellular base stations. A lot of attention is now being paid to GaN HEMT, and several power amplifier architecture, design, implementation, and measurement examples with this technology are introduced. Chapter 13 describes power supply circuits with capacitors and switches.

We hope that this book will be helpful for electronics engineers from various fields in understanding these interesting and important areas and the readers will enjoy reading all the chapters.

Finally, we would like to thank Dr. Masashi Ochiai for reviewing the manuscript and providing valuable comments.

Haruo Kobayashi

Takashi Nabeshima

Winter 2015

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