ENERGY SERIES

Smart Power Integration

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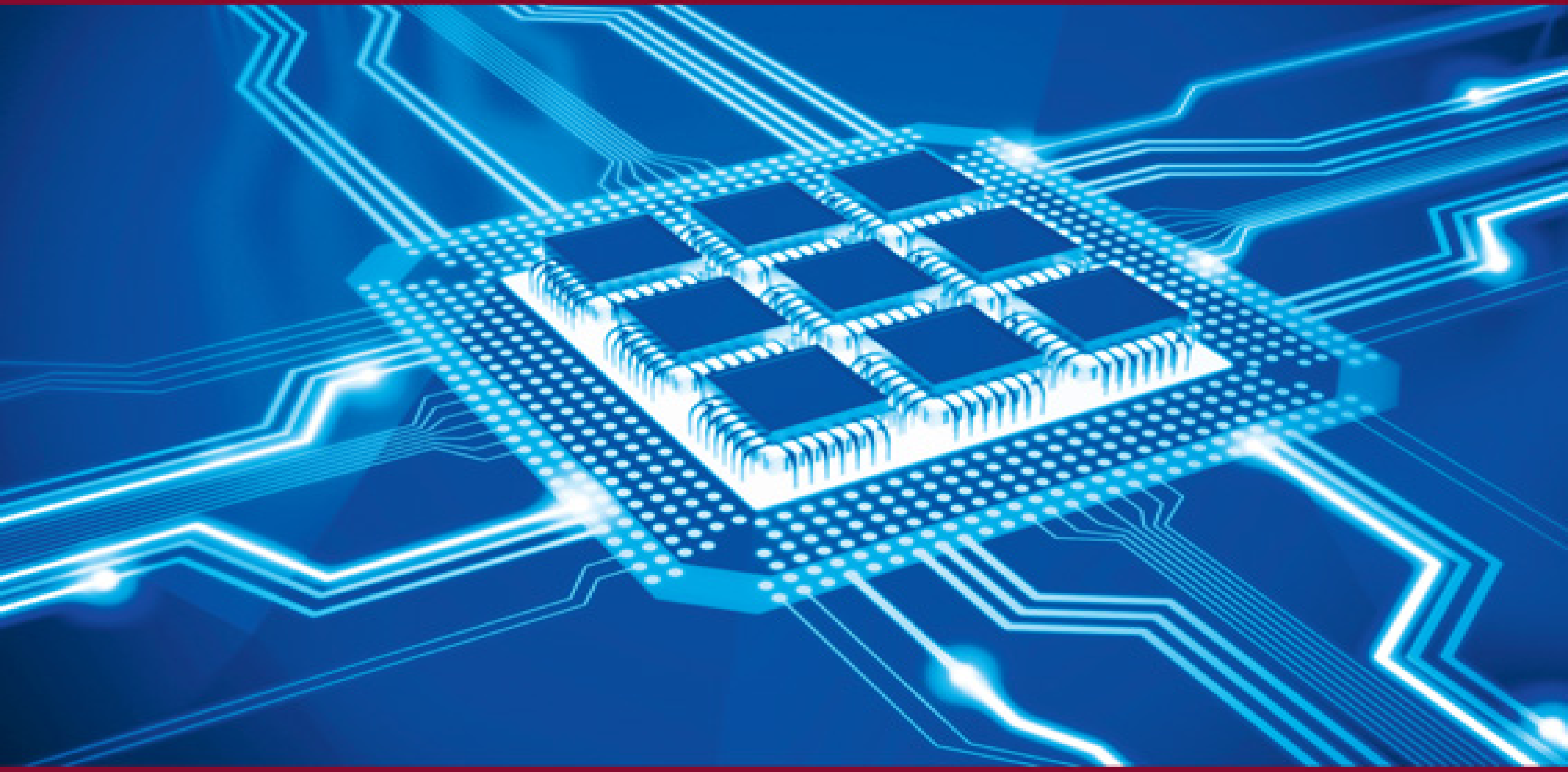

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Preface

Smart integration is a process in which an existing system infrastructure is upgraded through the integration of multiple technologies, for example, automated sensors, advanced automated controls and forecasting systems. A smart grid allows for interaction between the consumers and enables optimal use of energy and communication systems based on price preferences and system technical stresses, without forgetting the environmental aspect.

The continuous reduction in dimensions and the need for increasingly high power density have highlighted the need for ever more efficient structures. Smart power technology has been developed to meet this demand. This technology makes specific use of (L)DMOS devices, offering new solutions because of its unique high voltage and high current characteristics. The operation of these devices is accompanied by a number of phenomena. Good modeling makes it possible to account for these phenomena and predict the physical behavior of the transistor prior to production. To this, we add an axis that has become unavoidable: the entanglement between devices, circuits, connections and substrates.

(Micro)grid designs have evolved significantly in recent years with the incorporation of information and communication technology (ICT) solutions, such as artificial intelligence (AI) and machine learning (ML). A smart microgrid, equipped with sensors and automation controls, can efficiently perform load profiling and forecasting, generation management, load prioritization, etc. A go-to example is the vehicles that are quickly becoming a center of communication, navigation and connectivity. Automotive solutions will integrate with smart city infrastructures, personal devices and in-vehicle services to become part of a connected whole.

This book introduces different domains and tools and allows the reader to develop their understanding of smart power systems through real studies. Knowledge of high school mathematics is sufficient to progress through these studies.

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Overview of Smart Power Integration

1.1. Introduction

Since 1965, integrated circuit (IC) technology has followed Moore's law which states that the number of integrated devices doubles every 18 months. This growth is partly due to an increase in the size of ICs that can be produced. However, the dominant effect is due to the reduction in feature size of component devices that are integrated. The reduction of feature size tends to bring advantages of increased speed and the possibility to operate at lower voltages, allowing reduced power consumption. These advantages make technology shrinkage very attractive for technical performance reasons, as well as cost.

However, there are many applications where voltage cannot be reduced for external reasons. There are three areas where this is the case: power electronics, automotive applications and wide dynamic range circuits. In such applications, system integration of high voltage, analog and digital circuitry on a single IC is attractive in order to gain advantage in terms of miniaturization, reliability, efficiency and cost. However, in order to make these gains, the conflict of reducing voltage due to technology feature size has to be resolved with the requirements for operation at continued relatively high voltage.

The different operation and interface requirements of high voltage, analog and digital require a technology development optimized for these system requirements. Different technologies have been developed to address these applications, such as smart power and various bipolar-CMOS-DMOS (BCD) processes.

Smart power integrated circuits (PICs) that monolithically integrate low-loss power devices and control circuitry have attracted much attention across a wide range of applications. These ICs improve system reliability, reduce volume and weight and increase overall efficiency. Considerable effort has been put into the development of smart power devices for automotive electronics, peripheral computer appliances and portable equipment, such as cell phones, video cameras, and so on.

Commonly used smart power devices are the lateral double diffused MOS Field Effect Transistor (LDMOSFETs) and lateral insulated gate bipolar transistors (LIGBTs) implemented in bulk silicon or silicon on insulator (SOI). The main challenges in the development of these devices are obtaining the best trade-off between specific ON-resistance RON,SP (RON × area) and breakdown voltage (BV), and shrinking feature size without degrading device characteristics.

1.2. Smart PIC applications

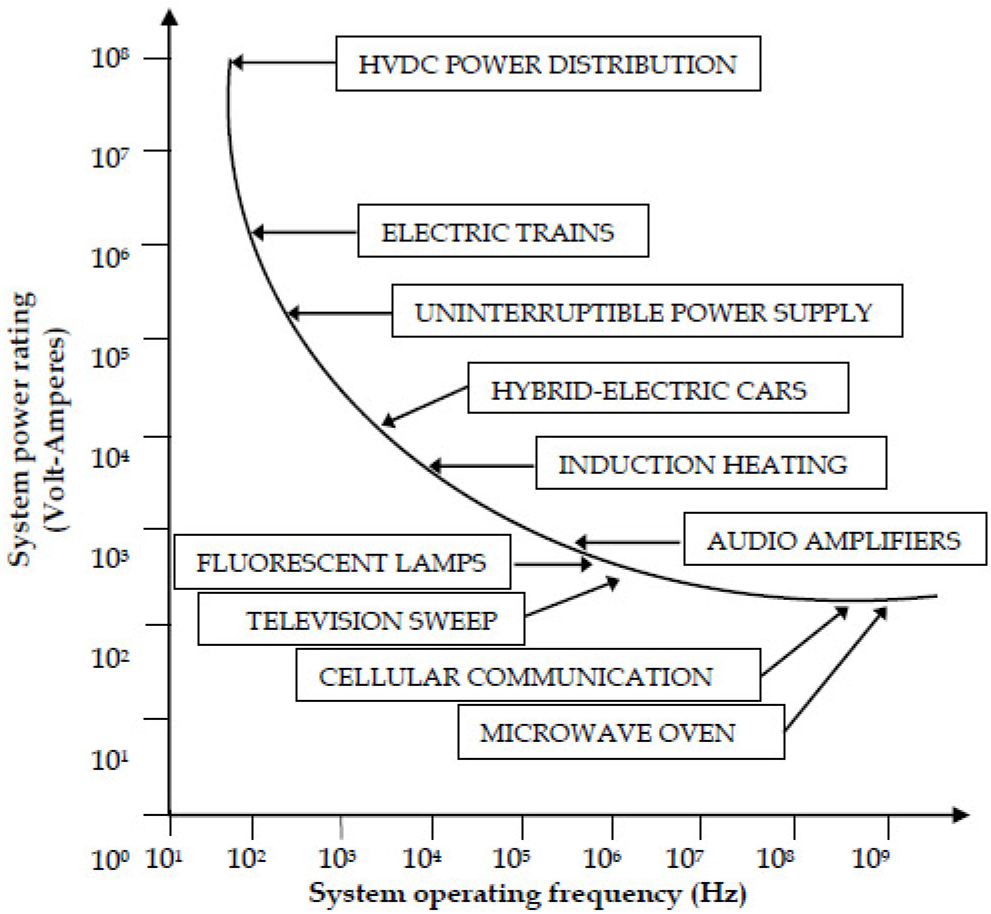

Figure 1.1. *Applications of power devices*

Smart PIC technology is expected to have an impact in all areas in which discrete power semiconductor devices are currently being used. It is anticipated that this technology will open up new applications based upon the added features of smart controls. In Figure 1.1, applications of power devices are shown as a function of operating frequency. Another classification approach of these applications involves current and voltage handling requirements, as shown in Figure 1.2. Some of these applications are listed in the following subsections.

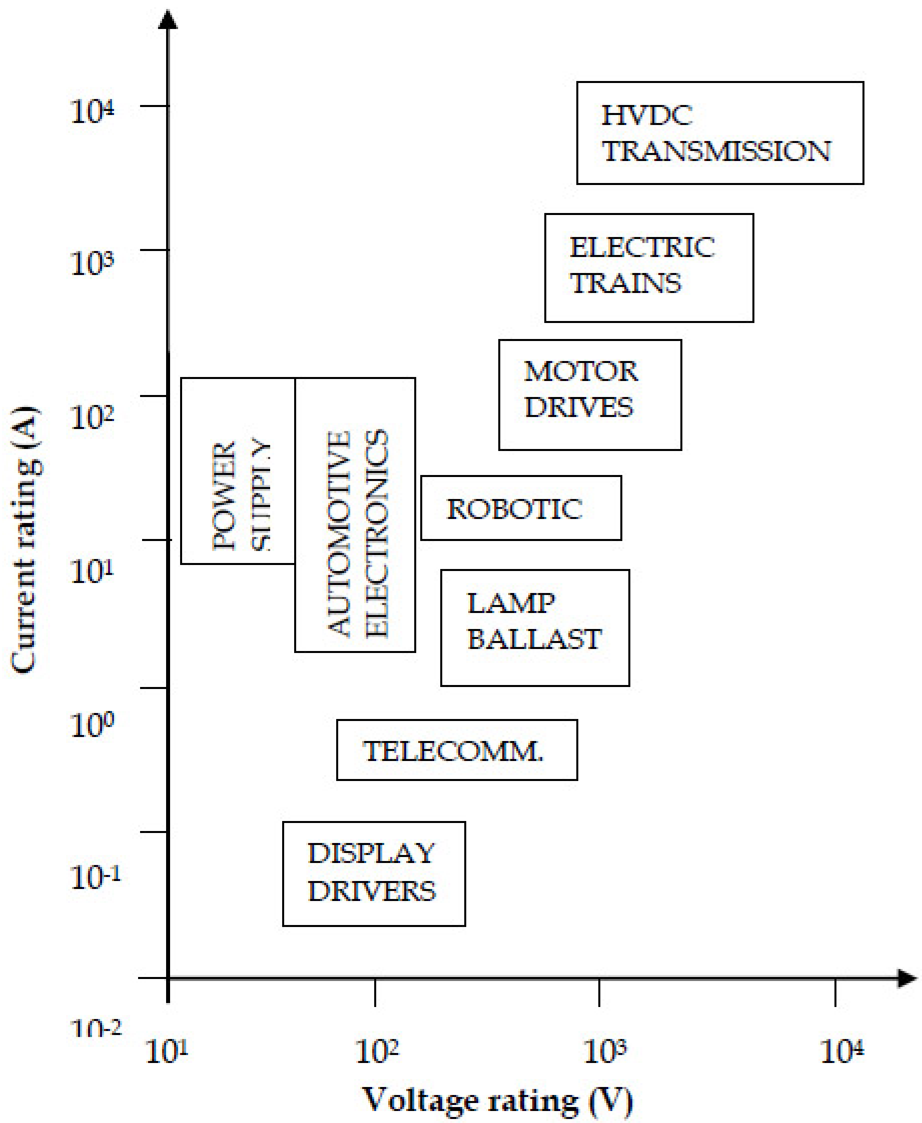

Figure 1.2. *System ratings of power devices*

1.2.1. *Flat panel displays*

The popularity of portable electronic products such as cell phones and notebook computers has generated significant demand for flat panel displays. These displays are usually liquid crystal displays (LCD) or electro-luminescence (EL) panels arranged in a matrix with large number of column and row drivers (e.g. 640 × 480 for VGA resolution). Although the required voltage may be high, the current level is low (usually in the mA range). Smart PICs with as many as 80 output channels have been fabricated on a monolithic chip.

1.2.2. *Computer power supplies and disk drivers*

Computer systems are developing continuously in terms of speed and processing capabilities. This is made possible by using higher density Very Large-Scale Integration (VLSI) technology. However, the increased power requirement has resulted in an increase in the physical size of the power supply. In 1976, the CPU board and power supply each represented one-third of the total physical volume of a computer system. By the 1990s, the power supply had grown to 50% of the physical volume while the CPU board had shrunk to about 20%. To reverse this trend, it is necessary to develop smart PIC technology to improve the density and hence the volume of the power supplies.

1.2.3. *Variable speed motor drives*

Variable-speed motor drives are being developed to reduce power loss in all applications. The improvement in performance requires smart power technology that can operate at relatively high frequencies with low power losses. This translates to a low ON-state voltage drop at high current levels, fast switching speed and rugged operation. For smart PIC implementation, additional consideration, such as level shifting to and from high voltages, over-temperature, over-current, over-voltage and short-circuit protection are more critical.

1.2.4. *Factory automation*

Advanced numerical control and robotic systems require efficient smart PIC technology to create a distributed power control network under the management of a central computer. The smart PICs for this application must be capable of providing AC or DC power to various loads, such as motors, solenoids, arc welders, and so on. They are also required to perform diagnostic, protection and feedback functions.

1.2.5. *Telecommunications*

One of the high-volume markets for smart power technology is in telecommunications. The technology required for these applications must be capable of integrating multiple high-voltage, high-current devices on a single chip. At present, this has been achieved using MOS devices fabricated using dielectric insulation. Improvements are required to reduce the cost of the dielectric insulation fabrication process. Ongoing development on direct wafer bonding has been promising in terms of providing a cost-effective process.

1.2.6. *Appliance controls*

The main benefit of using smart PICs in appliance control is to provide improvements in performance and efficiency. Onboard sensors can also provide more precise controls (e.g. temperature settings). Simple domestic appliances, such as toasters, washing machines and irons, are appearing with smart PICs for this reason.

1.2.7. *Consumer electronics*

Smart PICs are required for a large variety of entertainment systems such as CD players, tape recorders, VCRs, etc. For example, a monolithic motor control IC that regulates the speed of the motor, while minimizing power losses, is essential to all battery-operated consumer entertainment systems. Development of improved lateral