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The Art of Software Thermal Management for Embedded Systems

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*For Mandy, my steadfast and beautiful wife,
who shows me daily what it means to live
well, work selflessly, and love abundantly*

Preface

Thermal performance is the new bottleneck in embedded systems design. As processing requirements increase, and physical device sizes continue to decrease, it is becoming more and more difficult to efficiently get heat out of embedded systems efficiently.

This book focuses on the root cause of heat in an embedded system: power. And since software has an enormous impact on power consumption in an embedded system, if we are to manage heat effectively, we need to therefore understand, categorize, and develop new ways to aggressively reduce power.

The Art of Software Thermal Management (STM) explores both the science and the art of reducing power consumption in a computing system as a means to manage heat, improve component reliability, and increase system safety. This book is a pragmatic guide to the field of STM for embedded systems, a catalog of software thermal management techniques, and a call to action for future areas of research and development.

Plymouth, November 2013 Mark Benson

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Contents

Acronyms

ACM	Association for Computing Machinery
ACPI	Advanced Configuration and Power Interface
ADC	Analog to Digital Converter
AE	Auto Exposure
AF	Auto Focus
AMD	Advanced Micro Devices
AMP	Asymmetric Multiprocessing
AMR	Absolute Maximum Rating
APM	Advanced Power Management
AV	Audio Visual
AVS	Adaptive Voltage Scaling
AWB	Auto White Balance
CAD	Computer-Aided Design
CAGR	Compound Annual Growth Rate
CG	Clock Gate
CMOS	Complementary Metal-Oxide Semiconductor
CODEC	Portmanteau of Coder-Decoder
CPU	Central Processing Unit
DAC	Digital to Analog Converter
DARPA	Defence Advanced Research Projects Agency
DDR	Double Data Rate SDRAM
DFS	Dynamic Frequency Scaling
DMA	Direct Memory Access
DMIPS	Dhrystone Million Instructions Per Second
DPM	Dynamic Power Management
DPS	Dynamic Power Switching
DPTC	Dynamic Process Temperature Compensation
DRAM	Dynamic Random Access Memory
DSP	Digital Signal Processor
DVFS	Dynamic Voltage and Frequency Scaling
DVS	Dynamic Voltage Scaling
EEPROM	Electrically Erasable Programmable Read-Only Memory
FSM	Finite State Machine
GUI	Graphical User Interface
HW	Hardware

IC	Integrated Circuit
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IP	Intellectual Property
ISP	Image Signal Processor
MCU	Microcontroller Unit
MPEG	Moving Picture Experts Group
NJTT	Near-Junction Thermal Transport
NTI	Nano-Thermal Interfaces
OEM	Original Equipment Manufacturer
OMAP	Open Multimedia Applications Platform
OPP	Operating Performance Point
OS	Operating System
PC	Personal Computer
PCB	Printed Circuit Board
PDA	Personal Digital Assistant
PM	Power Management
PMIC	Power Management Integrated Circuit
PWM	Pulse-Width Modulation
RAM	Random Access Memory
RF	Radio Frequency
ROC	Recommended Operating Conditions
RTC	Real-Time Clock
SD	Secure Digital
SDR	Software-Defined Radio
SLM	Static Leakage Management
SMP	Symmetric Multiprocessing
SOC	System on Chip
SPI	Serial Peripheral Interface
SDRAM	Synchronous Dynamic Random-Access Memory
STM	Software Thermal Management
SW	Software
TDP	Thermal Dynamic Power
TGP	Thermal Ground Plane
TMT	Thermal Management Technologies
TRM	Technical Reference Manual
TV	Television
UART	Universal Asynchronous Receiver/Transmitter
UML	Unified Modeling Language
USB	Universal Serial Bus
VDD	Positive Supply Voltage
VLSI	Very Large-Scale Integration

Part I
Foundation

Thermal performance is the new bottleneck in embedded systems design. As processing requirements have increased, and physical device sizes continue to decrease, it has become more and more difficult to get heat out of embedded systems.

Excessive heat generated by consumer cell phones and tablets and other electronic devices can reduce component reliability, reduce performance, or even cause discomfort or personal injury when in close contact with skin. This is especially true when the device is in an enclosure without fans or other avenues of convection.

Heat problems such as these affect nearly every electronic device, and particularly those with high computational requirements such as video streaming devices, automobile infotainment systems, high-performance factory equipment, portable hand-held industrial instrumentation, implantable medical devices, and multimedia military combat radios.

The fundamentals of heat transfer are based in the laws of thermodynamics, and are studied by physicists, mechanical engineers, material scientists, and chemists. Researchers and corporations are putting forth great effort to invent solutions to get unwanted heat out of a system quickly and efficiently.

Much focus has been placed on the topic of heat transfer and mechanical or chemical means to extract heat from a system effectively. These are good and fine advancements. However, software engineers play a special role in thermal management since software dictates the types and amounts and durations of computation, all of which will require power and produce heat. Software helps us minimize the root cause of heat in embedded systems (power) and is the focus of this book. In this part, the following three chapters introduce *The Art of Software Thermal Management for Embedded Systems* and the goals of this book.

Chapter 1 Introduction: In this chapter, we introduce the premise of the book and goals, including a discussion of the microcontroller market, existing thermal management solutions, and whether Software Thermal Management is a science, an art form, or both.