

APPLE I REPLICA CREATION

Back to the Garage

“Apple I took the biggest step of all. Some very simple concepts are very hard to do the first time.”

—Foreword by Steve Wozniak, Co-Founder of Apple Computer

- Build a Working Replica of the Revolutionary Apple I Computer
- Go “Old School” With BASIC and Assembly Language Programming
- Solve the Same Challenges That Forced Early Microcomputer Design Innovations

Tom Owad, Applefritter.com



Register for Free Membership to

solutions@syngress.com

Over the last few years, Syngress has published many best-selling and critically acclaimed books, including Tom Shinder's *Configuring ISA Server 2000*, Brian Caswell and Jay Beale's *Snort 2.1 Intrusion Detection*, and Angela Orebaugh and Gilbert Ramirez's *Ethereal Packet Sniffing*. One of the reasons for the success of these books has been our unique **solutions@syngress.com** program. Through this site, we've been able to provide readers a real time extension to the printed book.

As a registered owner of this book, you will qualify for free access to our members-only solutions@syngress.com program. Once you have registered, you will enjoy several benefits, including:

- Four downloadable e-booklets on topics related to the book. Each booklet is approximately 20-30 pages in Adobe PDF format. They have been selected by our editors from other best-selling Syngress books as providing topic coverage that is directly related to the coverage in this book.
- A comprehensive FAQ page that consolidates all of the key points of this book into an easy to search web page, providing you with the concise, easy to access data you need to perform your job.
- A "From the Author" Forum that allows the authors of this book to post timely updates links to related sites, or additional topic coverage that may have been requested by readers.

Just visit us at **www.syngress.com/solutions** and follow the simple registration process. You will need to have this book with you when you register.

Thank you for giving us the opportunity to serve your needs. And be sure to let us know if there is anything else we can do to make your job easier.

SYNGRESS®

This Page Intentionally Left Blank



SYNGRESS®

APPLE I REPLICA CREATION

Back to the Garage

Tom Owad

with Foreword by
Steve Wozniak, Co-Founder of Apple Computer

Syngress Publishing, Inc., the author(s), and any person or firm involved in the writing, editing, or production (collectively “Makers”) of this book (“the Work”) do not guarantee or warrant the results to be obtained from the Work.

There is no guarantee of any kind, expressed or implied, regarding the Work or its contents. The Work is sold AS IS and WITHOUT WARRANTY. You may have other legal rights, which vary from state to state.

In no event will Makers be liable to you for damages, including any loss of profits, lost savings, or other incidental or consequential damages arising out from the Work or its contents. Because some states do not allow the exclusion or limitation of liability for consequential or incidental damages, the above limitation may not apply to you.

You should always use reasonable care, including backup and other appropriate precautions, when working with computers, networks, data, and files.

Syngress Media®, Syngress®, “Career Advancement Through Skill Enhancement®,” “Ask the Author UPDATE®,” and “Hack Proofing®,” are registered trademarks of Syngress Publishing, Inc. “Syngress: The Definition of a Serious Security Library”™, “Mission Critical™,” and “The Only Way to Stop a Hacker is to Think Like One™” are trademarks of Syngress Publishing, Inc. Brands and product names mentioned in this book are trademarks or service marks of their respective companies.

KEY SERIAL NUMBER

001	HJIRTCV764
002	PO9873D5FG
003	829KM8NJH2
004	BNB3288BN6
005	CVPLQ6WQ23
006	VBP965T5T5
007	HJJJ863WD3E
008	2987GVTWMK
009	629MP5SDJT
010	IMWQ295T6T

PUBLISHED BY

Syngress Publishing, Inc.
800 Hingham Street
Rockland, MA 02370

Apple I Replica Creation: Back to the Garage

Copyright © 2005 by Syngress Publishing, Inc. All rights reserved. Printed in the United States of America. Except as permitted under the Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written permission of the publisher, with the exception that the program listings may be entered, stored, and executed in a computer system, but they may not be reproduced for publication.

Printed in the United States of America

1 2 3 4 5 6 7 8 9 0

ISBN: 1-931836-40-X

Publisher: Andrew Williams
Acquisitions Editor: Gary Byrne
Technical Editor: John Greco
Cover Designer: Michael Kavish

Page Layout and Art: Patricia Lupien
Copy Editor: Darlene Bordwell
Indexer: J. Edmund Rush



Acknowledgments

Syngress would like to acknowledge the following people for their kindness and support in making this book possible.

Thank you to Steve Wozniak for contributing his insights.

Thank you to John Soluk of VAMP Inc., for contributing both his software and expertise to this project.

Syngress books are now distributed in the United States and Canada by O'Reilly Media, Inc. The enthusiasm and work ethic at O'Reilly is incredible and we would like to thank everyone there for their time and efforts to bring Syngress books to market: Tim O'Reilly, Laura Baldwin, Mark Brokering, Mike Leonard, Donna Selenko, Bonnie Sheehan, Cindy Davis, Grant Kikkert, Opol Matsutaro, Steve Hazelwood, Mark Wilson, Rick Brown, Leslie Becker, Jill Lothrop, Tim Hinton, Kyle Hart, Sara Winge, C. J. Rayhill, Peter Pardo, Leslie Crandell, Valerie Dow, Regina Aggio, Pascal Honscher, Preston Paull, Susan Thompson, Bruce Stewart, Laura Schmier, Sue Willing, Mark Jacobsen, Betsy Waliszewski, Dawn Mann, Kathryn Barrett, John Chodacki, and Rob Bullington. And a hearty welcome to Aileen Berg—glad to be working with you.

The incredibly hard working team at Elsevier Science, including Jonathan Bunkell, Ian Seager, Duncan Enright, David Burton, Rosanna Ramacciotti, Robert Fairbrother, Miguel Sanchez, Klaus Beran, Emma Wyatt, Rosie Moss, Chris Hossack, Mark Hunt, and Krista Leppiko, for making certain that our vision remains worldwide in scope.

David Buckland, Marie Chieng, Lucy Chong, Leslie Lim, Audrey Gan, Pang Ai Hua, and Joseph Chan of STP Distributors for the enthusiasm with which they receive our books.

Kwon Sung June at Acorn Publishing for his support.

David Scott, Tricia Wilden, Marilla Burgess, Annette Scott, Andrew Swaffer, Stephen O'Donoghue, Bec Lowe, and Mark Langley of Woodslane for distributing our books throughout Australia, New Zealand, Papua New Guinea, Fiji Tonga, Solomon Islands, and the Cook Islands.

Winston Lim of Global Publishing for his help and support with distribution of Syngress books in the Philippines.



Author

Tom Owad is a Macintosh consultant in southern Pennsylvania and the D.C., area and vice president of Keystone MacCentral. He serves on the board of directors of the Apple I Owners Club, where he is also Webmaster and archivist. Tom is the owner and Webmaster of Applefritter, a Macintosh community of artists and engineers. Applefritter provides its members with discussion boards for the exchange of ideas and hosts countless member-contributed hardware hacks and other projects. Tom holds a BA in computer science and international affairs from Lafayette College, PA.



Technical Editor

John Greco is a professor of electrical and computer engineering at Lafayette College, where he has taught digital circuit and system design for 28 years. He holds a Ph.D. in electrical engineering from the City University of New York. In addition, John has taught at the University of Petroleum and Minerals in Saudi Arabia. He has worked for GTE-Sylvania and has performed consulting work for (the former) Bell Laboratories and Moore Products.



Foreword Contributor

Steve Wozniak, a Silicon Valley icon and philanthropist for the past three decades, Founder, Chairman and CEO of Wheels of Zeus (wOz), helped shape the computing industry with his design of Apple's first line of products (the Apple I and II) and influenced the popular design of Macintosh. For his achievements at Apple Computer, Steve was awarded the National Medal of Technology by the President of the United States in 1985; the highest honor bestowed upon America's leading innovators.

In 2000 Steve was inducted into the Inventors Hall of Fame and was awarded the prestigious Heinz Award for Technology, The Economy and Employment for "single-handedly designing the first personal computer, and for then redirecting his lifelong passion for mathematics and electronics toward lighting the fires of excitement for education in grade school students and their teachers."

Making significant investments of both his time and resources in education, Wozniak "adopted" the Los Gatos School District, providing students and teachers with hands-on teaching and donations of state-of-the-art technology equipment. Wozniak founded the Electronic Frontier Foundation, and was the founding sponsor of the Tech Museum, Silicon Valley Ballet, and Children's Discovery Museum of San Jose.

Steve is currently a member of the board of directors for Jacent, a developer of cost-effective telephony solutions, and Danger, Inc., developer of an end-to-end wireless Internet platform.



Author Acknowledgments

Much thanks goes to my parents, John and Cindy Owad, who always supported my interests but nevertheless are happy that my racks of PDP-11 equipment no longer fill their living room. Were it not for their munificent toleration of my hobby, this book would not exist.

Dr. John Greco, my technical editor, has offered great guidance and been of immeasurable help in structuring and error-checking this book. Sandra Veresink deserves thanks for her editing and stylistic help. Should any part of this book resemble 19th century Irish prose, I owe it to her influence.

Vince Briel designed the Replica I circuit described in this book and has generously shared his design with us. Sarah McMenomy wrote the plot for the BASIC game in chapter five.

John and George Soluk at VAMP Inc. provided valuable assistance in moving our designs to McCAD EDS and have generously allowed us to include their software with this book.

Thanks also to Achim Breidenbach, who provided the image for Figure 1.1 in Chapter 1.

Joe Torzewski founded the Apple I Owners Club back in 1977 and kept it alive all these years. And thanks to Steve Wozniak, who started it all.

Contents

Forewordxix
Chapter 1 The History of the Apple I	1
Introduction	2
The Apple I	2
The Apple I Owners Club	6
Apple I Pioneer Interviews	8
Joe Torzewski	8
Larry Nelson	11
Ray Borril	13
Liza Loop	15
Steve Fish	18
Allen Baum	21
Summary	22
Chapter 2 Tools and Materials	23
Introduction: Tools You'll Need	24
Multimeter	24
Logic Probe	26
Breadboard	27
Wire-Wrap Tools	28
Soldering Iron and Materials	29
Power Supply	32
TTL Chips	34
Circuit Boards and Software Tools	35
Chip Pullers and Straighteners	36
Keyboard and Monitor	37
Ambience	38
Chapter 3 Digital Logic	39
Introduction	40
Breadboarding	40
Electricity	43

Voltage and Current	.43
Resistors and Diodes	.45
Capacitors	.48
Gates	.49
AND	.49
Inverter, NAND	.53
OR, NOR	.56
XOR	.59
Circuits with Algebra	.60
Logic Expressions	.60
DeMorgan's Laws	.62
Boolean Algebra	.62
All You Need Is NAND	.63
Latches and Flip-Flops	.65
SR Latch	.65
Flip-Flop	.67
What Is Data?	.68
Counting in Binary and Hexadecimal	.68
Bytes	.71
ASCII and the Alphabet	.72
A Few More Chips	.75
Shift Register	.75
Buffer and Tri-State Buffer	.76
Encoders and Decoders	.77
Summary	.81
Chapter 4 Building the Replica	.83
Introduction	.84
Learning to Solder	.84
Assembling the Replica I	.86
Parts List	.87
Resistors	.89
Diodes and Bypass Capacitors	.90
Buttons	.91
Sockets	.91
ASCII Keyboard Socket	.92
Capacitors	.93
The Header and Jumper	.94

Crystals	94
Connectors	95
Finishing the Assembly	97
Serial I/O Board	101
Using McCAD EDS SE	103
McCAD Schematics	104
McCAD PCB-ST	105
Summary	106
Chapter 5 Programming in BASIC	107
Introduction	108
Setting Up BASIC	108
Hello World	108
The PRINT Command	108
The TAB Command	109
The GOTO Command	110
Input, Variables, Strings	110
Math	111
FOR/NEXT	113
IF/THEN	114
Expressions	114
GOSUB	116
Arrays	119
Strings, In Depth	120
Substrings	120
The LEN Function	121
Appending Strings	121
Conditionals	122
Sample String Program	122
PEEK and POKE	124
The CALL Command	125
Commands	125
Error Codes	126
Richard III: Interactive Fiction	126
Walkthrough	127
Structure	130
Variables	131
Skeleton	132

Initialization	133
Intro and Conclusion Subroutines	133
Print Room Subroutine	136
Outside Tower	136
Bottom of the Tower	137
Middle of the Tower	139
Top of the Tower	140
Richard III Code	141
Summary	149
Chapter 6 Programming in Assembly	151
Introduction	152
Using the Monitor	152
Setting Up the Assembler	153
Registers	155
Hello World	155
TV Typewriter	158
X and Y	160
Memory Addressing	161
Accumulator: A	162
Implied: i	162
Immediate: #	162
Absolute a	162
Zero Page: zp	162
Relative: r	162
Absolute Indexed with X: a,x	162
Absolute Indexed with Y: a,y	163
Zero Page Indexed with X: zp,x	163
Zero Page Indexed with Y: zp,y	163
Absolute Indexed Indirect: (a,x)	163
Zero Page Indexed Indirect: (zp,x)	163
Zero Page Indirect Indexed with Y: (zp),y	164
Interacting with Memory	164
Printing Strings	165
String Subroutines	167
Bit Representation	169
Using the Stack	172

Bit Manipulation	175
Math Calculations	178
Summary	182
Chapter 7 Understanding the Apple I	183
Introduction	184
Bus	185
Data Bus	185
Address Bus	186
Clock	188
Processor	189
Pins and Descriptions	190
Address Bus (A0–A15)	191
Clock ($\phi 0, \phi 1, \phi 2$)	191
Data Bus (D0–D8)	191
Interrupt Request (IRQ)	191
No Connection (NC)	192
Nonmaskable Interrupt (NMI)	192
Ready (RDY)	192
Reset (RES)	192
Read/Write (R/W)	192
Set Overflow Flag (SO)	192
SYNC	192
Voltage Common Collector (VCC)	192
Voltage Source (VSS)	192
Registers	193
The Accumulator	194
Index Registers X and Y	194
The Program Counter (PC)	194
The Stack Pointer	194
The Processor Status Register	195
The Arithmetic and Logic Unit	195
The Stack	195
What Can You Do with the Apple I?	196
Memory	196
Where Is It?	196
Implementing 8KB RAM	199
Address Lines (A0–A12)	199

Data Lines (D0–D7)	199
Chip Enable (/CE1, CE2)	199
Write Enable (/WE)	200
Output Enable (/OE)	200
Implementing 32KB RAM	202
Implementing the EPROM	203
Implementing the Expanded ROM	204
Wiring the 74LS138	204
Wiring the 28c64	205
I/O with the 6821	206
DDR Access	210
CA1 (CB1) Control	210
CA2 (CB2) Control	211
IRA Interrupt Flags	211
Behavior of Apple 1 Components	211
The Keyboard	211
Video	211
Keyboard In	211
Video Out	214
Summary	216
Appendix A ASCII Codes	217
Appendix B Operation Codes and Status Register	221
Appendix C OpCode Matrix	225
Appendix D Instructions by Category	227
Load and Store	228
LDA – Load Accumulator with Memory	228
LDX – Load Index X with Memory	228
LDY – Load Index Y with Memory	229
STA – Store Accumulator in Memory	229
STX – Store Index X in Memory	230
STY – Store Index Y in Memory	230
Arithmetic	231
ADC – Add Memory to Accumulator with Carry	231
SBC – Subtract Memory from Accumulator with Borrow	231
Increment and Decrement	232

INC – Increment Memory by One	232
INX – Increment Index X by One	232
INY – Increment Index Y by One	232
DEC – Decrement Memory by One	233
DEX – Decrement Index X by One	233
DEY – Decrement Index Y by One	233
Shift and Rotate	234
ASL – Accumulator Shift Left One Bit	234
LSR – Logical Shift Right One Bit	234
ROL – Rotate Left One Bit	235
ROR – Rotate Right One Bit	235
Logic	236
AND – AND Memory with Accumulator	236
ORA – OR Memory with Accumulator	236
EOR – Exclusive-OR Memory with Accumulator	237
Compare and Test Bit	237
CMP – Compare Memory and Accumulator	238
CPX – Compare Memory and Index X	238
CPY – Compare Memory and Index Y	239
BIT – Test Bits in Memory with Accumulator	239
Branch	239
BCC – Branch on Carry Clear	239
BCS – Branch on Carry Set	240
BEQ – Branch on Result Zero	240
BMI – Branch on Result Minus	240
BNE – Branch on Result not Zero	241
BPL – Branch on Result Plus	241
BVC – Branch on Overflow Clear	241
BVS – Branch on Overflow Set	242
Transfer	242
TAX – Transfer Accumulator to Index X	242
TXA – Transfer Index X to Accumulator	242
TAY – Transfer Accumulator to Index Y	243
TYA – Transfer Index Y to Accumulator	243
TSX – Transfer Stack Pointer to Index X	243
TXS – Transfer Index X to Stack Register	244
Stack	244

PHA – Push Accumulator on Stack	244
PLA – Pull Accumulator from Stack	244
PHP – Push Processor Status on Stack	245
PLP – Pull Processor Status from Stack	245
Subroutines and Jump	245
JMP – Jump to New Location	245
JSR – Jump to New Location Saving Return Address	246
RTS – Return from Subroutine	246
RTI – Return from Interrupt	246
Set and Clear	247
SEC – Set Carry Flag	247
SED – Set Decimal Mode	247
SEI – Set Interrupt Disable Status	247
CLC – Clear Carry Flag	248
CLD – Clear Decimal Mode	248
CLI – Clear Interrupt Disable Bit	248
CLV – Clear Overflow Flag	249
Miscellaneous	249
NOP – No Operation	249
BRK – Break	249
Appendix E Hacking Macintosh	251
Compubrick SE	252
Preparing for the Hack	252
Performing the Hack	254
Taking Apart the Mac	254
Encasing the Speaker	260
Covering the Mouse and the Keyboard	261
Encasing the Disk Drive	263
Encasing the Hard Drive	265
Encasing the Motherboard	267
Encasing the CRT	269
How the Hack Works	271
Building a UFO Mouse	272
Preparing for the Hack	273
Performing the Hack	274
Opening the Mouse	274

Drilling the Hole	276
Soldering the LED	277
Reassembling the Mouse	278
How the Hack Works	280
Adding Colored Skins to the Power Macintosh G4 Cube	280
Preparing for the Hack	281
Performing the Hack	282
Under the Hood: How the Hack Works	285
Other Hacks and Resources	285
Desktop Hacks	285
Laptop Hacks	286
Electrical and Optical Hacks	286
Case Mods	286
Software	287
Discussion	287
Appendix F Electrical Engineering Basics	289
Introduction	290
Fundamentals	290
Bits, Bytes, and Nibbles	290
Reading Schematics	294
Voltage, Current, and Resistance	296
Direct Current and Alternating Current	297
Resistance	298
Ohm's Law	298
Basic Device Theory	299
Resistors	299
Capacitors	301
Diodes	304
Transistors	306
Integrated Circuits	308
Microprocessors and Embedded Systems	310
Soldering Techniques	311
Hands-On Example: Soldering a Resistor to a Circuit Board	311
Desoldering Tips	313
Hands-On Example: SMD Removal Using ChipQuik	314
Common Engineering Mistakes	317

Web Links and Other Resources	318
General Electrical Engineering Books	318
Electrical Engineering Web Sites	319
Data Sheets and Component Information	319
Major Electronic Component and Parts Distributors	320
Obsolete and Hard-to-Find Component Distributors	320
Index	321