

Contents

Introduction	xv
1 USB Basics	1
Uses and limits	1
Benefits for users	2
Benefits for developers	5
Addressing USB's limits	7
USB and Ethernet	10
USB and Thunderbolt	10
Evolution of an interface	10
USB 1.0.....	11
USB 1.1.....	11
USB 2.0.....	11
USB 2.1.....	12
USB 3.0.....	14

Table of Contents

USB 3.1	14
Embedded Host and On-The-Go	15
Bus components	15
Topology	16
Bus speed considerations	17
Terminology	18
Division of labor	20
Host responsibilities	20
Device responsibilities	22
Bus speeds and data throughput	24
Developing a device	25
Components	25
Tools for developing	25
Steps in developing a project	26
USB 3.1 essentials	27
Features	27
Compatibility	28
Cables	29
Power	30
2 Inside USB Transfers	33
Transfer basics	33
Essentials	33
Purposes for communication	34
Managing data on the bus	35
Elements of a transfer	36
Endpoints: the source and sink of data	36
Transaction types	37
Pipes: connecting endpoints to the host	37
Transfer types	38
Stream and message pipes	39
Initiating a transfer	40
USB 2.0 transactions	41
Transaction phases	43
Packet sequences	45
Timing constraints and guarantees	46
Split transactions	46
Ensuring successful transfers	47
Status and control	47
Reporting the status of control transfers	50

Table of Contents

Error checking.....	50
Enhanced SuperSpeed transactions	53
Packet types	53
Transferring data.....	55
Link Management Packets.....	61
3 A Transfer Type for Every Purpose	63
Control transfers	63
Availability	63
Structure.....	64
Data size	70
Speed.....	70
Detecting and handling errors	71
Device responsibilities.....	72
Bulk transfers	73
Availability	73
Structure.....	73
Data size	76
Speed.....	76
Detecting and handling errors	77
Device responsibilities.....	77
Interrupt transfers	77
Availability	78
Structure.....	78
Data size	79
Speed.....	79
Detecting and handling errors	81
Device responsibilities.....	81
Isochronous transfers.....	81
Availability	82
Structure.....	82
Data size	85
Speed.....	86
Detecting and handling errors	86
Device responsibilities.....	87
More about time-critical transfers	87
Bus bandwidth	87
Device capabilities	88
Host capabilities.....	88
Host latencies	89

Table of Contents

4 Enumeration: How the Host Learns about Devices.....	91
Events and requests	92
Getting to the Configured state	92
Device removal	98
Tips for successful enumeration	98
Descriptors.....	99
Types	99
Device	101
Device_qualifier	105
Configuration	105
Other_speed_configuration.....	106
Interface association.....	107
Interface	109
Endpoint	111
SuperSpeed endpoint companion	115
SuperSpeedPlus isochronous endpoint companion.....	116
String	117
Binary device object store (BOS) and device capability	118
OTG descriptor	120
Microsoft OS descriptors	120
Updating descriptors to USB 2.0.....	121
Updating descriptors to USB 3.1.....	121
5 Control Transfers: Structured Requests for Critical Data	123
Elements of a control transfer	123
Setup stage	124
Data stage.....	125
Status Stage	127
Handling errors.....	128
Device firmware	128
Standard requests	130
Get Status	132
Clear Feature	133
Set Feature	134
Set Address.....	135
Get Descriptor.....	136
Set Descriptor	137
Get Configuration	138
Set Configuration.....	138
Get Interface	139

Table of Contents

Set Interface	139
Synch Frame	140
Set SEL	141
Set Isochronous Delay	141
Other requests	142
Class-specific requests	142
Vendor-defined requests	142
6 Chip Choices	143
Components of a USB device	143
Inside a USB 2.0 controller	144
Other device components	145
Simplifying device development	147
Device requirements	147
Documentation and example code	148
Host driver	149
Development boards	149
USB microcontrollers	152
Microchip PIC18	153
Cypress EZ-USB	157
ARM processors	159
Controllers that interface to CPUs	160
Maxim MAX3420E	160
PLX Technology USB 3380	161
FTDI interface chips	162
7 Device Classes	165
Purpose	165
Approved specifications	166
Elements of a class specification	166
Defined classes	167
Audio	167
Audio/Video	170
Billboard	172
Communications	172
Content security	179
Device firmware upgrade	180
Human interface	182
IrDA bridge	184
Mass storage	186
Personal healthcare	189

Table of Contents

Printer.....	190
Smart card	192
Still image capture.....	194
Test and measurement	196
Video	198
Classes defined by other specifications	202
Implementing non-standard functions.....	204
Choosing a driver.....	204
Using a generic driver.....	204
Converting from RS-232	204
Converting from the parallel port	206
Connecting two PCs	206
8 How the Host Communicates	209
Device drivers	209
The layered driver model	209
User and kernel modes	210
Inside the layers.....	211
Applications.....	211
User-mode client drivers.....	213
Kernel-mode client drivers	213
Low-level host drivers.....	214
USB 3.0 drivers	215
USB 2.0 drivers	216
Writing drivers	217
Kernel mode.....	217
User mode	218
Testing tools	218
Using GUIDs.....	218
Device setup GUIDs.....	219
Device interface GUIDs	220
9 Matching a Driver to a Device	221
Using Device Manager	221
Viewing devices	221
Property pages	223
Device information in the registry	224
The hardware key.....	224
The class key	225
The driver key	227
The services key	228

Using INF files	229
Driver signing requirements	229
File structure	232
Inside an INF file.....	232
Using device identification strings	234
Finding a match.....	237
When to provide an INF file.....	237
Tools and diagnostic aids	238
Tips for using INF files	238
What the user sees	239
10 Detecting Devices	241
A brief guide to calling API functions	241
Managed and unmanaged code	242
Managing data	246
Finding a device	248
Obtaining the device interface GUID	249
Requesting a pointer to a device information set	250
Identifying a device interface	251
Requesting a structure with the device path name	252
Extracting the device path name.....	254
Closing communications	254
Obtaining a handle	255
Requesting a communications handle	255
Closing the handle	257
Detecting device attachment and removal	257
Using WMI	257
Adding a handler for newly arrived devices	257
Detecting the target device.....	259
Adding a handler for removed devices	261
11 Human Interface Devices: Capabilities	263
What is a HID?	263
Hardware requirements	264
Firmware requirements.....	265
Descriptors	266
The HID interface.....	266
HID class descriptor	269
Report descriptors.....	269
HID-specific requests	272
Get Report	273

Table of Contents

Get Idle.....	273
Get Protocol.....	274
Set Report.....	274
Set Idle.....	275
Set Protocol.....	275
Transferring data.....	276
Writing firmware.....	276
Tools.....	276
12 Human Interface Devices: Reports.....	277
Report structure.....	277
Control and data item values.....	278
Item format.....	278
The Main item type.....	279
Input, Output, and Feature items.....	279
Collections.....	282
The Global item type.....	283
Identifying the report.....	283
Describing the data's use.....	285
Converting units.....	286
Converting raw data.....	287
Describing the data's size and format.....	290
Saving and restoring Global items.....	290
The Local item type.....	290
Physical descriptors.....	293
Padding.....	293
13 Human Interface Devices: Host Application.....	295
HIDClass support routines.....	295
Requesting information about the HID.....	297
Sending and receiving reports.....	297
Providing and using report data.....	298
Managing HID communications.....	298
Identifying a device.....	299
Reading the Vendor ID and Product ID.....	300
Getting a pointer to device capabilities.....	301
Getting the device's capabilities.....	302
Getting capabilities of buttons and values.....	303
Sending and receiving reports.....	304
Sending Output reports with interrupt transfers.....	304
Reading Input reports with interrupt transfers.....	307

Writing Feature reports	310
Writing Output reports with control transfers	311
Reading Feature reports	311
Reading Input reports with control transfers	312
Closing communications	312
14 Using WinUSB for Vendor-defined Functions	313
Capabilities and limits	313
Device requirements	313
Host requirements	314
Driver requirements	314
Device firmware	314
Accessing the device	318
Creating a SafeWinUsbHandle	319
Obtaining a WinUSB handle	321
Requesting an interface descriptor	322
Identifying the endpoints	323
Setting pipe policies	325
Writing bulk and interrupt data	328
Reading bulk and interrupt data	331
Using vendor-defined control transfers	334
Selecting an alternate interface	336
Writing data: isochronous transfers	337
Reading data: isochronous transfers	339
Closing communications	341
15 Using WinUSB's System INF File	343
Microsoft OS 1.0 descriptors	344
Microsoft OS string descriptor	344
Extended compat ID OS feature descriptor	347
Extended properties OS feature descriptor	348
Enumeration	350
Microsoft OS 2.0 descriptors	351
Microsoft OS 2.0 platform capability descriptor	351
Microsoft OS 2.0 descriptor set	355
Enumeration	357
16 Using Hubs to Extend and Expand the Bus	359
USB 2.0	360
The hub repeater	362
The transaction translator	363
The hub controller	368

Table of Contents

Speed	369
Maintaining active links	369
USB 3.1	371
Bus speeds	371
SuperSpeed	372
SuperSpeedPlus	372
Managing traffic	373
The hub class	373
Hub descriptors	374
Hub class requests	374
17 Managing Power	375
Power options	375
Using bus current	376
Bus voltage	377
Bus-powered devices	378
Hub power	378
Power sources	380
Over-current protection	381
Power switching	381
Conserving power	381
USB 2.0 Link Power Management	381
Suspend	382
Sleep	384
Enhanced SuperSpeed power management	385
Advanced power delivery capabilities	389
Requirements	389
Negotiating power	390
Role swapping	391
Vendor-defined messages	391
Power management under Windows	391
Computer power states	392
Utilities	393
Battery charging	394
Charger types	395
Charger detection	397
Charging dead or weak batteries	398
18 Testing and Debugging	399
Tools	399
Hardware protocol analyzers	400

Table of Contents

Software protocol analyzers	402
Traffic generators	410
Compliance testing	411
Checklists	412
USB Command Verifier software	412
Device Framework tests	413
Interoperability tests	415
Current measurement	416
Electrical tests	418
Certified USB Logo	418
Windows hardware certification	418
Windows hardware certification	420
Driver signatures	422
Test-signing a driver	424
Microsoft USB Test Tool (MUTT)	427
19 Packets on the Bus	429
USB 2.0	429
Low speed and full speed bus states	429
High speed bus states	431
Data encoding	433
Staying synchronized	434
Timing accuracy	435
Packet format	436
Inter-packet delay	437
Test modes	437
USB 3.1	438
Data scrambling	438
Encoding	438
Link layer	439
Reset	440
Signaling	440
Negotiating speed	440
20 Electrical and Mechanical Interface	443
USB 2.0	443
Transceivers	443
Cables and connectors	453
USB 3.1	458
Transmitters and receivers	458
Cables and connectors	458

Table of Contents

USB Type-C cables	462
Benefits	463
Cables and connectors	464
New cable connections	465
Data routing	469
Other ways to connect	472
Inter-Chip	472
Isolated interfaces	473
Long distance links	474
Going wireless	475
21 Hosts for Embedded Systems	481
The Targeted Host	481
The Targeted Peripheral List	482
Targeted Host types	482
Bus current	483
Turning off bus power	483
The Micro-AB receptacle	485
Embedded Hosts	486
Differences from conventional host ports	486
Host connectors	486
Functioning as a USB device	486
OTG devices	487
Requirements	487
Cables and connectors	489
The A-Device and B-Device	490
The OTG descriptor	491
Host Negotiation Protocol (HNP)	492
Role Swap Protocol	494
Choosing a development platform	494
Comparing options	495
Embedded PC	495
General-purpose microcontroller	496
Interface chip	496
Host module	496
Index	499