Introduction to Embedded USB Development

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USB History

- Version 1.0 (January 1996)
  - low and full speed
- Version 1.1 (September 1998)
  - added interrupt OUT transfers
- Version 2.0 (April 2000)
  - added high speed option
- Various ECNs
  - defined new mini-B connector
  - etc.

OS Support for USB

- Windows
  - Windows 95 OEM SR2 (Aug 1996 - limited and buggy)
  - Windows 98 (Jun 1998), 98SE (May 1999), ME (Sep 2000)
  - Windows 2000 (Feb 2000)
  - Windows XP (Oct 2001)
  - Windows Server 2003 (Apr 2003)
- Linux
  - Kernel 2.4.0 (Jan 2001) and greater
- MacOS
  - Mac OS 8.1 (Jan 1998) and greater

USB Bus Speeds

- Low speed
  - 1.5 Mbits/sec bus speed
  - 800 bytes/sec max data throughput
  - relaxed electrical specifications
    - low cost
    - flexible cables, e.g. mice
- Full speed
  - 12 Mbits/sec bus speed
  - 1.2 Mbytes/sec max data throughput
- High speed
  - 480 Mbits/sec bus speed
  - 53 Mbytes/sec max data throughput

USB Attributes

- Universal – one interface for many types of devices
- Easy to connect
  - External connectors: no need to open enclosure
  - Automatic configuration
  - Inexpensive cables (5 meters max), reliable connectors
  - Hot pluggable
- No user settings
- Efficient resource usage (only the host controller consumes I/O ports, IRQs, memory)
- Supplies power to devices (+5V @ 500 mA)

USB Development Challenges

- Protocol complexity
  - USB 2.0 Specification is 650 pages
  - EHCI Specification is 155 pages
  - HID Device Class Definition is 97 pages
- Operating system support
  - Try to use an existing class driver
  - Try to adapt an existing driver
- Host controller to device
  - Not peer-to-peer -- partial solution is “USB On-The-Go” specification released in 2001
  - No broadcasts as in Ethernet or Firewire (IEEE-1394)
- Fee for Vendor ID (VID)

VID/PID

- Every device must have a unique VID/PID
- Vendor ID - 16 bits
  - e.g. 0x04d8 = Microchip
- Product ID - 16 bits
  - e.g. 0x000a = Microchip RS-232 CDC example
- VID/PID in firmware must match VID/PID in driver, e.g. in Windows .INF file

VID/PID Alternatives

- Purchase a VID from usb.org
  - $1500 (~$0.04/PID)
- Purchase a small quantity of PIDs within someone else's VID, e.g. Wouter van Ooijen
  - http://www.voti.nl/shop
    - 10/€20 (about $33 with S/H)
    - 100/ €90 (about $116 with S/H)
- Free for lab use ("may not leave your desk") from Wouter van Ooijen
  - VID 5824 = 0x16c0
  - PID 1000-1009 = 0x03e8 through 0x03f1

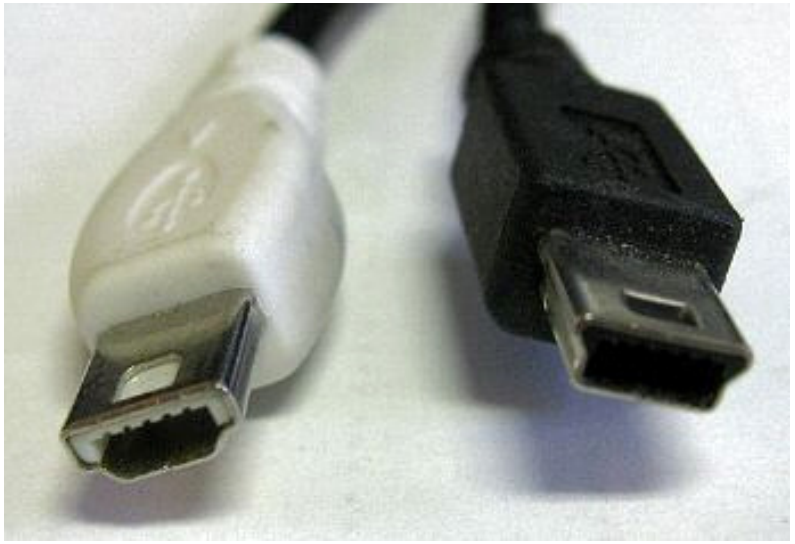
USB Terminology

- Host
  - USB host controller
  - USB root hub
- Hub
  - contains 1 upstream connector and 1 or more downstream ports
  - repeats USB traffic in both directions
  - manages power
  - sends and responds to status and control messages
  - can cascade up to 5 hubs in series
  - up to 127 peripherals and hubs including root hub
  - a USB 2.0 hub MUST support low, full, and high speed devices

USB Terminology (cont.)

- Function
  - a device that provides a capability to the host
    - mouse
    - speakers
    - storage
  - a single physical device can contain more than 1 function
- Device
  - a function or hub
  - communicates with host
- Compound Device
  - contains a hub and 1 or more functions
- Port
  - each connector represents a USB port

Common USB Connectors

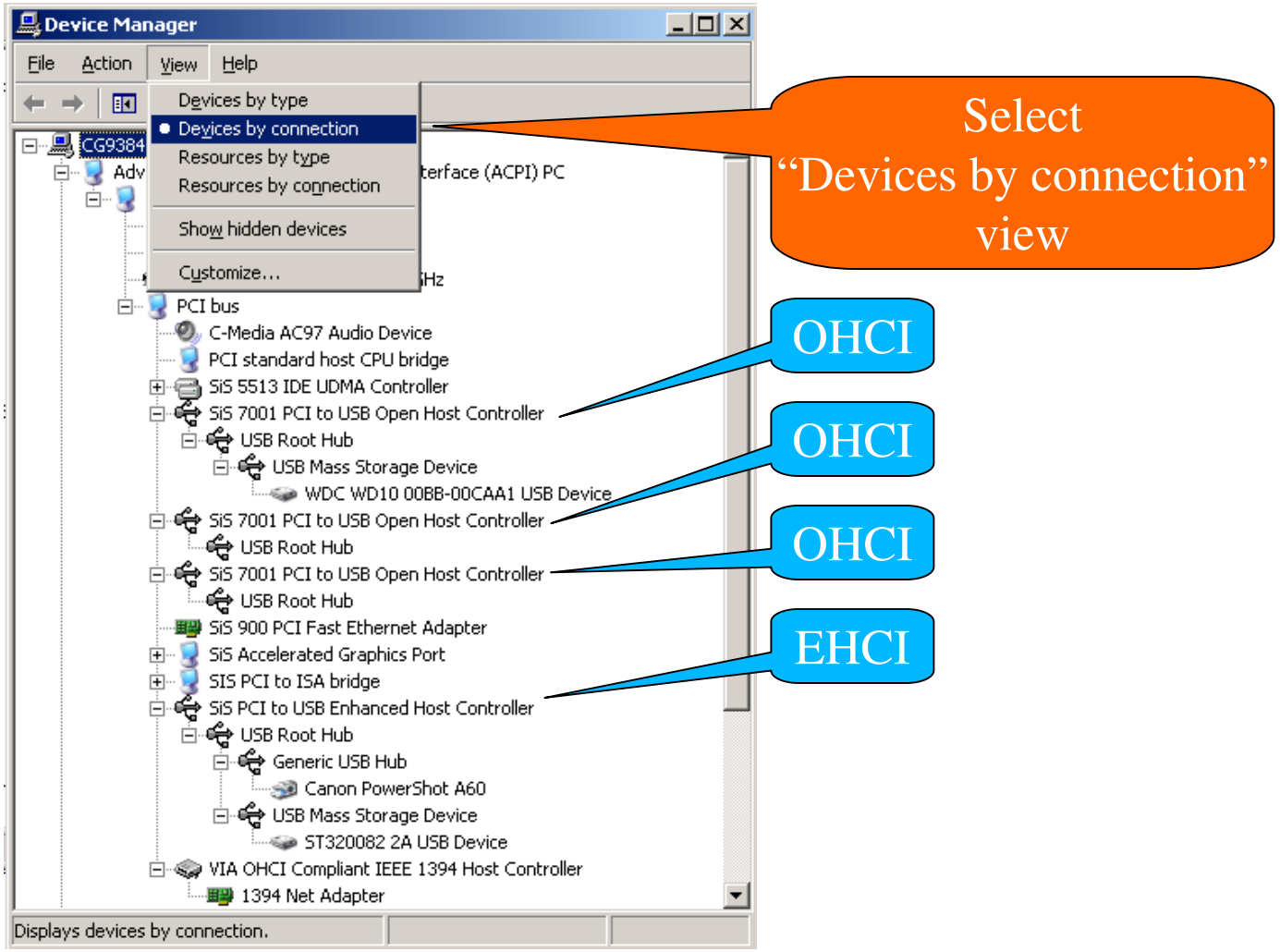


Type A Type B Mini-A Mini-B

USB Host Controller Types

- OHCI - Open Host Controller Interface
  - Developed by Compaq, Microsoft, and National Semiconductor
  - Adopted as version 1.0 and 1.1 (low and full speed) standard by USB-IF
  - Simple SW, more complex HW
  - All chipsets except Intel and VIA
- UHCI - Universal Host Controller Interface
  - Competing specification developed by Intel, requires licensing fee
  - Simple HW, more complex SW
  - Intel and VIA chipsets only
- EHCI - Enhanced Host Controller Interface
  - High speed USB only

Multiple Host Controllers on Motherboard



Types of USB Transfers

- Control
  - Identification and configuration
  - The only required type, the only defined functions
- Bulk
  - Printer, scanner, disk
- Interrupt
  - Mouse, keyboard
- Isochronous
  - Streaming audio or video

USB Project Alternatives

- RS-232/USB Converter
  - FTDI Chip FT232BM USB UART
  - Usually no changes required to application SW
- IEEE-1284 (Parallel)/USB Converter
  - USB controller with 17 or more I/O bits required
    - 8 bidirectional data pins
    - 5 status outputs
    - 4 control inputs
  - Prolific Technology PL-2305
  - Application SW changes required

USB Controllers that Interface to External CPUs

- Agere Systems USS-820D
- FTDI Chip FT232BM (serial), FT245BM (parallel)
  - No USB-specific firmware required
  - Can use FTDI Chip's driver and Vendor ID
- National Semiconductor
- Philips Semiconductor
- PLX Technology

USB Controllers with Embedded CPU

- Cypress EZ-USB (originally Anchor Chips)
  - Full or full/high speed, can load firmware from host or ROM
- Cypress enCoRe II
  - Inexpensive low speed controllers
- Freescale MC68HC908JB16
  - Low speed
- Freescale MCF5482 ColdFire
  - 32-bit CPU + full/high speed
- Microchip PIC16C745/765
  - Low speed
- Microchip PIC18F2455/2550/4455/4550
  - Full speed

Why Microchip?

- Chips readily available in small quantities
- Chips reasonably priced in small quantities
- Free or inexpensive development tools
- Full documentation freely available
- Free example code
  - Human Interface Device (HID) firmware
  - Communication Device Class (CDC) firmware
  - Mass Storage Class firmware
  - Bootloader firmware
  - Custom driver

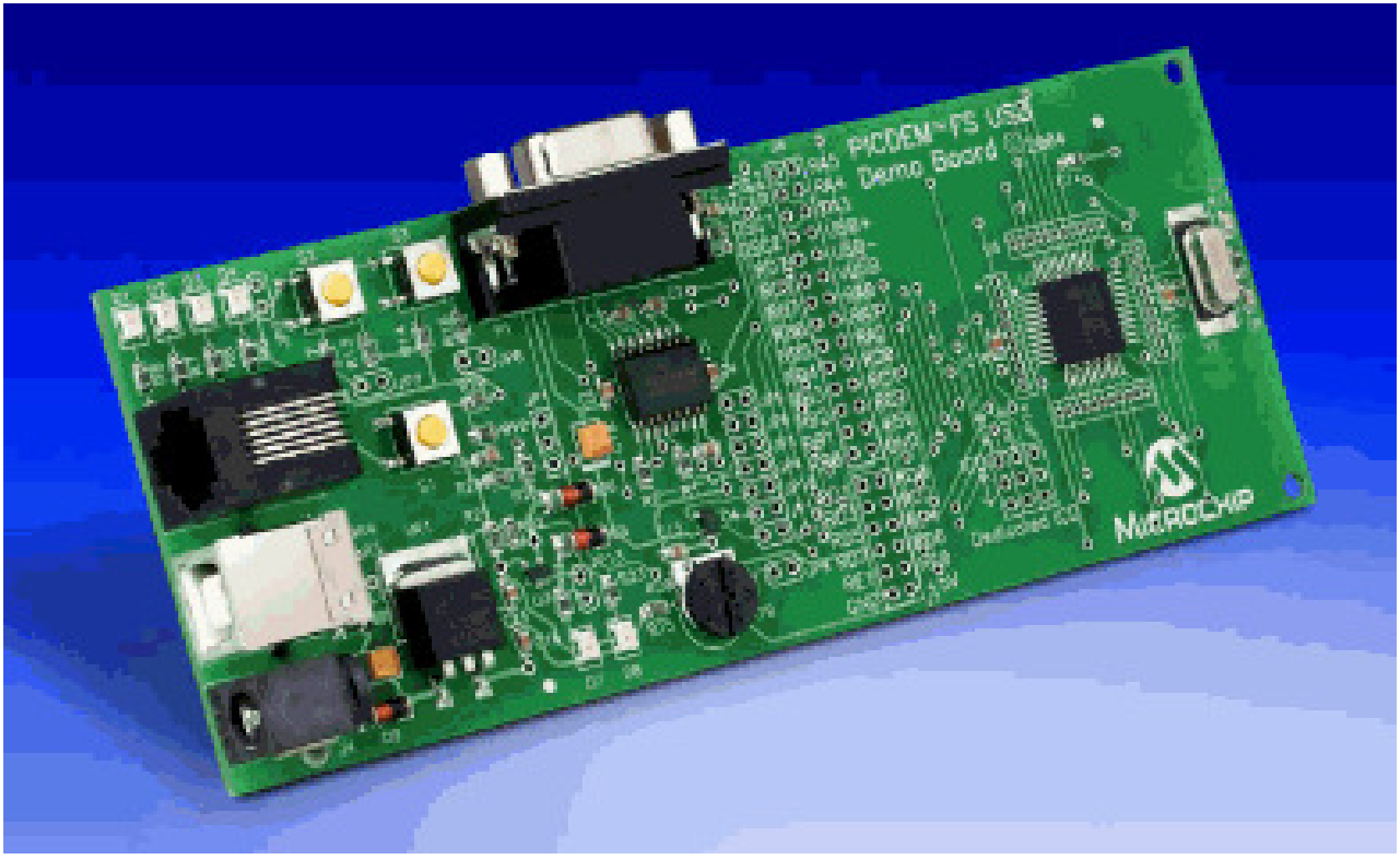
Microchip Full Speed USB

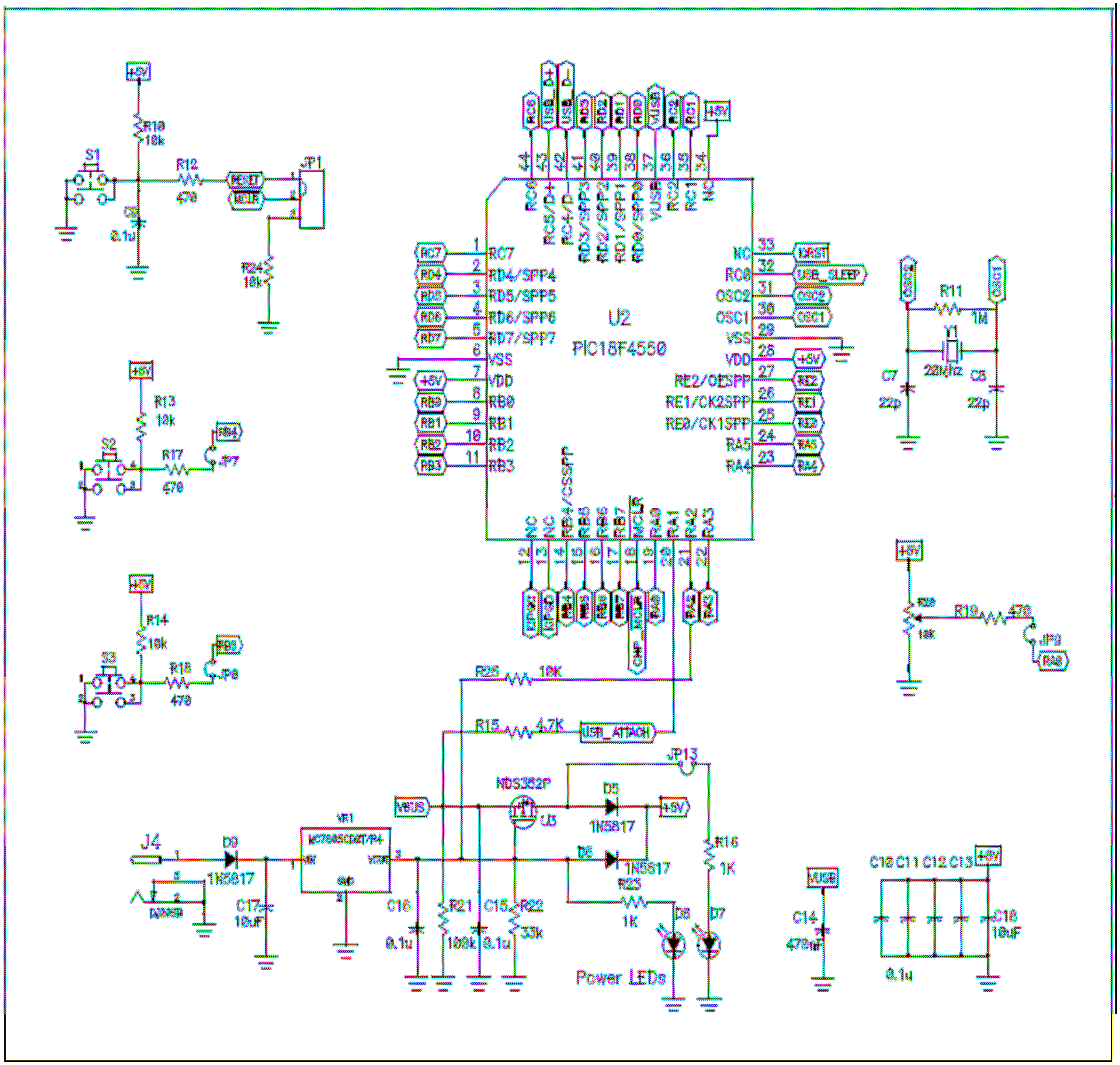
- PIC18F2455
  - 24 KB Flash, 24 I/O, 10 channel 10-bit ADC
- PIC18F2550
  - 32 KB Flash, 24 I/O, 10 channel 10-bit ADC
- PIC18F4455
  - 24 KB Flash, 35 I/O, 13 channel 10-bit ADC
- PIC18F4550
  - 32 KB Flash, 35 I/O, 13 channel 10-bit ADC
- All have 2 KB RAM, 256 bytes EEPROM

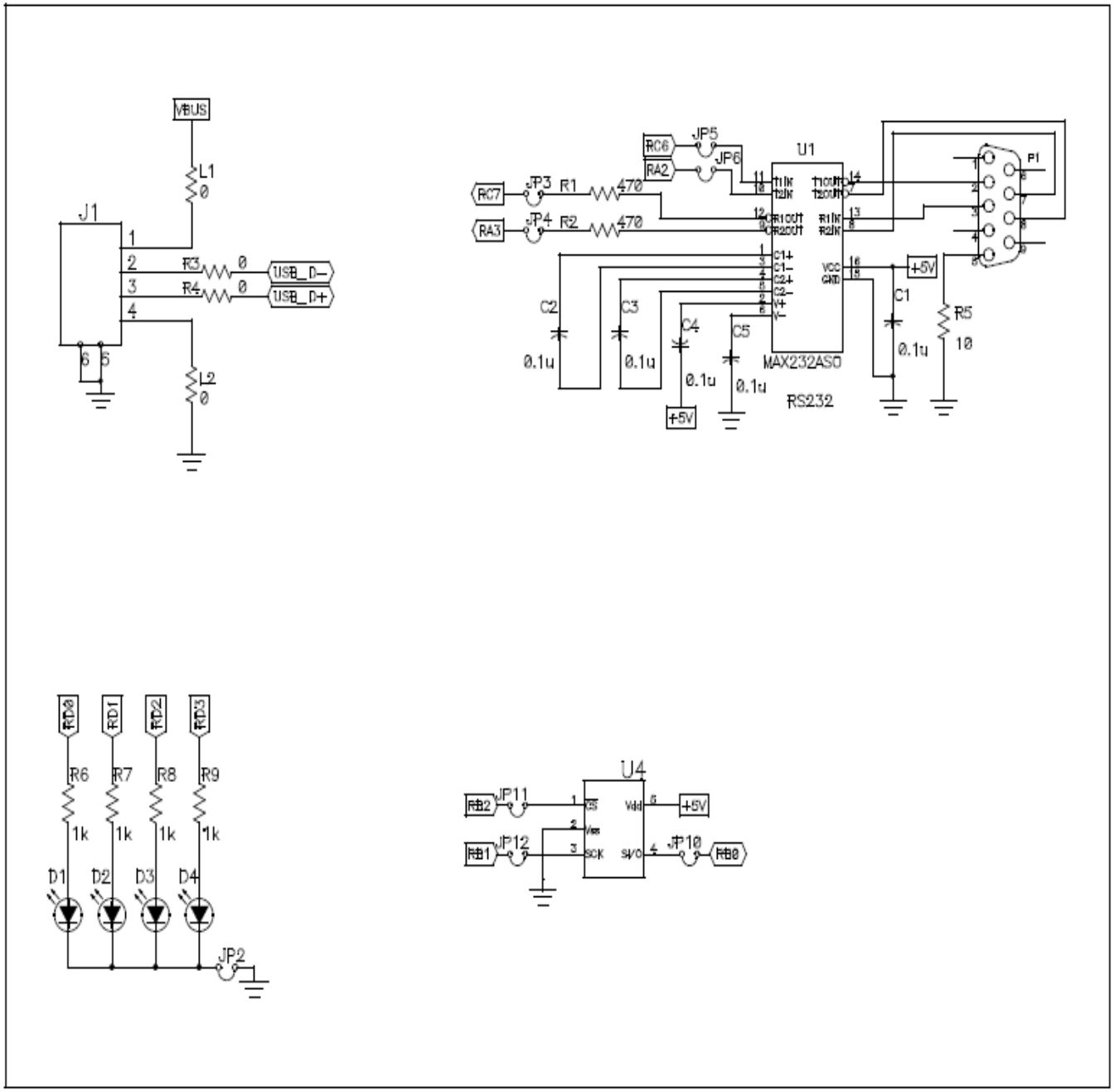
Microchip PICDEM FS-USB

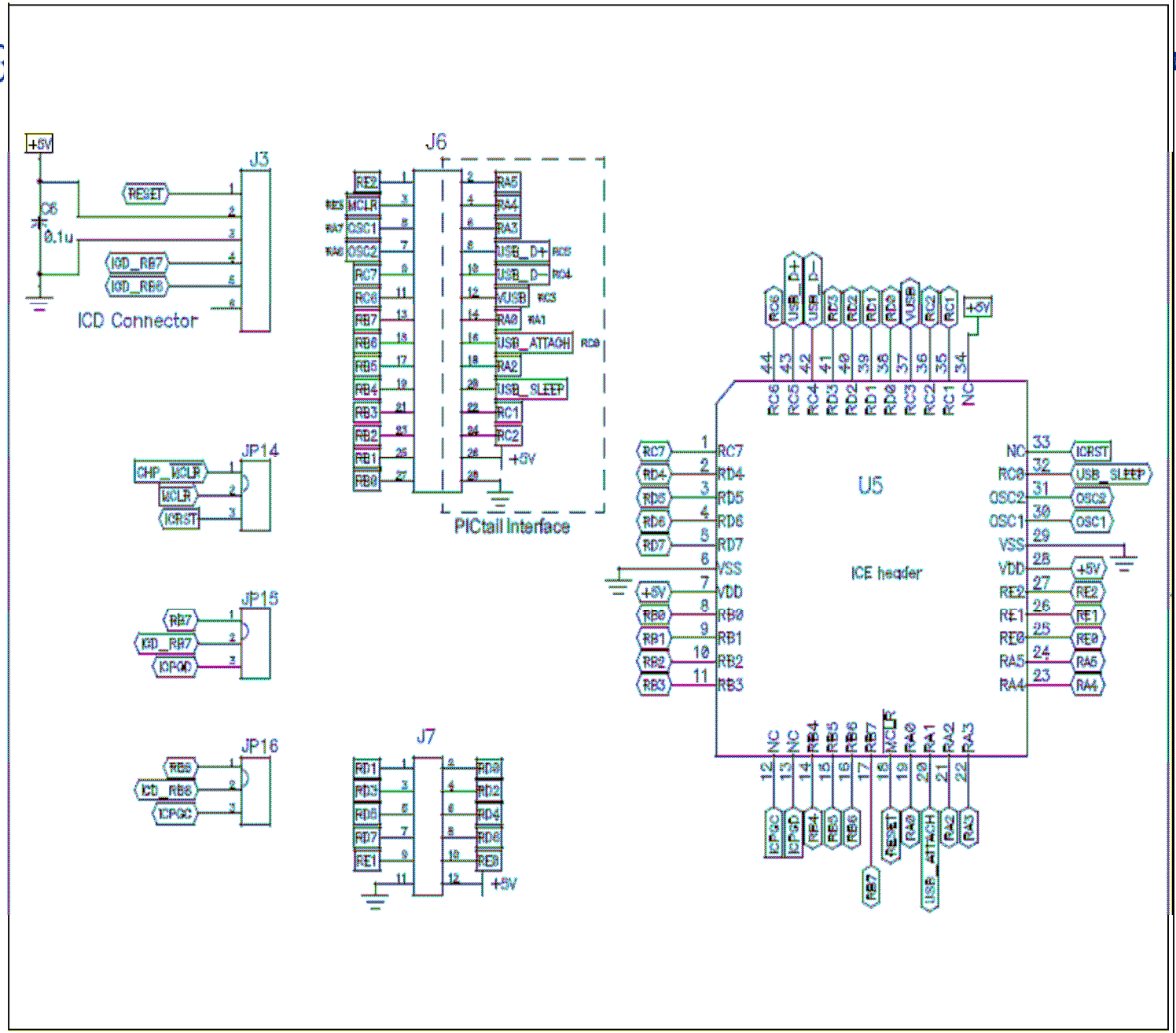
- Inexpensive ($59.99) development board
  - PIC18F4550 full speed USB microcontroller, 20 MHz crystal
  - RS-232 serial port connector/interface (for demonstration of migration from legacy applications)
  - connection to the MPLAB® ICD 2 In Circuit Debugger
  - voltage regulation, with the ability to switch from external power supply to USB bus supply
  - expansion connector, compatible with the PICtail™ daughter boards standard
  - temperature sensor TC77 (connected to the SPI bus)
  - potentiometer (connected to RA0 input) for A/D conversion demonstrations
  - 2 LEDs for status display, 2 LEDs for power indication
  - 2 input switches
  - reset button
  - bootloader firmware, demo applications

PICDEM FS-USB




U2
PIC18F4550
RC7
RD4/SPP4
RD5/SPP5
RD6/SPP6
RD7/SPP7
VSS
VDD
RB0
RB1
RB2
RB3
NC
RC0
OSC2
OSC1
VSS
VDD
RE2/OESPP
RE1/CK2SPP
RE0/CK1SPP
RA5
RA4
RB4/CSSPP
MCLR
S1
S2
S3
R10
10k
R12
470
JP1
R24
10k
R13
10k
R17
470
JP7
R14
10k
R18
470
JP8
R11
1M
Y1
20MHz
C7
22p
C8
22p
R20
10k
R19
470
JP9
R25
10K
R15
4.7K
USB_ATTACH
JP13
NDS352P
U3
D5
1N5817
D6
1N5817
J4
D9
1N5817
C17
10uF
C16
0.1u
R21
100k
C15
0.1u
R22
33k
R23
1K
R16
1K
D8
D7
Power LEDs
C14
470nF
C10 C11 C12 C13
C18
10uF
0.1u
+5V
VUSB


VBUS
L1
0
J1
1
2
3
4
R3
R4
0
0
USB_D-
USB_D+
6
5
L2
0
U1
JP5
JP6
RC6
RA2
RC7
RA3
JP3
JP4
R1
R2
470
470
P1
+5V
C1
C2
C3
C4
C5
0.1u
0.1u
0.1u
0.1u
0.1u
R5
10
MAX232ASO
RS232
RD0
RD1
RD2
RD3
R6
R7
R8
R9
1k
1k
1k
1k
D1
D2
D3
D4
JP2
U4
JP11
JP12
JP10
RB2
RB1
RB0
Vdd
Vss
CS
SCK
SI/O
+5V


J3
ICD Connector
C6
0.1u
RESET
ICD_RB7
ICD_RB6
J6
PICtail Interface
JP14
JP15
JP16
J7
U5
ICE header

Microchip Development SW

- MPLAB IDE
  - Free
  - MPASM Assembler, MPLINK Linker, MPLIB Librarian
  - MPLAB SIM Simulator
- MPLAB C18 Compiler
  - Free Student/Demo Edition (some optimizations disabled after 60 days)
  - $495 for full version

Microchip Development HW

- PICkit 2 ICSP (In-circuit Serial Programmer)
  - $49.99 Starter kit
    - ICSP
    - Low pin count demo board
- MPLAB ICD 2 (In-circuit Debugger)
  - $160
  - Real-time “background” debugger
    - 1 stack level
    - 12 bytes (0x3f4-0x3fff) file registers
    - 64 bytes (0x7dc0-0x7dff) memory
  - Programmer

PICkit 2 Starter Kit

ICD 2 In-Circuit Debugger

USB Firmware Development

- With Microchip bootloader installed, embedded system can self-host over USB
  - Upload/download code
  - Program Flash memory
- Use ICD 2 to program/debug in-circuit
- Use PICkit 2 to program via ICSP (In-Circuit Serial Programming)

USB Driver Development

- Use an existing driver
  - Microchip-furnished driver
  - Standard USB class driver
- Create a driver from scratch
  - Not a trivial task
  - Use Windows Driver Development Kit (DDK)
  - Or use a commercial driver toolkit (expensive!)

USB Application Development

- Windows
  - http://libusb-win32.sourceforge.net/
  - http://www.steelbrothers.ch/jusb/
- Mac OS
  - http://developer.apple.com/devicedrivers/usb/
- Linux
  - http://www.linux-usb.org/
  - http://libusb.sourceforge.net/
  - http://jusb.sourceforge.net/

References

- USB Implementers Forum
  - Free download of USB specifications
  - http://www.usb.org
- *USB Complete, 3rd Edition*, Jan Axelson
  - The best USB book
  - http://www.Lvr.com
- Microchip USB Controller Resources
  - http://www.microchip.com/usb