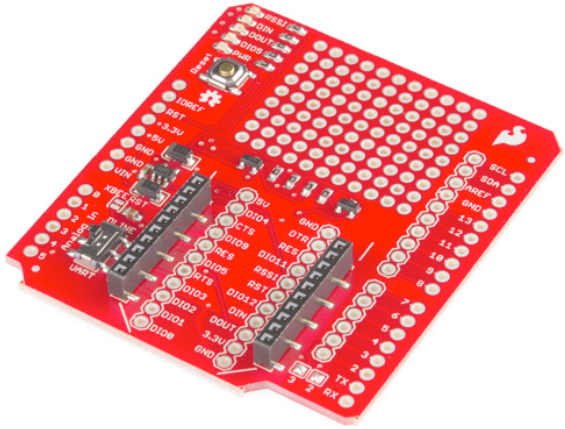
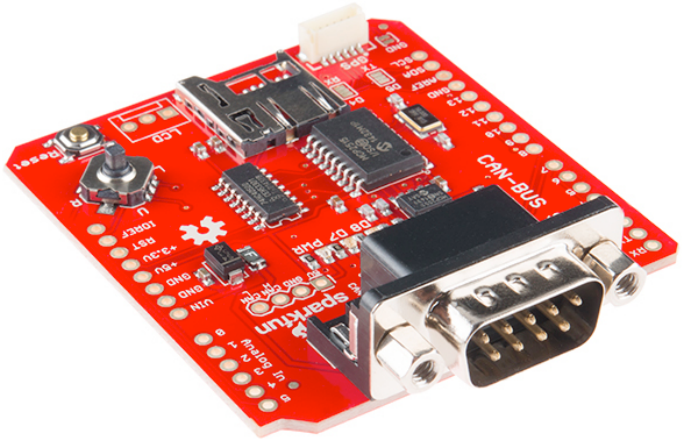
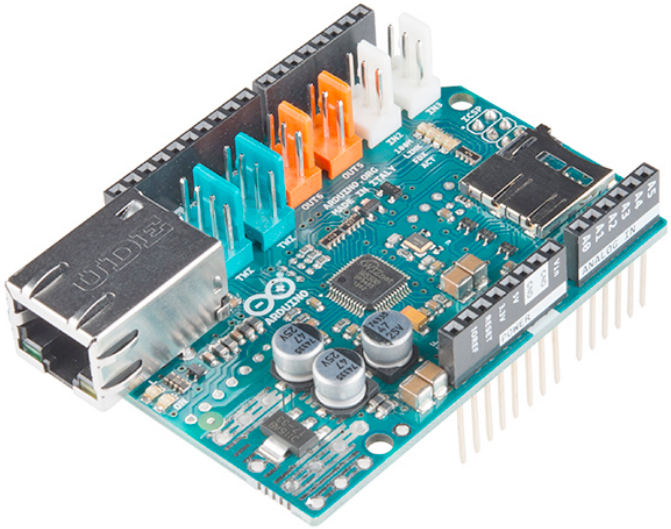
I/O: External Peripherals

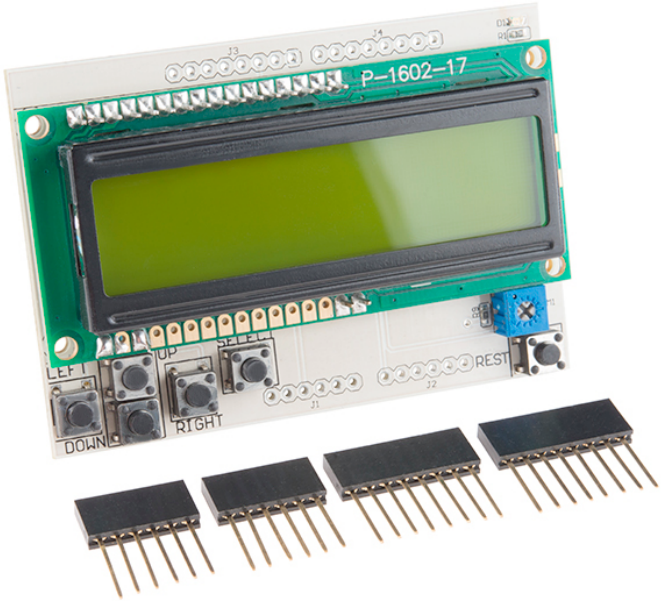
UART, SPI, and PS/2 (vs. USB)

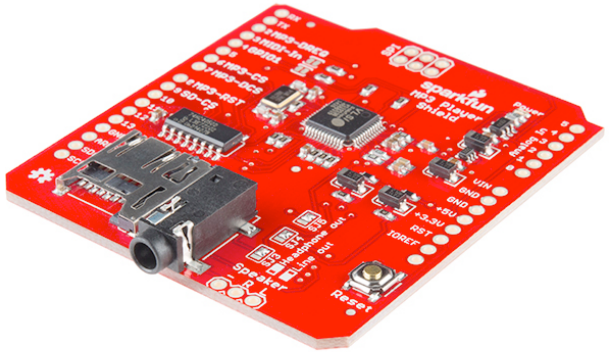
gpio
timer
uart
printf
malloc
keyboard
shell
fb
gl
console

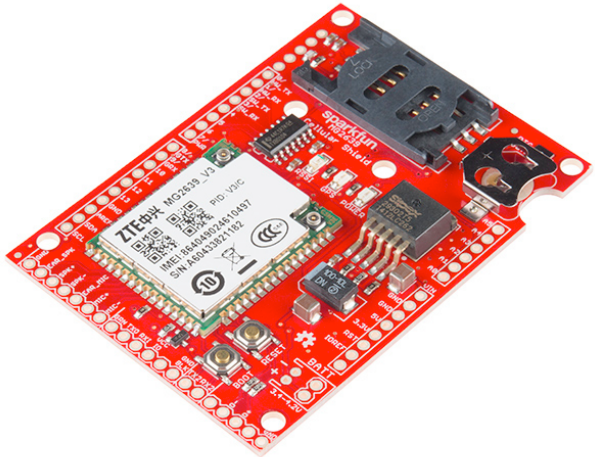


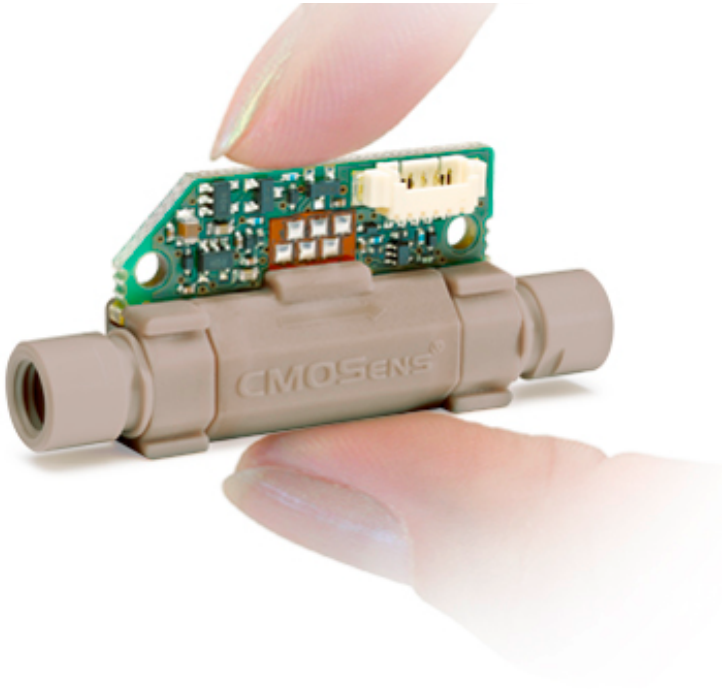

CAN-BUS

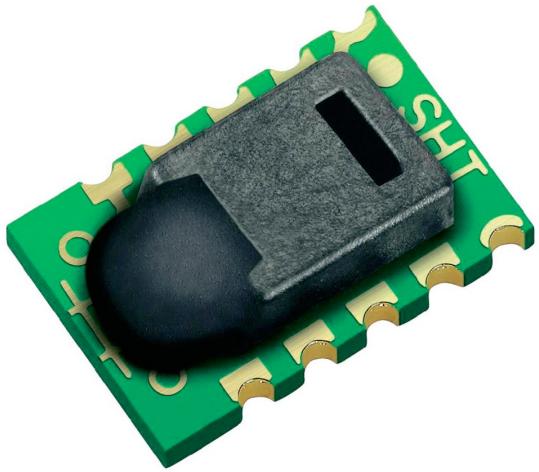



P-1602-17
LEFT
UP
SELECT
RIGHT
DOWN
REST






CMOSENS


SHT


LG

Serial vs. Parallel

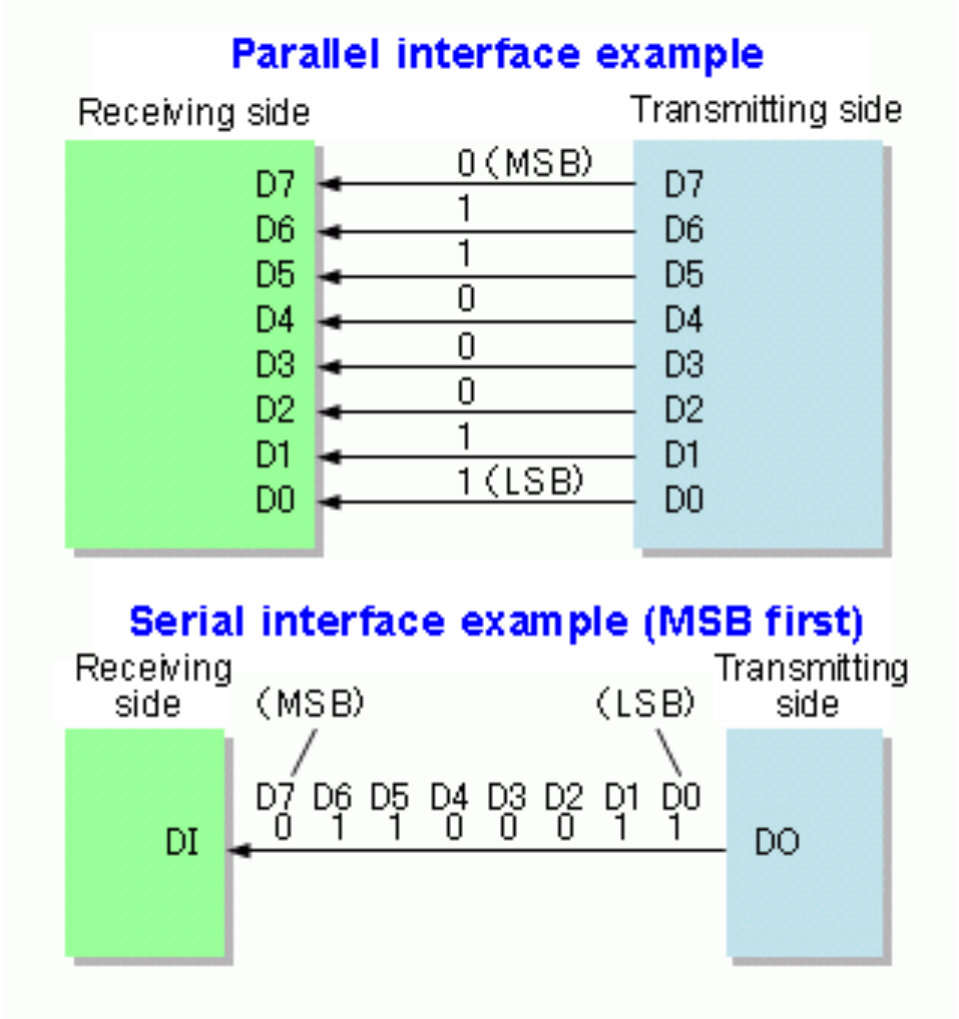
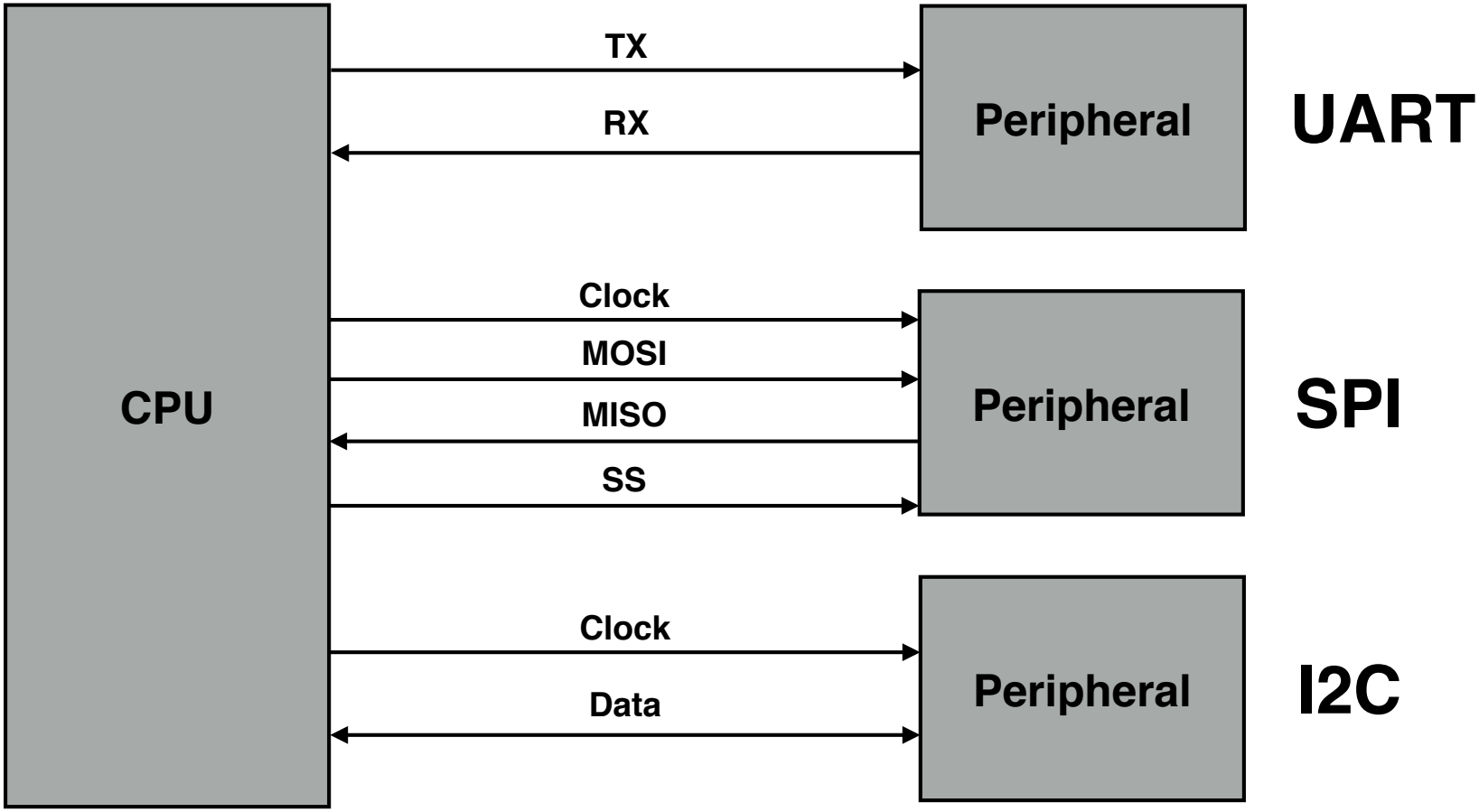


Figure from https://en.wikipedia.org/wiki/Parallel_communication#/media/File:Parallel_and_Serial_Transmission.gif

Bus Protocols



UART

- Used in your printf & the bootloader
- Asynchronous — no clock line
- Start bit, (5 to 9) data bits, (0 or 1) parity bit, (1 or 2) stop bits

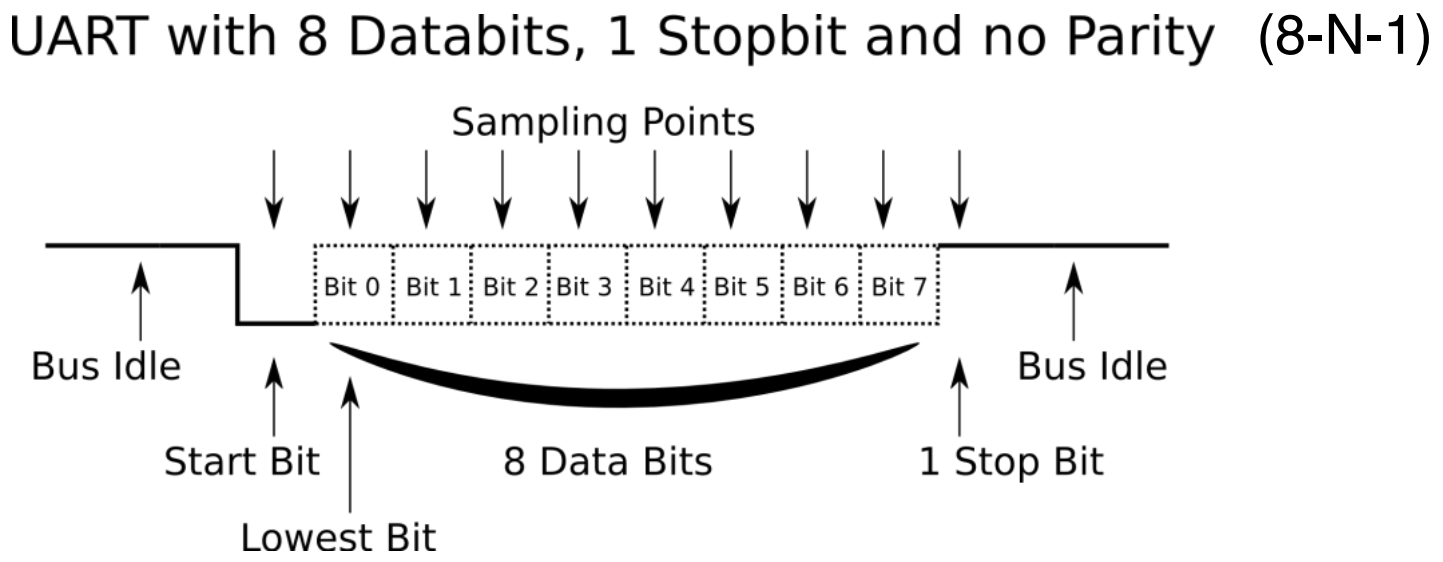


Figure from http://old.myhdl.org/lib/exe/detail.php/projects:rs232image.png?id=projects%3Auart_rs232_receiver_transmitter

UART timing demo

Parity Bits

- Error detection — discard if parity bit wrong
- Even parity: parity = XOR of data bits, ensures an even number of 1s (w/ parity bit)
- Odd parity: !even parity, ensures an odd number of 1s

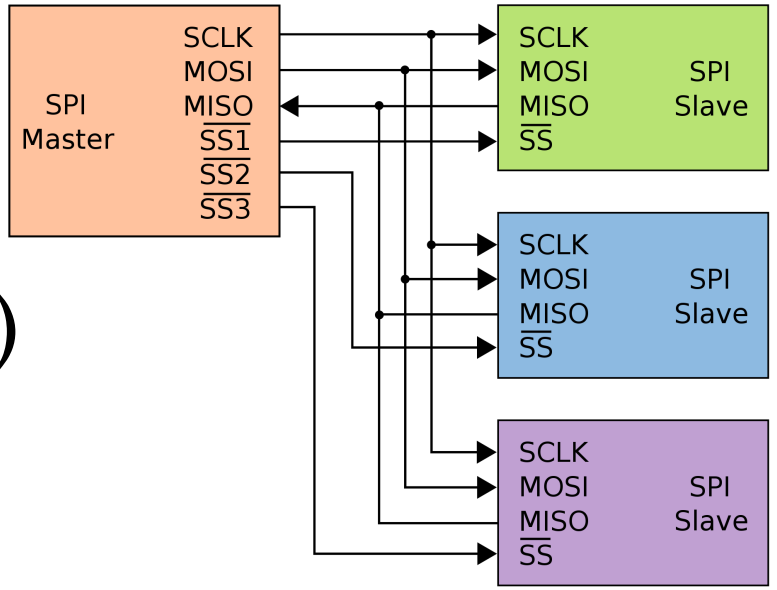
even

data	data	data	data	data	data	data	data	parity
1	1	0	1	0	1	1	0	1

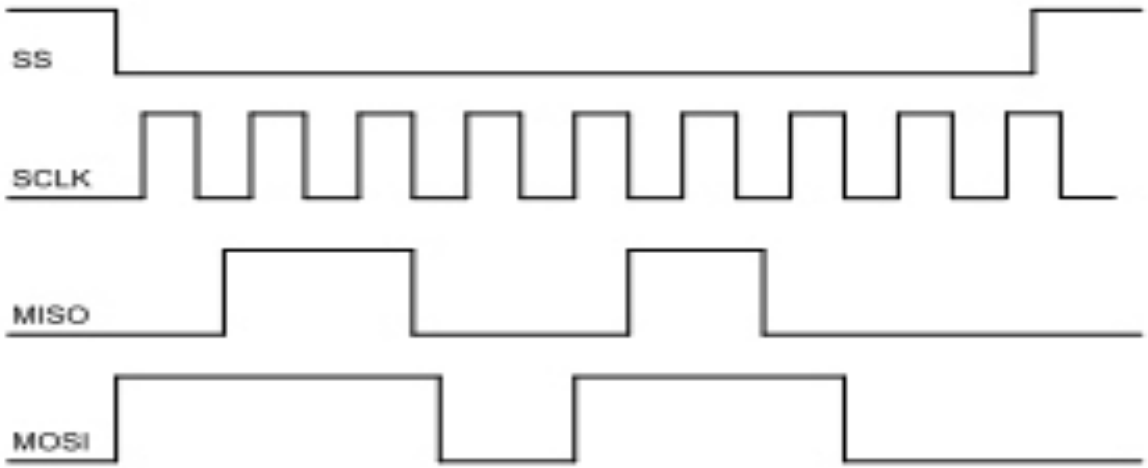
odd

data	data	data	data	data	data	data	data	parity
1	1	0	1	0	1	1	0	0

SPI

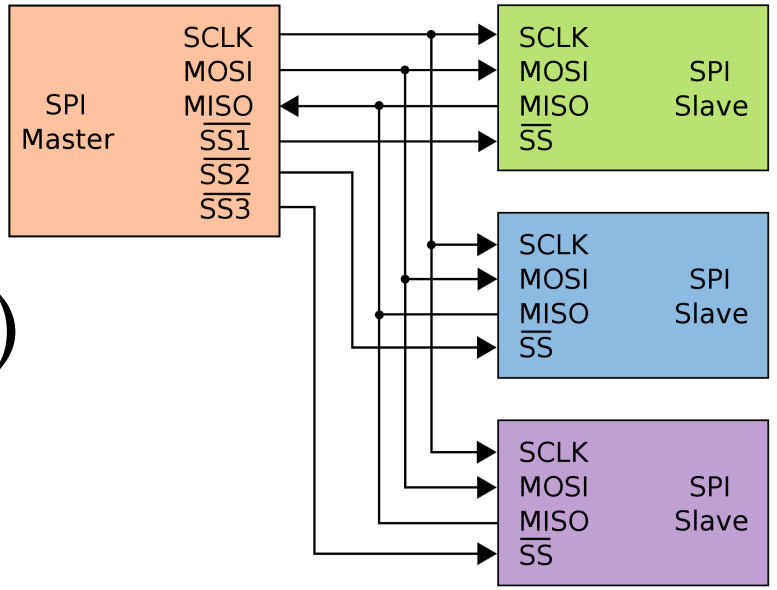


- Clocked by controller (master)
- Shared CLK, MOSI, MISO lines
- Active low chip select (SS) lines to specify which peripheral is active



Figures from https://upload.wikimedia.org/wikipedia/commons/thumb/f/fc/SPI_three_slaves.svg/2000px-SPI_three_slaves.svg.png (top), http://www.tequipment.net/RigolSD-SPI-DS4.html (bottom)

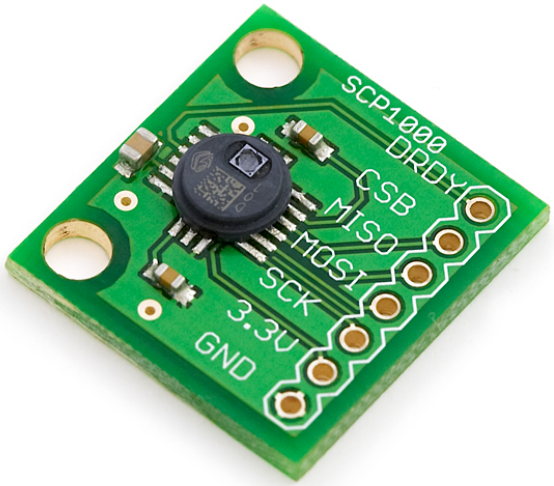
SPI



- Clocked by controller (master)
- Shared CLK, MOSI, MISO lines
- Active low chip select (SS) lines to specify which peripheral is active

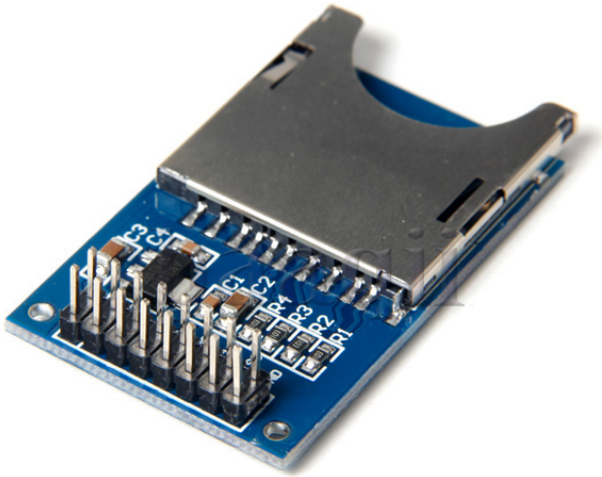
Historically, the device controlling the clock was called the "master" and the device following the clock was called the "slave". There's been a concerted shift away from this terminology to "controller" and "peripheral", but you will still see it in older documentation (like some of the acronyms and figures in this lecture). It's important to know this out-of-date terminology for when you encounter it.

Figures from https://upload.wikimedia.org/wikipedia/commons/thumb/f/fc/SPI_three_slaves.svg/2000px-SPI_three_slaves.svg.png (top), http://www.tequipment.net/RigolSD-SPI-DS4.html (bottom)



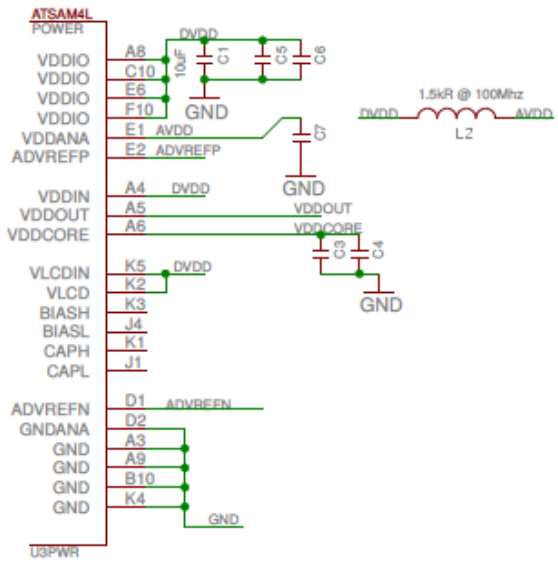
SPI Devices

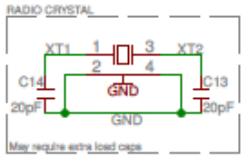
- Sensors (pressure, temperature, Hall effect)
- Control/Configure (ethernet switch, digital potentiometer, OLED display)
- SD Card
- Radios!

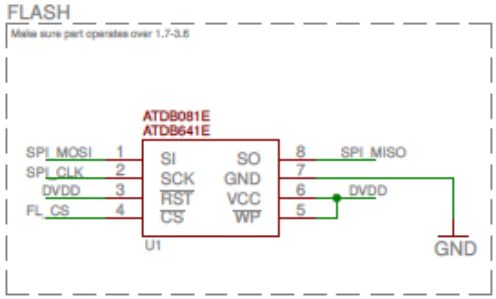


Figures from https://developer.mbed.org/media/uploads/MichaelW/scp1000d01.jpg (top)
http://raspberrypi.stackexchange.com/questions/28648/how-can-i-wire-this-sd-card-reader-to-raspberrypi (bottom)

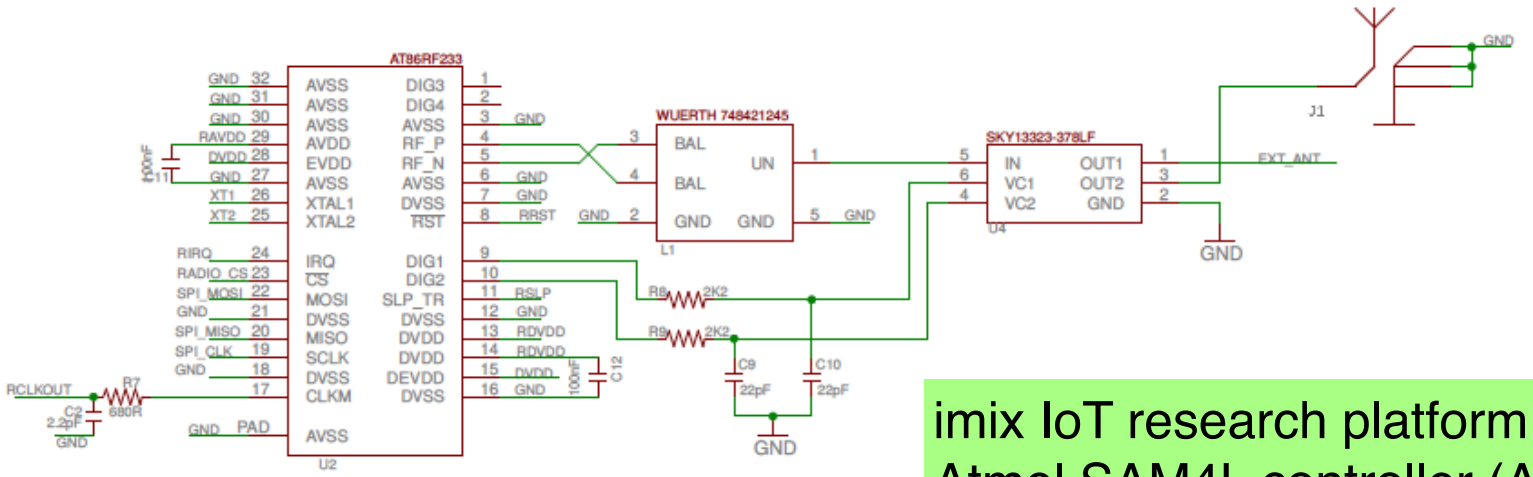
SPI Demo





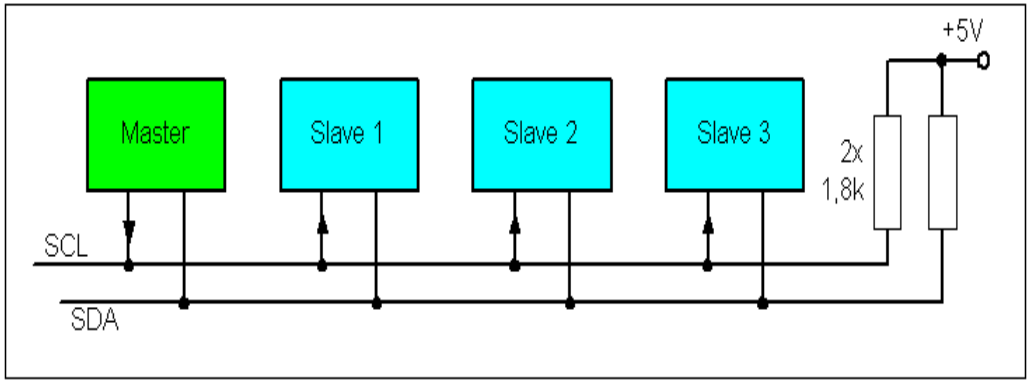


Errata:
C11 + C12 should be 100nF

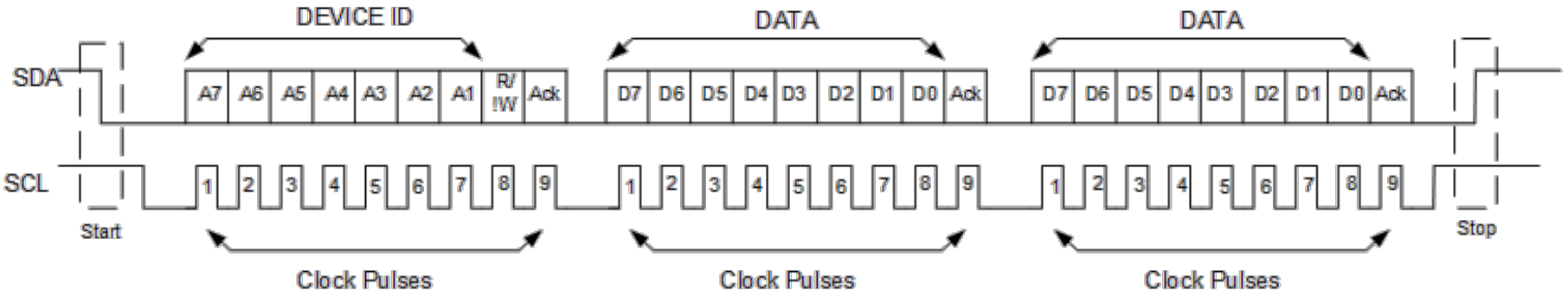


imix IoT research platform
Atmel SAM4L controller (ARM Cortex M)
Atmel RF233 peripheral (802.15.4 radio)

I2C



- Only CLK & DATA lines
- Clocked by controller, sides alternate who sends data
- Shared bus, peripheral identified by 7 (or 10) bit address



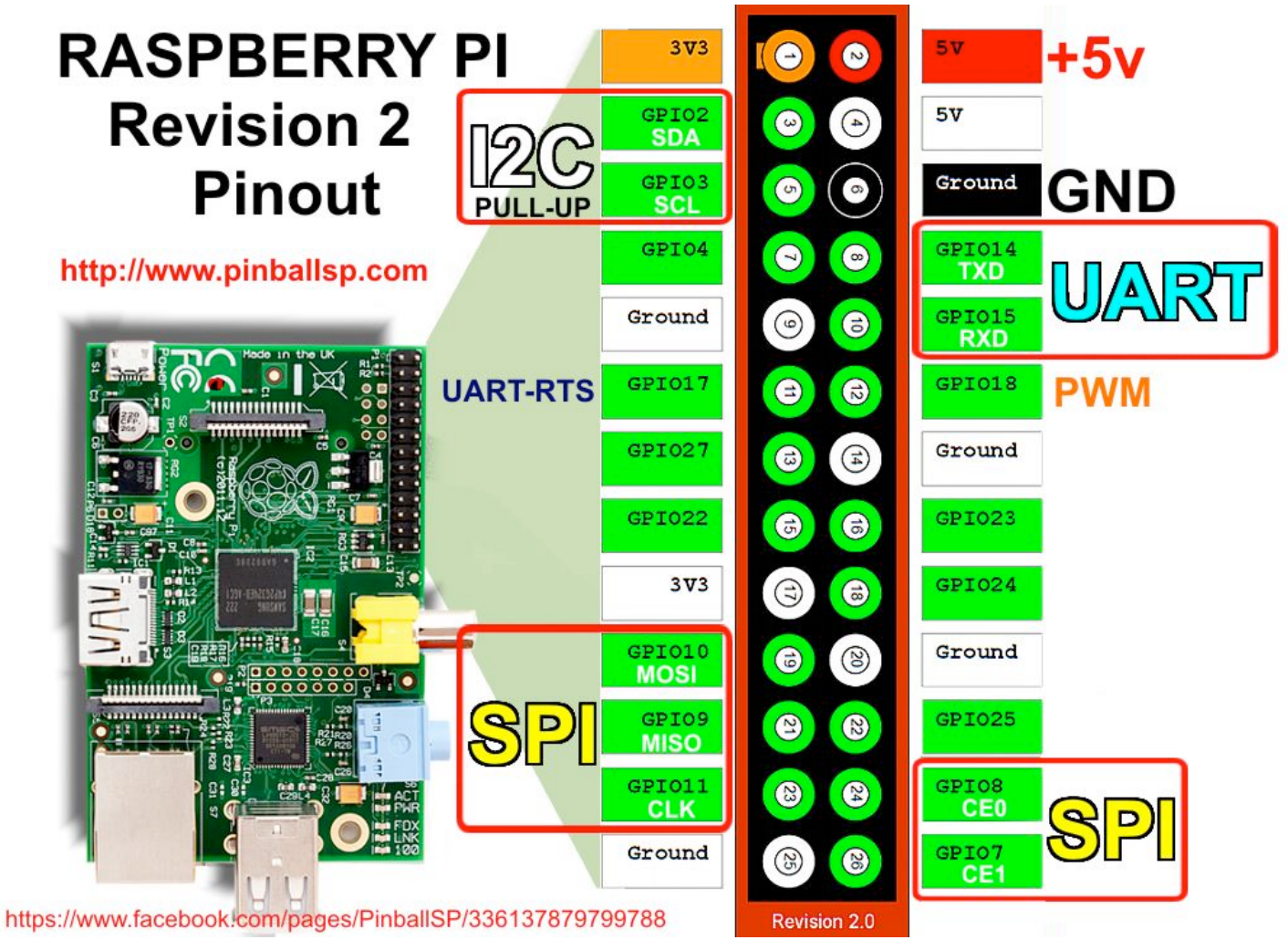
Figures from http://www.cs.fsu.edu/~baker/devices/notes/graphics/i2cbus3.gif (top)
https://learn.digilentinc.com/Documents/chipKIT/chipKITPro/P08/Fig_1_Waveform.png (bottom)

I2C Devices

- Sensors (pressure, temperature, colorimeter)
- Control/Configure (HDMI display)
- ADC & DAC

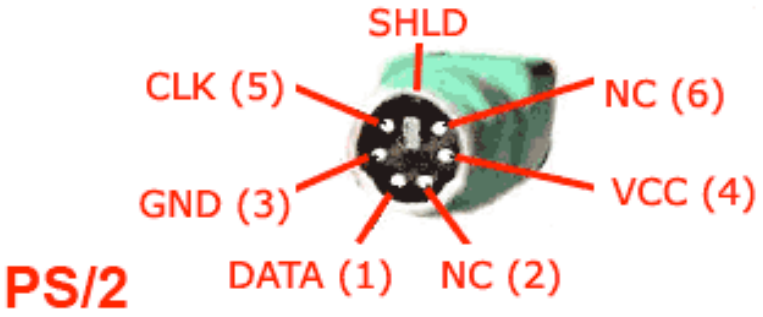
Figure from http://www.seeedstudio.com/wiki/Grove_-_I2C_Color_Sensor

Raspberry Pi Header Pins



PS/2 Keyboard

- PS/2 is an old serial protocol for keyboards
- Synchronous: *CLK* and DATA lines



PS/2 Protocol

- 8-Odd-1 (8 data bits, odd parity, 1 stop bit)
- Data changes when clock line goes high
- Read data when clock is low
- Open-collector CLK & DATA
  - High is an open circuit
  - Low is connected to ground
  - Need a pull-up resistor to make high actually high

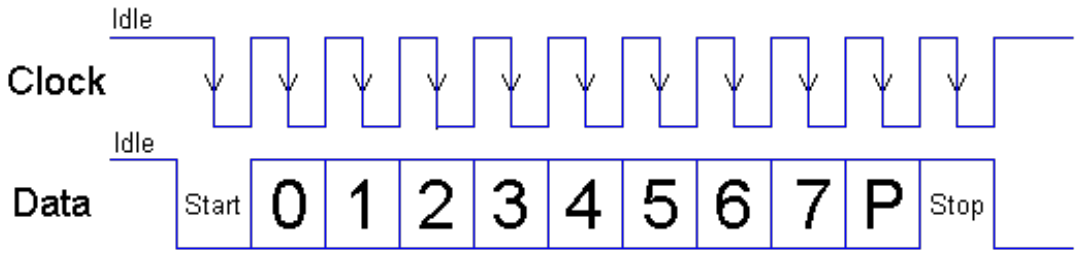
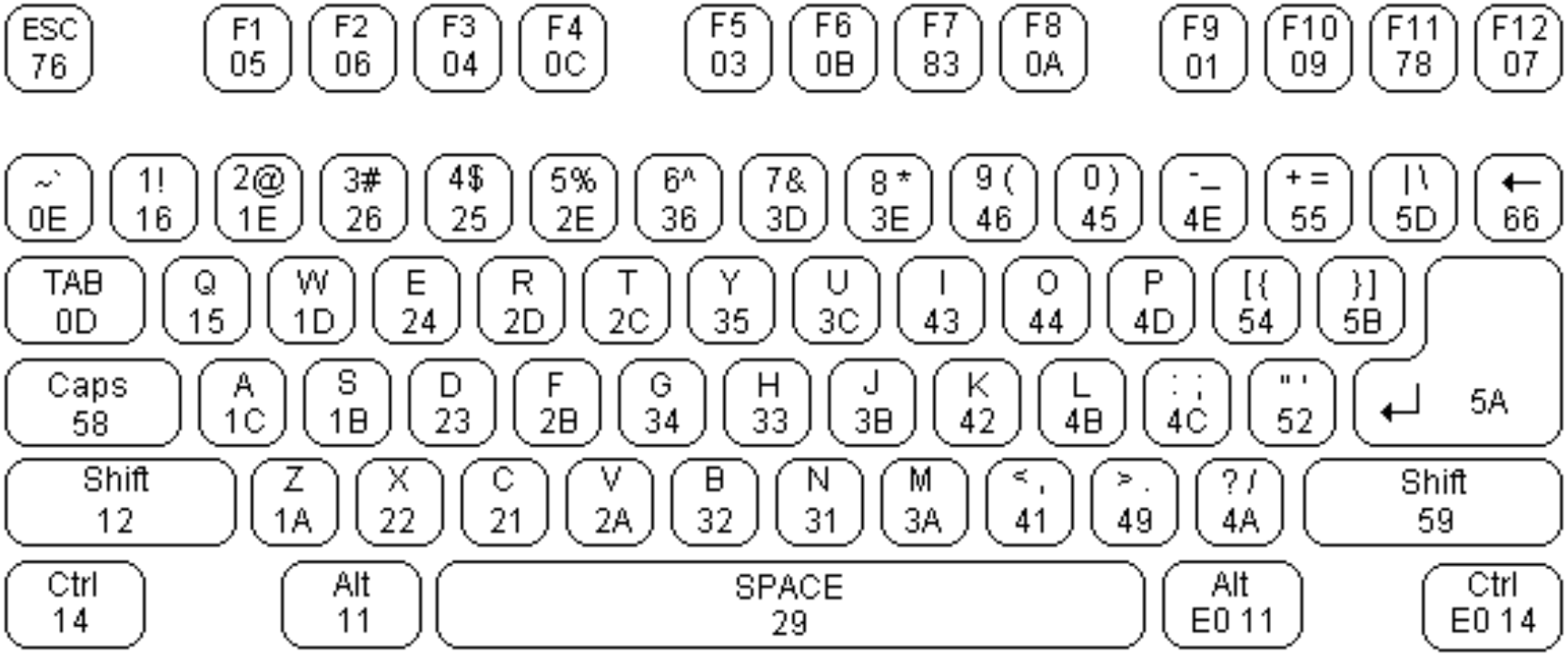


Figure from http://retired.beyondlogic.org/keyboard/keyboar1.gif

Keyboard Data



Key	Action	Scan Code
A	Make (down)	0x1C
A	Break (up)	0xF0 0x1C
Shift L	Make (down)	0x12
Shift L	Break (up)	0xF0 0x12

PS/2 Logic Analyzer Demo

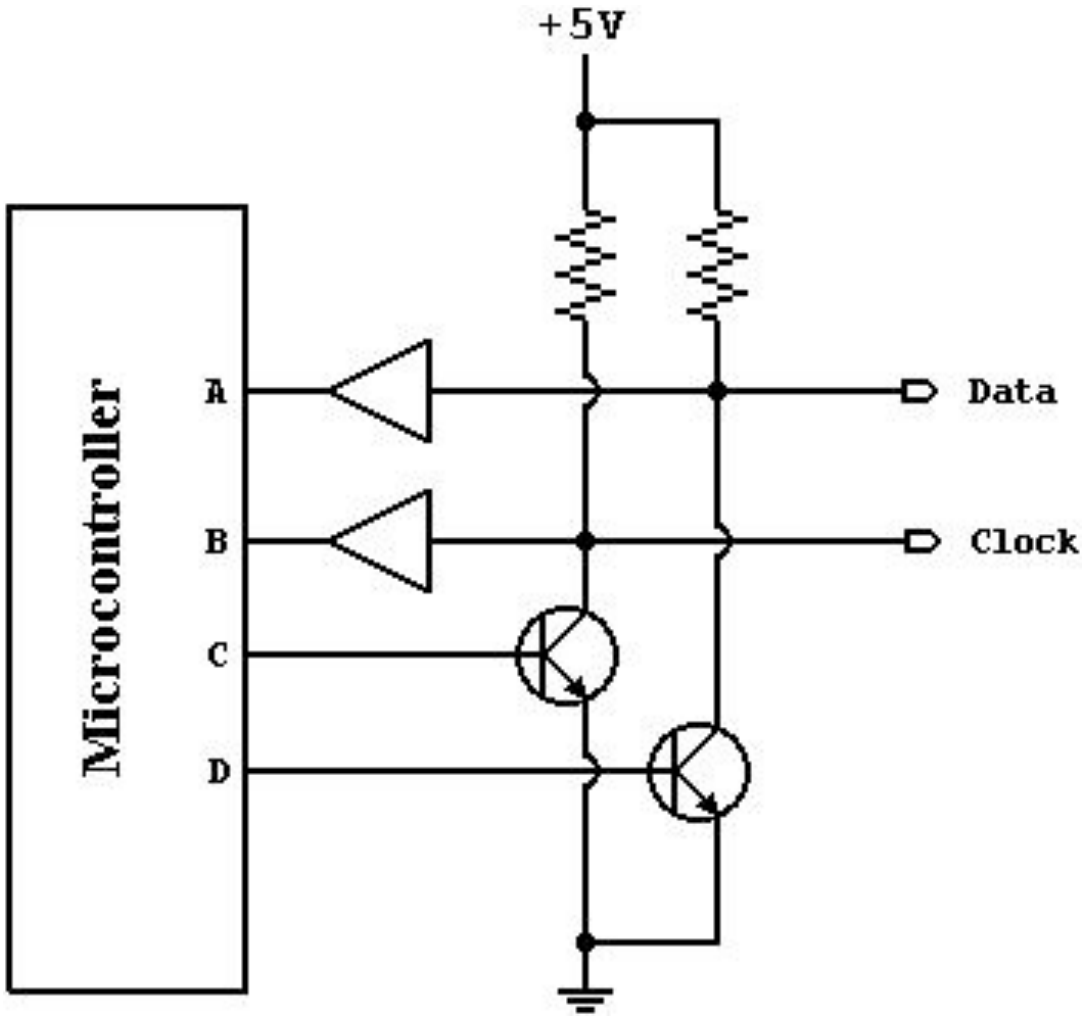
Reading PS2 Protocol

ps2/

Keyboard Scan Code Demo

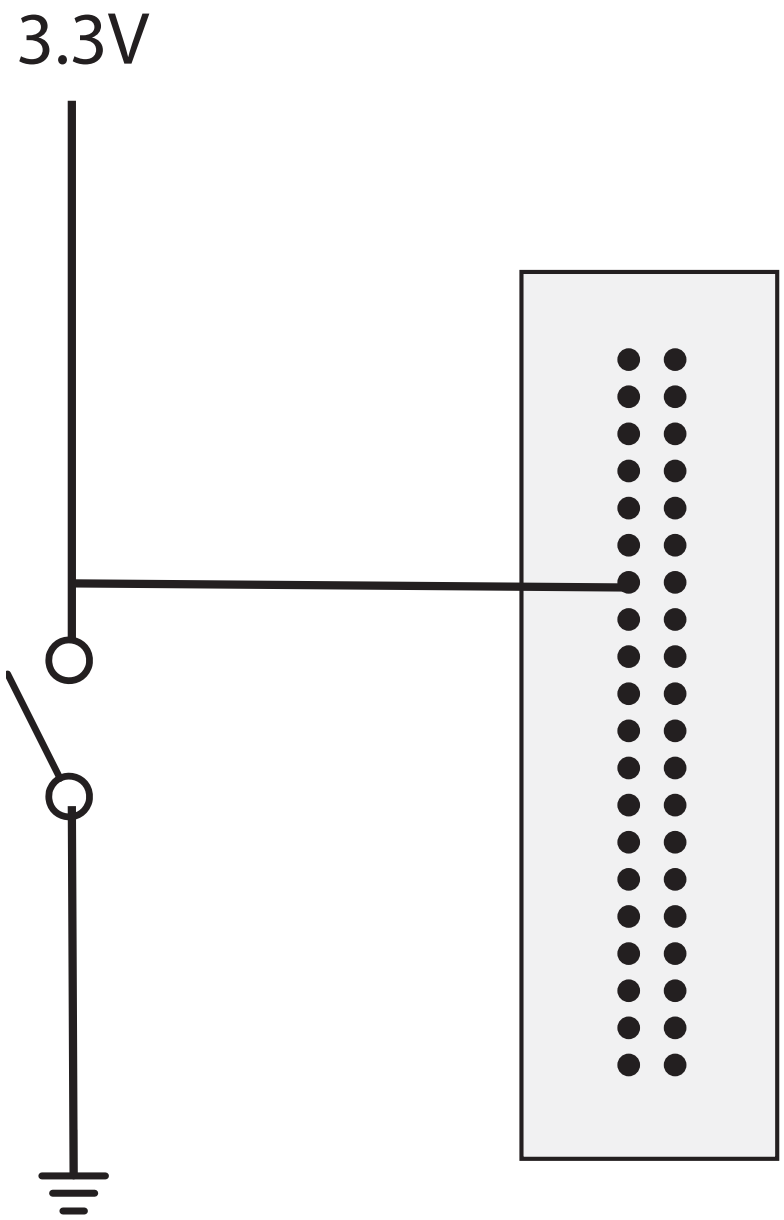
scancode/

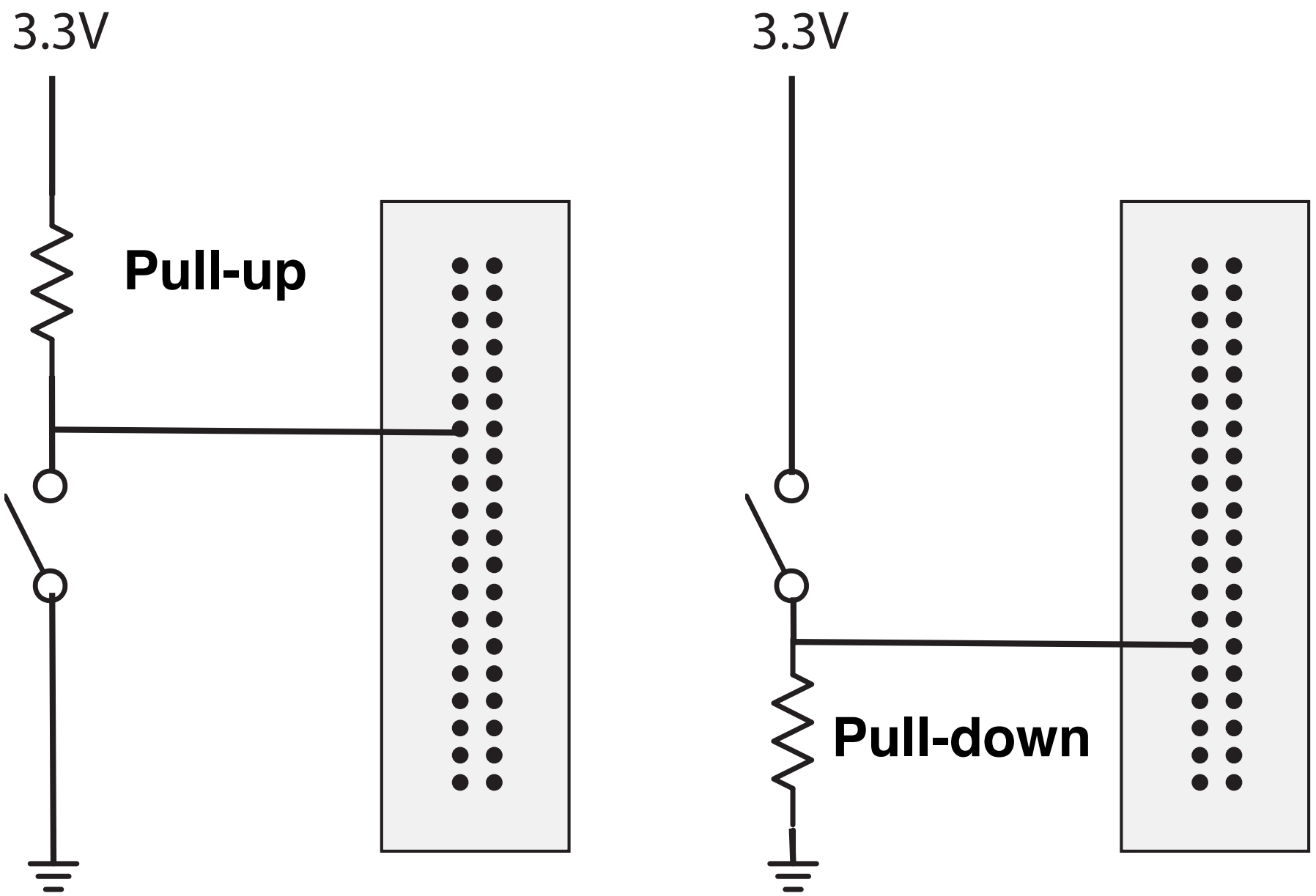
Open Collector



- Asserting C will bring clock low
  - Otherwise goes high from pull-up resistor
- Asserting D will bring data low
  - Otherwise goes high from pull-up resistor

Switch



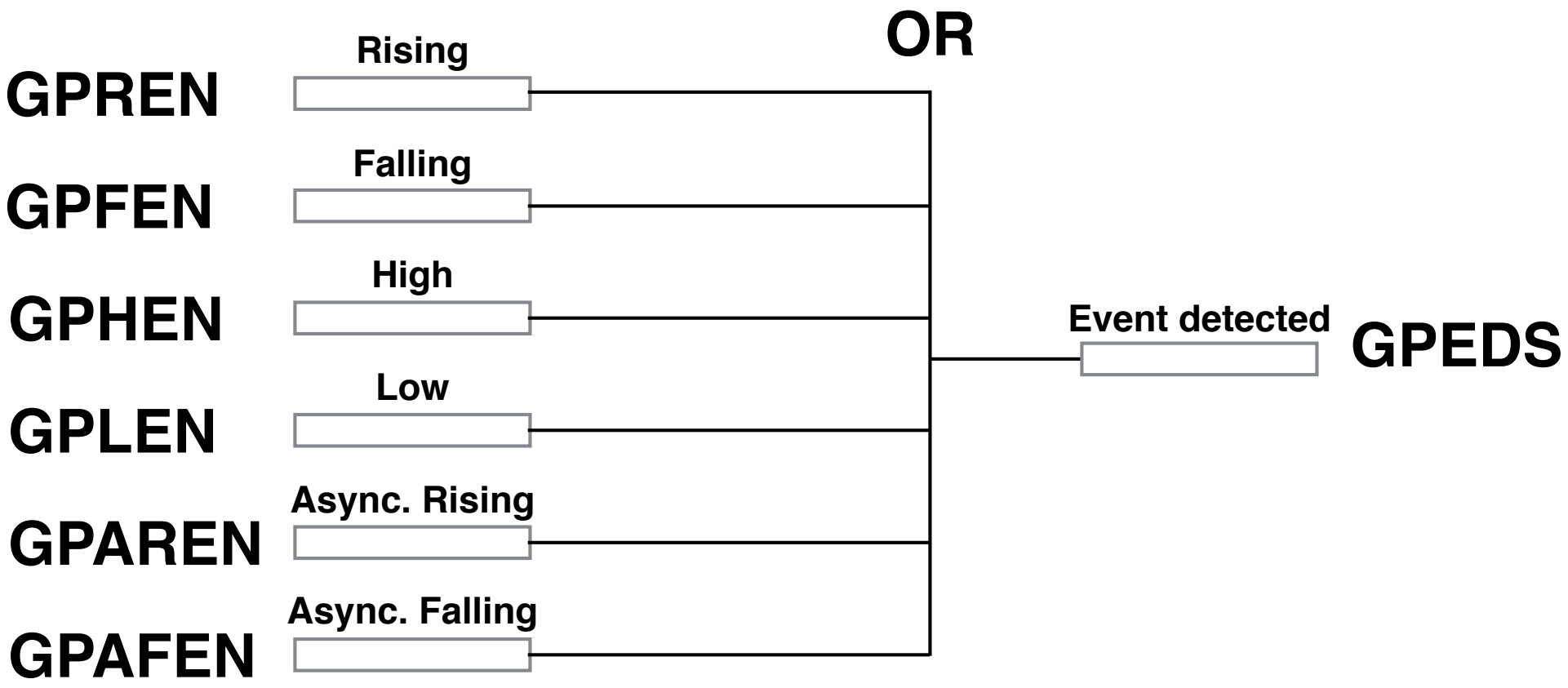

3.3V
Pull-up
3.3V
Pull-down

GPIO Event Detection

- Can detect falling / rising edge, low / high level
- Set bit for pin in appropriate GPIO event detect enable register (e.g. GPFEN)
- Once enabled, events on that pin will set a bit in the GPIO event detect status register (GPEDS)
- Check GPEDS register for event
- Clear event by writing 1 to bit in GPEDS

See BCM2835-ARM-Peripherals manual pages 96-100

GPIO Event Detection



Reading PS2 Protocol

gpioevents/

Keys != Characters

- Keyboard scancodes usually converted to ASCII bit stream
- Conversion throws away some info (left-shift vs. right-shift, multiple keys pressed, alt/cmd + key, etc.)
- Sometimes want the extra info (e.g. games) so interface directly with scancodes

Keys (Scan Codes) ≠ Characters (ASCII)

Scan code numbers ≠ ASCII character codes

- Typically 104 keys
- 127 ASCII character codes

Extra keys

- Special keys - interpreted by the OS or App
  - F1, …, F12
  - Arrows, insert, delete, home, …
- Multiple keys with same function
  - Left and right shift, …
  - Numbers on keypad vs. keyboard

```
% man ascii
…
     00 nul   01 soh   02 stx   03 etx   04 eot   05 enq   06 ack   07
bel
     08 bs    09 ht    0a nl    0b vt    0c np    0d cr    0e so    0f si
     10 dle   11 dc1   12 dc2   13 dc3   14 dc4   15 nak   16 syn   17
etb
     18 can   19 em    1a sub   1b esc   1c fs    1d gs    1e rs    1f us
     20 sp    21  !    22  "    23  #    24  $    25  %    26  &    27  '
     28  (    29  )    2a  *    2b  +    2c  ,    2d  -    2e  .    2f  /
     30  0    31  1    32  2    33  3    34  4    35  5    36  6    37  7
     38  8    39  9    3a  :    3b  ;    3c  <    3d  =    3e  >    3f  ?
     40  @    41  A    42  B    43  C    44  D    45  E    46  F    47  G
     48  H    49  I    4a  J    4b  K    4c  L    4d  M    4e  N    4f  O
     50  P    51  Q    52  R    53  S    54  T    55  U    56  V    57  W
     58  X    59  Y    5a  Z    5b  [    5c  \    5d  ]    5e  ^    5f  _
     60  `    61  a    62  b    63  c    64  d    65  e    66  f    67  g
     68  h    69  i    6a  j    6b  k    6c  l    6d  m    6e  n    6f  o
     70  p    71  q    72  r    73  s    74  t    75  u    76  v    77  w
     78  x    79  y    7a  z    7b  {    7c  |    7d  }    7e  ~    7f
del
…
```

Keyboard Viewer

Keyboard Viewer

[Shift]

Keyboard Viewer

[CAPS Lock]

Keyboard Viewer

[CAPS Lock + SHIFT]

Keys ≠ Characters

[OPTION] (orange keys are *dead keys*)

Keys ≠ Characters

[OPTION ']

USB vs. PS/2

USB bus is 480Mbps-2Gbps

PS/2 is 10-16.7 kbps

Gamers preferred PS/2 to early USB keyboards: why?

Polling vs. Interrupts

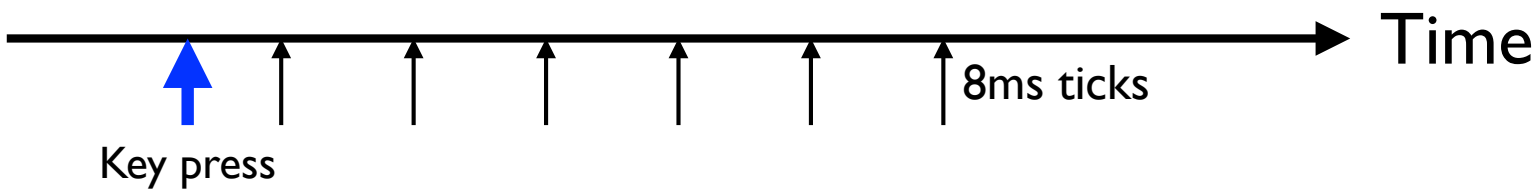
USB protocol uses *polling*: controller asks the keyboard at 125-1000Hz if there are any key presses: 1-8ms delay (old keyboards were 8ms)

Also, USB uses a shared bus: other devices transferring to/from the PC can delay the keyboard

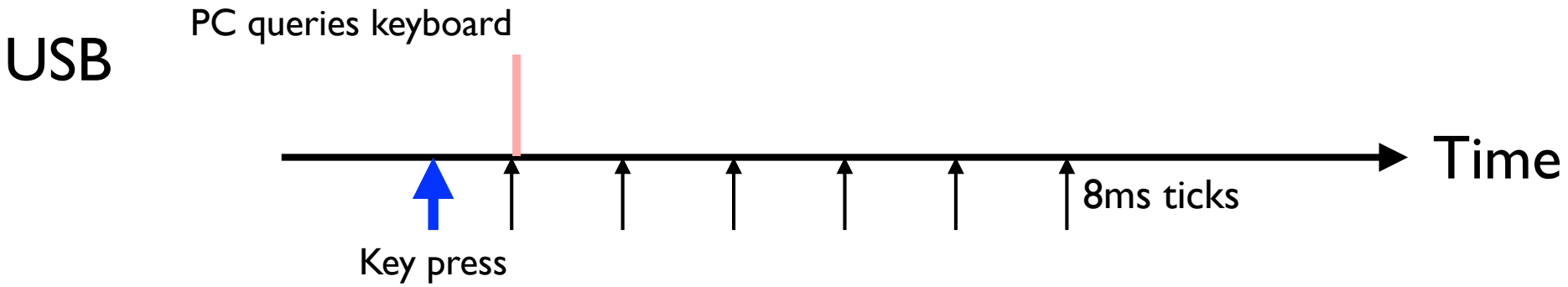
PS/2 protocol uses *interrupts:* when the PS/2 scan code is ready, it tells the processor immediately (assignment 7)

Polling vs. Interrupts

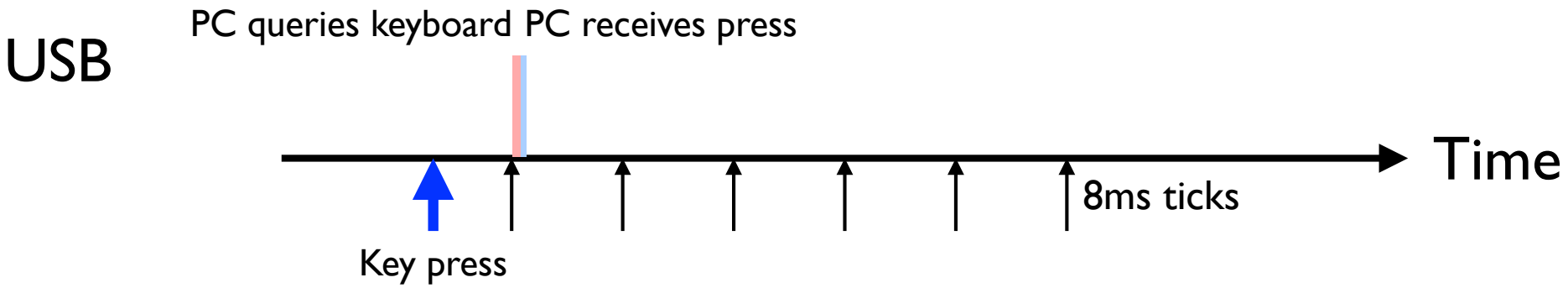
USB



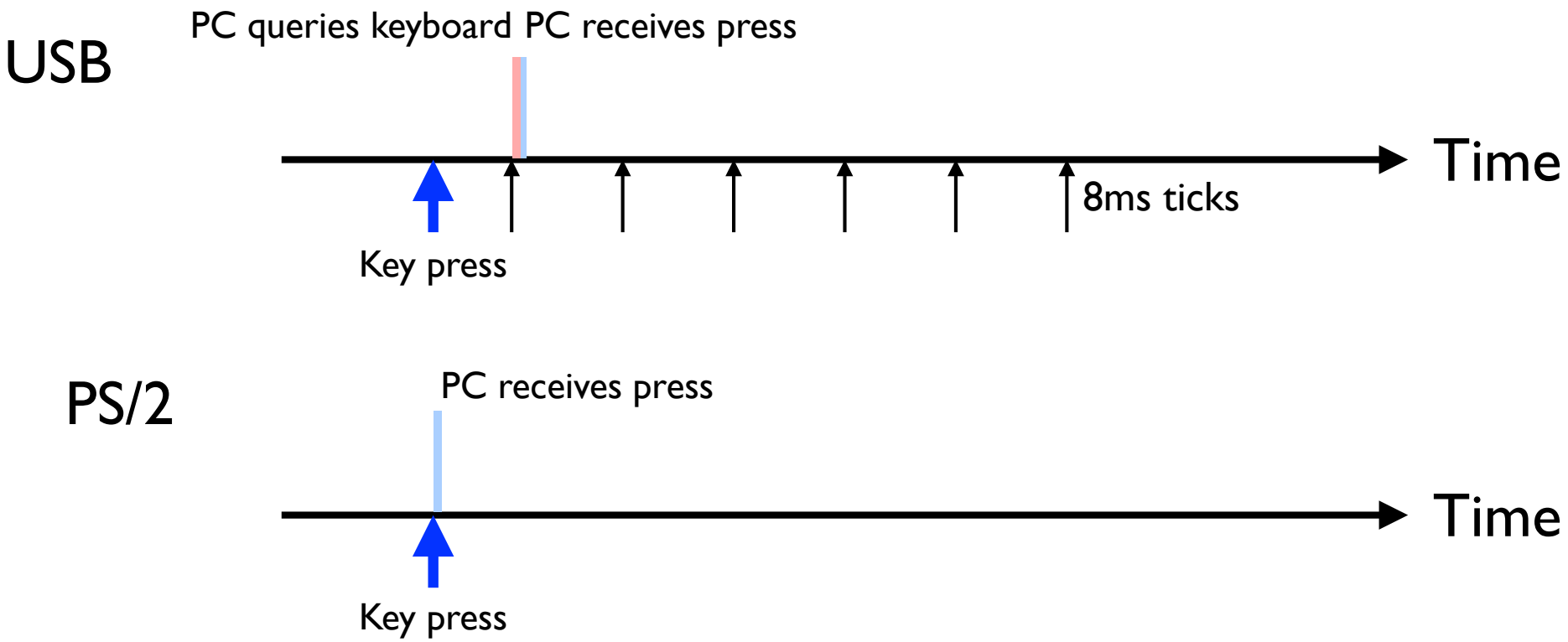
Polling vs. Interrupts



Polling vs. Interrupts



Polling vs. Interrupts



Latency vs. Throughput

USB protocol has higher *throughput* than PS/2 (sends data at Mbps vs. kbps)

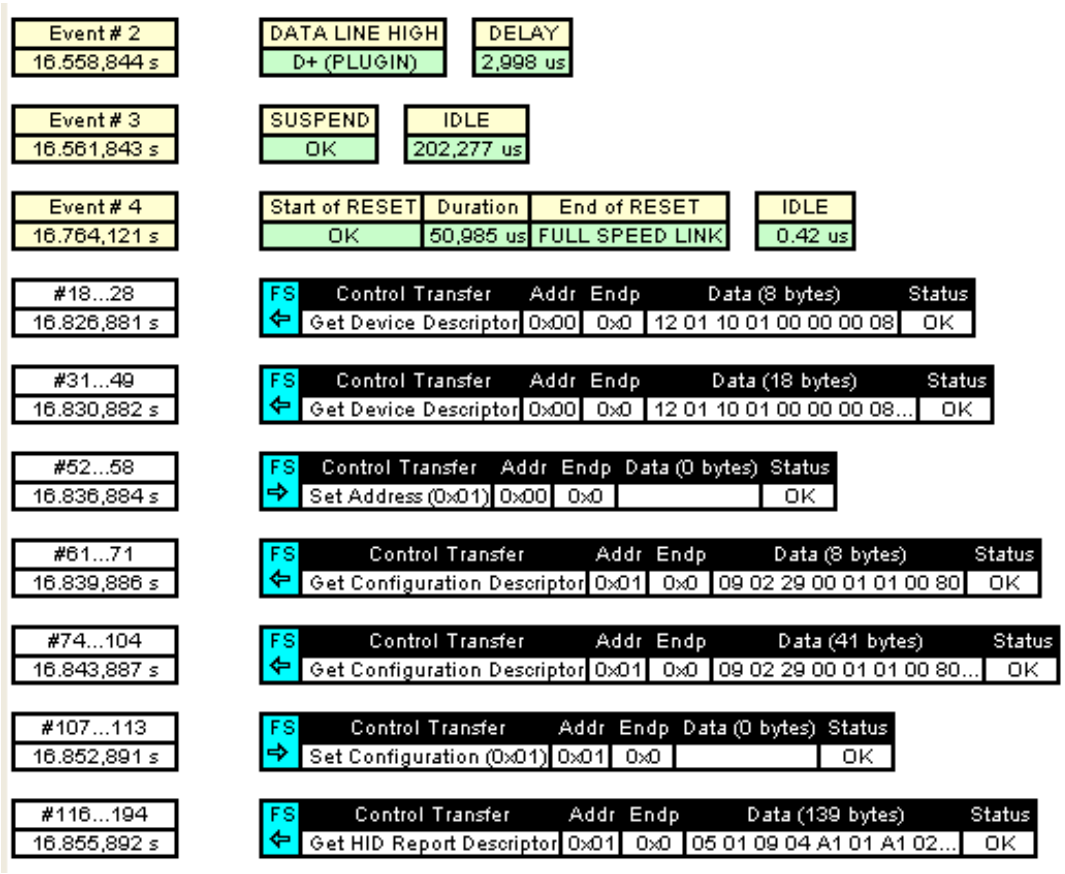
But early USB keyboards had higher *latency* because they would poll at 8ms intervals

Modern USB keyboards poll at 1ms; a PS/2 scan code takes about 1ms to send, so unless your USB has lots of data going across it, polling doesn't matter

USB

Extremely complex protocol!

Devices can be plugged in dynamically, extensible topology (adding hubs), your computer 'just knows' what a device can do



Event # 2 16.558,844 s	DATA LINE HIGH D+ (PLUGIN)	DELAY 2,998 us					
Event # 3 16.561,843 s	SUSPEND OK	IDLE 202,277 us					
Event # 4 16.764,121 s	Start of RESET OK	Duration 50,985 us	End of RESET FULL SPEED LINK	IDLE 0.42 us			
#18...28 16.826,881 s	FS ⇦	Control Transfer Get Device Descriptor	Addr 0x00	Endp 0x0	Data (8 bytes) 12 01 10 01 00 00 00 08	Status OK	
#31...49 16.830,882 s	FS ⇦	Control Transfer Get Device Descriptor	Addr 0x00	Endp 0x0	Data (18 bytes) 12 01 10 01 00 00 00 08...	Status OK	
#52...58 16.836,884 s	FS ⇨	Control Transfer Set Address (0x01)	Addr 0x00	Endp 0x0	Data (0 bytes)	Status OK	
#61...71 16.839,886 s	FS ⇦	Control Transfer Get Configuration Descriptor	Addr 0x01	Endp 0x0	Data (8 bytes) 09 02 29 00 01 01 00 80	Status OK	
#74...104 16.843,887 s	FS ⇦	Control Transfer Get Configuration Descriptor	Addr 0x01	Endp 0x0	Data (41 bytes) 09 02 29 00 01 01 00 80...	Status OK	
#107...113 16.852,891 s	FS ⇨	Control Transfer Set Configuration (0x01)	Addr 0x01	Endp 0x0	Data (0 bytes)	Status OK	
#116...194 16.855,892 s	FS ⇦	Control Transfer Get HID Report Descriptor	Addr 0x01	Endp 0x0	Data (139 bytes) 05 01 09 04 A1 01 A1 02...	Status OK	