Keyboards

The PS/2 Protocol

Engineering Best Practices

Test, test, test, and test some more; test as you go

Start from a known working state, take small steps

Make things visible (gdb, printf, logic analyzer)

Methodical, systematic approach. Form hypotheses and perform experiments to confirm

Fast prototyping, embrace automation, one-click build, clean compile, check-in often

Don't let bugs get you down, natural part of engineering, relish the challenge -- you will learn something new!

Wellness important! sleep, healthy food, maintain perspective

I have been having good luck with a somewhat different approach, first used in 1960 to debug an ALGOL compiler. The idea is to construct a test file that is about as different from a typical user application as could be imagined. Instead of testing things that people normally want to do, the file tests complicated things that people would never dare to think of, and it embeds these complexities in still more arcane constructions. Instead of trying to make the compiler do the right thing, the goal is to make it fail (until the bugs have all been found).

To write such a fiendish test routine, one simply gets into a nasty frame of mind and tries to do everything in the unexpected way. Parameters that are normally positive are set negative or zero; borderline cases are pushed to the limit; deliberate errors are made in hopes that the compiler will not be able to recover properly from them.

A torture test for TeX, D. Knuth, 1985

gpio
timer
uart
printf
malloc
keyboard
shell
fb
gl
console

UART

- **Used in `printf` & the `bootloader`**
- **Start bit, 8 data bits, stop bits**
- **No clock, requires precise timing**

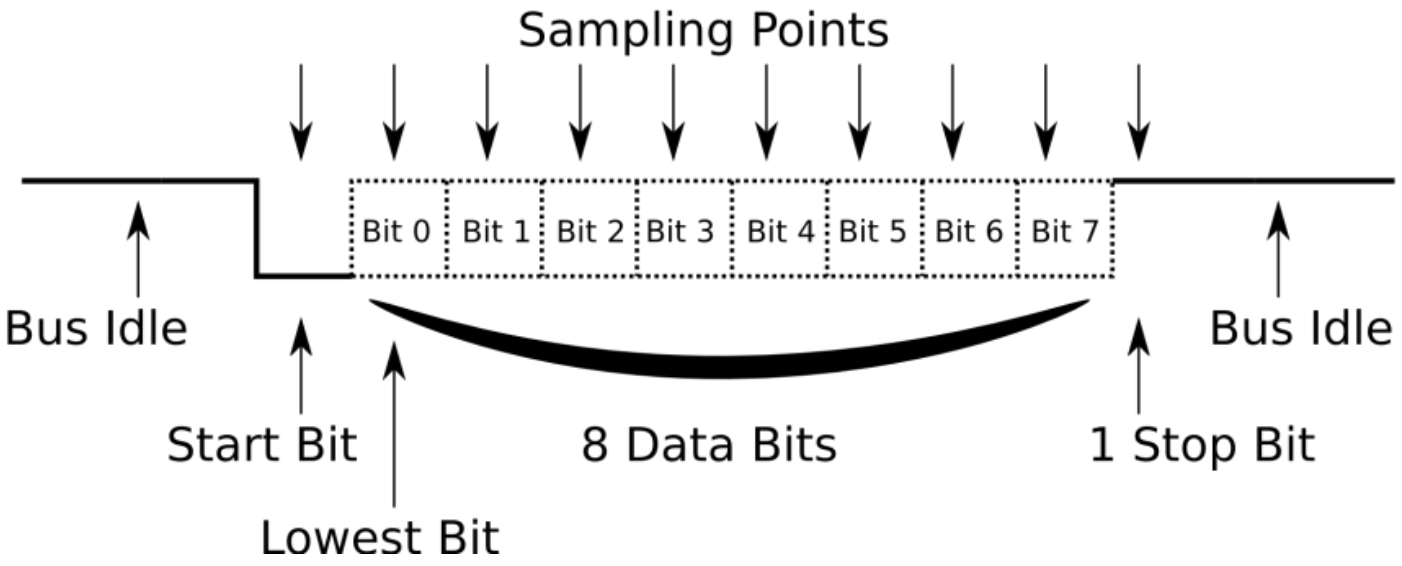


Figure from http://old.myhdl.org/lib/exe/detail.php/projects:rs232image.png?id=projects%3Auart_rs232_receiver_transmitter

PS/2 Interface

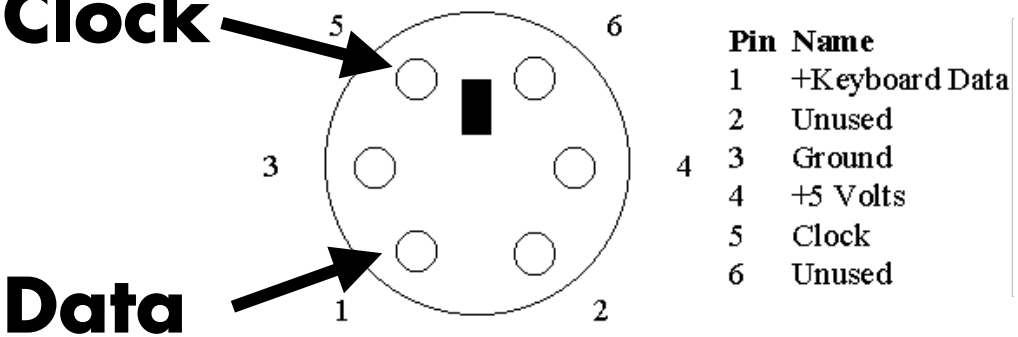
PS/2 is the original serial protocol for keyboards and mouse (replaced by usb)

Computer PS/2 ports

http://www.computerhope.com

6-pin mini-DIN connector

PS/2 Keyboard and Mouse Cable



Pin	Name
1	+Keyboard Data
2	Unused
3	Ground
4	+5 Volts
5	Clock
6	Unused

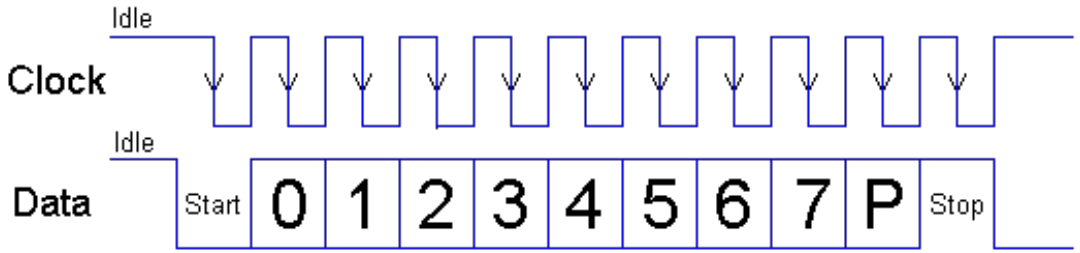
Cable (male) pinout

PS/2 Protocol

Synchronous protocol: keyboard sends clock

- **Data changes when clock line is high**
- **Host reads data when clock is low**

Payload: *start bit*, 8 data bits (lsb-first), *1 parity bit*, 1 *stop bit* (11 total)

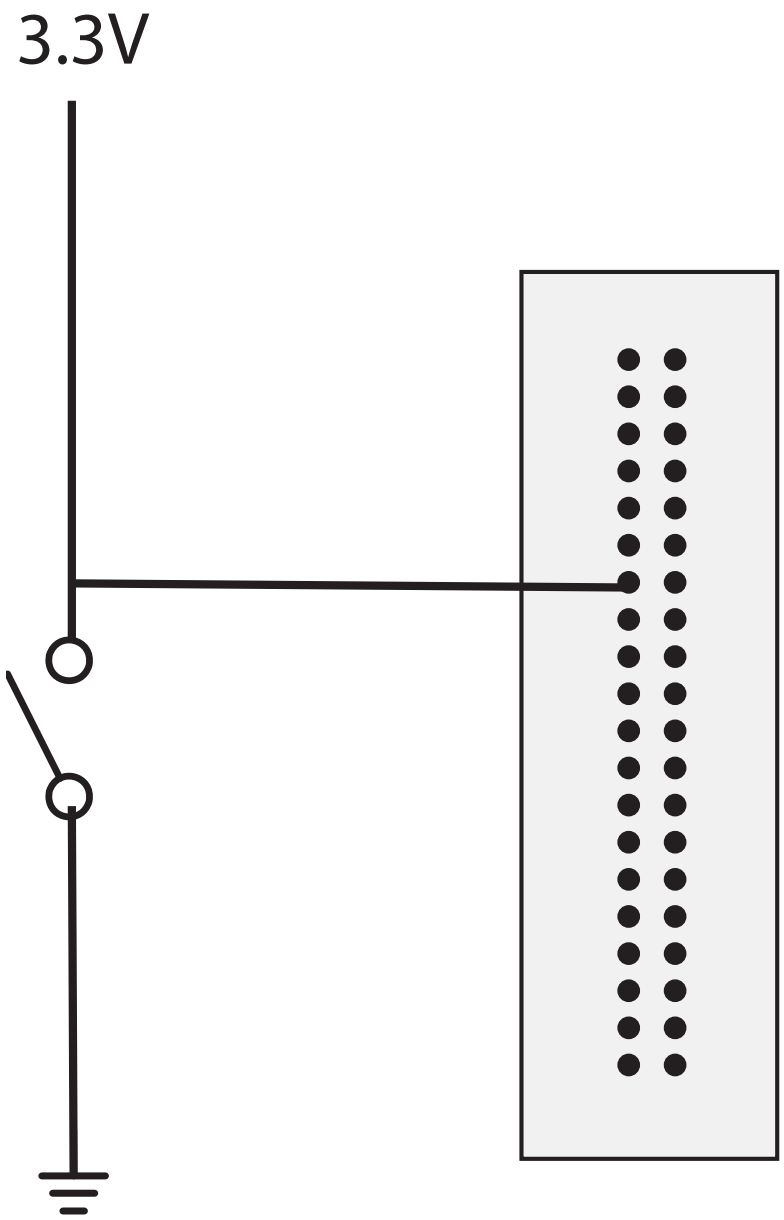


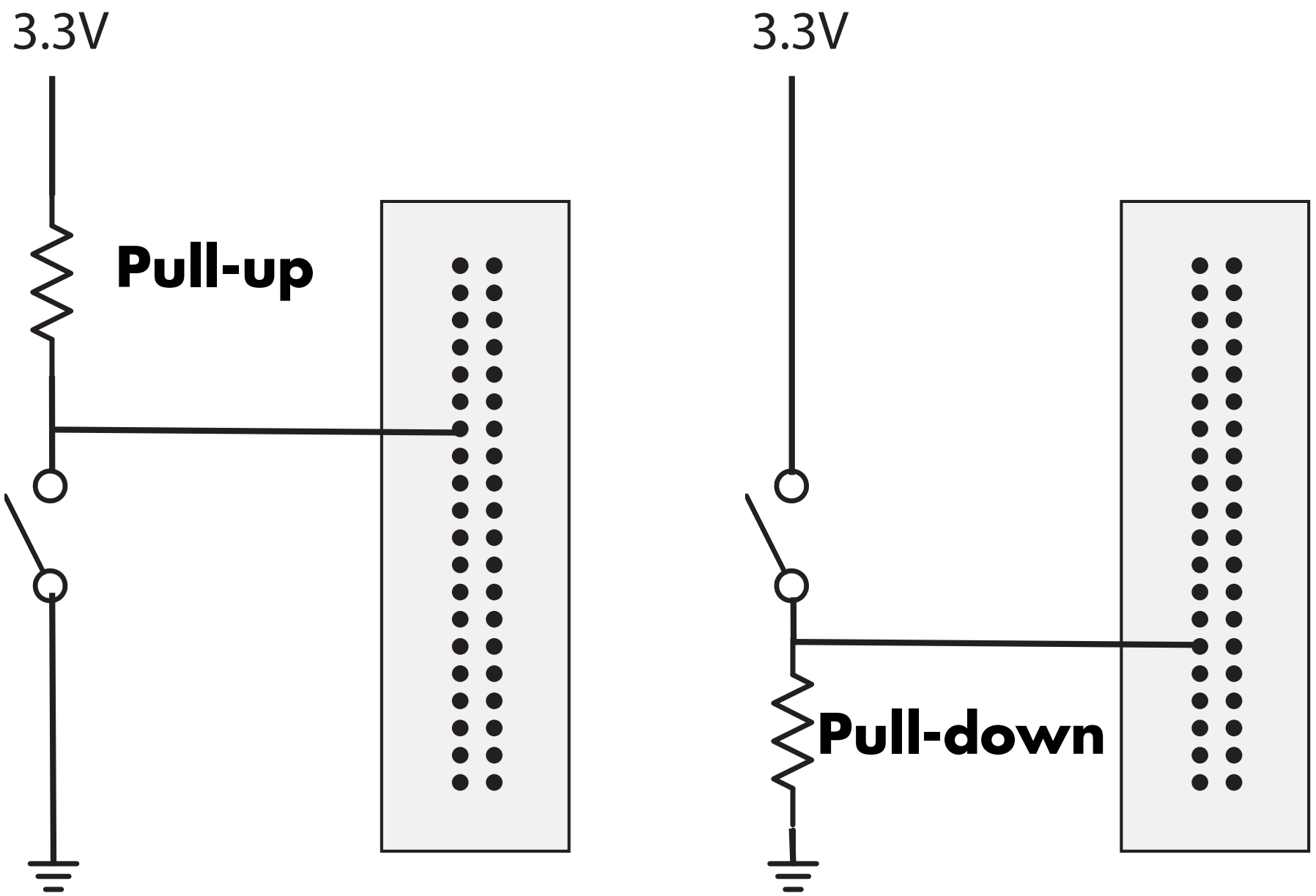
Reading PS2 Protocol

ps2/

PS/2 Logic Analyzer Demo

Switch




3.3V
Pull-up
3.3V
Pull-down

GPIO pull-up mode

See `gpioextra.h`

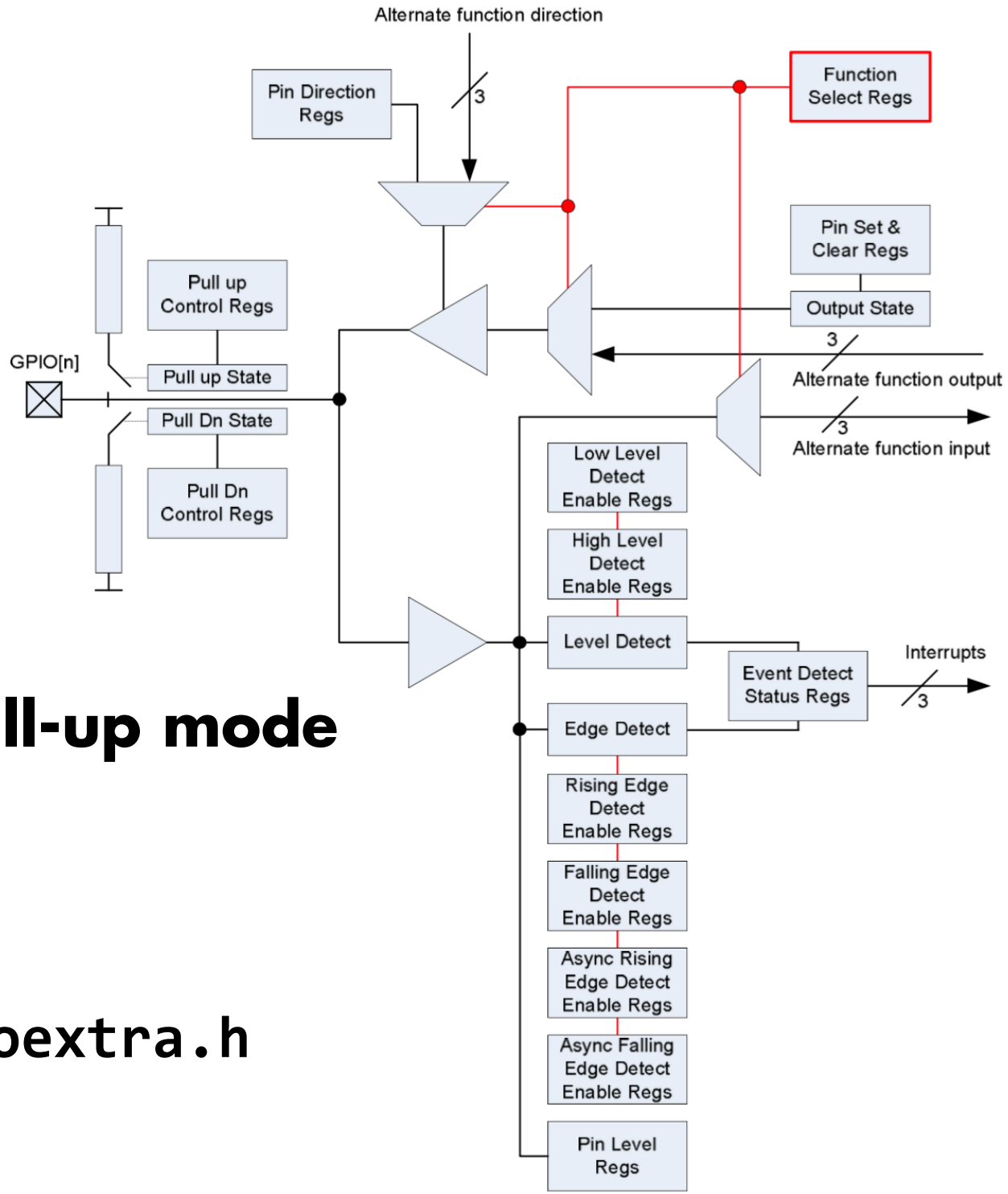
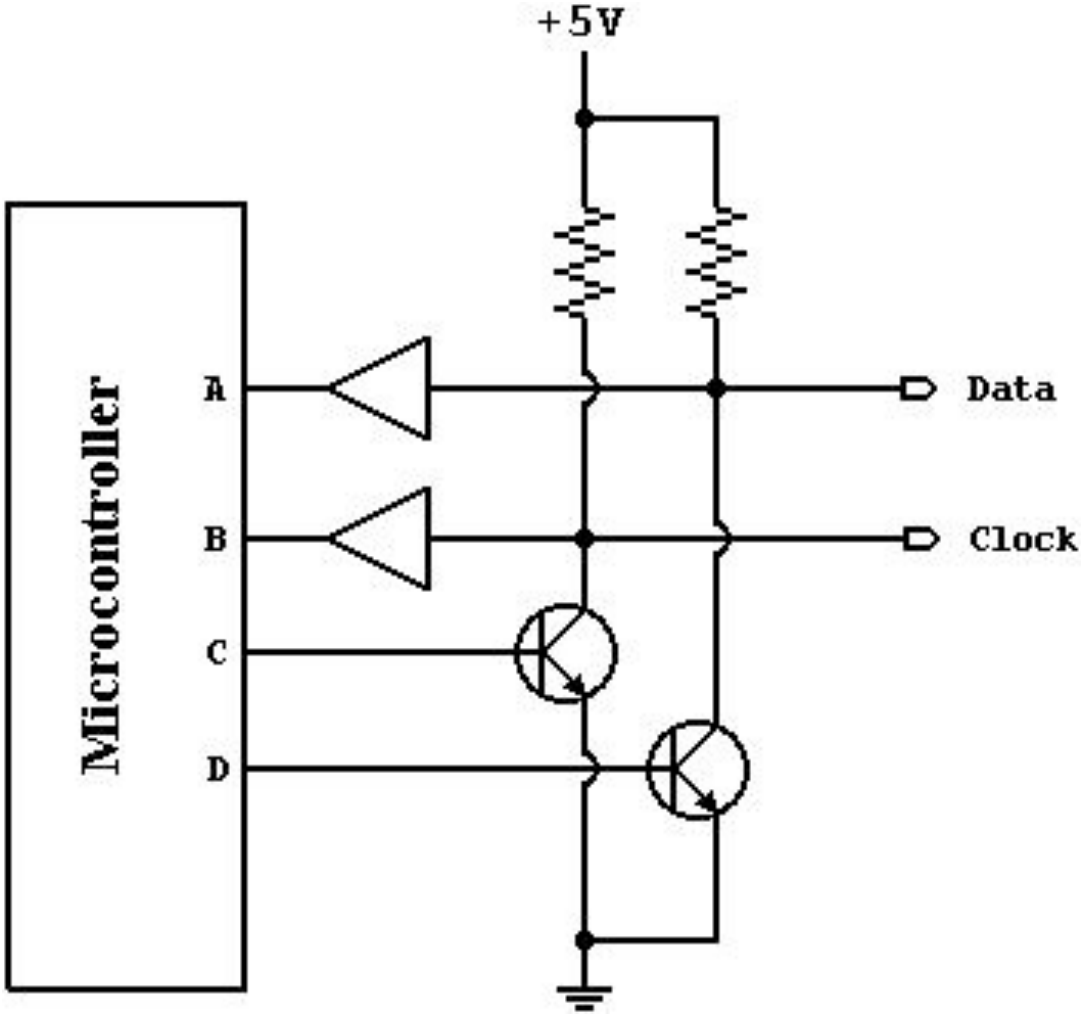


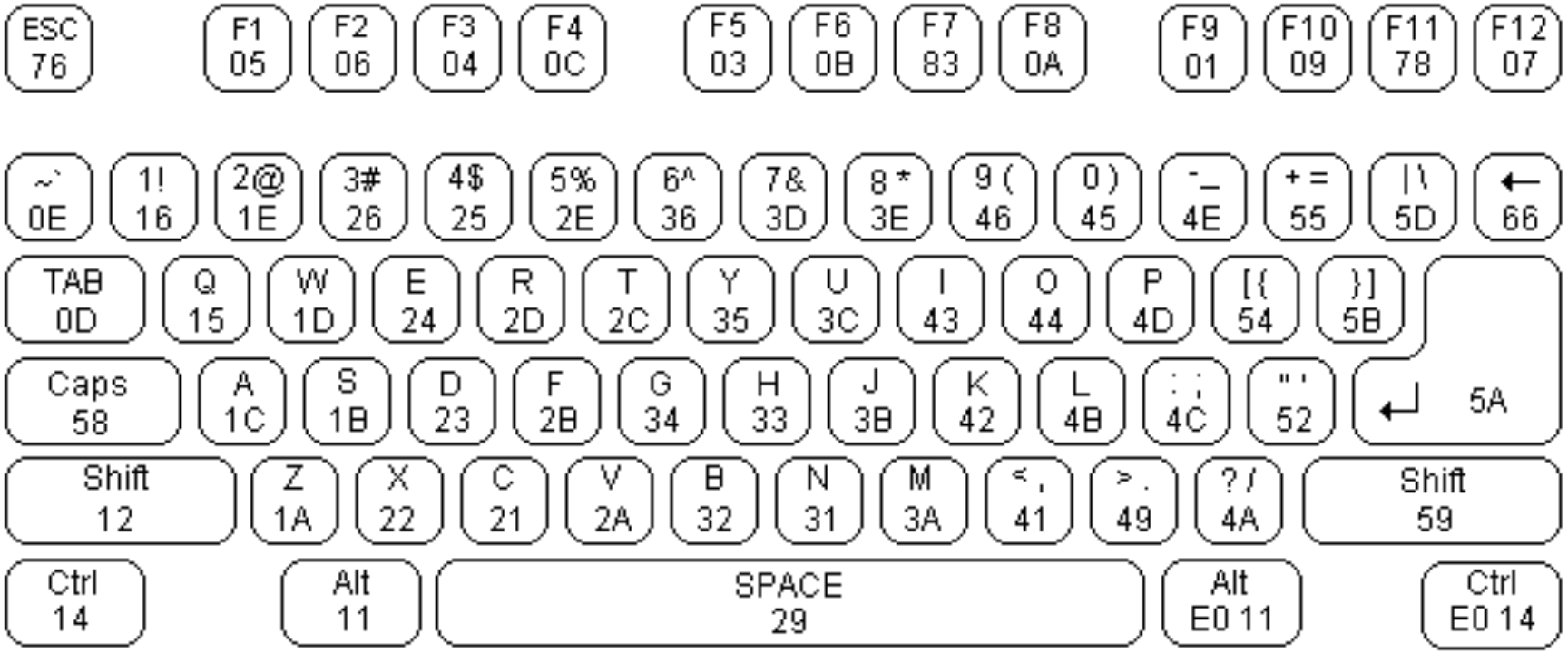
Figure 6-1 GPIO Block Diagram



- **DATA and CLK lines are *pulled up* to 5V**
- **Switching on the transistor sets line to 0V**
- **Enables bi-directional communication (keyboard or Pi can provide data)**

Keyboard Scan Codes

http://www.computer-engineering.org/ps2keyboard/



Make (press) and Break (release) codes `0xF0`

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

Keyboard Scan Code Demo

`scancode/`

Parity Bits

Parity = XOR of all of the data bits

Even/odd parity: an even/odd number of 1s (including parity bit)

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

Error in transmission

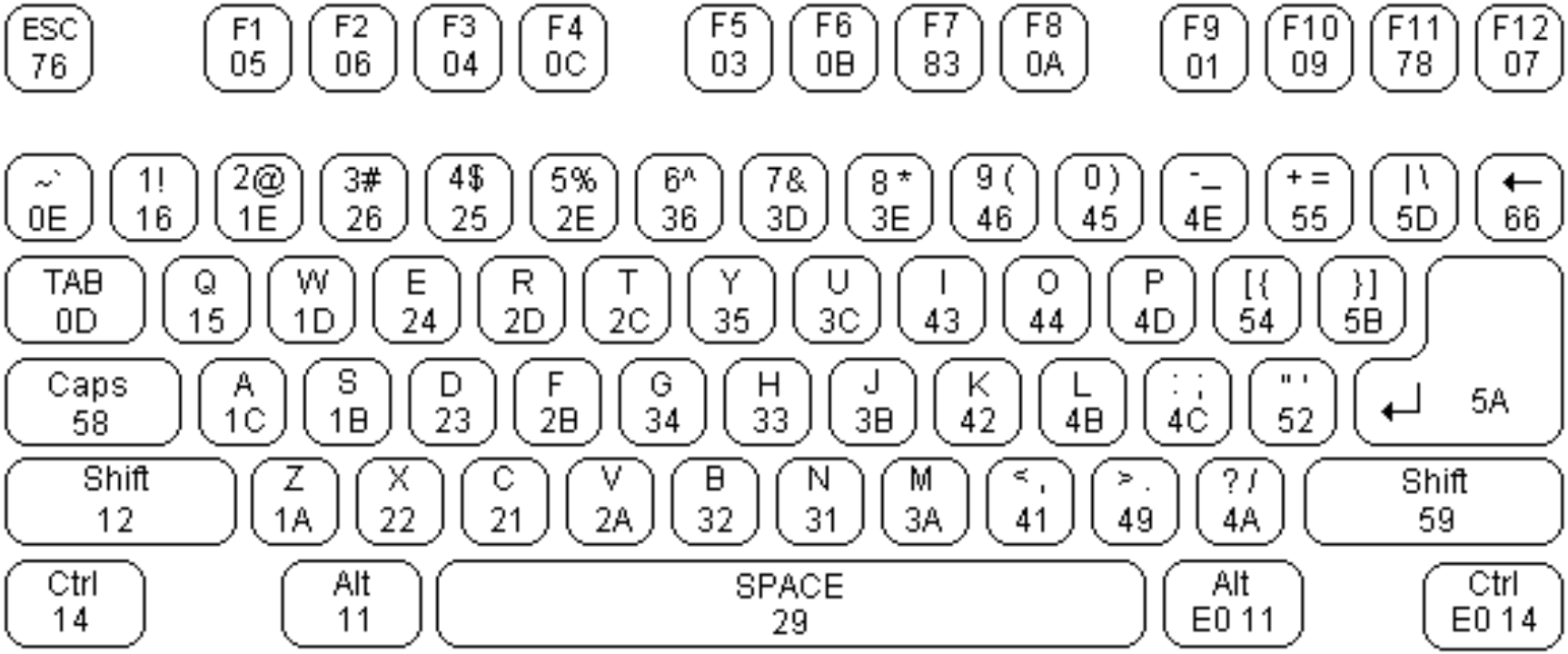
- **Parity is not correct (one bit was flipped)**
- **Similar to checksum in boot loader**

PS2 protocol is odd parity (parity bit makes the number of bits odd)

Keyboard Abstractions

Recall Keyboard Scan Codes

http://www.computer-engineering.org/ps2keyboard/



Make (press) and Break (release) codes `0xF0`

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Keys (Scan Codes) ≠ Characters (ASCII)

Scan codes ≠ ASCII character codes

- **e.g ‘A’ - scan code 0x1C, ascii 0x41**
- **Typically keyboard has 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 ']

Layered Abstractions (keyboard.h)

```
unsigned char keyboard_read_scancode(void)

  returns when receives well-formed scancode

key_action_t keyboard_read_sequence(void)

  returns key pressed or released

  sequence of up to 3 scan codes (includes one or both of
  PS2_CODE_RELEASE=0xF0 and PS2_CODE_EXTEND = 0xE0)

key_event_t keyboard_read_event(void)

  returns key along with modifier key state

unsigned char keyboard_read_next(void)

  returns ASCII character, modifier and special keys >= 0x90
```

Reading PS2 Protocol

`gpioevents/`

GPIO pull-up mode

See `gpioextra.h`

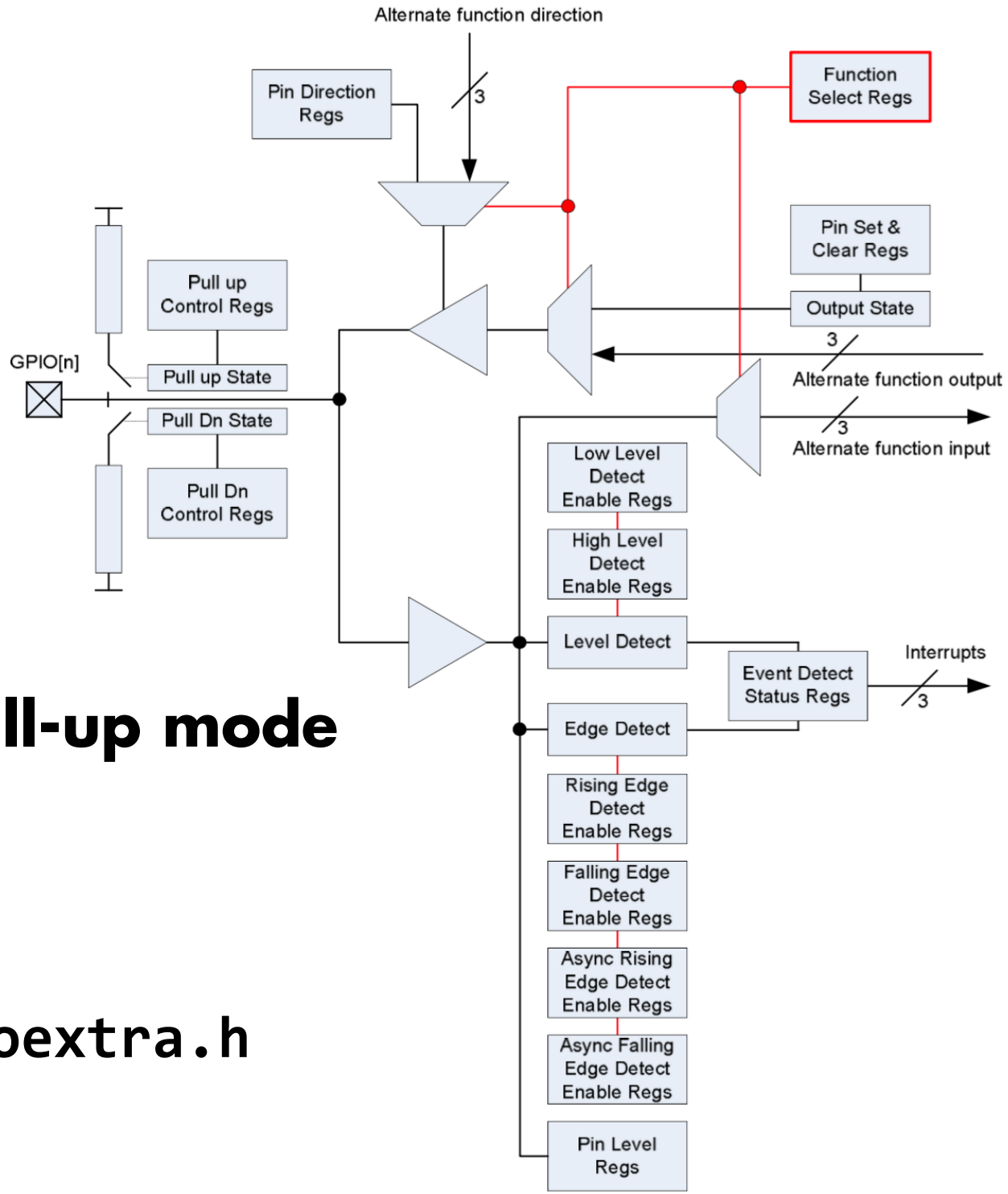
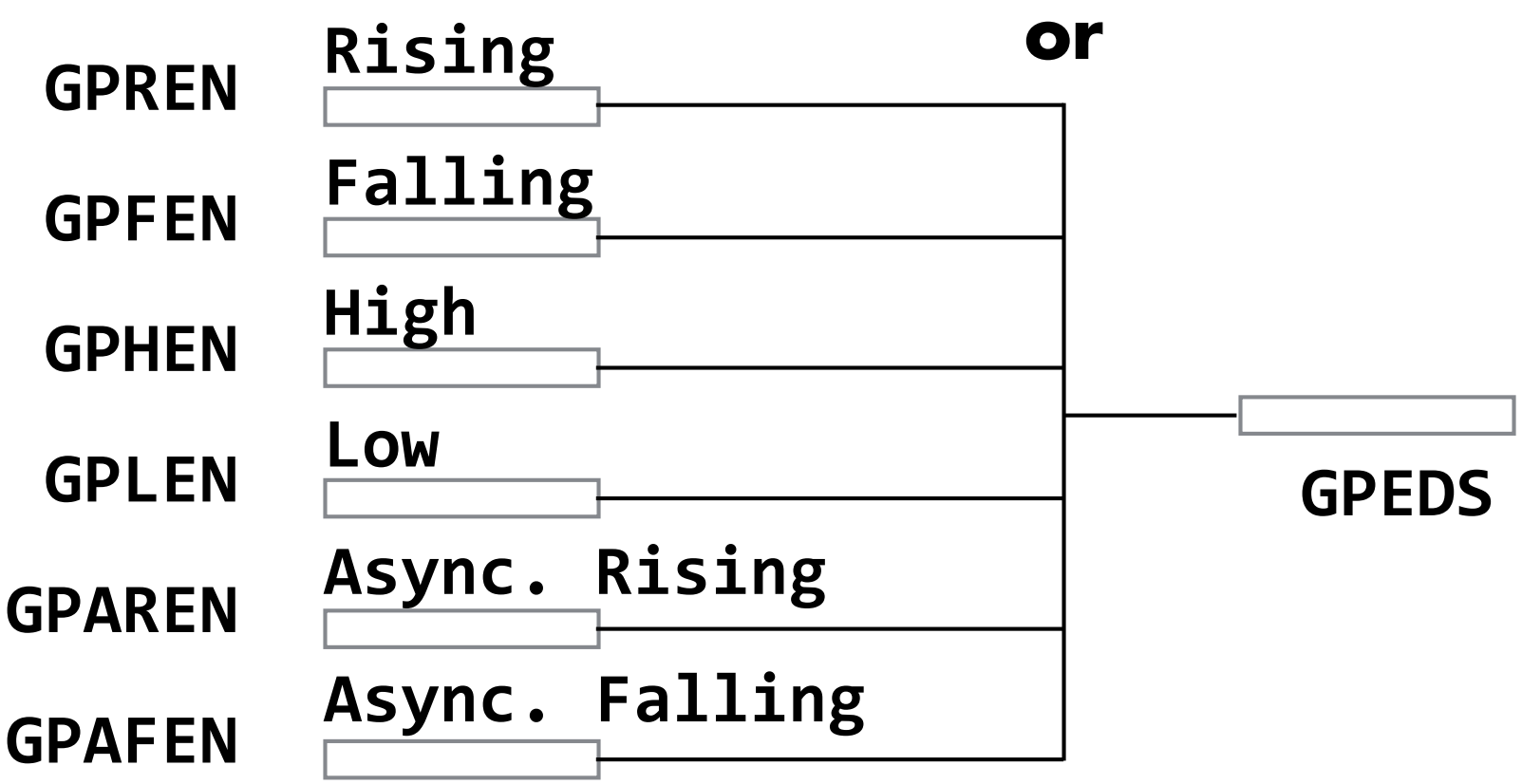


Figure 6-1 GPIO Block Diagram

GPIO Event Detection



MIDI

Musical Instrument Digital Interface

MIDI

Simple interface to control musical instruments

Emerged from electronic music and instruments in 1970s

First version described in Keyboard magazine in 1982

MIDI

31250 baud 8-N-1 serial protocol

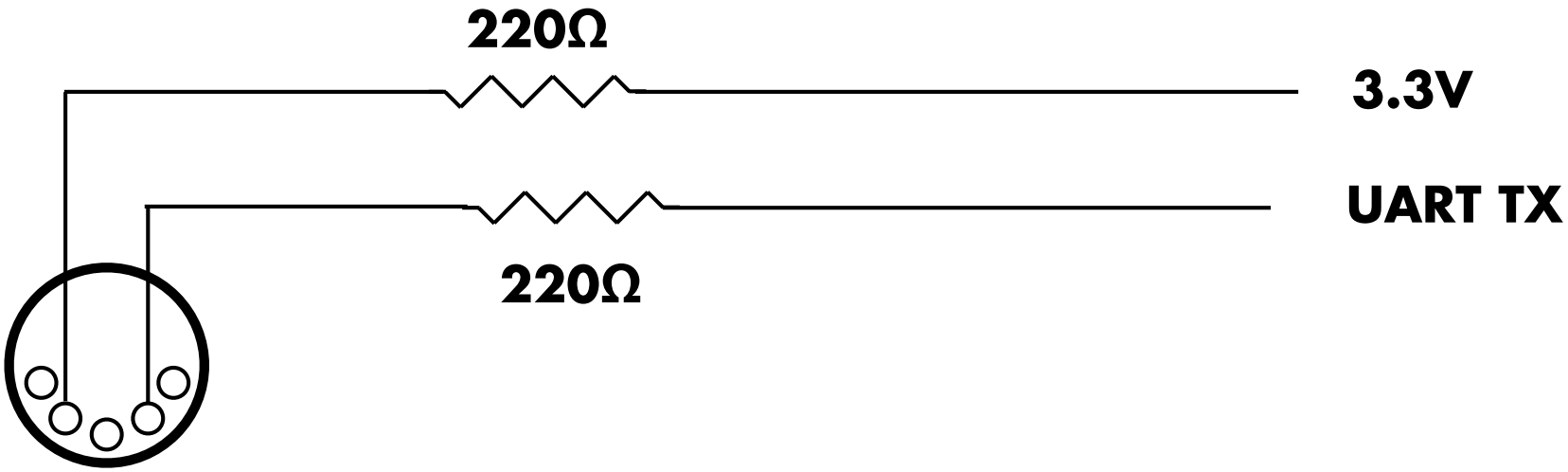
Commands are 1 byte, with variable number of parameters (c=channel, k=key, v=velocity)

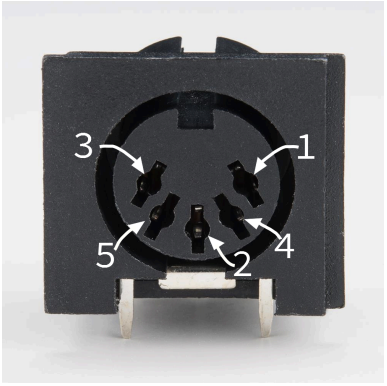
Command	Code	Param	Param
Note on	`1001cccc`	`0kkkkkkk`	`0vvvvvvv`
Note off	`1000cccc`	`0kkkkkkk`	`0vvvvvvv`
Pitch bender	`1110cccc`	`0lllllll`	`0mmmmmmm`

A bit of “beat”

`code/midi/midi-beat.c`

MIDI Transmit Circuit





MIDI Receive Circuit