ECE 471 – Embedded Systems
Lecture 14

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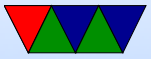
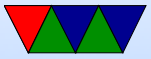
Announcements

- Homework #4 was due.
- Homework #5 will be posted today
- Will loan out i2c displays. Be careful with them!
  If not working, let me know.
- Raspberry Pi5 announced yesterday



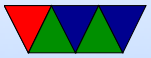
i2c

- Inter-Integrated Circuit, Invented by Philips (now NXP) in 1982
- Broadcom and others for some reason call it TWI "Two Wire Interface"
- Two-wires (4 if you include Vdd and Ground)
- Since 2006, no licensing fees (though do have to pay to reserve number)



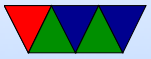
Why is i2c popular?

- Stable standard
- Relatively easy to implement
- Not many wires
- Good enough
- Cheap



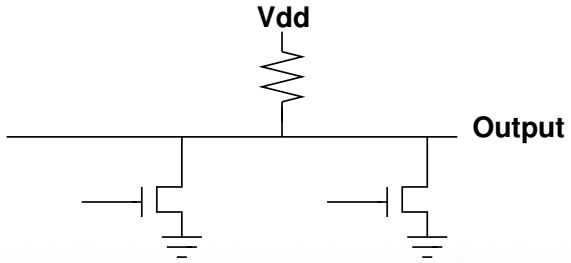
Uses of i2c

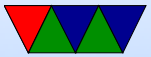
- SMbus
- DDC (VGA/HDMI) (video card / monitor communication)
- Configuring SDRAM
- Temp sensor and fan chips on motherboards
- Wii nunchuck



Hardware Overview

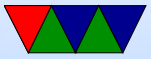
- Serial Data Line (SDA) and Serial Clock (SCL), Open Drain, Pulled up by resistors
- Open drain means output can be wired together
  If not driven, high-Z, line floats high
  If driven, pulls to zero
  Can have multiple connected to one line, "wired-and" (wired-nor)





Limitations

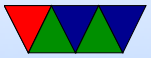
- Need unique address for each device
  7-bit (or 10-bit) address
- Length of bus limited to a few meters (400pF)
  You can get extenders (LTC4311?)



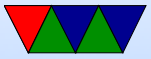
Protocol Revisions/ Speed

Speed: (actual transfers slower due to overhead)

- Standard=100kbits/s
- slow=10kbits/s
- v1 1992 added fast=400kbits/s + 10-bit addr
- v2 1998 High-speed 3.4Mbits/s w power saving
- v3 2007 fast plus 1Mbits/s (20ma)
- v4 2012 5MHz UFm (Ultra Fast mode), USDA, USCL, no pull-ups, unidirectional
- v5, v6 no major changes

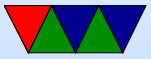


- i3c = “Improved” i2c, fancy new protocol, falls back to i2c



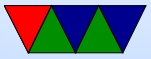
Master/Slave Terminology

- Traditionally the main controller driving the bus was called the “Master” and the devices were called “Slaves”
- There has been a recent movement to use other terms for this
- I will use “controller” and “device” instead, but you will find that various specs, documents, and Linux interfaces use the old terminology



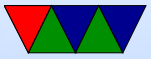
High-level Protocol

- Controller (generates clock, init transaction)
  Device (responds)
- Can be multiple controllers / devices
- Controller sends start bit, 7-bit device address, then read/write bit
- Device responds with ACK
- Reads and writes are 8 bits data, followed by 1 ACK bit
- Send stop bit when done
- Address and Data sent Most-significant Bit first



Low-level Protocol

- Busses start out floating high (by pull-up resistors)
- Start bit: SDA transition high-low while SCL high
- To transmit bit, master sets SCL low, then sets SDA to value, lets SCL float high, wait 4us, set SCL low for next cycle
- After every 8-bits other side sends ACK bit. The master toggles the clock then reads the SDA value.
  - If master reads 0, everything is OK
  - If writing, and read 1, means error or not there (why?)



- If reading, and read 1, means done reading

- Stop bit: SDA transition low-high while SCL high (only start/stop SDA transitions happen when SCL is high).

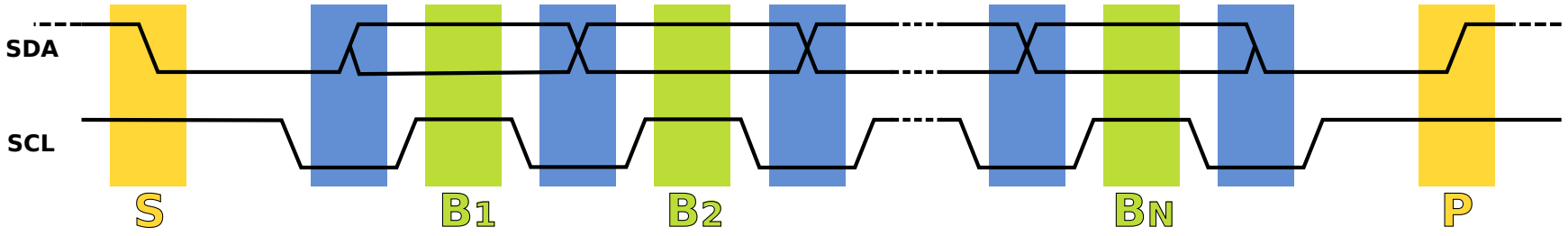
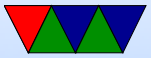
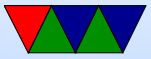


Figure 1: Protocol diagram from Wikipedia



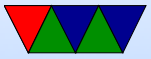
Other Features – Clock Stretching

- If device not ready, can indicate it needs more time
- Device can hold SCL low until it is done processing, master should check to be sure SCL floated back high before continuing
- Note: this was broken on Raspberry Pis before the Pi4



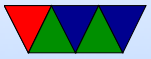
Other Features – Arbitration

- What happens if multiple controllers send at once? How do you share the bus?
- Arbitration: controllers monitor SDA and won't start unless idle.
- Deterministic arbitration.
  If tries to send a 1 and notices something else is pulling to zero, then a collision and stops. Low addresses automatically win.



Other Features – Repeated Start

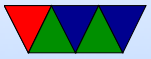
- Can send multiple messages or to multiple devices without sending stop but instead sending a new start bit



Message Types

- Controller writing **to** device:
  Sends start, address, write bit (0), waits for ACK (low), then sends 8 bits of data, waits for ACK, etc.

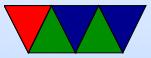
- Controller reading **from** device:
  Sends start, address, read bit (1), waits for ACK (low), then waits for 8 bits, sends ACK if wants more, otherwise stop if done.



i2c Reserved Addresses

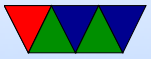
Address	R/W Bit	Description
000 0000	0	General call address
000 0000	1	START byte (helps make polling cheaper)
000 0001	X	CBUS address
000 0010	X	Reserved for different bus format
000 0011	X	Reserved for future purposes
000 01XX	X	Hs-mode master code
111 10XX	X	10-bit slave addressing
111 11XX	X	Reserved for future purposes

10-bit addresses work by using special address above with first 2 bits + R/W, then sending an additional byte with the lower 8 bits.



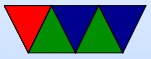
SMbus

- Enhanced i2c bus interface
- Has stricter rules about some signals
- Can do more advanced things, such as have slaves send notifications to master



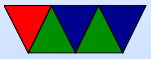
i2c and Rasp-pi

- 3.3V
- default speed is 100kHz. You can change this with the baudrate= module parameter.
- The Pi actually has multiple i2c busses, only one commonly used
  - i2c-1: The generic one on pins 3+5 (built-in pullups)
  - i2c-0: on Model B and newer one on camera interface
  - on Model 2B/3B one for "hat" EEPROM
  - on Model 3B/4B GPIO extender, driven by GPU?



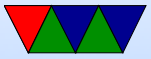
Setting up i2c Rasp-pi Linux Driver

- These days the best way to do this is run `sudo raspi-config` and select (5) Interfacing Options, (P5) i2c, then say yes enable it. You might have to reboot
- In the old days you might have to manually set things up
  - `modprobe i2c-bcm2835` (in even older days this was called i2c-bcm2708) and `i2c-dev`
    May also want to edit `/etc/modules` and remove from blacklist `/etc/modprobe.d/raspi-blacklist.conf`



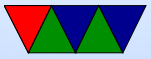
Other i2c Rasp-pi Linux Driver Notes

- May want to install i2c-tools if possible `apt-get i2c-tools`
- i2c port 1 (`/dev/i2c-1`). Used to be i2c-0 in really old days. Other boards (beaglebone black) likely different.
- Note that clock-stretching does not work on Pi before model 4.
- Note that repeated-start also might not be supported, though the driver might have workaround, use `struct i2c_rdwr_ioctl_data` ioctl for this



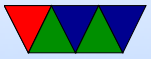
Linux i2c interface

- Like with GPIOs, kernel can drive it, or be exposed to userspace
- i2c-dev module must be installed (and i2c driver)
- Open the device node, `/dev/i2c-1`
- Use ioctls I2C_SLAVE to set the address of the device we wish to talk to.
- Use standard read or write calls to communicate with



the device

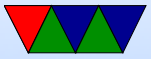
- Close the device when done.
- i2c device addresses are 7 bits, but when sent the r/w bit is put at end. This can be confusing; some spec sheets will list a slave address as 0xE0/0xE1 (8 bits, including r/w) but Linux exports this as 0x70 (0xE0 shifted right by 1).



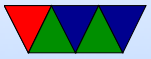
Sample i2c Linux code

For more details on this, see the HW#5 handout.

```
unsigned char buffer[17];
int display_fd;

/* open */
display_fd = open("/dev/i2c-1", O_RDWR);
if (display_fd < 0) fprintf(stderr,"Error!\n");

/* set slave address */
result=ioctl(display_fd, I2C_SLAVE, 0x70);
if (result < 0) fprintf(stderr,"Error!\n");

/* writing */
buffer[0]= HT16K33_REGISTER_SYSTEM_SETUP | 0x01;
```

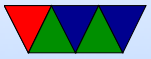


```
if ( (write(display_fd, buffer, 1)) !=1) {
      fprintf(stderr,"Error!\n");
}

/* closing */
close(display_fd);
```



i2c on the Pi – detecting

```
i2cdetect -y -r 1
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:             -- -- -- -- -- -- -- -- -- -- -- --
10: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
20: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
40: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
50: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
60: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
70: 70 -- -- -- -- -- -- --
```



LED Driver Chip

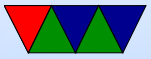
- This is a ht16k33, datasheet available:

  `http://www.adafruit.com/datasheets/ht16K33v110.pdf`

- Supports up to 16x8 LEDs, as well as keypad input. Can dim display, also blink. Common cathode.

  ```
  -|>|- common
  ```

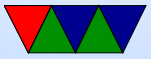
- Works by rapidly scanning all segments fast enough cannot see.



- To set up, write byte commands, high 4 bits command lower 4 bits data. (note, datasheet lists these as bits 15-8, because if you were doing things manually the i2c write address byte would be bits 7..0)

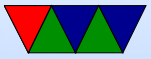
- To set up full display, write the pointer offset of internal framebuffer, than 16 bytes of on/off data.

- Actual LED hooked up is a BL-Q56D-43UG 4x7 segment Ultra-Green display (or similar, colors vary), common cathode.



Multiple Displays

- Could you hook up multiple of these displays to one i2c bus?
- But they all have the same address (0x70)!
- Often boards will let you configure the address by pulling pins up/down/floating
- These boards have solder pads on the back which you can short to change the address to any in the range 0x70 to 0x78



Benefit of OS

- Code is portable across all machines with i2c bus
- Can use same code on Gumstix, Rasp-Pi, Beaglebone, etc.
- Only change would be to update the bus number (It's i2c-3 on gumstix for example).