**Unit 14**

Noise Margins, Interfacing, and Tri-States

**Signal Types**

- Recall even digital signals are *just voltages*...
- Analog signal
  - Continuous time signal where each voltage level has a unique meaning
- Digital signal
  - Continuous signal where voltage levels are mapped into 2 ranges meaning 0 or 1

**Signals and Meaning**

- Each voltage value has unique meaning
- Each voltage maps to '0' or '1'
  (There is a small illegal range where meaning is undefined since threshold can vary based on temperature, small variations in manufacturing, etc.)

**NOISE MARGINS, LEVEL SHIFTERS, & DRIVE STRENGTH**
14.5 A Motivating Example

Example 1
- You connect an output port to an LED (light emitting diode) and connect everything correctly. The light should turn on when you set your output bit to a high voltage (logic '1').
- When you turn the system on the LED does not glow. You measure the voltage at the gate output with a voltmeter and find it is not 5V but 1.8V? Why isn't it a logic 1?
- The ______________ output ability from the output port is not ____ enough to adequately ______ the LED which then drags the voltage _______.

Example 2
- You buy two digital chips (say a microprocessor and GPS reader)
- You correctly wire them together and write software to turn 'on' a pin on the microprocessor to a '1' to enable the GPS reader
- When the software runs the GPS unit does not turn on. Why?
- Different circuit implementation techniques use different voltage ______ to indicate ______ and may be _____________

Lesson To Be Learned: Not all 1's or 0's are created equal!

14.6 The Digital Abstraction
- Digital is a nice abstraction of voltage and current
  - Lets us just think 'on' or 'off' but not really worry about the voltages and currents underneath
    - ______________
- Not all 1's and 0's are created equal
  - A '1' can be any 'HIGH' voltage (maybe in the range ___________)
  - A '0' can be any 'LOW' voltage (maybe in the range ___________)
  - So 3V and 5V both mean ________ but they aren't equal
- Similarly certain outputs of a chip may connect to other devices that require more _________ than the output can ___________
  - Think of connecting a ______________ to your garden spigot
  - Or even worse your garden hose to a fire ____________... would shred it
  - In the same way, inputs and outputs of different devices must be matched to the _______________ of what they connect to

14.7 Digital Voltage Noise Margins
- Consider the output of one digital circuit feeding the input of another
  - Assume the devices are from different vendors (families of devices)
  - There may be different ___________ and requirements of the two devices
    - Example: The output may produce 3V to mean logic '1' while the next device's input requires 5V to be used as logic '1'
  - Analogy 1: Grades. Suppose the cutoff for an A is 90% (i.e. _________ input)
    - If you get a 91% (i.e. output result)... _______
    - If you get an 89%...__________ for this class! But ______ from the cutoff's perspective.)
  - Analogy 2: Tickets. Suppose there are 100 available tickets to an event (i.e. input limit)
    - If you are the 99th person (i.e. output result)... _______
    - If you are the 101st person...__________

14.8 Digital Voltage Noise Margins
- Consider one digital gate feeding another
  - As long as _________ and _________ we are in good shape... Electromagnetic interference & power spikes can cause this to break down
Class Activity

- Do an internet search for "74LS00 datasheet" (this is a chip w/ some 2-input NAND gates) and try to find any PDF and open it.
- Skim the PDF and try to find:
  - VOH, VIH, VOL, VIL

Analogy

- Consider a sprinkler system...what will happen if you add 100 new sprinklers to your backyard?
- Pressure (voltage) will go ______________ and ___________ water (current) flow coming out of each

Current Limitations

- When a circuit outputs a 'HIGH' ('1') it can only supply (__________) so much current (think of your garden hose spigot) = IOH
- When a circuit outputs a 'LOW' ('0') it can only suck up (__________) so much current = IOL
- When a circuit receives a 'HIGH' signal on the input side it may need a certain amount of current to recognize the input as 'HIGH' = IH
- When a circuit receives a 'LOW' signal on the input side it may need a certain amount of current to recognize the input as 'LOW' = IL

Example

- Consider the example where device A's output connects to device B's input
  - Are the voltage requirements compatible?
  - How many device B inputs can a single device A output drive?
    - Always use worst case of ______________ output drive capability

<table>
<thead>
<tr>
<th>Dev.</th>
<th>VOH</th>
<th>VIH</th>
<th>VOL</th>
<th>VIL</th>
<th>IOH</th>
<th>IOH</th>
<th>IOL</th>
<th>IIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.4V</td>
<td>3.3V</td>
<td>0.5V</td>
<td>1.0V</td>
<td>-4 mA</td>
<td>-1 mA</td>
<td>10 mA</td>
<td>2 mA</td>
</tr>
<tr>
<td>B</td>
<td>3.2V</td>
<td>3.0V</td>
<td>0.6V</td>
<td>0.7V</td>
<td>-2 mA</td>
<td>-1 mA</td>
<td>6 mA</td>
<td>2 mA</td>
</tr>
</tbody>
</table>

Voltage requirement are ______________ Dev. A VOH ____ Dev. B VIH
AND
Dev. A VOL ___ Dev. B. VIL

Dev. A's output can drive 4 Dev. B inputs
When outputting '1':
- (Dev. A IOH / Dev. B IIH) = (______) = _____
When outputting '0':
- (Dev. A IOL / Dev. B IIL) = (______) = _____
Drive capability = _______
Consideration

- If we attach too many gates to one output it may not be enough to drive those gates
- Need to make sure the current requirements and capabilities match
- Let’s say we connect one of the NAND gates on the 74LS00 chip to an input of N other NAND gates...
- Can it produce/suck up the required current...
- ...if N = 6?
- ...if N = 12?

All In the Family

- There are many families of circuit devices that talk different language (Each has a different VOH, VIH, VOL, VIL, IOL, IIL, etc.)
- Examples:
  - __________
  - __________
  - __________
- Must make sure if you interface two different devices that they are ______________ (i.e. VOH of device A is greater than VIH of device B) or use a buffer/amplifier/level shifter circuit to help them talk to each other

Arduino Limits

- Arduino outputs can sink (suck up) and source (produce) around a maximum of 20 mA on a pin
- Do an internet search for "Standard Servo Motor Datasheet" and find the maximum current it may need
- It doesn’t seem like the Arduino would be able to drive the servo motor. How is it working?
  - Remember the 3-pin interface: R = Power, B = Ground, W = Signal
  - The signal is __________ from the power
  - The power source is used to amplify the signal

Another Example

- Now consider a speaker system where the power and signal are provide together
  - Given our Arduino use 5V = Vcc and its current limitations per pin, how much power can we supply to the speaker?
  - 5V * ____________ = ____________
  - You need an ________________...
**TRI-STATE GATES**

**Typical Logic Gate**

- Gates can output two values: 0 & 1
  - Logic '1' (Vdd = 3V or 5V), or Logic '0' (Vss = GND)
  - But they are ALWAYS outputting something!!!
- Analogy: a sink faucet
  - 2 possibilities: Hot ('1') or Cold ('0')
- In a real circuit, inputs cause **EITHER** a pathway from output to VDD *OR* VSS

```
Hot Water = Logic 1
Cold Water = Logic 0
(Strapped together so always one type of water coming out)
```

```
PMOS  NMOS
Output
```

```
<table>
<thead>
<tr>
<th>Inputs</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vdd</td>
<td>PMOS</td>
</tr>
<tr>
<td>Vss</td>
<td>NMOS</td>
</tr>
</tbody>
</table>
```

**Output Connections**

- Can we connect the output of two logic gates together?
- ____! Possible ______________ (static, low-resistance pathway from Vdd to GND)
- We call this situation “______________”

```
Inputs  PMOS  NMOS  Output
Vdd     Inputs
Vss
```

**Tri-State Buffers**

- Normal digital gates can output two values: 0 & 1
  1. Logic 0 = 0 volts
  2. Logic 1 = 5 volts
- Tristate buffers can output a third value:
  3. ____ = __________________ = “Floating”
     (no connection to any voltage source...infinite resistance)
- Analogy: a sink faucet
  - 3 possibilities:
    1.) Hot water,
    2.) Cold water,
    3.) ____ water

```
<table>
<thead>
<tr>
<th>Inputs</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>+3V</td>
<td>PMOS</td>
</tr>
<tr>
<td>Vdd</td>
<td>Inputs</td>
</tr>
<tr>
<td>Vss</td>
<td>NMOS</td>
</tr>
</tbody>
</table>
```

```
Hot Water = Logic 1
Cold Water = Logic 0
___ Water = Z (High-Impedance)
```
Tri-State Buffers

- Tri-state buffers have an extra enable input.
- When disabled, output is said to be at high impedance (a.k.a. Z).
  - High Impedance is equivalent to no connection (i.e. floating output) or an infinite resistance.
  - It's like a brick wall between the output and any connection to source.
- When enabled, normal buffer operation:
  \[ \text{In} \rightarrow \text{Out} = \text{In} \]

<table>
<thead>
<tr>
<th>En</th>
<th>In</th>
<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>Z</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Tri-State Buffers

- We use tri-state buffers to share one output amongst several sources.
- Rule: Only one source enabled at a time.

Enable Polarity

- Side note: Some tri-states are designed to pass the input (be enabled) when the enable is 0 (rather than 1).
  - A inversion bubble is shown at the enable input to indicate the "____" polarity needed to enable the tristate.

<table>
<thead>
<tr>
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<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>Z</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
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</tr>
<tr>
<td>1</td>
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</tr>
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<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Communication Connections

• Multiple entities need to communicate
• We could use
  – Point-to-point connections
  – A ______________________________

Separate point to point connections

Shared Bus

Bidirectional Bus

• 1 transmitter (otherwise bus contention)
• N receivers
• Each device can send (though 1 at a time) or receive

Tri-State Gates

• Big advantage: don’t have to know in advance how many devices will be connected together
  – Tri-State gates give us the option of connecting together the outputs of many devices without requiring a circuit to multiplex many signals into one
• Just have to make sure only one is enabled (output active) at any one time.

Problem: How can you use the serial I/O lines of the Arduino, which are also used for programming it?

Two active devices, both trying to output a signal, collide here.
Solution: Use a Tri-State gate to isolate the transmitter's data from the µC until programming is over.

Output of gate is floating until µC program makes $P_{xx}$ a zero.