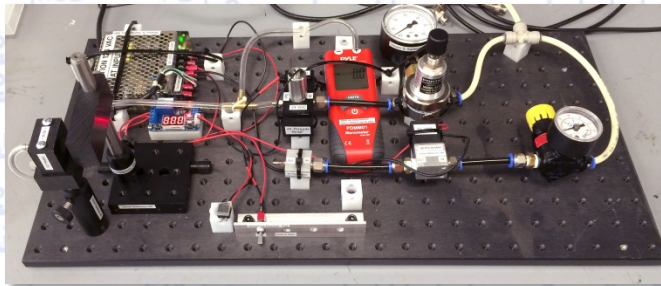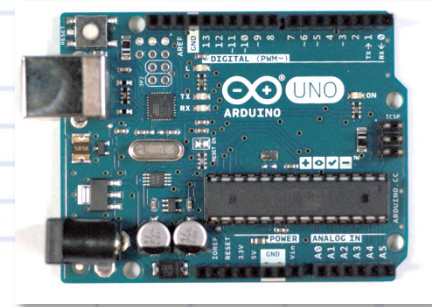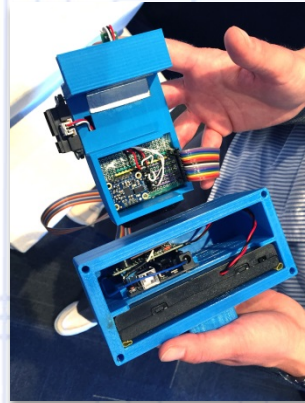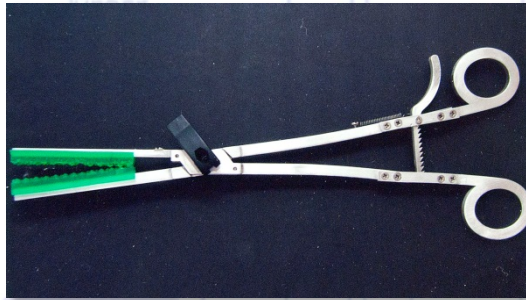# Introductory Medical Device Prototyping

## *Digital Circuits Part 2 - Applications*

Prof. Steven S. Saliterman, http://saliterman.umn.edu/
Department of Biomedical Engineering, University of Minnesota
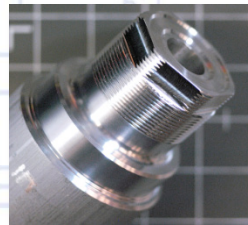
Topics

- Schmitt triggers:
  - Contact debouncing
  - Simulation and elimination of noise; voltage summing
  - Leading edge detection
- One-and-only one synchronized pulse.
- Drivers for LEDs, lamps and relays.
- Analog to Digital (ADC) and Digital to Analog Converters (DAC).
- Addendum – Communication Protocols
  - I^2C - *Inter-Integrated Circuit* (preferred communication protocol).
  - SPI - *Serial Peripheral Interface* (an older communication protocol).
  - Ethernet.
  - Wireless networks.
    - WLAN
    - Bluetooth

Switch Contact Noise…
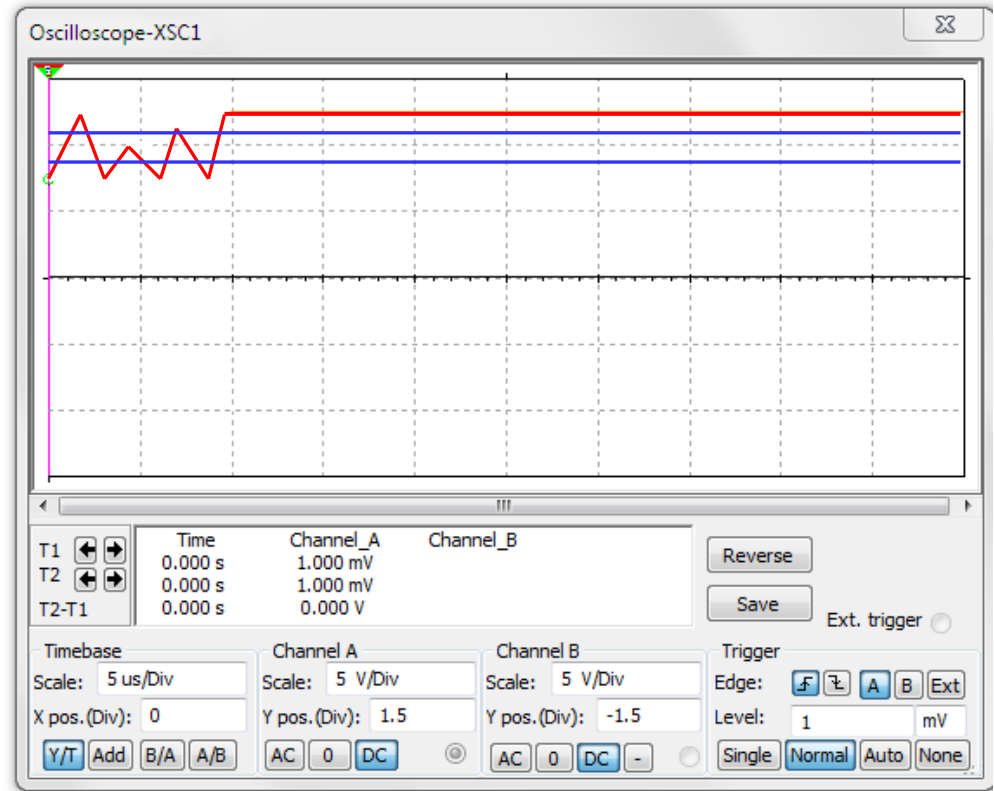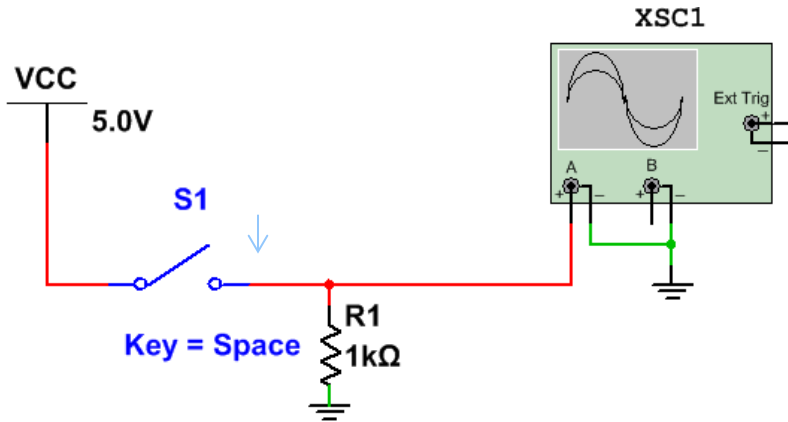
Mechanical contact noise can cause multiple pulses to occur the first 100 µS or so. In this example, three pulses would be generated.

Contact Debouncer – Schmitt Trigger…
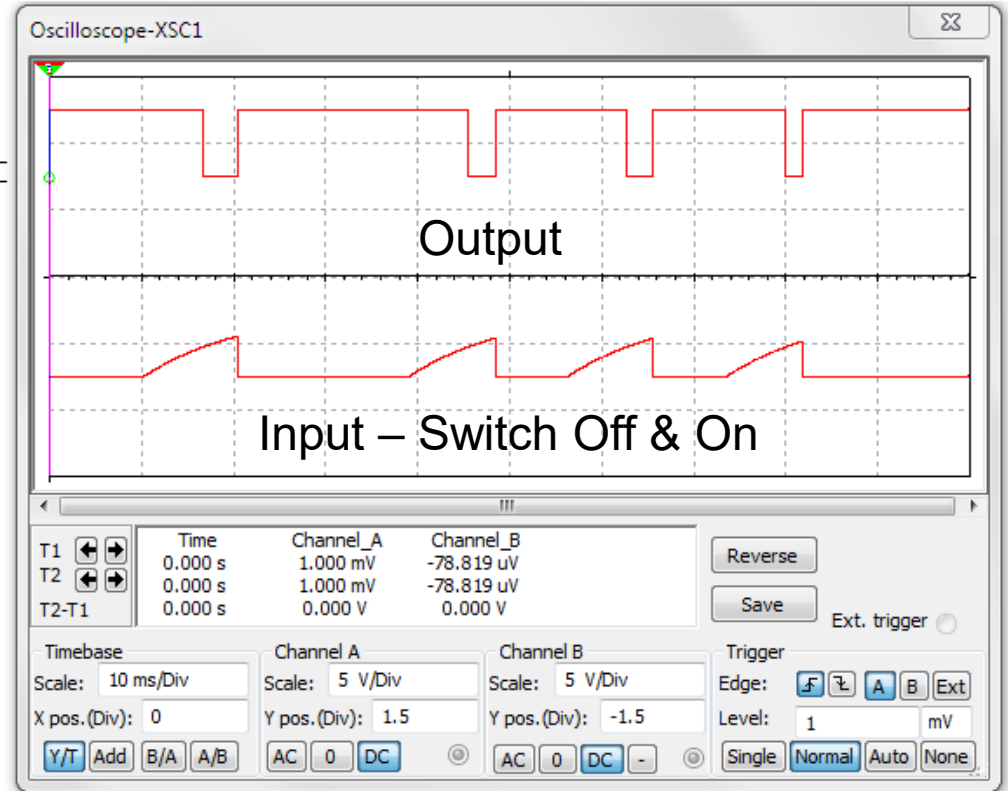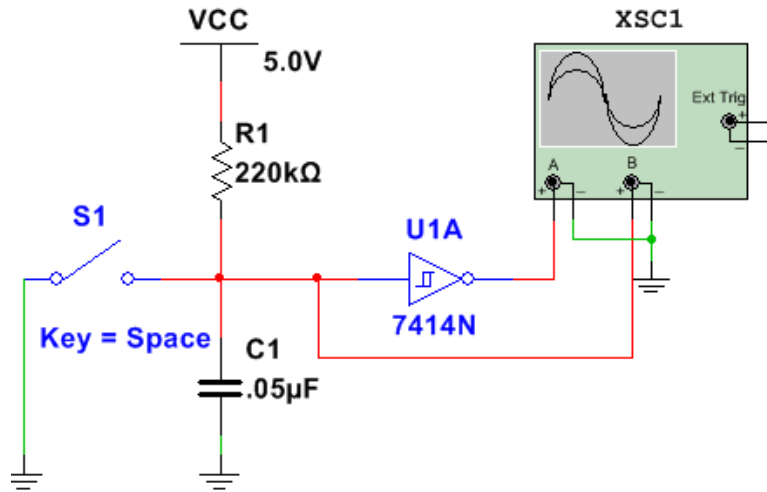
Debouncer on Lab Trainer Board…

Switch Contact Debouncer with Schmitt Trigger

Switch Contact Debouncer

Start of Button Press | End of Button Press | Next Button Press
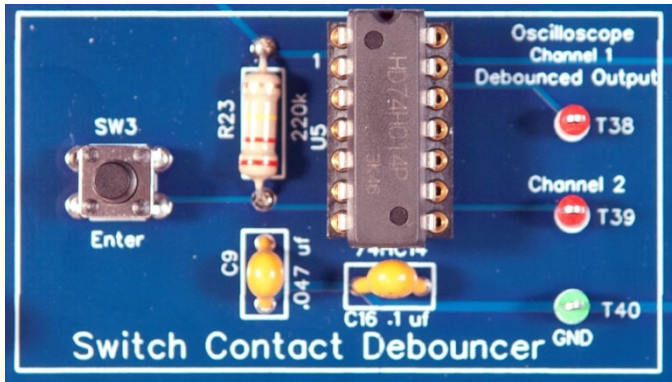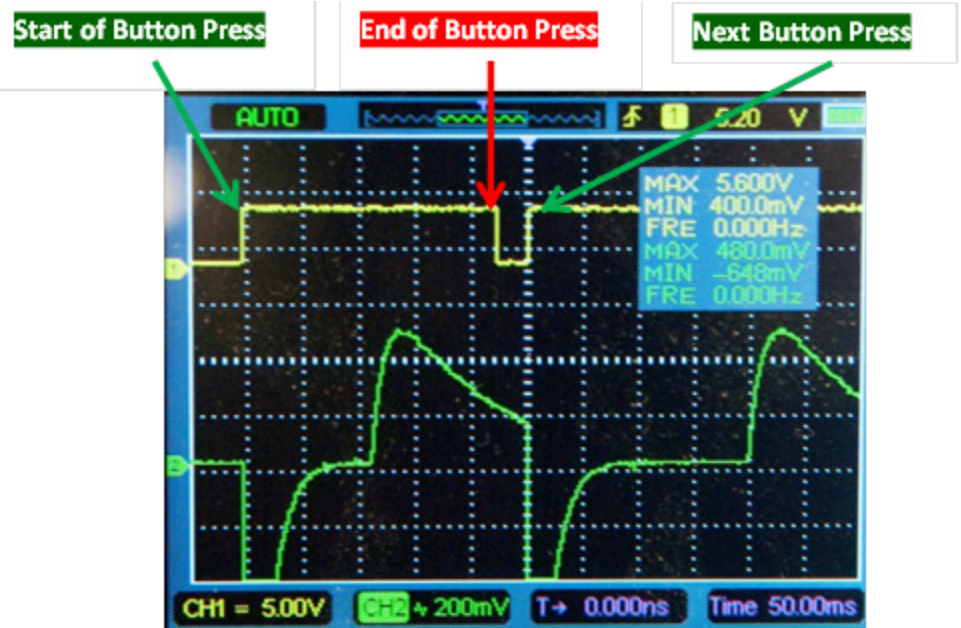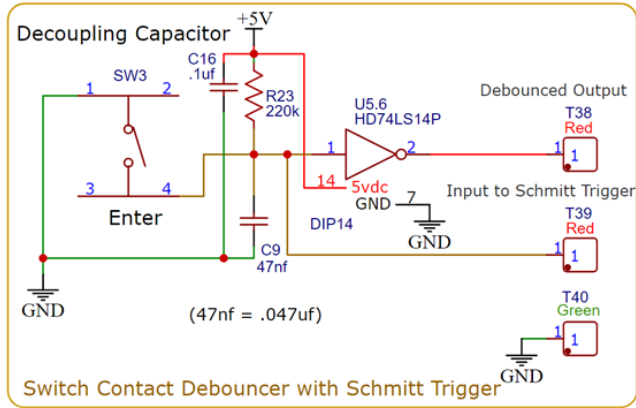
Leading Edge Detector – Schmitt Trigger…

Prof. Steven S. Saliterman

One-and-only One Synchronized Pulse

Output is a synchronized pulse with the clock, while the button push is not.
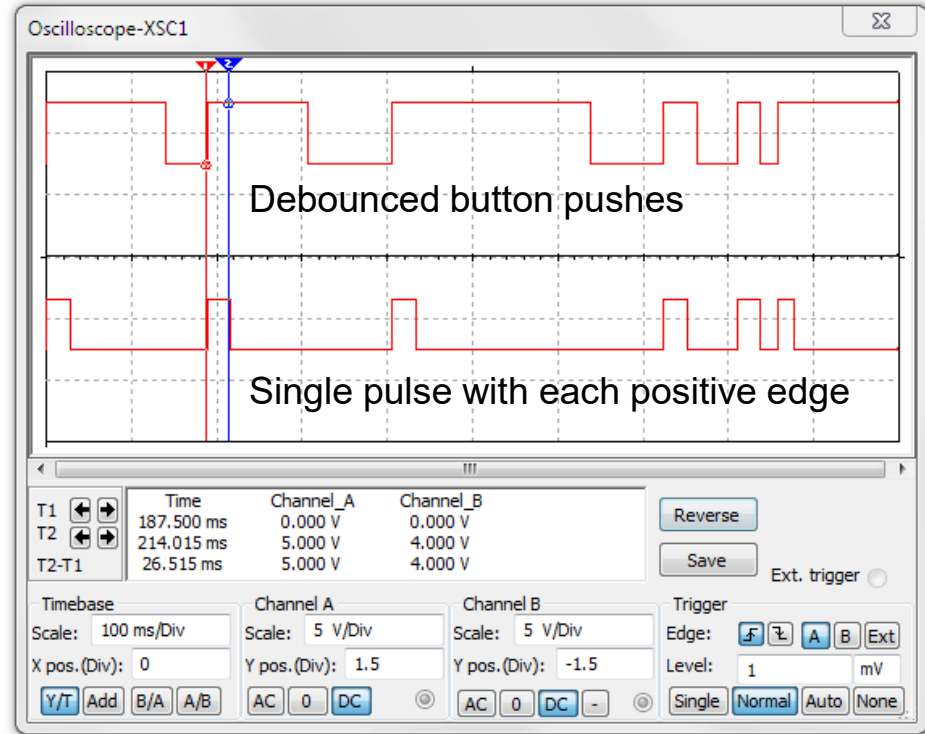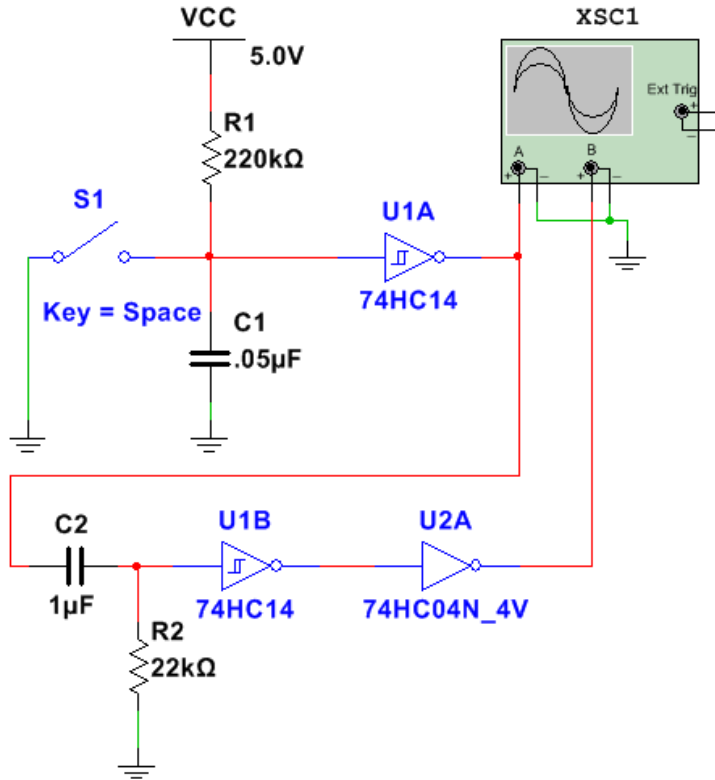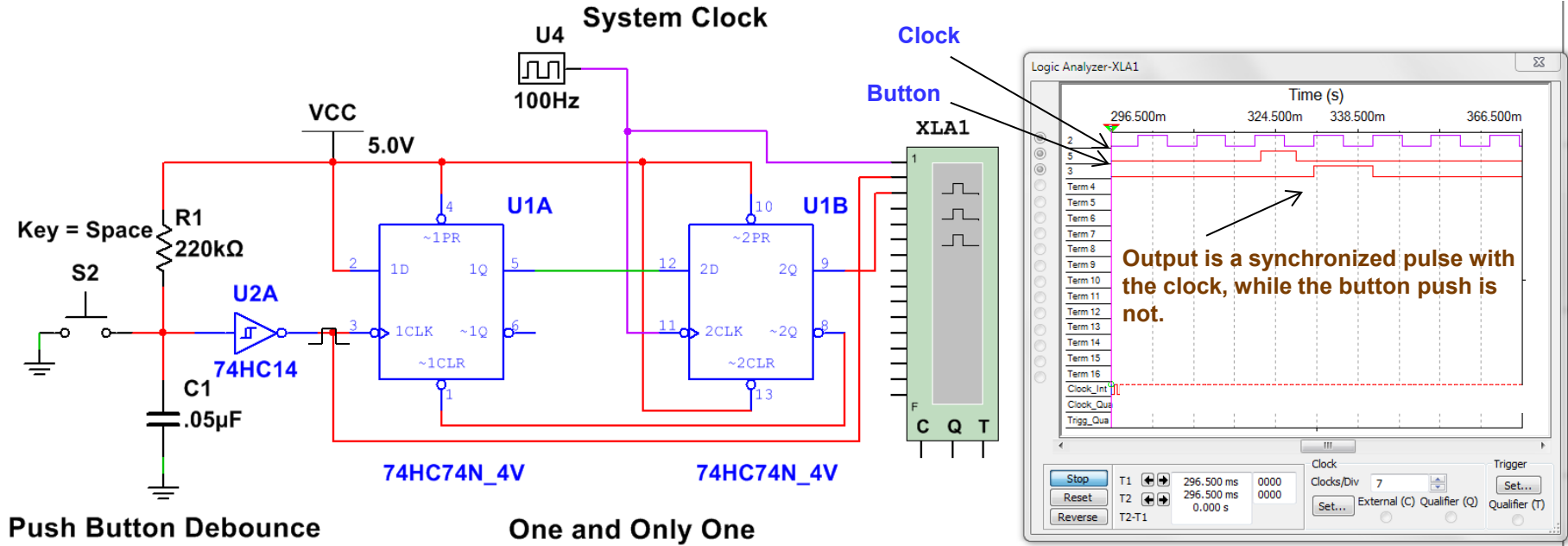
Synchronized Pulse…
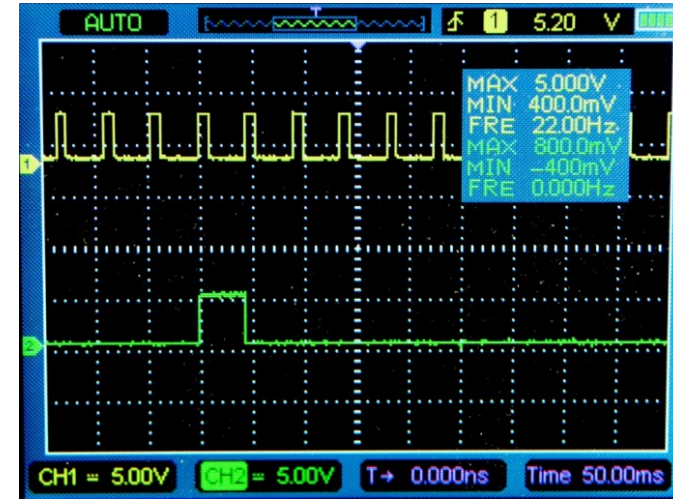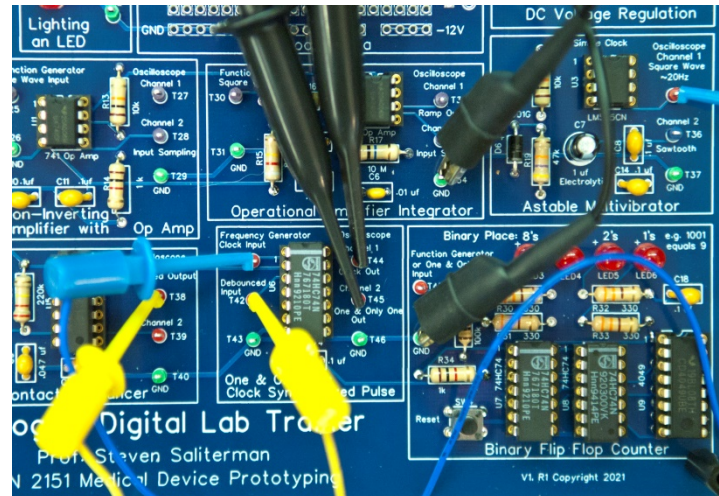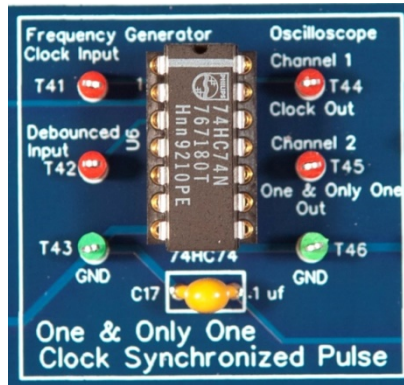
Driving LEDs – *4049B*

$$R_{1 \, or \, 2} = \frac{V_F}{I_F}$$

VCC 5V

R3 1kΩ

S1

Key = Space

U1A

4049BP_5V

LED1

R1 330Ω

Current sourcing.

VCC 5V

R2 330Ω

Current sinking.

LED2

U1B

4049BP_5V
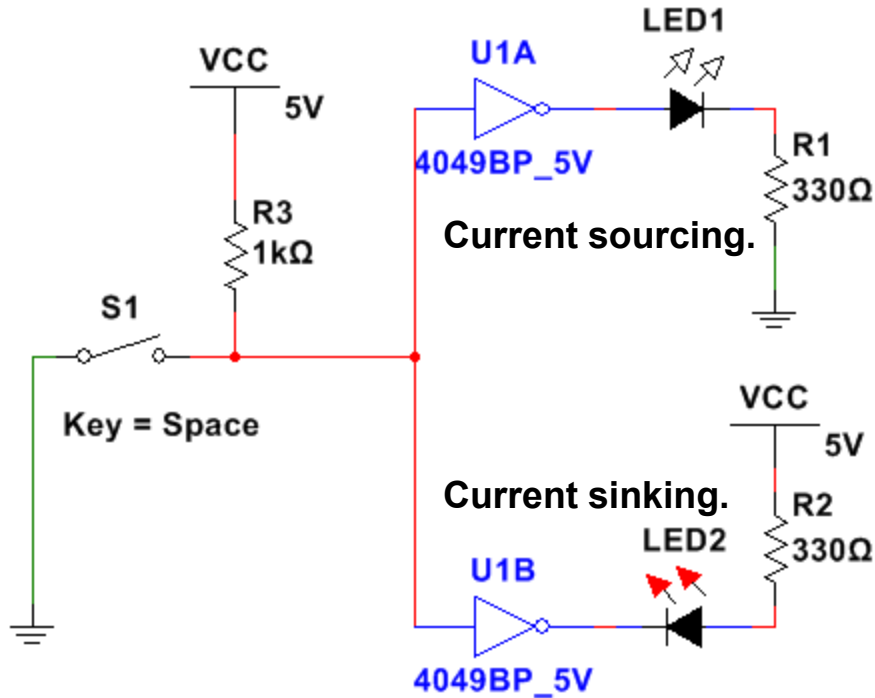
The 4049 Inverter- Buffer can source or sink sufficient current to light the LED directly.

For other CMOS logic you need to have a transistor.

Certain devices, like counters, may have built in LED drivers.

Push Button Debounce

Available Logic Gates in the 4049B…

HEX INVERTING BUFFER & TTL DRIVER

TOP VIEW

+3 TO +15 V

Lancaster, D. and Berlin, H.M. *CMOS Cookbook*. H.W. Sams, Indianapolis, IN (1988)

Creating Noise with Voltage Summing…

Voltage Summing

Voltage Inverter

Noise Eliminator – Schmitt Trigger 4093B…

Summer

Voltage Follower

U5
V3 12V 1kHz
V4 12V
R7 1kΩ
R8 1kΩ
U6 741
R9 1kΩ
XFG1
R11 1MΩ
741
R10 1MΩ

XSC1

U3A
4093BP_5V

Function generator-XFG1

Waveforms

Signal options

Frequency:	60	Hz
Duty cycle:	50	%
Amplitude:	800	mVp
Offset:	0	V

Set rise/Fall time

+ Common −

Oscilloscope-XSC1

Input

Output

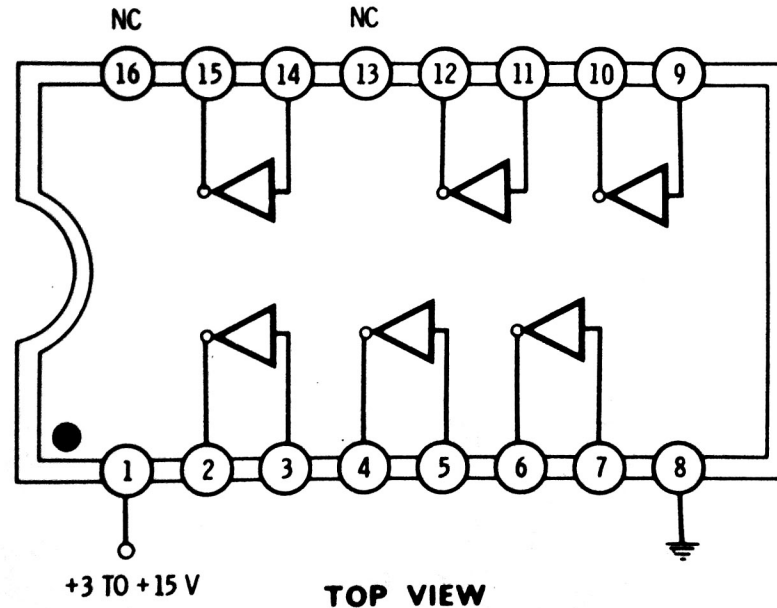|	Time	Channel_A	Channel_B
T1	11.174 ms	5.847 V	0.000 V
T2	19.697 ms	-715.657 mV	5.000 V
T2-T1	8.523 ms	-6.563 V	5.000 V

Reverse

Save

Ext. trigger

Timebase Scale: 5 ms/Div X pos.(Div): 0 Y/T Add B/A A/B

Channel A Scale: 5 V/Div Y pos.(Div): 1.5 AC 0 DC

Channel B Scale: 5 V/Div Y pos.(Div): -1.5 AC 0 DC -

Trigger Edge: A B Ext Level: 0 V Single Normal Auto None

Prof. Steven S. Saliterman

Schmitt Trigger – 74C14

Simple ~1 kHz Square Way Oscillator

Prof. Steven S. Saliterman

HEX SCHMITT TRIGGERS (Inverting)
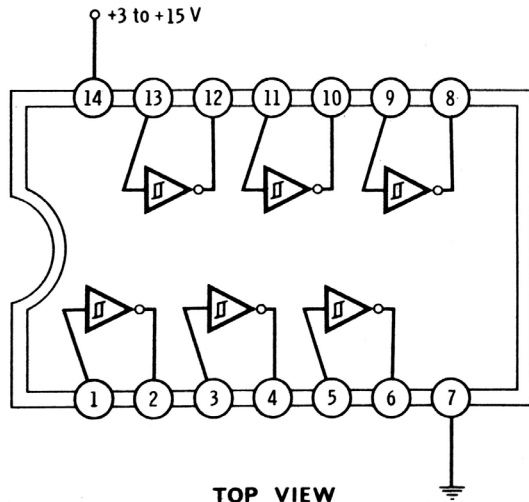
QUAD 2-INPUT NAND SCHMITT TRIGGER
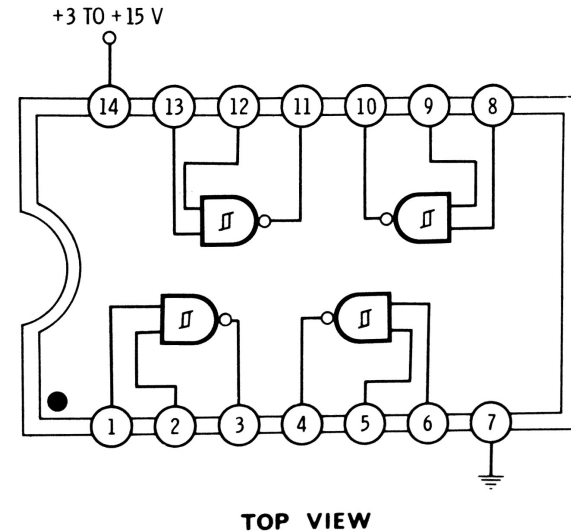
Lamp Driver with Transistor
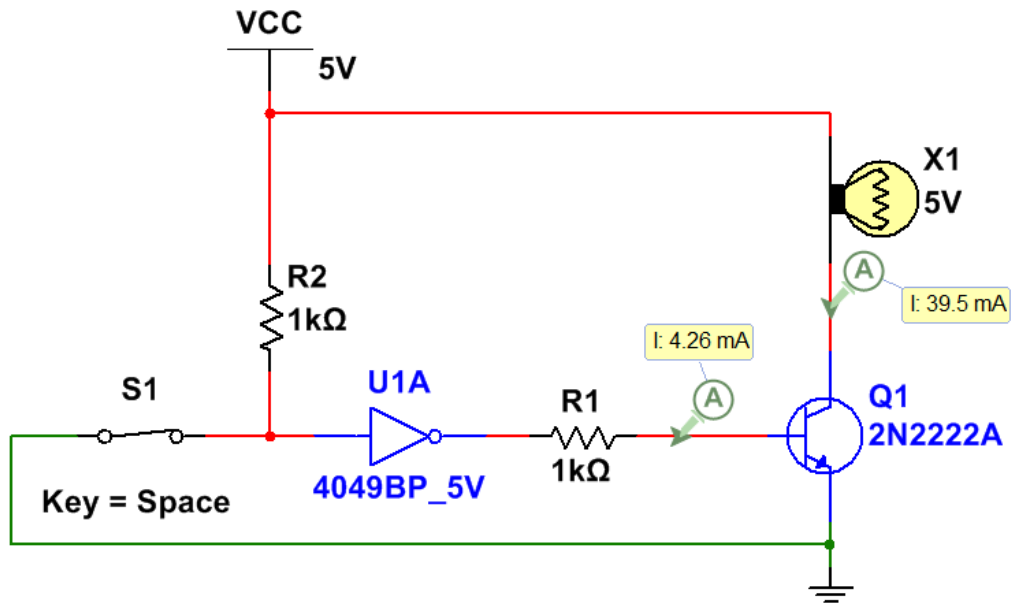
Lamp is rated 5 V and power of 200 mW. Required current:

$$Power_W = I^2R = VI$$
$$I = \frac{Power_W}{V} = \frac{200\ mW}{5} = 40\ mA$$

The 2N2222 is a general purpose medium power amplifier and switch, for I_C of up to 500 mA (max. 1 A).
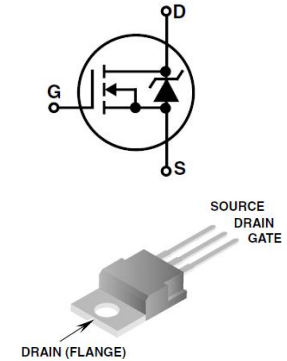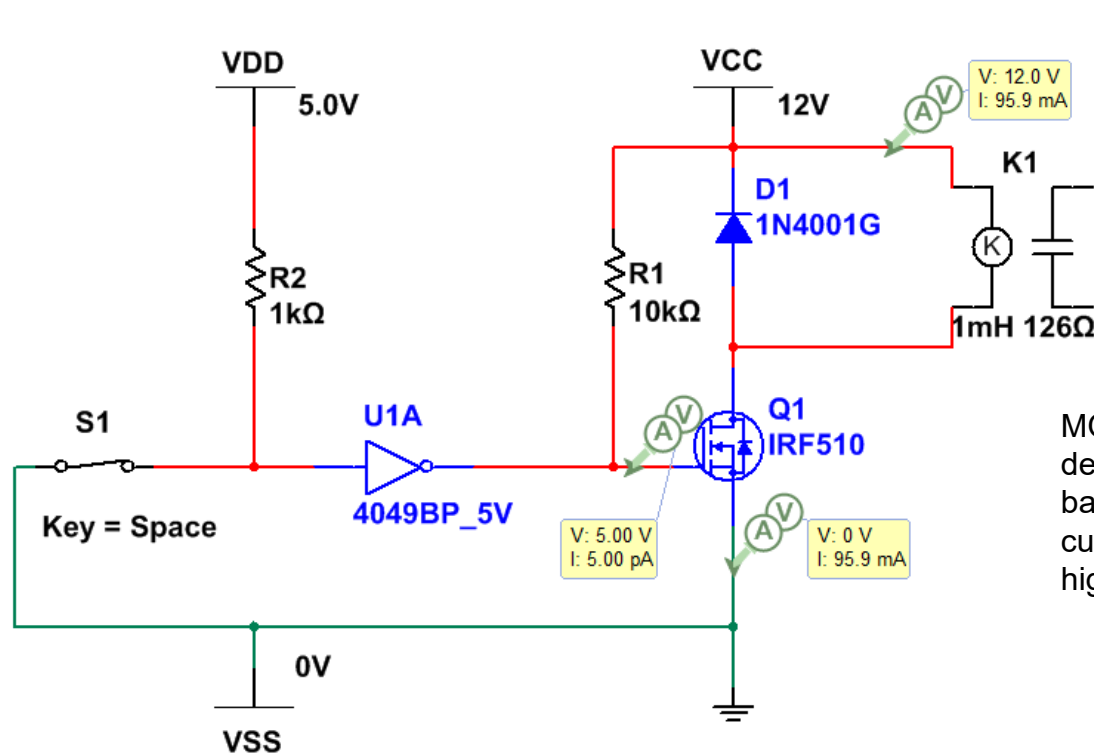
MOSFET is a transconductance device (base current is negligible, base voltage controls collector current). The MOSFET allows for higher collector current than the BJT.

Analog to Digital Converters

- Analog to Digital Converters (ADC)
  - Convert an analog signal – such as voltage, into a digital signal.
  - Resolution is the number of discrete values the converter can produce over the range of the analog signal. For example, an 8-bit encoder can decode an analog value to 2^8, or 256 different values.
  - Sampling rate is subject to the Nyquist-Shannon sampling theorem. In simple terms, you must sample minimally at a rate twice that of the frequency in order to reproduce the original analog signal.

Digital to Analog Converters…

- Digital to Analog Converters (DAC)
  - Convert digital data into an analog signal, such as voltage or current.
  - Commonly used to reproduce music from CD to amplifiers, speakers and headphones.
- The Arduino pins can be configured for ADC and DAC.

Summary

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  - Wireless networks.
    - WLAN
    - Bluetooth

Communication: I^{2}C or "Inter-Integrated Circuit"

- Only two bus lines are required; a serial data line (SDA) and a serial clock line (SCL).
- Each device connected to the bus is software addressable by a unique address and simple master/slave relationships exist at all times; masters can operate as master-transmitters or as master-receivers.
- *Advanced Users:*
  - *It is a true multi-master bus including collision detection and arbitration to prevent data corruption if two or more masters simultaneously initiate data transfer.*
  - *Serial, 8-bit oriented, bidirectional data transfers can be made at up to 100 kbit/s in the Standard-mode, up to 400 kbit/s in the Fast-mode, up to 1 Mbit/s in Fast-mode Plus, or up to 3.4 Mbit/s in the High-speed mode.*

I²C and Arduino…
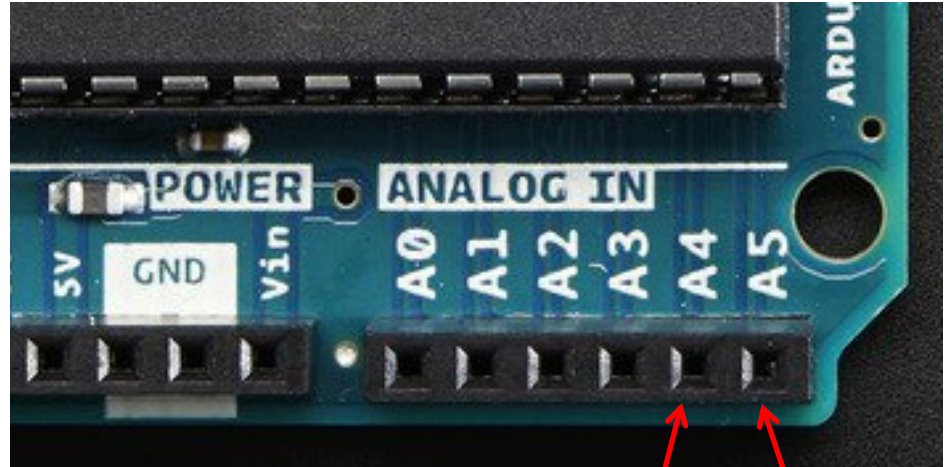
SDA   SCL

I²C Communication Lines…

- The I²C bus drivers are "open drain", meaning that they can pull the corresponding signal line low, but cannot drive it high.

- The result is there can be no bus contention where one device is trying to drive the line high while another tries to pull it low, eliminating the potential for damage to the drivers or excessive power dissipation in the system.

- Each signal line has a pull-up resistor on it, to restore the signal to high when no device is asserting it low.

SPI – Serial Peripheral Interface

- A Motorola protocol implemented on 4 signal lines:
  - A clock signal named SCLK, sent from the bus master to all slaves; all the SPI signals are synchronous to this clock signal;
  - A slave select signal for each slave, SSn, used to select the slave the master communicates with;
  - A data line from the master to the slaves, named MOSI (Master Out-Slave In)
  - A data line from the slaves to the master, named MISO (Master In-Slave Out).
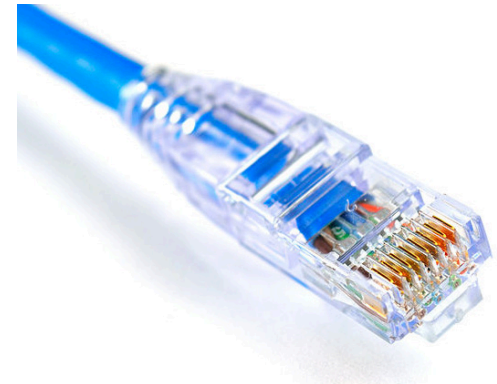
Master-Slave Transfer Diagram…
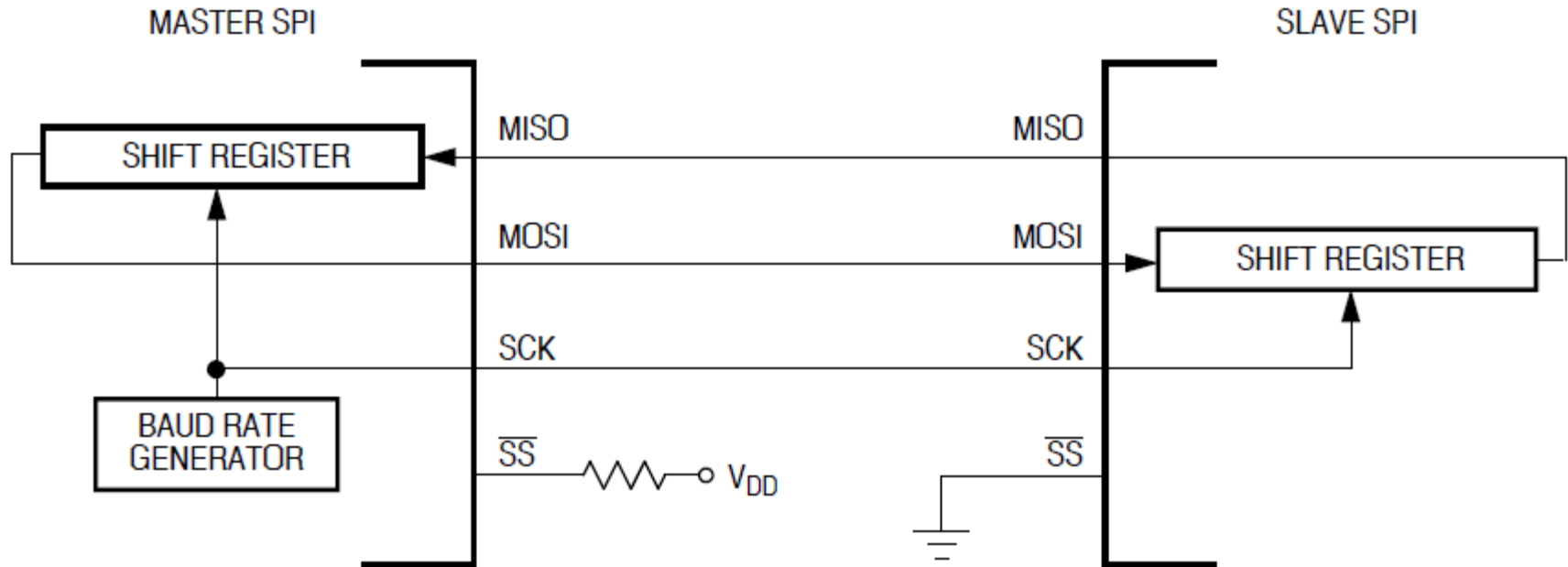
SPI Signals…
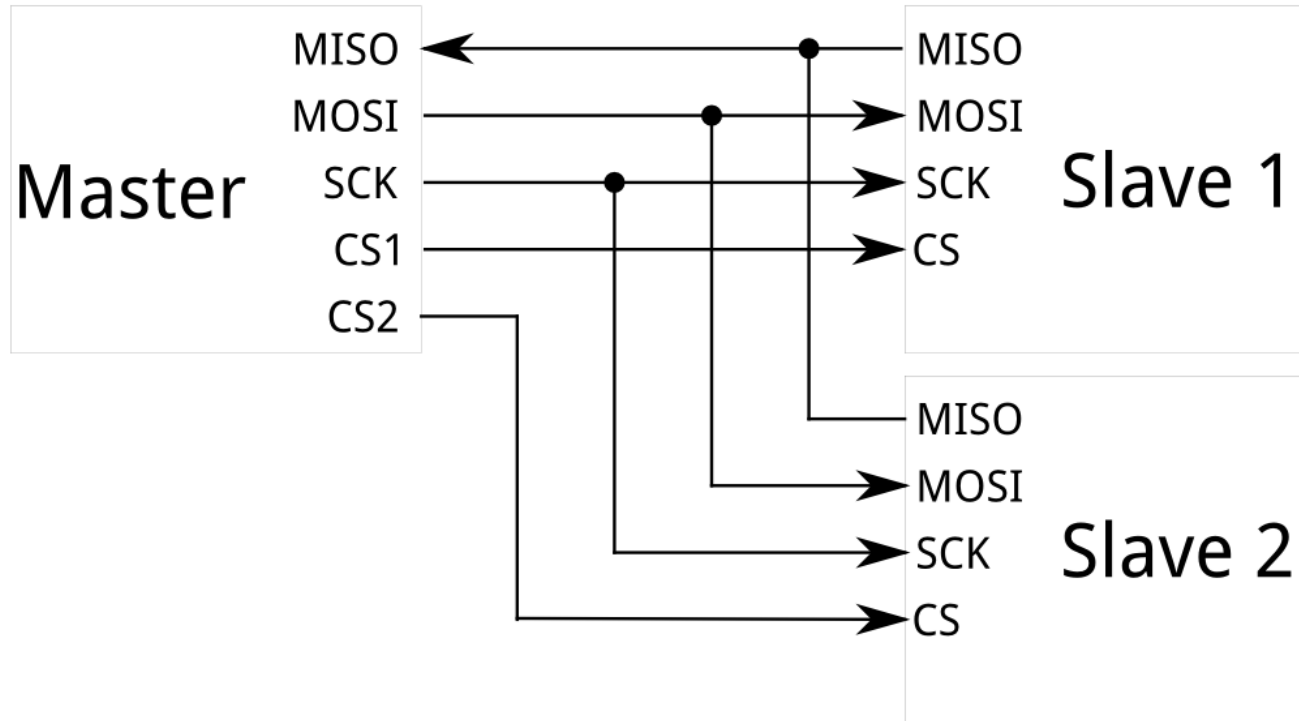
Ethernet

- Networking method for home, business and communities.
- Speed ups to 100 Gbit/s; with 400 Gbit/s coming.
- Data streams are divided into frames.
- Each frame contains source and destination addresses and error checking.
- Communication via twisted
  pair copper wire, fiber optics or
  wireless.

Adding Ethernet to Arduino…

- Although available, Arduino is no longer supporting this Ver. 3 board. Consider instead a wireless interface discussed next.
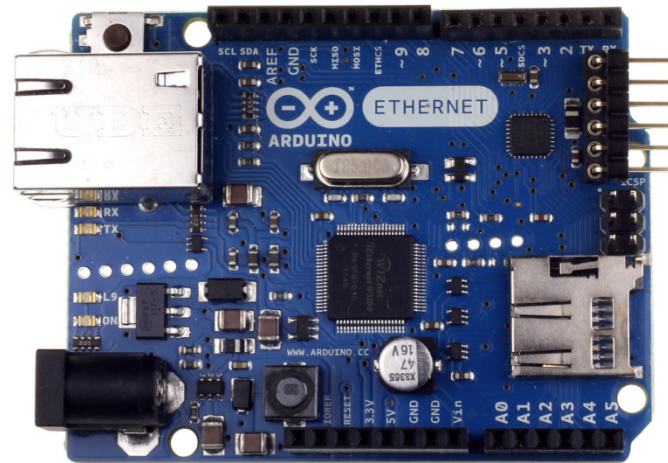
Wireless Network

- Wireless data connection between nodes, using radio frequencies.
- Includes internet, cell phones, sensor networks, stellite and terrestrial communication.
- WLAN (wireless local area network) links two or more devices over a short distance – usually through an internet access. Wi-Fi.
- Bluetooth is a licensed spread spectrum based communication protocol for short range.

Adding Wi-Fi to Arduino…

- Arduino Wi-Fi Shield 101 connects the Arduino to the internet.
- Open source documentation, software and even board files.
- Operating voltage both 3.3V and 5V (supplied from the host board)
- Connection via: IEEE 802.11 b/g/n for up to 72 Mbps networks
- Encryption types: WEP and WPA2 Personal
- Support TLS 1.1 (SHA256)
- Connection with Arduino on SPI port
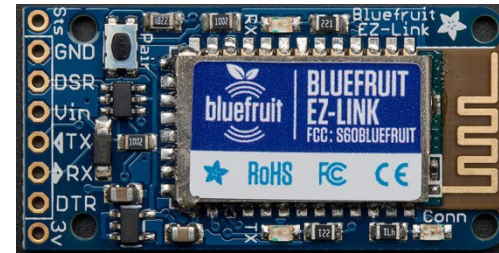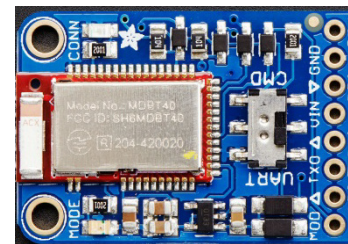- Onboard Crypto Authentication by ATMEL
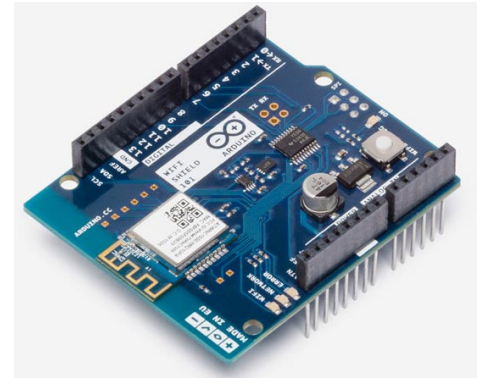
Bluetooth…

- Bluetooth operates at frequencies between 2402 and 2480 MHz, or 2400 and 2483.5 MHz including guard bands 2 MHz wide at the bottom end and 3.5 MHz wide at the top.
- Uses the Industrial, Scientific and Medical (ISM) 2.4 GHz short-range radio frequency band.
- Bluetooth uses a radio technology called frequency-hopping spread spectrum.
  - Bluetooth divides transmitted data into packets, and transmits each packet on one of 79 designated Bluetooth channels.
  - Each channel has a bandwidth of 1 MHz
  - It usually performs 800 hops per second, with Adaptive Frequency-Hopping (AFH) enabled.
  - Bluetooth low energy uses 2 MHz spacing, which accommodates 40 channels.

Adding Bluetooth to Arduino…

- The Bluefruit EZ-Link - Bluetooth Serial Link & Arduino Programmer - v1.3

- The Bluefruit LE UART Friend adds Bluetooth Low Energy connectivity

Adafruit, https://www.adafruit.com/products/1588
https://learn.adafruit.com/introducing-the-adafruit-bluefruit-le-uart-friend
Image courtesy of Kevin Townsend