Raspberry Pi Hardware Interfacing

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Raspberry Jam

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REV -

Introduction

- Who am I ?
  - Electrical engineer for a large U.S. company
  - Wide background including embedded, analog, digital, power, RF and circuit board design
  - Novice Raspberry Pi user, experienced Arduino user, 20 years experience using 8051, PIC, ARM processor in custom applications
  - Passionate engineering hobbyist for 30+ years
- What am I doing here ?
  - Basic electrical engineering relevant to Raspberry Pi / Arduino users
  - Targeted audience is hardware novices and software centric people that want to delve into using Raspberry Pi to interface to hardware
  - Most of the techniques shown here are generic techniques that are applicable to other platforms (i.e. Arduino)
  - Show techniques that can be implemented with a limited number of very basic and inexpensive parts

Raspberry Pi I/O Pins

- Raspberry Pi 3 is based around a Broadcom BCM2837 CPU
- 40 GPIO (General Purpose Input Output) pins
  - 3.3 volt logic – Will not tolerate 5V or greater input voltages – Immediate damage will occur
  - Can source or sink up to 16mA per pin depending on how pins are configured
    - Raspberry Pi 3 was designed for ~3mA per pin for a maximum total of 120mA
  - Pins used as inputs can be configured to utilize hysteresis which is good for “sloppy” input signals to reduce chatter
  - Input pins can utilize built in “pull up / down” resistors
    - Good for reading switches and keypads
    - Saves additional resistors that would normally be required
  - I/O pins are not intended to drive substantial loads directly

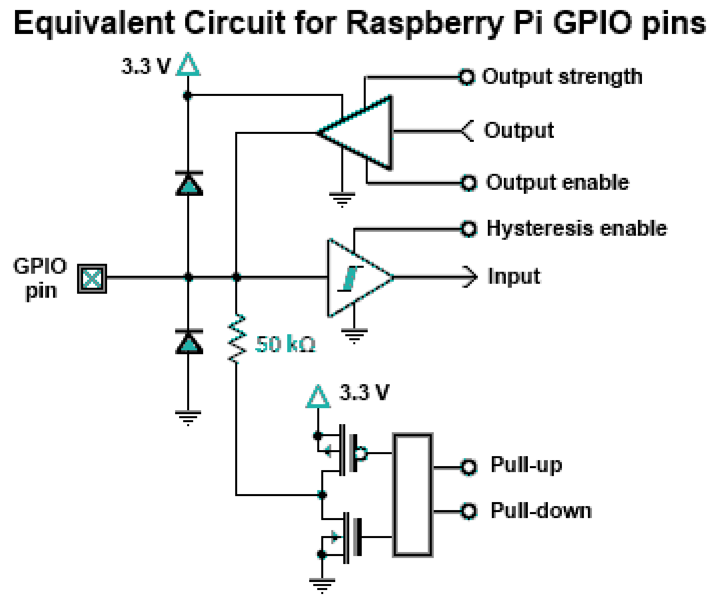


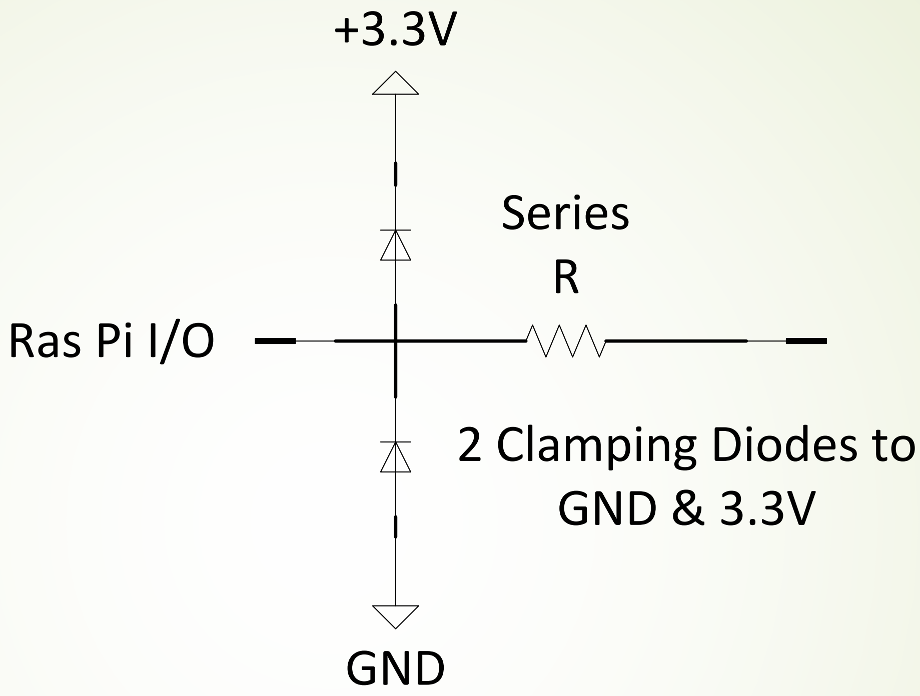
Image Source
http://www.mosaic-industries.com/embedded-systems/microcontroller-projects/raspberry-pi/gpio-pin-electrical-specifications

Good Links:
http://www.mosaic-industries.com/embedded-systems/microcontroller-projects/raspberry-pi/gpio-pin-electrical-specifications

https://www.scribd.com/doc/101830961/GPIO-Pads-Control2

Don't Scorch Your Pi !

- Raspberry Pi and many other electronics are quite susceptible to damage by static electricity (ESD).
  - Invest in an ESD mat and wrist strap – weakly conductive but enough to drain off static electricity. *This is especially important in the winter when humidity is low !*
  - *You must ground the mat and strap properly for it to work !*
- If your application can tolerate it, putting a resistor in series with an I/O pin is simple protection against over current damage caused by shorting I/O's to ground or 3.3V
  - R = V/I so to limit current to say 10mA, R = 3.3V / 0.01A = 330 ohms
  - Somewhere between 1k and 10k ohms is a good choice if there is little current draw
- TVS diodes (Transorb) or MOV's can provide additional protection against over voltage damage, particularly when combined with series resistance
  - *May have to solder wires to surface mount device to get low voltage parts (3.3V) for TVS diodes*
  - *Can also use 2 schottky diodes such as 1N5817 between GND and +3.3*

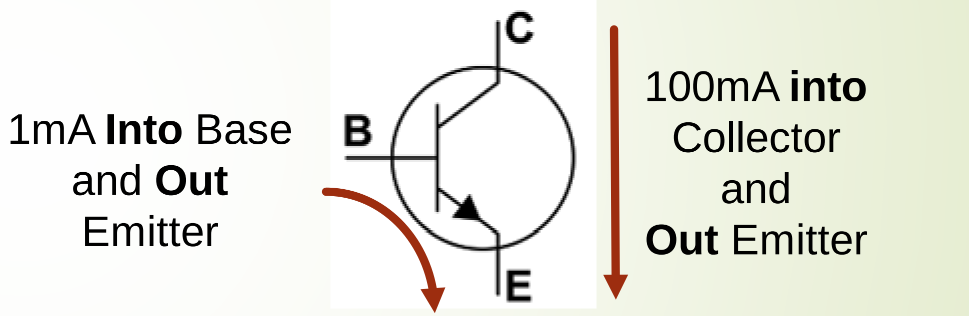


Protecting Raspberry Pi I/O pins with series resistance and optional clamping diodes

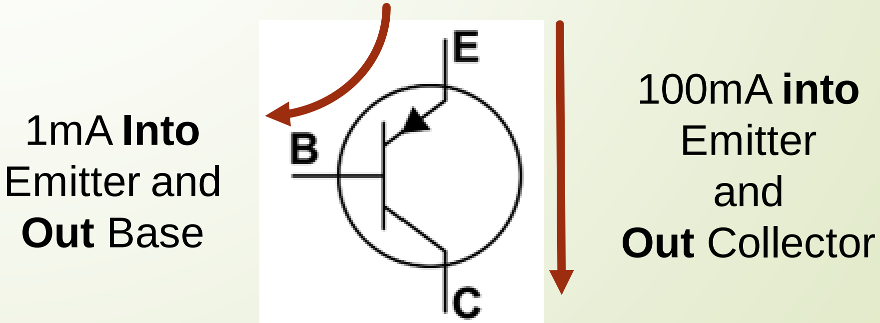
Outputs and Power Switching

The Bipolar Transistor

- Bipolar Transistor – 2 Simple Rules
  - A tiny current flowing between the base and the emitter causes a MUCH larger current to flow between the collector and the emitter. Typical current gain is ~100 – 500 for a modern small signal transistor.
  - Transistor starts to turn on when voltage between base and emitter exceeds ~0.7V
- Transistors can be used to :
  - Amplify (make bigger) voltages
  - Amplify current
  - Act as an on / off switch
- NPN vs. PNP Transistors
  - "Complementary"
  - Opposite Polarity



NPN Transistor With Gain of 100



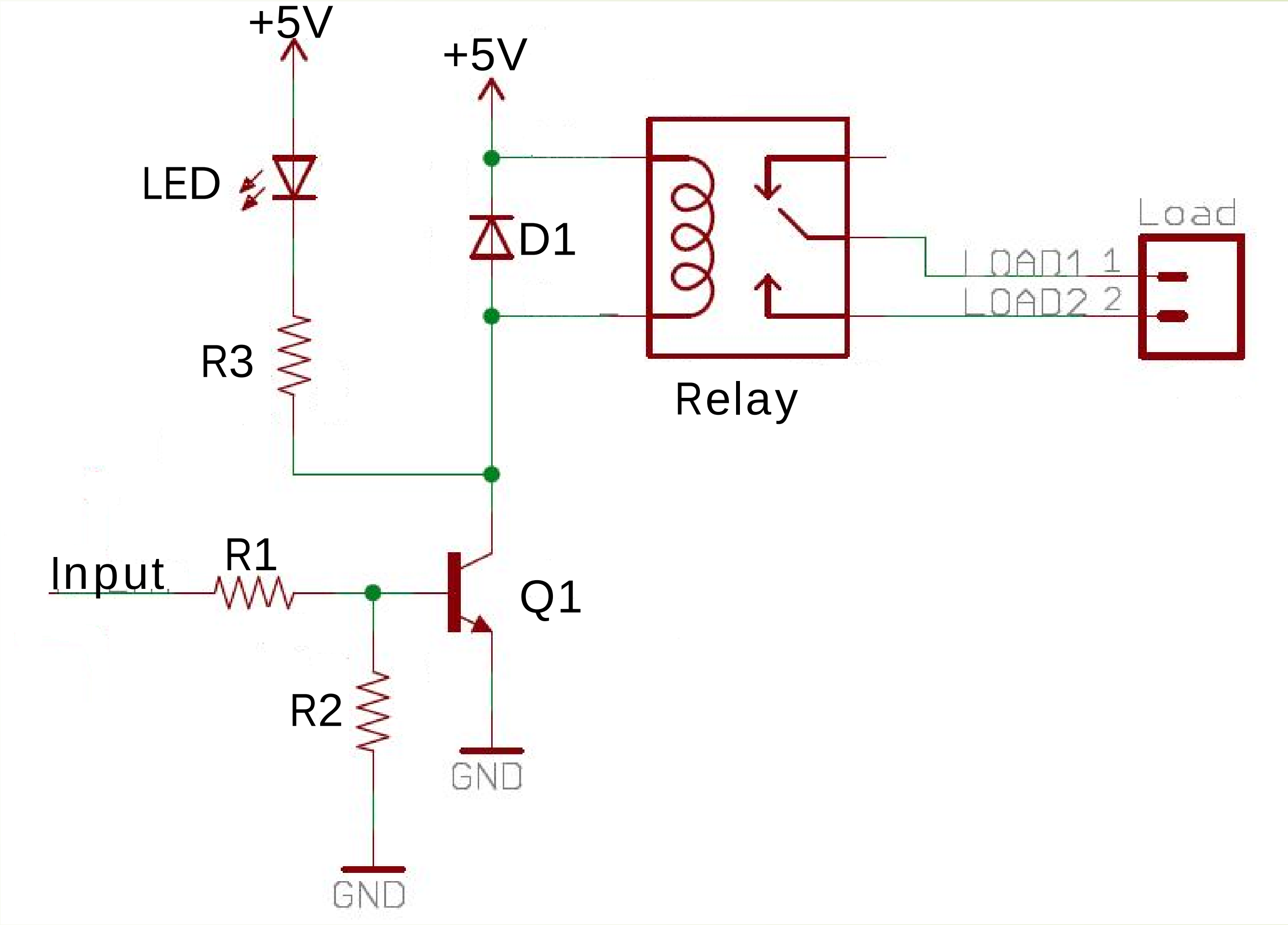
PNP Transistor With Gain of 100

Driving Relays

- What is a Relay?
  - Relay is an electromechanical switch that uses an electromagnet to open and close a set of contacts.
  - Good for turning on big loads like motors
  - Rugged, easy to use, lots of options on contacts
    - Normally on/off contacts, multiple poles etc.
  - Electrical isolation lets us easily operate something like a 115VAC load safely
- Can’t drive a relay directly with a GPIO pin; need some additional circuitry
  - Need a transistor to boost the available drive current from the GPIO pin

Driving Relays Ctd.

- Q1 is a bipolar transistor which amplifies the very small output current from the Raspberry Pi and allows it to turn the relay coil on and off
- **D1 is very important and must not be omitted !**
  - This diode safely shunts what is known as the “flyback” voltage that the coil of the relay generates when it turns off.
  - **Q1 and possibly the Raspberry Pi will be destroyed if D1 is omitted !**
- R1 is needed to limit the current into the base of Q1
- R2 is optional, but helps ensure that Q1 does not turn on accidentally if input is disconnected.
- LED and R3 are optional to show when relay is energized



Driving Relays – Circuit Design Example

- Use relay part number 8-1419125-0 made by TE Connectvity
  - Available from Digikey for $1.35
  - 5 volt coil, 46.3 ohm resistance
  - SPST-NO (Single Position, Single Throw, Normally Open) contacts rated for 10A
  - How much current will relay coil ned ? I=V/R so I=5/46.3 = 108mA
- Use a 2N2222 bipolar transistor to switch the coil
  - Can flow 600mA between collector and emitter, rated for 40V
  - Has minimum gain of 100 with a current of 150mA
  - Want to make sure transistor is saturated as a switch, so base resistor must flow at least 1.08mA – Choose 3mA to add some margin
  - Voltage drop across base – emitter is 0.7V and GPIO voltage is 3.3V so:
    - R=V/I = (3.3 – 0.7)/ .002 = 1350 ohms –> Use 1k ohm resistor
- Use Red LED – Forward Voltage of 1.7V at 10mA
  - Resistor required: R = V/I =(5V – 1.7V)/0.01 = 330 ohms

Driving Relays – Sample Parts List

Component	Part Value	Manufacturer	Part Number	Price (Qty1)
Relay		TE Connectivity	8-1419125-0	$1.35
Transistor (Q1)	2N2222A	Fairchild	KSP2222ABU	$0.21
Diode (D1)	1N4148	Fairchild	1N4148	$.10
Resistor (R1)	1k ohm, 1/8W	Stackpole	RNF18FTD1K00	$.10
Resistor (R2)	10k ohm, 1/8W	Stackpole	RNF18FTD10K0	$.10
LED	Red	Cree	C556D-RFE-CV0X0BB1	$.15
Resistor (R3)	330 ohm, 1/8W	Stackpole	CF18JT330R	$.10

All parts above available from Digikey
http://www.digikey.com

Solid State Relays

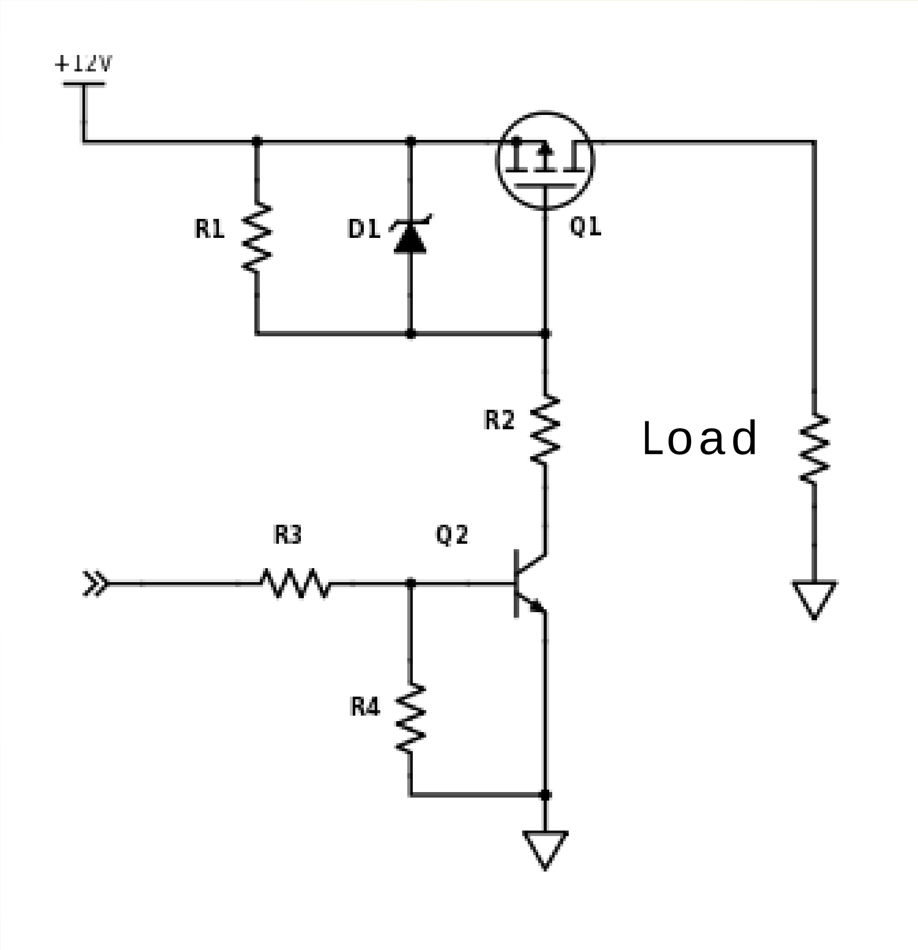
- Act like a relay, but with no moving parts
  - Easy to use, no moving parts, can switch very fast
  - Use transistors and other semiconductors to perform switching
  - Provide electrical isolation for safety similar to electromechanical relay
  - Can switch both AC and DC depending on model
  - Can be expensive ($15 to $50)
- Most of these will still need an external transistor similar to what was used for the electromechanical relay due to the input current required to actuate them

MOSFET's

- Metal Oxide Shielded Field Effect Transistor
  - Have 3 terminals (Gate Source and Drain)
  - Come in N channel and P channel types akin to NPN and PNP transistors
  - A voltage between the gate and the source controls the current flow between the source and drain
  - No current flows into the gate
- Make excellent high current switches – Extremely low resistance when on
- For an N-channel device, making the gate positive with respect to the source turns it on.
- For a P-channel device, making the gate negative with respect to the source turns it on.
- Must be cognizant of maximum gate-source voltage or part will be damaged

Make Your Own Solid State Switch

- Q1 is a P-channel mosfet and is the device which will control the current through the load.
- D1 is a zener diode to protect the gate of the mosfet from overvoltage
- Q2 is an NPN transistor which "pulls" the gate of Q1 low with respect to its source
- R1 keeps Q1 off by driving the gate high when Q2 is off.
- R2 limits the current through Q2 when D1 starts to conduct.



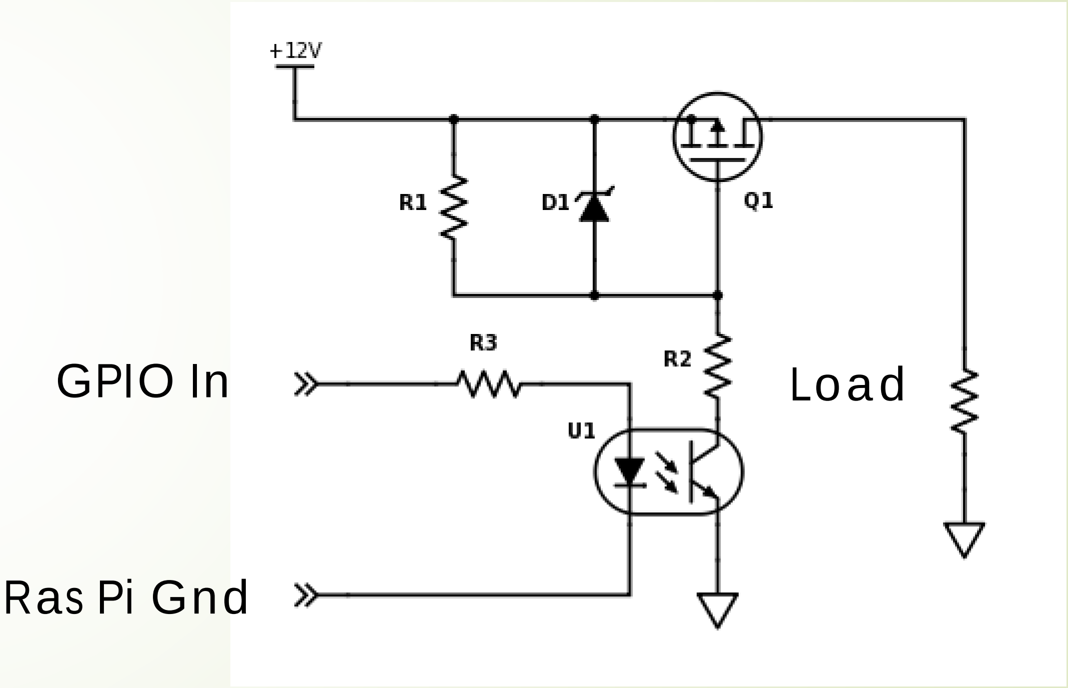
Make Your Own Solid State Switch

Component	Part Value	Manufacturer	Part Number	Price (Qty1)
MOSFET (Q1)	MOSFET P-CH 55V 74A TO-220AB	Infineon	IRF4905PbF	$1.80
Transistor (Q1)	TRANS NPN 40V 0.6A TO-92	Fairchild	KSP2222ABU	$0.21
Zener Diode	15V, 1/2W	Fairchild	1N5245BTR	$0.14
Resistor (R1,R4)	49.9k ohm, 1/8W	Stackpole	RNF18FTD49K9	$.10
Resistor R2,R3	4.75k ohm, 1/8W	Stackpole	RNF18FTD4K75	$.10

All parts above available from Digikey
http://www.digikey.com

Isolated Solid State Switch

- The simple switch previously described can be converted into an electrically isolated version by swapping Q2 for an opto-isolator as shown.
- In an opto-isolator, an LED shies light onto the base of a transistor which turns it on
  - There is no electrical connection between the input side (LED) and the output side (transistor)
  - This is a very good way to provide an extra layer of protection to a Raspberry Pi and to users.

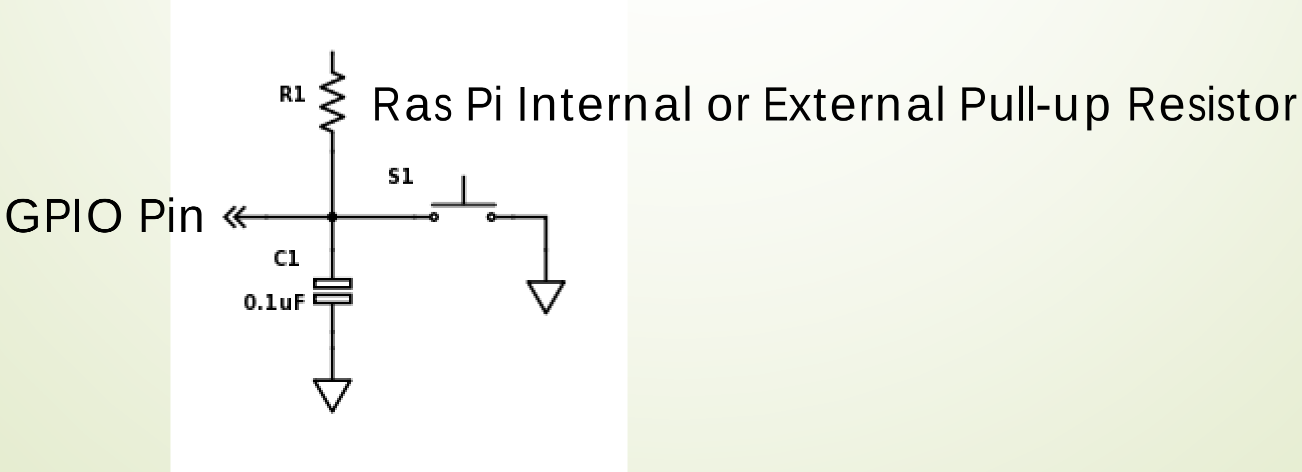


U1 could be a Lite-On LTV-816
Available at Digikey for $0.41 ea.

Digital Inputs

Pushbuttons

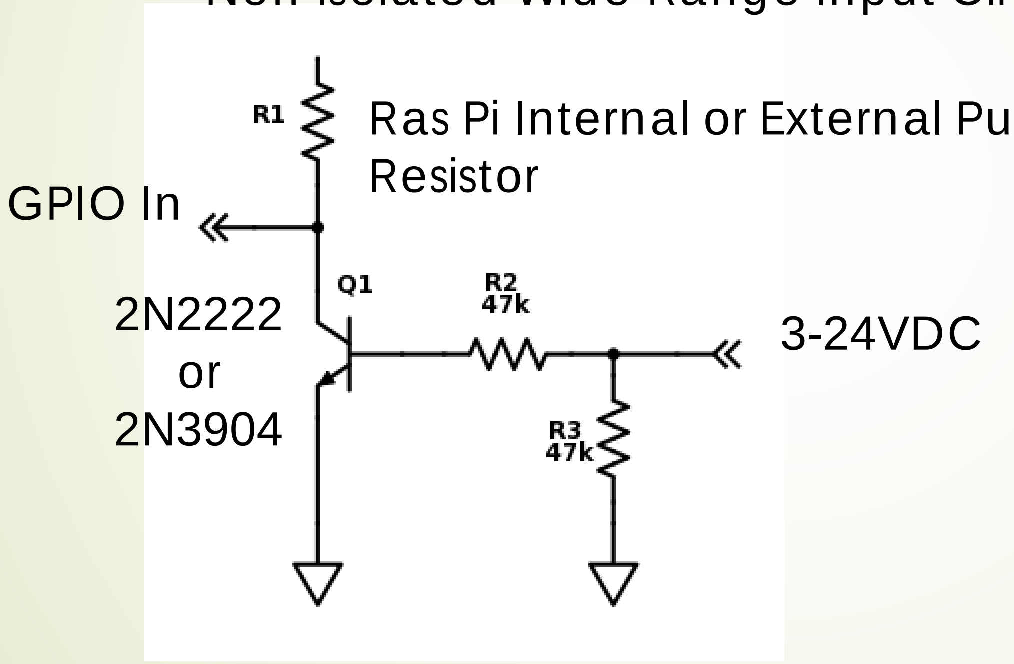
- Simple pushbuttons connected to GPIO pins
  - You can use the built in software definable pull up / down resistors, or you can use external ones connected to either the +3.3V or GND pins
  - Good idea to add a 0.1uF ceramic capacitor between the GPIO pin connected to the switch and the Raspberry Pi ground for a number of benefits
    - Mechanical switches are electrically “noisy”. The presence of the capacitor will provide a good deal of de-bouncing and avoid spurious switch reads
    - The capacitor will make the GPIO pin much less susceptible to ESD damage from a static spark from a person touching the button
    - The capacitor is a low impedance path for electromagnetic interference, and can bypass noise to ground which could otherwise be interpreted as a button press



Input Level Shifting

- Suppose you have an input signal that can be anywhere from 3 to 24VDC

Non-Isolated Wide Range Input Circuit

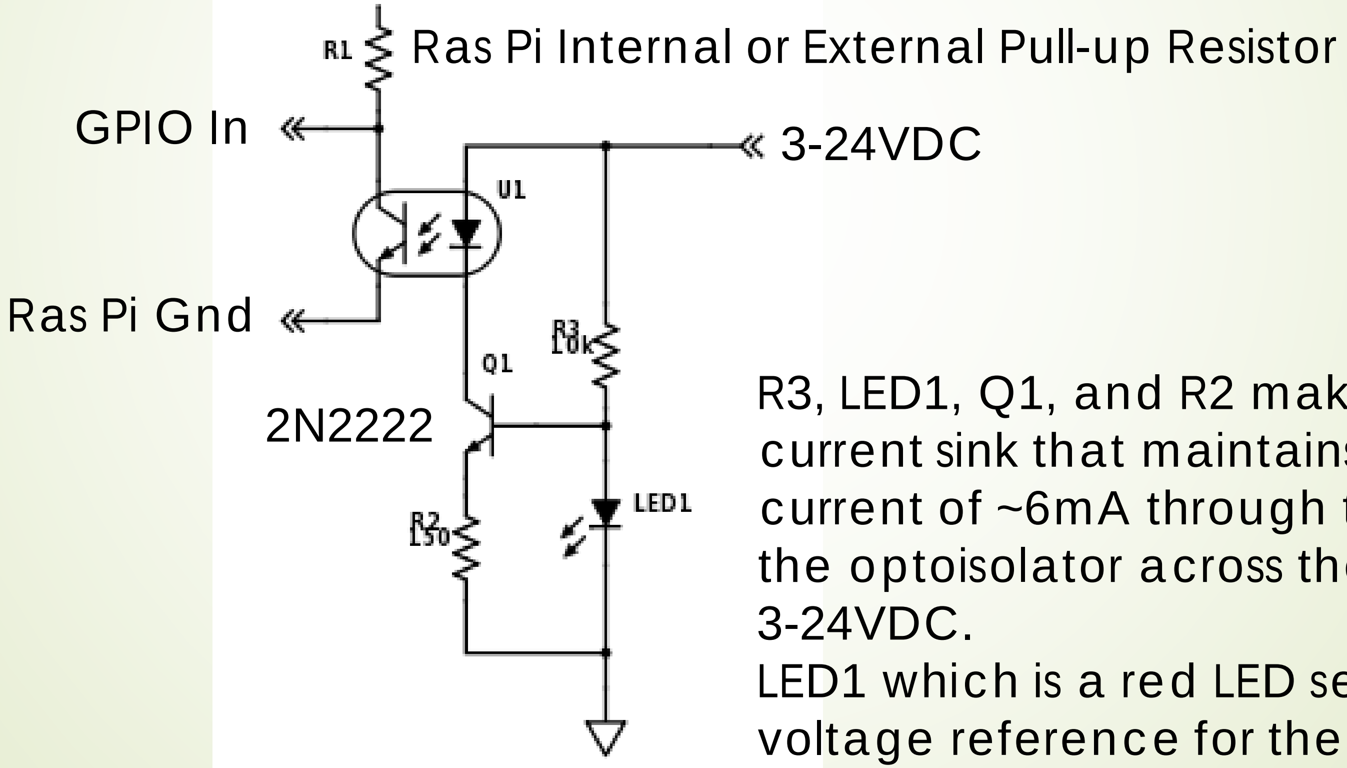


Simple NPN Switch pulls GPIO low when input goes high

Isolated Digital Inputs

- Suppose you have an input signal that can be anywhere from 3 to 24VDC
- This circuit offers electrical isolation so that there is no path through from the inputs to the Ras Pi

Isolated Wide Range Input Circuit

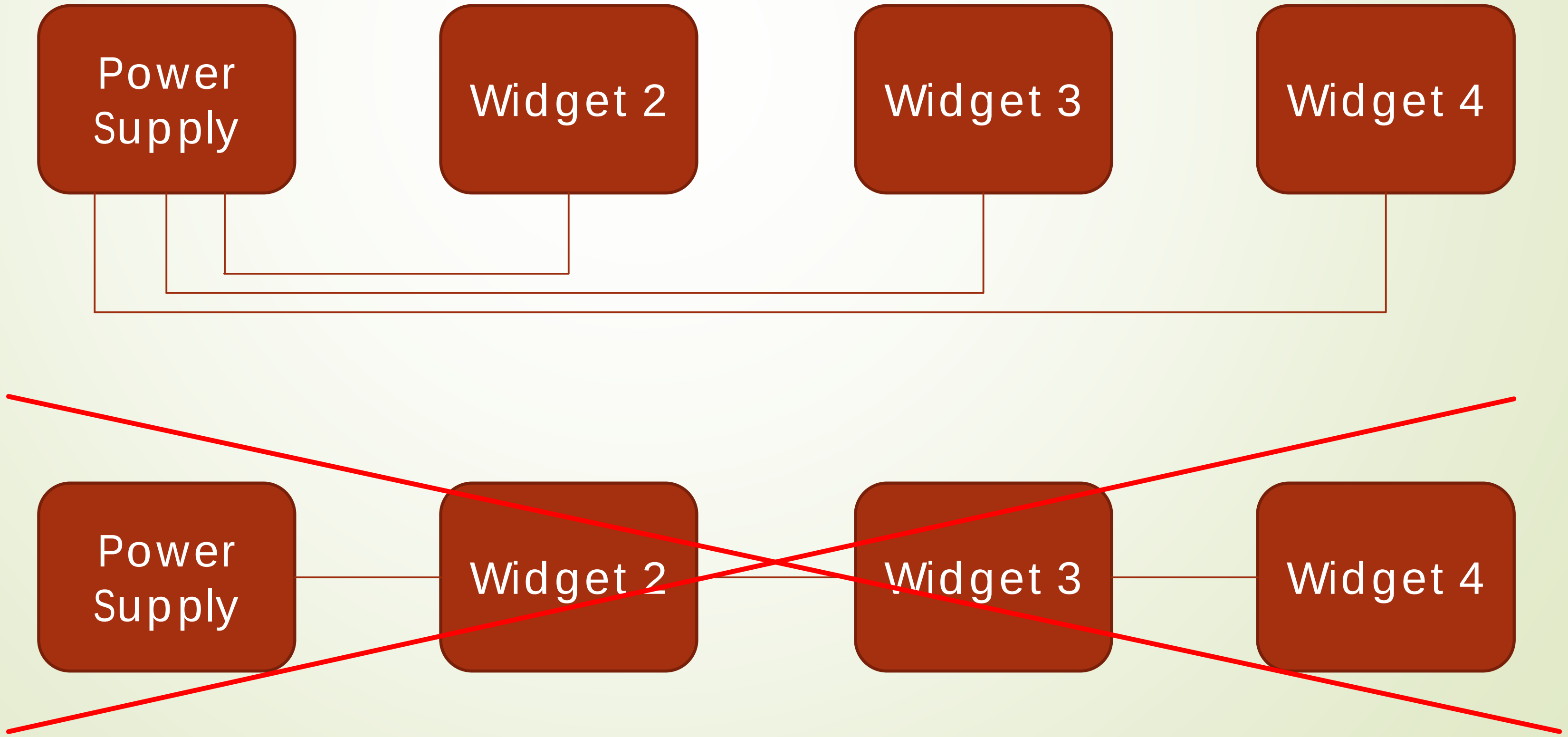


R3, LED1, Q1, and R2 make a constant current sink that maintains a constant current of ~6mA through the LED portion of the optoisolator across the input range of 3-24VDC.
LED1 which is a red LED serves as a voltage reference for the current sink

Grounding, Signal Integrity and Electrical Noise

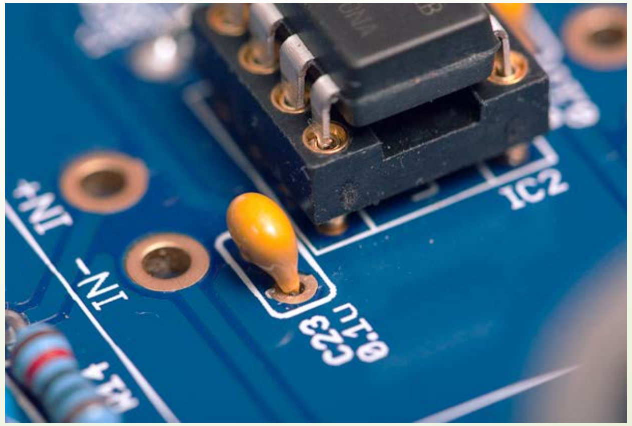
Grounding & Power Distribution

- To the greatest extent possible, try to use a single point grounding scheme when you build systems.
- Use of a poor grounding scheme in systems can lead to all kinds of issues



Bypass Capacitors

- Use bypass capacitors on sensors and IC’s like A/D converters etc.
  - 0.1uF is a common value used for local decoupling capacitors on IC’s
- Provides a local reservoir of charge at the sensor or IC which can combat the effects of interconnect inductance such as wires.
- Without the bypass capacitor, there can be an excessive amount of voltage ripple at the input to the device
- Many IC’s and sensors will exhibit erratic behavior if decoupling capacitors are not used.
- Put the decoupling capacitor as close to the input voltage pin as possible



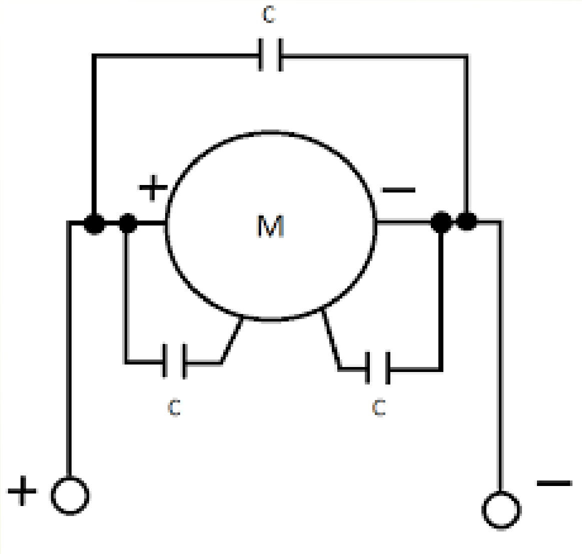
EMI Control / Signal Integrity

- EMI (Electro Magnetic Interference)
- Using simple twisted pairs for power distribution and routing of signals can go a long way towards controlling EMI and maintaining good signal integrity.
- Remember that when a current flows in a wire, it generates a magnetic field around the wire according to the right hand rule.
  - If we have two wires that are tightly twisted together with equal and opposite currents in them, then the magnetic fields cancel each other.
  - This prevents those fields from coupling into adjacent wires !
- By the same token, twisting signal wires together makes them much less susceptible to picking up noise by stray magnetic fields
  - A magnetic field cutting across a single separated wire can generate a voltage in it.
  - A magnetic field cutting across a twisted pair generates equal and opposite signals that cancel
- Twisted pairs are also very good for data communications like Ethernet and RS-422 because they have what is known as a characteristic impedance which allows us to avoid reflections if our circuit is designed properly.
- You can make long consistent twisted pairs with a cordless drill using a simple metal hook made from coat hanger wire !

Image credits:
https://electronics.stackexchange.com/questions/19517/why-connect-capacitors-to-motor-body
https://electronics.stackexchange.com/questions/239321/how-to-connect-flyback-diodes-on-a-h-bridge

DC Motors

- Brush type DC motors can generate very large magnitude EMI spikes in the hundreds of volts which can cause all kinds of problems !
  - Arcing brushes produce broadband (kHz to hundreds of MHz) noise
  - Capacitor across terminals shunts (short circuits) differential mode noise. Capacitors to motor case shunt common mode noise.
- Need to control this problem at the motor before it has a chance to propagate
- Using a medium frequency range ferrite core with 1-3 turns of both wires through it at the motor can provide additional suppression by making it difficult for the noise to travel down the cable.
  - Laird LFB090050-000 available at Digikey for $0.19 each



Solder a 0.1uF ceramic capacitor across the two motor terminals

Solder a 0.1uF ceramic capacitor between each motor terminal and the case

Resources

Books

- The Art of Electronics
  - Paul Horowitz & Winfield Hill
  - Best book on applied electronics ever written !
  - 3rd Edition was just published in 2016