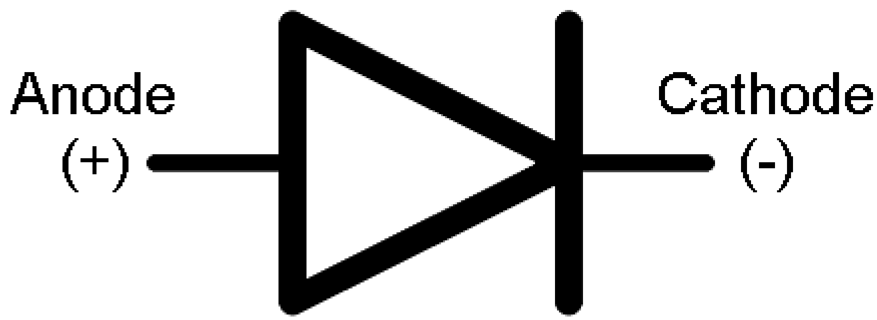
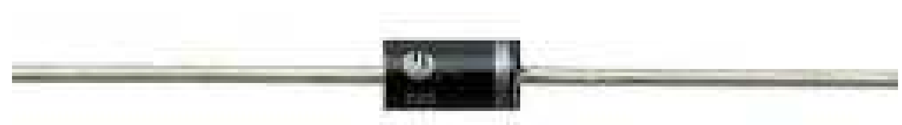
Semiconductor Electronics

9/21/2015

Starting simple…the diode.





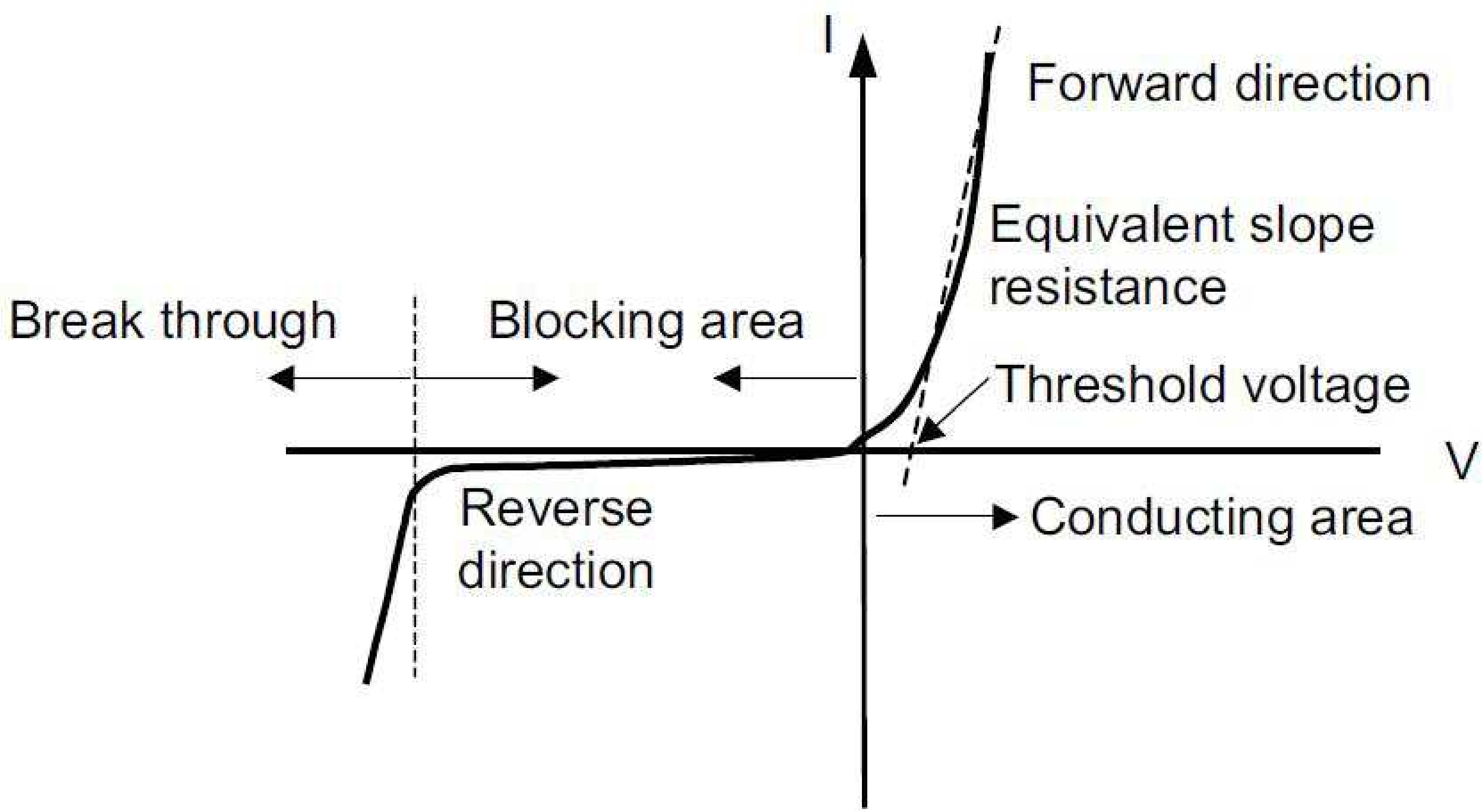
The diode is one of the simplest semiconductor devices. It is comprised of two layers of semiconductor. One is impregnated with an electron donor such as arsenic, creating an n-type layer. The other layer is doped with an electron acceptor such as aluminum creating a p-type. The materials are fused and the interface is call a pn junction. Within limits, this junction only allows the flow of electricity in one direction.

(Image from learn.sparkfun.com)

To a mechanical engineer a diode can be thought of as a one way valve for the flow of electric current. We often see them used in:

- Charging systems - so the generated power doesn’t back flow out of storage batteries and get dissipated as heat in the generating device such as photovoltaic cells or the windings in a vehicle alternator.
- Rectifiers – we use them in “bridges” to turn AC current into a waveform which can be filtered into DC current.
- Voltage regulators – If we completely over power them in the reverse direction they will flow enough current to keep a steady voltage on their leads.
- Spike suppression when turning off coils or solenoids.

The actual functioning of a diode is slightly more complicated than the check valve model. They require a threshold voltage of .2-.6V to flow current in the forward direction and they can be "forced open" if enough reverse voltage is applied. The reverse breakdown voltage can be hundreds or thousands of volts.



(Image from www.learningaboutelectronics.com)

Transistors…The muscle for electronics

This seminar will omit current controlled transistors called bipolar junction transistors and focus strictly on voltage controlled devices or metal oxide field effect transistors (MOSFETS) because they do not tax the current handling capacity of a device like a microcontroller.

A mechanical engineer can think of a typical MOSFET as a voltage controlled, normally closed valve for DC electric current . AC would require a device called a triac.

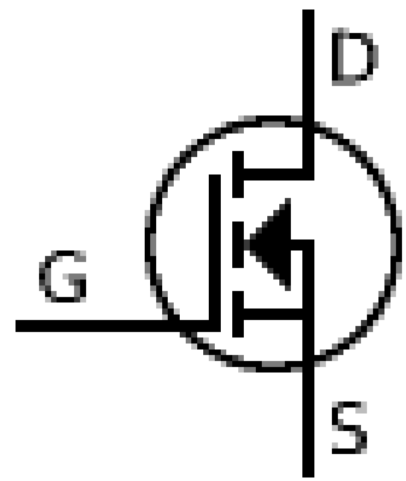
(Image from digikey catalog)

We often use this schematic shorthand

Equals

Drain
(Load current in)

Gate
(The control pin)



Source
(Load current out)

Image from: http://blog.oscarliang.net/how-to-use-mosfet-beginner-tutorial/

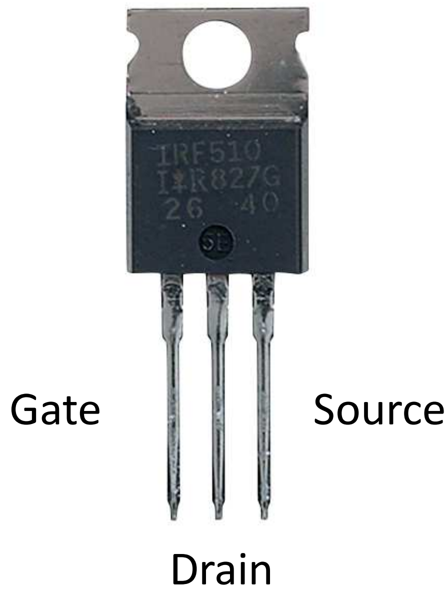
Gate Source

Drain

N-Channel Device

When voltage is applied between the gate and source pins, current can start to flow into the drain and out the source. The more voltage that is applied, the more current is able to flow. For some devices 5V between the gate and source can result in a drain-source resistance in the .03 ohm range and the device acts as a switch. When doing a power application like a motor drive the transistor should be run completely on or off. Running partially on, in “linear mode” causes excessive heat to build up and the device to run inefficiently.

MOSFETS have a glass insulated gate-source connection so the resistance is VERY high. This also results in an unintended capacitance which must be dealt with.



P-Channel Device

P channels are used far less frequently. To turn on a P-channel the voltage of the gate must be lower than the voltage of the source or drain.

So how much power can they handle WITH PROPER COOLING????.......The beast below is available from Digikey for $7.12

STH270N8F7-2, STH270N8F7-6, STP270N8F7

life.augmented

N-channel 80 V, 0.0017 Ω typ., 180 A, STripFET™ F7 Power MOSFETs in H²PAK-2, H²PAK-6 and TO-220 packages

Datasheet — production data

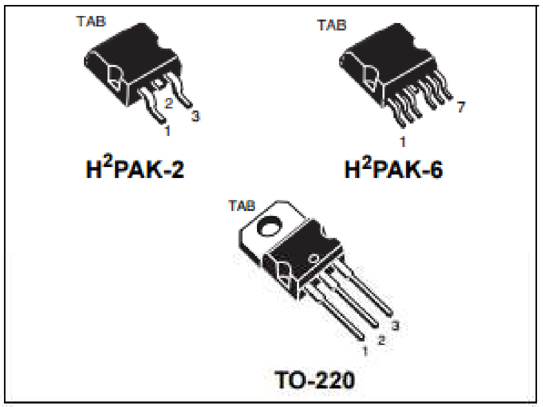
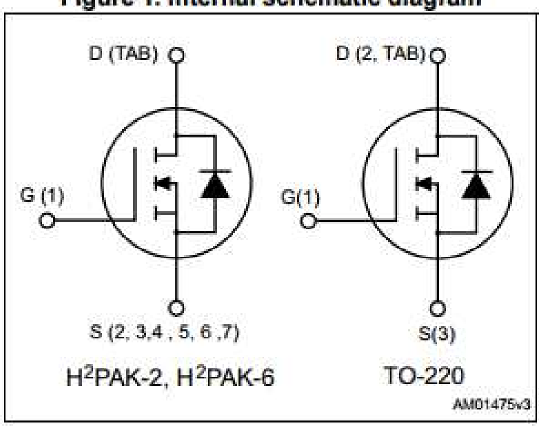


Figure 1. Internal schematic diagram



Features

Order codes	V_{DS}	$R_{DS(on)}$ max	I_D
STH270N8F7-2	80 V	0.0021 Ω	180 A
STH270N8F7-6			
STP270N8F7		0.0025 Ω	

- Among the lowest $R_{DS(on)}$ on the market
- Excellent figure of merit (FoM)
- Low C_{rss}/C_{iss} ratio for EMI immunity
- High avalanche ruggedness

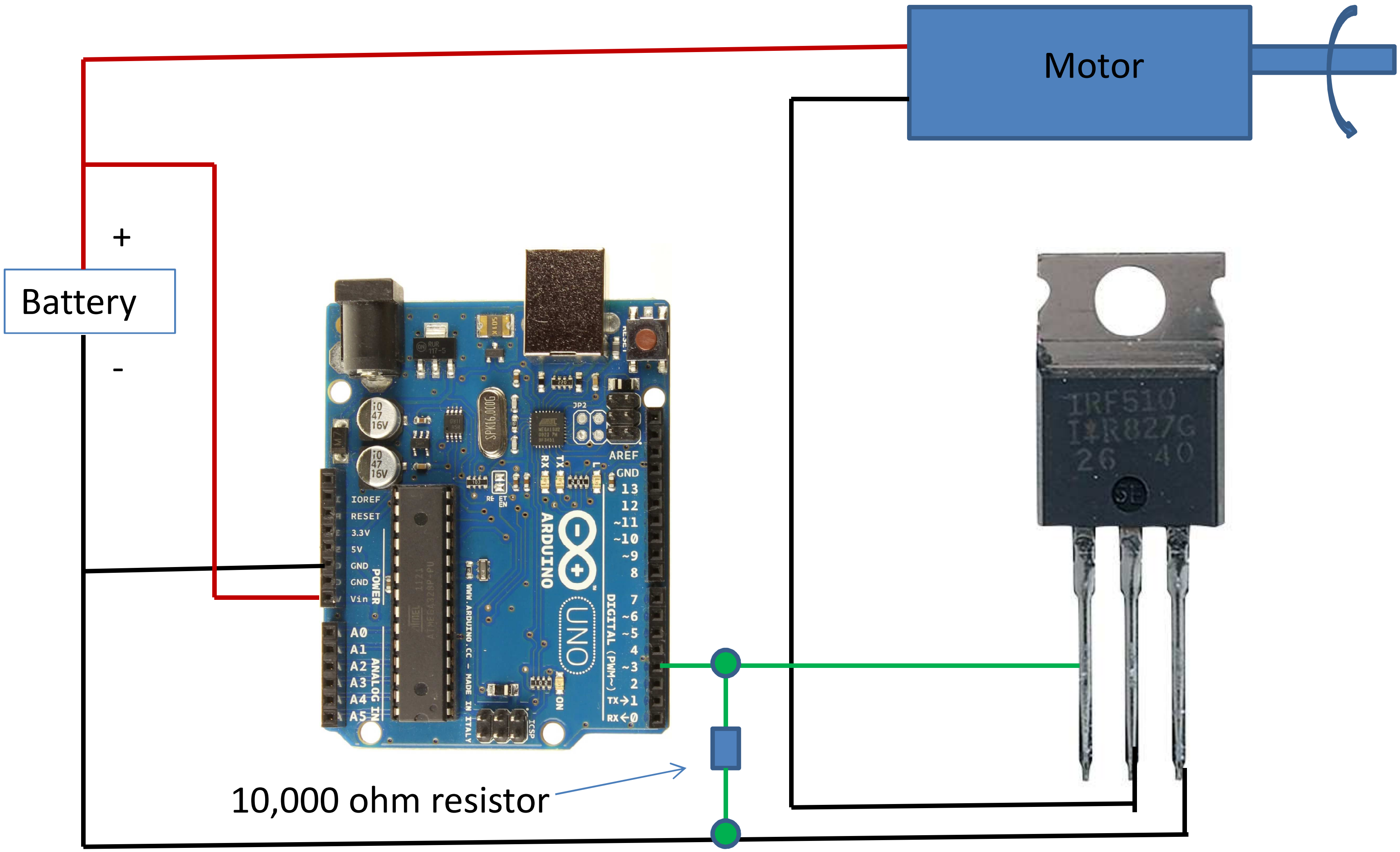
Applications

- Switching applications

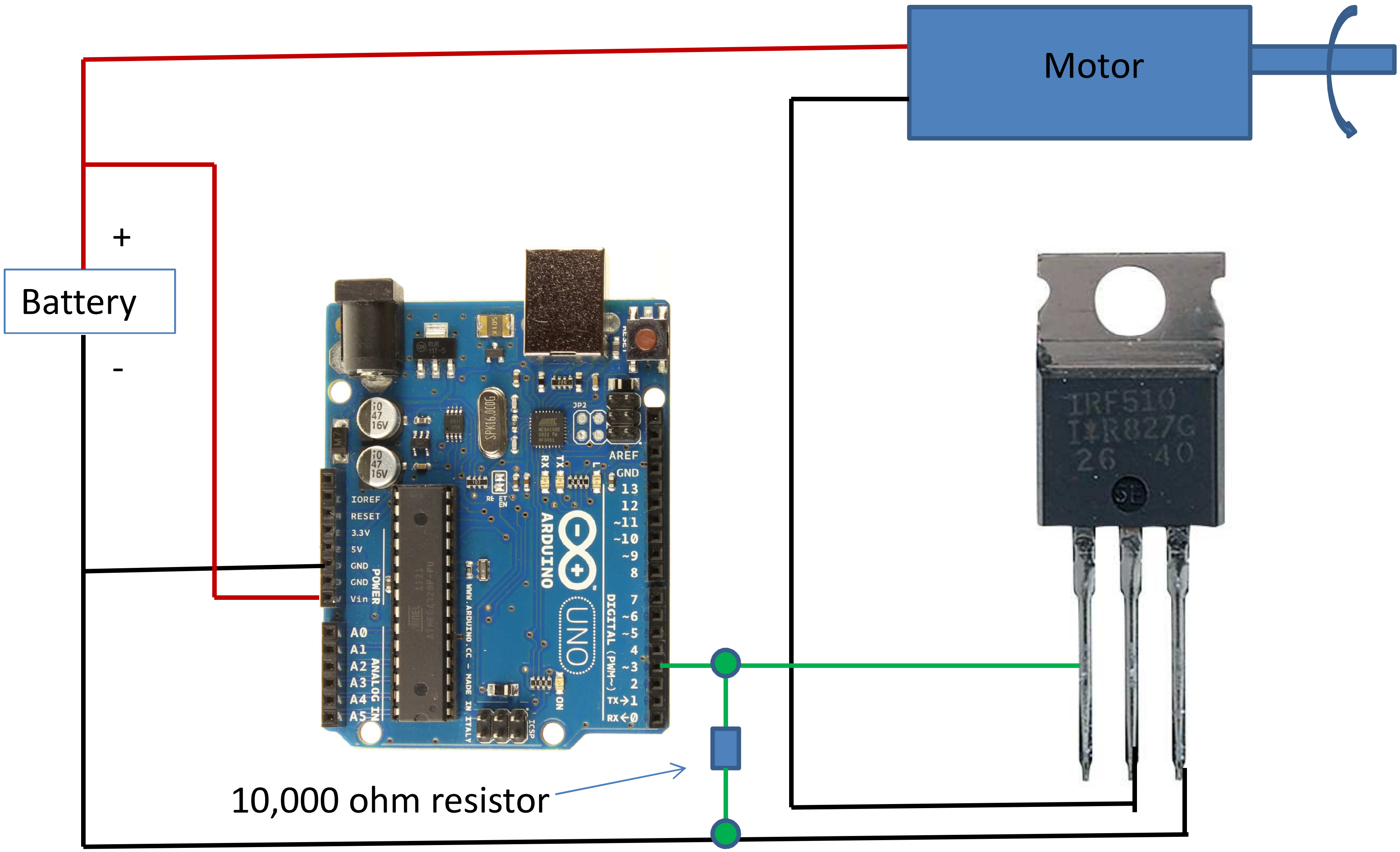
Description

These N-channel Power MOSFETs utilize STripFET™ F7 technology with an enhanced trench gate structure that results in very low on-state resistance, while also reducing internal capacitance and gate charge for faster and more efficient switching.

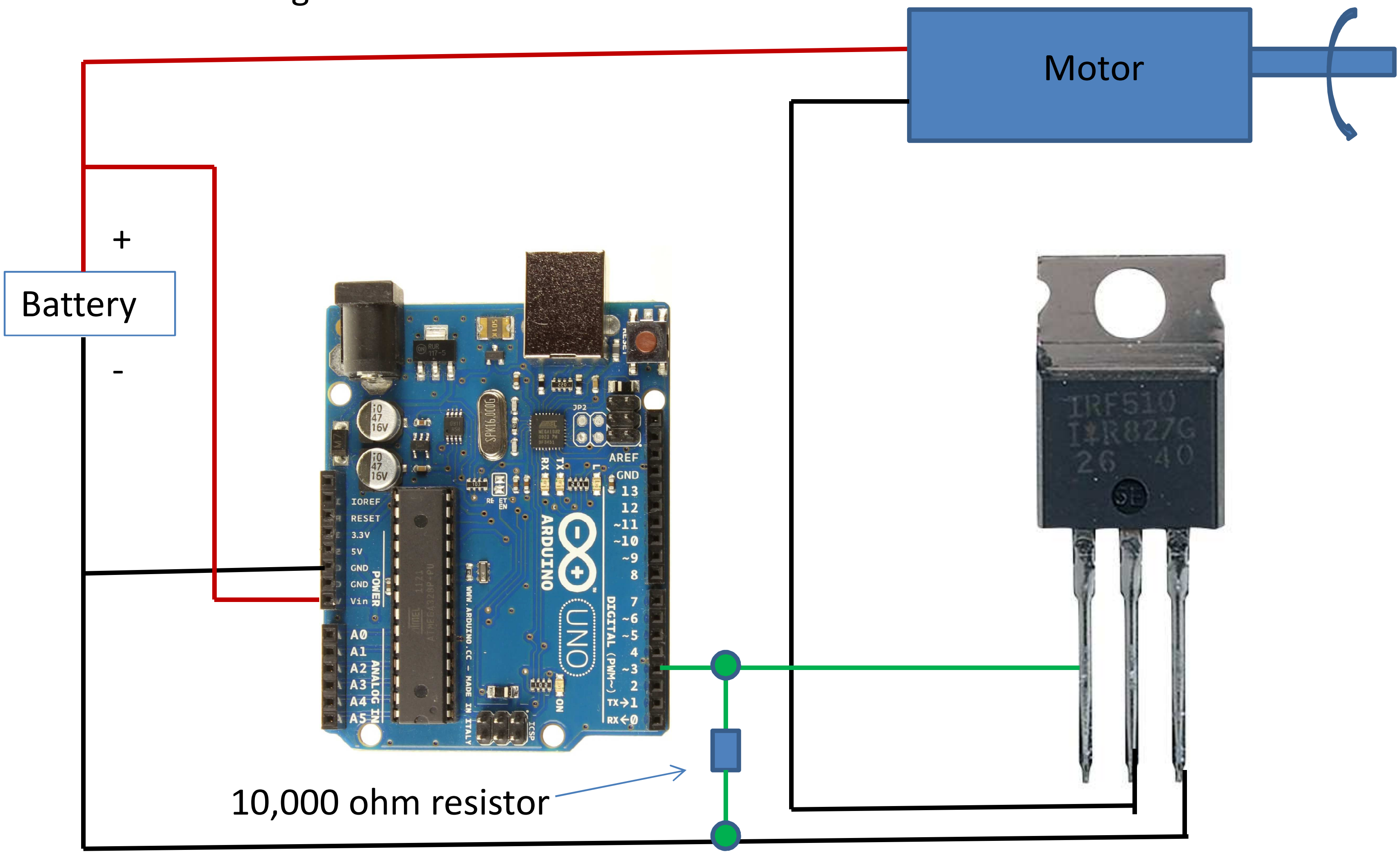
For this example we will use the N-channel metal oxide field effect transistor(MOSFET) as a switch on a motor's negative wire. If you want the ARDUINO to turn on a large DC motor you could wire it like this:



Now whenever we tell the Arduino to make pin 3 “high” or have 5V on it, the motor will spin. DO NOT leave out the 10k ohm resistor. This is to discharge the gate capacitance and allow the device to turn off.

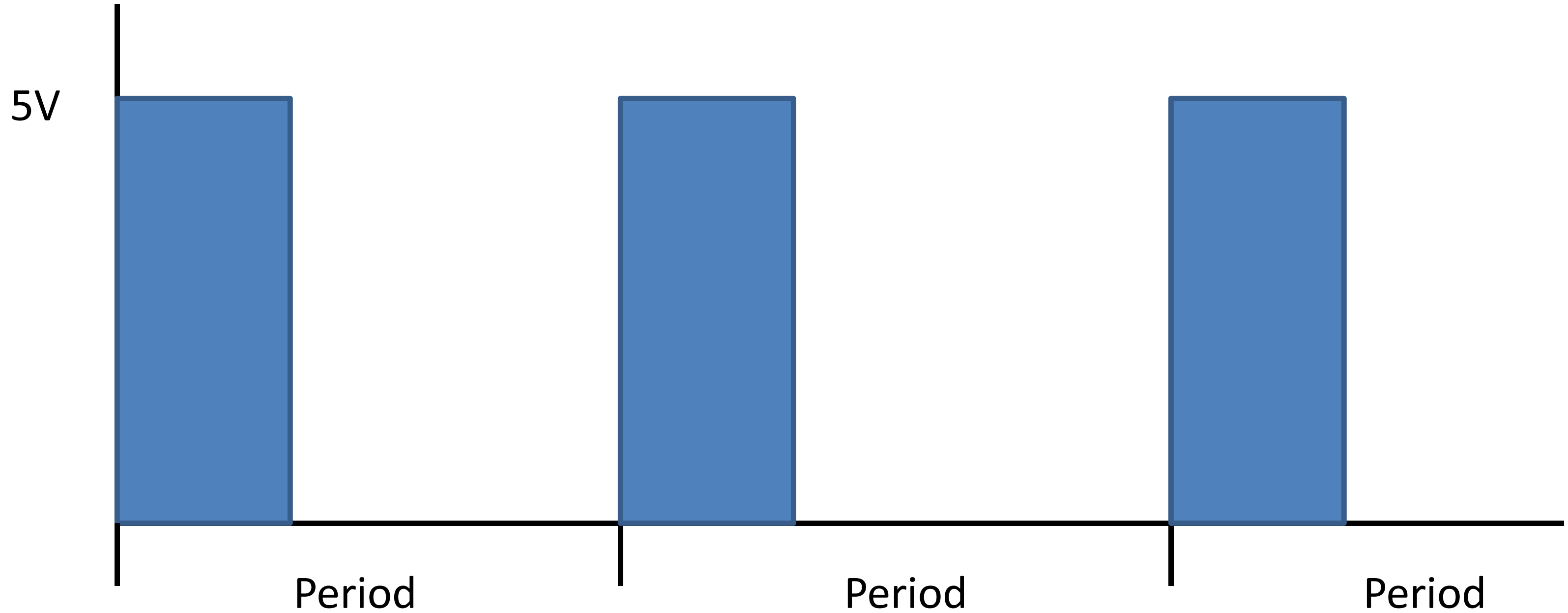


If we really want to be trick we can turn on pin 3’s pulse width modulation and make the motor run at variable speeds. PWM outputs a very fast set of pulses which are “on” a variable percentage of the time. The result is that the motor “feels” like it is receiving more or less voltage.



Pulse Width Modulation-

This is just a fancy term for turning the power on and off a variable percentage of the time to increase or decrease the power going to a device like a motor.



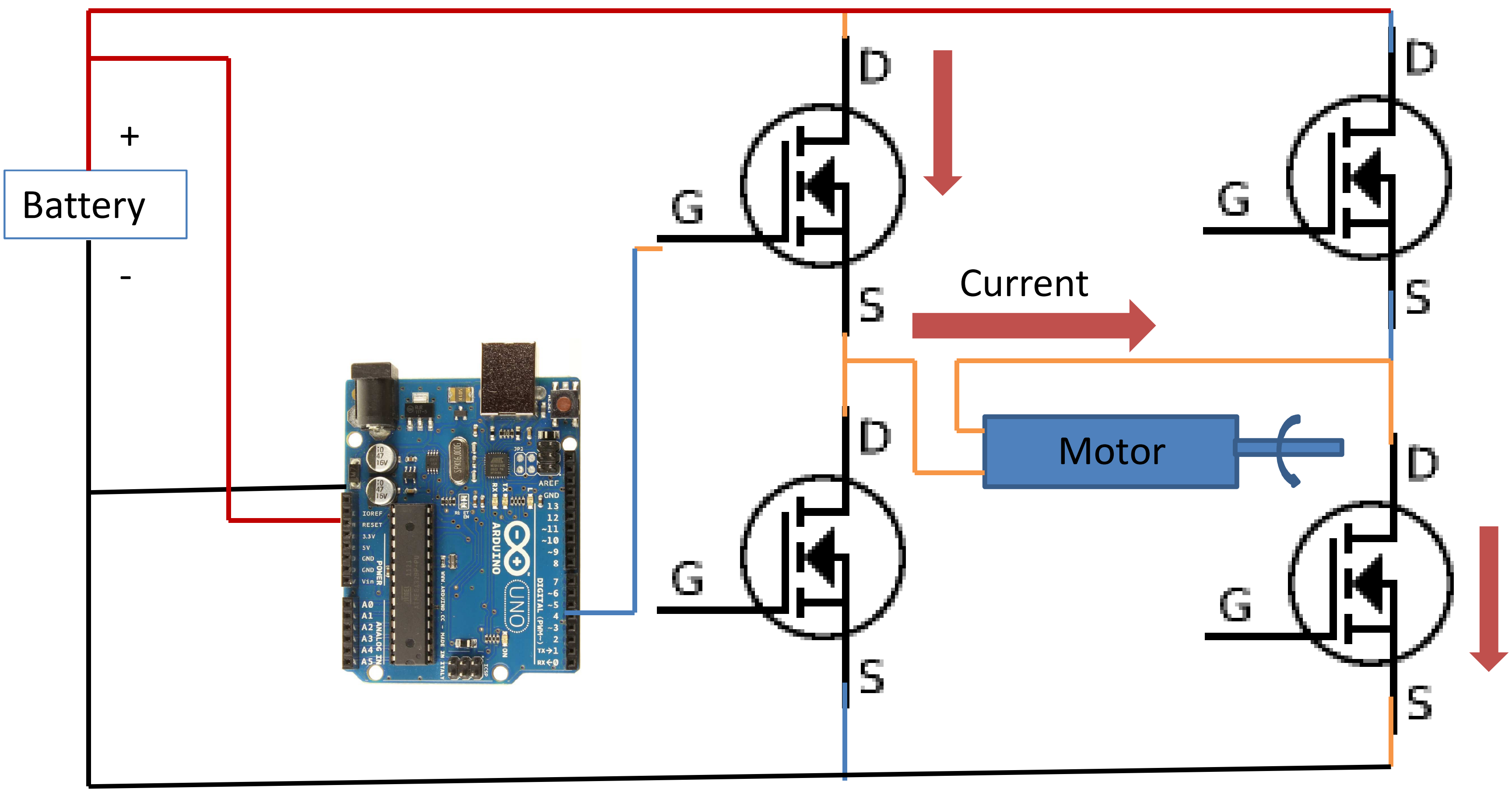
If this pulse train has an "on" voltage of 5V and is on 33% of the time, then the average voltage delivered to a device is:

5V * .333 = 1.667V

PWM can be filtered to create an actual constant voltage without transients.

Typically PWM is done at high frequencies above the range of human hearing so the drive does not develop a noisy hum.

OK great. I can make a rock crushing, steel shredding robot go forward, but what if I need it to back up??? This is where we use something called an H-bridge.

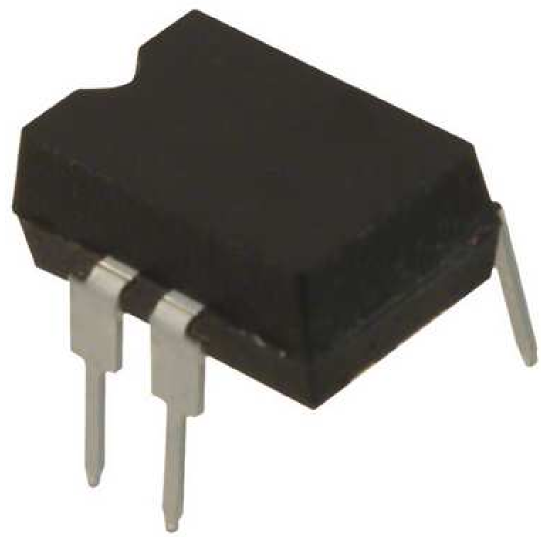


By turning on opposite diagonals on the bridge we can reverse the motor current and therefore the rotation direction.

BUT!! There is a problem. Transistors in general want to see about 5V between the gate and source. Things get dicey when there are parts stacked up and motors have varying voltages so you can't blindly run a line from the Arduino output pin.

The better way is to have an optically isolated independent voltage generating source like this:

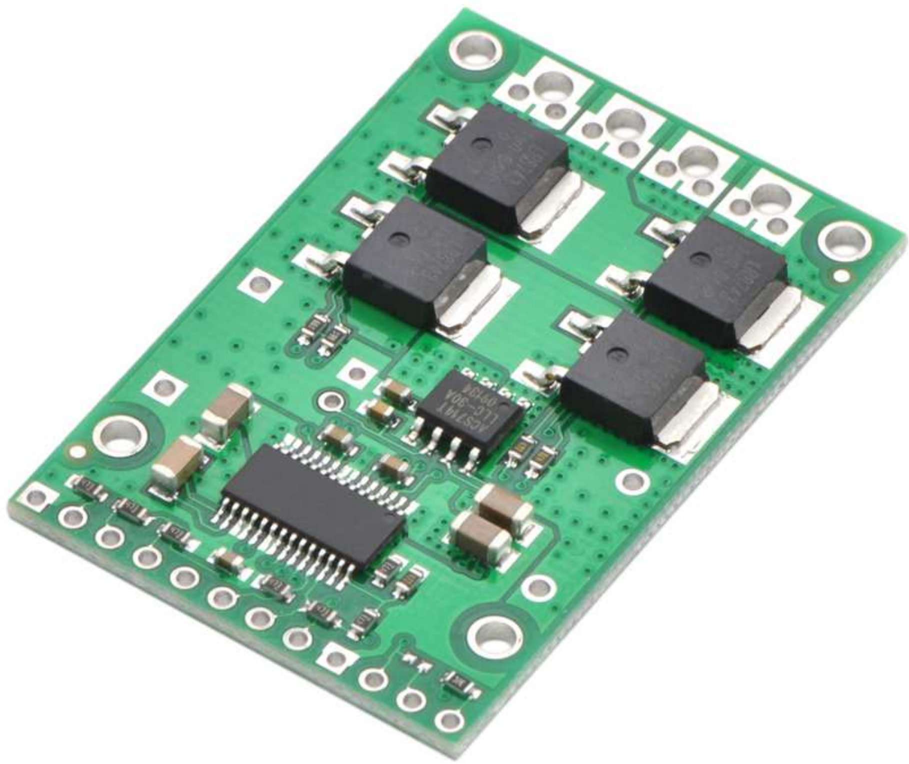
http://www.irf.com/product-info/datasheets/data/pvin.pdf



It is a PVI-N from International Rectifier. Inside the case is an LED shining on a photovoltaic cell so it can make a completely independent 5 or 10VDC. They are specifically designed to drive power MOSFET's. Just place the positive output on the transistor gate and the negative output on the source. Light the LED to turn things on.

Still sounding too hard??? You can always buy one of these:

https://www.pololu.com/product/1455



30V and 25A is a lot of power for $60

Motors:

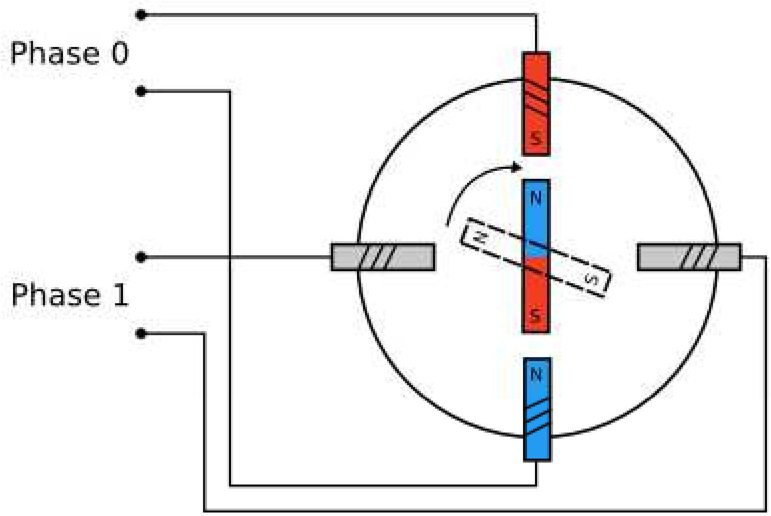
There seems to be an ever increasing number of electric motors available to design with. Some of the more common ones are:

1.) The DC brush motor – The oldest and simplest form of motor. Its power and speed is proportional to the current passing through the rotor.

2.) The "universal" or series motor. In this motor the incoming power goes through one field coil, the rotor via brushes, and then the opposite field coil. They accept AC or DC and always run in the same direction. They are commonly used in applications which need to run over 3600rpm such as vacuum cleaner blowers or applications which need high power to weight like drills.

3.) Stepper motors – These motors are generally used for motion control instead of simple power like a fan.

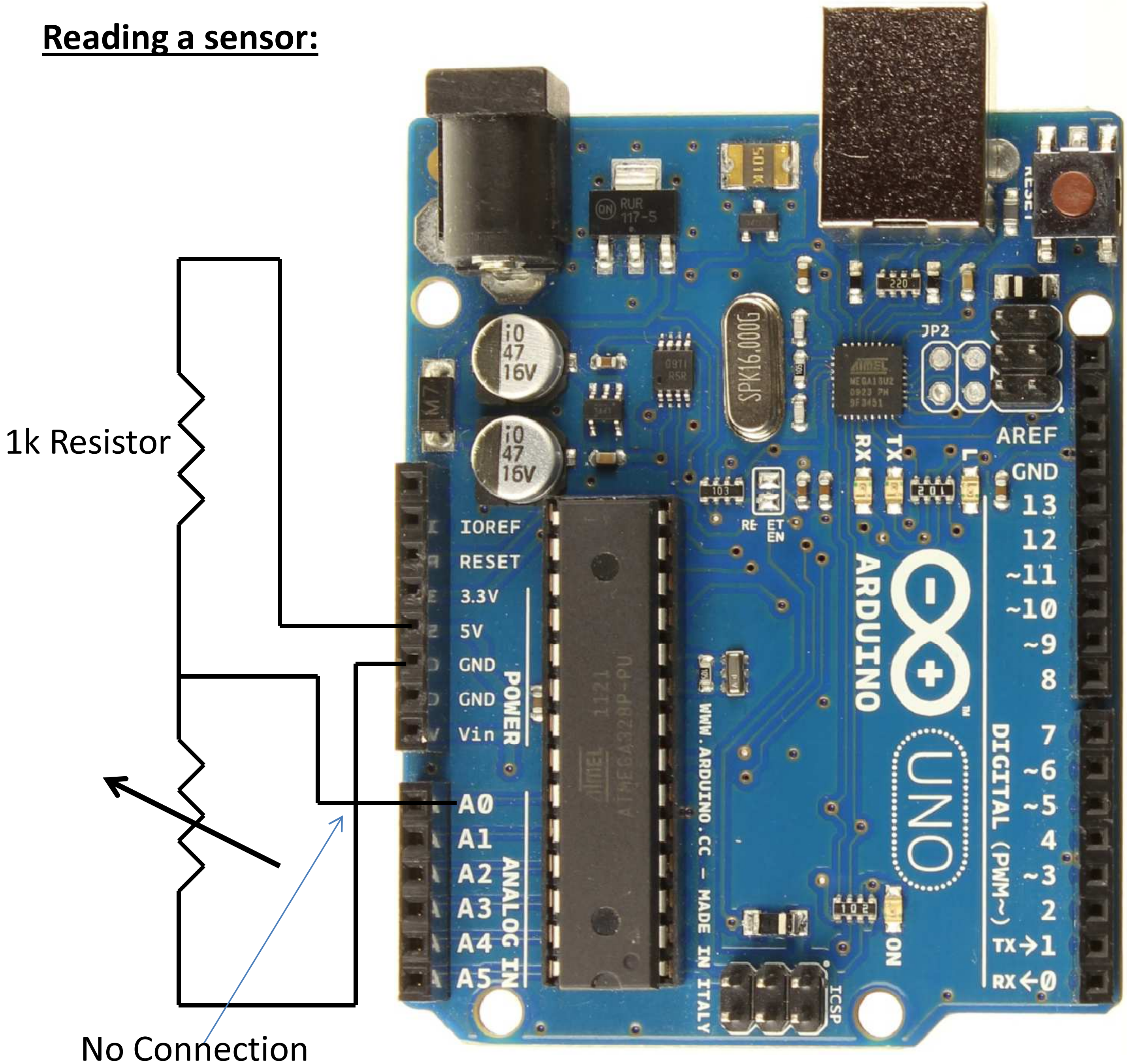
Often stepper motors have two independent coils and require 200 or 400 coil switches per revolution.



4.) Brushless DC motors – These are motors which are generally optically commutated to change the magnetic field polarity and keep the rotor turning.

Image from : http://www.savagehomeautomation.com/projects/raspberry-pi-stepper-motor-control-breakout-board.html

Reading a sensor:



This is how a photocell or thermistor is read.

Running an RC servo:

Running a model airplane servo with an Arduino is a very simple task. In fact there is a prewritten example for it. A servo is controlled by sending out a pulse fifty times per second. The longer the pulse is, the more the servo arm deflects :