Batteries

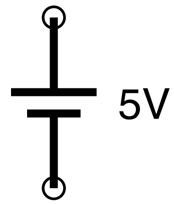
Overview

A battery is a voltage source, meaning that it provides a fixed voltage over a wide range of currents.

Batteries have two terminals—positive and negative (or ground). The rated voltage for the battery is the typical voltage between these two terminals. However, a battery's actual voltage will vary quite a bit over the battery's lifetime.

Batteries also exhibit a small amount of *internal resistance* (also known as *equivalent series resistance*) which limits the amount of current they can provide.

Battery



Schematic Symbol

Notes

Putting batteries together in parallel increases their available current but does not alter their voltage. Putting batteries together in series adds their voltages but does not change the available current.

Coin cell batteries are designated CRxxxx, where the first two digits of xxxx is the diameter in millimeters and the remaining digits tell the height in tenths of millimeters.

Variations

Battery Type	Typical Voltage	Voltage Range	Typical Capacity
AAA	1.5	1.1-1.5	540mAh
AA	1.5	1.1-1.5	1100mAh
C	1.5	1.1-1.5	3800mAh
D	1.5	1.1-1.5	8000mAh
E (9V)	9	7.2-9.6	1200mAh
Coin Cell (all sizes)	3	2-3.6	30-620mAh

Resistors

Overview

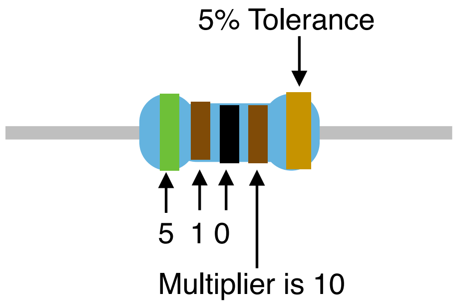
Resistors are devices that resist the flow of current from one terminal to the other. The resistance of a resistor is measured in Ohms.

The power (in watts) dissipated by a resistor is measured by the current flowing through it multiplied by the voltage drop across it. Resistors are rated for their maximum safe amount of power dissipation.

Resistors are often used to provide a safe limit to the amount of current flowing in a circuit or to provide a voltage drop for an input to another circuit.

Resistor

Schematic Symbol



510 * 10 = 5,100
Resistor is 5,100 ohms ± 5%

Finding a Resistor Value

The colored bands on a resistor tell you how much resistance it has. However, these are very tiny and sometimes it is easier just to measure it with a multimeter.

To interpret the colored bands, you first need to orient your resistor so that the last band is on the right (it is usually slightly thicker and set off from the others). This band is the *tolerance* band (use the tolerance column on the right).

The next band to the left is the *multiplier*. Use the multiplier column to read this value. The other bands are used as digits of a number which are then multiplied by the multiplier

Color	Digit	Multiplier	Tolerance
Black	0	1	
Brown	1	10	± 1%
Red	2	100	± 2%
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	± 0.5%
Blue	6	1,000,000	± 0.25%
Violet	7	10,000,000	± 0.1%
Grey	8	100,000,000	± 0.05%
White	9	1,000,000,000	
Gold		0.1	± 5%
Silver		0.01	± 10%

Diodes

Overview

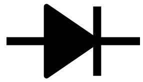
A diode is a device that only permits current to flow in one direction, and block current in the other direction.

All diodes exhibit a *forward voltage drop*, which is the amount of voltage they consume when current is flowing. This is typically 0.6V, though it varies a little based on current flow.

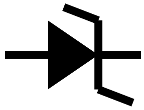
Diodes also have a *reverse breakdown voltage* which is the amount of voltage they can handle in the blocking direction before they start conducting anyway.

Variations

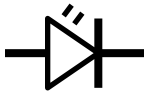
- An LED is a Light-Emitting Diode. LEDs vary in their forward voltage drop based on their color (red=1.8; blue=3.3).
- A Zener diode is a diode that is built for a specific (usually lower than usual) reverse breakdown voltage. The reverse breakdown voltage of a Zener is more fixed/reliable than its forward voltage drop.
- A Schottky diode has a lower forward voltage drop (0.15-0.45V) and is able to turn on and off faster than ordinary diodes, and accordingly also dissipates less heat.



Diode
(schematic symbol)



Zener Diode
(schematic symbol)



LED

Forward Voltage Drop

Diodes are often considered to not have a resistance, but instead to have a simple voltage drop. That is, you apply the voltage drop and ignore resistance. That works for the math, but the reality is a bit different. Essentially, a diode is a variable resistor, where the resistance varies in order to keep the voltage drop essentially fixed. Therefore, diodes dissipate power just like other components, with the voltage drop multiplied by the current flowing through it.

Usages

- Prevent batteries from being inserted backwards in a circuit
- Provide a fixed voltage drop between two points on a circuit, either through the forward voltage drop (regular diode) or the reverse breakdown voltage (Zener diode)
- Convert AC current to DC current by only allowing the positive flows through the circuit

Capacitors

Overview

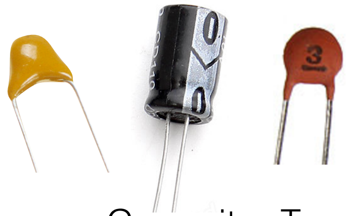
A capacitor is a device that stores energy using a charged electric field. The size of the capacitor is proportional to the amount of charge that it can store. This size is measured in Farads.

Changes in the voltage of one side of the capacitor will be transmitted through to the other side, but a steady-state DC voltage will not after the capacitor initially charges up.

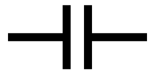
This means that capacitors are ideal for sending AC signals through different DC bias levels, as merely the changes in voltage (the AC component) will be transmitted through the capacitor, while the bias voltages themselves will be blocked. A simplified description says that capacitors allow AC and block DC.

Variations

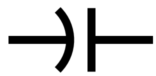
- Capacitors can be made of a variety of materials, which affect several of their properties.
- Capacitors can be non-polar (it doesn't matter which side is which) or polar (one side should always be more positive than another).
- Ceramic disk capacitors are the classic example of non-polar capacitors, and electrolytic capacitors are the classic example of polar capacitors.
- Capacitors also vary in the amount of voltage that can be used with them.



Common Capacitor Types
(tantalum, electrolytic, ceramic disk)



Schematic Symbol (nonpolar)



Schematic Symbol (polar)
(straight line is the positive side)

Finding Capacitance Values

Larger capacitors simply have their capacitance values printed on them. Smaller capacitors just have a set of digits printed on them, such as "104," sometimes with a letter after them. These are a little harder to interpret.

On these capacitors, the first digits should be read as-is, and the last digit is the number of additional zeroes that should be tacked onto the end. This value is then interpreted as picofarads.

So, the value "104" means we take "10" and then add "4" zeroes, giving us "100000". This is the capacitance in picofarads. This is the same as 100 nanofarads. If there is any code starting with a letter, this is a tolerance marking.

Inductors

Overview

An inductor is a device that stores energy in its magnetic field. The size of the inductor (in Henries) is proportional to the size of the magnetic flux it can create for a given level of current.

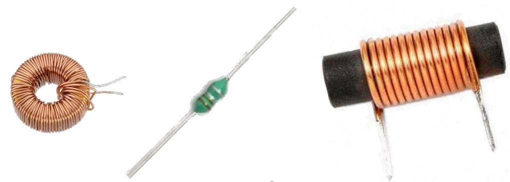
Inductors prevent changes in current by varying their electric field. Reducing the current through an inductor causes a partial collapse of the field, creating a voltage on the other side, which feeds current.

A simplified way of understanding inductors is to think of them as allowing DC current but blocking AC current.

Inductors are generally constructed by winding wire around an iron core material.

Uses

- Inductors serve as the main gateway between electrical and mechanical action through the magnetic field.
- Inductors are used to open and close valves and switches magnetically.
- Inductors are used to drive electric motors.
- Inductors are used to limit certain frequencies in circuits.
- Inductors are used in speakers, where changes in magnetism cause the speakers to move.
- Inductors can be used as transformers to convert power from one voltage/current combination to another of equal power.



Various styles of inductors

Schematic Symbol

Inductive Kick

Inductors use current to maintain their magnetic fields. When the current decreases suddenly, the magnetic field is converted into a large voltage, creating what is known as an inductive kick.

This kick can be damaging to electronic components. To mitigate this, a diode can be placed backwards across the inductor so that, under normal circumstances, it does not conduct, but when an inductor produces a voltage spike, it re-routes the current back through the inductor where it can dissipate slowly in a loop rather than building up and damaging other components with a large voltage spike.

Inductor Color Codes

Simple inductors (i.e., those in packaged casings) are marked identically to resistors, except that the resulting value is in *micro*Henries rather than just Henries.

NPN BJT Transistors

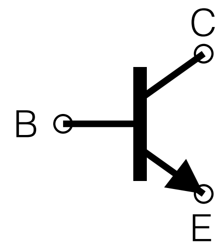
Overview

Transistors come in a variety of configurations. BJT (bipolar junction transistors) are *current amplifying* devices.

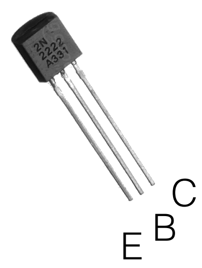
In an NPN (negative-positive-negative) transistor, small changes to the current at the base result in large changes in current coming into the collector.

In a transistor, the voltage at the emitter is one diode drop (0.6V) below the base, and if it is not the transistor does not conduct. The transistor's beta is the multiplier between the base current and the collector current. The collector's voltage must be above the base voltage or the transistor is saturated (acts as a short circuit from collector to emitter).

If these conditions are met, the transistor acts as a variable resistor which keeps the collector current as an amplification of base current.



Schematic Symbol



Transistor

Pin Configuration

- Base (B) - this is the terminal that contains the current to be amplified.
- Collector (C) - this is the terminal where the amplified current will flow into.
- Emitter (E) - this is the terminal where the currents from both the base and the collector will flow out of, at a voltage level of one diode drop (0.6V) less than the base.

Variations

- A PNP transistor is the opposite of an NPN—the current applied at the base *reduces* the flow of current into the collector.

- A FET (field-effect transistor) operates using voltages rather than current. This allows for negligible current usage on the inputs, but also reduced gain and more complicated support considerations.

Design Considerations

Transistor designs are based on which terminals the signal itself passes through (the third terminal is referred to as the "common" terminal).

In common collector configurations (also called emitter followers) the signal passes from base to emitter with an increased current but no increased voltage.

In common emitter configurations, the signal passes from the base to the collector, with the increase in current converted to a voltage through a collector on the resistor.

YwRobot Power Module

Overview

This device allows you to supply power to your breadboard projects from a variety of sources through its barrel jack. The module down-steps the voltage to 5V or 3.3V (selectable with jumpers).

The power module comes with an on/off switch, and a set of header pins that can be used to wire power to other places.

The module is made to fit on a standard breadboard, where the output pins align directly onto the power rails of the breadboard.

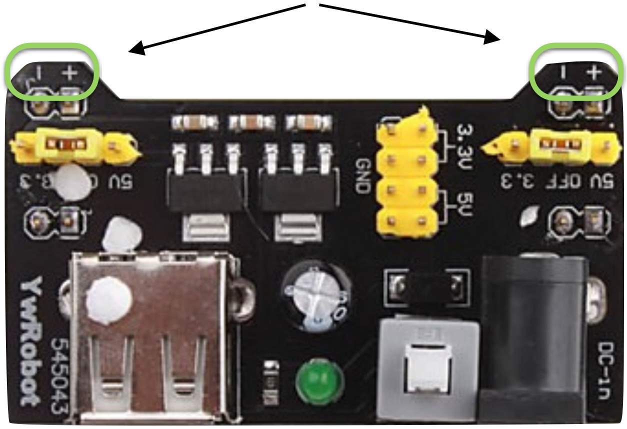
Be sure to align the positive and negative markings on the module with their matching power rails!

Note that this part is not technically part of any schematic, and simply acts as a voltage source within a schematic.

Variations

- On some boards the USB jack can be used as an power input, and on some it is a power output only.
- The popularity of this module has prompted a number of manufacturers to build similar devices with a variety of shapes and input/output methods.

Align these with the +/- power rails on your breadboard



Pin Configuration

The power module connects directly to your breadboard. Each side can be independently selected for 3.3V or 5V power via jumpers.

In the middle is a set of male headers for 3.3V, 5V, and ground.

Limitations

- Minimum input voltage: 6.5V (DC)
- Maximum input voltage: 12V (DC)
- Output voltage: 3.3/5V (selectable)
- Maximum output current: 700 mA
- Barrel jack plug size: 5.5mm x 2.1mm

555 Timer

Overview

The 555 timer is a collection of components that can be configured to provide timings and oscillations.

It uses two voltage levels—one-third supply voltage and two-thirds supply voltage. Internally, it consists of:

- Two comparators (one for each voltage level)
- A flip-flop (single bit storage) to know what state it is in and to switch states at the appropriate time
- An output driver
- A reset input

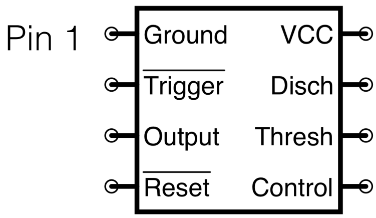
The timer relies on external circuitry (such as an RC time circuit) to supply timings.

The timer effectively has two states. In the “charging” state, when the **Discharge** pin is disconnected, and the **Threshold** pin is waiting for a high (2/3) voltage. In the “discharging” state, the **Discharge** pin is connected to ground, and the **Trigger** pin is waiting for a low (1/3) voltage. The typical usage is to provide an oscillating circuit.

Variations

- Can be implemented using CMOS/ FETs or BJTs. FET implementation consumes less power, but can source less output

- Many variations in maximum oscillation frequency



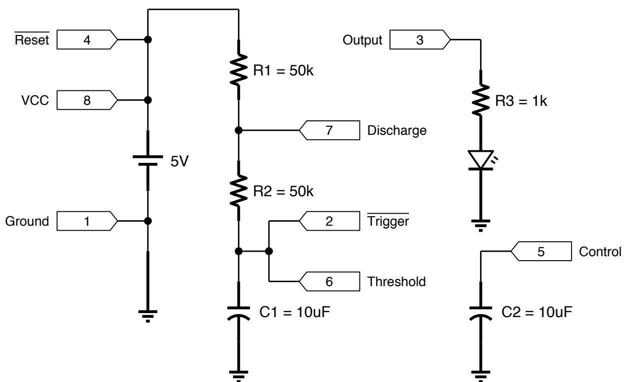
Pin Configuration

- **Trigger** and **Threshold** detect going below 1/3 and above 2/3 voltage, respectively
- **Discharge** provides a ground that is only attached when the chip is in the discharging state.
- **Output** supplies a high voltage when the chip is in the charging state, and a low voltage when it is in the discharging state.
- **Reset** should be normally tied to a positive supply - it resets the circuit when it goes low.
- **Control** is normally connected to ground with a capacitor (10 μF recommended).

Specifications

- Supply Voltage: Usually 2V to 15V
- Output current: 100mA—200mA

Implementation Example



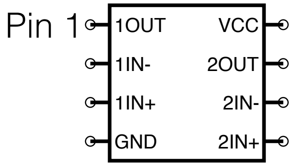
LM393 and LM339 Voltage Comparator

Overview

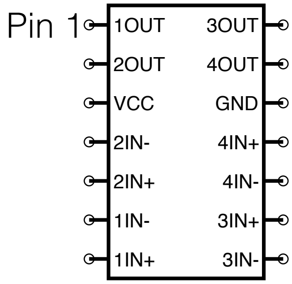
The LM393 is a dual voltage comparator. Each channel has two inputs—designated IN+ and IN-. When the voltage at IN+ is greater than the voltage at IN- the output (OUT) is positive (actually, it is disconnected; see more later). Otherwise, the output is connected to ground.

The output is called an “open collector” output, which means that the “positive” state has no output current, and is essentially disconnected. However, in the negative state the output is connected to ground. This means that to use the output, you need to provide your own positive voltage through a pull-up resistor (this allows you to set your own output voltage).

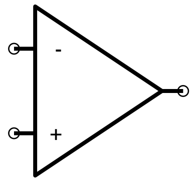
The LM339 is identical except that it has four channels instead of two. Note that the schematic symbol for this is the same as that of an op-amp, largely because they perform similar (though not identical) functions.



LM393



LM339



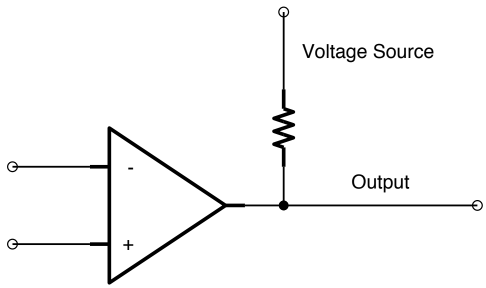
Schematic Symbol
(per channel)

Specifications

- Supply voltage: 2V to 36V
- Input voltage: -0V to 1.5V less than supply voltage.
- Maximum sink current: 20mA (when output is grounded)
- Input impedance: high (inputs use very negligible amounts of current)
- Quiescent chip current: 1mA

Variations

Various chips differ in the amount of current they can sink, how fast they respond to changes in input voltage, how smooth the transition is from one state to the other, and the minimum amount of difference required to trigger.



Usage of the Comparator
with a pull-up resistor

CD4081 & 7408 Quad AND Gate

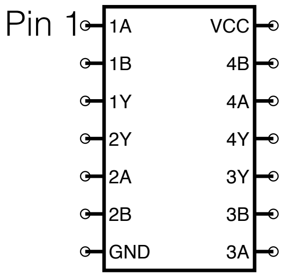
Overview

The quad AND gate is a set of four AND logic gates on a single chip. The output (Y) will be high only if *both* inputs (A & B) are high.

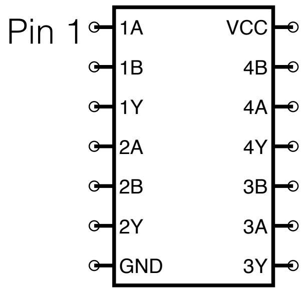
The required voltages for low and high on input and the guaranteed voltages for low and high on output are listed in the specifications section.

For the output to be high, both A & B must be high. Otherwise, the output (Y) will be low.

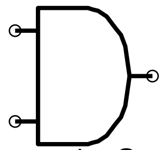
The 7408 and the CD4081 are the TTL and CMOS versions of the chip, respectively.



CD4081



7408



Schematic Symbol
(per channel)

Variations

- 74HC08 - pin-compatible with the 7408; voltage and current characteristics of the CD4081
- 74HCT08 - pin-compatible and voltage-level compatible with 7408; similar current usage as the CD4081
- 74LS08 - fast-switching version of the 7408

Specifications (CD4081)

- Supply voltage: 3V to 15V
- Input (high) voltage: > 2/3 supply
- Output (high) voltage: supply - 0.05
- Input (low) voltage: < 1/3 supply
- Output (low) voltage: 0V - 0.5V
- Maximum output current: ~5mA

Specifications (7408)

- Supply voltage: 5V
- Input (high) voltage: > 2V
- Output (high) voltage: > 2.7V
- Input (low) voltage: < 0.8V
- Output (low) voltage: < 0.4V
- Maximum output current: 100mA

CD4071 & 7432 Quad OR Gate

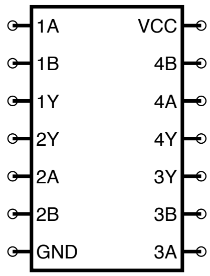
Overview

The quad OR gate is a set of four OR logic gates on a single chip. The output (Y) will be high if *either or both* inputs (A & B) are high.

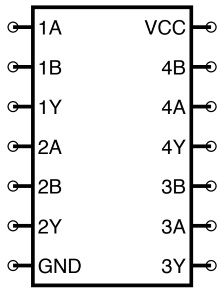
The required voltages for low and high on input and the guaranteed voltages for low and high on output are listed in the specifications section.

For the output to be high, either A or B (or both) must be high. Otherwise, the output (Y) will be low.

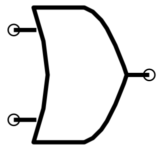
The 7432 and the CD4071 are the TTL and CMOS versions of the chip, respectively.



CD4071



7432



Schematic Symbol
(per channel)

Specifications (CD4071)

- Supply voltage: 3V to 15V
- Input (high) voltage: > 2/3 supply
- Output (high) voltage: supply - 0.05
- Input (low) voltage: < 1/3 supply
- Output (low) voltage: 0V - 0.5V
- Maximum output current: ~5mA

Variations

- 74HC32 - pin-compatible with the 7432; voltage and current characteristics of the CD4071
- 74HCT32 - pin-compatible and voltage-level compatible with 7432; similar current usage as the CD4071
- 74LS32 - fast-switching version of the 7432

Specifications (7432)

- Supply voltage: 5V
- Input (high) voltage: > 2V
- Output (high) voltage: > 2.7V
- Input (low) voltage: < 0.8V
- Output (low) voltage: < 0.4V
- Maximum output current: 100mA

CD4001 & 7402 Quad NOR Gate

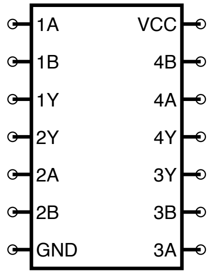
Overview

The quad NOR gate is a set of four NOR logic gates on a single chip. The output (Y) will be high if *both* inputs (A & B) are high or if *both* inputs are low.

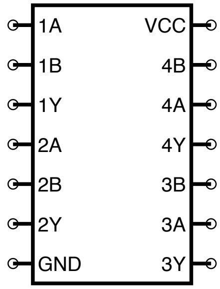
The required voltages for low and high on input and the guaranteed voltages for low and high on output are listed in the specifications section.

For the output to be high, either both A and B must be high or neither must be high. Otherwise, the output (Y) will be low.

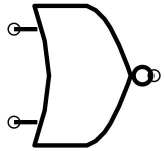
The 7402 and the CD4001 are the TTL and CMOS versions of the chip, respectively.



CD4001



7402



Schematic Symbol
(per channel)

Specifications (CD4001)

- Supply voltage: 3V to 15V
- Input (high) voltage: > 2/3 supply
- Output (high) voltage: supply - 0.05
- Input (low) voltage: < 1/3 supply
- Output (low) voltage: 0V - 0.5V
- Maximum output current: ~5mA

Variations

- 74HC02 - pin-compatible with the 7402; voltage and current characteristics of the CD4001
- 74HCT02 - pin-compatible and voltage-level compatible with 7402; similar current usage as the CD4001
- 74LS02 - fast-switching version of the 7402

Specifications (7402)

- Supply voltage: 5V
- Input (high) voltage: > 2V
- Output (high) voltage: > 2.7V
- Input (low) voltage: < 0.8V
- Output (low) voltage: < 0.4V
- Maximum output current: 100mA

CD4011 & 7400 Quad NAND Gate

Overview

The quad NAND gate is a set of four NAND logic gates on a single chip. The output (Y) will be low unless *both* inputs (A & B) are high.

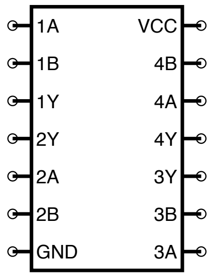
The required voltages for low and high on input and the guaranteed voltages for low and high on output are listed in the specifications section.

For the output to be high, A and B can be anything as long as they are not both high. Otherwise, the output (Y) will be low.

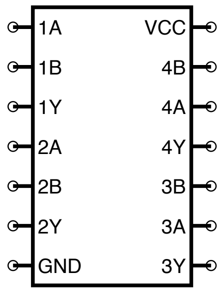
The 7400 and the CD4011 are the TTL and CMOS versions of the chip, respectively.

Variations

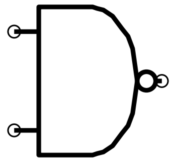
- 74HC00 - pin-compatible with the 7400; voltage and current characteristics of the CD4011
- 74HCT00 - pin-compatible and voltage-level compatible with 7400; similar current usage as the CD4011
- 74LS00 - fast-switching version of the 7400



CD4011



7400



Schematic Symbol
(per channel)

Specifications (CD4011)

- Supply voltage: 3V to 15V
- Input (high) voltage: > 2/3 supply
- Output (high) voltage: supply - 0.05
- Input (low) voltage: < 1/3 supply
- Output (low) voltage: 0V - 0.5V
- Maximum output current: ~5mA

Specifications (7400)

- Supply voltage: 5V
- Input (high) voltage: > 2V
- Output (high) voltage: > 2.7V
- Input (low) voltage: < 0.8V
- Output (low) voltage: < 0.4V
- Maximum output current: 100mA

CD4070 & 7486 Quad XOR Gate

Overview

The quad XOR (exclusive-OR) gate is a set of four XOR logic gates on a single chip. The output (Y) will be high if either input (A or B) *but not both* are high.

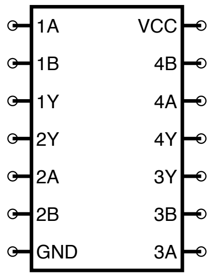
The required voltages for low and high on input and the guaranteed voltages for low and high on output are listed in the specifications section.

For the output to be high, either A or B must be high but not both of them. Otherwise, the output (Y) will be low.

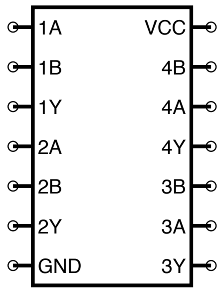
The 7486 and the CD4070 are the TTL and CMOS versions of the chip, respectively.

Variations

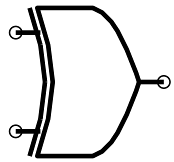
- 74HC86 - pin-compatible with the 7486; voltage and current characteristics of the CD4070
- 74HCT86 - pin-compatible and voltage-level compatible with 7486; similar current usage as the CD4070
- 74LS86 - fast-switching version of the 7486



CD4011



7400



Schematic Symbol
(per channel)

Specifications (CD4070)

- Supply voltage: 3V to 15V
- Input (high) voltage: > 2/3 supply
- Output (high) voltage: supply - 0.05
- Input (low) voltage: < 1/3 supply
- Output (low) voltage: 0V - 0.5V
- Maximum output current: ~5mA

Specifications (7486)

- Supply voltage: 5V
- Input (high) voltage: > 2V
- Output (high) voltage: > 2.7V
- Input (low) voltage: < 0.8V
- Output (low) voltage: < 0.4V
- Maximum output current: 100mA

LM78xx Voltage Regulator

Overview

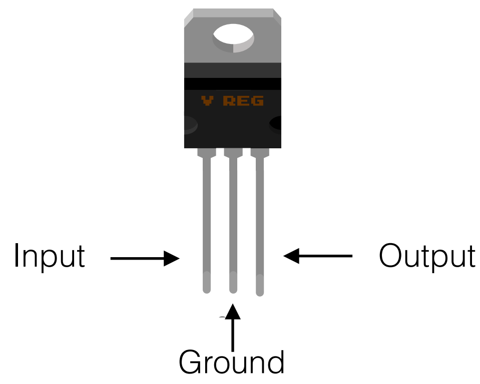
The LM78xx voltage regulator is actually a series of chips to provide a consistent voltage output from a variety of voltage inputs. Each chip is named with the number of volts it supplies in its output. For instance, the LM7805 outputs a constant 5V and the LM 7812 outputs a constant 12V.

These chips are linear voltage regulators, which means that they regulate voltage by dissipating excess power as heat. If significant heat develops, the LM78xx can have a heat sink attached to the back plate, which also serves as a second ground.

The LM78xx requires an input voltage at least 2.5V above the regulated voltage. This is known as the “drop-out” voltage of the chip.

Variations

- The 78xxSR is a line of switching regulators, meaning that they do not dissipate significant power when regulating (they operate by turning the power on and off quickly rather than dissipating excess power). They waste significantly less current but do have a significant cost.
- The TL750Mxx chips are similar to the LM78xx chips, but have a very low “drop-out” voltage (~0.6V).
- The LM79xx chips are similar to the LM78xx chips, but act as *negative* voltage supplies (-5V, etc).

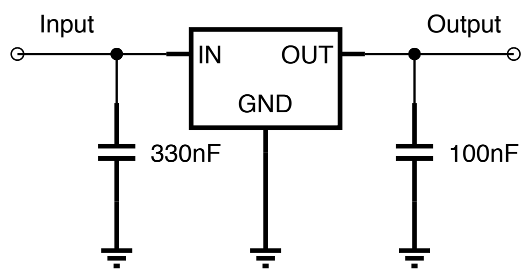


Specifications

- Maximum input voltage: 35V
- Maximum output current: 1A
- Built-in overcurrent protection
- Protection against short circuits
- Overheating protection (shuts off when overheating)

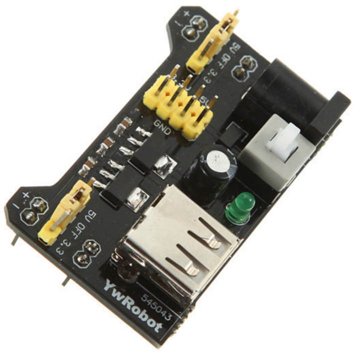
Usage Notes

- The specifications require two capacitors for operation—a 330nF capacitor on the input and a 100nF capacitor on the output (see below).
- These capacitors are generally not required for very simple projects—you can simply hook the input directly to your positive power source, the ground to your ground, and the output to your project.



The L293 H-Bridge

Overview



Pin Configuration

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Variations

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Limitations

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