Today's plan

0. Announcements
1. Driving external loads
2. Motors: dc motors, stepper motors, servos
3. Op-amps
4. Comparators

Next time:
- Powering your project
- Measuring capacitance
- midterm solutions

Announcements

- Project Status Report

  In your lab: March 7/9/13 (3^{rd} week of project time) I would like a short written status report turned in. The report should discuss your progress so far: what has been accomplished, what remains to be done. If you have encountered problems, discuss them, and your plans to move forward. If you need help to make progress, please mention it.

  These reports need not be long, just a few sentences is fine.

Controlling things with the microcontroller

MSP430 P1.x maximum output current: +/- 6 mA (x 3.3V = 20mW)

To drive external loads that are more demanding than logic chips, the MSP430 needs some help.

Some possibilities:

- Beefier logic
- op-amps
- Buffer/driver
- Transistor (bipolar or MOSFET)
- opto-isolators
- Relay
- Solid-state relay
- H Bridge chip (eg for bi-directional motors)

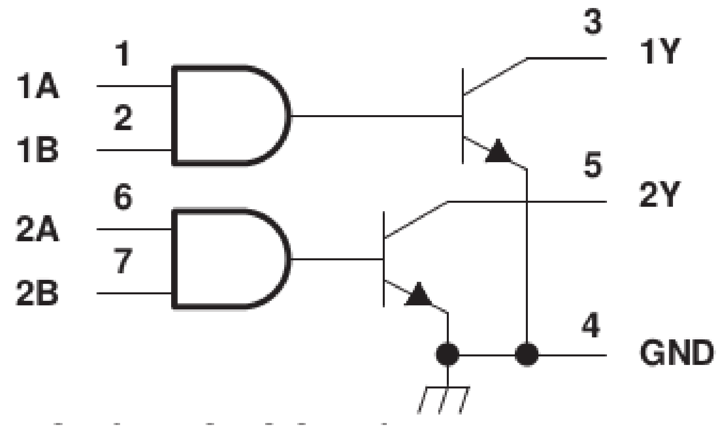
REFERENCE: The Art of Electronics (Horowitz and Hill)

Controlling things with the microcontroller

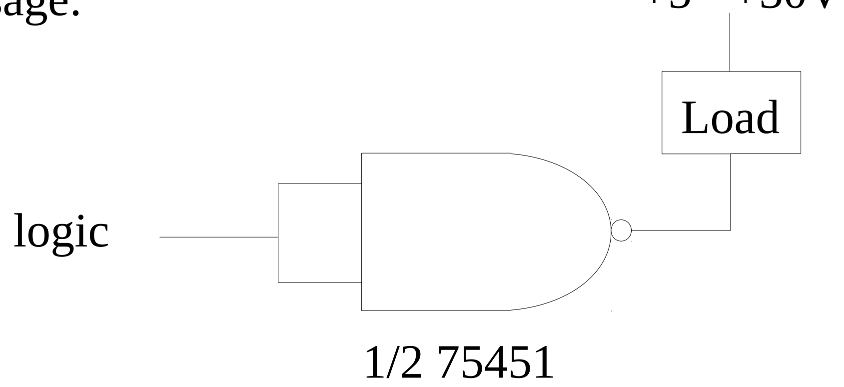
Driver eg SN75451

up to 300 mA

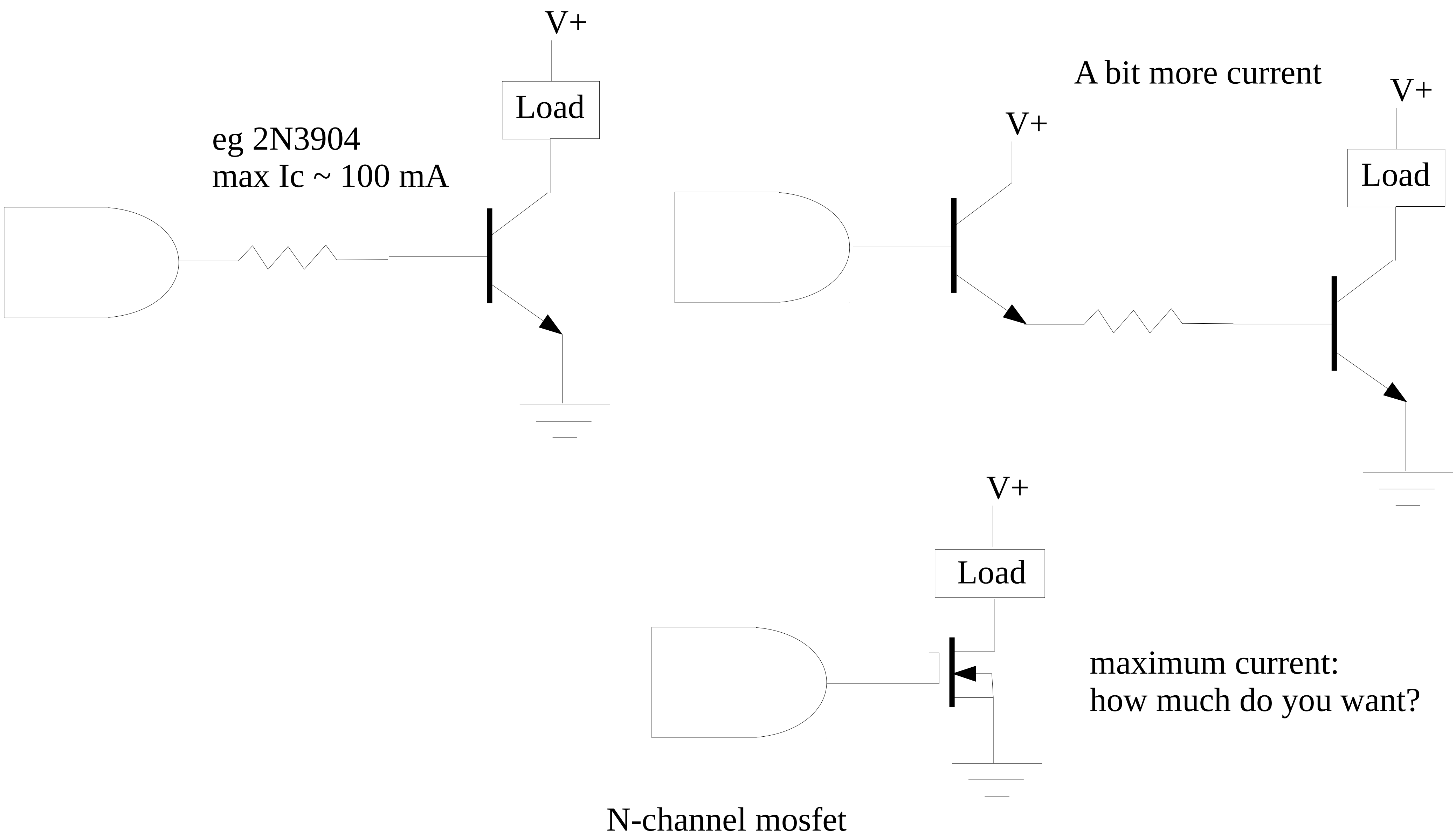
logic diagram (positive logic)



usage:

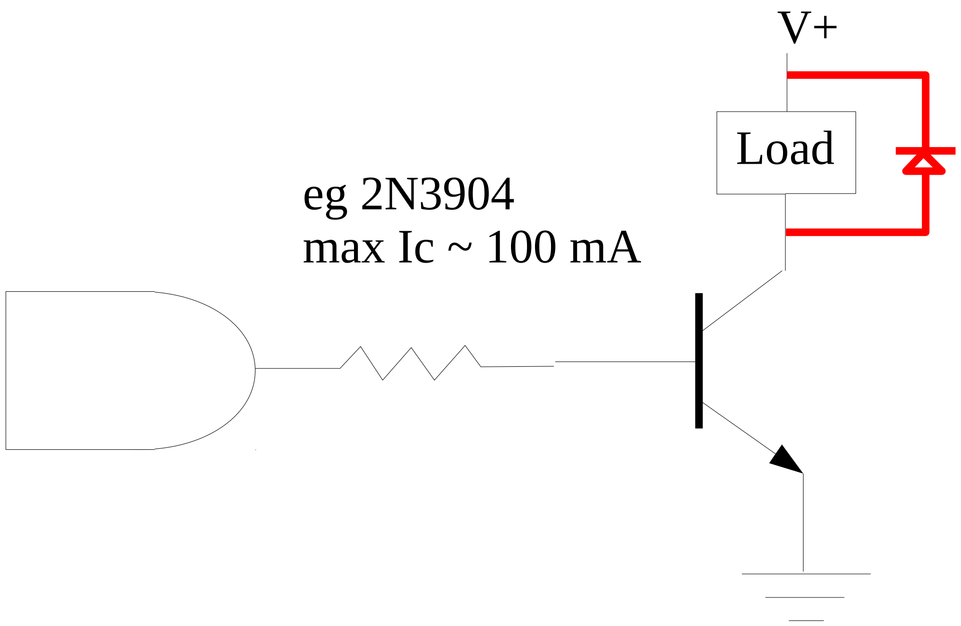


Driving loads: Transistors

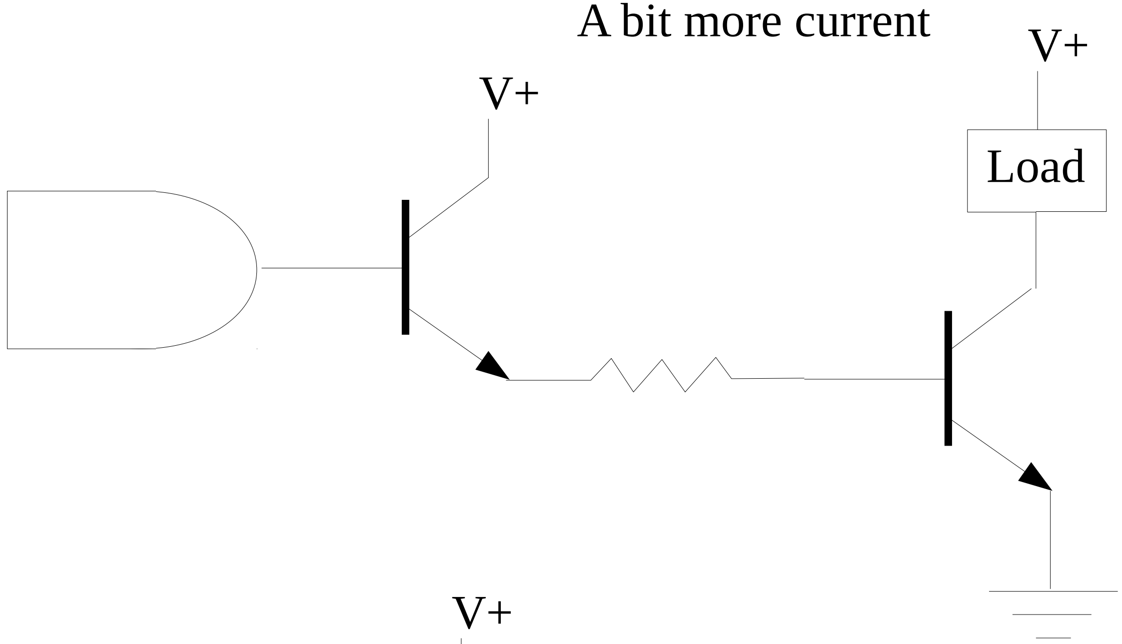


Driving loads: Transistors

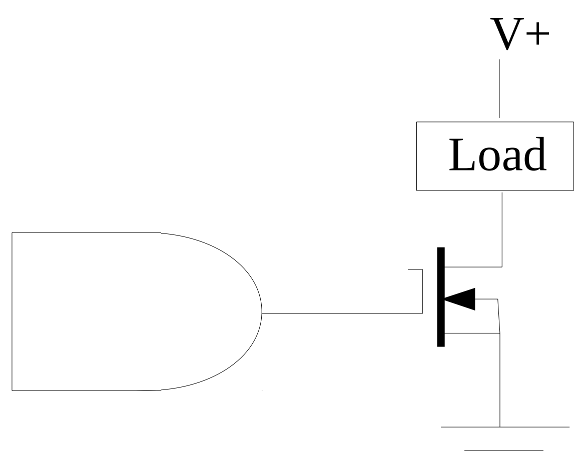
eg 2N3904
max Ic ~ 100 mA



A bit more current



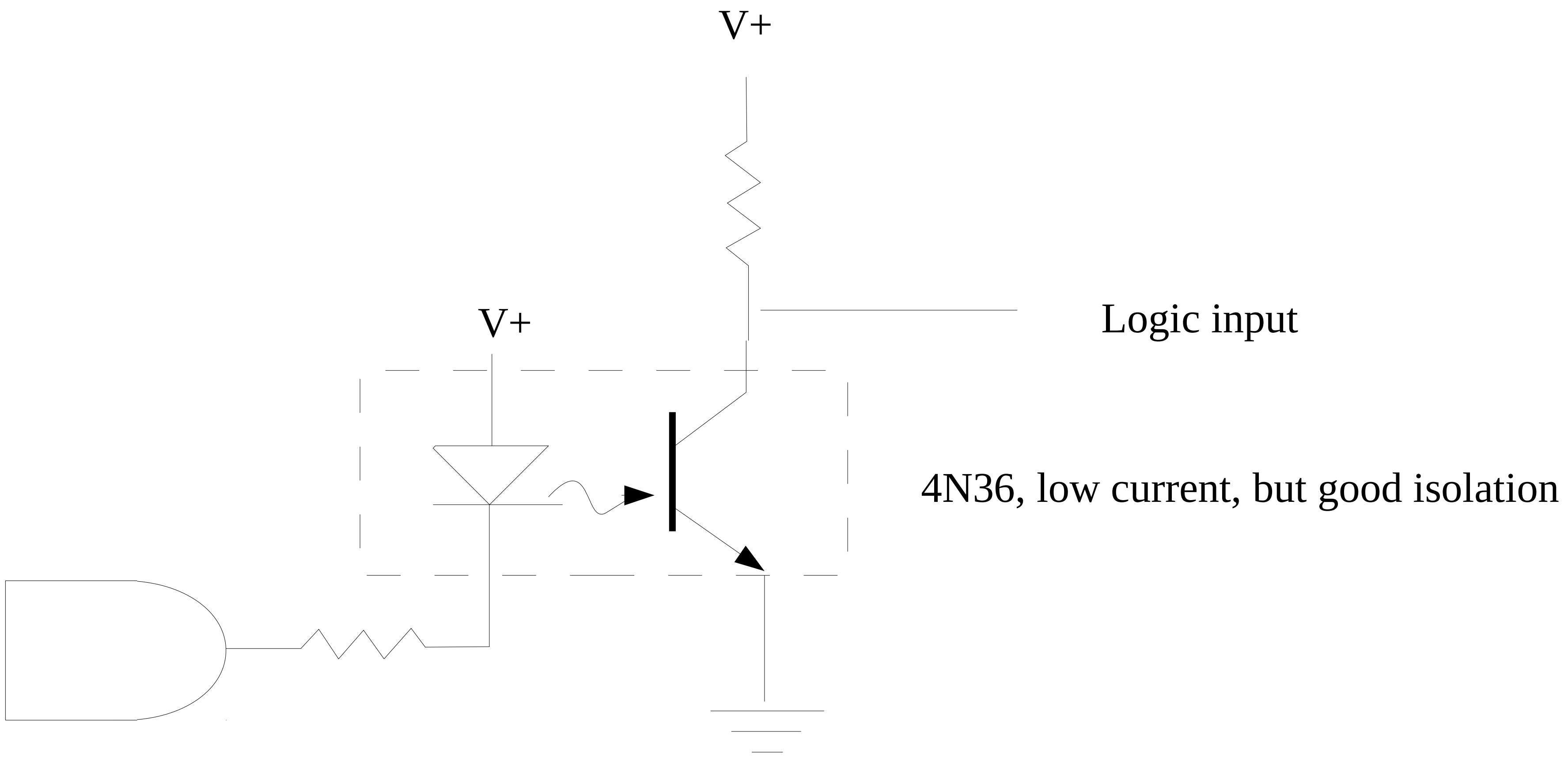
Inductive loads require that
you protect the transistor with a diode!



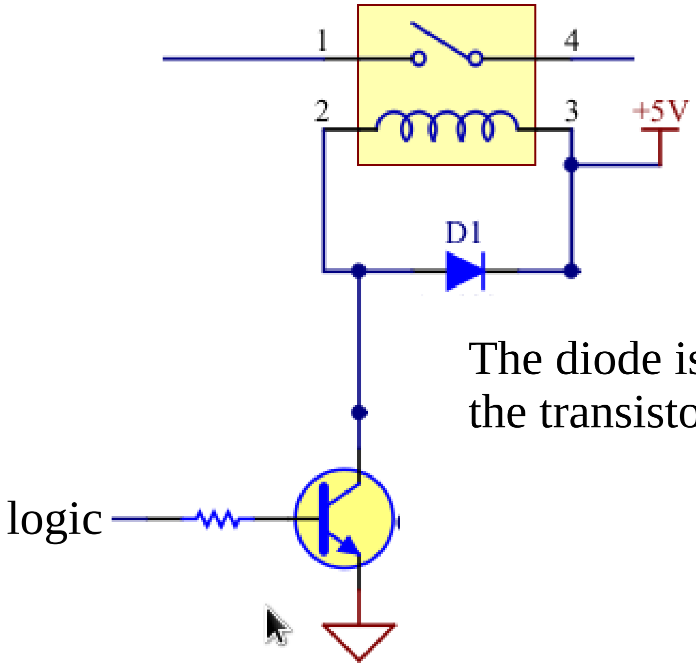
maximum current:
how much do you want?

N-channel mosfet

Driving loads: Optoisolators



Driving loads: Relays



The diode is essential to prevent destroying the transistor on turn-off!

There are some small low-current relays that can be driven directly by logic chips, again, a diode is essential to protect the logic circuit from the inductive spike on turn-off!

Driving loads: Solid-state Relays

good for AC, large loads, fast, repeated switching
(expensive, may need a heat sink), Often will synchronize to line voltage.

eg Crydom D2425: 280VAC, 25A !
$44

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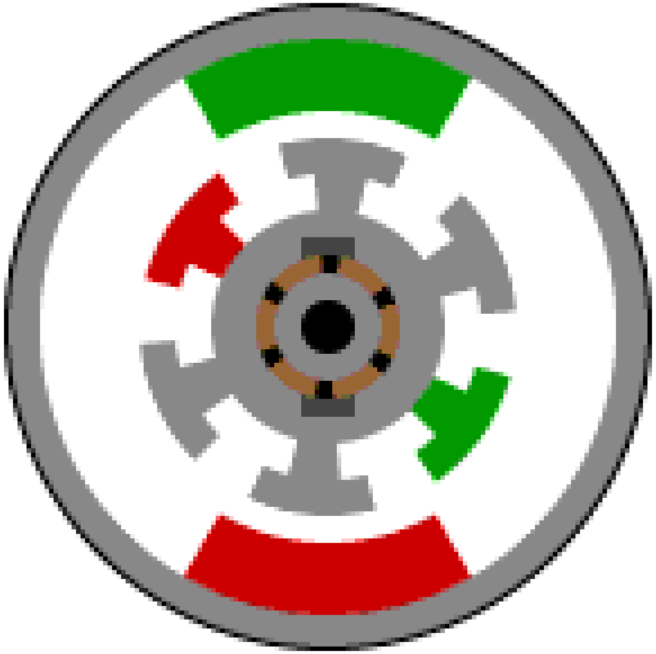
(expensive, may need a heat sink), Often will synchronize to line voltage.

eg Crydom D2425: 280VAC, 25A !
$44

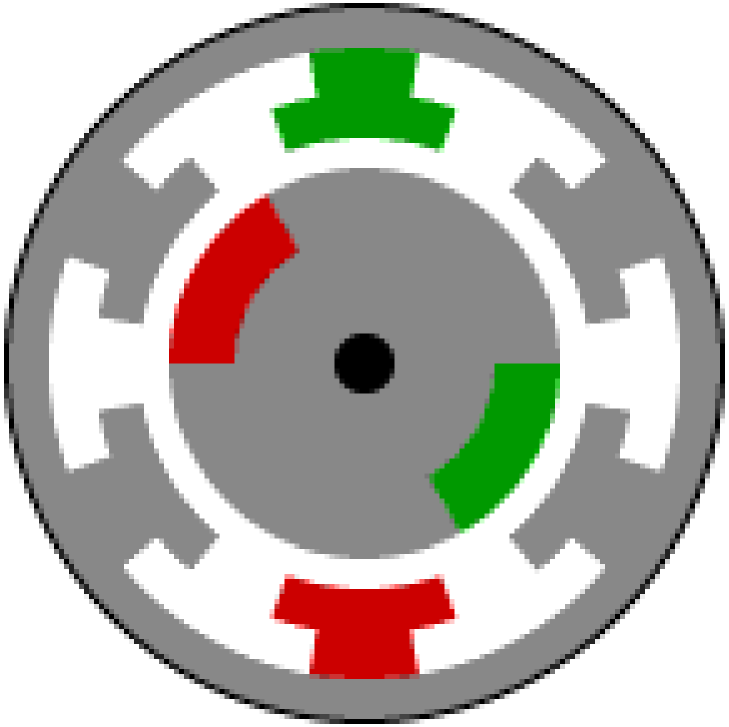
Be careful buying solid-state relays on the grey (Ebay etc) market, there are many 'fakes' out there.

Motors: DC motors



http://www.freescale.com/webapp/sps/site/overview.jsp?code=WBT_MOTORDCTUT_WP

Motors: Brushless DC motors



http://www.freescale.com/webapp/sps/site/overview.jsp?code=WBT_MOTORBLDCTUT_WP

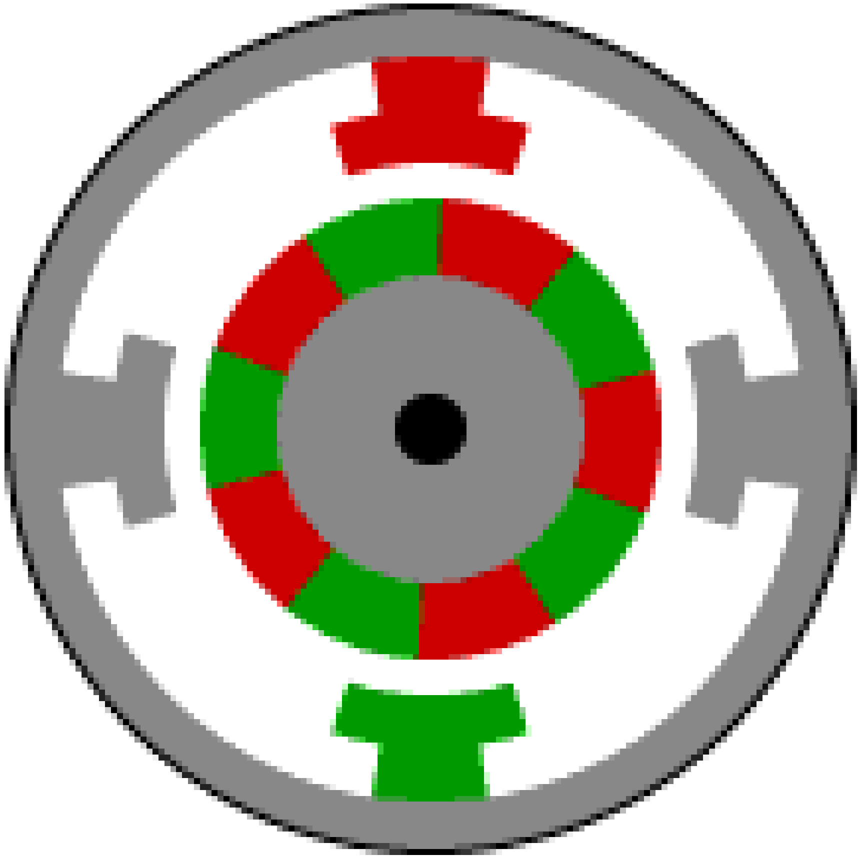
Motors: Servos

photo from Hobby Servo Fundamentals by Darren Sawicz

- precise position control
- provide a PWM signal to specify position
- typical range of 0-180 degrees

- contains a DC motor, gearing, a potentiometer, control electronics.
- The average PWM voltage is compared to the position, as measured by the potentiometer. The control electronics then drive the motor forward or backward to set the angle as requested.
- Typical PWM period of 20 ms with on time of ~1 – ~2 ms (1.5 ms is 'center'). Wire colours often: red = +5 V, black = ground, white = PWM control.
- Position depends on length of on-pulse, not on duty cycle.

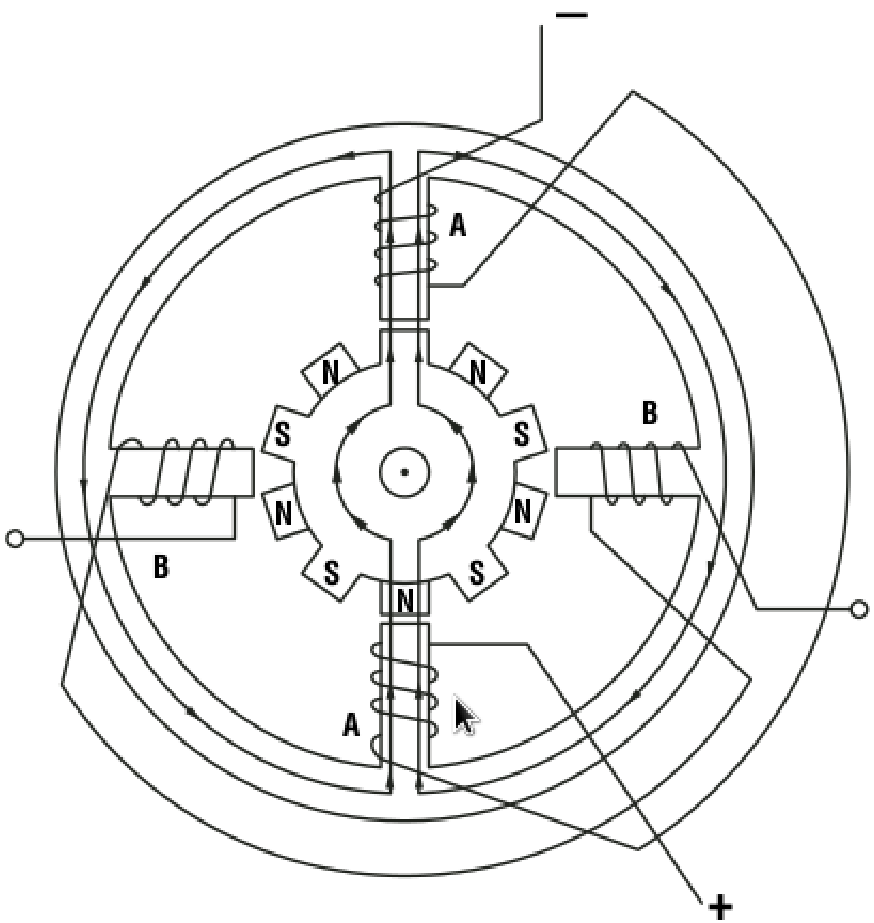
Motors: Stepper motors



Fixed step size, often
200 steps per revolution.

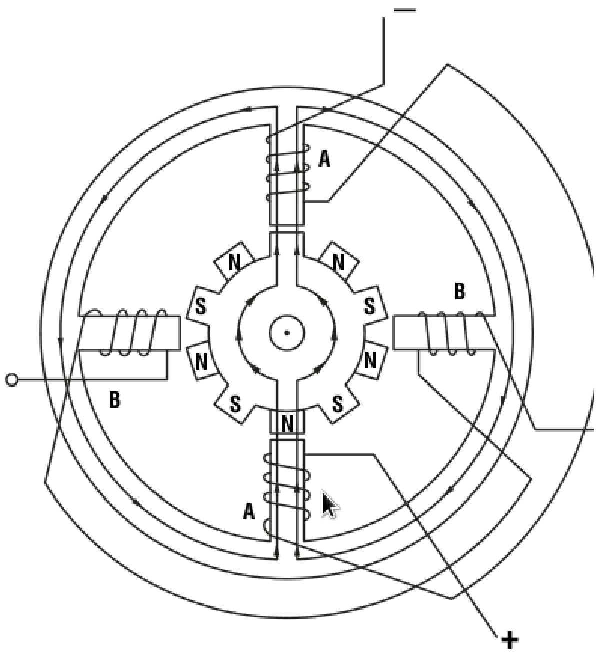
http://www.freescale.com/webapp/sps/site/overview.jsp?code=WBT_MOTORSTEPTUT_WP

Motors: Stepper motors

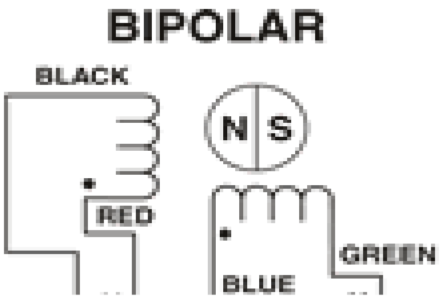


From: Introduction to Step Motors, Applied Motion Products. http://www.omega.ca/auto/pdf/REF_IntroStepMotors.pdf

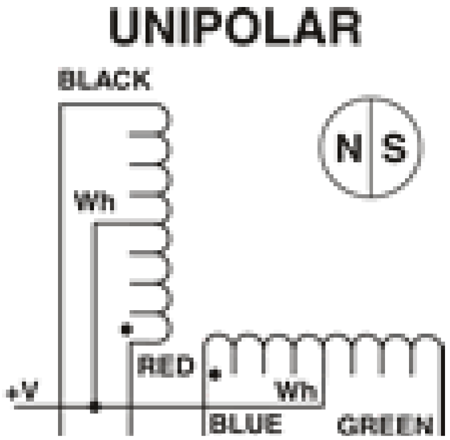
Motors: Stepper motors



Unipolar vs bipolar windings:



4 wires (usually)

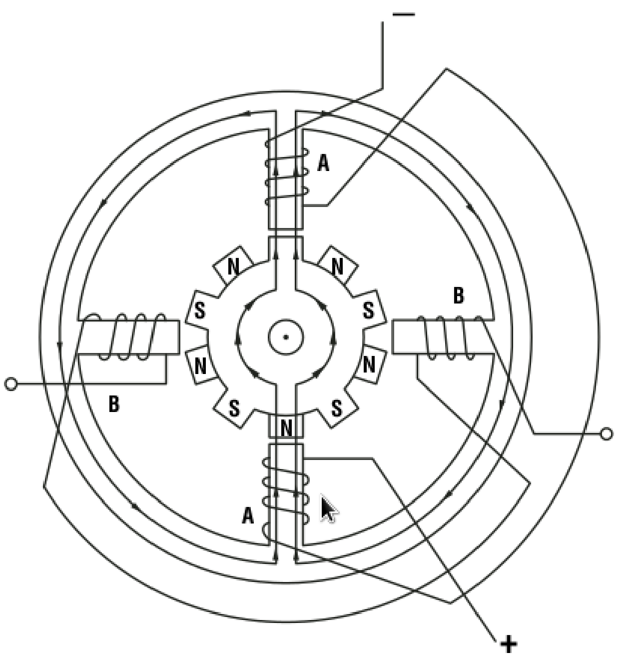


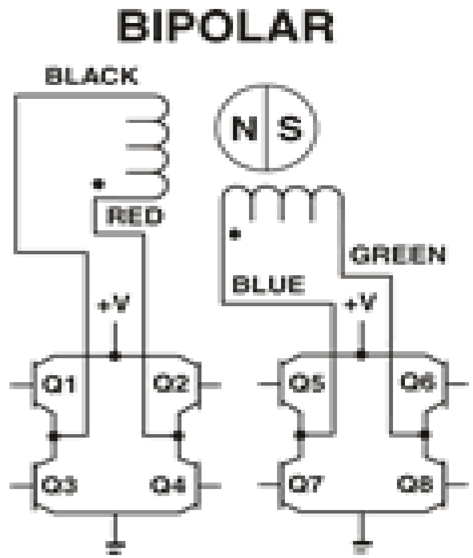
Unipolar stepper (5, 6 or 8 wires)

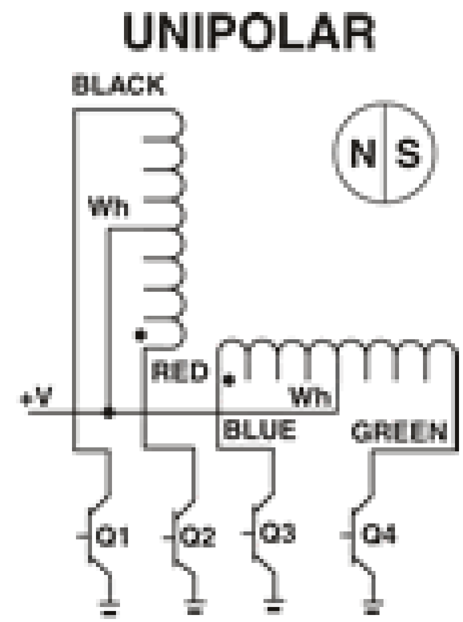
http://www.haydonkerk.com/Resources/StepperMotorTheory/tabid/192/Default.aspx

Motors: Stepper motors

Unipolar vs bipolar windings:



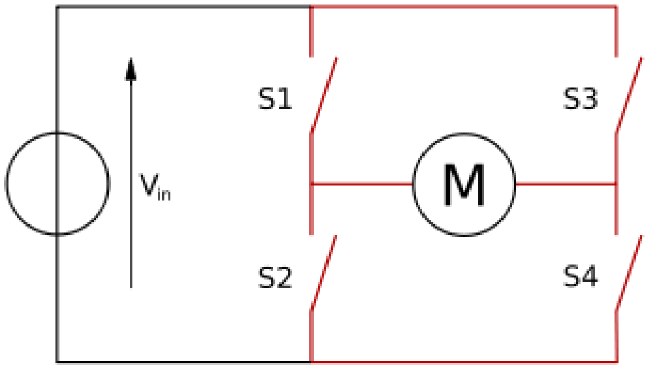




http://www.haydonkerk.com/Resources/StepperMotorTheory/tabid/192/Default.aspx

Driving Motors: H-bridge

To drive a dc motor in either direction with a single power supply, close S1 and S4 OR S2 and S3.



http://en.wikipedia.org/wiki/File:H_bridge.svg

The switches are often transistors: bipolar or MOSFETs

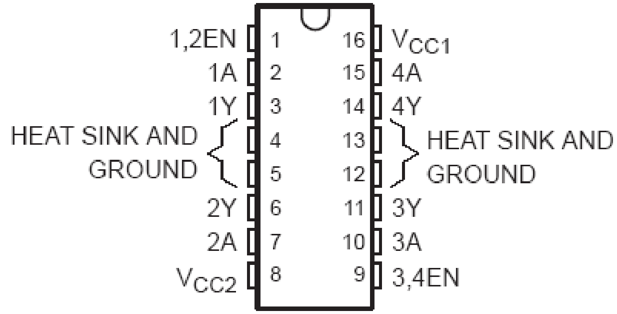
Driving Motors: H-bridge

SN754410
QUADRUPLE HALF-H DRIVER

SLRS007B – NOVEMBER 1986 – REVISED NOVEMBER 1995

- **1-A Output-Current Capability Per Driver**
- **Applications Include Half-H and Full-H Solenoid Drivers and Motor Drivers**
- **Designed for Positive-Supply Applications**
- **Wide Supply-Voltage Range of 4.5 V to 36 V**
- **TTL- and CMOS-Compatible High-Impedance Diode-Clamped Inputs**
- **Separate Input-Logic Supply**
- **Thermal Shutdown**
- **Internal ESD Protection**
- **Input Hysteresis Improves Noise Immunity**
- **3-State Outputs**
- **Minimized Power Dissipation**
- **Sink/Source Interlock Circuitry Prevents Simultaneous Conduction**
- **No Output Glitch During Power Up or Power Down**
- **Improved Functional Replacement for the SGS L293**

NE PACKAGE
(TOP VIEW)



FUNCTION TABLE
(each driver)

INPUTS†		OUTPUT
A	**EN**	**Y**
H	H	H
L	H	L
X	L	Z

H = high-level, L = low-level
X = irrelevant
Z = high-impedance (off)
† In the thermal shutdown mode, the output is in a high-impedance state regardless of the input levels.

description

The SN754410 is a quadruple high-current half-H driver designed to provide bidirectional drive currents up to 1 A at voltages from 4.5 V to 36 V. The device is designed to drive inductive loads such as relays, solenoids, dc and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

Driving Motors: H-bridge

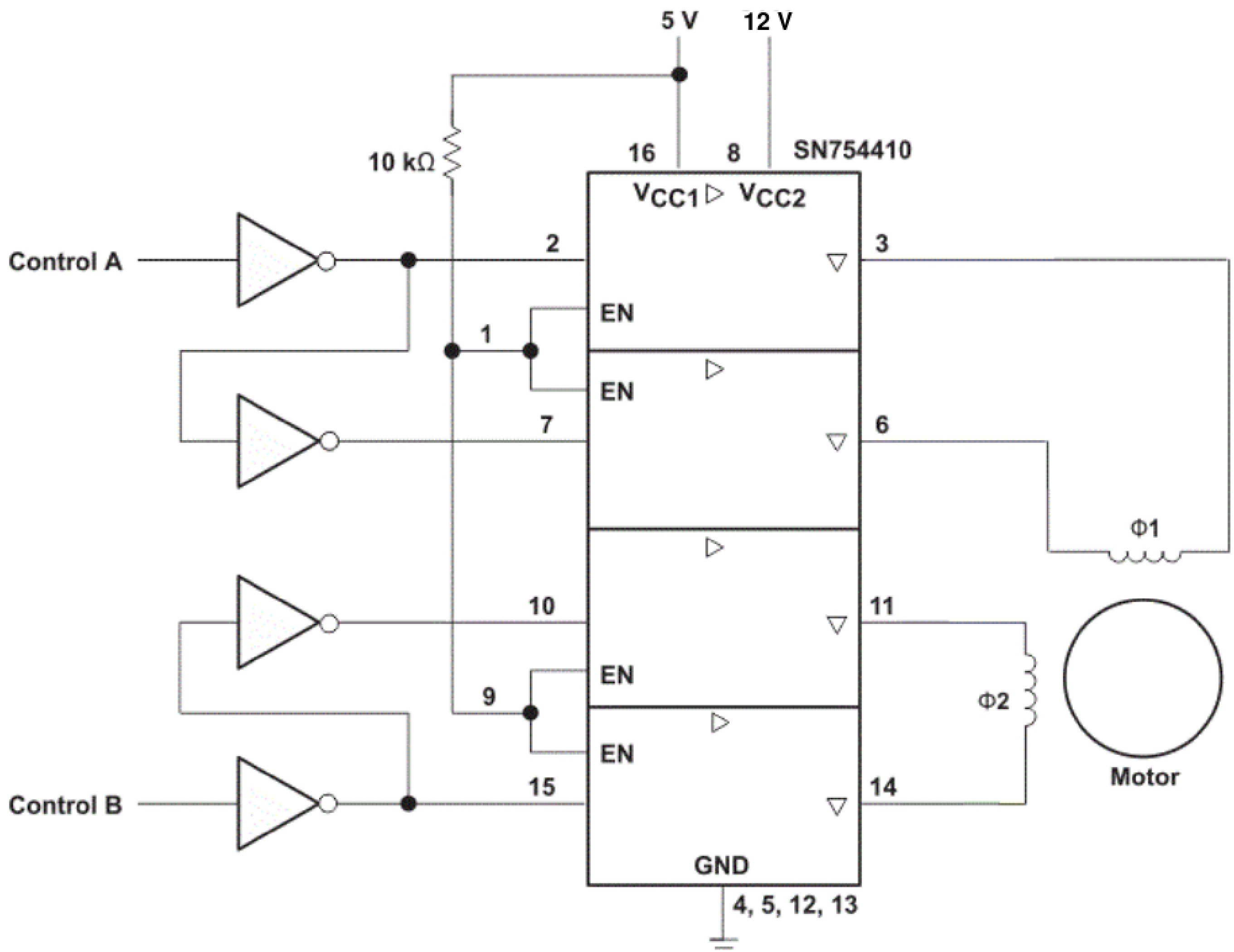


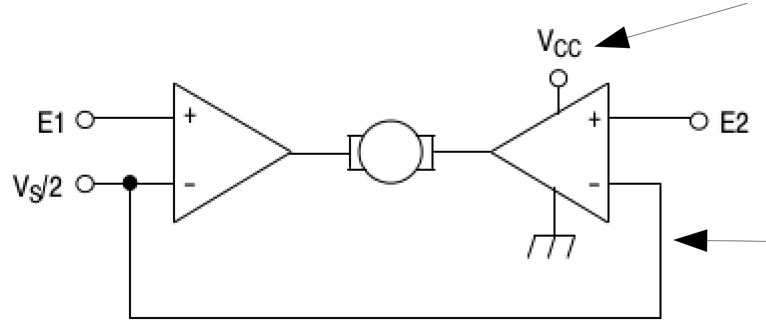
Figure 7. Typical Application Schematic

This is for a bipolar stepper motor (or a unipolar stepper ignoring the center taps

Driving Motors: high current op-amp

dual op-amp with 1A output current
and thermal protection: TCA0372

eg 6V, 12V, 15V for motor



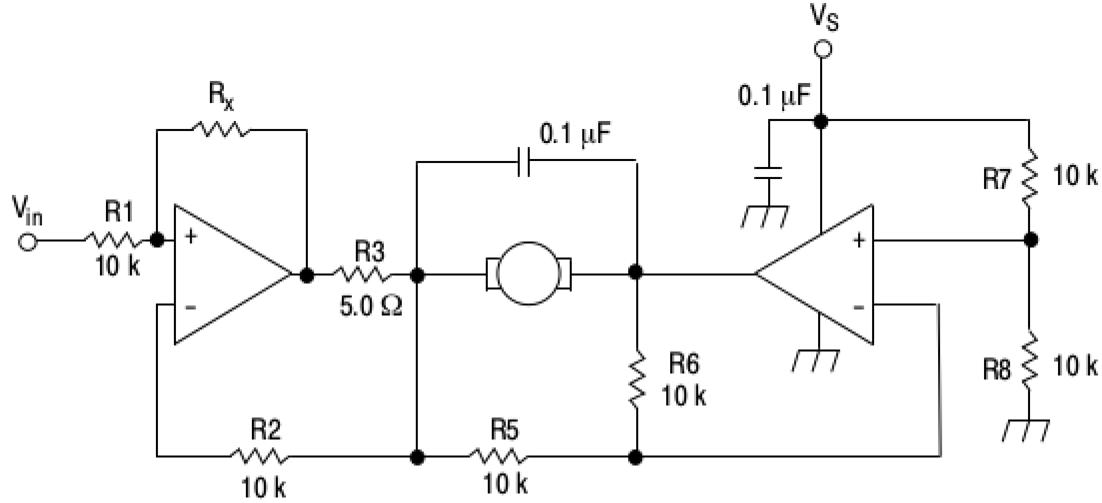
logic threshold

V_S = Logic Supply Voltage
Must Have $V_{CC} > V_S$
E1, E2 = Logic Inputs

Figure 9. Bidirectional DC Motor Control with Microprocessor–Compatible Inputs

Driving Motors: high current op-amp

dual op-amp with 1A output current
and thermal protection: TCA0372



For circuit stability, ensure that $R_x > \frac{2R3 \cdot R1}{R_M}$ where, R_M = internal resistance of motor.

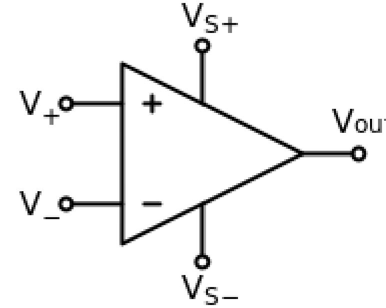
The voltage available at the terminals of the motor is: $V_M = 2\left(V_1 - \frac{V_S}{2}\right) + |R_o| \cdot I_M$

where, $|R_o| = \frac{2R3 \cdot R1}{R_X}$ and I_M is the motor current.

Figure 10. Bidirectional Speed Control of DC Motors

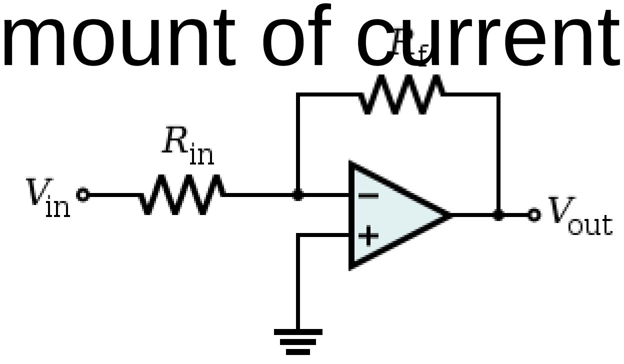
Op-amps

- Vout = A (V_+-V_-), where A is a large number (10^4-10^6)
- Exact value of A is usually not very important.
- (Almost) always use in a circuit with feedback.
- Needs power supplies, often not shown on circuit diagrams. Typical supplies are +/- 15V, but can vary.



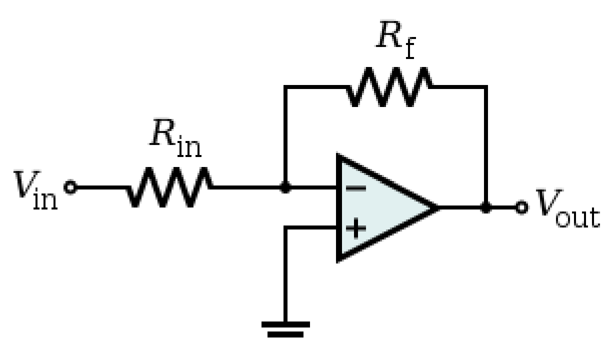
Golden Rules

- (1) The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.
- (2) The inputs draw no current.
- Both rules are approximations! Rule (1) is only obeyed in a circuit with negative feedback, and the difference is usually not quite 0. The inputs draw a tiny amount of current.



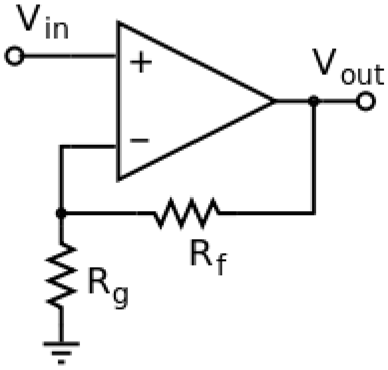
Inverting amplifier

- $V_{out} = -V_{in}\ R_f/R_{in}$
- Often the preferred topology, except:
- Low-ish input impedance (R_{in})



Non-inverting amplifier

- $V_{out} = V_{in} (1+ R_f/R_g)$
- input impedance limited by the op-amp itself (usually very high!)



Imperfections

- Gain, A, is not frequency independent. The op-amp gain will roll off at high frequency (design choice for stability).
- inputs do draw some current (input bias current) – must provide a dc current path!
- Output cannot swing beyond (or in some cases even too close to) the power supply rails.
- many other small imperfections (input bias voltage, input offset voltage, input offset current etc)

Single supply amplifier

- When working with microcontrollers it is often convenient to have an amplifier that can be powered from 0/5V or 0/3.3V rather than +/-15V.
- Previous circuits need some modifications: (a) need to reference inputs from the supply midpoint. (b) often want to AC couple the input.

TI has some nice documents:

https://courses.cit.cornell.edu/bionb440/datasheets/SingleSupply.pdf

www.ti.com/lit/ml/sloa091/sloa091.pdf

www.ti.com/lit/an/sloa030a/sloa030a.pdf

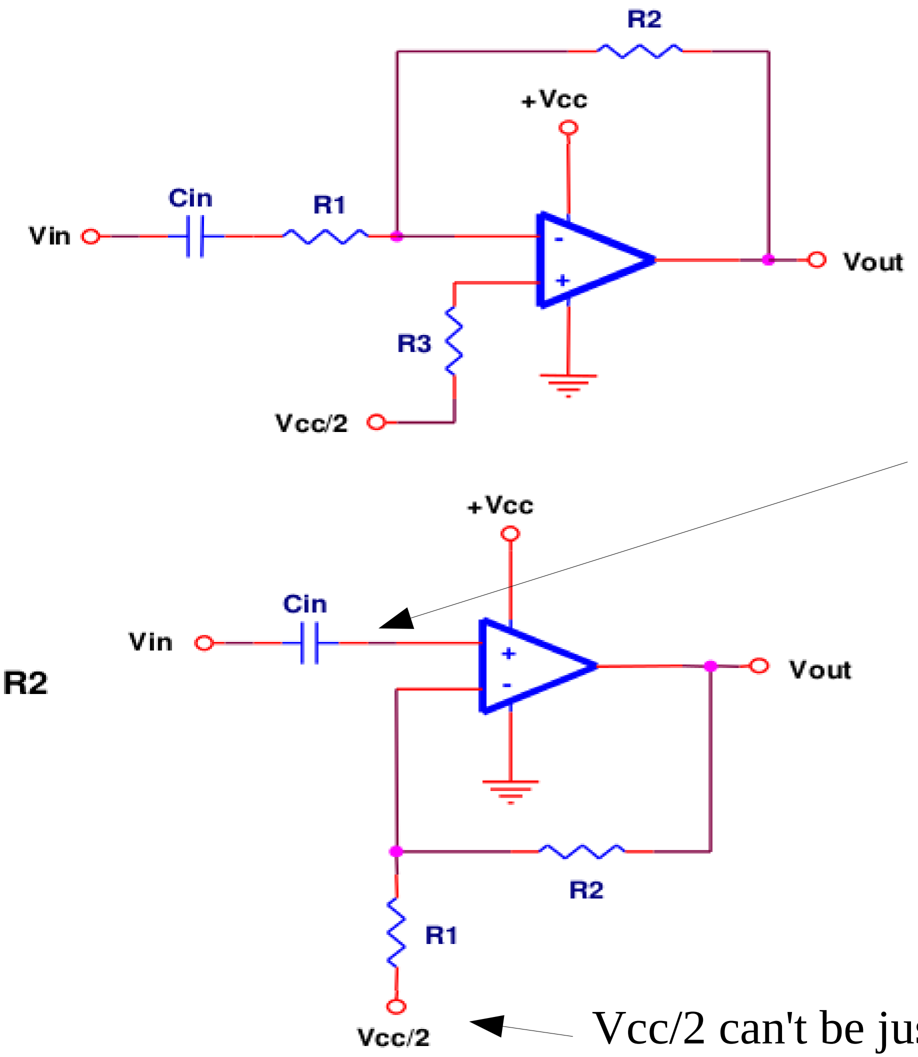
Somewhat awkward choices:

INVERTING

Gain = – R2/R1
R3 = R1||R2
for minimum error due
to input bias current

NONINVERTING

Gain = 1 + R2/R1
Input Impedance = R1||R2
for minimum error due
to input bias current



no dc path for bias current?

Vcc/2 can't be just a divider.

Figure 3. AC-Coupled Gain Stages

https://courses.cit.cornell.edu/bionb440/datasheets/SingleSupply.pdf

- Easier choice for inverting AC amplifier:

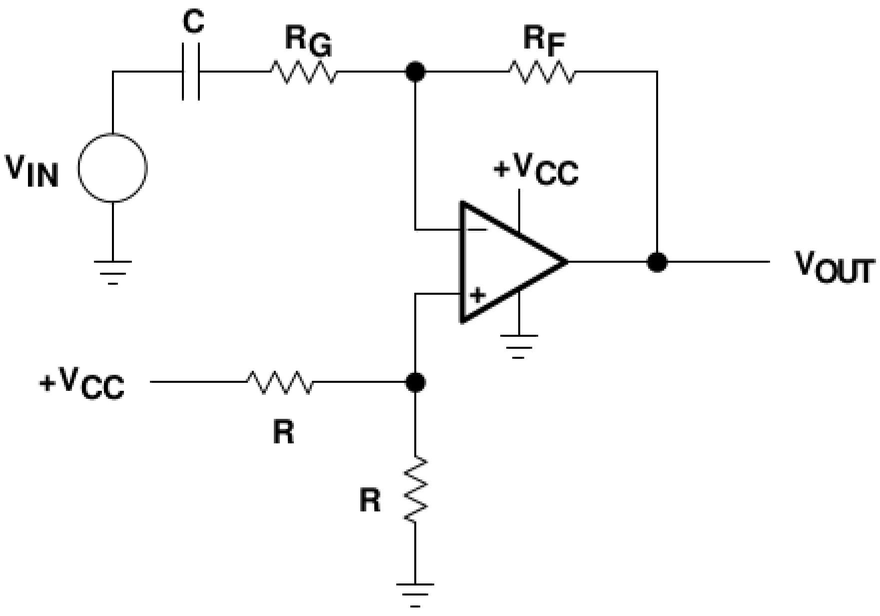


Figure A–22. Inverting AC Amplifier

- Easier choice for inverting AC amplifier:

add a capacitor in parallel with R_F to low-pass filter

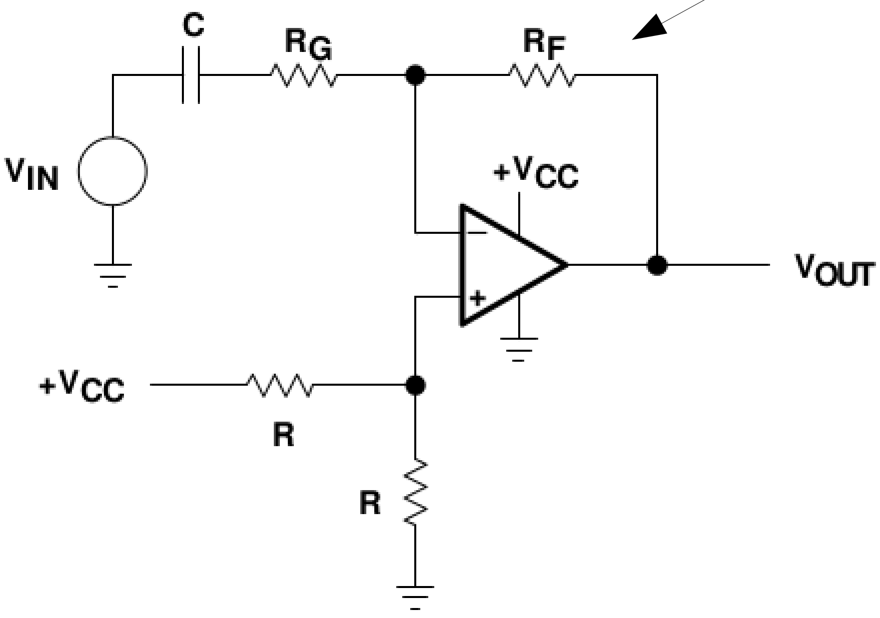


Figure A–22. Inverting AC Amplifier

- And non-inverting amplifier:

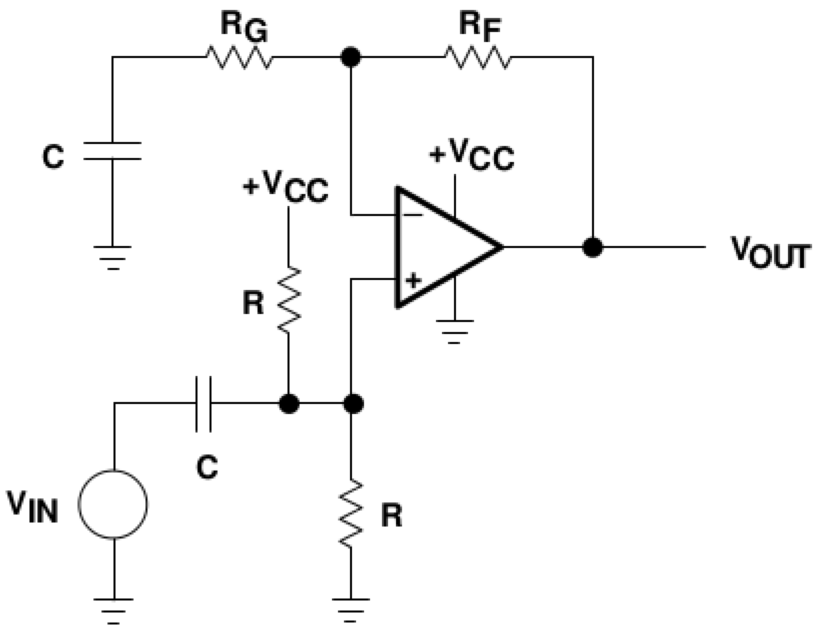


Figure A–23. Noninverting AC Amplifier

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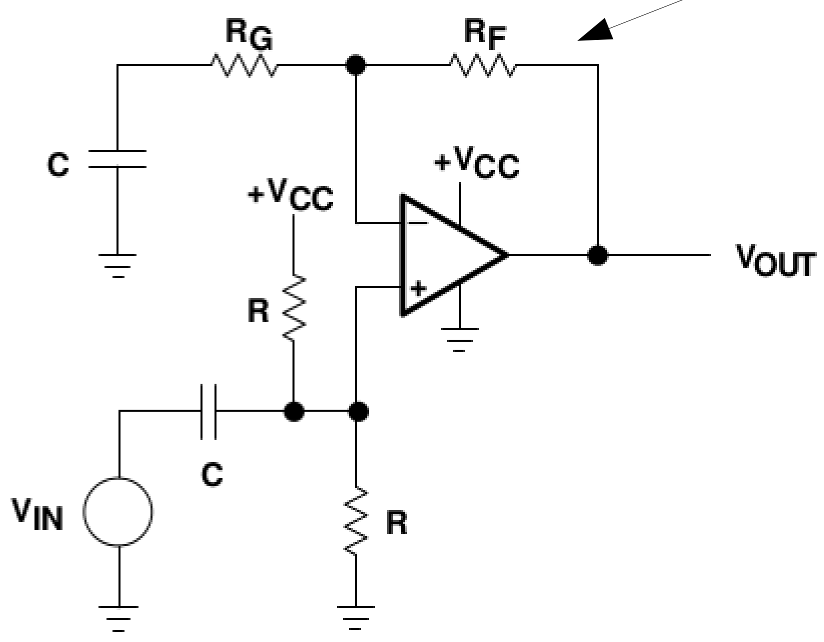
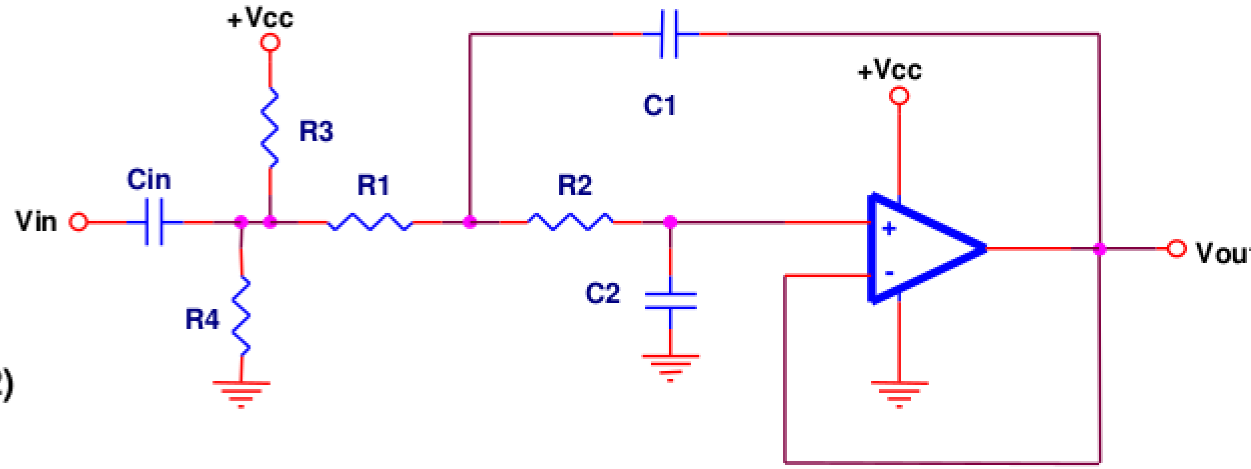


Figure A–23. Noninverting AC Amplifier

2^{nd} order filters:

LOW PASS

Unity Gain
Butterworth
R3 = R4 (HIGH)
R1 = R2
C1 = 2C2
$Fo = \sqrt{2} / (4\pi\, R1C2)$



HIGH PASS

Unity Gain
Butterworth
C1 = C2
R1 = R
R = 2R1
$Fo = \sqrt{2} / (4\pi\, R1C1)$

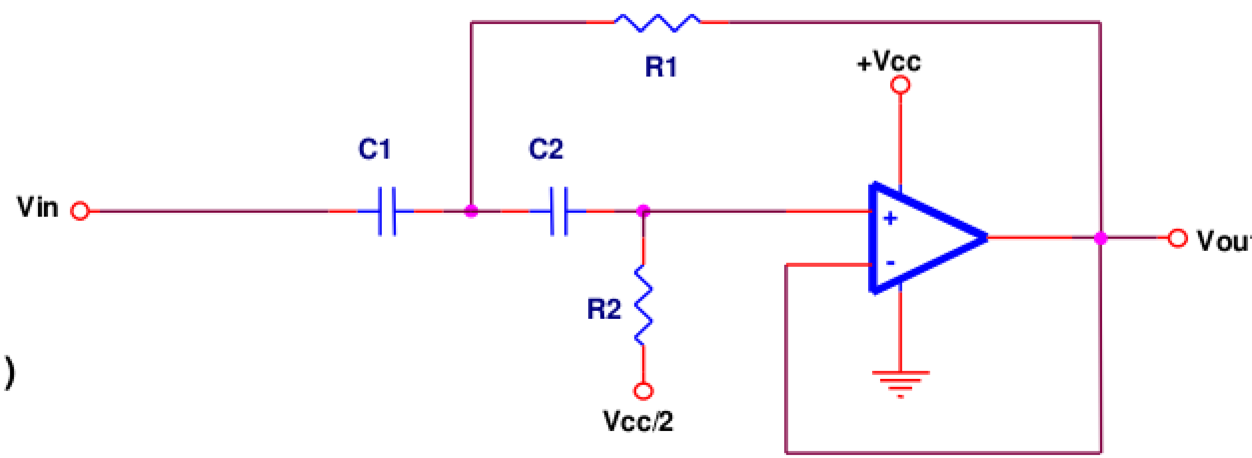
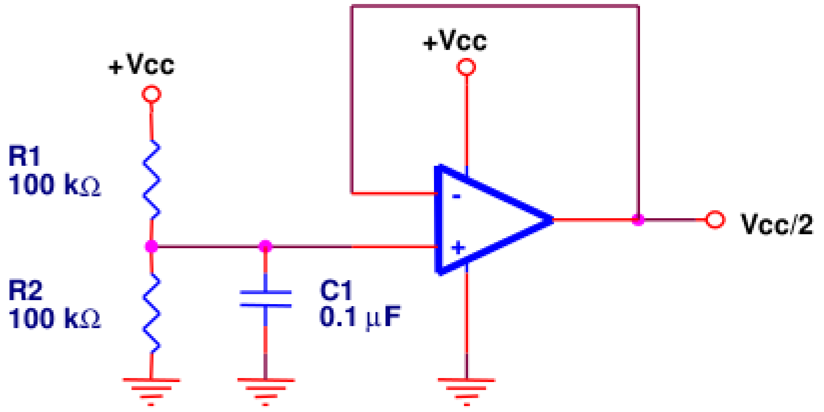


Figure 16. Sallen-Key Low- and High-Pass Filter Topologies

- If you need to generate Vcc/2 (which is the op-amp "ground") use a second op-amp:



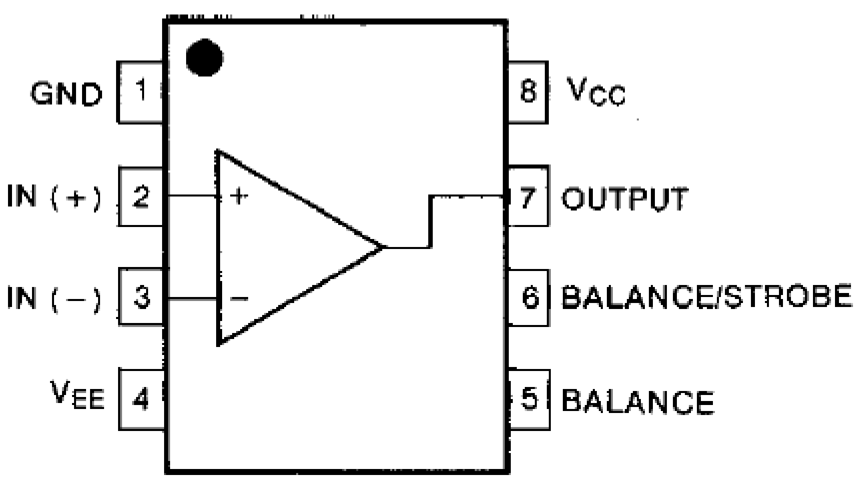
Comparators

Comparators

Basic device function: compare two voltages, indicate which is greater.

But also useful for:
- logic level shifting,
- threshold detection/ generating square waves
- driving the P-channel mosfet or pnp transistor on H-bridges
- turning a logic output into a 'tri-state' output.

LM311 Pinout

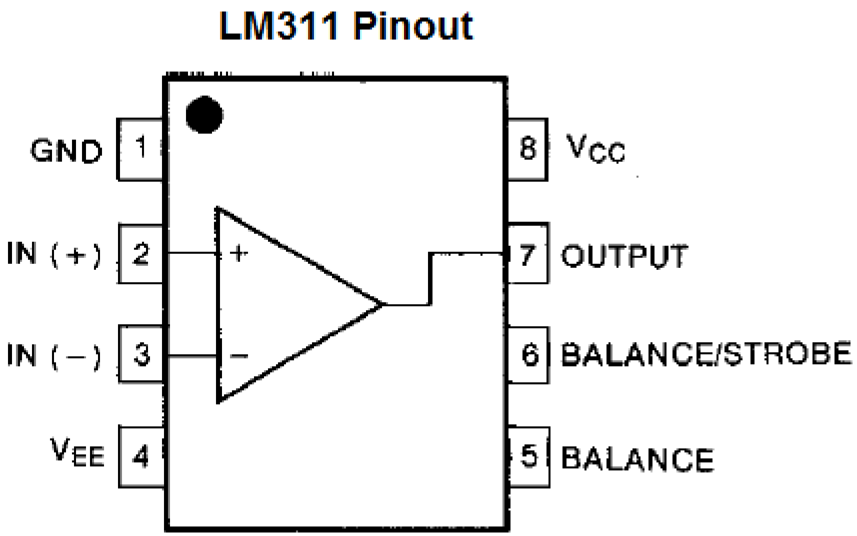


Comparators

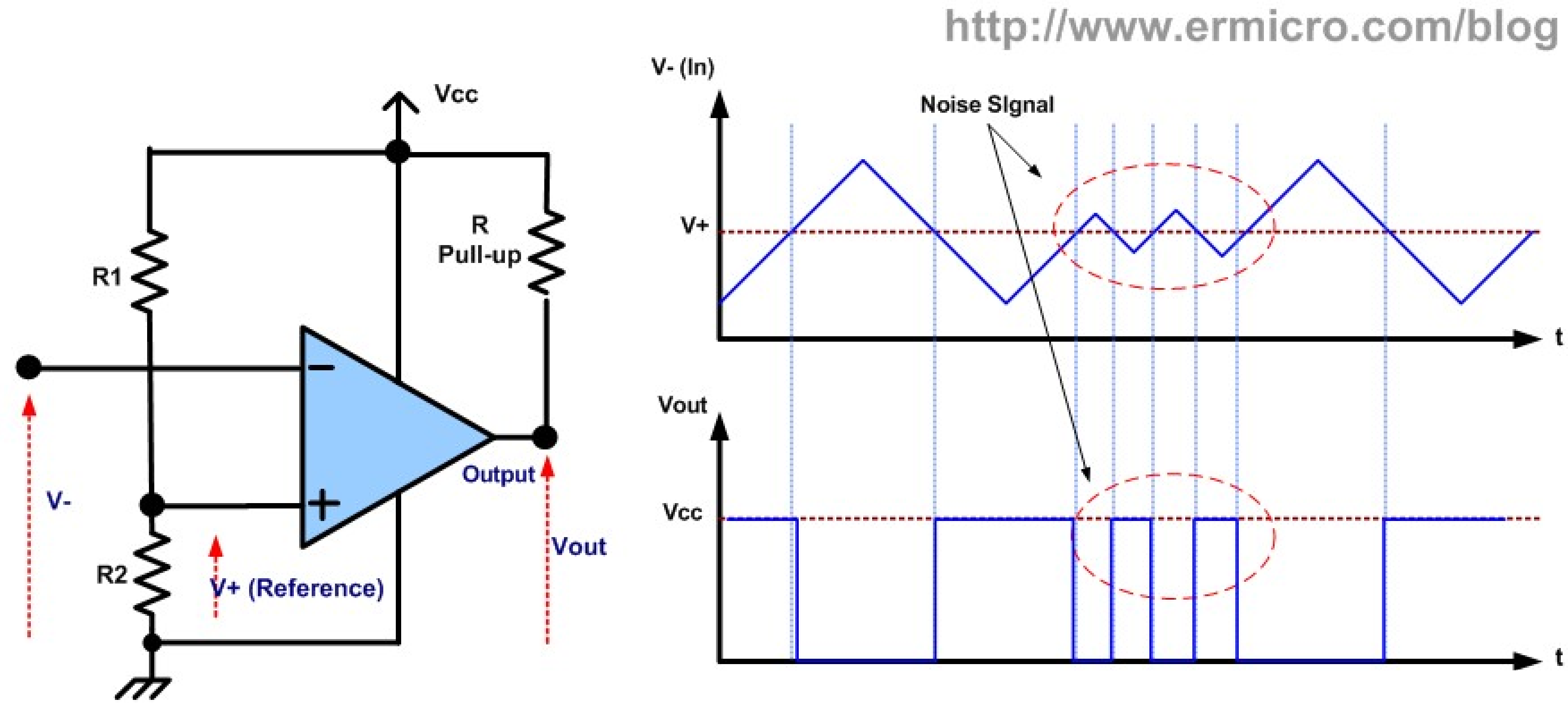
V_{CC}, V_{EE} - +, - supplies. The inputs must stay between the supply voltages. Can be +/-15V or +

When V- > V+, then the output is connected to GND. When V+ > V-, the output floats.

Balance: used to trim internal V+ vs V- offsets. Not usually needed.
Strobe: pull to ground to disable comparator.

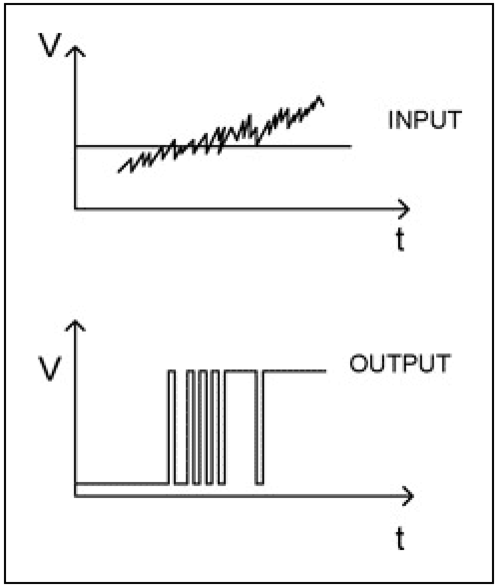


Comparators



Comparators

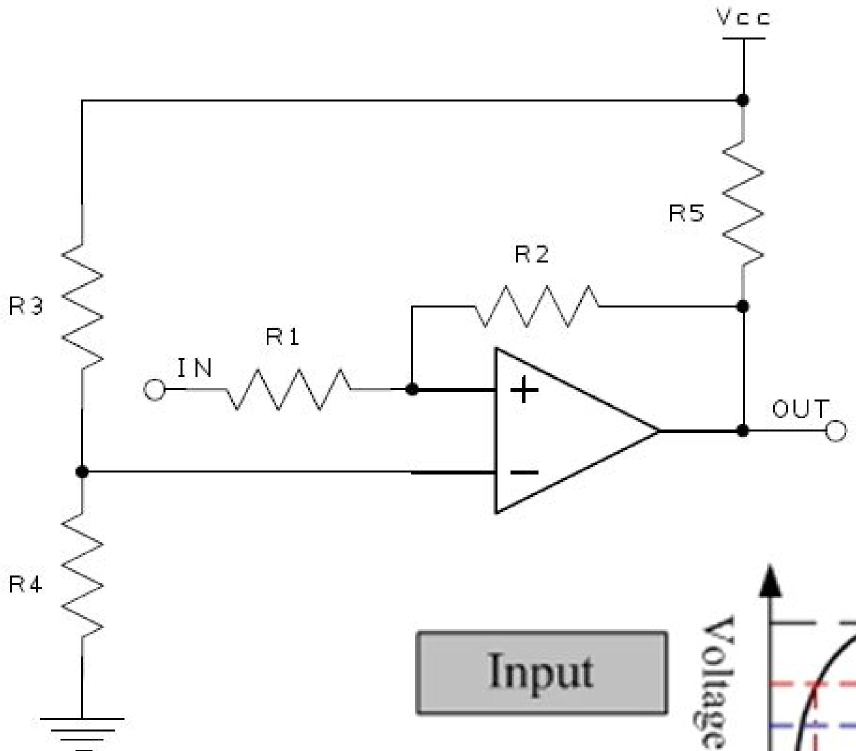
Noisy signals:



http://hades.mech.northwestern.edu/index.php/Comparators

Comparators

Hysteresis for noise immunity: add positive feedback.

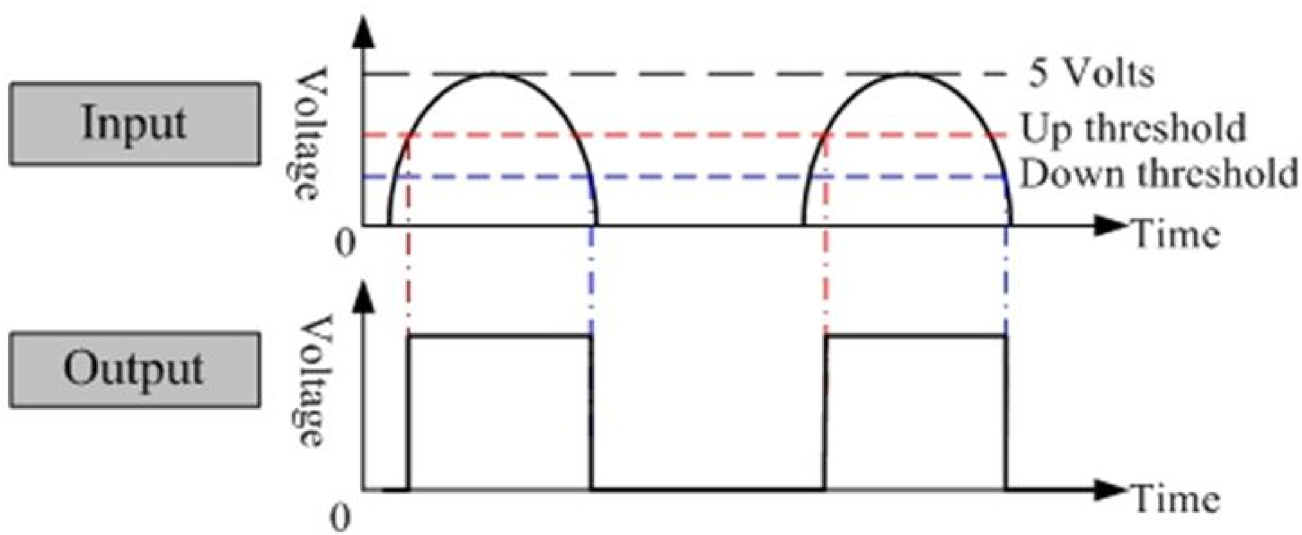


$$V_{ref} = V_{cc}\left(\frac{R4}{R4+R3}\right)$$

$$V_U = V_{ref}\left(\frac{R1+R2}{R2}\right)$$

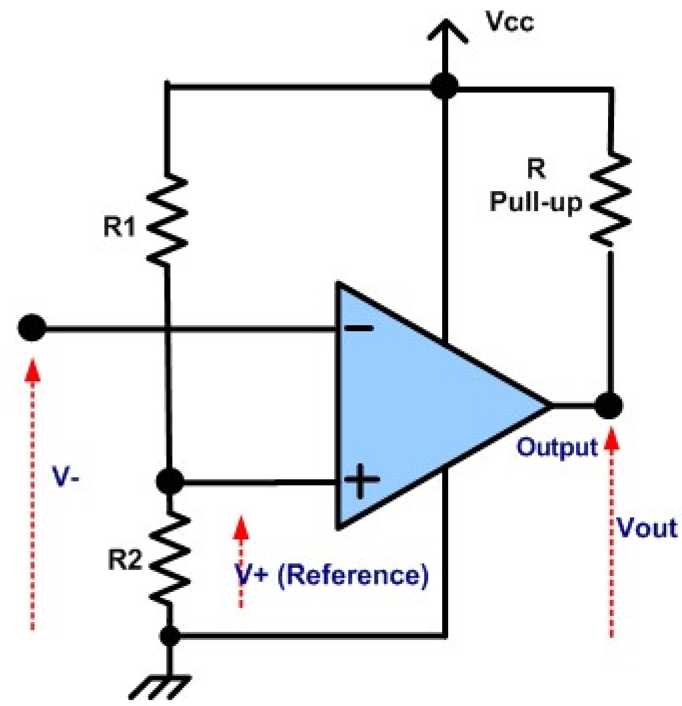
$$V_L = \frac{V_{ref}\,(R1+R2) - V_{cc}\,(R1)}{R2}$$

(Assumes $R_5 << R_2$)



http://hades.mech.northwestern.edu/index.php/Comparators

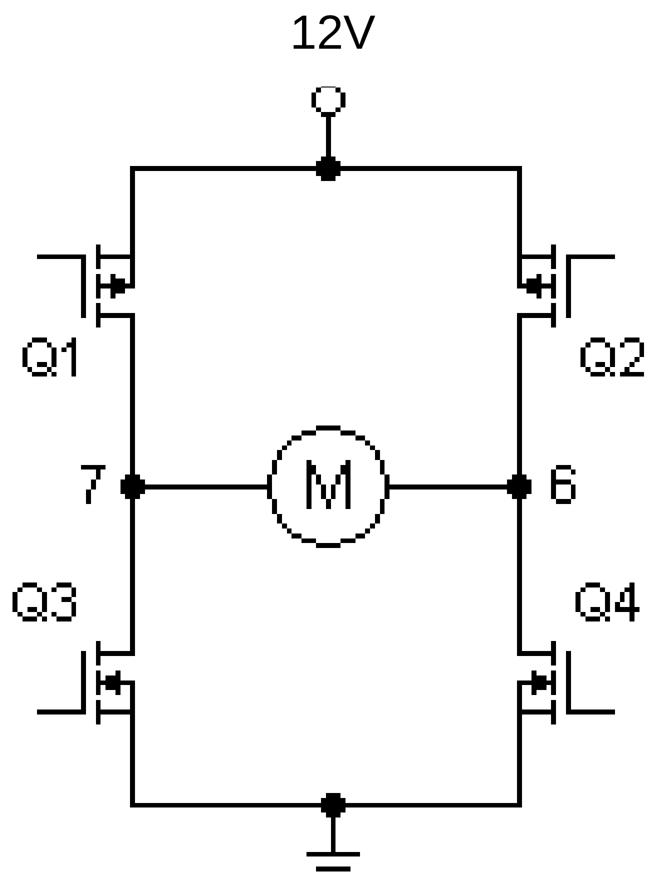
Comparators



The pull-up doesn't have to be connected to the same supply voltage as the comparator supply, it can be higher or lower. This makes the comparator output very flexible for level shifting!

Comparators

Example: Level shifting:

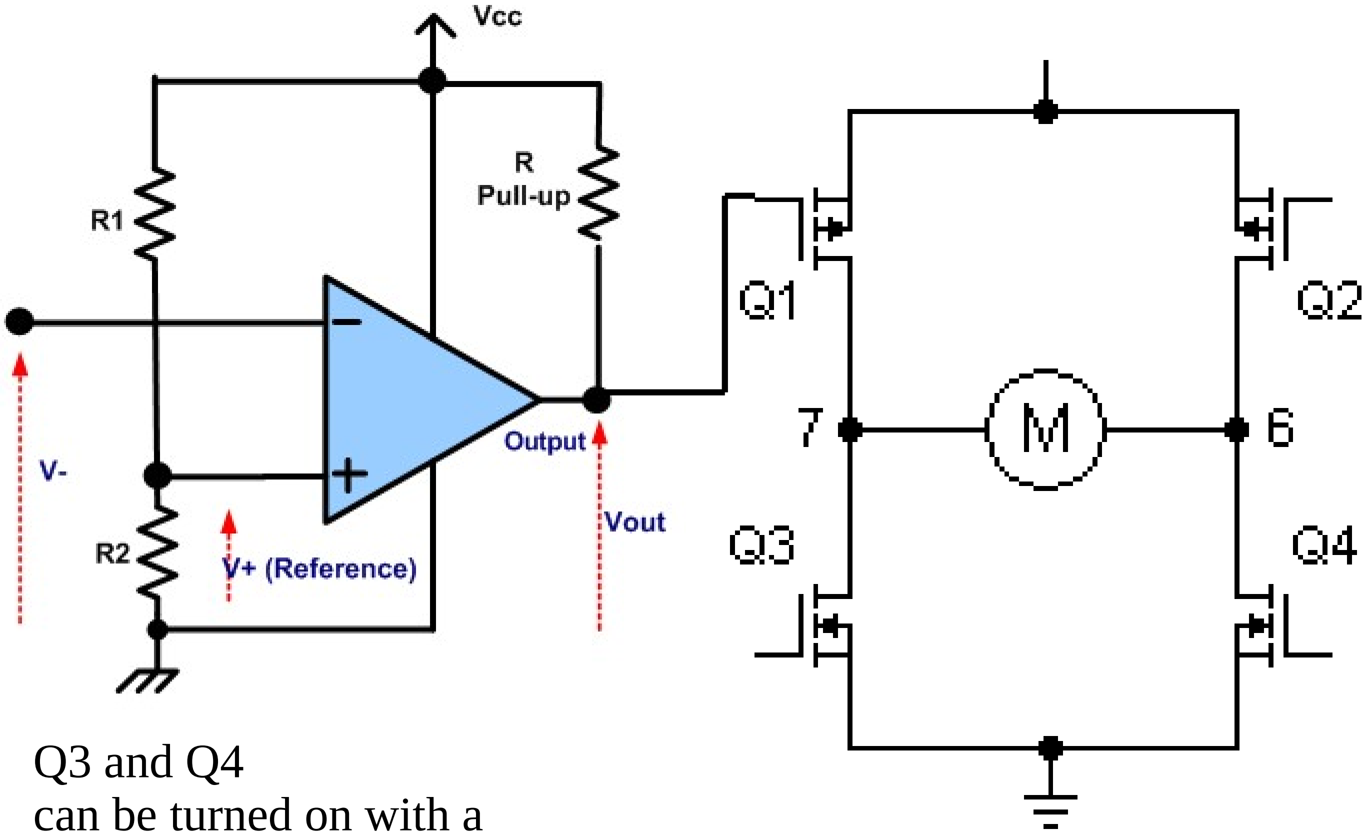


Q3 and Q4
can be turned on with a
5V logic device, off at 0.

But Q1 and Q2 need to be up at 12V to be turned off, then pulled down to turn on.

Comparators

Example: Level shifting:



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But Q1 and Q2 need to be up at 12V to be turned off, then pulled down to turn on.