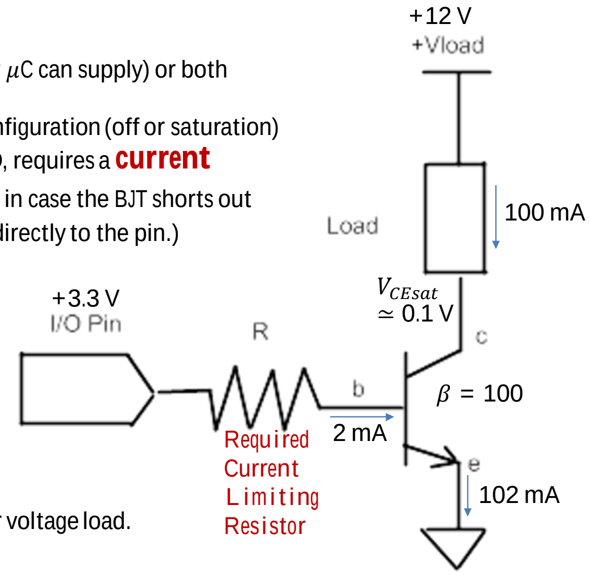
Controlling higher-power loads

Could be higher voltage load, or higher current (than the SoC or μC can supply) or both

A NPN bipolar junction transistor (BJT) in a common emitter configuration (off or saturation) works well up to maybe even a few tens of W. A BJT, like an LED, requires a **current limiting resistor**. The resistor also protects the SoC or μC in case the BJT shorts out from collector to base. (The +Vload supply will not be shorted directly to the pin.)

An enhancement-mode n-channel MOSFET in a common source configuration (off or triode) often works better than a BJT of equal cost will in today's technology. Since a MOSFET has no source current, the current-limiting resistor may be omitted, but it is often left in the circuit to protect the SoC or μC in case the MOSFET shorts.

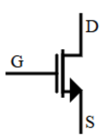
The negative side of the load is typically the switched terminal.
This way a low voltage such as V_{OH} = 3.3 V can control a higher voltage load.

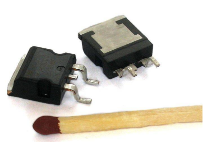


$$R = \frac{V_{OH} - 0.7\text{ V}}{2\text{ mA}} = \frac{3.3\text{ V} - 0.7\text{ V}}{2\text{ mA}} = 1.3\ k\Omega$$

1

Transistors, when used as switches—two popular types, Field Effect and Bipolar. THIS PAGE, FET





Field Effect Transistor (FET, MOSFET)
Discussed here: n-channel enhancement type FETs
The key specification for switching applications is the Transistor's *threshold voltage*, V_t.

If $v_{gs} > V_t$ the transistor conducts current. (is "ON")

Typically you need a half-volt or a volt more than V_t for to make the transistor act like a nearly zero ohm resistance.
For the purposes of this class, say that we require

$v_{gs} > V_t$ + (1 V) "ON"

or

$v_{gs} < V_t$ "OFF"

Typically 0.4 V < V_t < 3 V for devices used as switches.

https://commons.wikimedia.org/wiki/File:Mosfet_N-Ch_Sedra.svg
https://commons.wikimedia.org/wiki/File:D2PAK.JPG
https://320volt.com/en/160w-hifi-amfi-devresi-mosfet-irf240-irf9240/

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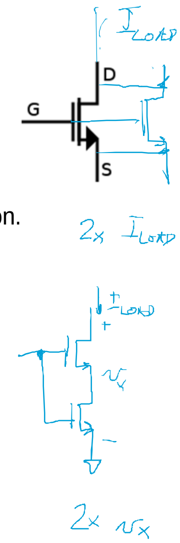
Types of switching devices and relative advantages

Metal-Oxide Semiconductor Field Effect Transistor,
aka MOSFET
aka "field-effect transistor"

--Switching action is from drain to source
--Gate controls on-off action. If there is enough Gate *voltage*, it is on.
--Source is usually grounded (n-channel shown) or
connected to +*Vcc* (p-channel, not shown).
--Gate can be directly wired to the uC, no resistor needed.
--Has a residual resistance when on, typically a fraction of an ohm.
--Can be connected in parallel to handle more current and in series
to handle more voltage.

--No ground isolation. Load and uC must share same ground.
--Very cost competitive with BJT's for many applications with loads
of less than hundreds of kW.
--Gate is somewhat sensitive to static zap. Usually it must be
protected.
--Has grabbed the market share for most "middle of the road" needs.



Physically, a MOSFET comes in the same package styles as a BJT.

Schematic: Wikimedia Commons, used by permission CC by-SA 3.0

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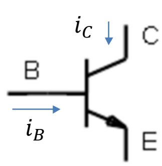
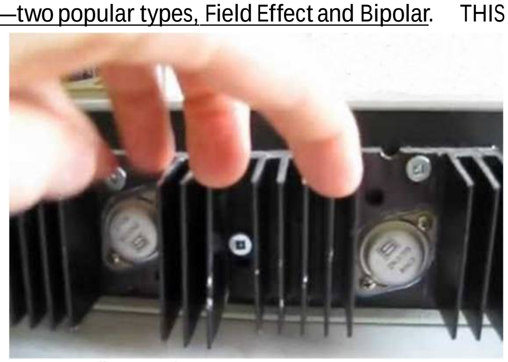
Transistors, when used as switches—two popular types, Field Effect and Bipolar. THIS PAGE, BJT





Bipolar Junction Transistor (BJT)
Discussed here: npn type BJTs
The key specification for switching applications is the transistor's *forward current gain*, β.

If $i_b > i_c/\beta$ the transistor conducts current. (is "ON")

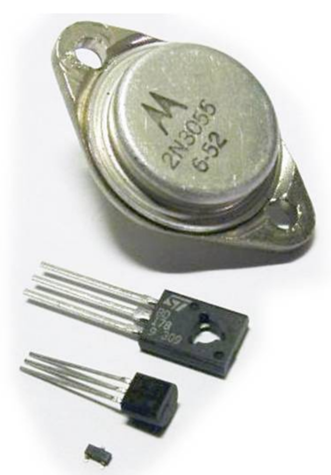
Typically you need about 20% to 50% more to make the transistor act like a nearly zero ohm resistance. For the purposes of this class, say that we require

$i_b \simeq 1.3 i_c/\beta$ "ON"

or

$i_b = 0$ "OFF"

Typically $50 < \beta < 200$ for devices used as switches.
Typically $v_{BE} = 0.7$ V if $i_B > 0$



https://wiki.analog.com/university/courses/electronics/text/chapter-8 https://commons.wikimedia.org/wiki/File:Transistorer_(cropped).jpg
https://www.youtube.com/watch?v=hNRacVQRgBc

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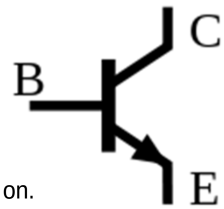
Types of switching devices and relative advantages

Bipolar junction transistor,
aka BJT
aka "transistor"



--Switching action is from collector to emitter
--Base controls on-off action. If there is base *current*, it is on.
Note: it is controlled by *current*
--Emitter is usually grounded (NPN shown) or
connected to +*Vcc* (PNP, not shown).
--Must use a resistor between uC and base
--Amplifies available drive current, typically by about 10 to 5000
e.g. x 100, from 0.5 mA to 50 mA.
--Some very high-power models are available as
"insulated gate bipolar transistors" (IGBT)
e.g. > 1000 V when "off" and >2000 A when "on."
IGBTs are actually hybrid devices that are partly
a MOSFET and partly a BJT.
--In some applications (usually very high current) BJTs
waste less power than other switching devices.
--No ground isolation. Load and uC must share same ground.
--Relatively robust against static zap, momentary overload.
--Relatively inexpensive for very low and very high-power loads

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Controlling higher-power loads

Example: Control a 14.4 V, 2.88 W incandescent lamp with a parallel port output pin.

I/O pin has V_{OHmin} = 3.0 V and V_{OLmax} = 0.3 V and $|I_{max}| \leq 2$ mA

The lamp will require $\frac{2.88\ \mathrm{W}}{14.4\ \mathrm{V}}$ = 0.2 A of current

For this example I choose a BJT as the switching element to be controlled by the μC.

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I assume V_{BE} = 0.7 V if the transistor is turned on.

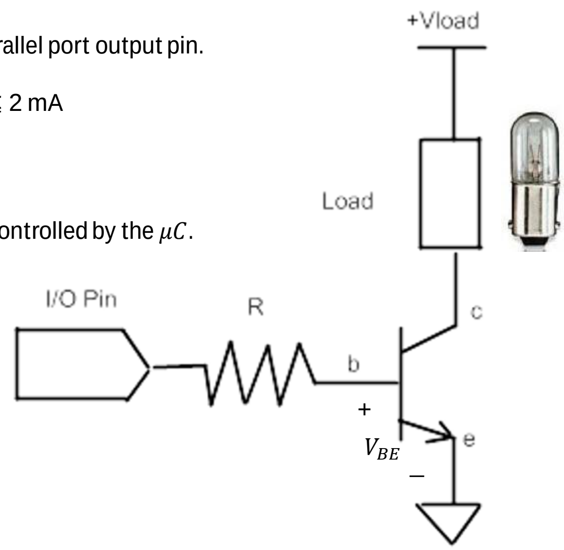

Photo of lamp: https://www.radioshack.com/products/radioshack-14v-200ma-incandescent-flashlight-bulb-2-pack

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Select a transistor with a current gain, β of at least 150.

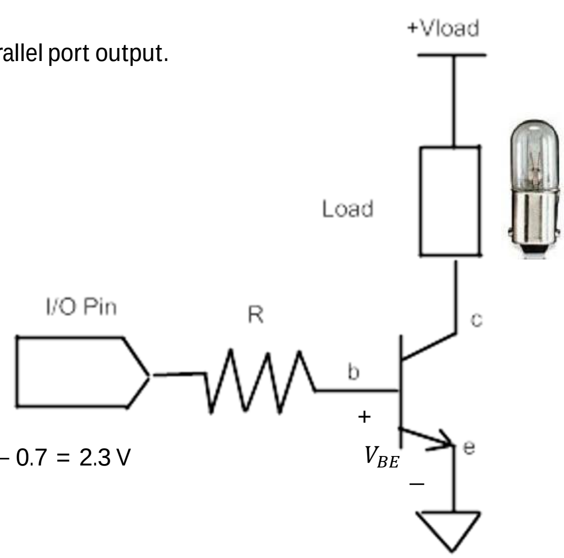
Calculate the needed base drive current, assume V_{BE} = 0.7 V

i_B = 1.3$\left(\frac{i_C}{\beta}\right)$ = 1.3$\frac{200\text{ mA}}{150}$ = 1.733 mA
(Note: This will be a near maximum load for the R-pi.)

The voltage drop across the resistor will be $V_{OHmin} - v_B$ = 3.0 – 0.7 = 2.3 V

$$R = \frac{2.3\text{ V}}{1.733\text{ mA}} = 1.3\text{ k}\Omega$$

(black, orange, red, gold)



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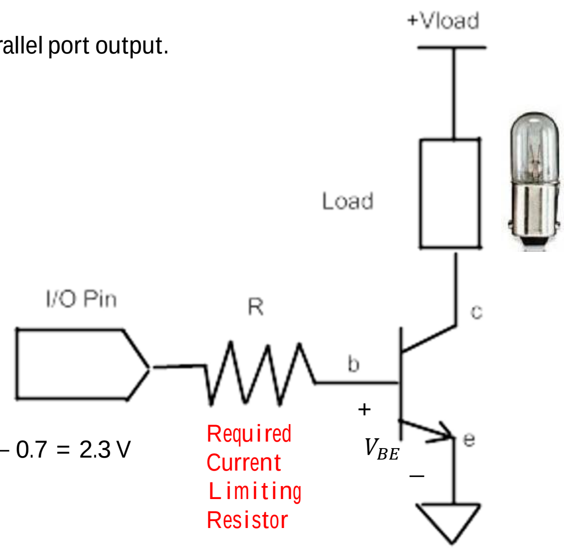

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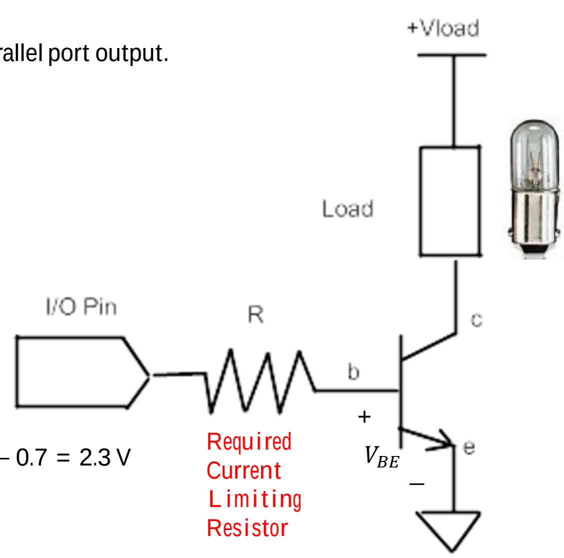

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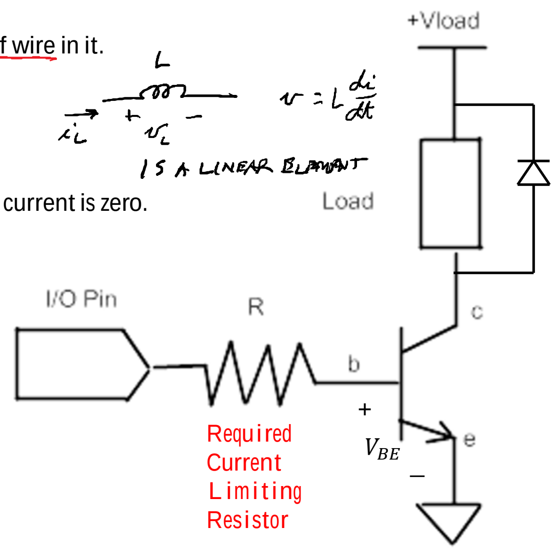
Controlling inductive loads—any power level

Inductive loads include motor and relays—anything with a coil of wire in it.

For an inductor $v = L\frac{di}{dt}$ or $i = \frac{1}{L}\int v dt + K$

The current can coast.
If the voltage is zero that does not assure or even imply that the current is zero.
To stop current you need an opposing voltage.
This leads to a phenomenon called "flyback."

When you switch an inductor off rapidly,
a *flyback voltage* is produced which will destroy the transistor (or any switching device), unless a flyback diode is added across the inductive load as shown. The diode allows the current to coast down to zero over some time and therefore limits the flyback voltage to a trivial amount.



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More details on inductive loads, current coasting, and flyback voltage.

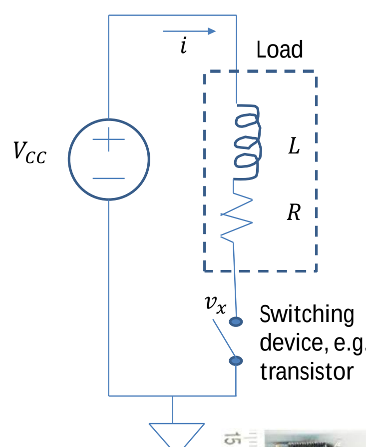
An inductive load contains a coil of wire.
If the load is designed for a DC power supply, the load is primarily resistive, R. Often R is substantial because the load is made of many turns of very fine wire (a long, thin wire). But, this wire is intended to make a magnetic field, so there is also prominent inductance, L.

Consider switching the inductive load on.
Node voltage v_x (with respect to ground) is instantly changed from V_{CC} to ground by the switching device.
Voltage V_{CC} is applied to the load and current begins to flow.

$$i(t) = \frac{V_{CC}}{R}\left(1 - e^{-\left(\frac{R}{L}\right)t}\right)$$

The time constant, $\tau = L/R$ is usually milliseconds, or for large coils, up to a few seconds.

When the magnetic field builds up to a certain point (typically in milliseconds), something useful starts happening, e.g. a motor starts running, a relay pulls in and makes contact, etc.



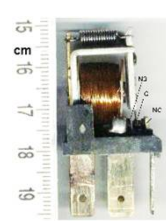


Photo: Wikimedia Commons, public domain

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More details on inductive loads, current coasting, and flyback voltage.

Now consider turning the load off.
The current was $i = V_{CC}/R$ but. . .
now it becomes zero quickly as the Switch opens

Suppose the switch successfully stops the current instantaneously.

For the inductor, $v = L\frac{di}{dt}$ and $\frac{di}{dt}$ was infinite and negative.

Thus an infinite negative voltage pulse, v is created.

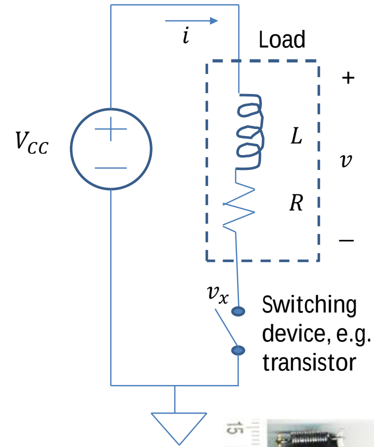
KVL around the loop gives the voltage across the switch contacts.

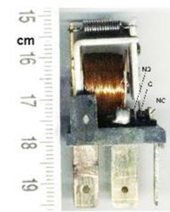
$$-V_{CC} + v + v_x = 0$$
$$-V_{CC} + (-\infty) + v_x = 0$$
$$v_x = \infty$$

Folks, this ain't gonna happen!

Instead, the voltage will build until an arc forms across the switch contacts.
The arc has practically zero resistance. The current just keeps going!

Don't believe it? Watch these videos of switches and large loads.
https://www.youtube.com/watch?v=PaAqklrFKgM
https://www.youtube.com/watch?v=Zez2r1RPpWY





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