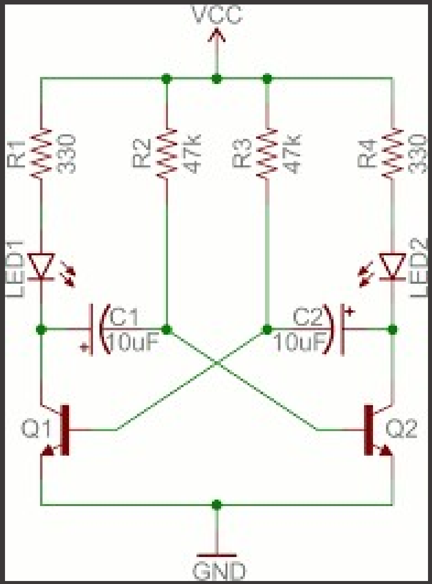
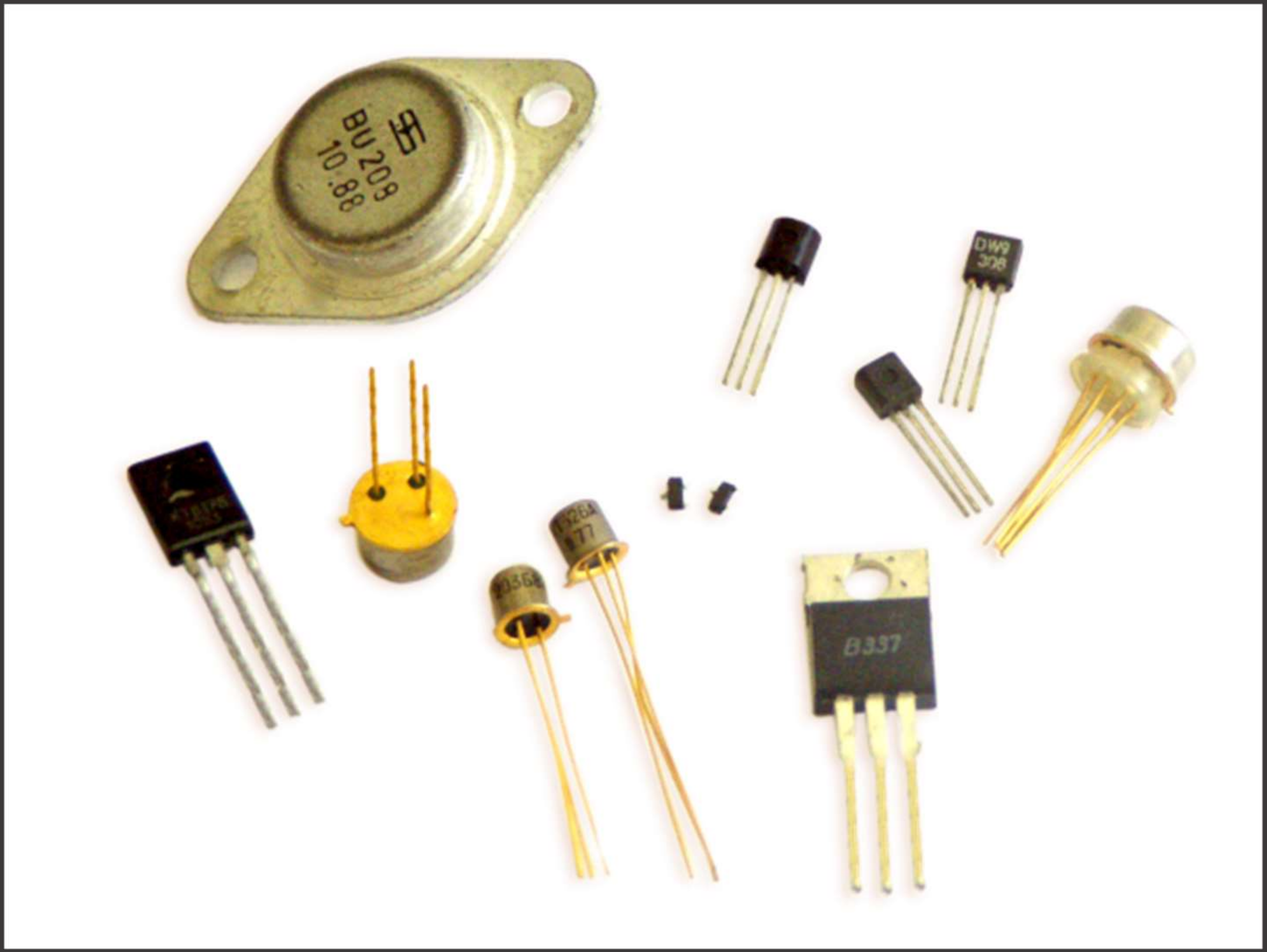
Using, Choosing and Abusing Transistors

Ray Crampton, Feb 2019

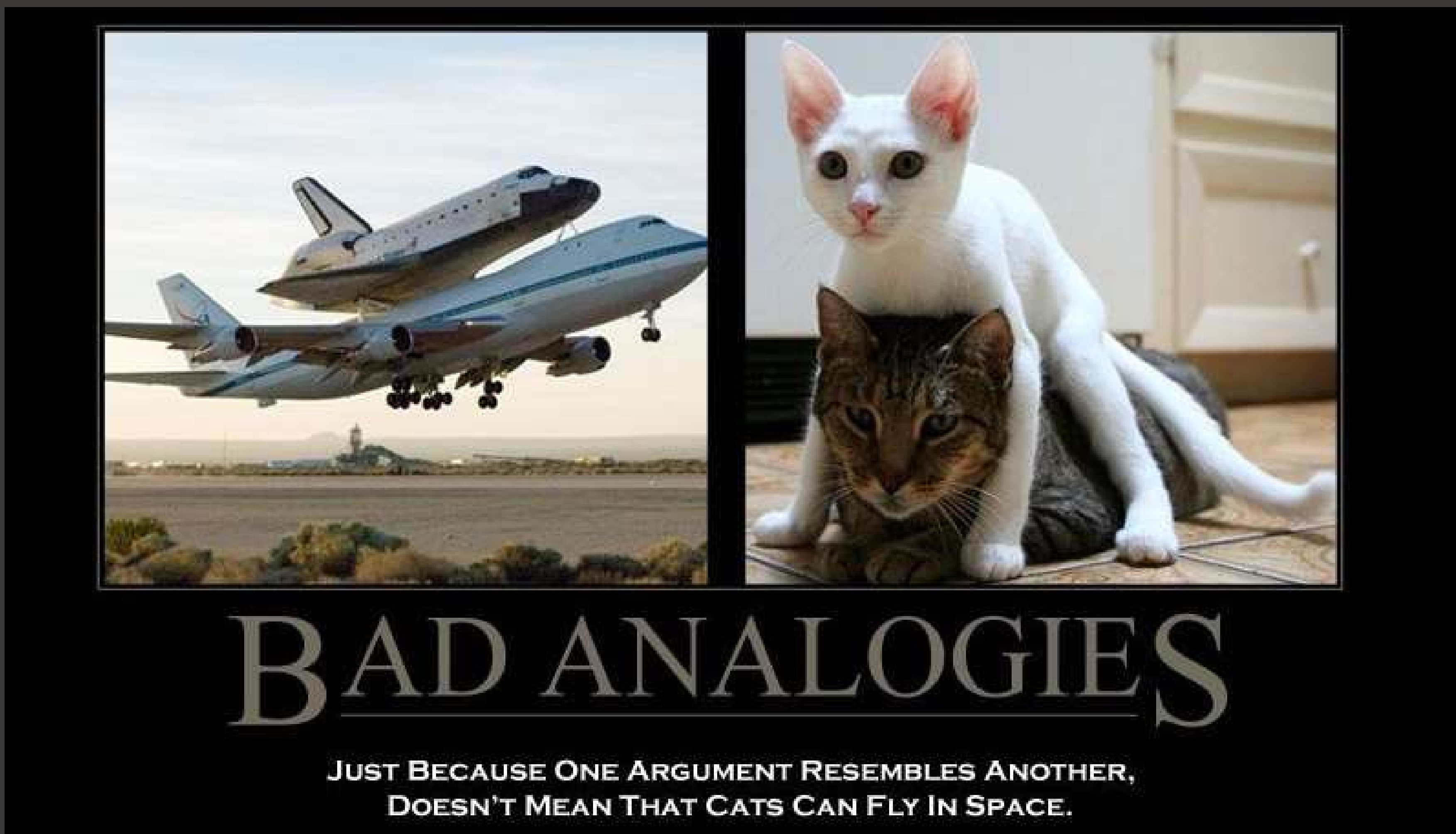
Add more practical examples



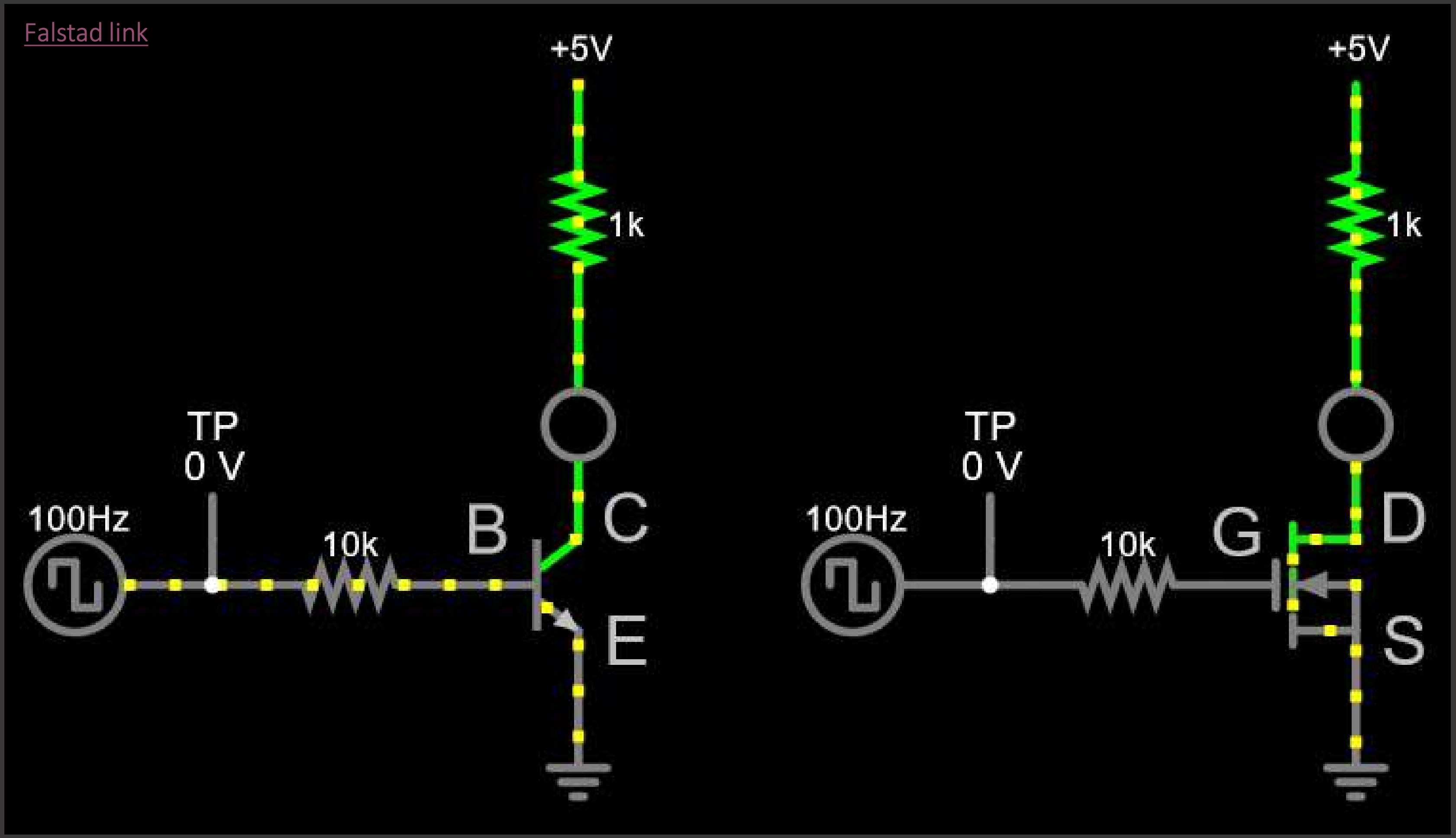


WARNING WARNING WARNING WARNING WARNING

Rules of thumb, assumptions and mixed-quality analogies to come!

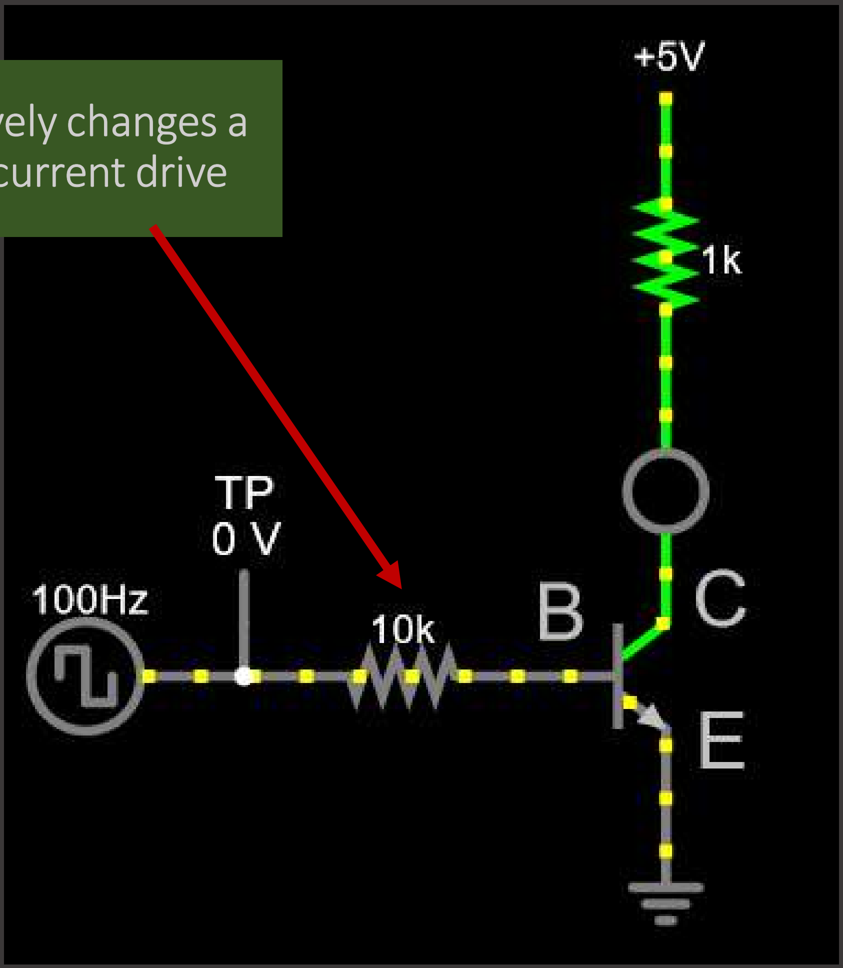


Two major types of transistors
Current controlled & *Voltage* controlled

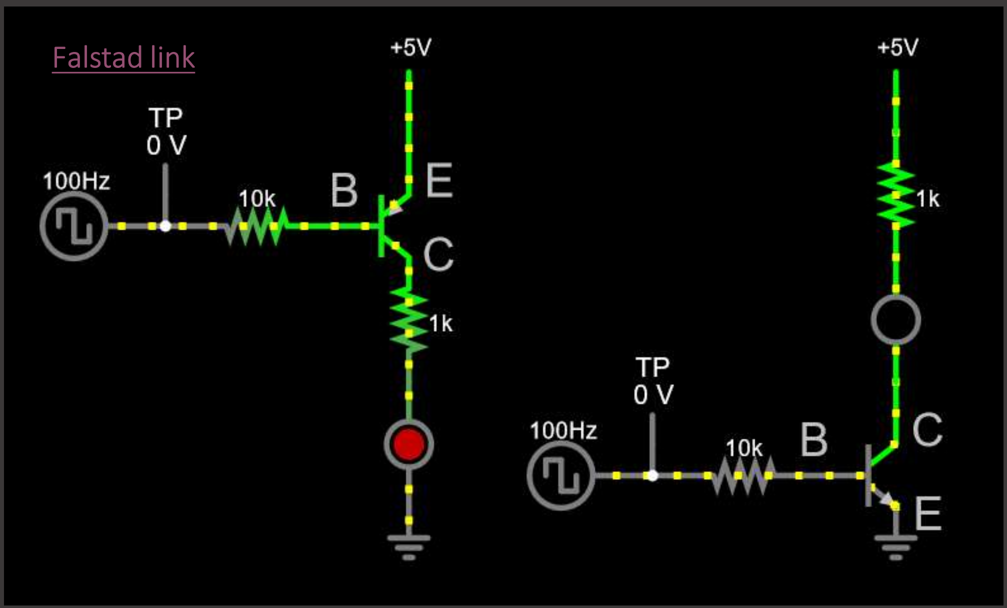


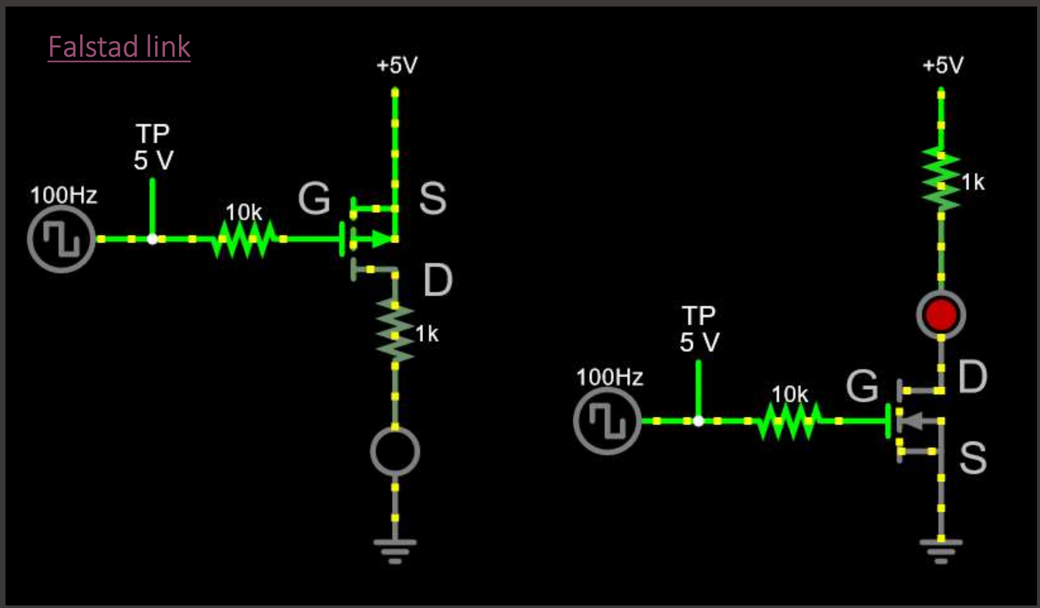
But, voltage drive can be converted into current drive

The resistor effectively changes a voltage drive to a current drive



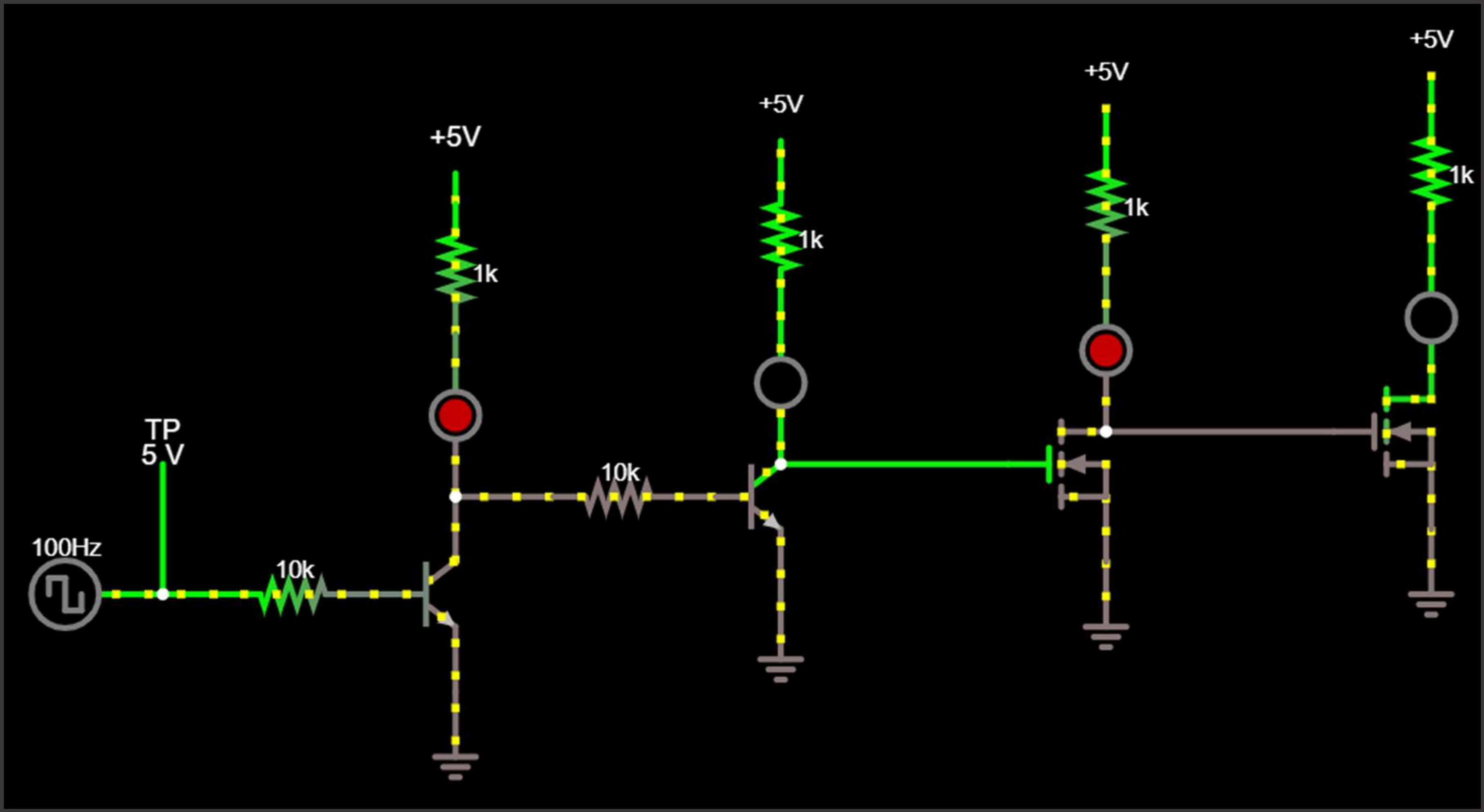
Each major type has <u>*complementary*</u> versions



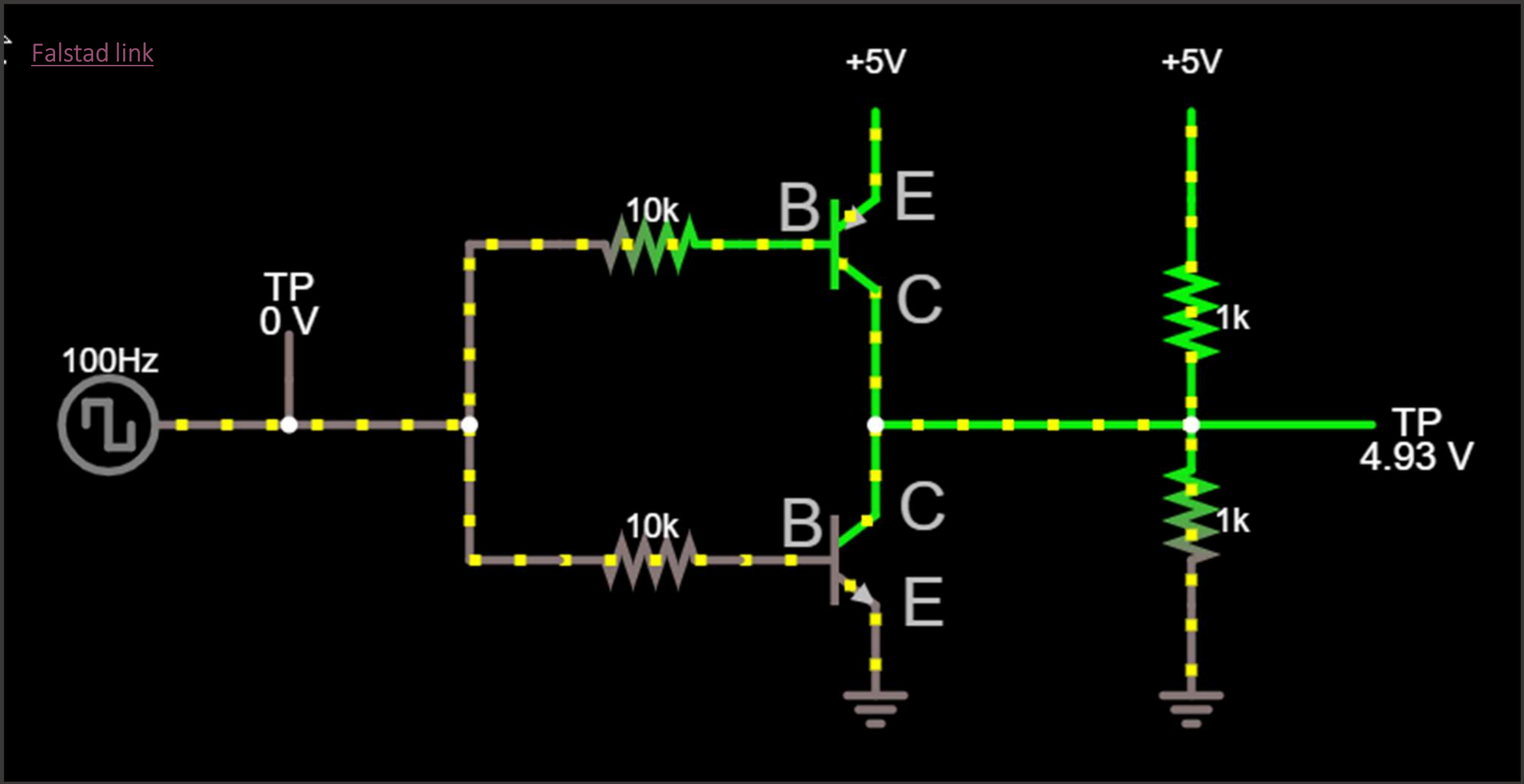


n-type is low side
p-type is high side

“Common Emitter/Source” Inverts

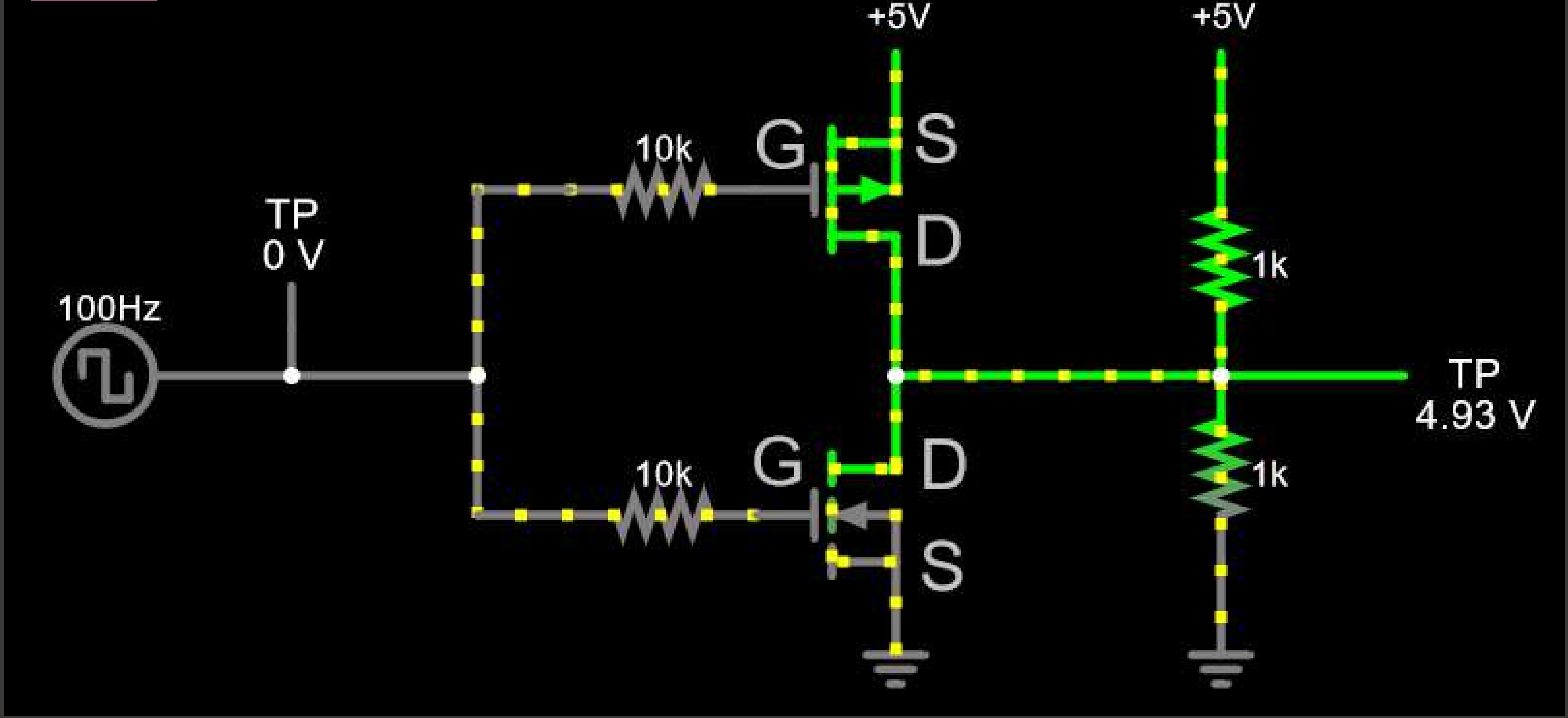


Complementary Bipolar Output



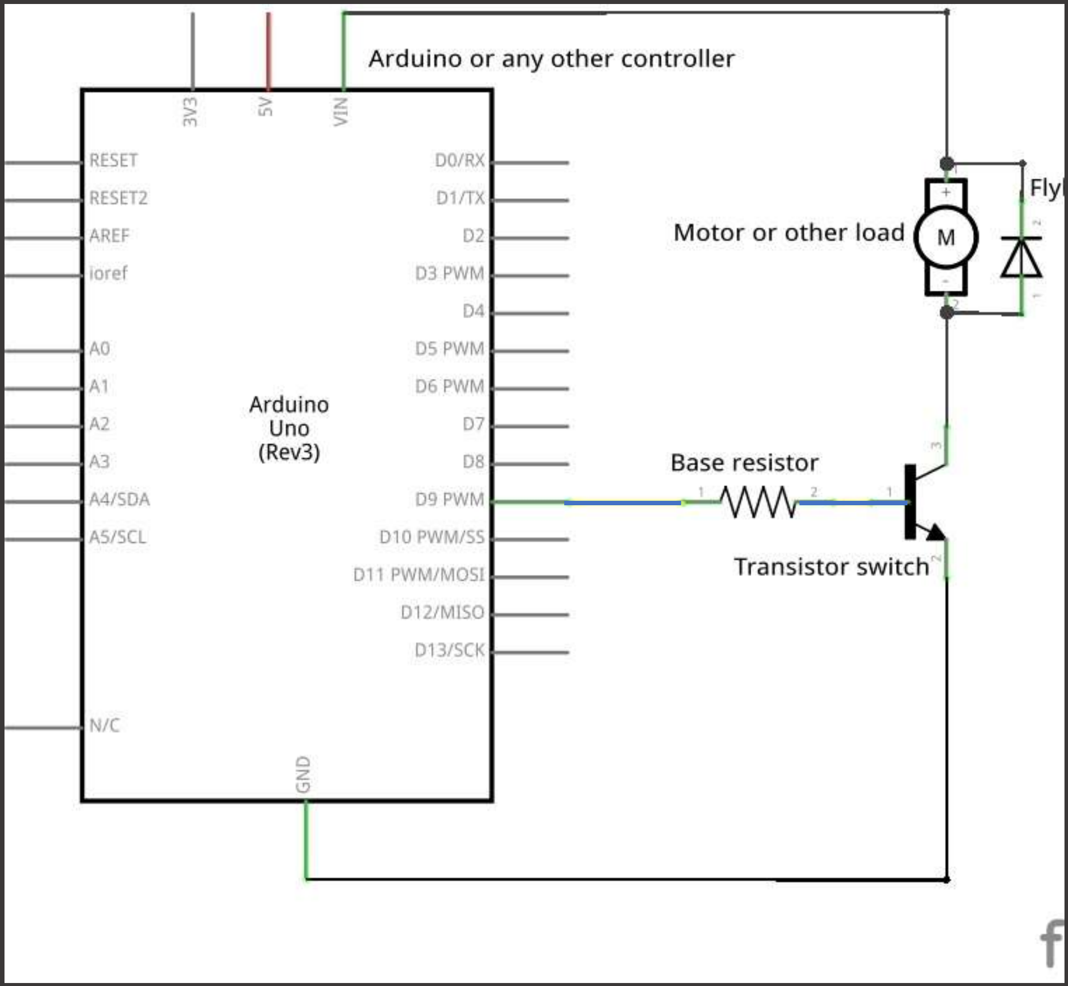
Complementary MOSFET Output

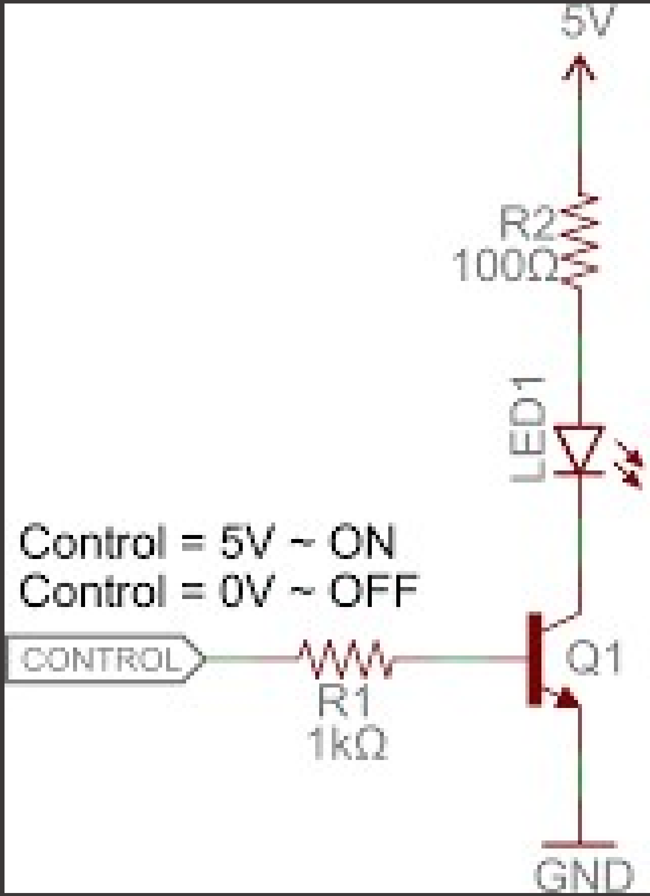
Falstad link



BJT Motor or LED Driver Example

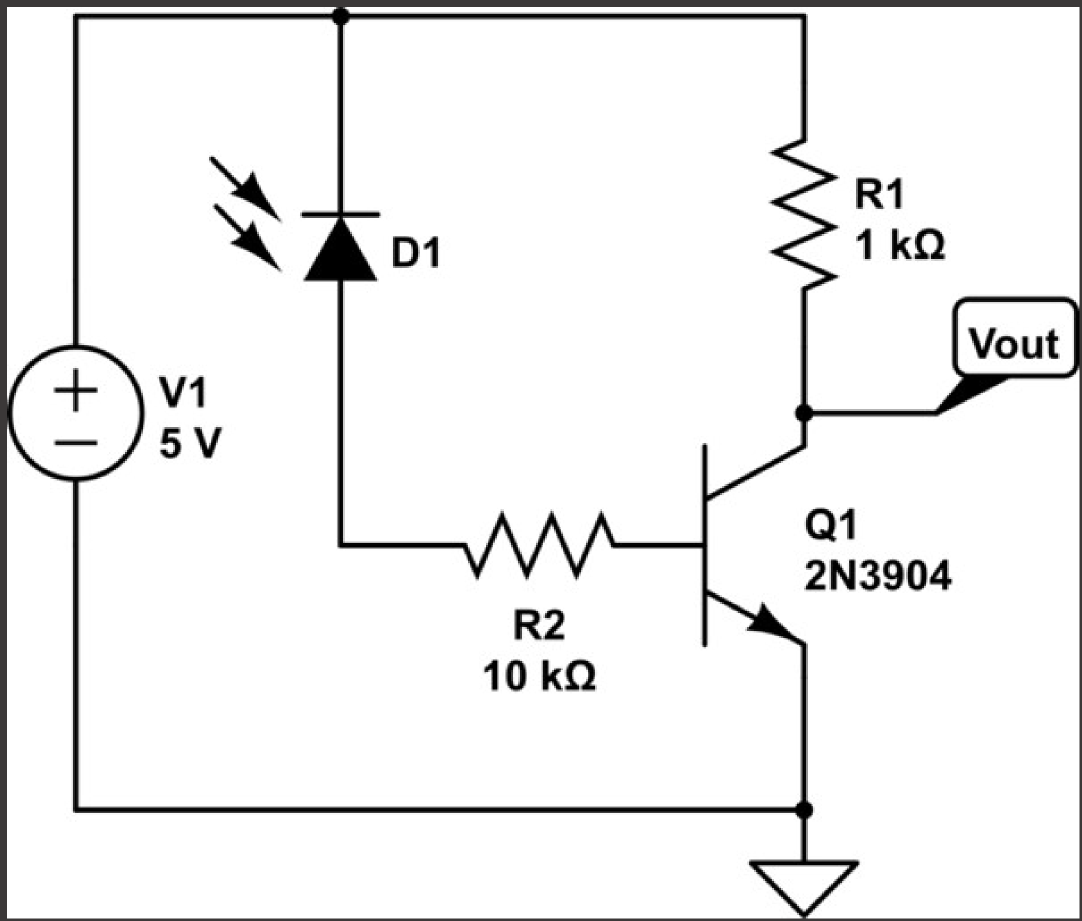
Why is a transistor used here?





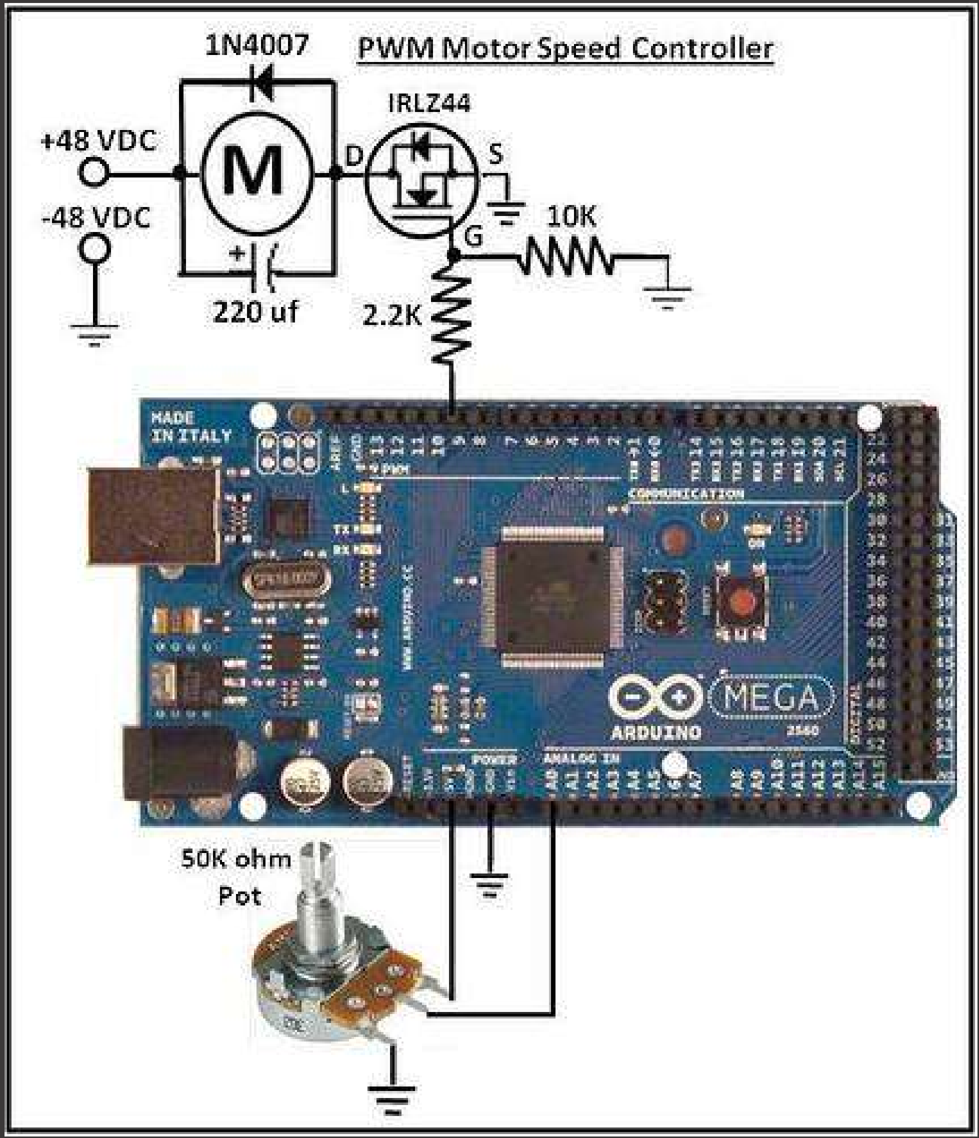
BJT Photodiode Example

Why is a transistor used here?

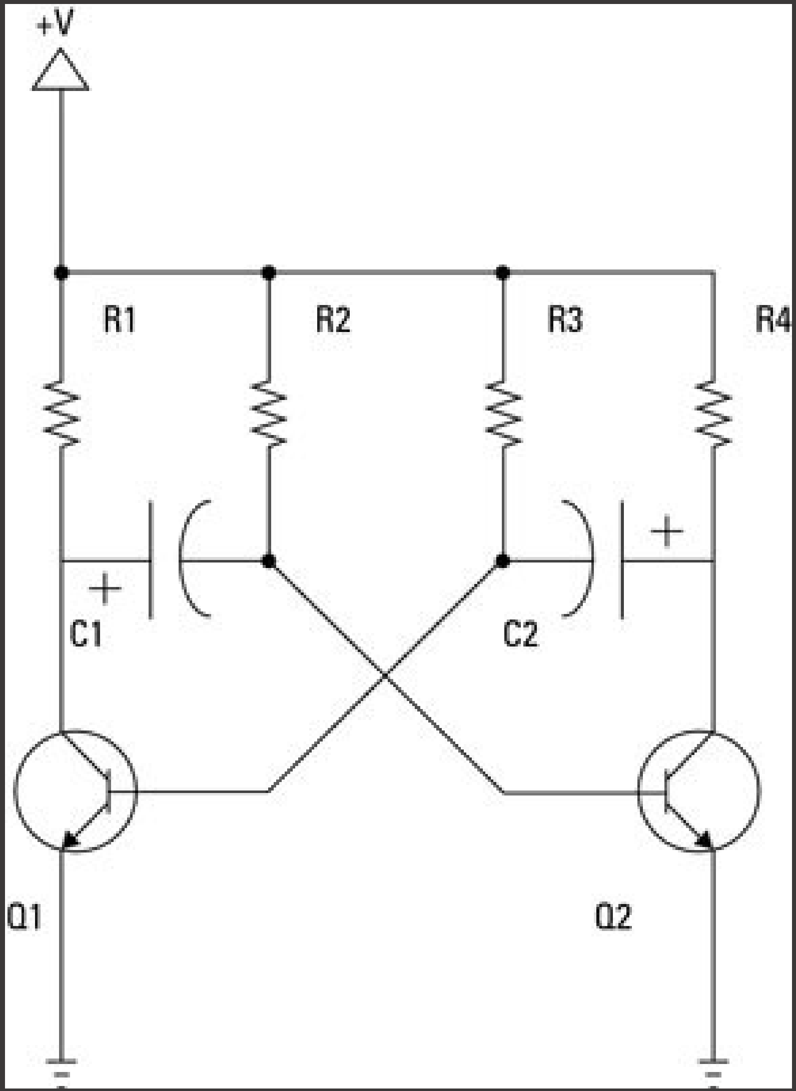


High voltage motor control

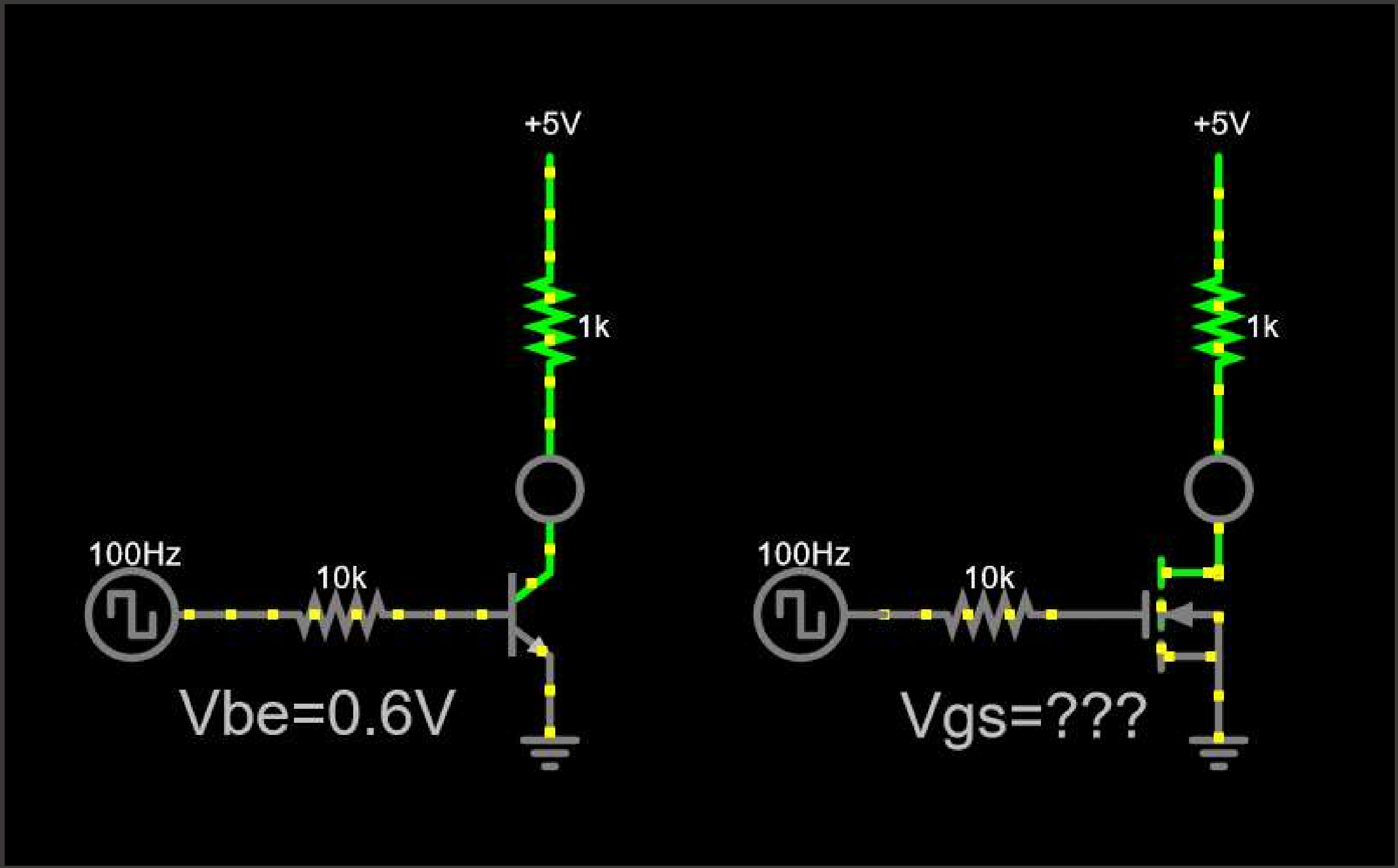
Why is a transistor used here?



Two transistor oscillator



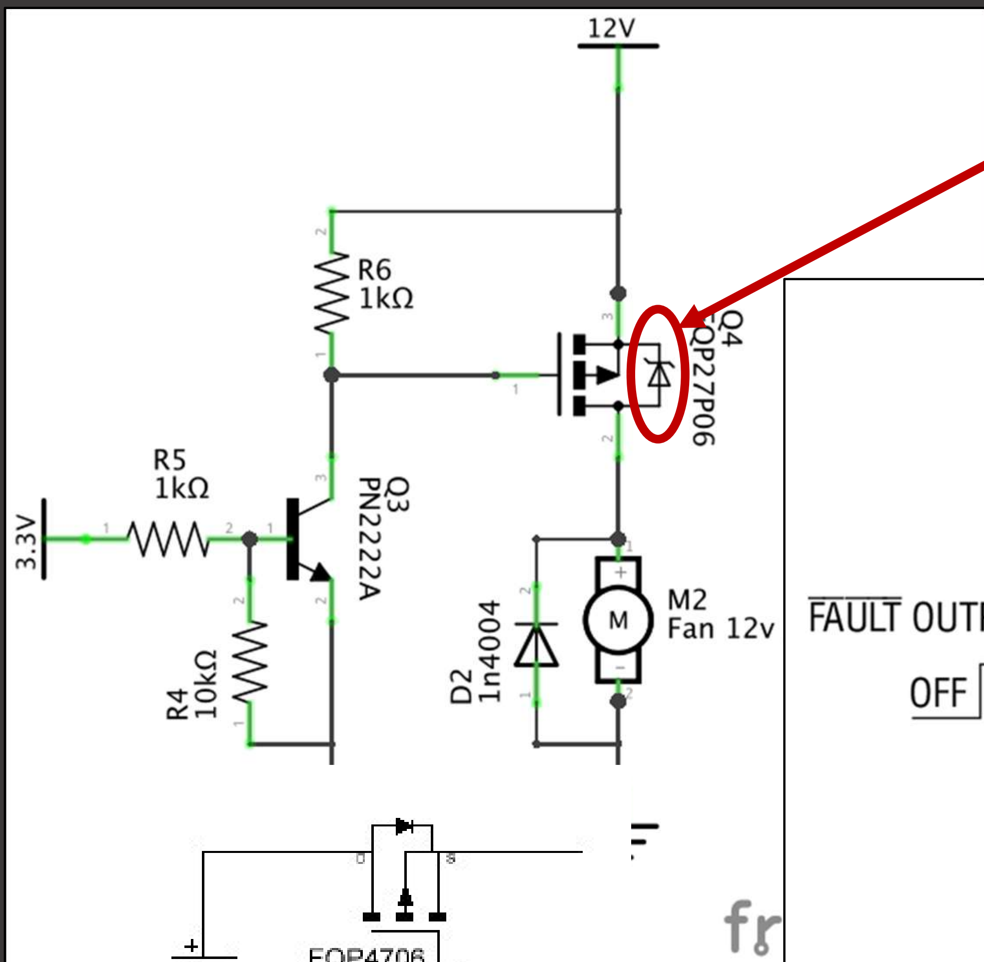
If they're the same, why choose one over the other?

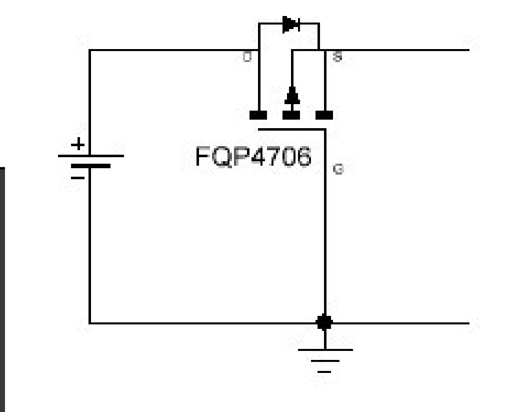


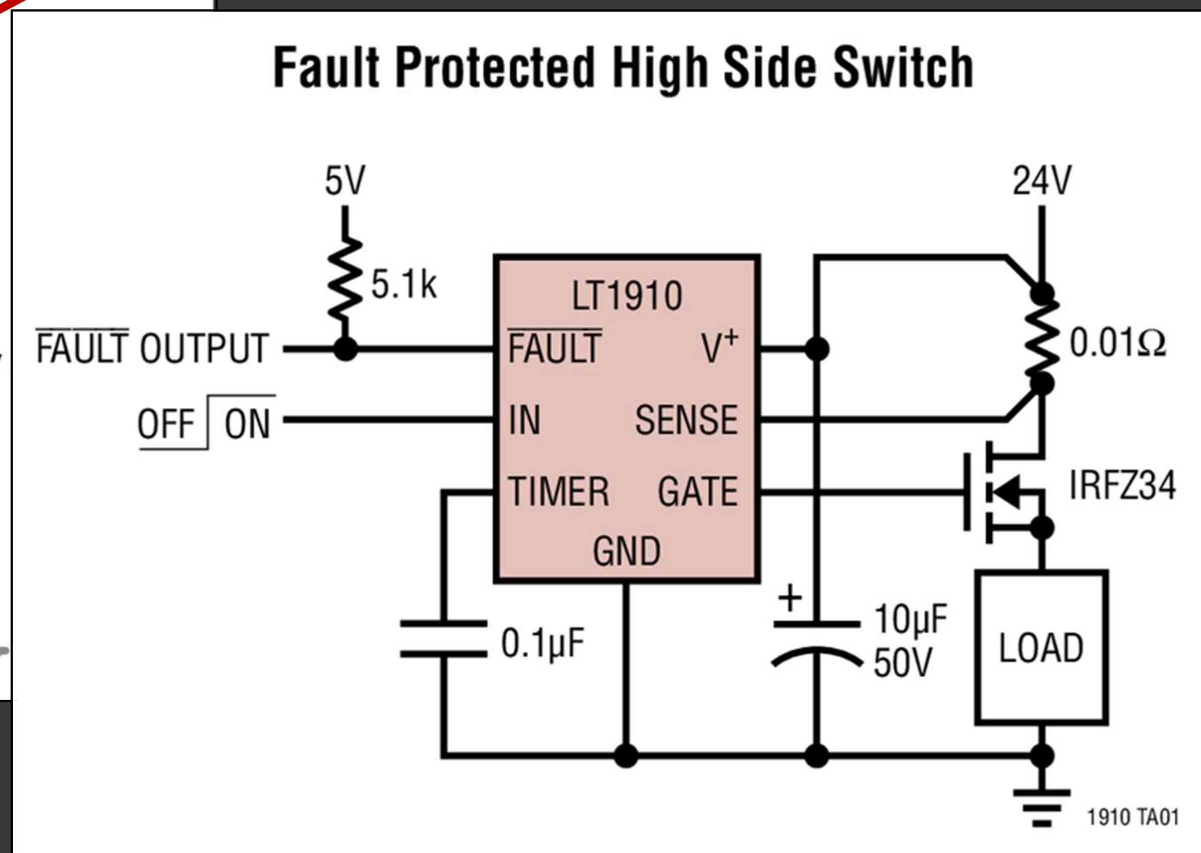
BJTs are generally easier to select and use but… not always

MOSFET Examples

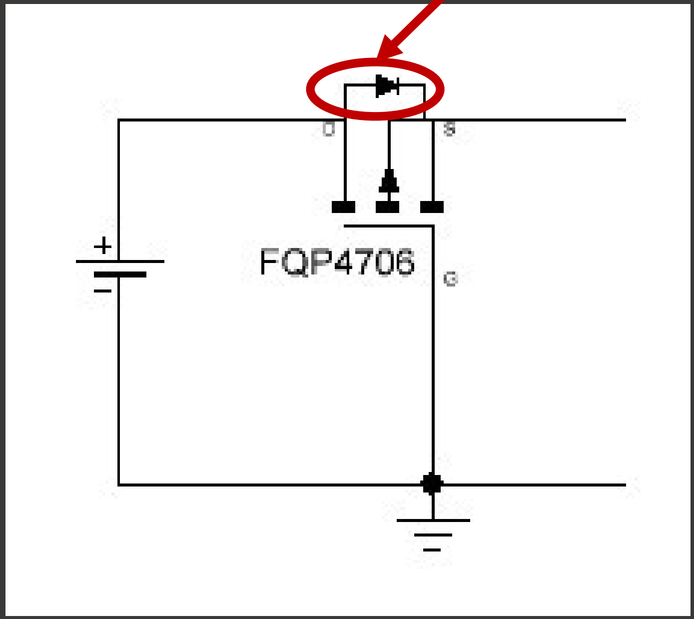
Note the “body diode” which is intrinsic to all MOSFETs







MOSFET, Body Diode Can be Useful



Normal operation is through body diode.

During reverse polarity, FET is off and diode blocks current flow

Key Bipolar Transistor Specs

OFF CHARACTERISTICS

Collector – Emitter Breakdown Voltage (Note 2) (I_C = 1.0 mAdc, I_B = 0)	$V_{(BR)CEO}$	40	–	Vdc

Collector-emitter Breakdown Voltage

- Maximum operating C-E should be 20-50% lower

Collector Current – Continuous	I_C	200	mAdc

Maximum continuous collector current

- You should be below this with some margin ~20%

SMALL–SIGNAL CHARACTERISTICS

Current – Gain – Bandwidth Product (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz)	2N3903 2N3904	f_T	250 300	– –	MHz

f_T – frequency at which gain falls to 1

- Should be > 100x your operating frequency
- Avoid super high frequency transistors (1GHz!)

Key MOSFET Specs

Characteristic		Symbol	Min	Max	Unit
OFF CHARACTERISTICS					
Drain–Source Breakdown Voltage	(V_{GS} = 0, I_D = 10 μAdc)	$V_{(BR)DSS}$	60	–	Vdc

Drain-Source Breakdown Voltage

- Maximum operating D-S should be 20-50% lower

ON CHARACTERISTICS (Note 1)					
Gate Threshold Voltage	(V_{DS} = V_{GS}, I_D = 1.0 mAdc)	$V_{GS(th)}$	0.8	3.0	Vdc

Gate threshold voltage

- You should be well above/below this

Static Drain–Source On–Resistance	(V_{GS} = 10 Vdc, I_D = 0.5 Adc) (V_{GS} = 4.5 Vdc, I_D = 75 mAdc)	$r_{DS(on)}$	– –	5.0 6.0	Ω
Drain–Source On–Voltage	(V_{GS} = 10 Vdc, I_D = 0.5 Adc) (V_{GS} = 4.5 Vdc, I_D = 75 mAdc)	$V_{DS(on)}$	– –	2.5 0.45	Vdc

On-Voltage (or On-Resistance)

- Should be low enough

MOSFET vs Bipolar Pros/Cons

Bipolar
- Easier to drive voltage-wise
- Rugged

MOSFET
- Can be more efficient
- Can switch faster
- Gate easier to drive current-wise
- Poor selection for 3.3V circuits
- Can be difficult to select proper Vt

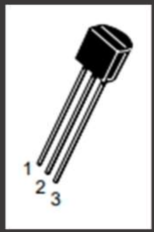
Very application dependent:
Switching power supplies
Audio Amplifiers
GPIO LED bias

Practical guidance/tendencies:
- Low power, low voltage -> bipolar
- High current -> FET
- High efficiency switching supplies -> FET

Go-to Transistors

Bipolar – the workhorse for enthusiasts

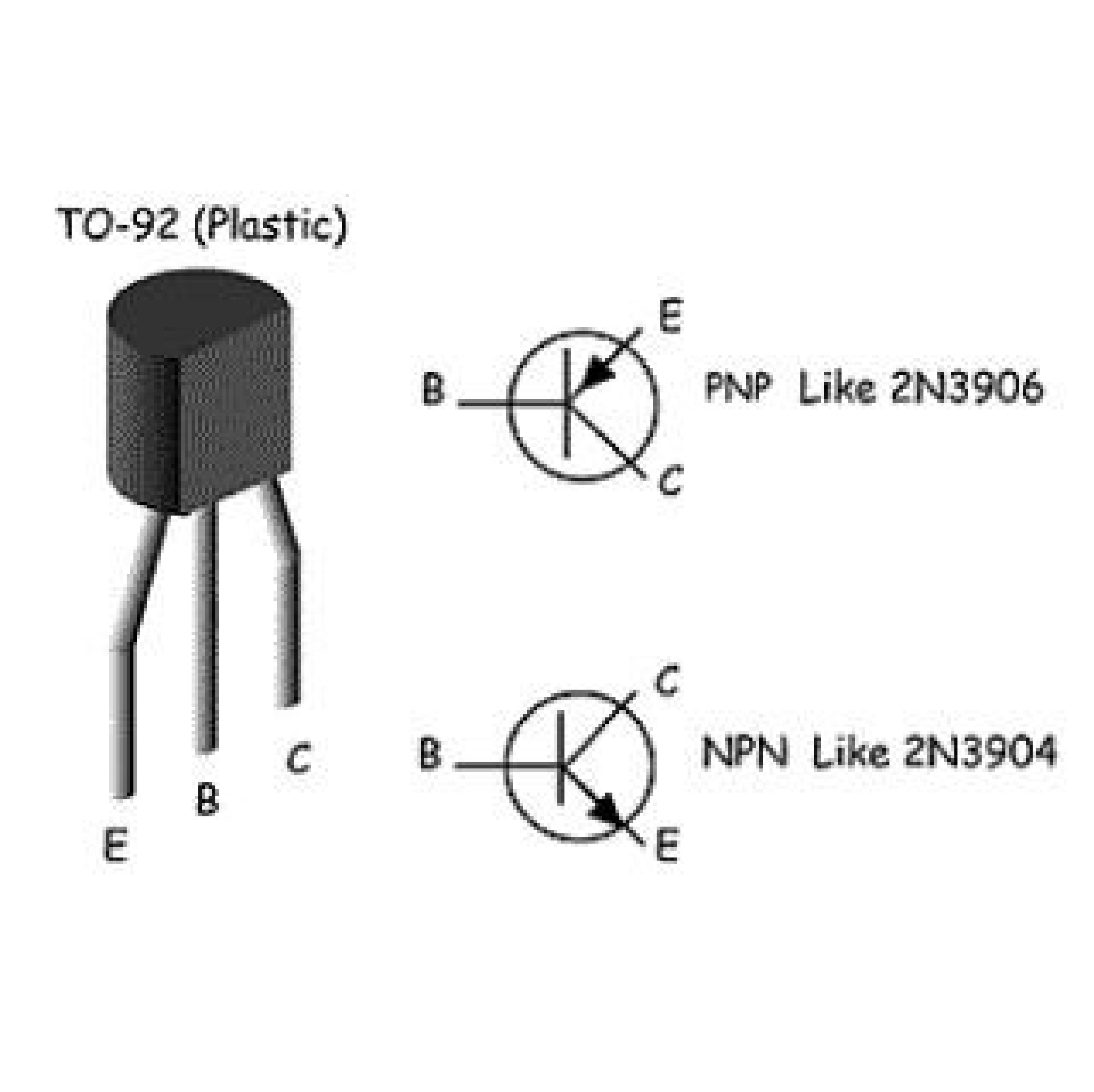
- 2N3904 – NPN, 40V, 200mA, 300MHz f_T
- 2N3906 – PNP, -40V. 200mA, 250MHz f_T
- TIP120 – NPN, 60V, 5A



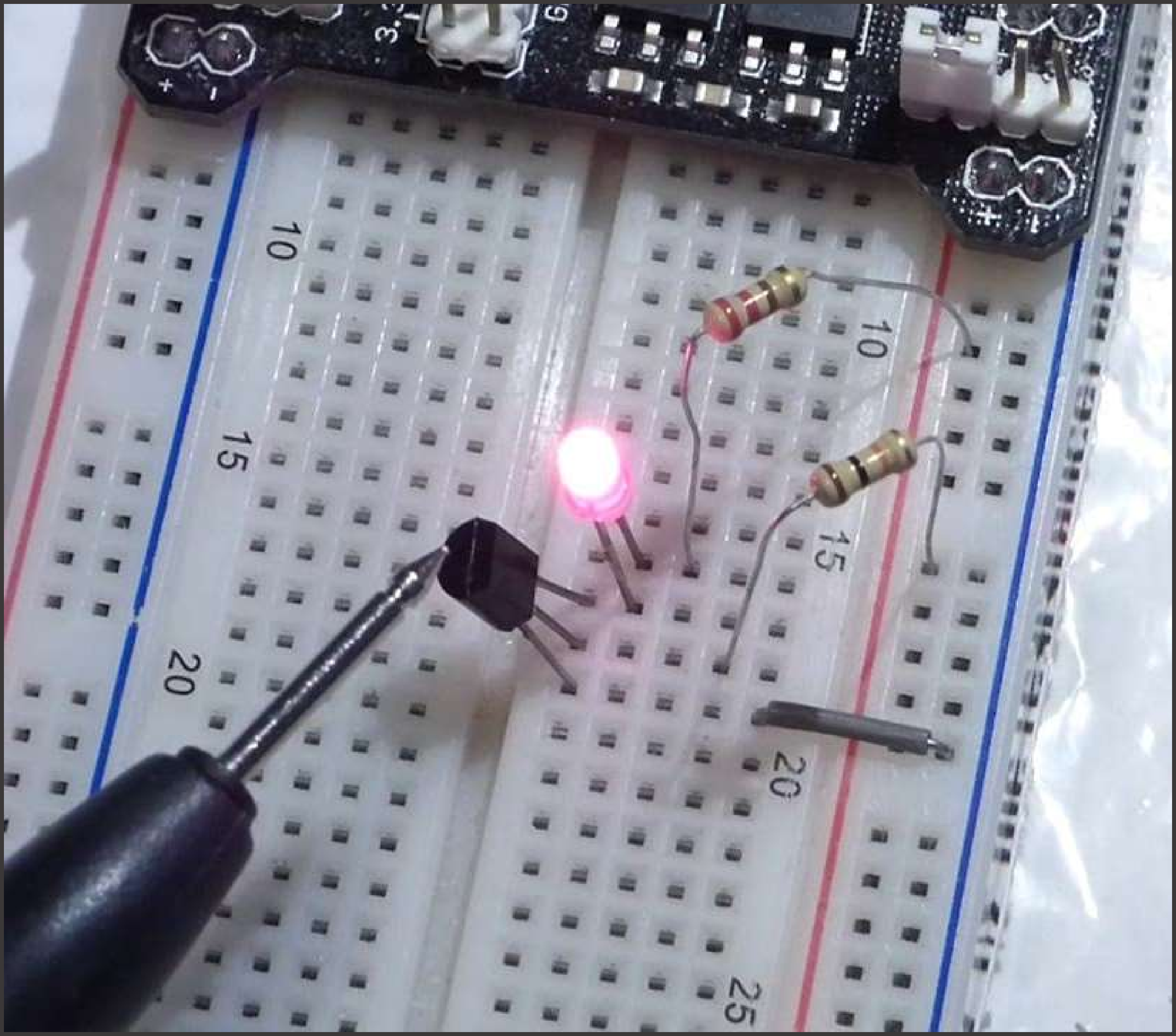
MOSFETs

- Probably don't want to stock FETs
- Wanna play? 2N7000, 2N7002 - NMOS

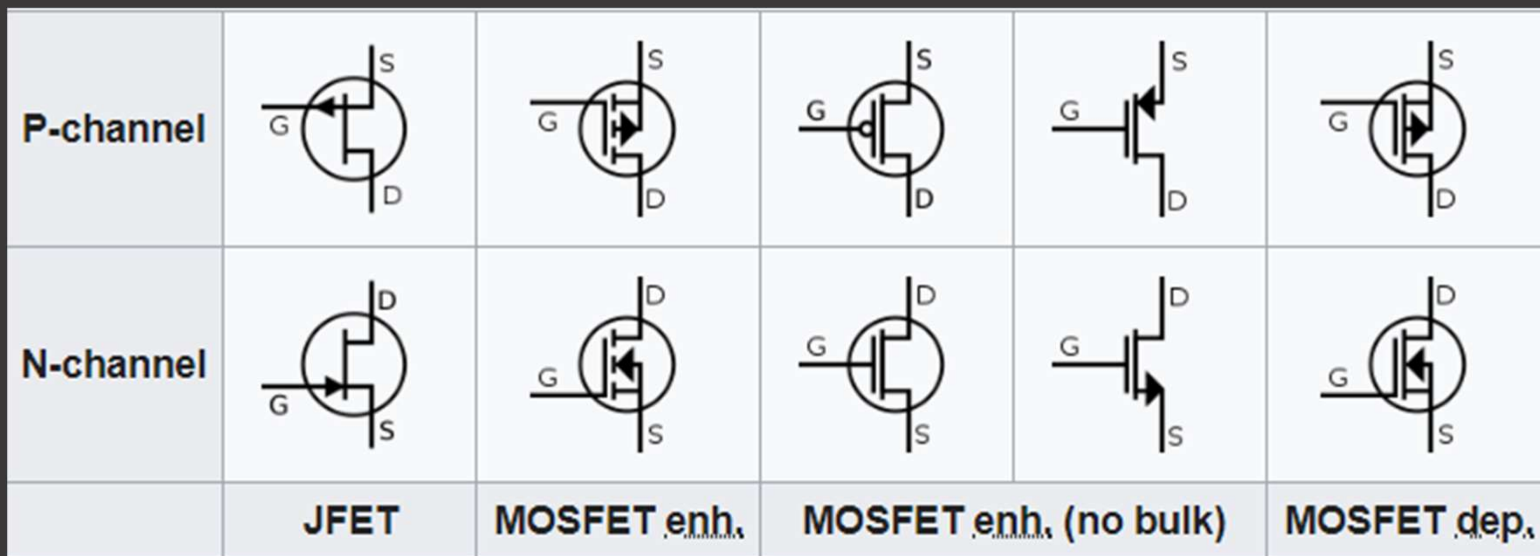
Common Bipolar Pinouts



Typical Breadboard Application



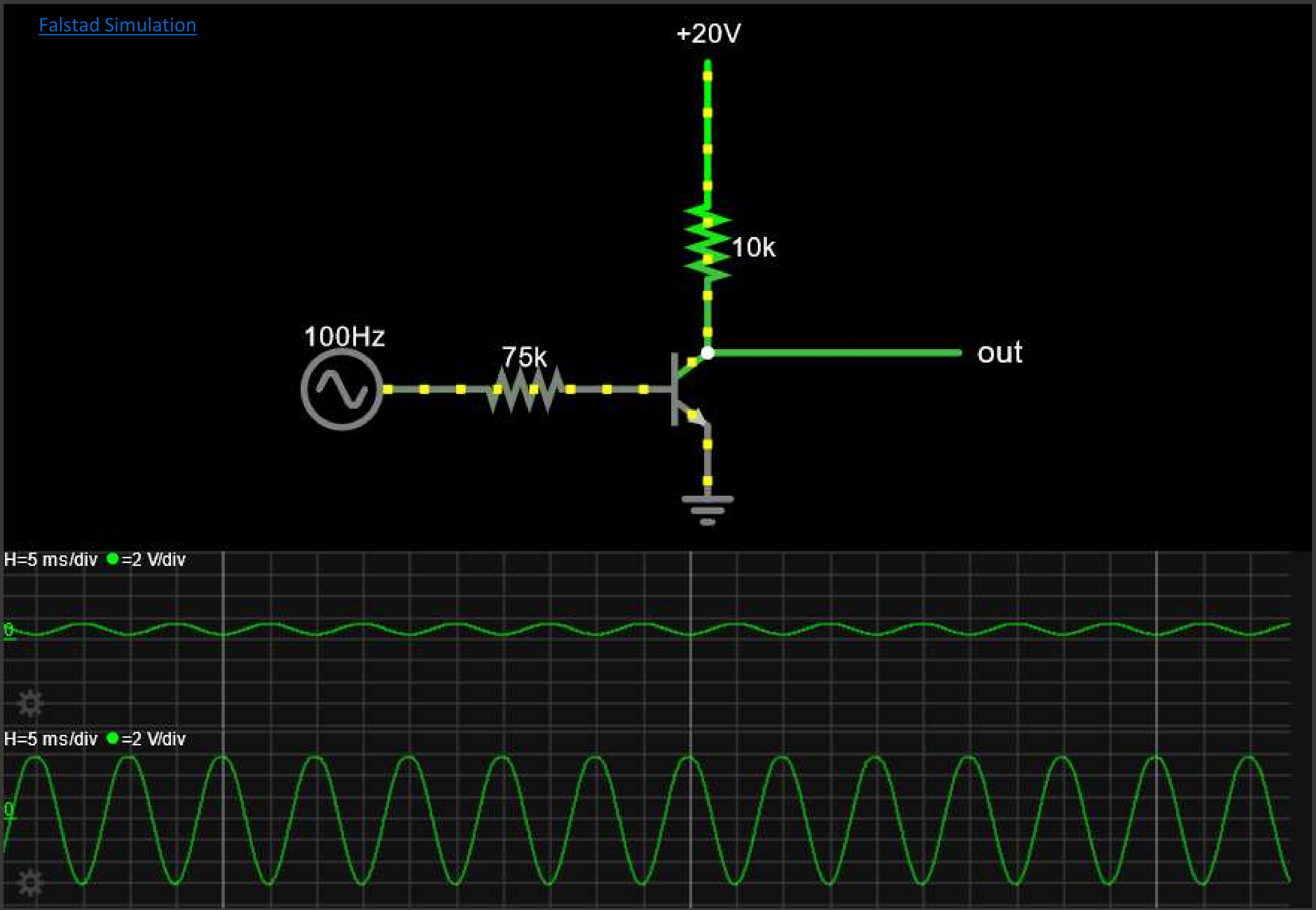
MOSFET Schematic Symbols



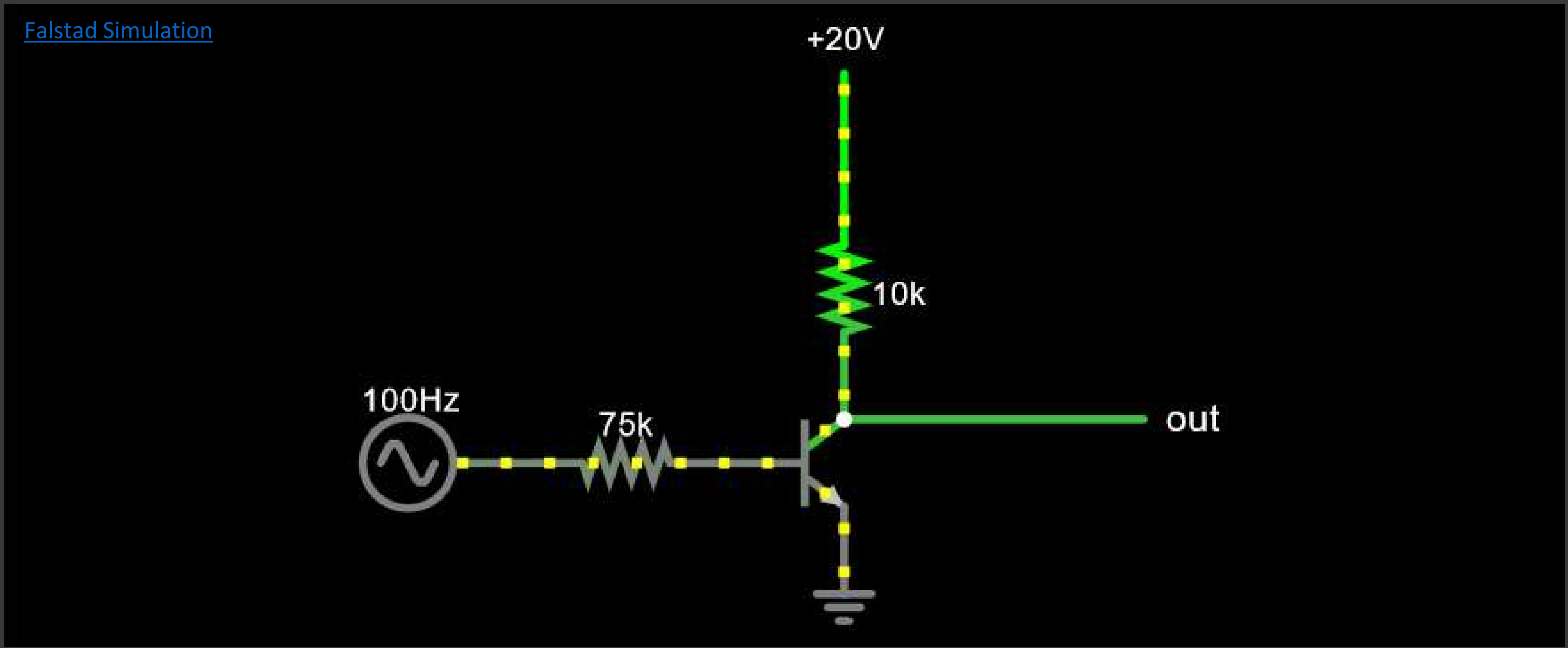
- There are many, many variations on these
- FETs of the same type (P vs N) behave similar to each other
- Be aware but don't fret over it too much

Transistors as Amplifiers

A Linear Amplifier



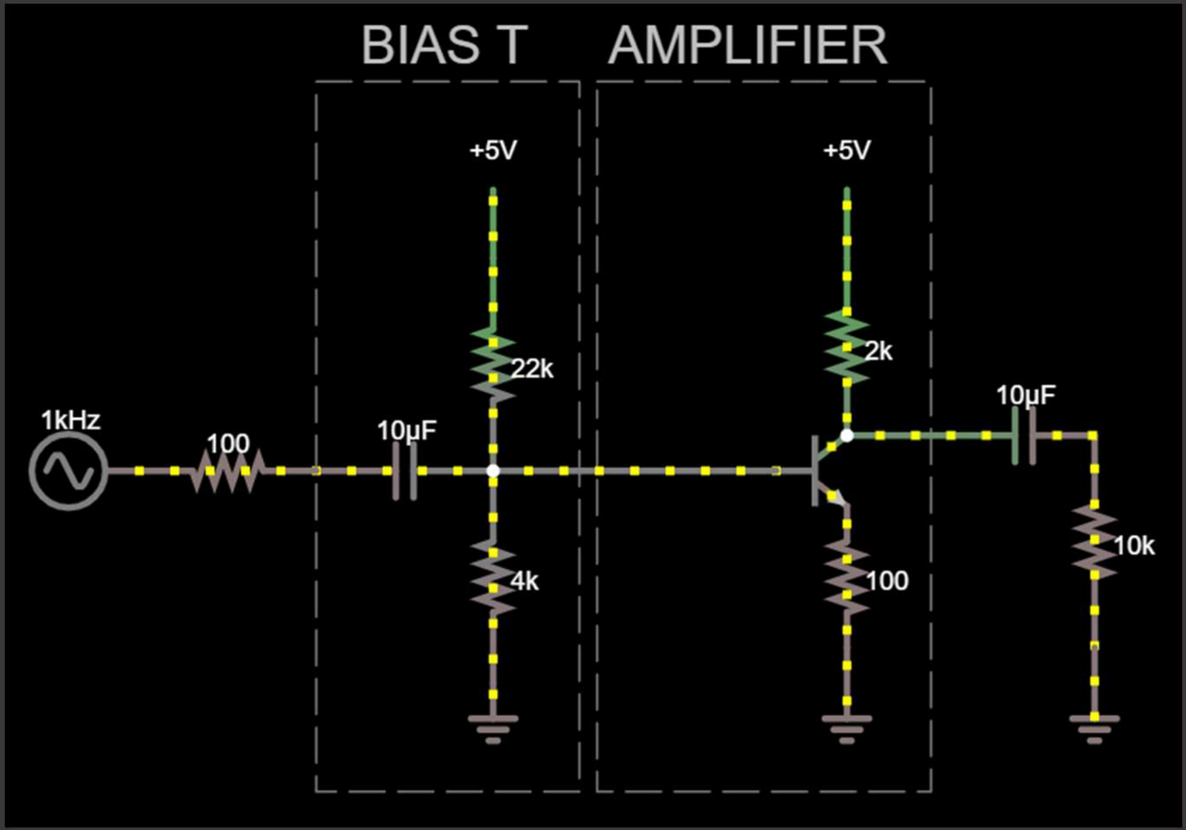
Not a good design



Problems

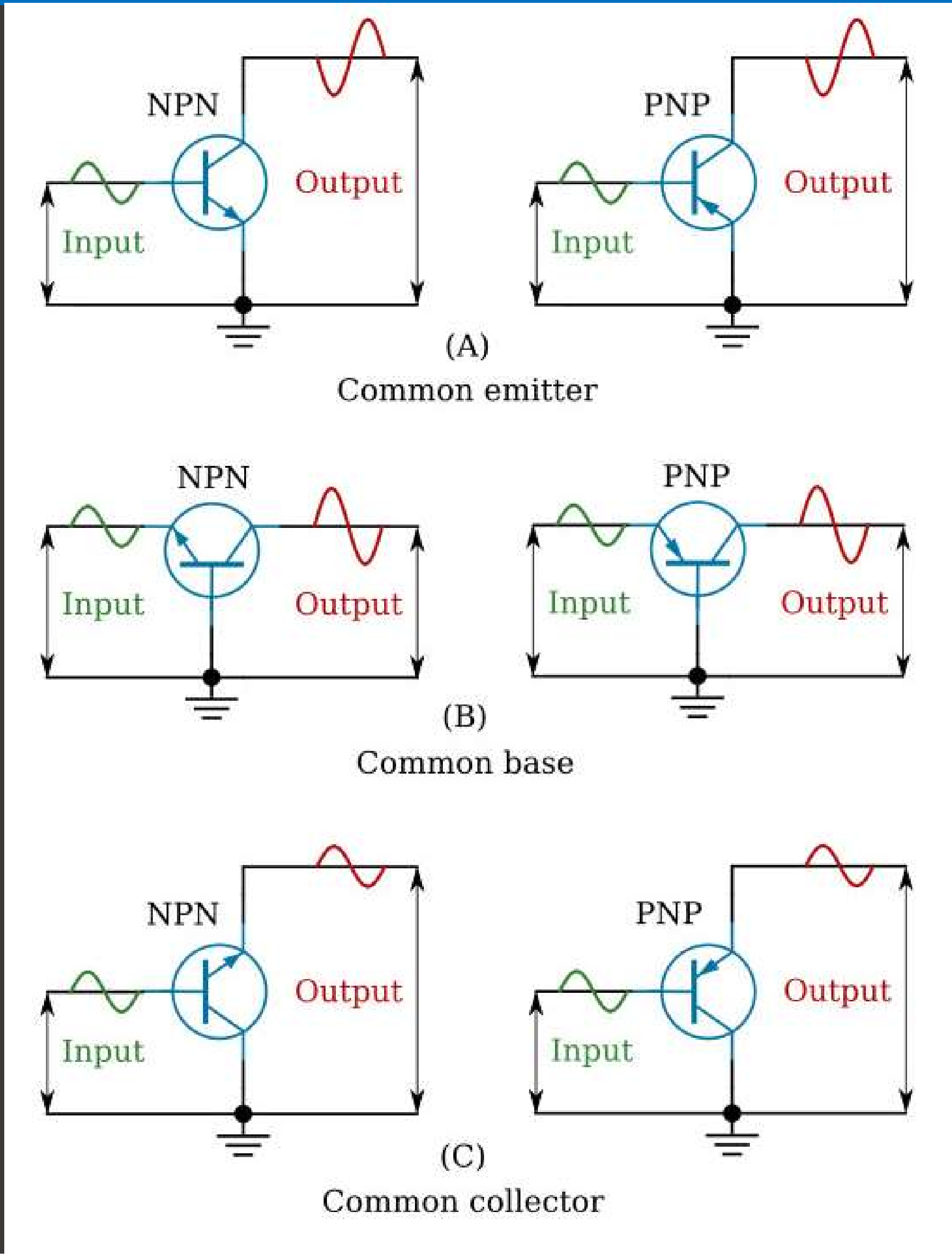
- Gain will vary too much with β (h_{fe}) variation
- Linearity isn't very good
- Input dynamic range is poor
- Circuit needs fine-tuning per transistor used

A Better Design



- Gain ~= -Rc/Re
- Improved distortion
- Improved dynamic range
- Less sensitive to individual transistor characteristics

Common Configurations



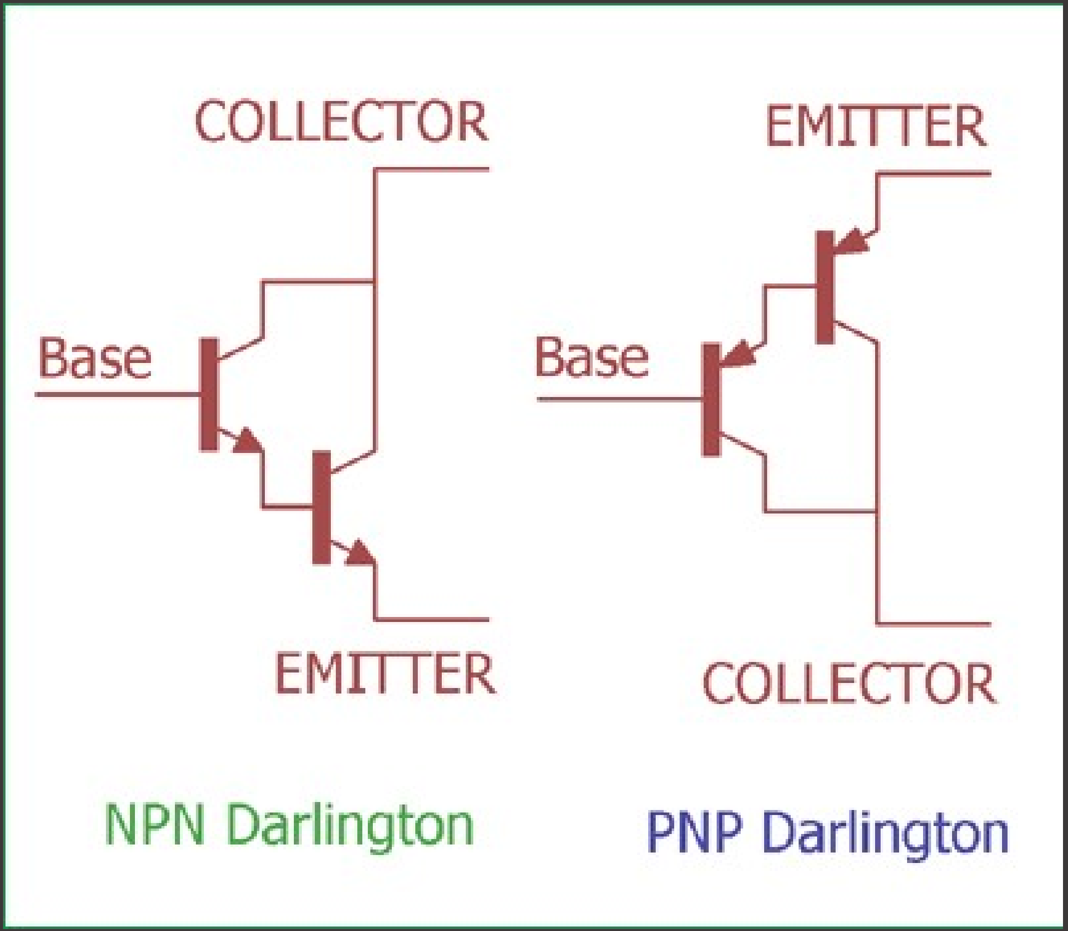
V and I gain
Low input R
Low output R

V gain
Low input R
High output R

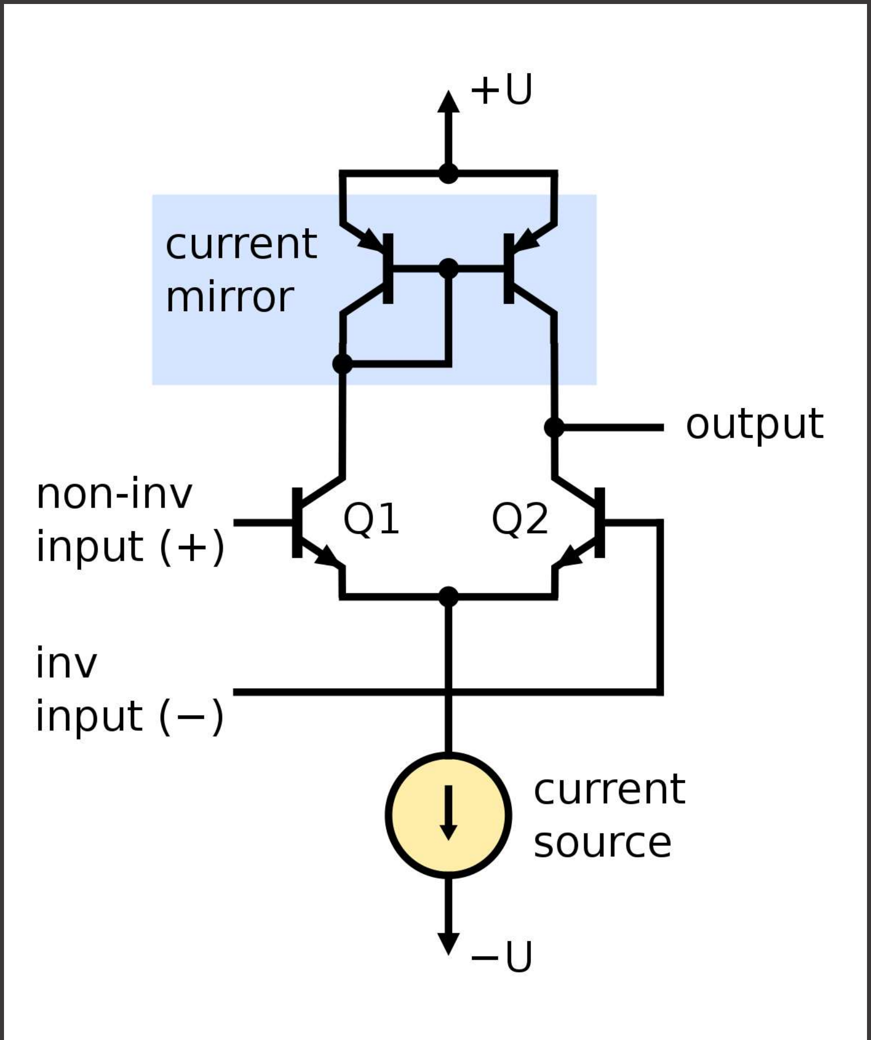
I gain
High input R
Low output R

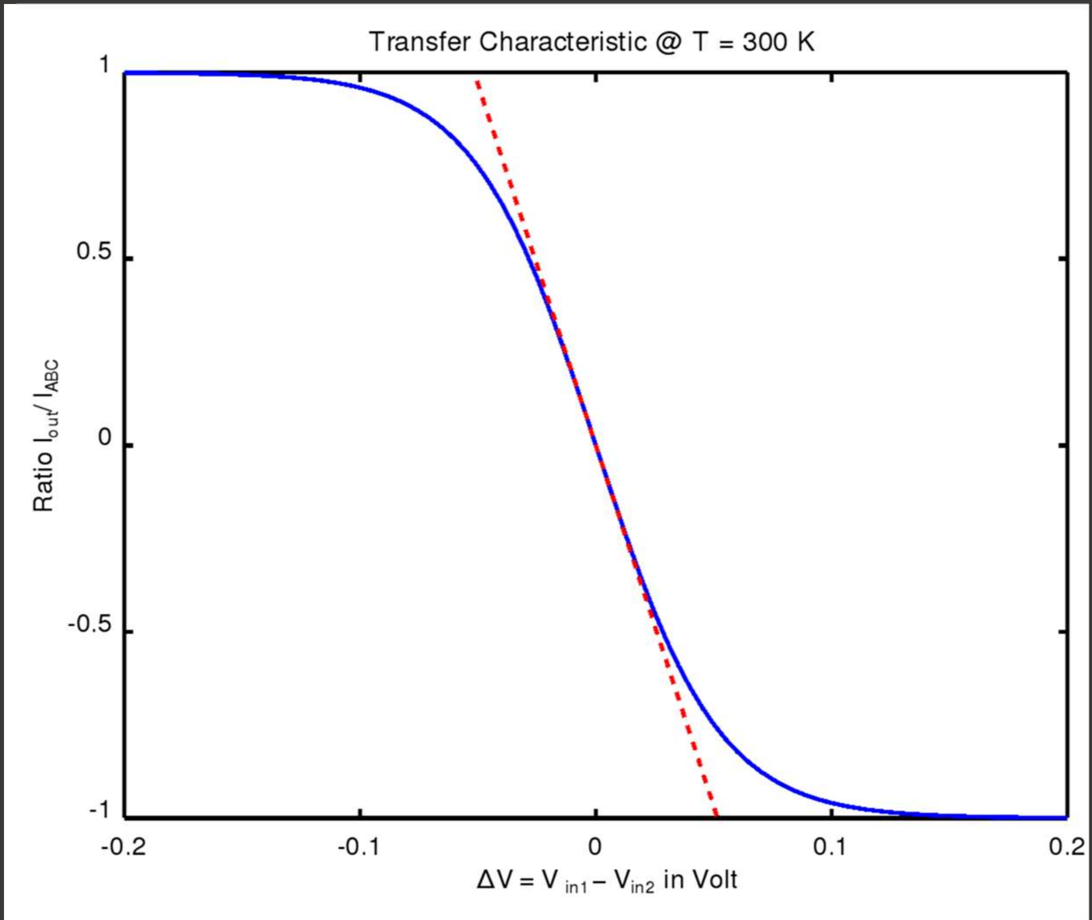
Darlington Pair

Gain is squared (100 becomes 10,000)

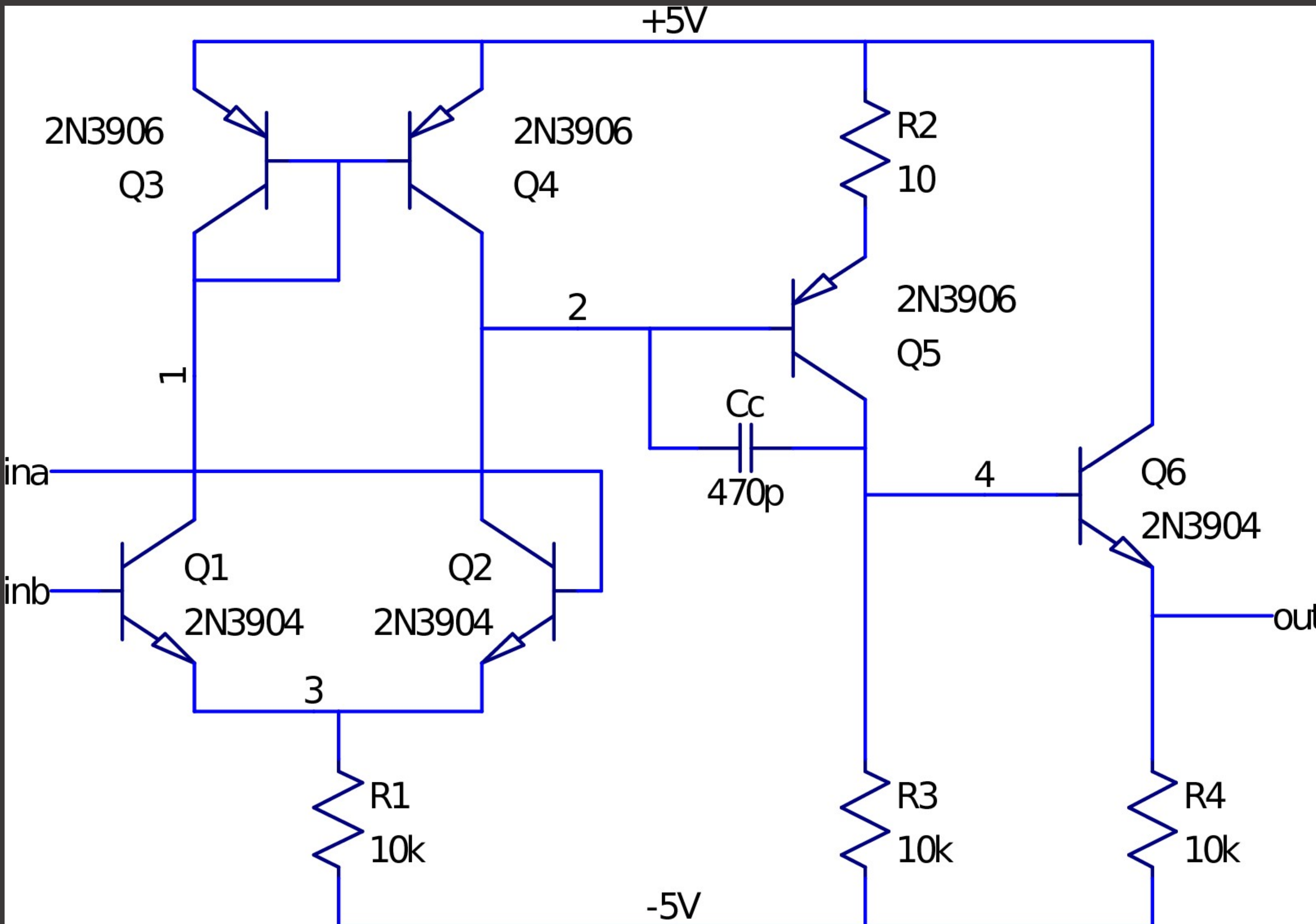


Differential Pair





Simple Op-Amp



Simple Op-Amp Usage

Simple circuit
Near ideal performance