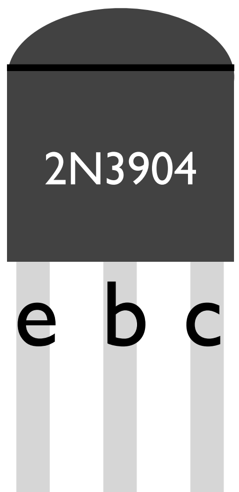
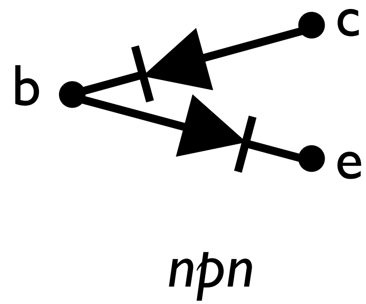
Transistors, so far



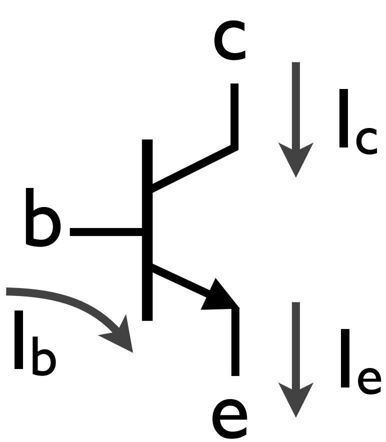


Rules

1. $V_c > V_e$
2. b-e and b-e circuits ~ diodes
3. max values of I_c, I_b, V_{ce}
4. if rules are obeyed,

$$I_c = \beta I_b$$

$\beta \sim 100$, but variable

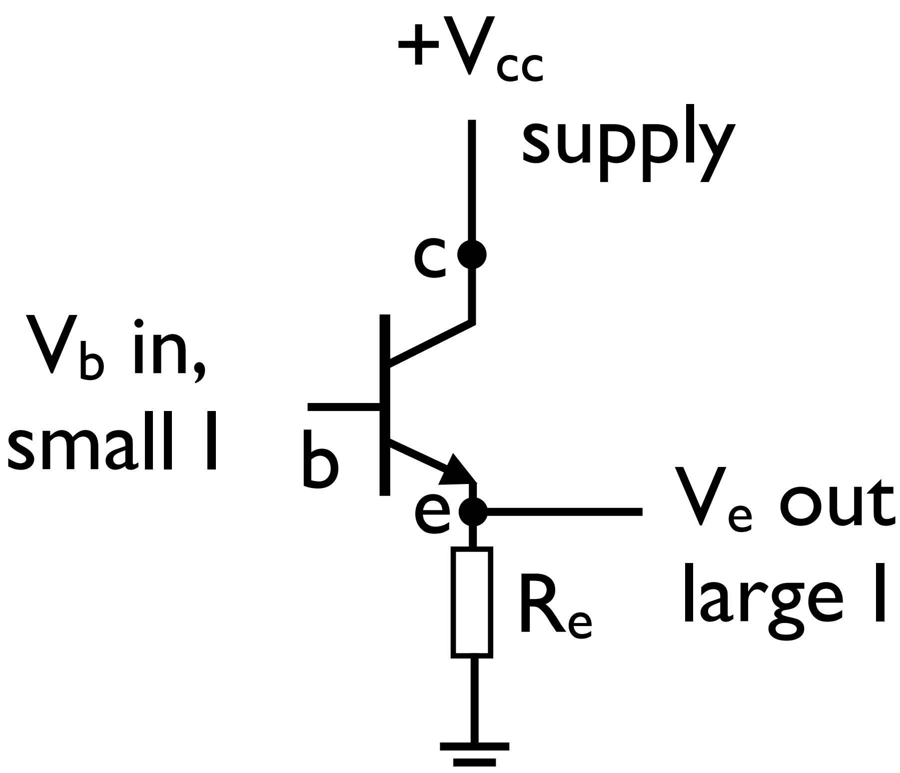


conservation of current:

$$I_e = I_c + I_b = \beta I_b + I_b = (1 + \beta)\, I_b \approx \beta I_b$$

Simple view

$$
\begin{aligned}
I_e &= (1+\beta) I_b \\
V_b &= V_e + 0.6
\end{aligned}
$$



follower:

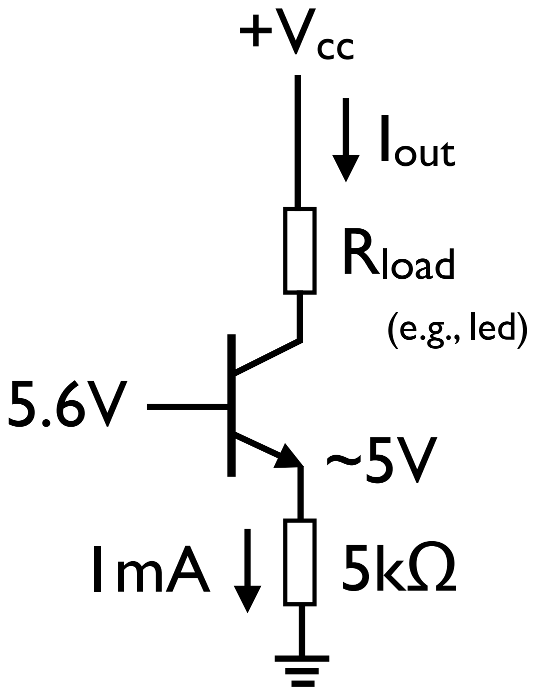
output voltage ~ same

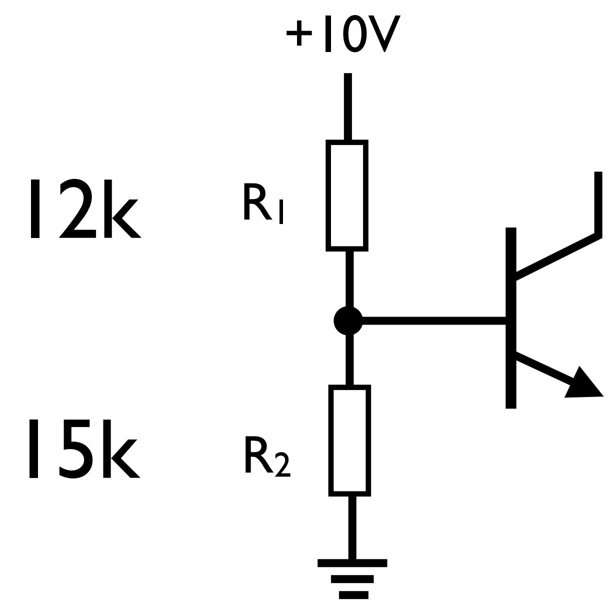
output *current* larger

output resistance lower

Current Source

1) pick load current
2) pick emitter resistor and bias
3) set up base V divider





want 1mA, pick 5V over 5k
(keep power ~mW)
make V_e ~ 1V for stability
sets base at 5.6V

given 10V supply, split to 5.6V
to ignore base current/load ...
resistance into base ~βR_e
divider R's smaller

caveats:

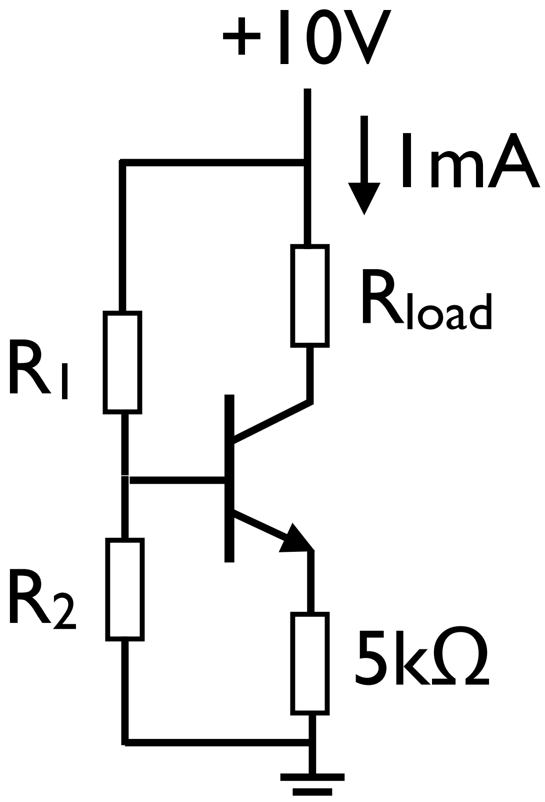
want divider 'stiff' c.f. βR_e so V_b ~ constant

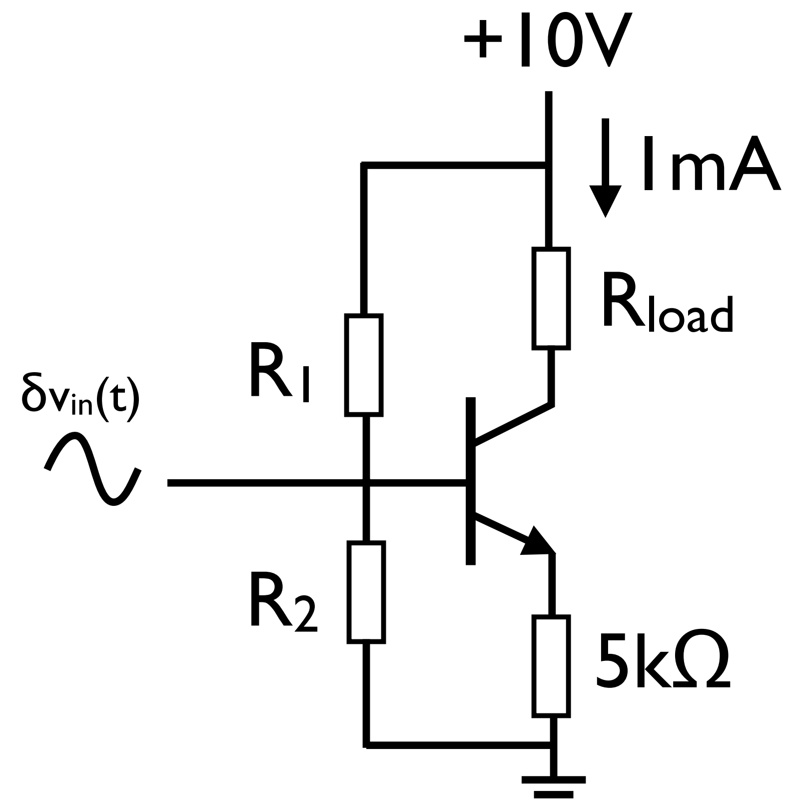
can't push V_e below ground

require $V_e < V_c$

limits voltage drop across load to a bit under V_{supply}

still: very good & stable I source, simple





programmable: add a signal at the base ...

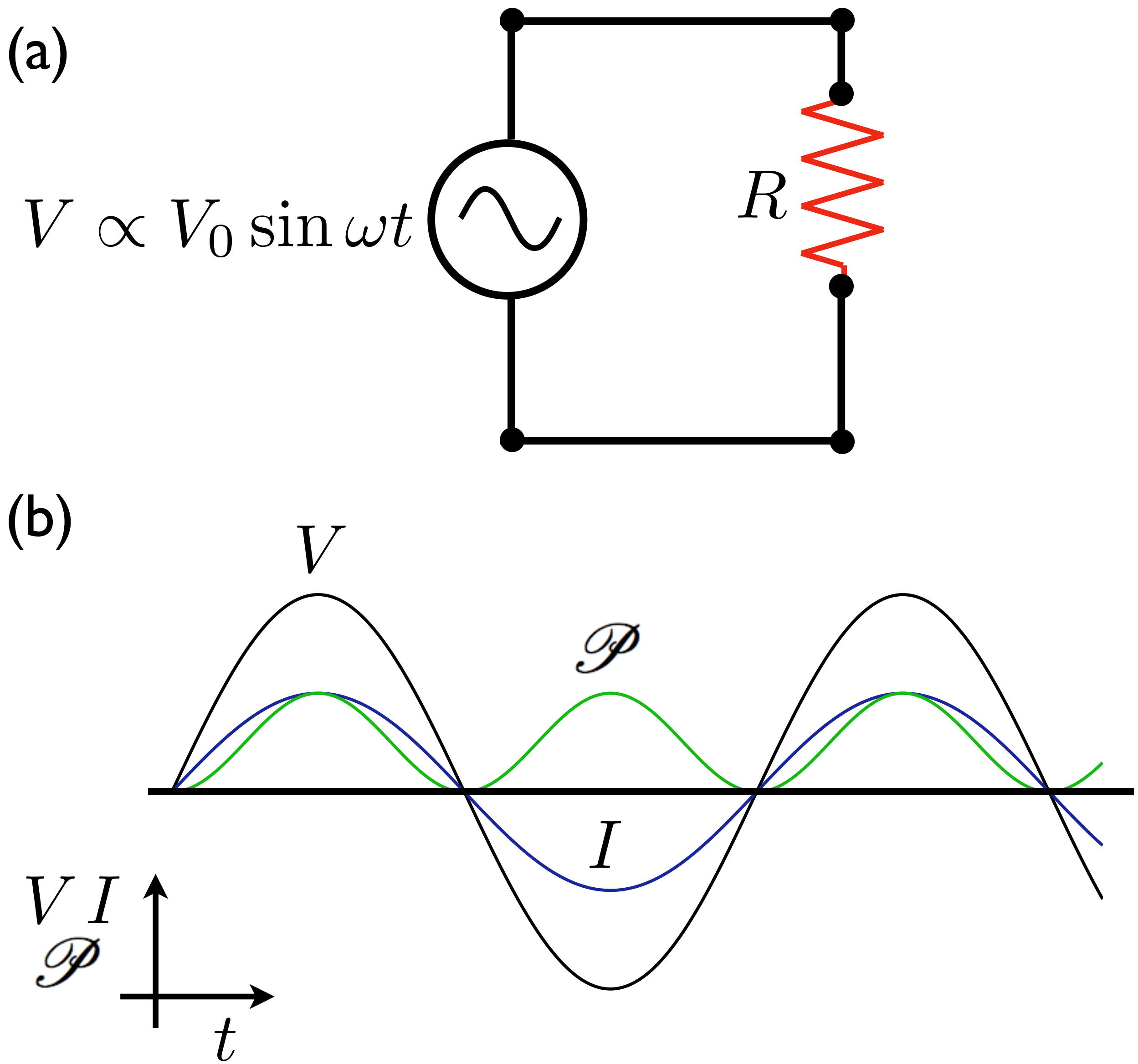
Signals: voltage & current varying in time

sine
ramp
pulse
noise

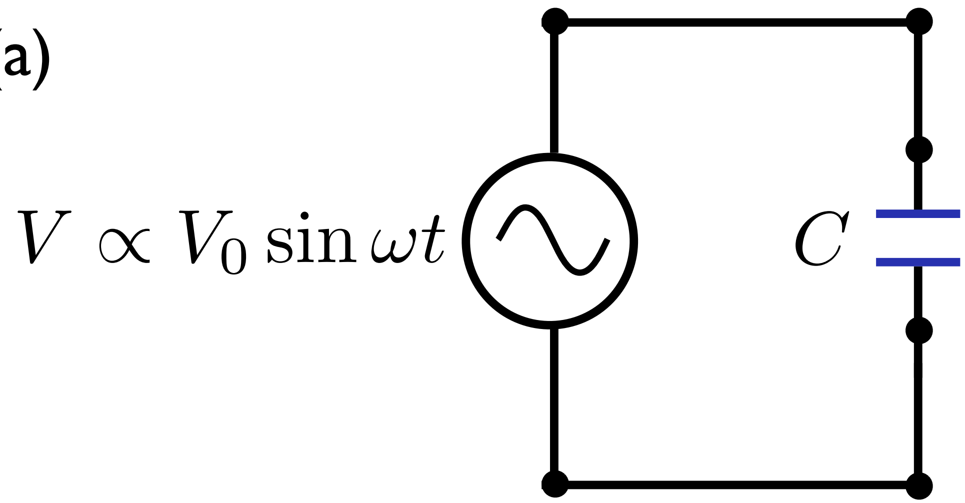
resistor doesn't care
capacitor follows $I = C\, dV/dt$

e.g., differentiator / integrator circuits
really analog signal processing

feed resistor a sine wave
it doesn't care



(a)



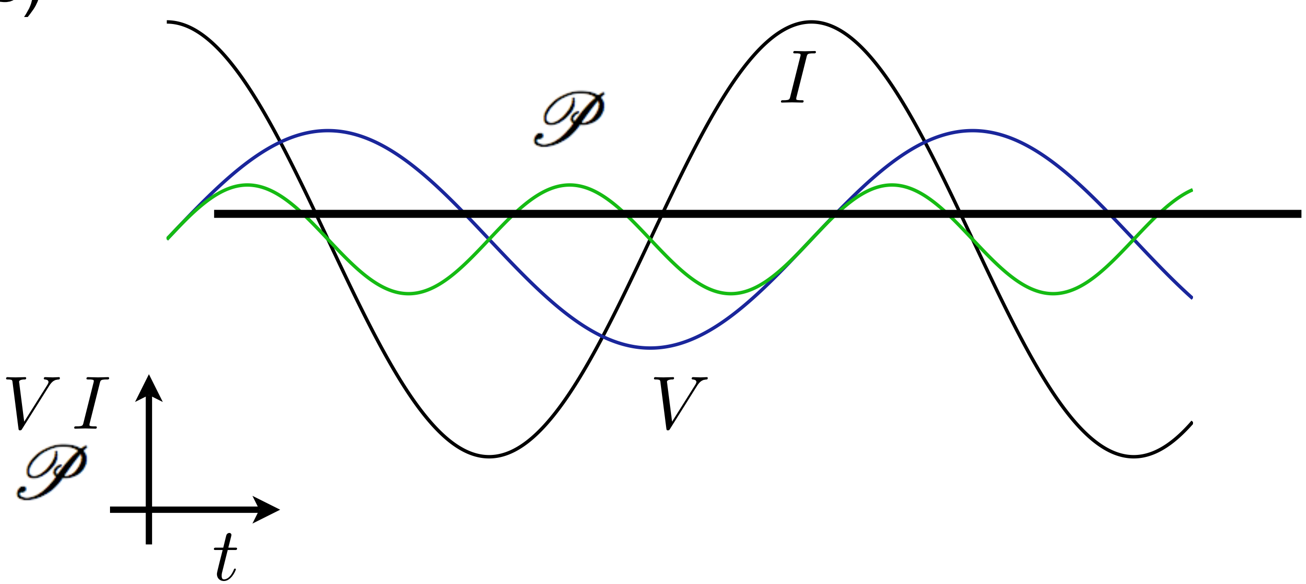
feed capacitor a sine wave ...

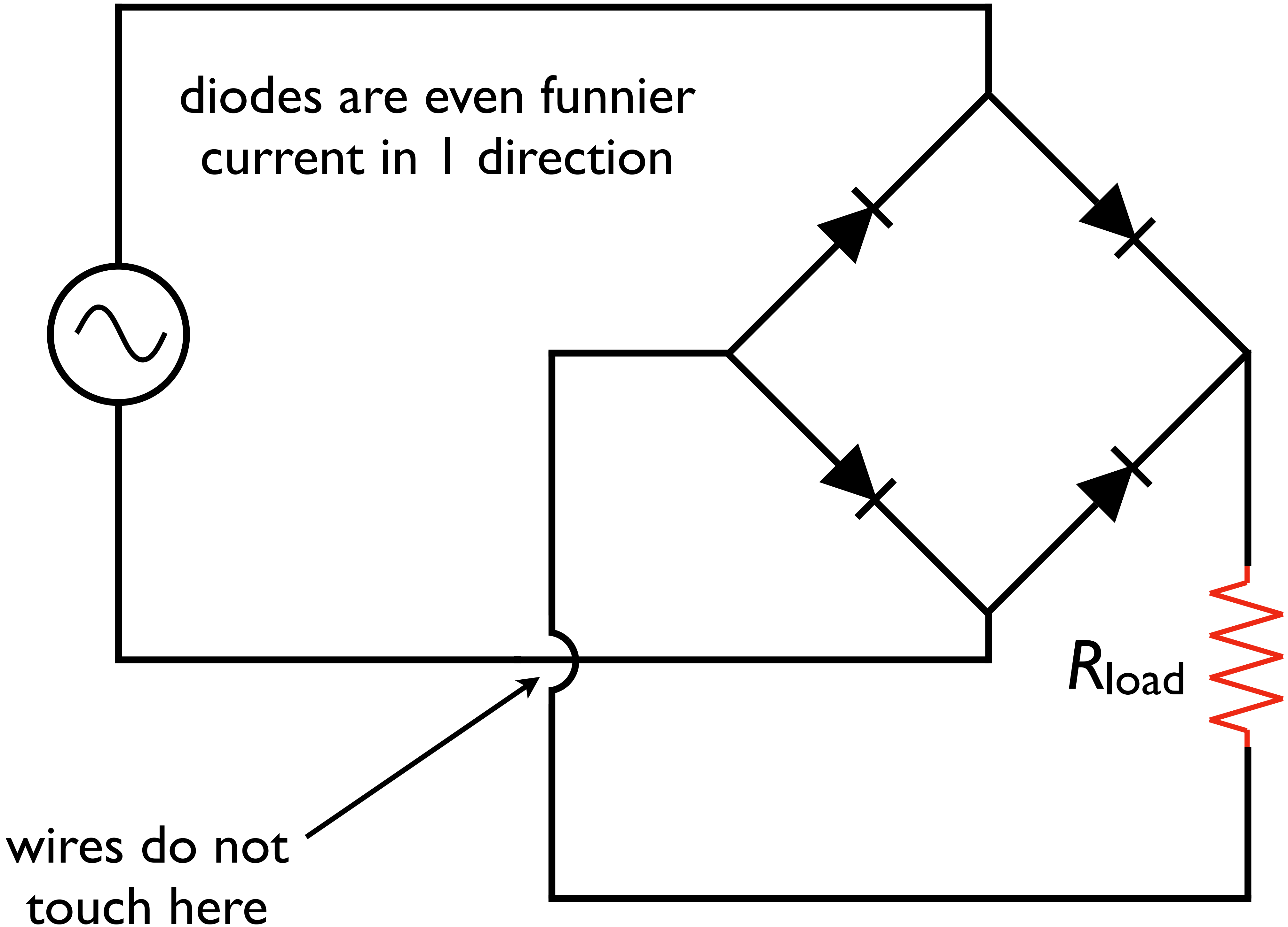
current is cosine! ~dV/dt

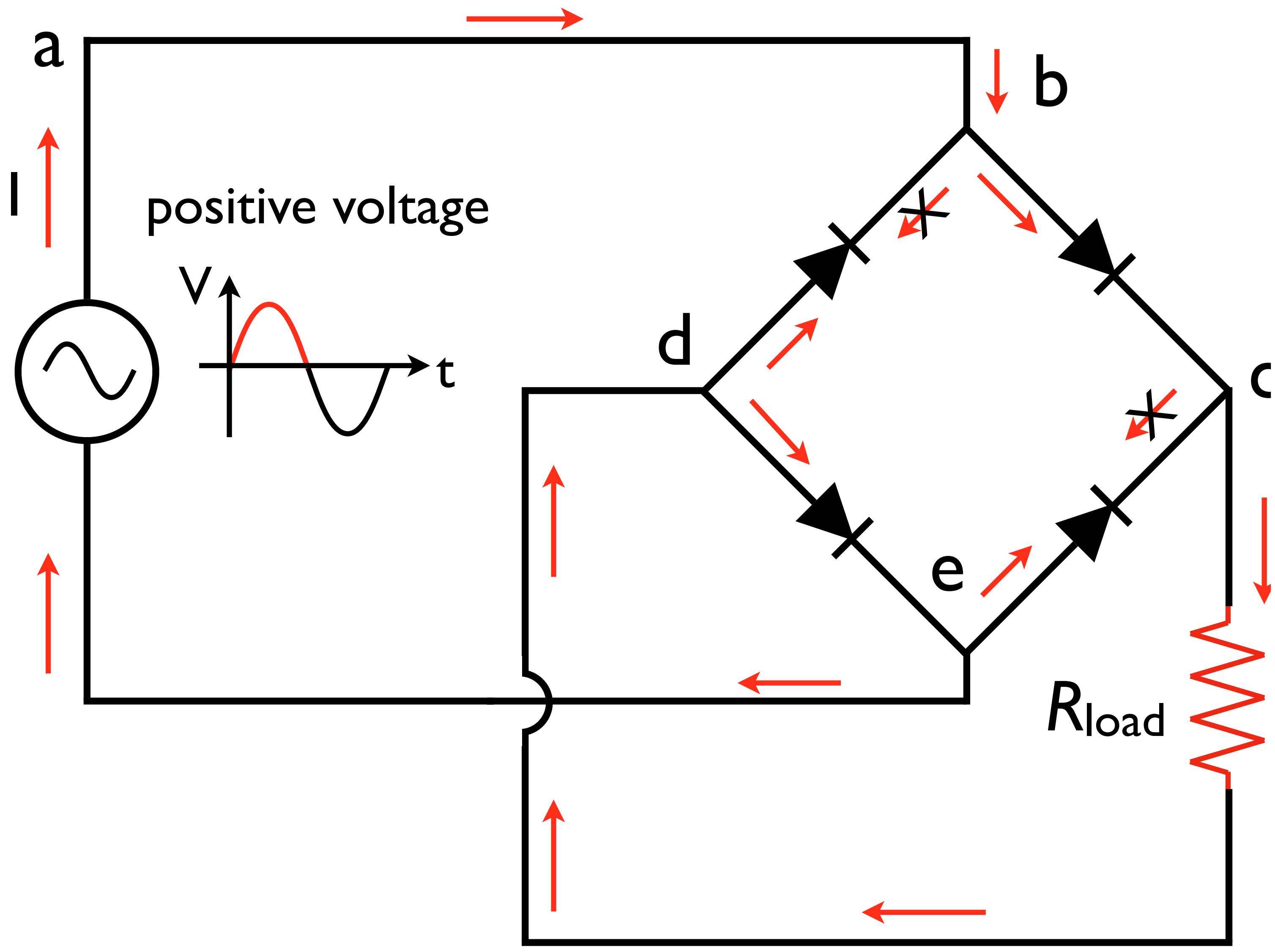
charging/discharging

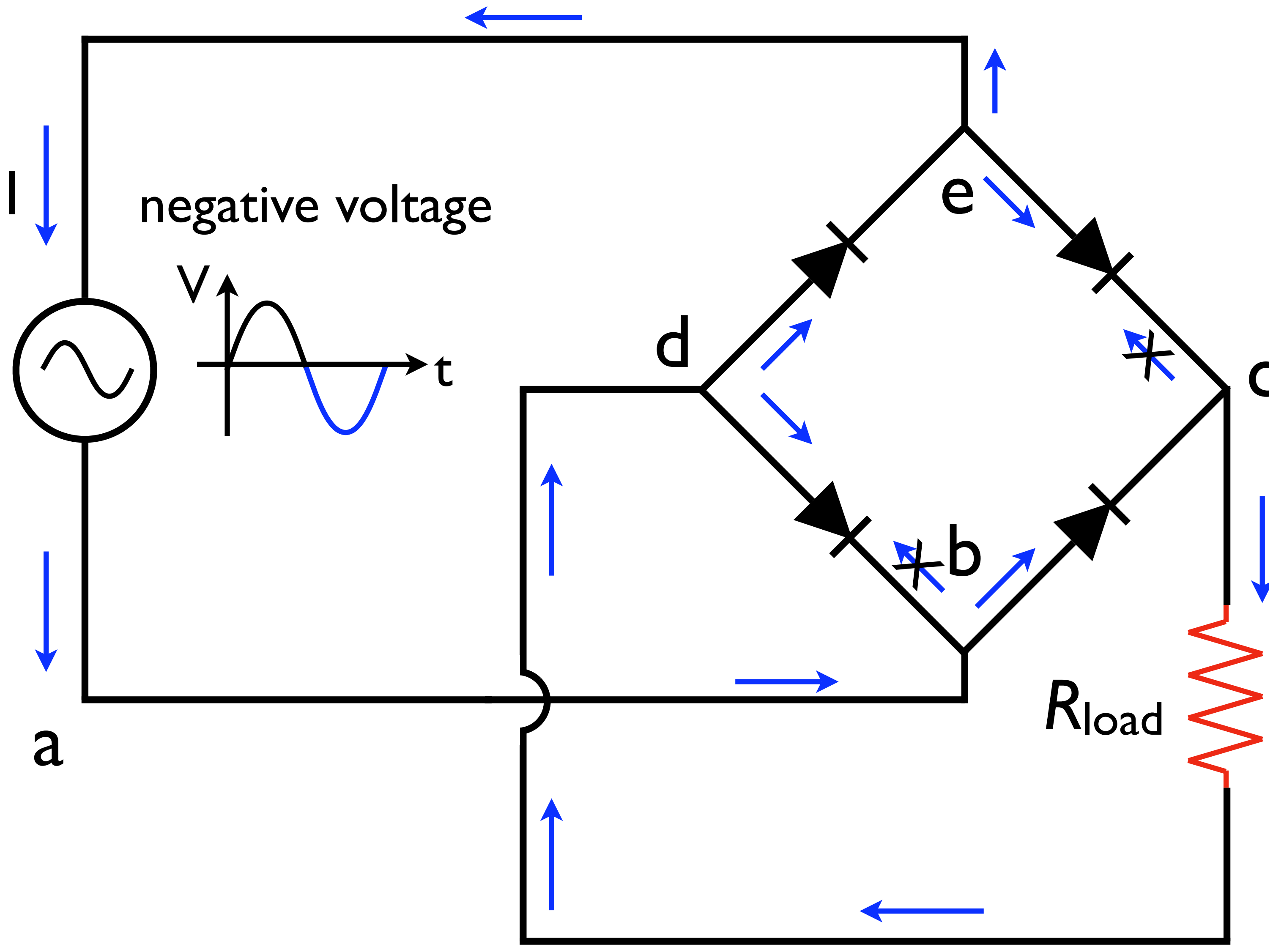
power goes in & out

(b)

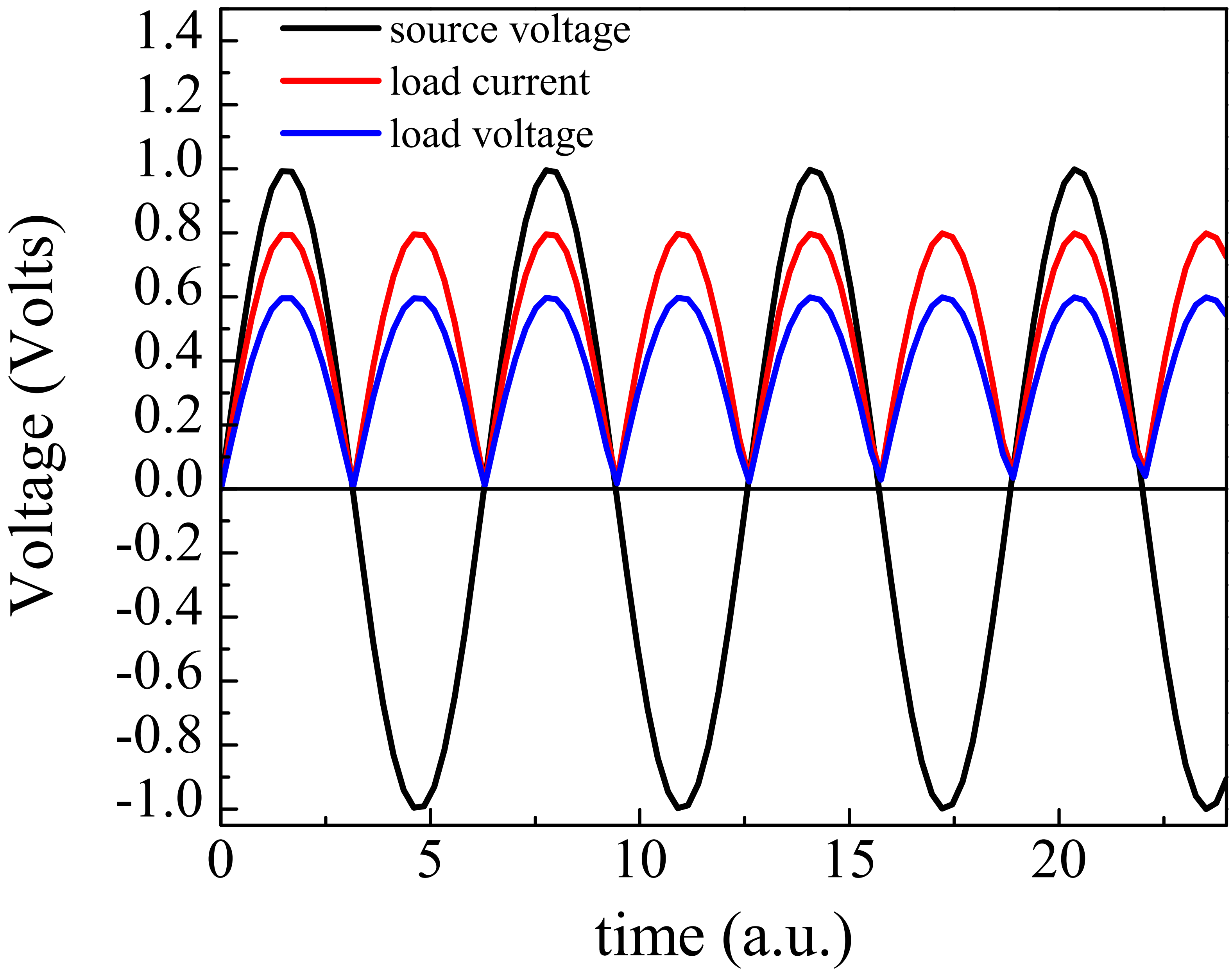



diodes are even funnier
current in 1 direction
R_{load}
wires do not
touch here

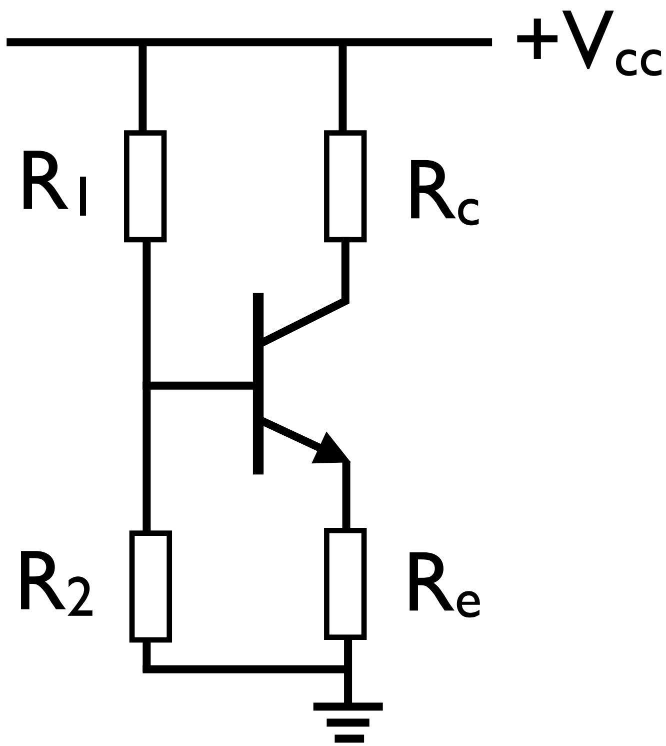

a
b
I
positive voltage
V
t
d
c
e
Rload

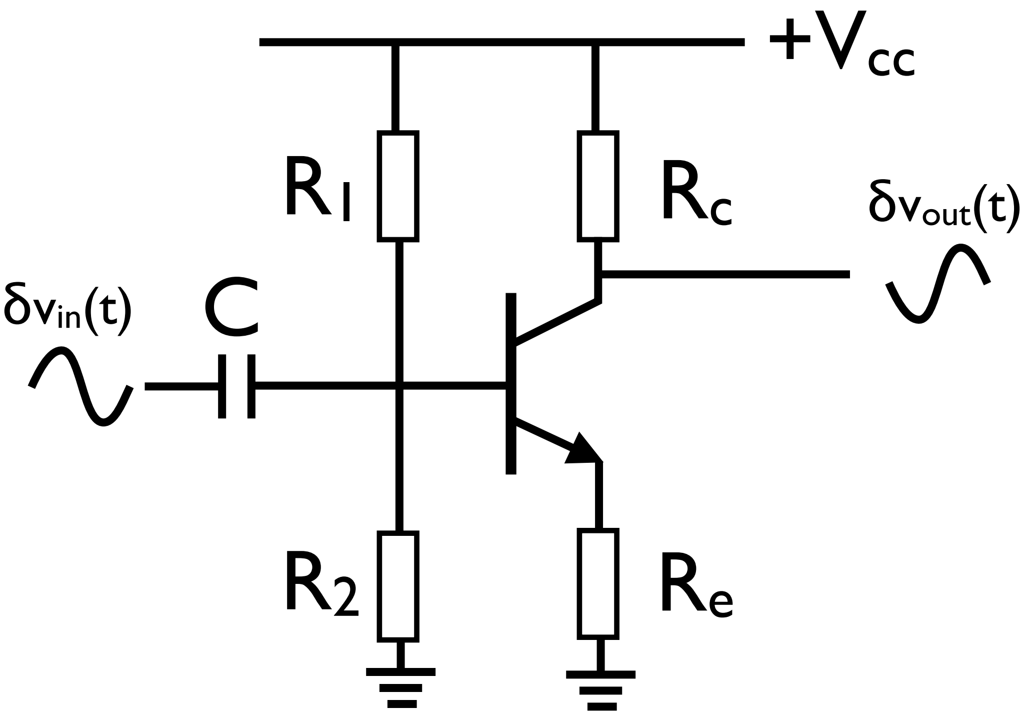


negative voltage
I
V
t
a
b
c
d
e
R load


source voltage
load current
load voltage
Voltage (Volts)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
5
10
15
20
time (a.u.)

look back at I source ... but feed it with a sine wave





just use C to block any constant voltages
(only time-varying gets through)

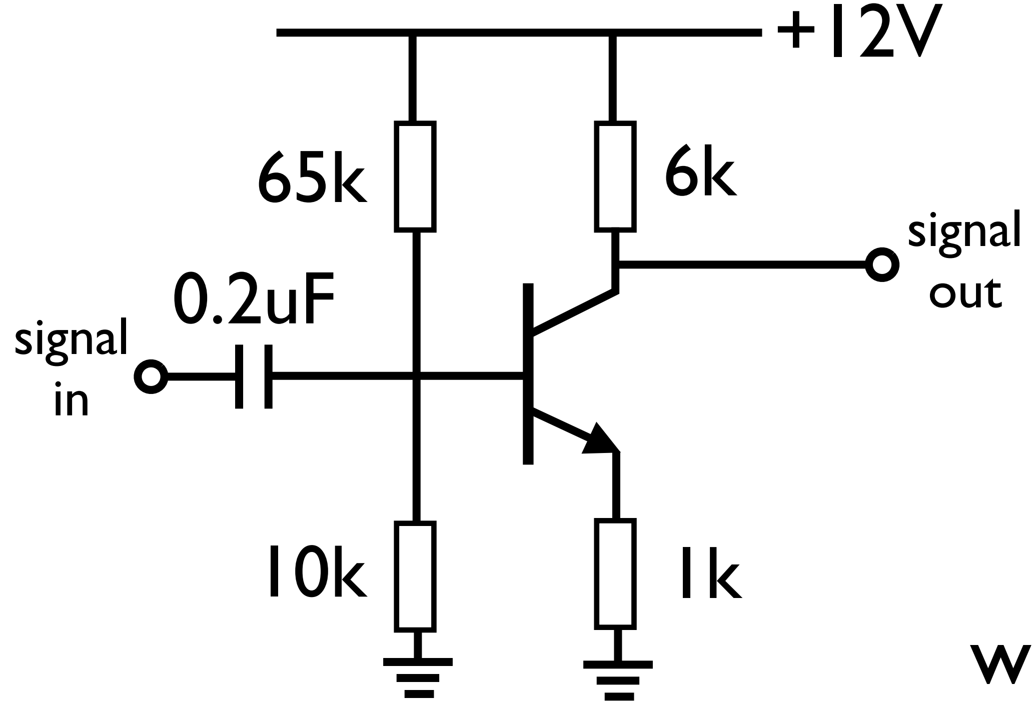
we'll see later: filtering

static analysis:

1mA through 6k load

base at 1.6V

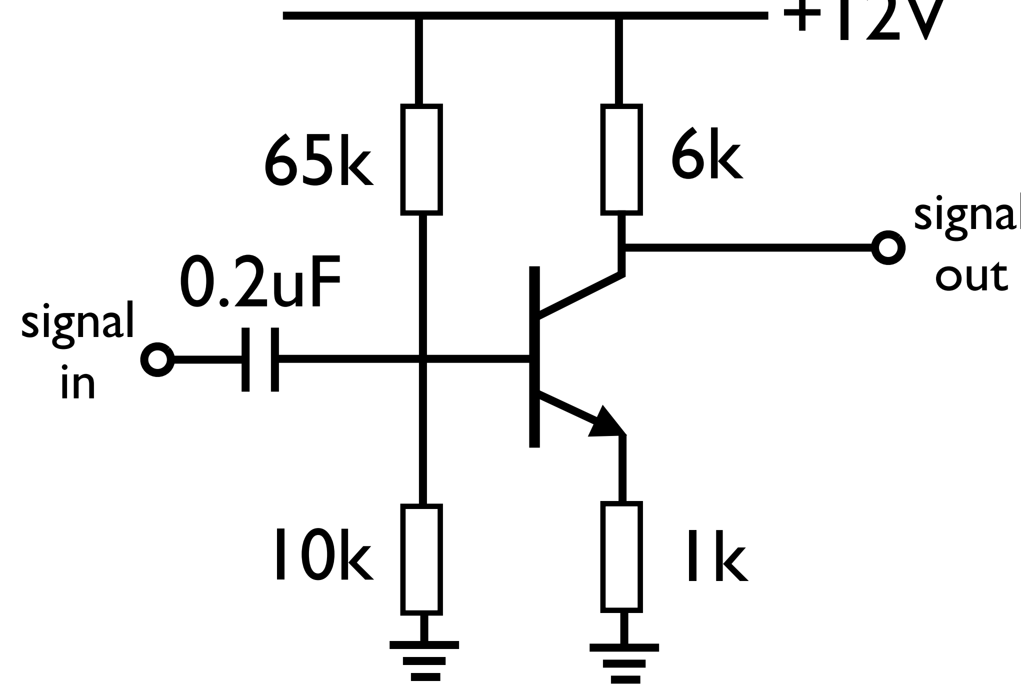
what happens for small change in base voltage?



$$V_b - V_e \sim \text{fixed}$$

$$\Longrightarrow \quad \delta V_e = \delta V_b$$

wiggle at base, emitter follows



$$\delta v_{\text{in}} = \delta v_{\text{e}}, \quad \delta i_{\text{e}} \approx \delta i_{\text{c}}$$

$$\delta i_{\text{e}} = \delta v_{\text{e}}/R_{\text{e}} = \delta v_{\text{in}}/R_{\text{e}}$$

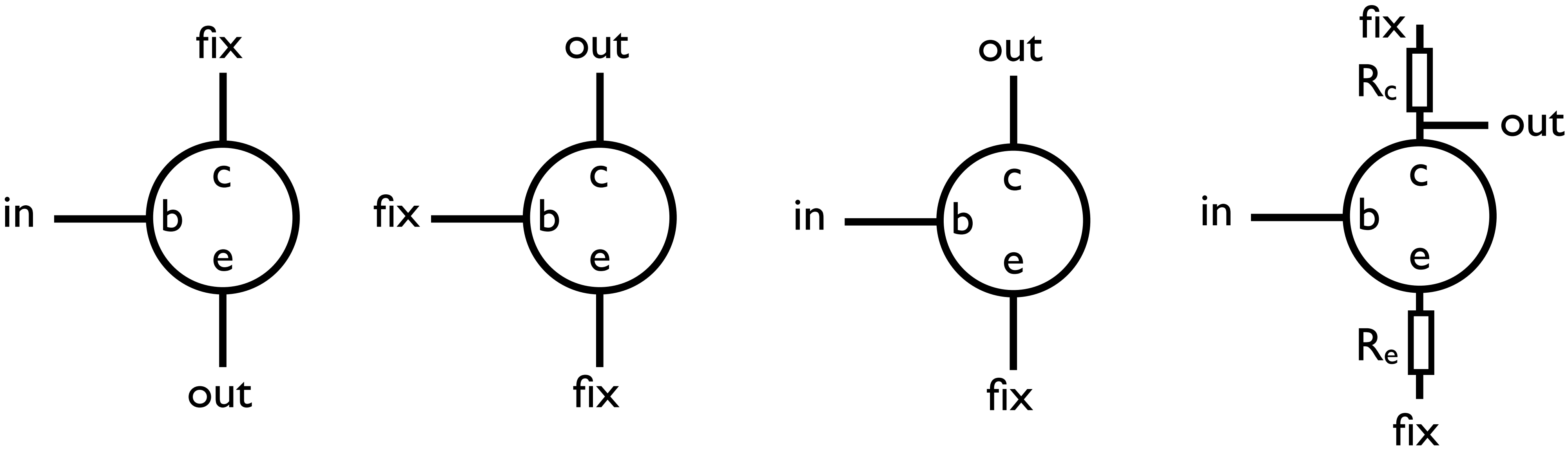
$$\delta v_{\text{out}} = \delta v_{\text{c}} = -\delta i_{\text{c}} R_{\text{c}} = -\frac{R_{\text{c}}}{R_{\text{e}}}\delta v_{\text{in}}$$

! wiggle input, output wiggles R_c/R_e times larger (but inverted)

*'common emitter amplifier', voltage **gain** of $G=-R_c/R_e$*

no, Re can't just be zero. thermal drift, instability, distortion ... and power limits

Some generic transistor circuits



follower

- $V_{in} \sim V_{out}$
- raises I
- lowers output R

I source

- fixing V_b fixes V_e
- fixing V_e fixes I_e
- fixing I_e fixes I_c

switch

- $V_b > V_e$, valve opens
- allows I to flow from supply to c

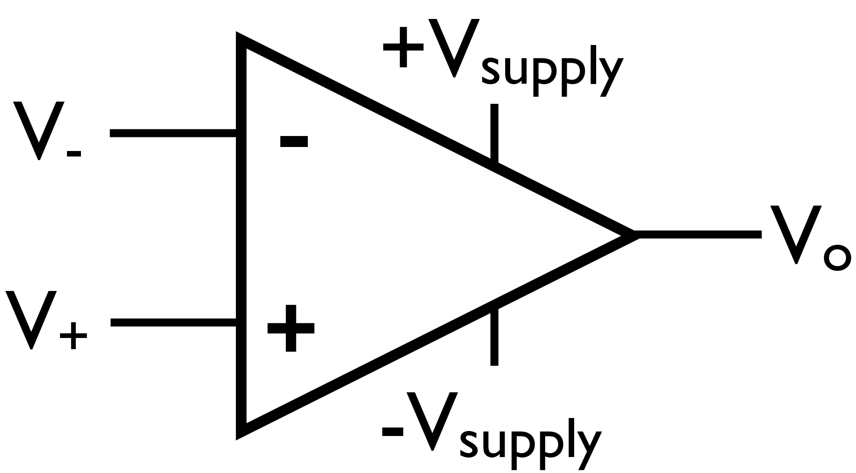
amplifier

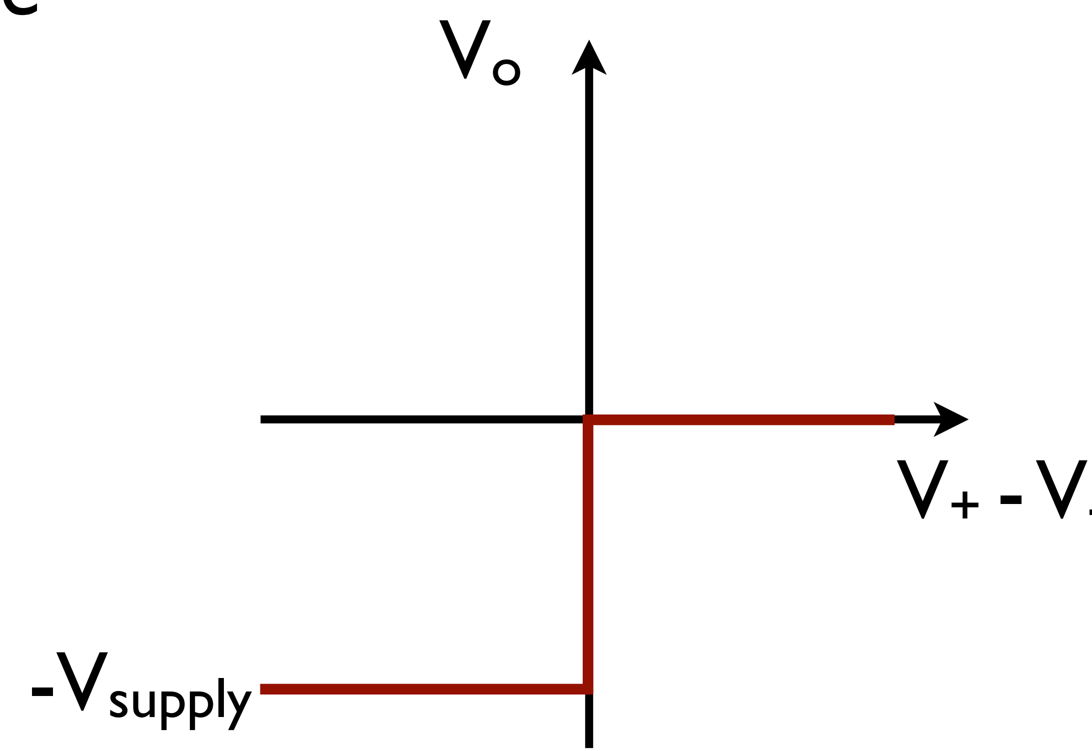
- input fixes V_e
- V_e fixes I_c
- out/in ~ R_e/R_b

the comparator

- two inputs: V_+, V_-
- one output: V_o
- if $V_+ > V_-$, output is open
- if $V_+ < V_-$, output is negative

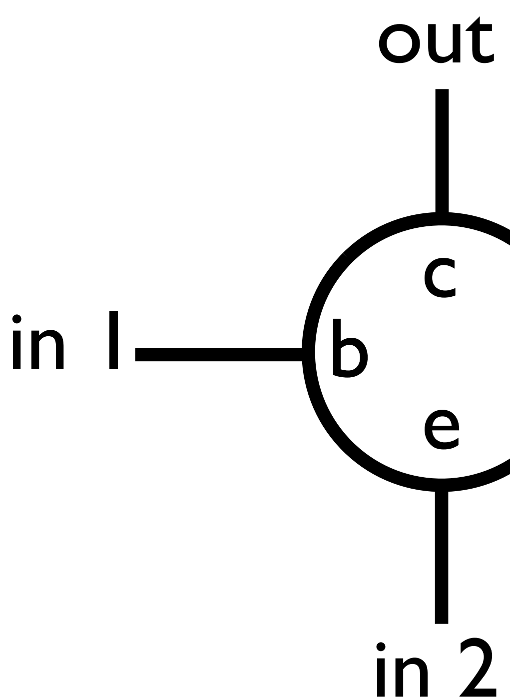
inputs	output
$V_- > V_+$	negative
$V_+ > V_-$	floating

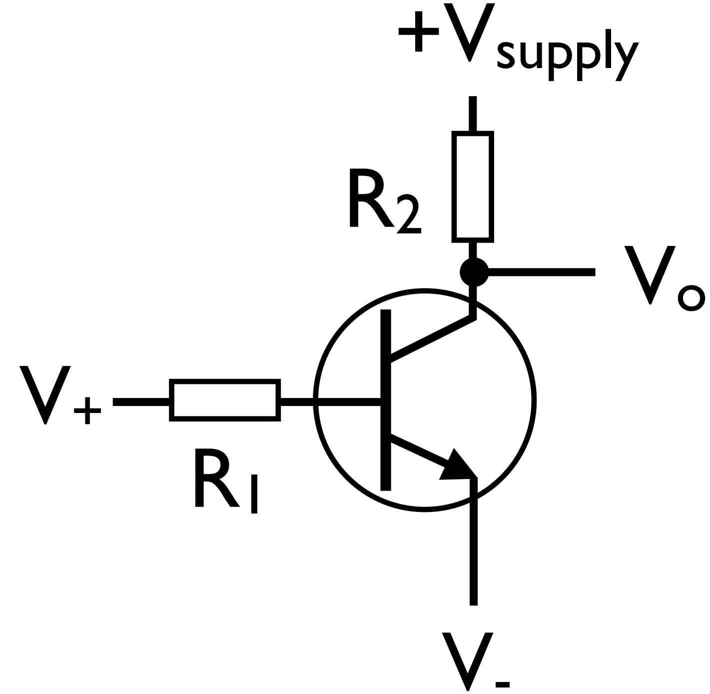


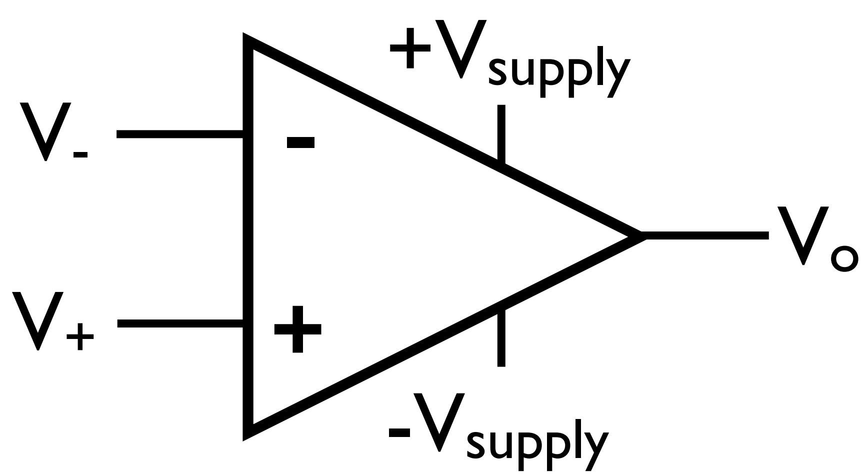


which input is larger?

realization & abstraction



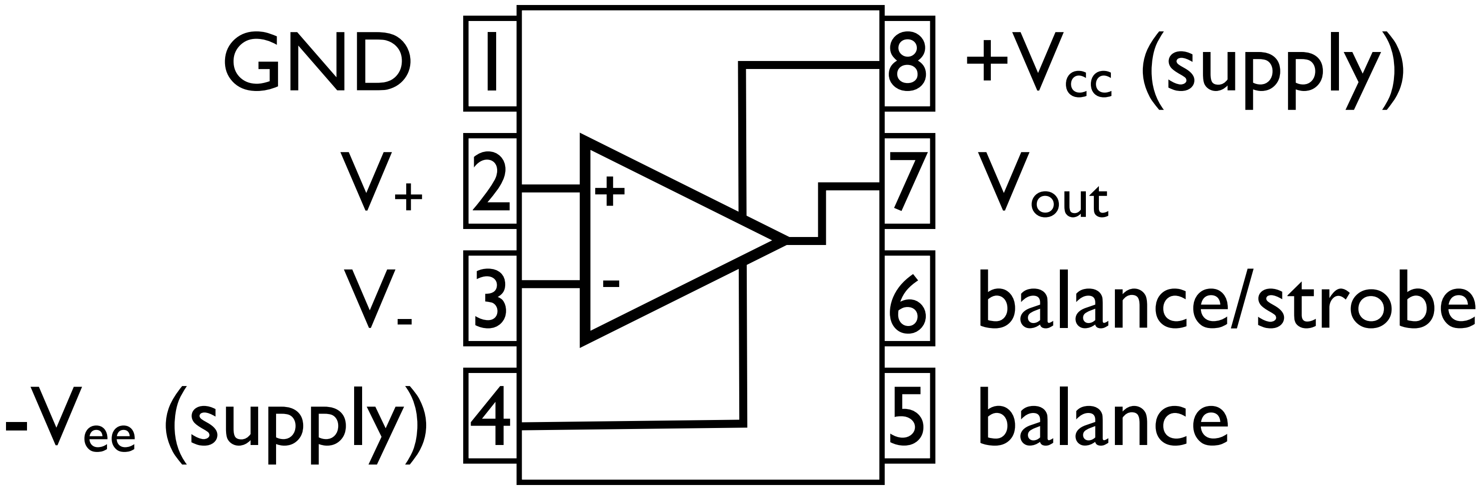




ideal comparator:

inputs draw no current

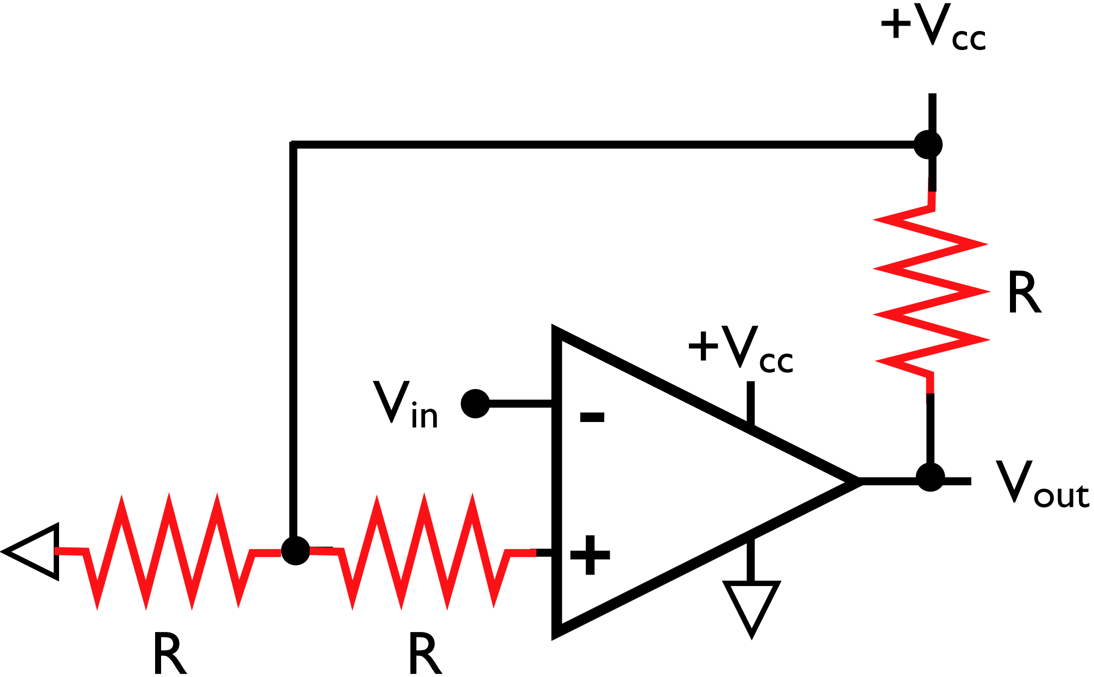
typical comparator (e.g., LM311)

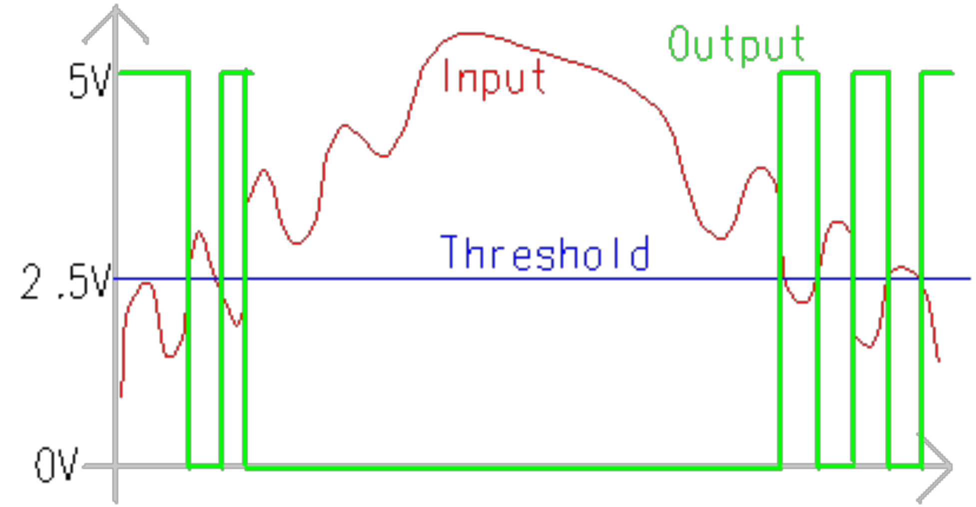


come in double & quad packages (L339)

what to do with them?

threshold detection





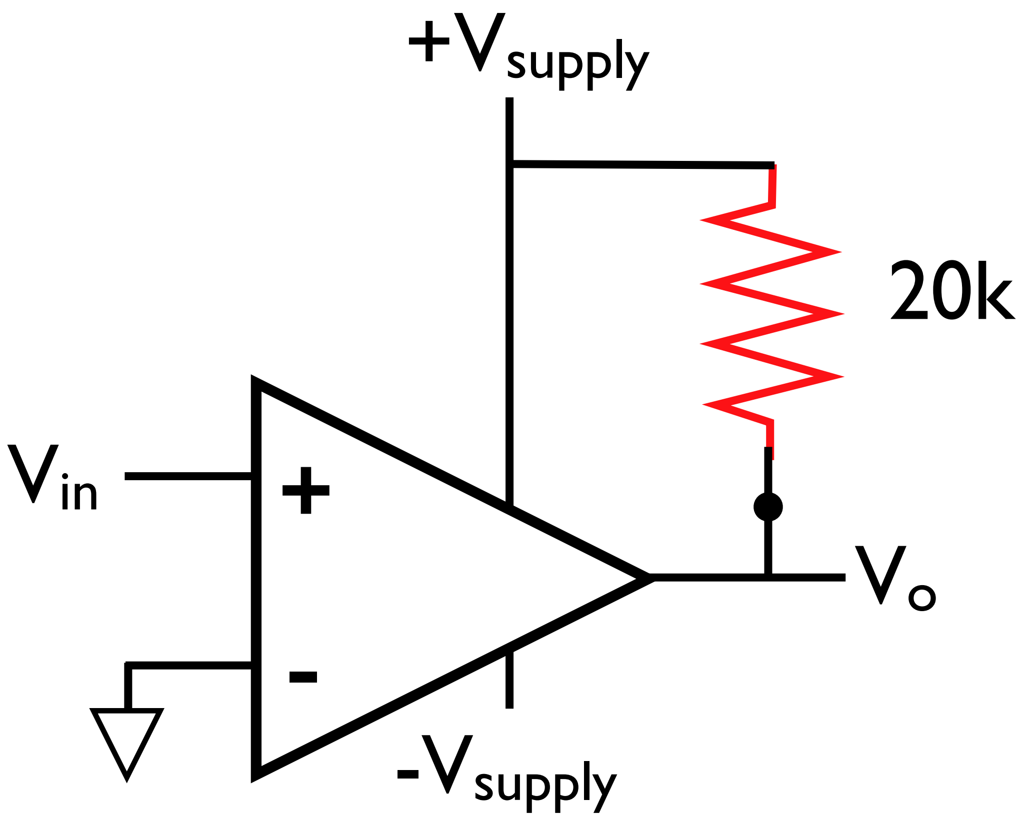
$$V_{out} = \begin{cases} V_{cc}, & V_{in} > V_{cc}/2 \\ 0, & V_{in} > V_{cc}/2 \end{cases}$$

divider ensures $V_+ = V_{cc}/2$ (threshold)
negative input: $V_- = V_{in}$

if $V_{in} < V_{cc}/2$, output is at negative supply (GND)
if $V_{in} > V_{cc}/2$, output floating (pulled up by 10k to V_{cc})

V- could just be a switch/photoR/transducer connected to V_{cc}!
disadvantage: sharp threshold gives ‘bouncing’ near transition. need some hysteresis ...

zero crossing detector



if $V_{in} > 0$, output is floating
but 20k to supply 'pulls up'

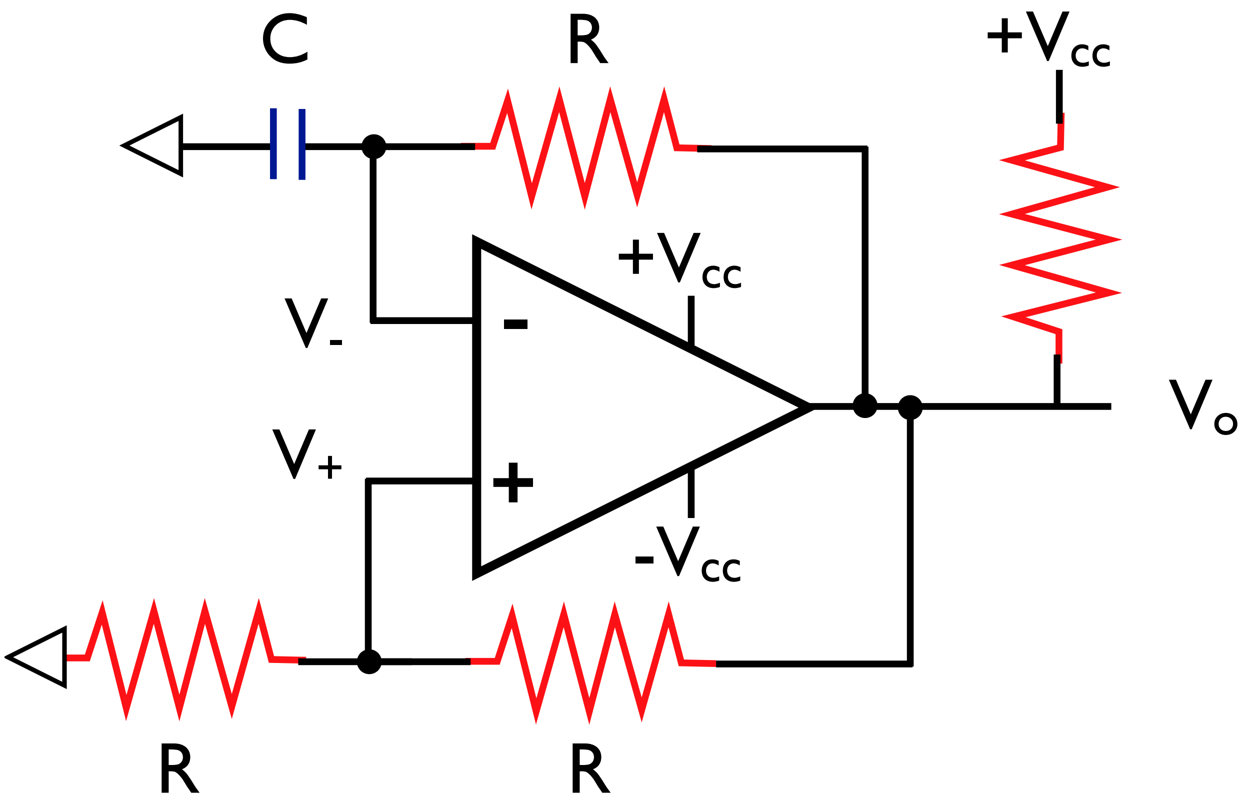
if $V_{in} < 0$, output is at $-V_{supply}$
but also pulled up

ground neg supply, 0/1 sig

some uses for comparators

- switching/amp (drive base of transistor)
- A/D conversion & interfacing
- pulse width modulation
- threshold/level detection
- use of feedback allows much more
  - memory (flip-flop, last state?)
  - hysteresis - better regulation (thermostat)
  - oscillators (intermittent wipers)

relaxation oscillator

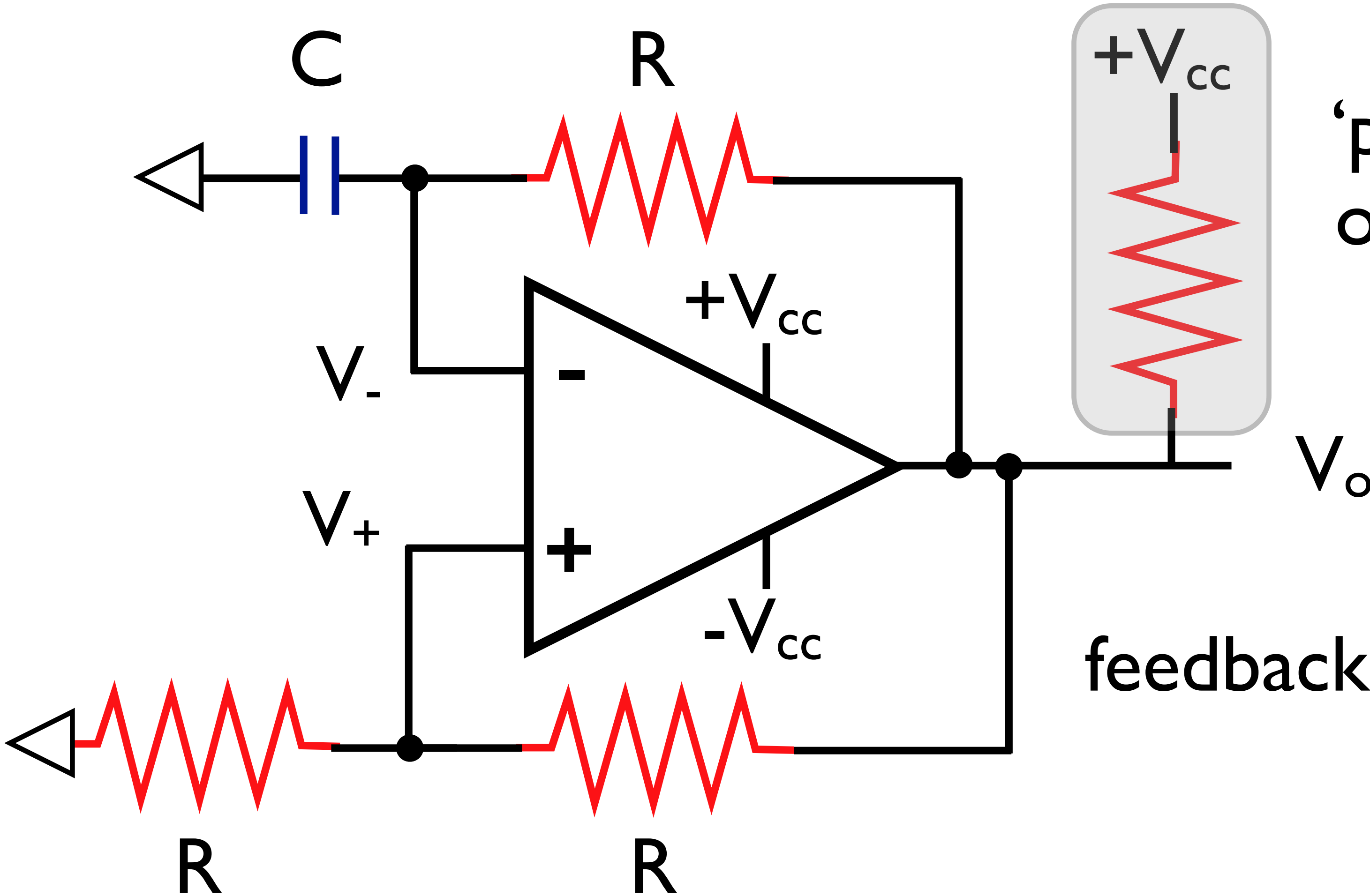


WTF?

use C charge
as comparator input

compare to fixed ref

output feeds back to RC

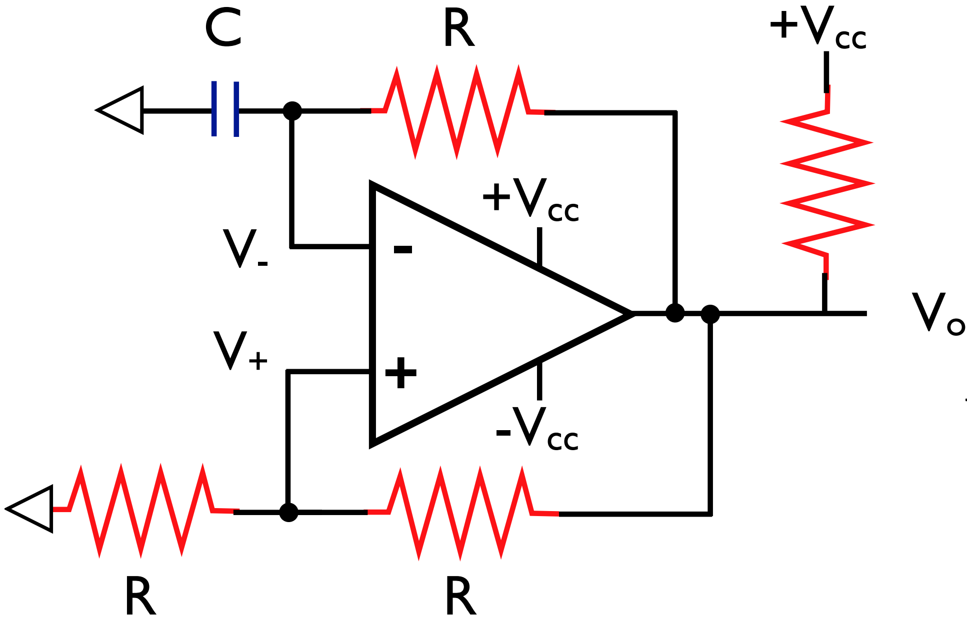


'pull up' to make output centered
(else -Vcc to 0)

feedback: V_o depends on V_+

V+ is fixed by voltage divider at $V_o/2 = (+/-)V_{cc}/2$
since inputs draw no current, R and C currents same

$$C\frac{dV_-}{dt} = \frac{V_o - V_-}{R} \qquad \frac{dV_-}{dt} + \frac{V_-}{RC} = \frac{V_o}{RC}$$



$$\frac{dV_-}{dt} + \frac{V_-}{RC} = \frac{V_o}{RC}$$

general solution:

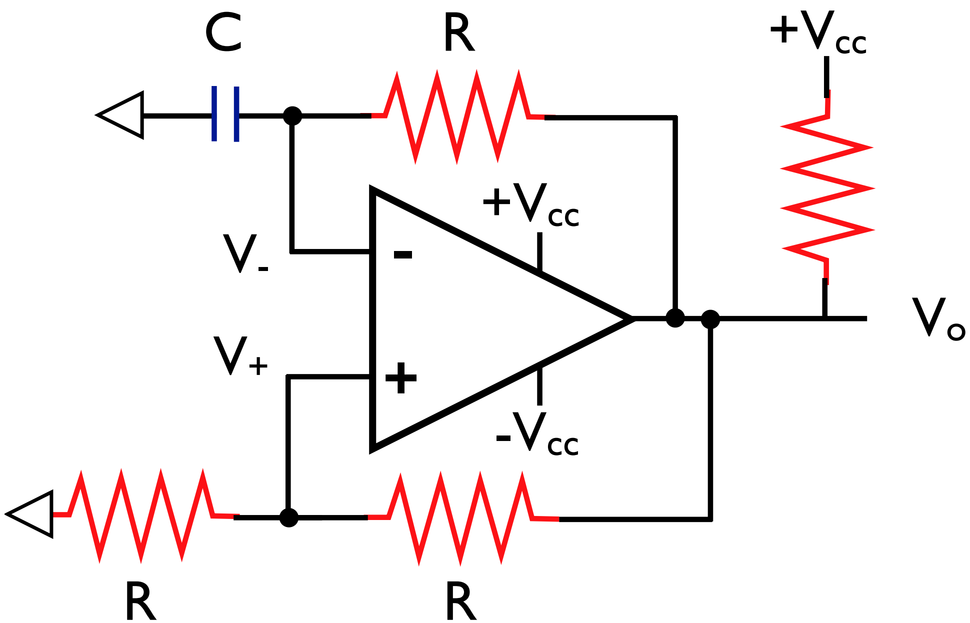
$$V_- = A + Be^{-t/RC} = V_o + Be^{-t/RC}$$

(steady state, $V_- = V_o$)

V+ is fixed at $V_{cc}/2$; when $V_- < V_{cc}/2$ output goes to $-V_{CC}$
this discharges C toward $-V_{cc}$ and makes V+ = $-V_{cc}/2$

when V- reaches $-V_{cc}/2$:
$V_- < V_+$ and output goes high (pull-up); this charges C

once V- reaches $V_{cc}/2$
$V_+ < V_-$ so output goes low, discharging C ... starts over



C cycles between $-V_{cc}/2$ and $V_{cc}/2$

this is a half period
we know capacitor V(t)!

at t=0, V- = $-V_{cc}/2$

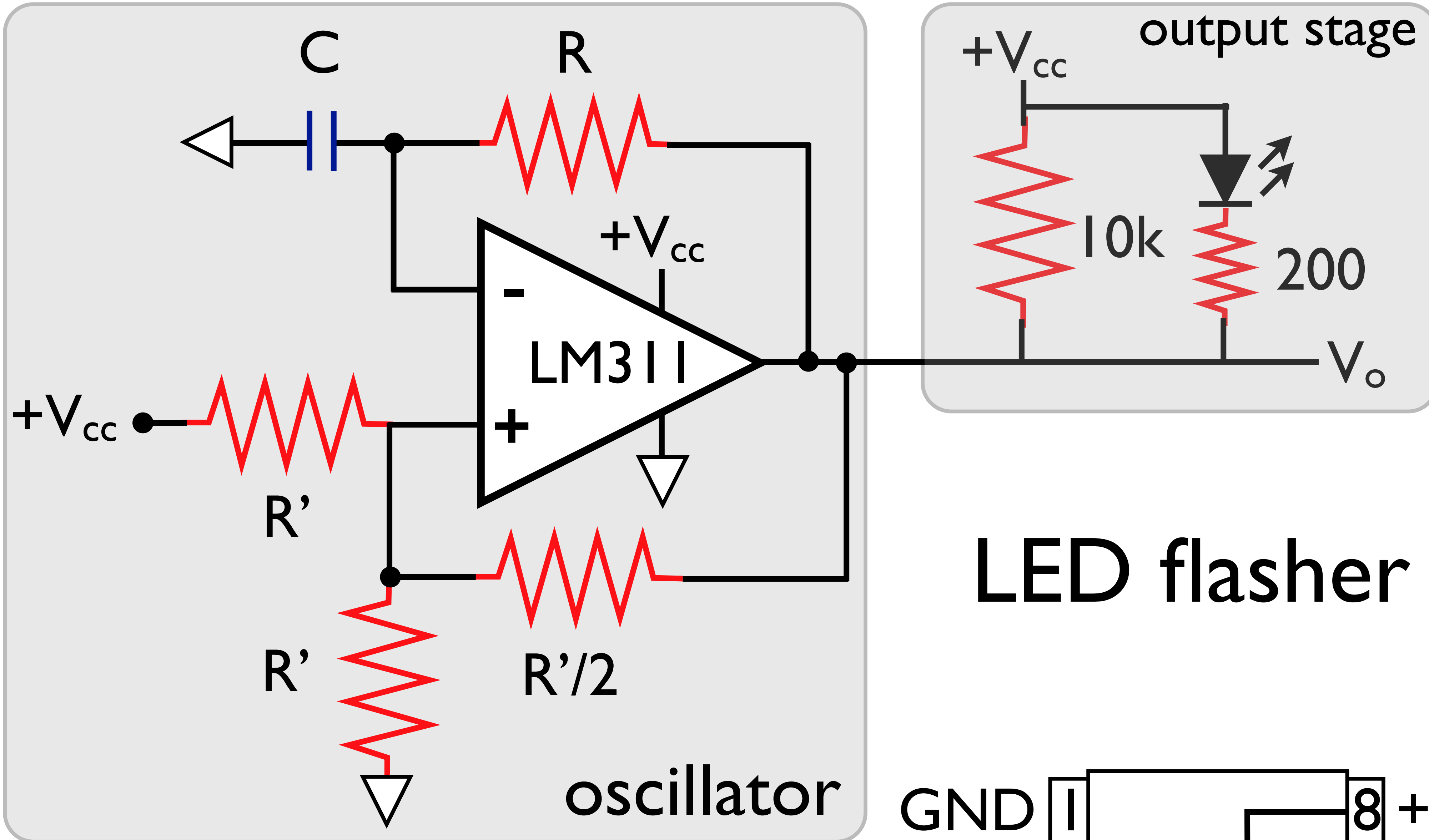
$$V_- = V_{cc} - \frac{3}{2}V_{cc}e^{-t/RC}$$

time for V- = $+V_{cc}/2$
is half period (T/2)

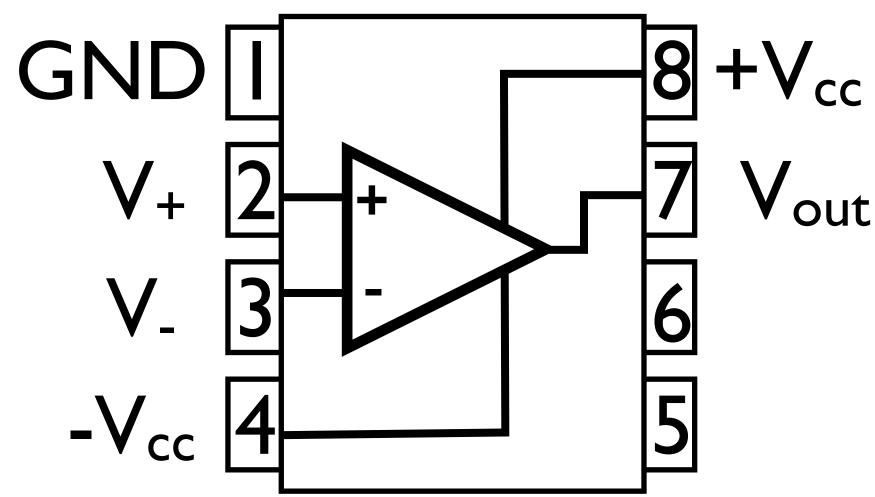
$$\frac{V_{cc}}{2} = V_{cc}\left(1 - \frac{3}{2}e^{-(T/2)/RC}\right)$$

period is thus:

$$T = 2RC\ln 3$$



LED flasher



pick RC~0.1-2 sec

R, R' ~10k-100k

C ~ uF

Vcc = 5V

the lab

- build a relaxation oscillator to drive an LED or speaker
    - LED: < 40Hz or so to see
    - speaker: ~100Hz-10kHz to hear
- make Arduino count every Nth cycle