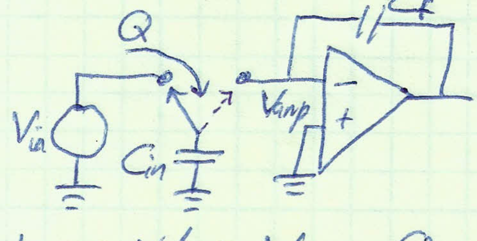
Switched capacitor circuits

Problem: large C can take a lot of chip area → use $C < 10pF$
but need $RC \simeq 10^{-3}$ so $R \simeq 10^8$ which is also to large for a chip

Solution: replace R with switched C



$Q_{in} = C_{in} V_{in}$
when switch to V_{in}

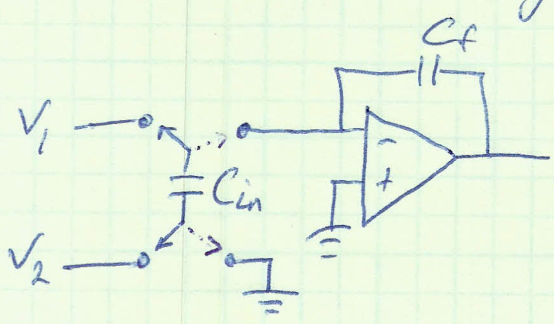
when switch to V_{amp}, Q_{in} goes to C_f, and C_{in} discharges completely because $V_{amp} = 0$.

$\underline{I_{avg}} = \Delta Q / \Delta t = Q_{in} f_{clock} = C_{in} V_{in} f_{clock}$

equivalent resistance $R_{eq} = \frac{1}{C_{in} f_{clock}}$

note smaller C_{in} → larger R_{eq}

f_{clock} must be more than twice as high as any frequency in the signal
- This is fine. We're talking about kHz signals. f_{clock} can be MHz or GHz



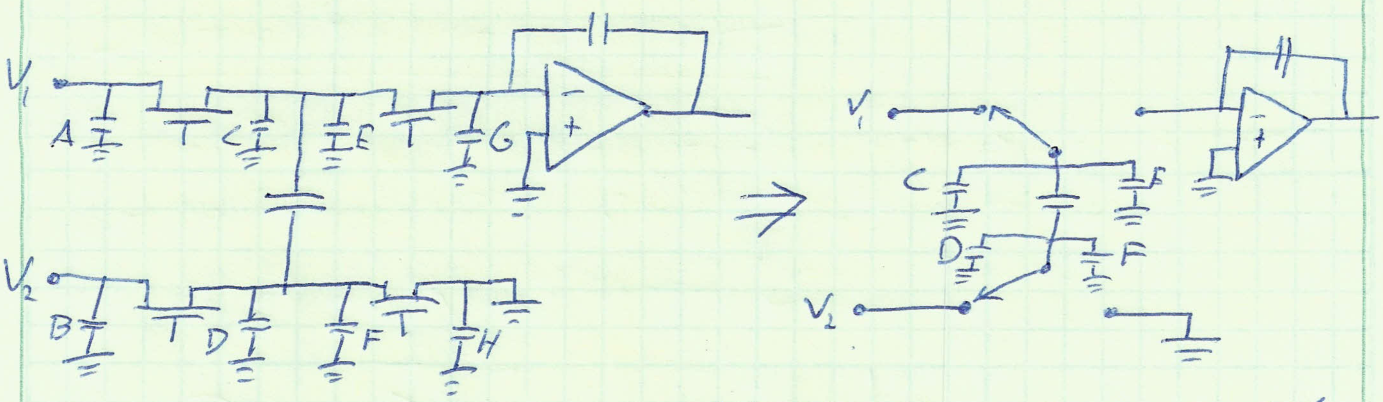
$Q_{in} = (V_1 - V_2) C_{in}$

R_{eq} is the same, but now we have both <u>positive</u> and <u>negative</u> integrators

This is useful for biquads and ladder simulators
where we need both positive and negative integrators

The details of the switches are also important:

continued ⟶



Caps A, B are connected to V_1, V_2 and don't transfer any Q through switches

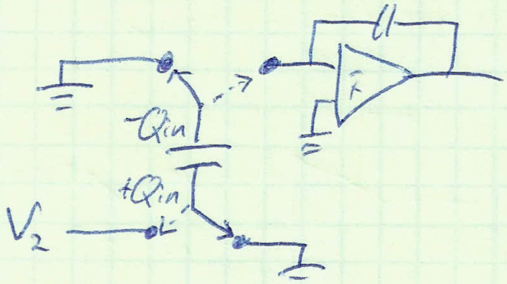
Caps G, H are always at 0 volts, with no charge

Caps D, F charge up to V_2 and transfer $Q_2 = V_2(C_D + C_F)$ to ground each cycle

Caps C, E are problems. They transfer $Q_1 = V_1(C_C + C_E)$ to the op-amp each cycle, so they look like extra resistors to V_1

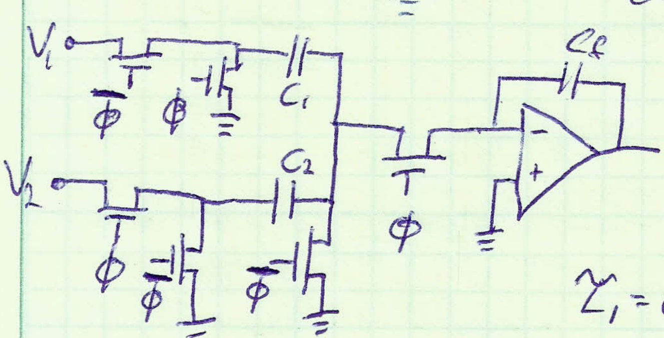
We set $V_1 = 0$, and V_2 works well as a positive integrator circuit

What about a negative integrator?



run the switches with opposite phase.

Think about which direction current flows in each case.

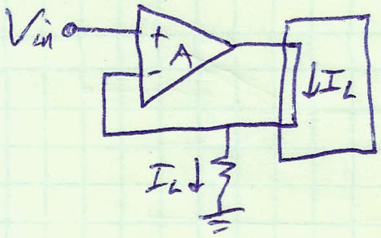


$$V_o(s) = \frac{V_1}{s\tau_1} - \frac{V_2}{s\tau_2}$$

$$\tau_1 = C_f R_{eq1} = \frac{C_f}{C_1 f_{clock}} = \frac{C_f}{C_1} T_{clock}$$

we want $\tau \gg T_{clock}$ so $C_f \gg C_1, C_2$

Current Driver

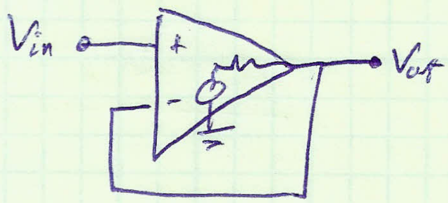


$V_{oc} = V_{in}A$

$$I_{sc} = \frac{A(V_{in} - I_{sc}R)}{R} = \frac{1}{R}\frac{A V_{in}}{1+A}$$

$$Z_{out} = \frac{V_{oc}}{I_{sc}} = R(1+A) \rightarrow \infty$$

Voltage Follower



$V_{oc} = A(V_{in} - V_{oc})$

$V_{oc}(1+A) = A V_{in}$

$$V_{oc} = \frac{A}{1+A} V_{in}$$

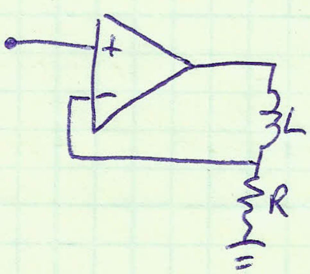
$$I_{sc} = \frac{A V_{in}}{R_o}$$

$$Z_{out} = \frac{V_{oc}}{I_{sc}} = \frac{R_o}{1+A} \rightarrow 0$$

Feedback makes either supply more constant (independent of load)

Current source wants high Z_{out}, Voltage Source wants low Z_{out}

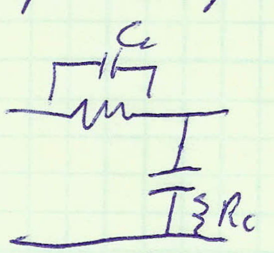
Note that stability depends on Z_{Load}, e.g. magnetic coil driver



$$B = \frac{R}{R+sL} = \frac{1}{1+sL/R} \rightarrow$$ low pass filter with $\tau = R/L$

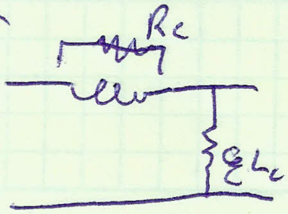
This pole in transfer function reduces phase margin, could lead to instability.

Compensate by adding a zero



either Cc or Rc works

or



either Rc or Lc works

$$B = \frac{R + sL_c}{R + sL_c + sL} = \frac{1 + sL_c/R}{1 + s(L+L_c)/R}$$

Power Supplies

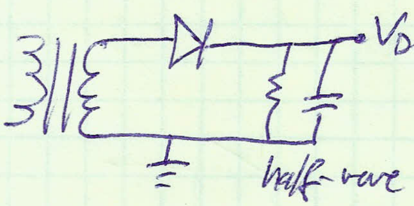
Standby power in residential appliances costs ~ \$3B/year in the USA alone, or 64×10^6 MWH/yr or 18 - 400MW power stations running full time

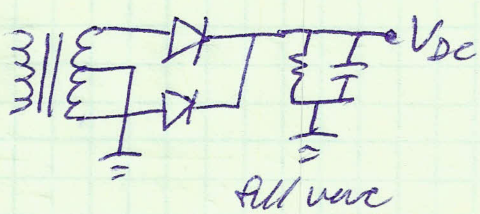
Converting to high efficiency power supplies would reduce by factor of 10.
Equivalent to 18 M cars worth of CO_2

Power supplies convert power from one source to another, e.g. 120VAC to 5VDC
Needs low output resistance so V_{out} independent of I_{out}
Also needs V_{out} independent of V_{in}

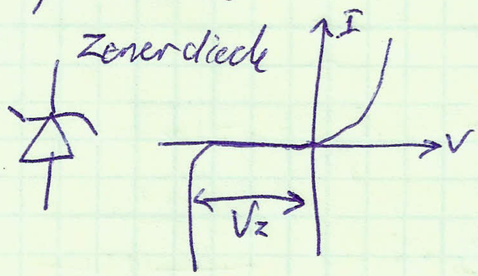
AC distribution: $P = VI$, but loss $= I^2R$, so usually use high V
It is easy to change AC voltages with transformers

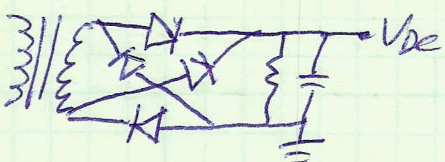
AC → DC rectification:





Voltage reference:

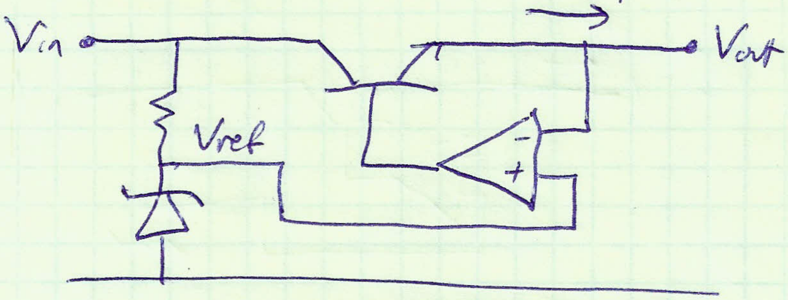




Zener diode provides a good reference voltage

However, power is drawn from the source regardless of the load

Series regulator

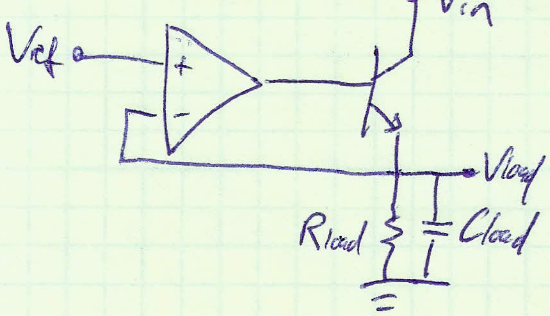


$P_{in} = I_{load} V_{in}$

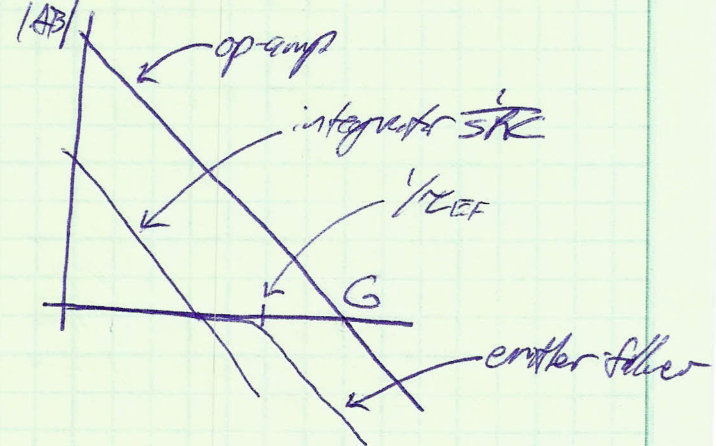
$P_{out} = I_{load} V_{out}$

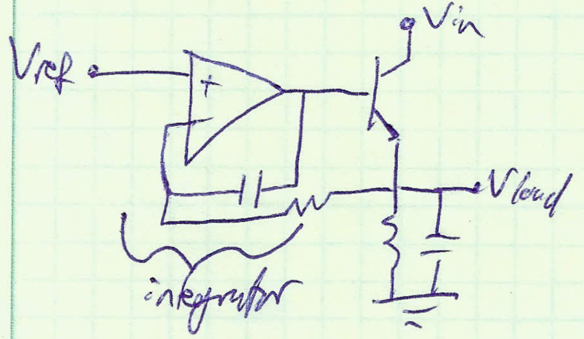
$\epsilon = \frac{P_{out}}{P_{in}} = \frac{V_{out}}{V_{in}}$

feedback circuit looks like this:

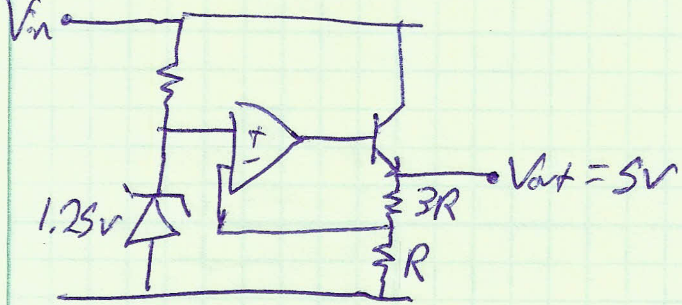


Emitter follower will have time constant due to load capacitance. This may affect phase margin.



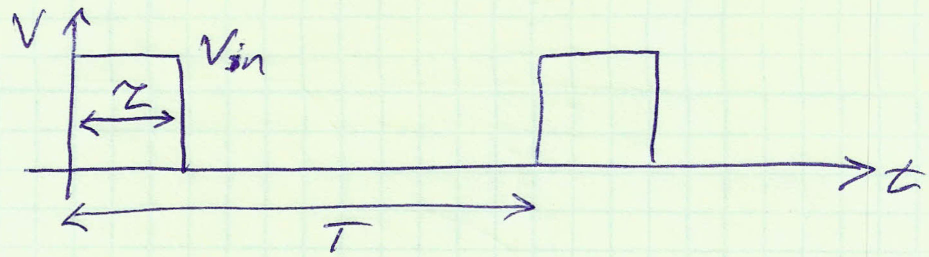


Voltage reference would likely be "bandgap reference" which compensates for temperature variations, gives $V \simeq 1.25$ near bandgap of silicon



we can generate 5v by dividing Vout by 4 before comparing with Vref

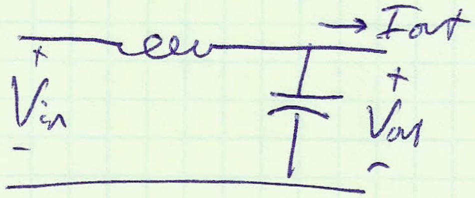
How do we handle $V_{in} >> V_{load}$?

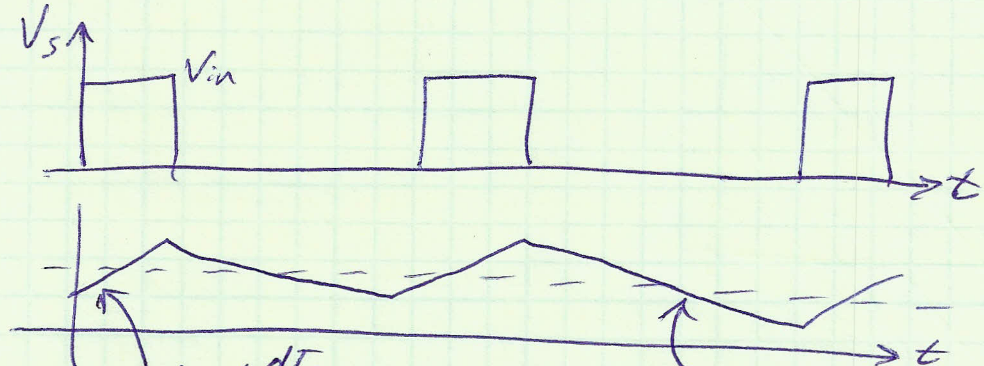


Average voltage $V_{avg} = V_{in}\frac{\tau}{T}$ can be $<< V_{in}$

Store energy in a reactance in between pulses

Need a reactive low-pass filter

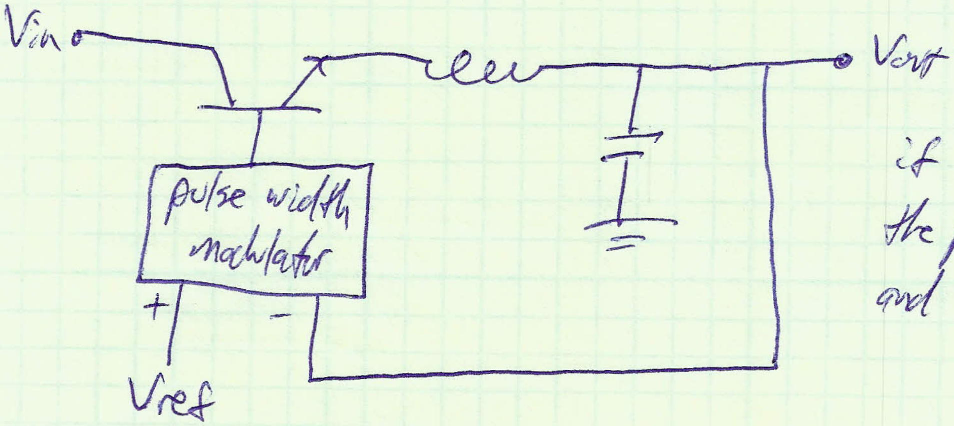




$V_L = L\frac{dI}{dt} = V_{in} - V_{out} > 0$

$V_L = L\frac{dI}{dt} = 0 - V_{out} < 0$

The larger the inductor, the smaller the current ripple



if $V_{out} < V_{ref}$,
the pulse width increases
and V_{out} starts to rise