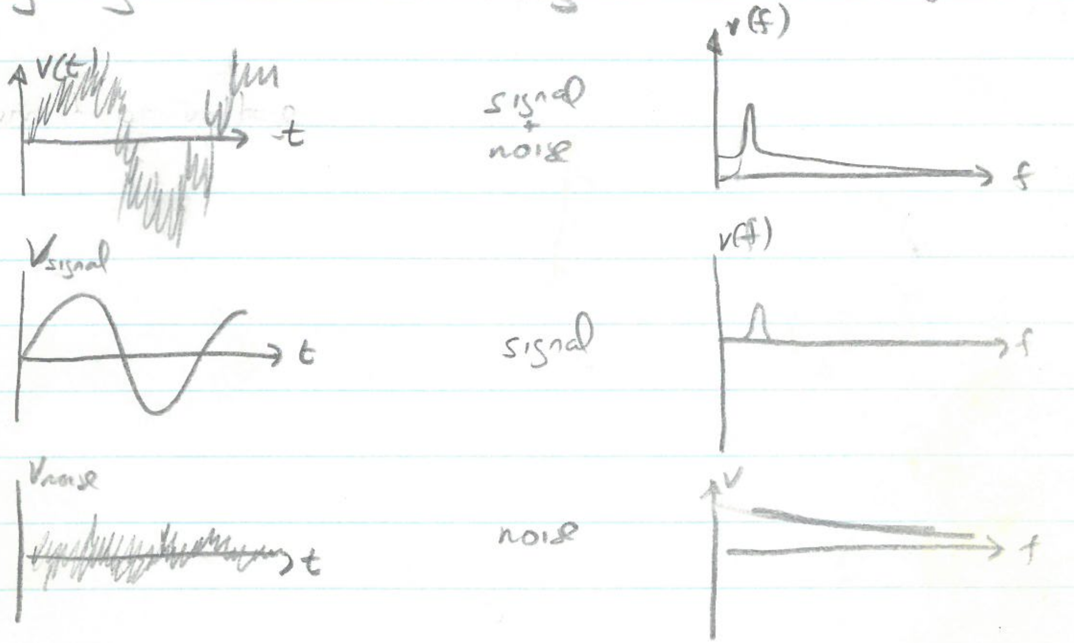
Noise in analog circuits

anything that obscures a signal (whether voltage or current)



time series — frequency spectrum

different sources of noise

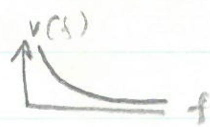
white noise — $v(f)$ is flat

→ Johnson noise —

pink noise — $v^2(f) \propto 1/f$

("flicker noise", "1/f noise")

something extra, at low freqs, on top of white noise, generated within transistors



shot noise — $v(t)$ is random spikes

a kind of white noise

~~for forward-biased diodes~~

interference — 60Hz pickup, RF emissions from motors, transmitters etc

time average — $\bar{V}$ or $\bar{I}$

rms — root mean square $\left[\overline{(V-\bar{V})^2}\right]^{1/2}$ or $\left[\overline{(I-\bar{I})^2}\right]^{1/2}$

where $\bar{V}$, $\bar{I}$ are the time averages

Johnson noise or "thermal noise" - white noise found in resistors

a ~~resistor~~ (or any analogous system that dissipates energy into heat)
has random fluctuations in the motion within it
consider a resistor just sitting around.
resistor has fluctuations in electron motion inside
⇒ random ~~[illegible]~~ current inside resistor
⇒ random voltage appears across leads.

[This is a special case of more general physical principle - "fluctuation dissipation theorem" of statistical physics - any dissipative system that turns organized energy into heat will have fluctuations in ~~[illegible]~~ it]

another example: Einstein relation for particle in viscous medium

$D_{\text{Brownian motion}} = \mu k_B T$

D: diff coeff (fluctuation)
μ: frictional drag coeff (dissipation)

$$V_{noise}\ (rms) = \sqrt{4 k_B T R B}$$

k_B	Boltzmann's const
T	temp (°K)
R	resistance (Ω)
B	bandwidth (Hz)

~~at room temperature, $k_B T = \frac{1}{40}$ eV~~

if T = room temp, R = 1 MΩ, B = 1 MHz, then $V_{rms} = 0.1$ mV

↳ indept of f ⇒ white noise

<u>Shot noise</u> generated in <u>forward biased diodes</u>

electrons are finite

small currents $\Rightarrow$ small no. of electrons per sec.

ea. electron is a "shot" of charge

$$I_{noise}\ (rms) = \left[2 q_e I_{DC} B\right]^{\frac{1}{2}}$$

q_e = electron charge 1.6×10^{-19} C

I_{DC} = steady state current (DC)

B = Bandwidth (Hz)

(story about IR detector)

note that:

I_{noise} is indept of f $\Rightarrow$ "white noise"

signal is I_{DC} ; $\Rightarrow$ signal-to-noise ratio

$$SNR = \frac{I_{DC}}{I_{noise}} \propto I_{DC}^{+\frac{1}{2}}$$

shot noise is a bigger problem for small signals

"1/f noise" - phenomenological - lots of different systems exhibit it

noise reduction methods -

reduce noise source
reduce bandwidth
increase signal to get higher SNR

SNR

if SNR < 1, you *really* need noise reduction methods to see & use signal