Noise in analog circuits

Anything that obscures a signal (whether voltage or current)

\[ v(t) \]

<table>
<thead>
<tr>
<th>Time series</th>
<th>Frequency spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Signal" /></td>
<td><img src="image2" alt="Noise" /></td>
</tr>
<tr>
<td><img src="image3" alt="Signal" /></td>
<td><img src="image4" alt="Noise" /></td>
</tr>
</tbody>
</table>

**White noise** \( v(t) \) is flat

- Johnson noise

**Pink noise** \( v(t) = 1/f \)

("Slicker noise", "White noise", often associated with exponential decay, or half of white noise, generated within transistors

**Shot noise** \( v(t) \) is random spike

Interference - 60Hz pickup, RF emissions from motors, transmitters etc.

\[
\text{The average} = \overline{V} \quad \text{or} \quad \overline{I}
\]

\[
\text{RMS} = \text{root mean square} \quad \frac{(v-\overline{V})^2}{(v-\overline{V})^2}^{1/2}
\]
Johnson noise or "thermal noise"

- a resistor (or any dissipative system that dissipates energy into heat)
- has random fluctuations in the motion without considering a resistor just sitting around
- resistor has fluctuations in electron motion inside
  - random thermal current inside resistor
  - random voltage appears across leads.

\[ V_{\text{noise (rms)}} = \sqrt{4kTRB} \]

- \( k_B \): Boltzmann's constant
- \( T \): temperature (K)
- \( R \): resistance (\( \Omega \))
- \( B \): bandwidth (Hz)

At room temperature, \( k_B = 25 \text{ eV} \)

- \( k_B = 1 \text{ meV}, B = 1 \text{ MHz}, \) max. \( V_{\text{rms}} = 0.1 \text{ mV} \)

\( \Delta f \) is the input signal of \( f \) = white noise
Shot noise is generated in forward biased diodes. Electrons are finite.

Small currents ⇒ small no. of electrons per sec.

Electron is a "shot" of charge.

\[ I_{\text{noise}} (\text{rms}) = \left[ 2qI_{\text{dc}}B \right]^{1/2} \]

\( q \) = electron charge \( 1.6\times10^{-19} \text{C} \)

\( I_{\text{dc}} = \) steady state current (DC)

\( B = \) Bandwidth (Hz)

(Story about IR detector)

Note: That:

\[ I_{\text{noise}} \propto \sqrt{f} = \text{"white noise"} \]

\[ \frac{\text{Signal}}{\text{Noise}} = \frac{I_{\text{dc}}}{I_{\text{noise}}} \Rightarrow \text{signal-to-noise ratio} \]

\[ \text{SNR} = \frac{I_{\text{dc}}}{I_{\text{noise}}} \propto I_{\text{dc}}^{1/2} \]

Shot noise is a bigger problem for small signal.
"1/f noise" - phenomenological - lots of different systems exhibit it

**Noise reduction methods**

- reduce noise source
- reduce bandwidth
- increase signal to get higher SNR

\[ \text{SNR} \]

If \( \text{SNR} < 1 \), you really need noise reduction methods to see & use signal