Two types of unwanted signals

1. Extraneous signals due to other circuits or systems
   - Power supply ripple
   - Unwanted signal couplings through parasitic components, power, ground, or substrate
   - Other conducted or radiated electro-magnetic interference (EMI)
   Solutions: fully differential circuits, layout, shielding

2. Intrinsic noise
   - Random motion of carriers, e.g. “thermal noise”
   - Material defects, e.g. “flicker noise”
   Limits minimum signal that can be detected and processed
Thermal noise: introduction

Physical origin: random thermal motion of electrons
Thermal noise exists in any conductor
Thermal noise model

Average
\[ \bar{v}_n = \frac{1}{T} \int_0^T v_n(t) dt = 0 \]

RMS
\[ v_{n,rms} = \frac{1}{T} \int_0^T v_n^2(t) dt \neq 0 \]
Thermal noise model: frequency domain

\[
\overline{v_n^2} = 4kT R \Delta f = S(f) \Delta f
\]

\[S(f) = \text{noise power spectral density } [V^2/Hz]\]

“Spot” noise RMS \((f)\)

\[\sqrt{S(f)} \quad [V/\sqrt{Hz}]\]

This is plotted as a function of frequency in Spice .noise analysis

Total RMS noise voltage (squared), in a given range of frequencies, \(f_1\) to \(f_2\)

\[
v_{n,\text{rms}}^2 = \int_{f_1}^{f_2} S(f) df
\]
Thermal noise model
Analysis of circuits with noise: a simple example
Output noise and equivalent input noise

![Diagram showing a circuit with components labeled R1, 1.5meg, R2, 0.5meg, Vin, and output.]
Analysis of circuits with noise in Spice
a simple example
.noise simulation results

CTRL-left click on the waveform name to display total RMS noise voltage value

Equivalent input RMS voltage limits the minimum detectable signal
Analysis of frequency-dependent circuits with noise: a simple example
Analysis of frequency-dependent circuits with noise: a simple example
.noise Spice simulation results

![Graph showing noise simulation results with intervals and RMS noise values.]

ECEN4827/5827 Analog IC Design
MOS transistor model with noise
Flicker ("1/f") noise
MOS transistor model: input noise
Example: common-source amplifier
\[ A(s) = \frac{v_{out}}{v_{in}} \] magnitude and phase responses
.noise Spice simulation results

Interval Start: 10Hz
Interval End: 100MHz
Total RMS noise: 3.4177mV
.noise Spice simulation results

![Graph showing noise simulation results]

- Interval Start: 10Hz
- Interval End: 100MHz
- Total RMS noise: 544.22uV
Example: diff pair with active load
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