4. PHYSICAL NOISES

There are several different noise processes in physical systems.

They are different in:

- probability density
- time domain, frequency domain properties
- origin (physical model)

4.1. Internal/excess noises

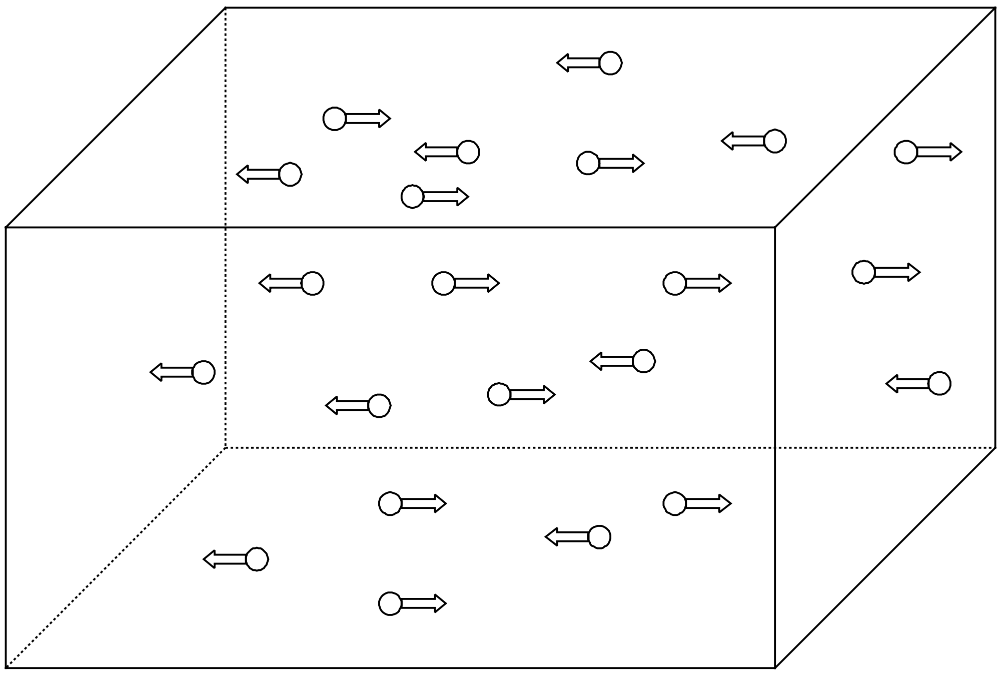
- the system emits noise without external excitations
- external excitations introduce excess noise (e.g. current in a resistor)

4.2. Thermal noise

(Johnson noise)

Resistor:

- what is the reason for resistance?
- thermal system: carrier fluctuations



White noise:

Correlation function:

$$R(\tau)=c\delta(\tau)$$

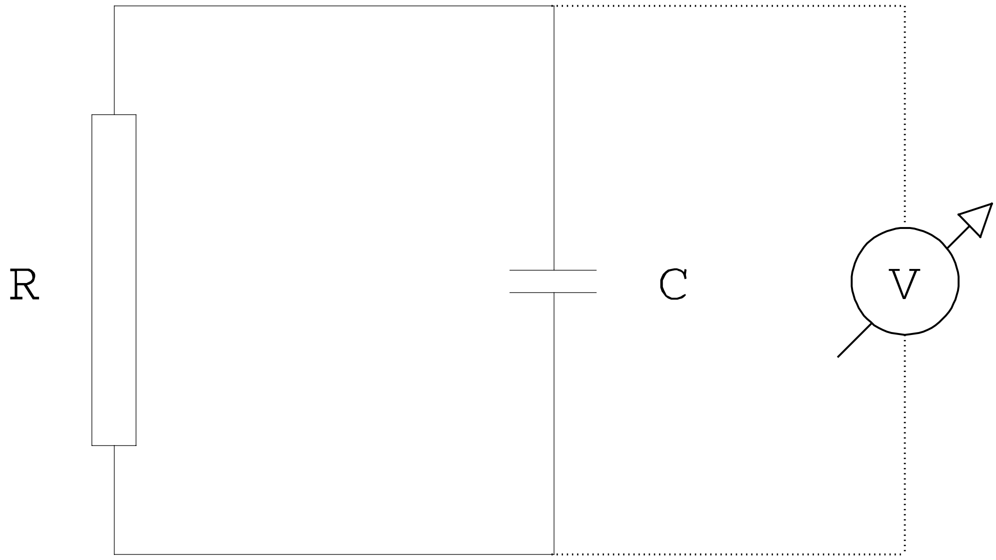
Spectrum:

$$S(f)=S_o=c^2$$

Probability density:

Gaussian

How to calculate the noise?



Equipartition theorem:

$$\frac{1}{2}kT = \frac{1}{2}C\langle V^2\rangle$$

Calculate the variance:

$$\langle V^2 \rangle = \int_0^\infty S(f)\, df = \int_0^\infty S_o \frac{1}{1 + \frac{f^2}{f_o^2}}\, df$$

$$\langle V^2 \rangle = \frac{kT}{C} = S_o \frac{\pi}{2} \frac{1}{2\pi RC}$$

Finally (Nyquist-formula):

$$S_o = 4kTR$$

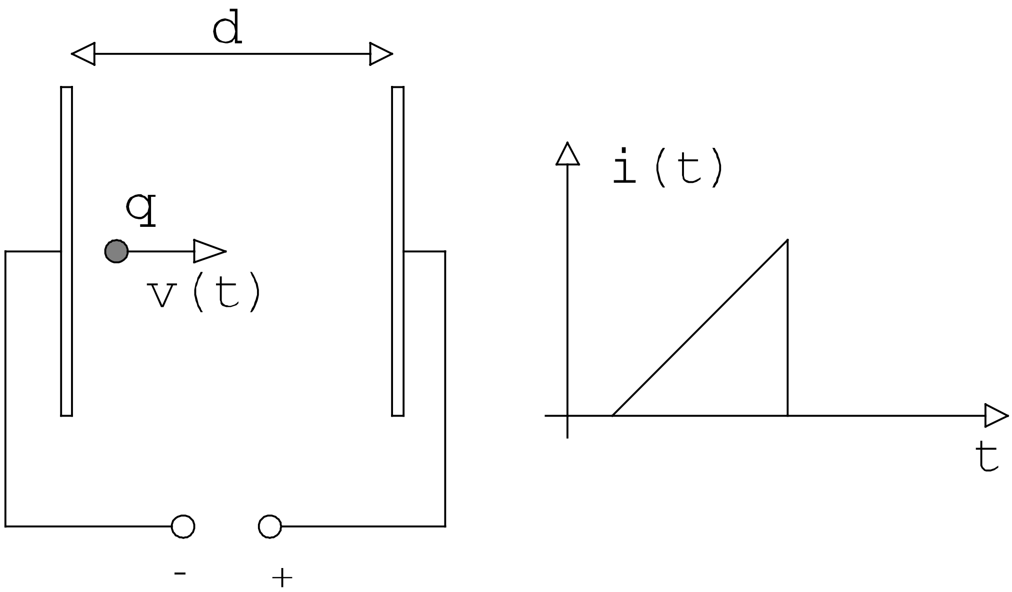
Universal: does not depend on kind of material

No ideal resistors without this kind of noise!

4.3. Shot noise

Particles have to overcome a potential barrier

- electronic tubes
- diode p-n junction



Spectrum:

$$S(f) = 2q\langle I\rangle$$

Depending on the shape of elementary pulses, can be different, e.g.:

$$S(f) = 2q\langle I\rangle\left(\frac{\sin(\pi f t_r)}{\pi f t_r}\right)^2$$

4.4. Brownian motion

Integrated white noise, can be found in several physical systems

Correlation function:

only for limited bandwidth

Spectrum:

$$S(f)=c/f^2$$

Probability density:

Time dependent, Gaussian

<u>Example:</u>

a particle driven by random forces

Properties:

- non-stationary, non-ergodic
- divergent

$$\sigma^2(t) \propto t$$

$$p(x,t) = \frac{1}{\sqrt{2\pi\sigma^2(t)}} e^{-\frac{x^2}{2\sigma^2(t)}}$$

- averaging increase measurement error of mean

4.5. Diffusion noise

- Diffusion of a particle: Brownian motion
- Quantities can be coupled to the diffused quantity
- Spectrum is typically $1/f^{1.5}$

4.6. 1/f noise (flicker, pink noise)

- Excess noise in conductors, semiconductors
- Generation-recombination noise
- Hooge formula for semiconductors (empirical)

$$\frac{S_R(f)}{R^2} = \frac{\alpha}{Nf}$$

Correlation function:

only for bandlimited noise

$$\frac{R(\tau)}{R(0)} \approx 1 - \frac{c \cdot \ln(2\pi f_2 \tau)}{\ln(f_2/f_1)}$$

Spectrum:

S(f)=c/f

Probability density:

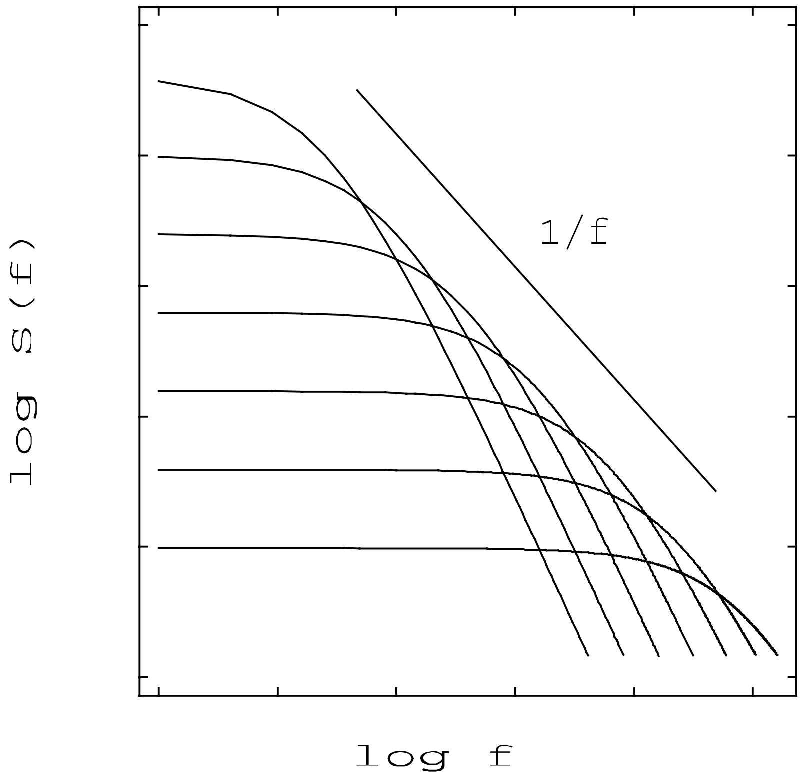
Gaussian, ...

McWorther model:

Spatially equally distributed, independent Lorentzian fluctuations with, different correlation times:

$$S(f) = \alpha \int_{\tau_1}^{\tau_2} \frac{\tau g(\tau)}{1 + (2\pi f)^2 \tau_i^2} d\tau$$

Distribution of τ is $g(\tau)=c/\tau$ -> 1/f noise.



1/f
log S(f)
log f

Properties/problems:

- general occurance
  - semiconductors
  - biological systems
  - natural systems (level of rivers)
  - traffic
  - economical processes
  - music, ...
- frequency range problems (McWorther m.)
- no general models
- special or general models to be found?
- difficult theoretical treatment
- stationarity problems

- averaging keeps measurement error of mean
- logarithmic divergence

$$\sigma^2 = \int_{f_1}^{f_2} S(f)\, df = const \cdot \ln\left(\frac{f_2}{f_1}\right)$$

- heavy arguments about the origin even in semiconductors
- not all the properties are known