Karlsruhe Institute of Technology

Noise in Communication Systems – Principles

Advanced Radio Communication I

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Noise in Communication Systems

Noise is any unwanted signal, random or deterministic, which interfere with the faithful reproduction of the desired signal in a system. This interfering signal is usually noticed as random fluctuations in voltage or current tending to obscure and mask the desired signals.

Man-made types of interference can practically arise from any piece of electrical or electronic equipment.

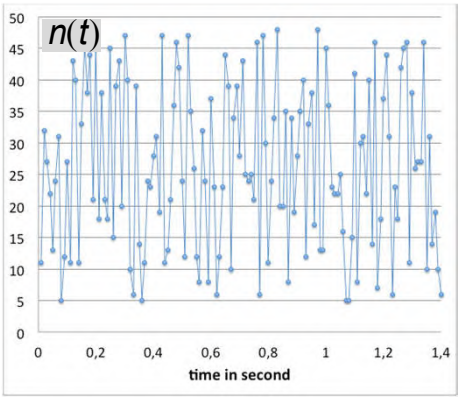
Natural noise comes from random thermal motion of electrons, atmospheric absorption and cosmic sources.
Their interference can best be described statistically.

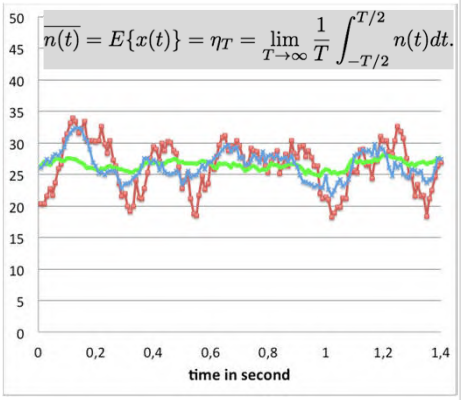
Statistical Description of Signals

- ✓ average
- ✓ variance
- ✓ spectral density
- ✓ correlation function

Time-Averaged Noise Representations

Random Noise Waveform	Average (Mean) Value

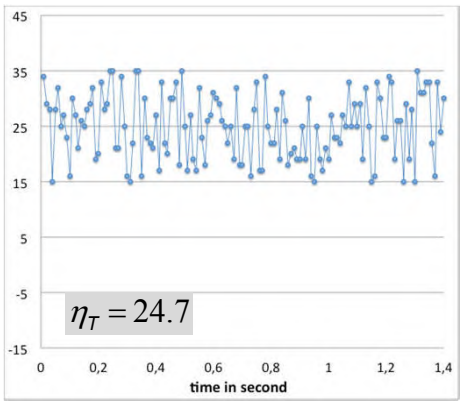




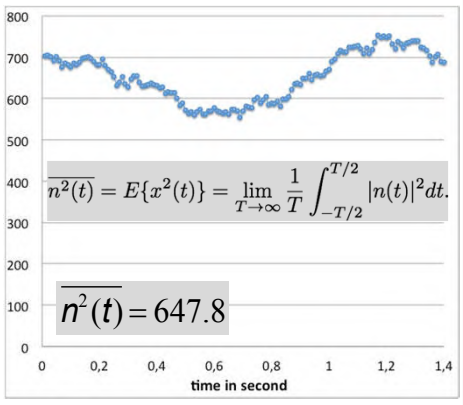
$$\eta_T = 27.16$$

Mean-Square Value

Random Noise Waveform

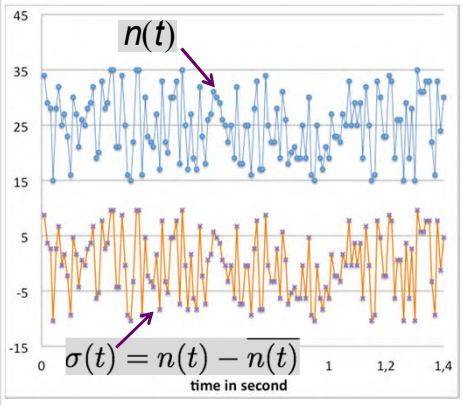


Mean-Square Value

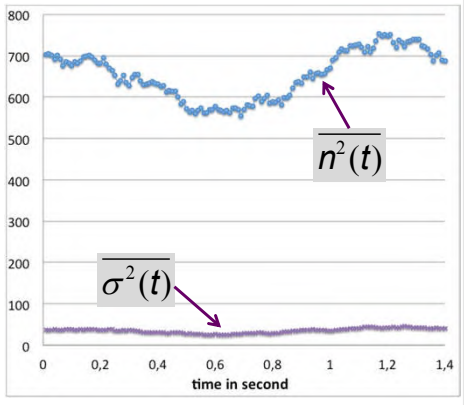


AC-Component and Variance

Random Waveform



Mean-Square Value and Variance



$\eta_T = 24.7$ $\overline{n^2(t)} = 647.8$ $\overline{\sigma^2(t)} = 34.2$

Fourier Transform

$$F(f) = \mathcal{F}\{f(t)\} = \int_{-\infty}^{\infty} f(t)e^{-j2\pi ft}dt$$

Integral will diverge for power signal, i.e., a signal with finite power but infinite energy.

finite observation time *rect(t/T)*

$$F_T(f) = \mathcal{F}\{f(t)\mathrm{rect}(t/T)\} = \int_{-T/2}^{T/2} f(t)e^{-j2\pi ft}dt$$

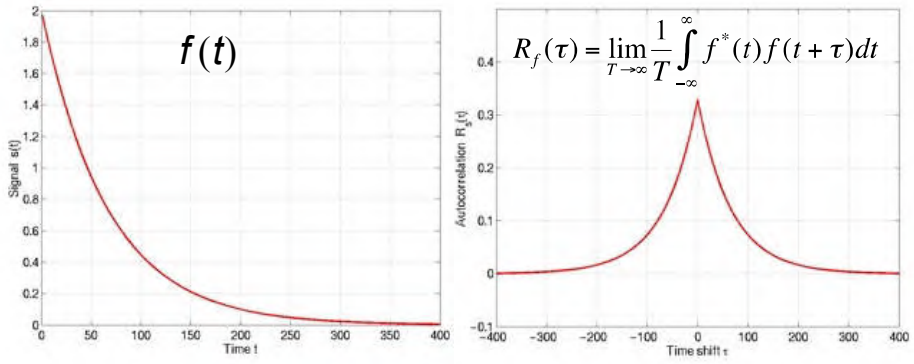
What is the effect of the rect-function ???

Auto-Correlation Function (Signal)

The auto-correlation function gives a similarity measure of the signal *f(t)* with itself versus a relative time shift by an amount τ

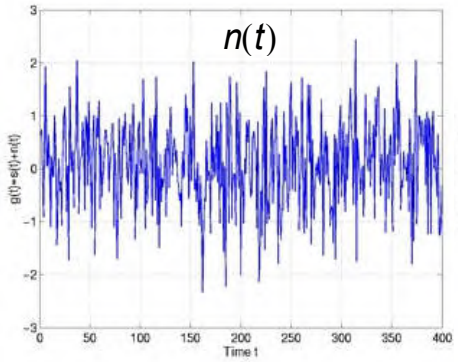
Time signal waveform

autocorrelation function



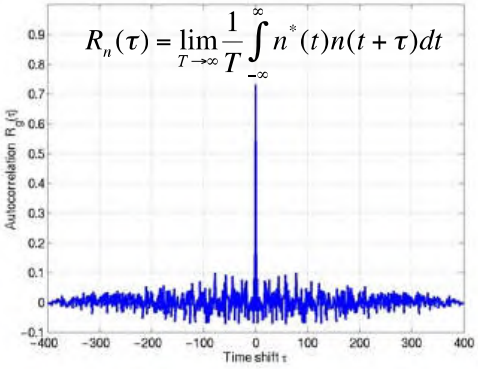
Autocorrelation Functionn (Noise)

Noise waveform



autocorrelation function

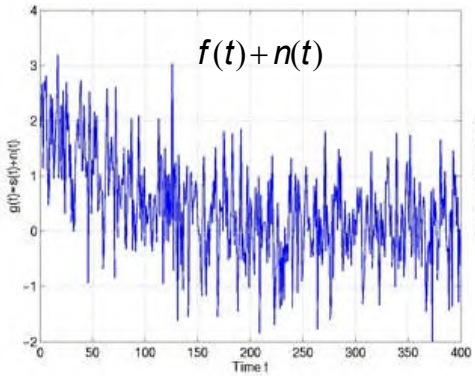
$$R_n(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-\infty}^{\infty} n^*(t) n(t+\tau) dt$$



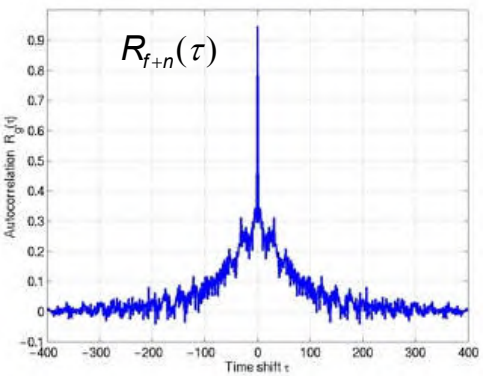
Why is the function multiplied by its complex conjugate ???

Cross-Correlation of Signal Plus Noise

Signal + Noise waveform



correlation function



The correlation function is a statistical quantity describing a random (stationary and ergodic) process

Power Spectral Density

remember $$F_T(f) = \int_{-\infty}^{+\infty} f(t) \cdot rect\left(\frac{t}{T}\right) \cdot e^{-j2\pi ft} dt = \int_{-T/2}^{T/2} f(t) e^{-j2\pi ft} dt$$

Parseval's theorem for truncated signals states that:

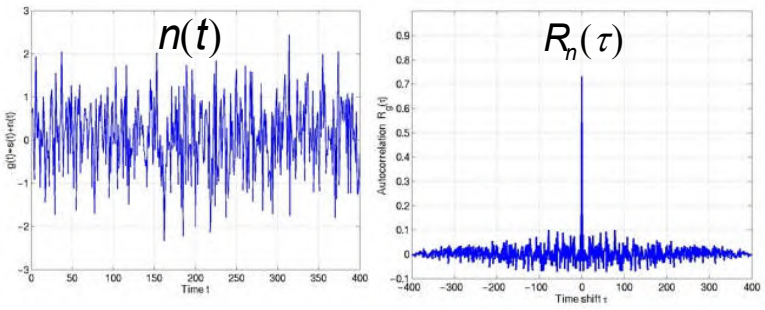
$$\int_{-T/2}^{T/2} |f(t)|^2 dt = \int_{-\infty}^{+\infty} |F_T(f)|^2 df$$

System Noise

- ✓ band limited white noise
- ✓ transmission of noise through an LTI system
- ✓ equivalent noise bandwidth
- ✓ signal-to-noise ratio

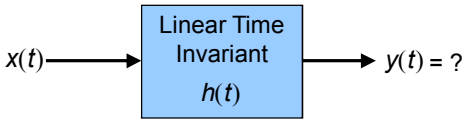
Band Limited White Noise

Noise waveform | autocorrelation function



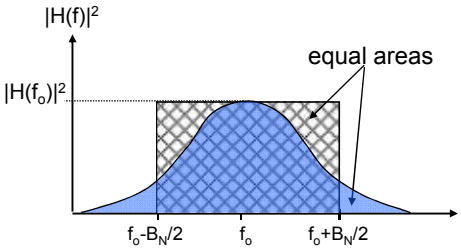
$$R_n(\tau) = \frac{N_0}{2}\delta(\tau)$$

Transmission of Noise through an LTI System



convolution integral $$y(t) = \int_{-\infty}^{\infty} x(t)h(t-\tau)d\tau$$

Equivalent Noise Bandwidth

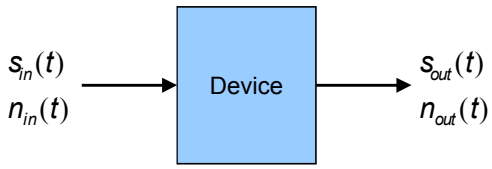


$$P_{out} = N_o \int_0^{\infty} |H(f)|^2 df \quad \text{Watt}$$

$$P_{out} = N_o \int_{f_o - B_N/2}^{f_o + B_N/2} |H(f_o)|^2 df \quad \text{Watt}$$

The equivalent noise bandwidth B_N is the bandwidth of an ideal filter, such that the output noise power from the ideal filter and the real system are equal.

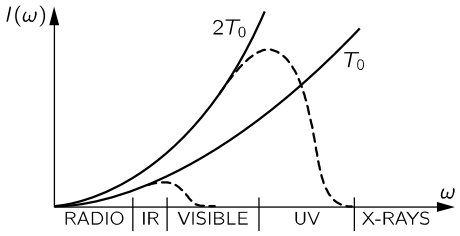
Signal-to-Noise Ratio



$$SNR_{in} = \frac{\overline{s_{in}^2(t)}}{\overline{n_{in}^2(t)}} \qquad SNR_{out} = \frac{\overline{s_{out}^2(t)}}{\overline{n_{out}^2(t)}}$$

Black Body Radiation – Classical Physics

$$I(\omega) = \frac{\omega^2 kT}{\pi^2 c^2}.$$



Noise Sources

- Naturally occurring noise
  - thermal radiation

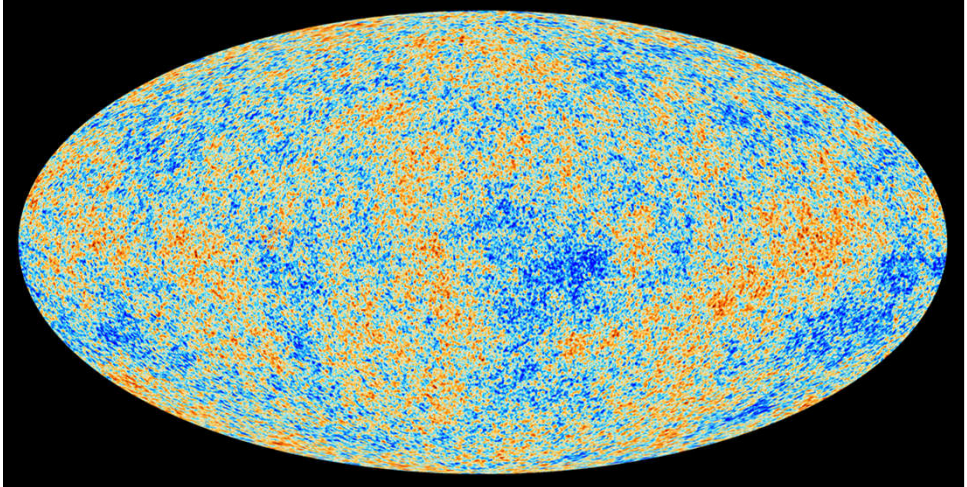
    generated through the random thermal motion of electrons in a conduction medium. Thermal noise is system inherent.
  - extraterrestrial noise

    the noise sources are both thermal and none-thermal emission from the Sun, the Moon, the Cassiopeia and planets and from elsewhere in our galaxy and other galaxies
  - absorption noise

    when energy is absorbed by a body the same energy is reradiated as noise as shown by the theory of black body emission
  - Shot- and 1/f noise
- Man-made noise sources
  - quantization noise

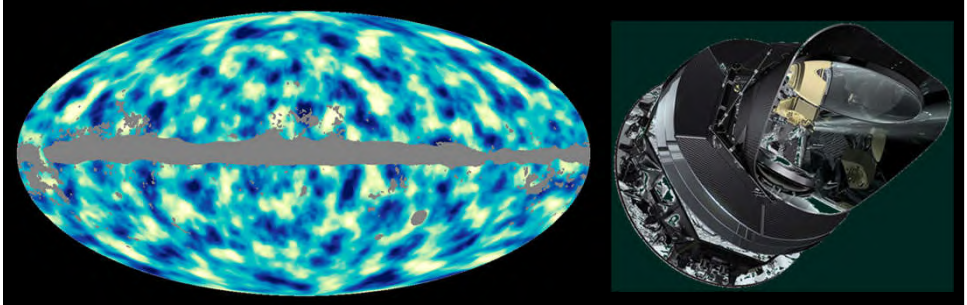
Thermal Radiation

The Cosmic Microwave Background observed by Planck Satellite



The cosmic microwave background is a snapshot of the oldest light in our Universe, imprinted on the sky when the Universe was just 380 000 years old. It shows tiny temperature fluctuations that correspond to regions of slightly different densities, representing the seeds of all future structure: the stars and galaxies of today.

The Distribution of Dark Matter



The distribution of dark matter across the entire history of the Universe as seen projected on the sky. It is based on data collected with ESA's Planck satellite.
The image was compiled by analyzing the tiny distortions imprinted on the photons of the Cosmic Microwave Background by the gravitational lensing effect of massive cosmic structures. As photons travelled through these structures, which consist primarily of dark matter, their paths were bent, slightly changing the pattern of the cosmic background radiation.

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