Information

- ➤ **Please hand in your 1 page progress summaries**

Project Performance Measures

- The project criteria are necessarily vague: you are only given a radio specification.
- Just the same all technical information is available on the web.
- Your achievement lies in understanding and applying the technical material.
- You cannot win marks by regurgitating the web material in your report.
- The novelty lay in your approach taken in the labs.

Approach

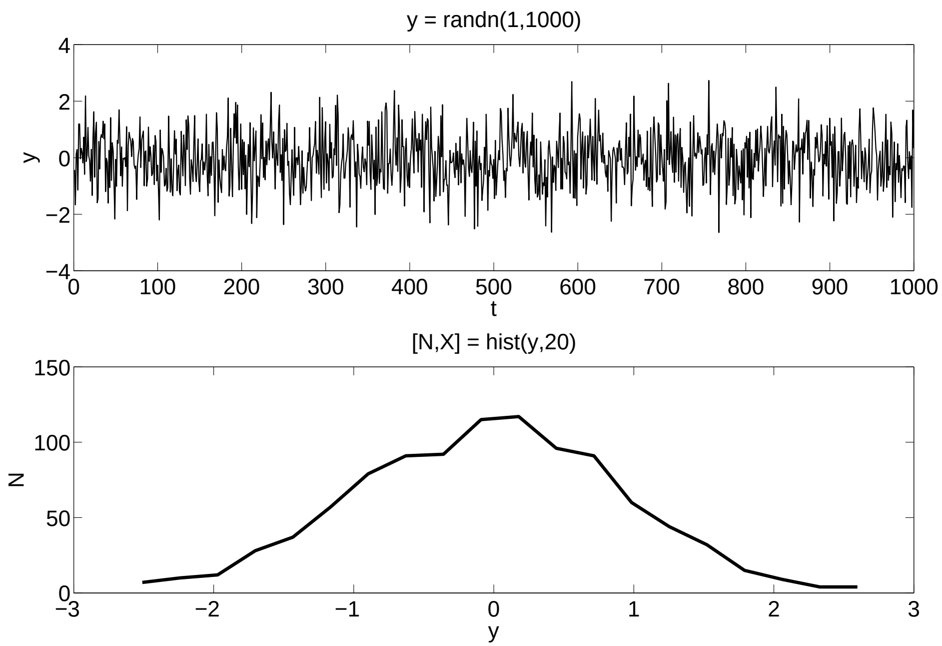
- Need a scrap book to write down your designs and what you did, as you did them in the lab.
- Need the log book to transfer your work in a readable form so that at least you understand what you did.
- You need the report to present to the boss.
- Each work examines different qualities in your approach.
- In the lab, the process is to do the design on the background technical material, think through the design before implementation, demonstrate competence in construction (layout soldering technique, ...) and perform and report on relevant tests.
- Examples for the oscillator might be, frequency tunability, phase noise, output power, total power consumption and harmonic generation.

Amplitude Noise in Radiofrequency Systems

- Noise refers to the random voltages and currents that are **always** observed in electronics circuits.
- Most often, noise has its origin in the random motions of electrons and can be studied using **thermodynamics**. *Thermal, Johnson or White noise*.
- Sometimes thermal noise is modeled as additive white and Gaussian (AWGN).
- However there is also man made noise which is usually much larger in amplitude than thermal noise and is usually not AWGN.
- Make a distinction between *amplitude* and *phase* noise. However all thermal and man made noise induces phase noise.

Additive White Gaussian Noise (AWGN)

- Often the noise is **additive**, **white** and **Gaussian**.
- **AWGN** is a special case of thermal noise.
- White means.. power is a constant function of frequency.
- Gaussian means that the noise possesses a *normally distributed* amplitude.



Probability Density Function

- The *Probabilty Density Function* (PDF) *f[x]* is defined by:

$$Pr[a \leq X \leq b] = \int_a^b dx \quad f[x]$$

- Of particular theoretical interest is the *Gaussian PDF*

$$P[x] = \frac{\mathrm{exp}[-x^2/(2\sigma^2)]}{\sqrt{2\pi\sigma^2}}$$

where σ^2 is referred to as the *variance*.

Where does noise come from? Noise in Electronic Systems.

- Random motion of electrons and electromagnetic fields generates noise power at *any finite temperature above absolute zero*. Only at absolute zero can we ever do an experiment in the absense of noise.
- Consider a resistor at temperature T. The noise power generated across the resistor terminals is given by

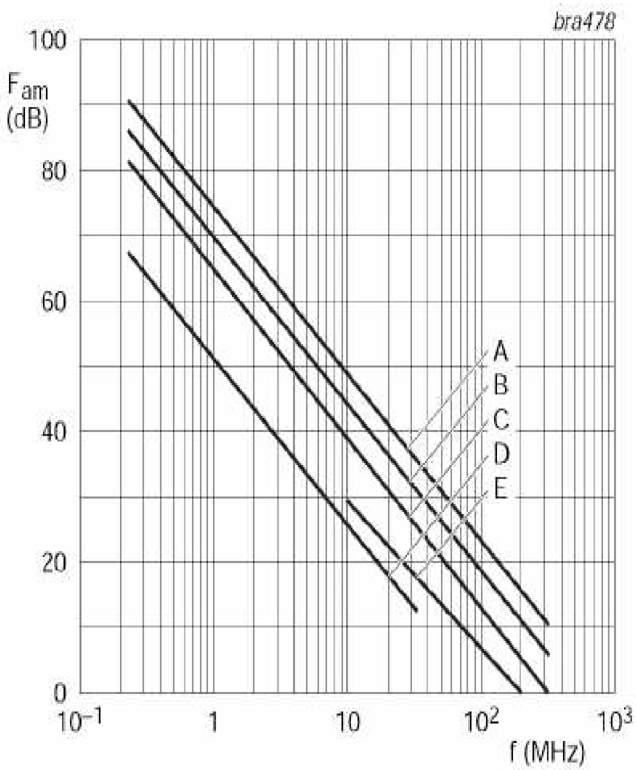
$$P = k_B T B$$

  where k_B is Boltzmann's Constant $= 1.38 \times 10^{-23} J/^oK$, T is the temperature and B is the bandwidth overwhich the power is measured.
- Example: The noise power generated by a circuit component at room temperature (300K) in a 200 kHz BW is 8.28×10^{-16} Watts = -120.8 dBm.

The Nature of Noise

- Random motion of electrons generates noise electromagnetic fields.
- Because noise is carried by electromagnetic fields, it can traverse a vacuum.
- Electromagnetic fields allow objects in a vacuum to maintain *thermal equilibrium*.
- Such electromagnetic fields come from both natural and man made sources.
- Antennas pickup noise from the environment or outer space and introduce it into a circuit.
- Antennas have *temperature* that is **unrelated** to how “warm” they are.

Man Made Noise



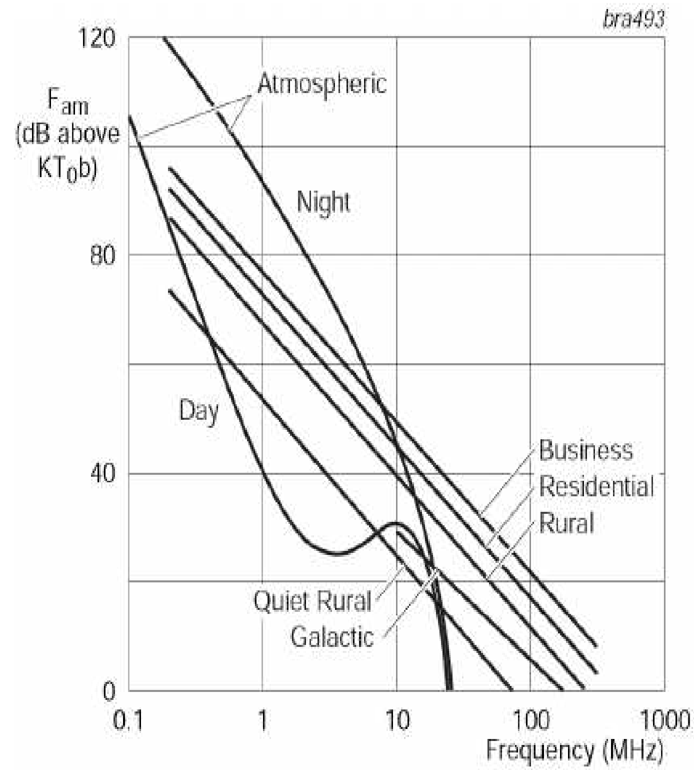
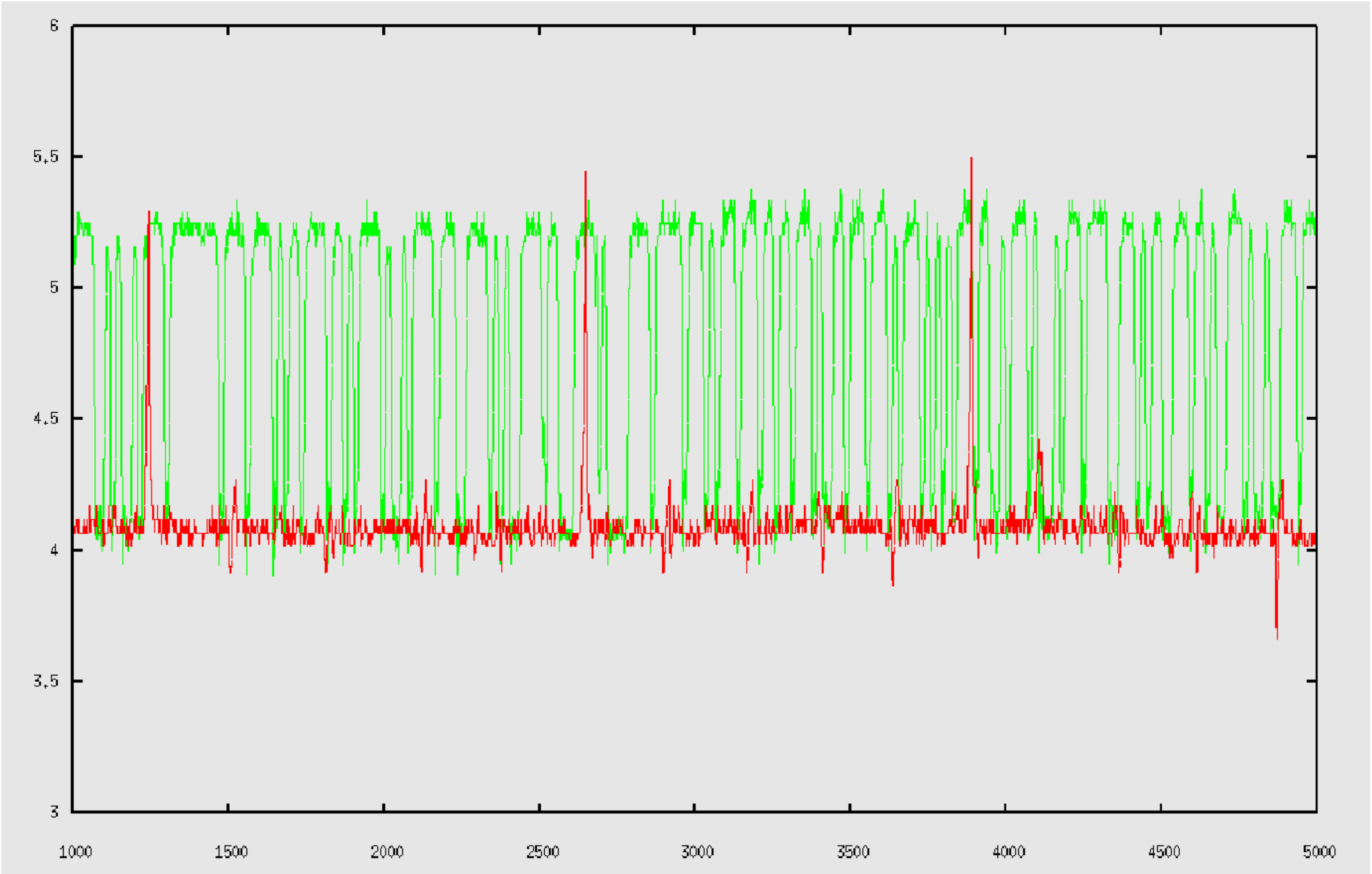


Figure 2.7: Ambient noise figures [4]. A: Business area, B: Residental area, C: Countrified area, D: Calm countrified area, E: Galactic noise.

Impulse Noise



Performance of Electronics Systems in the Presence of Noise

- In *analog telecommunications systems* we measure noise influence by *signal to noise ratio (SNR)*.
- In *digital telecommunications systems* we measure noise performance by *bit error rate (BER)*.
- Low amplitude signals are most susceptible to corruption by noise and these are common in radio systems.
- -160 dBm is possible in radio receivers in telecoms. For example -160 dBm = ?? Watts.
- Much lower received powers are possible in radio astronomy dictating the use of liquid nitrogen cooled receivers. Why?

White Noise Power

- Consider a *bandlimited* modulated carrier (f_o MHz). That is, signals with non-zero power in the spectral region $f_o - B/2$ to $f_o + B/2$ Hz.
- The *noise power* is given by

$$N_o = \int_{2\pi(f_o - B/2)}^{2\pi(f_o + B/2)} S_N(\omega) d\omega = \int_{f_o - B/2}^{f_o + B/2} \mathcal{N} df = \mathcal{N} B$$

where $S_N(\omega)$ is the *double sideband Power Spectral Density* of the noise.

- The amplitude of the noise increases with bandwidth for a fixed PSD $\mathcal{N}$

$$\frac{< V^2 >}{R} = \mathcal{N} B$$

where $< V^2 >$ is the *root mean square (r.m.s.)* voltage of the noise.

Signal to Ratio (SNR) in Analog Systems

- **SNR is the ratio of the signal power to the amount of power in the white noise contained within the signal bandwidth**
- The bandwidth is determined by the system. It must at least correspond to that occupied by any modulation.
- For a given set of signal conditions, the higher is the bandwidth, the greater is the noise power.
- Still use the same definition if the noise is not white.

$$SNR = \frac{P_s}{N_0 B}$$

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Noise Performance of Amplifiers

- When a signal of SNR, SNR_i, with noise power N_i enters an amplifier (any electronic device with gain) and exits with a new SNR, SNR_o with noise power N_o then we define the *Noise Factor (F)* of the network as,

$$F = \frac{SNR_i}{SNR_o}$$

- *Notice that SNR_i is always $> SNR_o$*.
- If the noise is **only** amplified then the NF is 0. In practice of course amplifiers make things worse.
- The *Noise Figure* is defined as,

$$NF = 10log_{10}(F)$$

The Noise Performance of Cascaded Amplifiers

- The noise factor of cascaded amplifiers is given by,

$$F_{TOT} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + ...$$

  where G_k are the power gains of the various amplifiers and F_k are the noise **factors**

- Provided that the amplifier gains are much larger than unity, the noise factor (and therefore the noise figure) of a receiver chain is dominated by that of the first amplifier.

Transfer Function, Insertion Loss (Conversion Loss) and Attenuation.

- *The Transfer function* of a four port network is the ratio of its output voltage V_o when terminated (in Z_o) to that when the network is replace by Z_o.
- **Transfer function must be unity if the network is lossless.**
- *Insertion loss* is the same as the transfer function.
- *Attenuation* only includes the loss from input to the output in terms of the voltage.

$$Transfer\ Function = \frac{2V_o}{Z_o}$$

$$Attenuation = \frac{V_o}{V_i}$$

$$Transfer\ Function = Attenuation \times (1 + \rho)$$

$$\rho = \frac{Z_i - Z_o}{Z_i + Z_o}$$

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Noise Performance of Passive Networks

- If noise enters a passive circuit then the NF is equal to the *insertion loss* (IL) of the circuit.

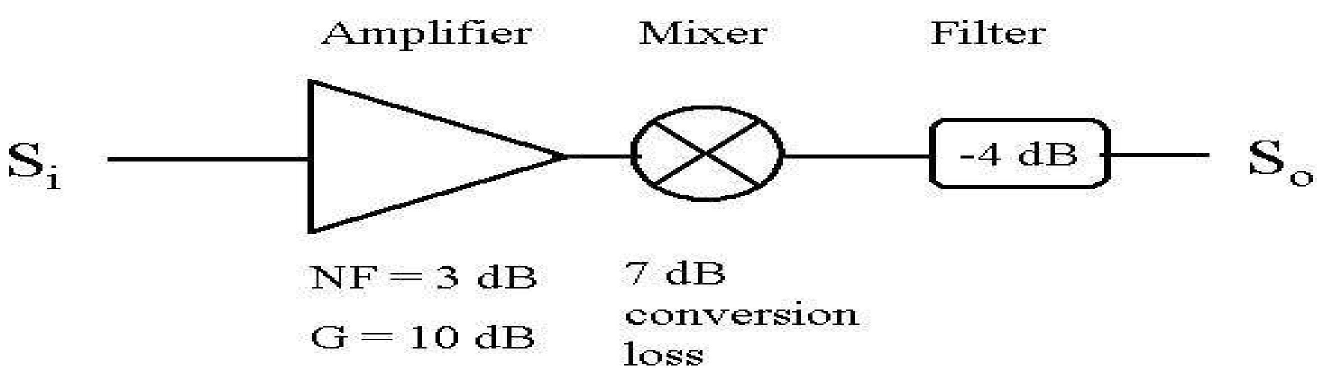
$$NF = IL(dB)$$

- Insertion Loss (IL) refers to that fraction of the signal power which is dissipated in the network.
- Insertion Loss (IL) is the transfer function of a lossy network like an attenuator, a filter or a passive mixer.

Example Noise Power Calculation.

- Consider the following receiver chain which is typical of that in a wireless receiver.

- The noise figure of the mixer and filter (both passive devices with the given insertion losses) is 11dB.
- **Find the overall noise figure of the receiver**



Example Noise Power Calculation. (Contd)

- The noise factor of the amplifier is 2 (=$10log_{10}(3)$).
- The noise figure of the mixer and filter is 11 dB and so the noise factor is 12.6 (=$10log_{10}(11)$). Thus,

$$F_{TOT} = F_1 + \frac{F_2 - 1}{G_1} = 2 + (12.6 - 1)/10 = 3.16.$$

- Finally we obtain

$$F_{TOT} = 10log_{10}(3.16) = 5dB.$$

Receiver Noise Calculations

- The thermal noise added to a signal when passing through a system is given by,

$$N_o = k_B T B$$

- In dBm

$$N_o = 10 log_{10} \frac{k_B T B}{1 \times 10^{-3}}$$

- If N_o and the NF are known, then the required input signal level for a given output SNR can be calculated,

$$S_i = NF + N_o + SNR_o$$

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Receiver Noise Calculations (Example)

- In the above example compute the required input signal level for a 10 dB output SNR and a 1.25 MHz bandwidth.

$$N_o = 10log_{10}\frac{(1.38 \times 10^{-23})(293)(1.25 \times 10^6)}{1. \times 10^{-3}} = -113dBm$$

- Therefore

$$S_i = NF + N_o + SNR_o = 5dB - 113dBm + 10dBm = -98dBm$$

- Notice that Johnson noise was assumed as the baseline input noise to the receiver. **This is rarely the case in practice**

Dealing with Noise

- In telecommunications the effects of noise are mitigated by the choice of receiver components that have a low NF. That is: NF is the parameter to look for in active component datasheets. Because it is that first amplifier in the receiver chain which determines the noise figure, it is usually chosen to be a Low Noise Amplifier (LNA) ($\ll 10dB$ NF).
- **To determine the sensitivity of a receiver in a particular application, one needs to measure the input noise from the antenna in situ and this will depend on the quietness of the site where the receiver is located.** *Site test*.
- In Radio astronomy, the antenna noise is the phenomenon under observation. Therefore one tries to minimise the receiver noise by judicious choice of components (NF) and cryogenics.

How to Measure Noise in Radio Receivers: SINAD (Signal to Noise And Distortion

- The method of measuring noise in arbitrary loads (e.g. antennas) and FM receivers