NOISE IN RADIO/OPTICAL COMMUNICATIONS

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Abstract

Noise is a random signal that affects the performance of all electronic and/or optical devices. Although the sources of different kinds of noise have their backgrounds in physics, engineers dealing with noise use different methods and units to specify noise. The intention of this tutorial is to describe the main effects of noise in electronics up to optical frequencies while providing links between the physics and engineering worlds. In particular, noise is considered harmful while degrading the signal-to-noise ratio or broadening the spectrum of signal sources. On the other hand, noise can be itself a useful signal. Finally, artificially generated signals that exhibit many properties of random natural noise are sometimes required.

NATURAL NOISE

Noise is a broadband signal. Therefore it makes sense to describe its intensity by the noise spectral density N_0 or amount of noise power per unit bandwidth. In electronics the most important type of noise is thermal noise. Thermal noise adds to any signal. In optics the most important type of noise is shot noise. Shot noise is a property of any signal made from a discrete number of photons.

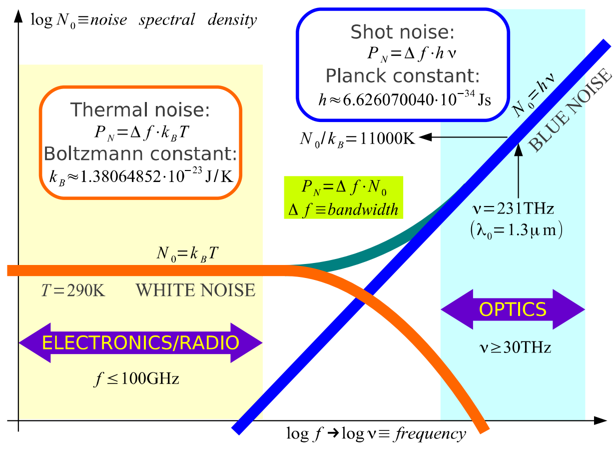

Figure 1: Noise spectral density.

Since the photon energy increases proportional with frequency, the higher the frequency the larger the shot noise spectral density. Such a noise is also called blue noise. Shot noise is unimportant in the radio-frequency range at room temperatures. Shot noise can only be observed at the highest end of the radio-frequency range at cryogenic temperatures.

Thermal noise is caused by thermal radiation. The Planck law describes the spectral brightness B_f or radiated power per unit bandwidth, unit area and unit solid angle of a black body. A black body with zero reflectivity Γ=0 is the most efficient thermal radiator while a perfect mirror |Γ|=1 does not radiate at all.

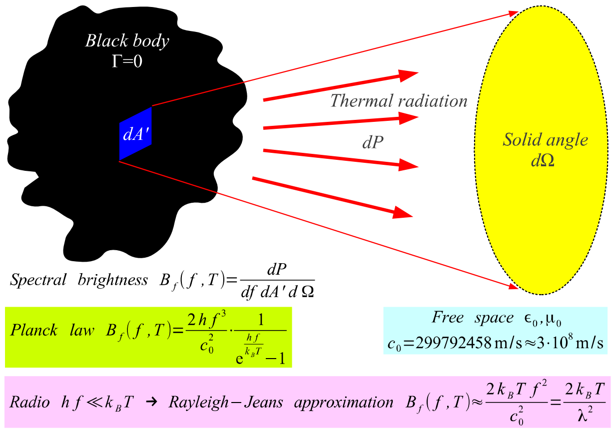

Figure 2: Black-body thermal radiation.

In the radio-frequency range it makes sense to use the Rayleigh-Jeans approximation of the Planck law to calculate the noise power collected by a lossless antenna. An antenna with a single electrical connector only collects half of the incident noise power on its effective area A_{eff}, the remaining half being orthogonally polarized.

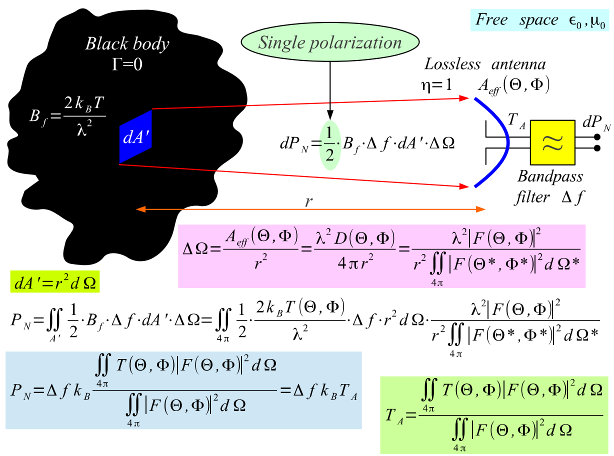

Figure 3: Received thermal-noise power.

In the radio-frequency range the noise spectral density is frequency independent. Thermal noise therefore behaves as white noise. Thermal noise spectral density is simply described by the black-body temperature T_A as observed by the radiation pattern of a lossless antenna.

Above a certain frequency the thermal noise power begins decreasing when the complete Planck law applies. However, the sum of both noise spectral densities, thermal noise and shot noise, remains a monotonic

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function of frequency. The white-noise behaviour is smoothly replaced by the blue-noise behaviour.

Expressing the noise spectral density with the noise temperature is so popular that the noise temperature is also used in cases when the noise is not of thermal origin.

SIGNAL-TO-NOISE RATIO

Any receiver (amplifier) adds its own noise therefore further degrading the signal-to-noise ratio. The additional receiver noise is usually specified as an equivalent noise temperature T_{RX} at the receiver input even if it is not of thermal origin. In the case of thermal noise, T_{RX} is usually of the same order of magnitude as the physical temperature of the amplifying device.

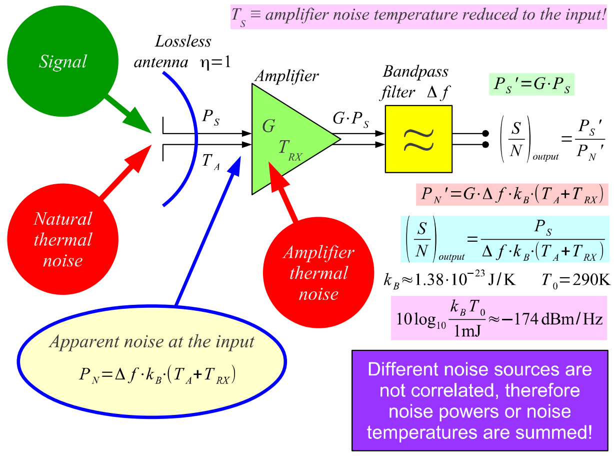

Figure 4: Receiver signal-to-noise ratio.

Alternatively the noise figure of a receiver can be specified. The noise figure has to be used carefully due to its unfortunate definition. In the case of thermal noise, selecting a reference temperature T_0=290 K allows a sensible definition of the noise figure F (in linear units) or F_{dB} (in logarithmic units) and a simple conversion from/to the receiver noise temperature T_{RX}.

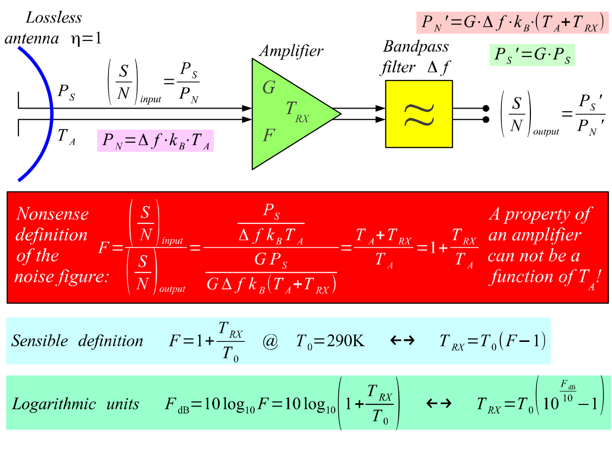

Figure 5: Amplifier noise figure.

A frequent case is an attenuator 0<a<1 between the antenna and receiver. Besides attenuating both the signal P_S and the antenna noise T_A, the attenuator adds its own thermal noise T_R.

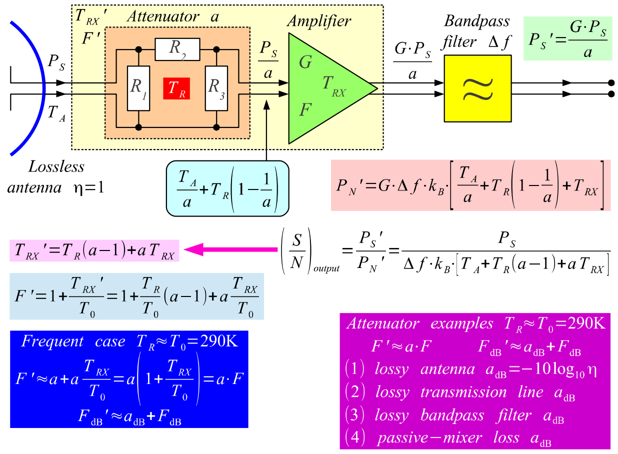

Figure 6: Attenuator noise.

OSCILLATOR PHASE NOISE

Any receiver (amplifier) adds its own noise theref