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Noise temperature

In electronics, **noise temperature** is one way of expressing the level of available noise power introduced by a component or source. The power spectral density of the noise is expressed in terms of the temperature (in kelvins) that would produce that level of Johnson–Nyquist noise, thus:

$$\frac{P_N}{B} = k_B T$$

where:

- P_N is the noise power (in W, watts)
- B is the total bandwidth (Hz, hertz) over which that noise power is measured
- k_B is the Boltzmann constant (1.381×10^{-23} J/K, joules per kelvin)
- T is the noise temperature (K, kelvin)

Thus the noise temperature is proportional to the power spectral density of the noise, P_N/B. That is the power that would be absorbed from the component or source by a matched load. Noise temperature is generally a function of frequency, unlike that of an ideal resistor which is simply equal to the actual temperature of the resistor at all frequencies.

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Noise voltage and current

A noisy component may be modelled as a noiseless component in series with a noisy voltage source producing a voltage of v_n, or as a noiseless component in parallel with a noisy current source producing a current of i_n. This equivalent voltage or current corresponds to the above power spectral density $\frac{P}{B}$, and would have a mean squared amplitude over a bandwidth B of:

$$\frac{\bar{v}_n^2}{B} = 4k_B RT$$

$$\frac{\bar{i}_n^2}{B} = 4k_B GT$$

where *R* is the resistive part of the component's impedance or *G* is the conductance (real part) of the component's admittance. Speaking of noise temperature therefore offers a fair comparison between components having different impedances rather than specifying the noise voltage and qualifying that number by mentioning the component's resistance. It is also more accessible than speaking of the noise's power spectral density (in watts per hertz) since it is expressed as an ordinary temperature which can be compared to the noise level of an ideal resistor at room temperature (290 K).

Note that one can only speak of the noise temperature of a component or source whose impedance has a substantial (and measurable) resistive component. Thus it doesn't make sense to talk about the noise temperature of a capacitor or of a voltage source. The noise temperature of an amplifier refers to the noise that would be added at the amplifier's *input* (relative to the input impedance of the amplifier) in order to account for the added noise observed following amplification.

Application to communication systems

A communications system is typically made up of a transmitter, a communication channel, and a receiver. The communications channel may consist of a combination of different physical media, resulting in an electrical signal presented to the receiver. Whatever physical media a channel consists of, the transmitted signal will be attenuated and corrupted with additive noise.[1]

The additive noise in a receiving system can be of thermal origin (thermal noise) or can be from other noise-generating processes. Most noise processes will have a white spectrum, at least over the bandwidth of interest, identical to that of thermal noise. Since they are indistinguishable, the contributions of all noise sources can be lumped together and regarded as a level of thermal noise. The noise power spectral density generated by all these sources (P/B) can be described by assigning to the noise a temperature T as defined above:[2]

$$T = \frac{P}{B} \cdot \frac{1}{k_B}$$

In a wireless communications receiver, the equivalent input noise temperature T_{eq} would equal the sum of two noise temperatures:

$$T_{\text{eq}} = T_{\text{ant}} + T_{\text{sys}}$$

The antenna noise temperature T_{ant} gives the noise power seen at the output of the antenna.[3] The noise temperature of the receiver circuitry T_{sys} represents noise generated by noisy components inside the receiver.

Note that T_{eq} refers not to the noise at the output of the receiver after amplification, but the equivalent *input* noise power. In other words, the output of the receiver reflects that of a noiseless amplifier whose input had a noise level not of T_{ant} but of T_{eq}. Thus the figure of merit of a communications system is not the noise level at the speaker of a radio, for instance, since that depends on the setting of the receiver's gain. Rather we ask how much noise the receiver *added* to the original noise level before its gain was applied. That additional noise level is Bk_BT_{sys}. If a signal is present, then the decrease in signal to noise ratio incurred using the receiver system with a noise temperature of T_{sys} is proportional to $1/T_{\text{ant}} - 1/(T_{\text{ant}} + T_{\text{sys}})$.

Noise factor and noise figure

One use of noise temperature is in the definition of a system's noise factor or noise figure. The noise factor specifies the increase in noise power (referred to the input of an amplifier) due to a component or system when its input noise temperature is T_0.

$$F = \frac{T_0 + T_{\text{sys}}}{T_0}$$

T_0 is customarily taken to be room temperature, 290 K.

The noise factor (a linear term) is more often expressed as the *noise figure* (in decibels) using the conversion:

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

The noise figure can also be seen as the decrease in signal-to-noise ratio (SNR) caused by passing a signal through a system if the original signal had a noise temperature of 290 K. This is a common way of expressing the noise contributed by a radio frequency amplifier regardless of the amplifier's gain. For instance, assume an amplifier has a noise temperature 870 K and thus a noise figure of 6 dB. If that amplifier is used to amplify a source having a noise temperature of about room temperature (290 K), as many sources do, then the insertion of that amplifier would reduce the SNR of a signal by 6 dB. This simple relationship is frequently applicable where the source's noise is of thermal origin since a passive transducer will often have a noise temperature similar to 290 K.

However, in many cases the input source's noise temperature is much higher, such as an antenna at lower frequencies where atmospheric noise dominates. Then there will be little degradation of the SNR. On the other hand, a good satellite dish looking through the atmosphere into space (so that it sees a much lower noise temperature) would have the SNR of a signal degraded by *more* than 6 dB. In those cases a reference to the amplifier's noise temperature itself, rather than the noise figure defined according to room temperature, is more appropriate.

Noise temperature of cascaded devices

The noise temperature of an amplifier is commonly measured using the Y-factor method. If there are multiple amplifiers in cascade, the noise temperature of the cascade can be calculated using the Friis equation:[4]

$$T_{\text{eq}} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \cdots$$

where

- T_{eq} = resulting noise temperature referred to the input
- T_1 = noise temperature of the first component in the cascade
- T_2 = noise temperature of the second component in the cascade

- T_3 = noise temperature of the third component in the cascade
- G_1 = power gain of the first component in the cascade
- G_2 = power gain of the second component in the cascade

Therefore, the amplifier chain can be modelled as a black box having a gain of $G_1 \cdot G_2 \cdot G_3 \cdots$ and a noise figure given by $NF = 10\log_{10}(1 + T_{\text{eq}}/290)$. In the usual case where the gains of the amplifier's stages are much greater than one, then it can be seen that the noise temperatures of the earlier stages have a much greater influence on the resulting noise temperature than those later in the chain. One can appreciate that the noise introduced by the first stage, for instance, is amplified by all of the stages whereas the noise introduced by later stages undergoes lesser amplification. Another way of looking at it is that the signal applied to a later stage already has a high noise level, due to amplification of noise by the previous stages, so that the noise contribution of that stage to that already amplified signal is of less significance.

This explains why the quality of a preamplifier or RF amplifier is of particular importance in an amplifier chain. In most cases only the noise figure of the first stage need be considered. However one must check that the noise figure of the second stage is not so high (or that the gain of the first stage is so low) that there is SNR degradation due to the second stage anyway. That will be a concern if the noise figure of the first stage plus that stage's gain (in decibels) is not much greater than the noise figure of the second stage.

One corollary of the Friis equation is that an attenuator prior to the first amplifier will degrade the noise figure due to the amplifier. For instance, if stage 1 represents a 6 dB attenuator so that $G_1 = \frac{1}{4}$, then $T_{\text{eq}} = T_1 + 4T_2 + \cdots$. Effectively the noise temperature of the amplifier T_2 has been quadrupled, in addition to the (smaller) contribution due to the attenuator itself T_1 (usually room temperature if the attenuator is composed of resistors). An antenna with poor efficiency is an example of this principle, where G_1 would represent the antenna's efficiency.

See also

- Noise spectral density

References

1. Proakis, John G., and Masoud Salehi. *Fundamentals of Communication Systems*. Upper Saddle River, New Jersey: Prentice Hall, 2005. ISBN 0-13-147135-X.
2. Skolnik, Merrill I., Radar Handbook (2nd Edition). McGraw-Hill, 1990. ISBN 978-0-07-057913-2
3. The physical temperature of the antenna generally has little or no effect on T_{ant}
4. McClaning, Kevin, and Tom Vito. *Radio Receiver Design.* Atlanta, GA: Noble Publishing Corporation, 2000. ISBN 1-884932-07-X.

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