**Equivalent Noise Temperature**

In addition to the external noise coupled into the receiver through the antenna, each component of a receiver generates its own internal noise!

For example, consider an amplifier with gain $G$ and bandwidth $B$:

\[
\begin{align*}
N_{in} & \quad \rightarrow \quad G \\
\quad & \quad \rightarrow \quad \frac{P_{out}}{G} = BN_{out}
\end{align*}
\]

Here there is no input signal at the amplifier input, other than some white (i.e., uniform across the RF and microwave spectrum) noise with average spectral power density $N_{in}$. At the output of the amplifier is likewise noise, with an average spectral power density of $N_{out}$.

This output average spectral power density $N_{out}$ is typically not wideband, but instead is uniform only over the bandwidth of the amplifier:

\[
N(f) \approx \begin{cases} 
N_{out} & \text{for } f \text{ in bandwidth } B \\
\ll N_{out} & \text{for } f \text{ outside bandwidth } B
\end{cases}
\]
Thus, the noise power at the output is:

\[
\begin{align*}
R_n^{\text{out}} &= \int_{-\infty}^{\infty} N(f) \, df \\
&= \int_{f_i}^{f_o} N_{\text{out}} \, df \\
&= B N_{\text{out}}
\end{align*}
\]

Q: The amplifier has gain \( G \). So isn’t \( N_{\text{out}} = G N_{\text{in}} \), and thus \( R_n^{\text{out}} = G \, B \, N_{\text{in}} \)?

A: NO!! This is NOT correct!

We will find that the output noise is typically far greater than that provided by the amplifier gain:

\[
N_{\text{out}} \gg G \, N_{\text{in}}
\]
Q:  Yikes! Does an amplifier somehow amplify noise more than it amplifies other input signals?

A:  Actually, the amplifier cannot tell the difference between input noise and any other input signal. It does amplify the input noise, increasing its magnitude by gain $G$.

Q:  But you just said that $N_{out} \gg G N_{in}$!?!?

A:  This is true! The reason that $N_{out} \gg G N_{in}$ is because the amplifier additionally generates and outputs its own noise signal! This internally generated amplifier noise has an average spectral power density (at the output) of $N_n$.

Thus, the output noise $N_{out}$ consists of two parts: the first is the noise at the input that is amplified by a factor $G$ (i.e., $G N_{in}$), and the second is the noise generated internally by the amplifier (i.e., $N_n$).

Since these two noise sources are independent, the average spectral power density at the output is simply the sum of each of the two components:

$$N_{out} = G N_{in} + N_n$$

Q:  So does this noise generated internally in the amplifier actually get amplified (with a gain $G$) or not?
A: The internal amplifier noise is generated by every resistor and semiconductor element throughout the amplifier. Some of the noise undoubtedly is generated near the input and thus amplified, other noise is undoubtedly generated near the output and thus is not amplified at all, while still more noise might be generated somewhere in the middle and thus only partially amplified (e.g., by 0.35 \( G \)).

However, it does not matter, as the value \( N_n \) does not specify the value of the noise power generated at any point within the amplifier. Rather it specifies the total value of the noise generated throughout the amplifier, as this total noise exits the amplifier output.

As a result, we can model a "noisy" amplifier (and they're all noisy!) as an noiseless amplifier, followed by an output noise source producing an average spectral power density \( N_n \):

\[
N_{out} = G N_{in} + N_n
\]
Note however that this is not the only way we can model internally generated noise. We could alternatively assume that all the internally generated noise occurs near the amplifier input—and thus all this noise is amplified with gain $G$.

\begin{align*}
N_{out} &= G(N_{in} + N_n/G) \\
&= G N_{in} + N_n
\end{align*}

Note here that the noise source near the input of the amplifier has an average spectral power density of $N_n/G$.

It is in fact this model (where the internal noise is assumed to be created by the input) that we more typically use when considering the internal noise of an amplifier!

To see why, recall that we can alternatively express the average SPD of noise in terms of a noise temperature $T$ (in degrees Kelvin):

$$N = kT$$
Thus, we can express the input noise in terms of an **input noise temperature**:

\[ N_{in} = kT_{in} \quad \Rightarrow \quad T_{in} = N_{in}/k \]

or the **output noise temperature** as:

\[ N_{out} = kT_{out} \quad \Rightarrow \quad T_{out} = N_{out}/k \]

Similarly, we can describe the **internal amplifier noise**, when modeled as being generated near the amplifier **input**, as:

\[ \frac{N_n}{G} = kT_e \]

Where noise temperature \( T_e \) is defined as the **equivalent (input) noise temperature** of the amplifier:

\[ T_e = \frac{N_n}{kG} \]

Note this equivalent noise temperature is a **device parameter** (just like gain!)—it tells us how noisy our amplifier is.

Of course, the **lower** the equivalent noise temperature, the **better**. For example, an amplifier with \( T_e = 0 \) \( K \) would produce no internal noise at all!
Specifying the internal amplifier noise in this way allows us to relate input noise temperature $T_{in}$ and output noise temperature $T_{out}$ in a very straightforward manner:

$$T_{out} = G(T_{in} + T_e)$$

Thus, the noise power at the output of this amplifier is:

$$P_n^{out} \approx N_{out} B = kT_{out} B = G k(T_{in} + T_e) B$$