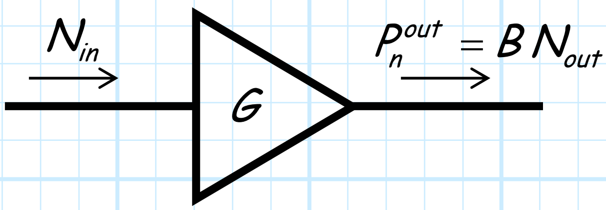
Equivalent Noise Temperature

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

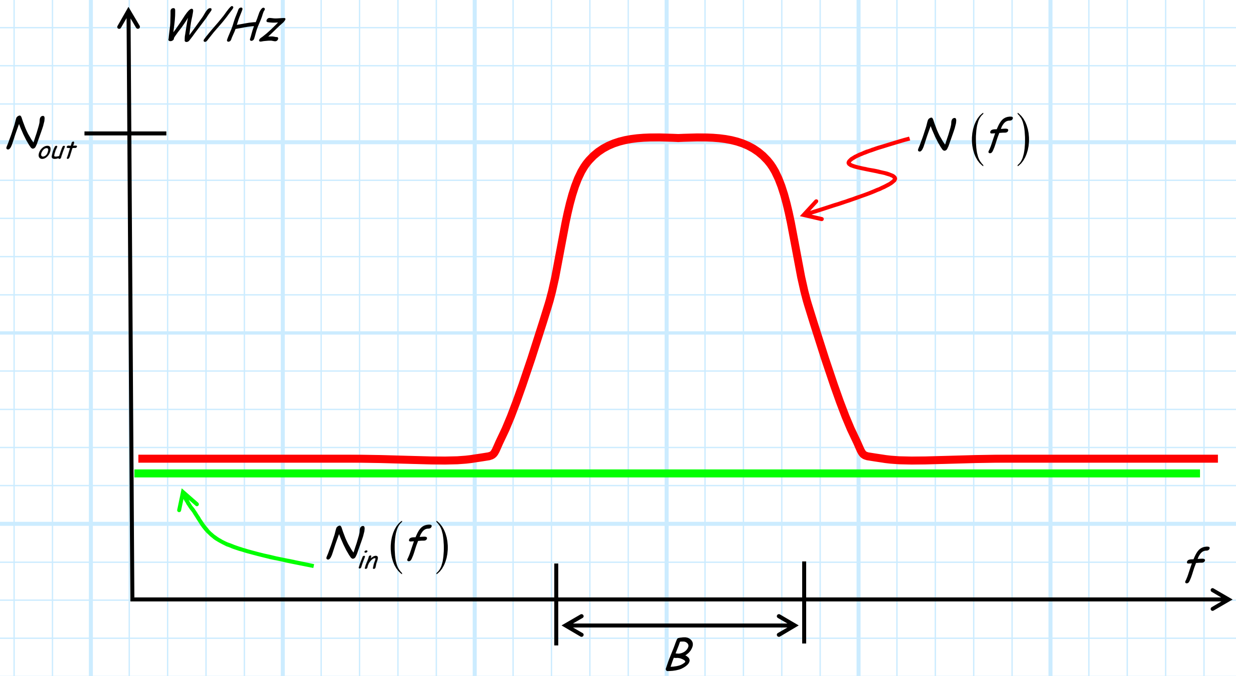
For example, consider an **amplifier** with gain G and bandwidth B:



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:

$$\begin{aligned} P_n^{out} &= \int_0^\infty N(f)\, df \\ &\cong \int_{f_1}^{f_2} N_{out}\, df \\ &= B\, N_{out} \end{aligned}$$

Q: *The amplifier has* ***gain*** *G. So isn't* $N_{out} = G\, N_{in}$*, and thus* $P_n^{out} = G\, B\, N_{in}$ *??*

A: NO!! This is **NOT** correct!

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

$$N_{out} \gg G\, N_{in}$$

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:

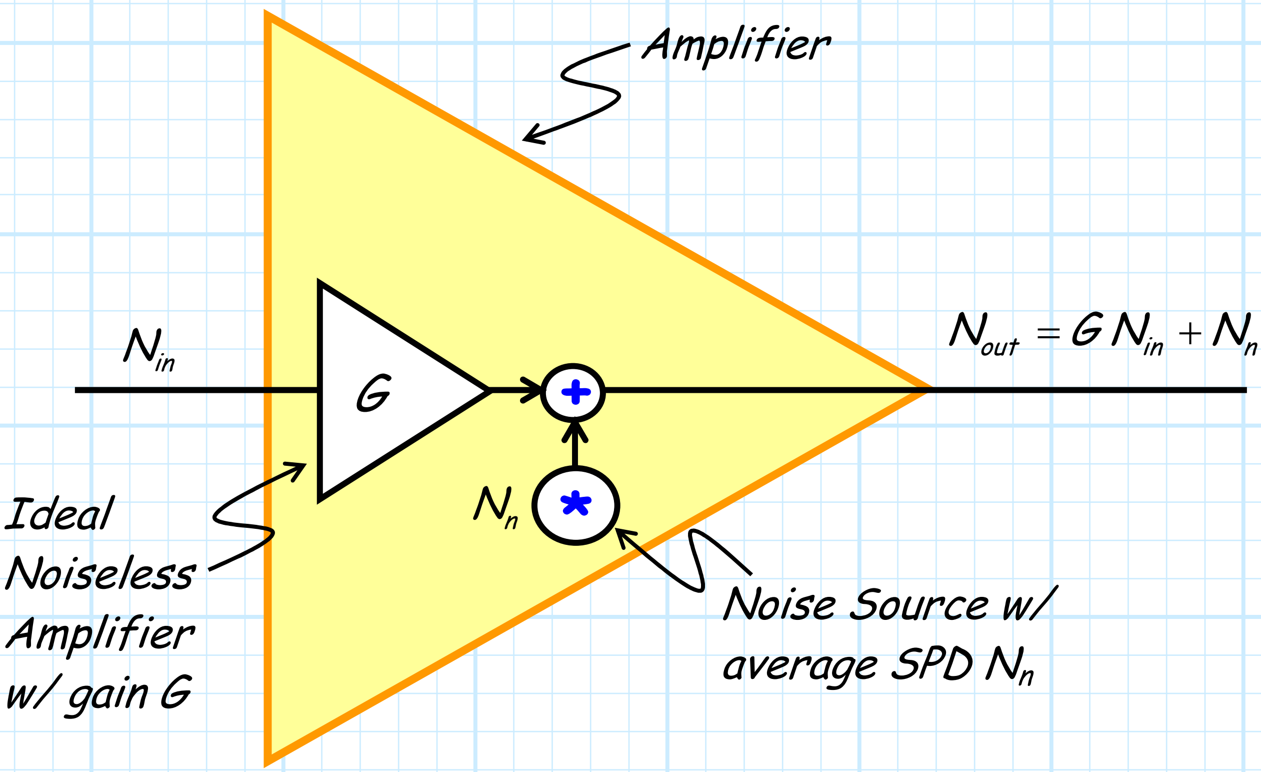
$$N_{out} = G\,N_{in} + N_n$$

Q: *So does this noise generated **internally** in the amplifier actually get **amplified** (with a gain G) or not?*

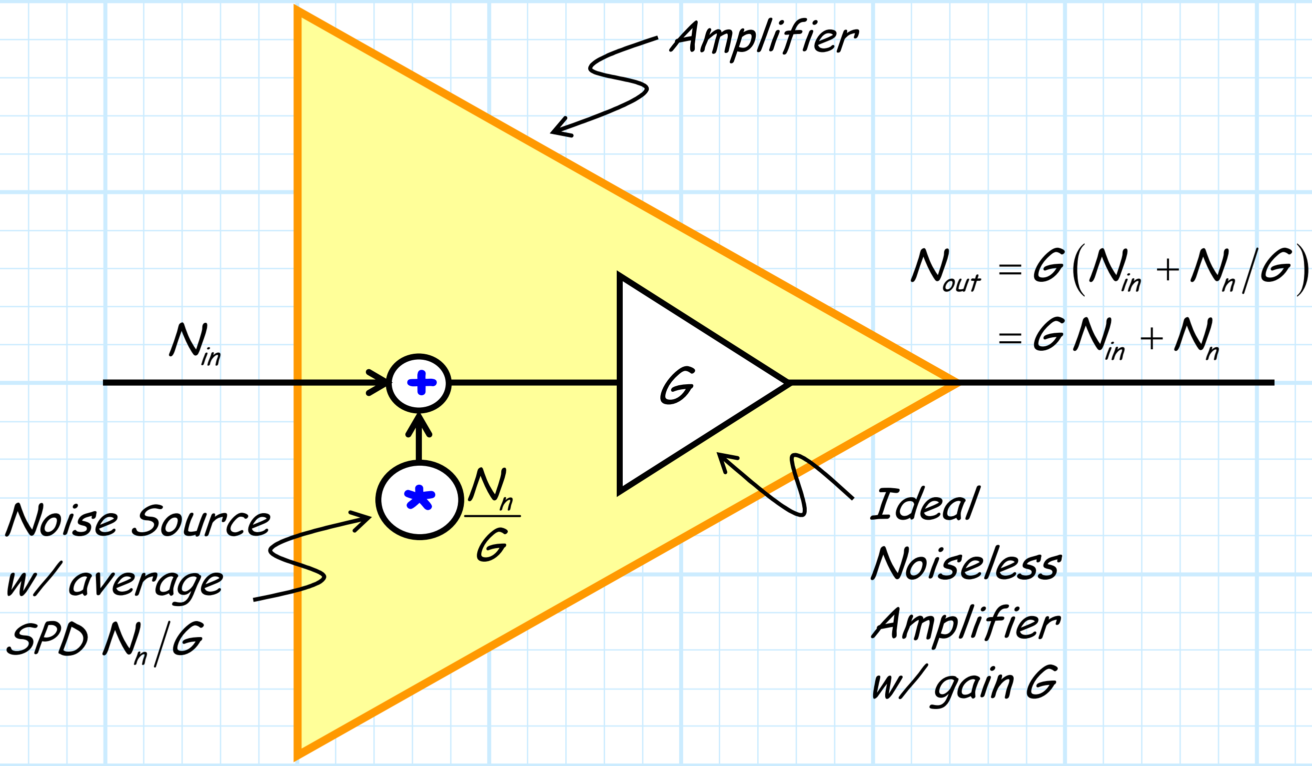
A: The internal amplifier noise is generated by **every** resistor and semiconductor element **throughout** the amplifier. Some of the noise undoubtedly is generated near the **input** and thus **amplified**, other noise is undoubtedly generated near the **output** and thus is **not** amplified at all, 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:



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!



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**:

$$N_{in} = kT_{in} \quad \Rightarrow \quad T_{in} \doteq N_{in}/k$$

or the **output noise temperature** as:

$$N_{out} = kT_{out} \quad \Rightarrow \quad T_{out} \doteq N_{out}/k$$

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

$$\frac{N_n}{G} = kT_e$$

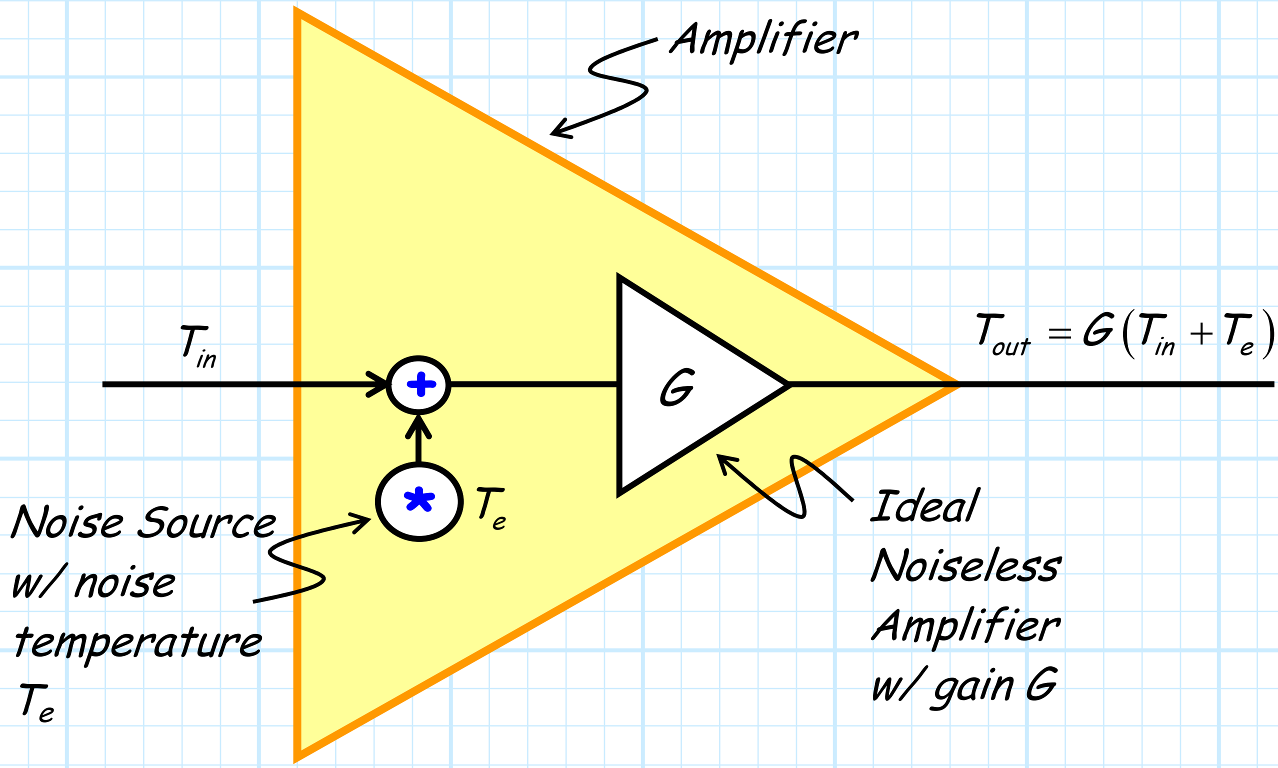
Where noise temperature T_e is defined as the **equivalent (input) noise temperature** of the amplifier:

$$T_e \doteq \frac{N_n}{kG}$$

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 $T_e = 0\ K^{\circ}$ 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:



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

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

$$\begin{aligned} P_n^{out} &\approx N_{out}\, B \\ &= k T_{out}\, B \\ &= G\, k\left(T_{in} + T_e\right) B \end{aligned}$$