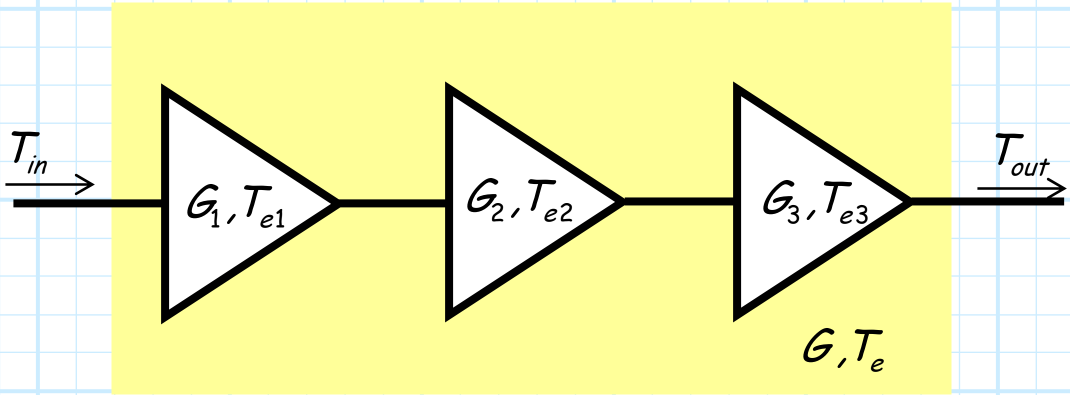
System Equivalent Noise Temperature

Say we **cascade** three microwave devices, each with a different **gain** and **equivalent noise temperature**:



These three devices together can be thought of as **one** new microwave device.

Q: *What is the equivalent noise temperature T_e of this* ***overall*** *device?*

A: First of all, we must **define** this temperature as the value T_e such that:

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

or specifically:

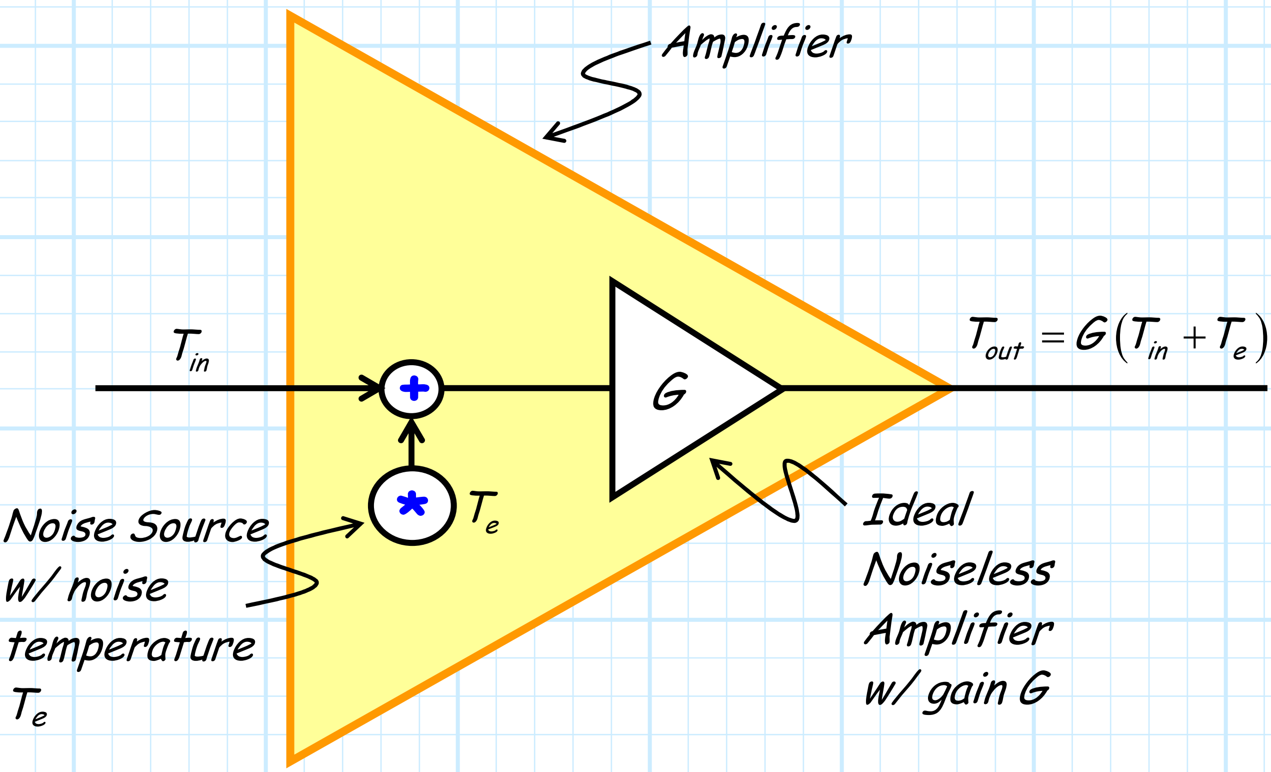
$$T_e = \frac{T_{out}}{G} - T_{in}$$

Q: *Yikes! What is the value of G ?*

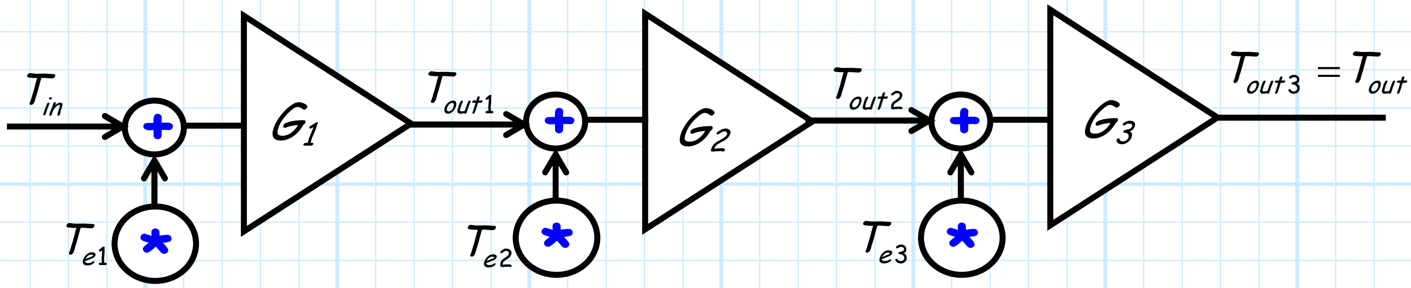
A: The value G is the **total system gain**; in other words, the overall gain of the three cascaded devices. This gain is particularly easy to determine, as is it simply the **product** of the three gains:

$$G = G_1 G_2 G_3$$

Now for the **hard part**! To determine the value of T_{out} , we must use our **equivalent noise model** that we studied earlier:



Thus, we cascade three **models**, one for each amplifier:



We can **observe** our model and note three things:

$$T_{out1} = G_1 \left(T_{in} + T_{e1} \right)$$

$$T_{out2} = G_1 \left(T_{out1} + T_{e1} \right)$$

$$T_{out3} = G_1 \left(T_{out2} + T_{e1} \right)$$

Combining these three equations, we find:

$$T_{out3} = G_1 G_2 G_3 \left(T_{in} + T_{e1} \right) + G_2 G_3 \left(T_{e2} \right) + G_3 \left(T_{e3} \right)$$

a result that is likewise **evident** from the model.

Now, since $T_{out} = T_{out3}$, we can determine the **overall** (i.e., system) equivalent noise temperature T_e:

$$\begin{aligned} T_e &= \frac{T_{out}}{G} - T_{in} \\ &= \frac{G_1G_2G_3\left(T_{in}+T_{e1}\right)+G_2G_3\left(T_{e2}\right)+G_3\left(T_{e3}\right)}{G_1G_2G_3} - T_{in} \\ &= T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1G_2} \end{aligned}$$

Moreover, we will find if we cascade an N number of devices, the overall noise equivalent temperature will be:

$$T_e = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1G_2} + \frac{T_{e4}}{G_1G_2G_3} + \cdots + \frac{T_{eN}}{G_1G_2G_3\cdots G_{N-1}}$$

I assume that you can use the above equation to get the correct answer—but I want to know if you understand **why** your answer is correct!

Make sure **you** understand where this expression comes from, and what it means.

Look closely at the above expression, for it tells us something very **profound** about the noise in a complex microwave system (like a receiver!).

Recall that we want the equivalent noise temperature to be as **small** as possible. Now, look at the equation above, **which** terms in this summation are likely to be the **largest**?

* Assuming this system has large gain *G*, we will find that the **first** few terms of this summation will **typically dominate** the answer.

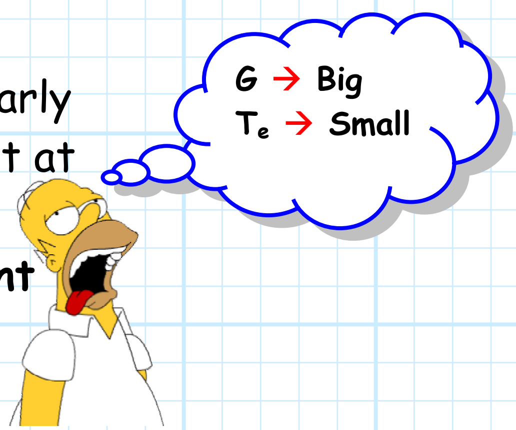
* Thus, it is evident that to make T_e as small as possible, we should start by making the **first term** as small as possible. Our **only** option is to simply make T_{e1} as small as we can.

* To make the **second** term small, we could likewise make T_{e2} small, but we have **another** option!

→ We could likewise make gain G_1 **large!**

Note that making G_1 large has **additional** benefits, as it likewise helps minimize **all** the other terms in the series!

Thus, good receiver designers are particularly careful about placing the proper component at the **beginning** of a receiver. They **covet** a device that has **high gain** but **low equivalent noise temperature** (or noise figure).



→ The ideal **first** device for a receiver is a **low-noise amplifier**!

Q: *Why **don't** the devices at the **end** of the system make much of a difference when it comes to noise?*

A: Recall that each microwave device **adds** more noise to the system, As a result, noise will generally **steadily increase** as it moves through the system.

* By the time it reaches the end, the noise power is typically **so large** that the additional noise generated by the devices there are **insignificant** and make **little** increase in the overall noise level.

* Conversely, the noise generated by the **first** device is amplified by **every** device in the overall system—this first device thus typically has the **greatest** impact on system noise temperature and system noise figure.