Signals & Noise

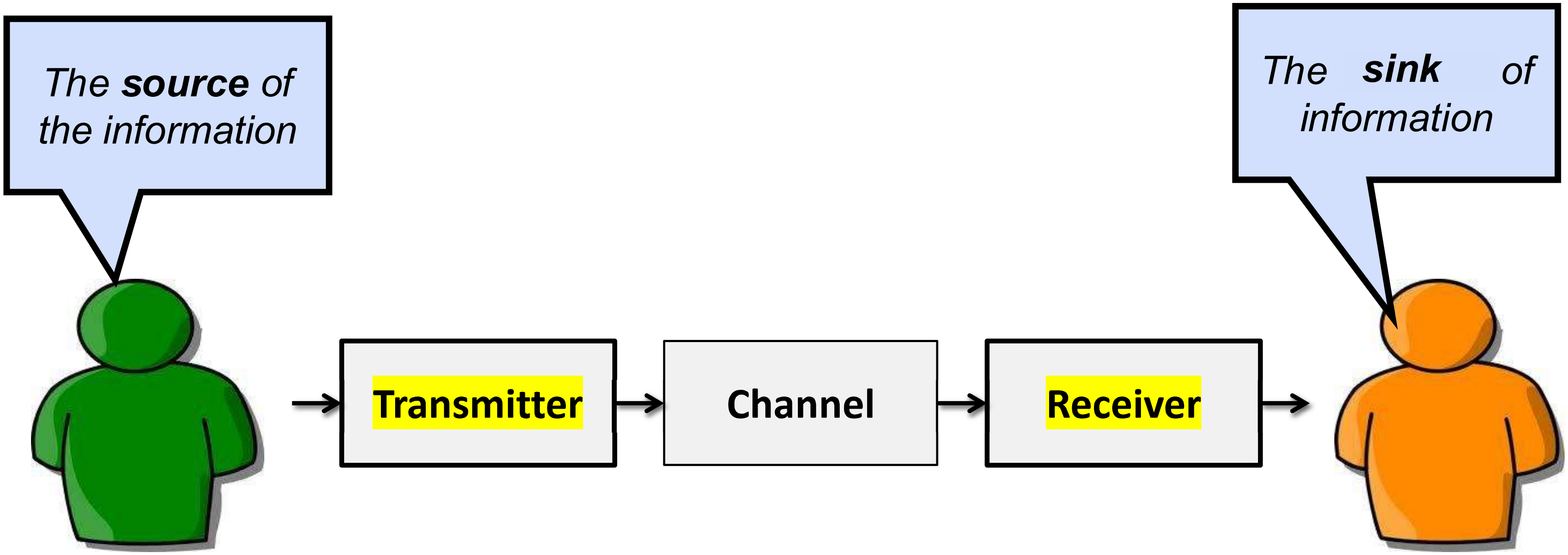
Wireless Communication Systems

In wireless communications, an antenna at the transmitter radiates the electromagnetic waves, which travel through the space and reach the receiving antenna. Two important points:

1) When radio waves travel, they lose a lot of power. That means we need to do two things:
    - When we transmit, **we must use a lot of power**.
    - When we receive, **we must handle a very, very small signal**.

2) In wireless communication systems, the most common form of signal degradation comes in the form of additive **noise** (external and internal).

Block Diagram of Communication System



When we transmit, **we must use a lot of power**:

- *Power Amplifier (PA)*

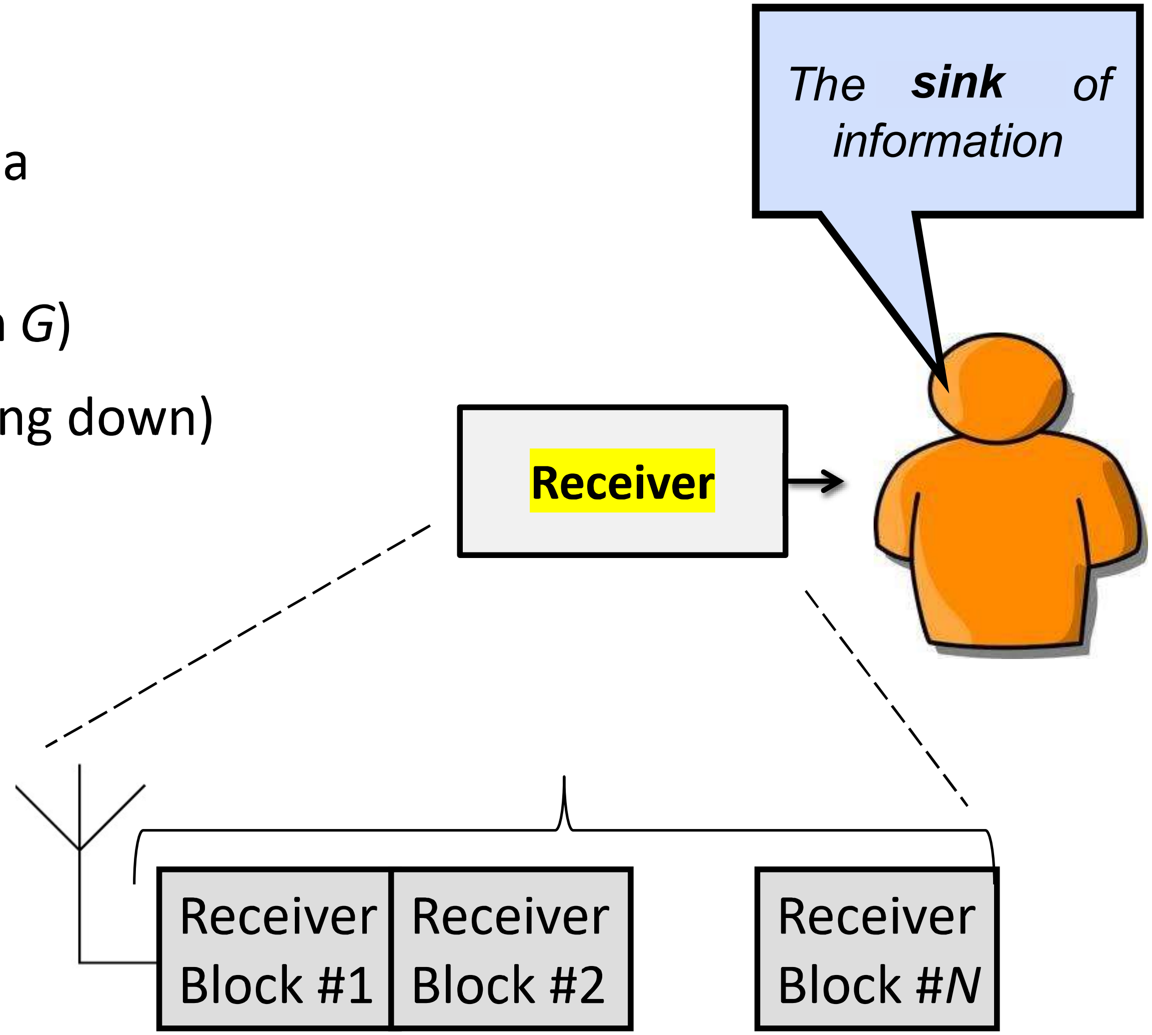
When we receive, **we must handle a very, very small signal**:

- *Low Noise Amplifier (LNA)*

Receiver Block

The typical functions of blocks in a telecommunication system are:

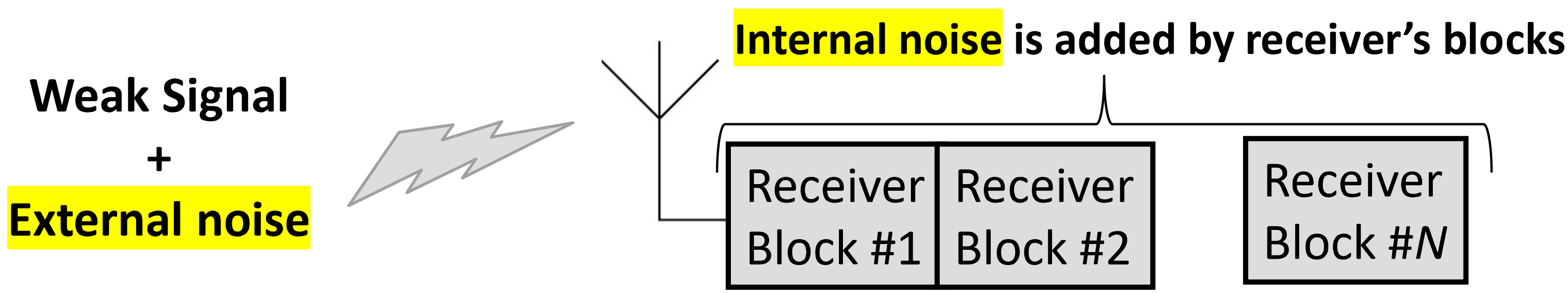
- Amplify (scaling up by a gain *G*)
- Filter (normally a slight scaling down)
- Frequency shifting



Receiver – Internal noise sources

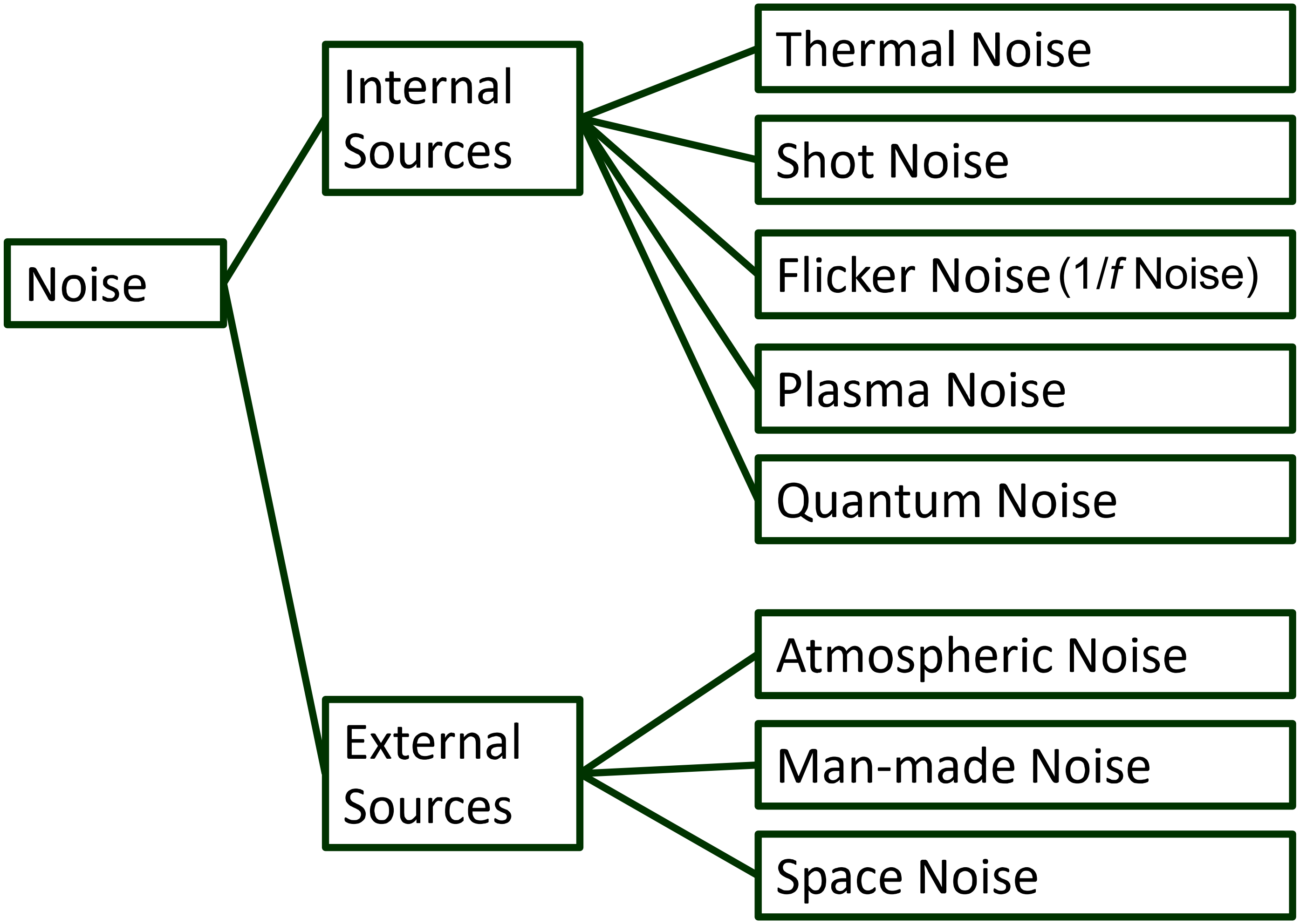
When designing a receiver, there are a couple of characteristics worth noting:

- the received signal is generally very weak
- the channel has added noise to the incoming signal (external noise)
- all electronics add noise to the signals (internal noise)



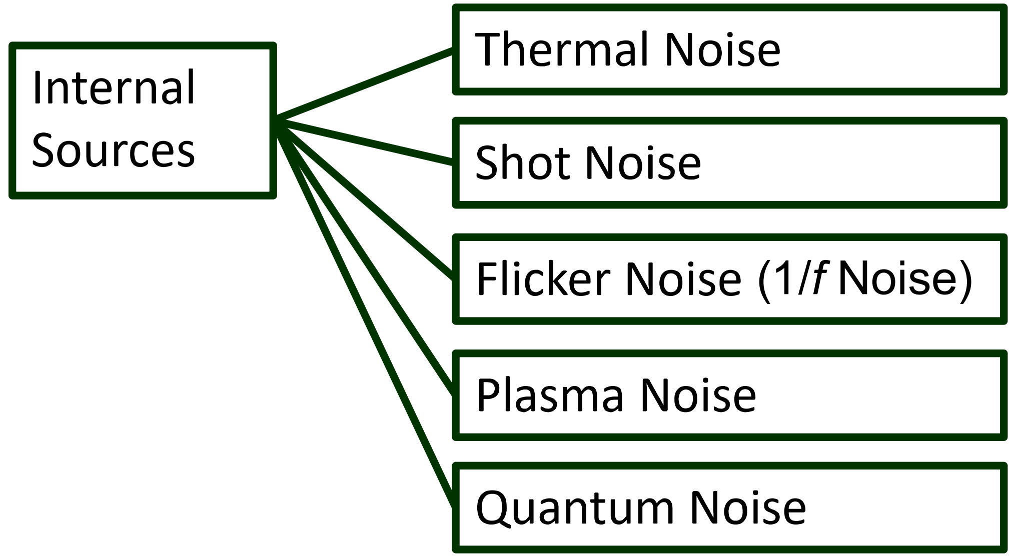
Noise power in a receiver will be introduced from the external environment through the receiving antenna, as well as generated internally by the receiver circuitry.

Noise sources classification



Receiver – Internal noise sources

Noise that is generated internally in a device or component is usually caused by random motions of charges or charge carriers in devices and materials.



Thermal noise: Caused by the thermal motion of charges.

Flicker noise: Occurs in solid-state devices and vacuum tubes with power inversely proportional to the frequency of operation.

Shot noise: Caused due to random fluctuations of charge carriers in an electron-tube or solid-state device. It is a result of the discrete nature of charge carriers.

Plasma noise: Caused due to random motion of charge carriers in an ionized gas, like the plasma, ionosphere, or sparkling electrical contacts.

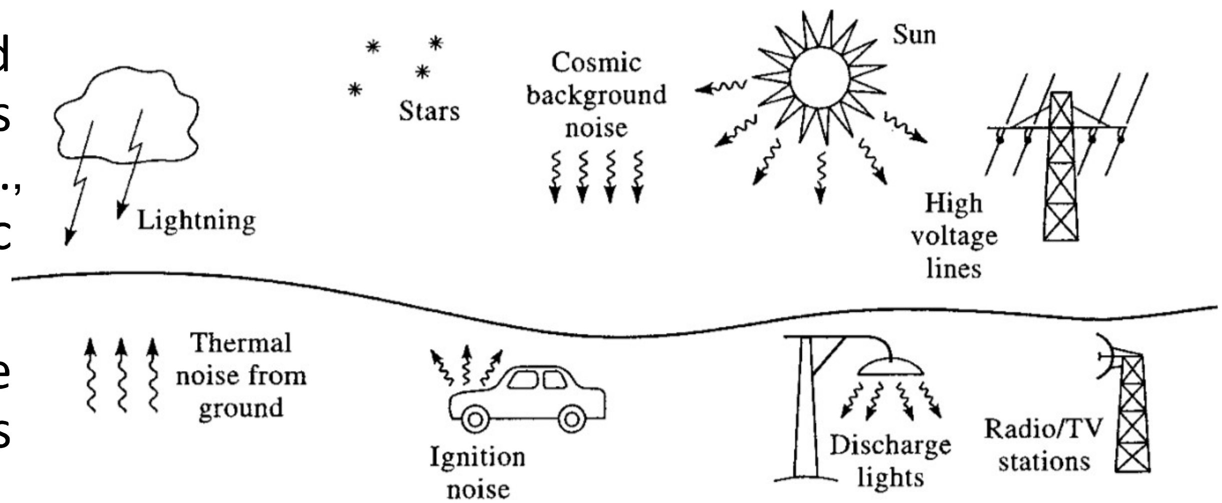
Quantum noise: Results from quantized nature of charged carriers and photons; negligible relative to other sources of noise.

Receiver – External noise sources

External Sources
- Atmospheric Noise
- Man-made Noise
- Space Noise

Atmospheric noise: It is produced by naturally occurring disturbances in the Earth's atmosphere, e.g., lighting discharges, electrostatic discharges.

Space noise: It is generated by the Sun (solar noise) and the stars (cosmic noise).



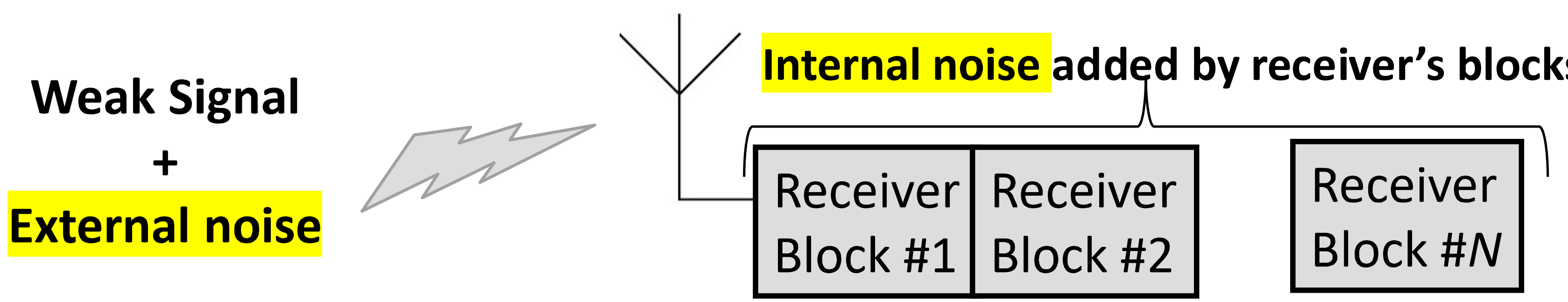
Man-made noise: Noise which is caused by equipment manufactured by man such as power lines, electric motors, fluorescent lights, engine ignition systems.

Signal-to-Noise Ratio (SNR)

The most common power ratio in communications is the ratio of signal power to noise power. This is called the ***signal-to-noise ratio (SNR)*** and is given by:

$$SNR = \frac{P_{signal}}{P_{noise}} \qquad\qquad SNR = 10\log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) \quad dB$$

SNR is a very important measure of **receive signal quality** since noise is the major cause of unwanted effects (e.g., noisy sound on the radio, data errors in digital systems).



Signal-to-Noise Ratio (SNR)

$$SNR = \frac{P_{signal}}{P_{noise}} \qquad SNR = 10\log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) \quad dB$$

The stronger the signal and the weaker the noise, *the higher the SNR ratio*.

If the signal is weak and the noise is strong, the SNR ratio will be low and the reception will be unreliable.

<u>If SNR is less than 1, the dB value will be negative and the noise will be stronger than the signal!</u>

The noise level sets the lower limit on the strength of a signal that can be detected in the presence of the noise in a system.

SNR: A simple Example

If the signal power is 5 µW and the noise power is 125 nW, SNR is:

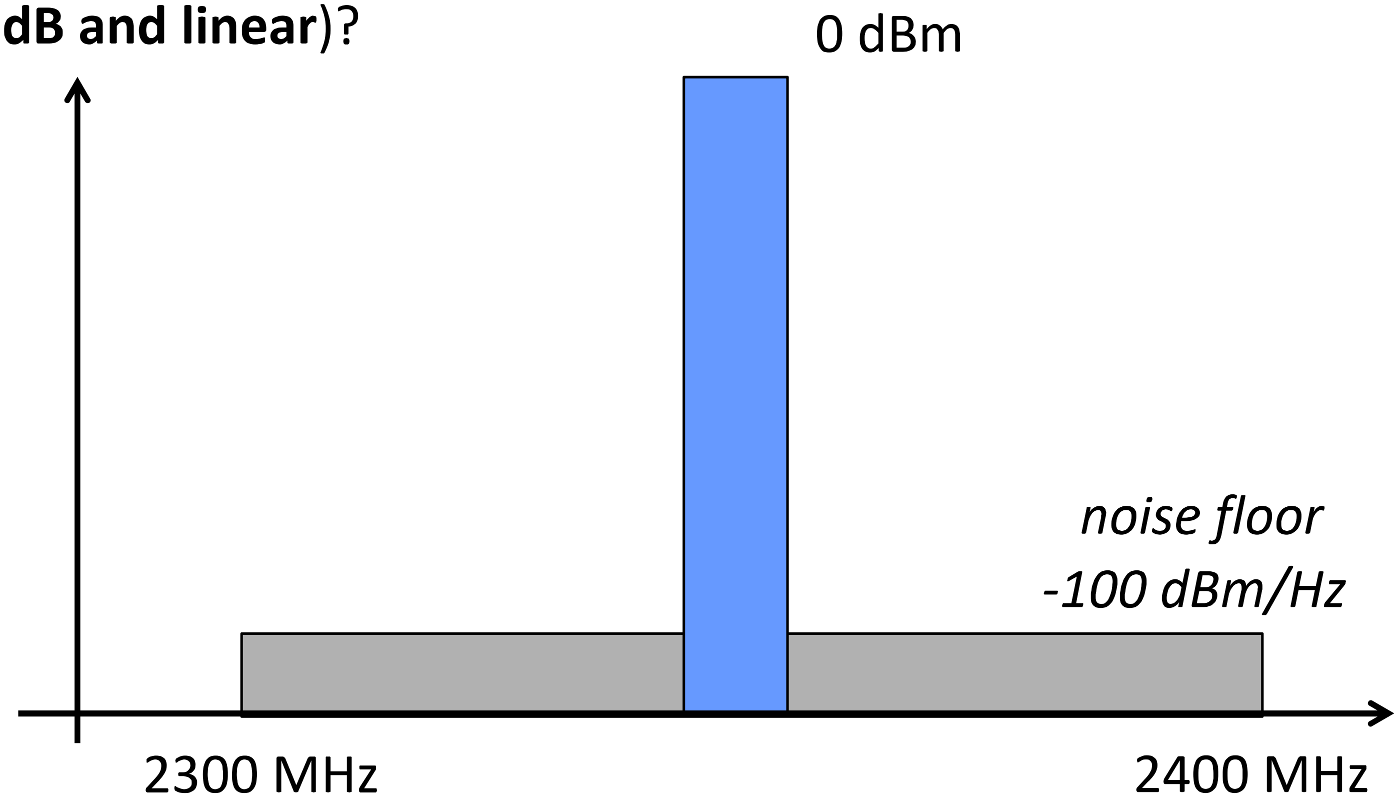
$$SNR = \frac{P_S}{P_N} = \frac{5 * 10^{-6}}{125 * 10^{-9}} = 40$$

SNR can be converted to decibels as follows:

$$dB = 10 * log10\left(\frac{P_S}{P_N}\right) = 10 * log10(40) = 16\text{ dB}$$

SNR: Another Example

My receiver sees the following radio bandwidth* (total bandwidth is 100 MHz). The noise floor is uniform and is at a level of -100 dBm/Hz. We receive a message signal of 5 MHz bandwidth * with a total power level of 0 dBm. What is the SNR (**in dB and linear**)?



**Bandwidth is the difference between the upper and lower frequencies in a continuous band of frequencies*.

SNR Calculation - An Example

Solution in dB

The main signal over 5 MHz is 0 dBm (P_{sig}=0 dBm)

The noise signal is -100 dBm/Hz, which over 100 MHz, means that it is equal to:

$P_{noise}/Hz = (10^{(-100/10)})/1000 = 10^{-13}$ W/Hz

$P_{noise} = 10^{-13}$ W/Hz * 100,000,000 Hz = 0.00001 **Watt**

P_{noise} = 10*log10(0.00001*1000)=-20 **dBm**

The SNR is therefore:

$P_{sig} - P_{noise} = 0 - (-20) = 20$ dB

SNR Calculation - An Example

Solution in linear

The main signal is 0 dBm over 5 MHz, which means that it is equal to

$P_{sig} = (10^{(0/10)})/1000 = 0.001$ **Watt**

The noise signal is -100 dBm/Hz, which over 100 MHz, means that it is equal to

$P_{noise}/Hz = 10^{(-100/10)}/1000 = 10^{-13}$ W/Hz

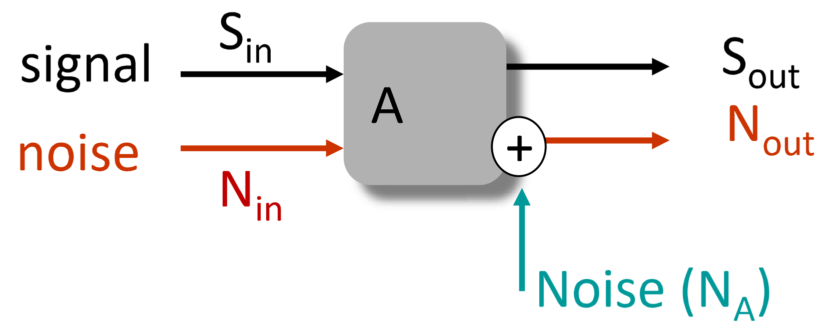
$P_{noise} = 10^{-10}$ mW/Hz * 100,000,000 Hz=0.00001 **Watt**

The SNR is therefore

$P_{sig}/P_{noise} = 0.001/(0.\ 00001) = 100$

Noise Analysis

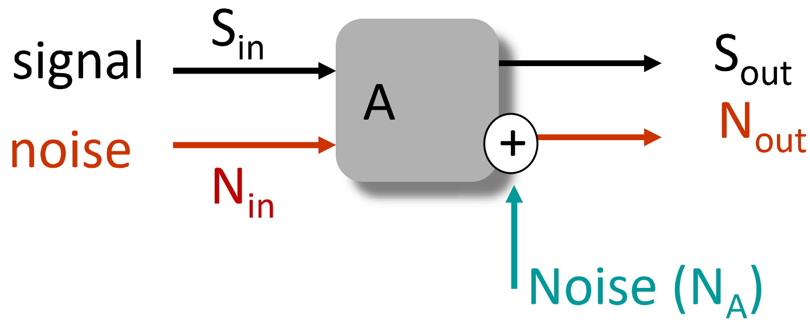
There is another way to describe how noise gets added into a system… this is just different terminology but it is widely used: the **noise figure.**



The **noise figure** of a component (for example an amplifier) is a measure of the degradation in the signal-to-noise ratio between the input and output of the component.

- When noise and a desired signal are applied to the input of a *noiseless network*, both noise and signal will be attenuated or amplified by the same factor, so that the signal-to-noise ratio will be unchanged.
- However, if the *network is noisy*, the output noise power will be increased more than the output signal power, so that the output signal-to-noise ratio will be reduced.

Noise Analysis



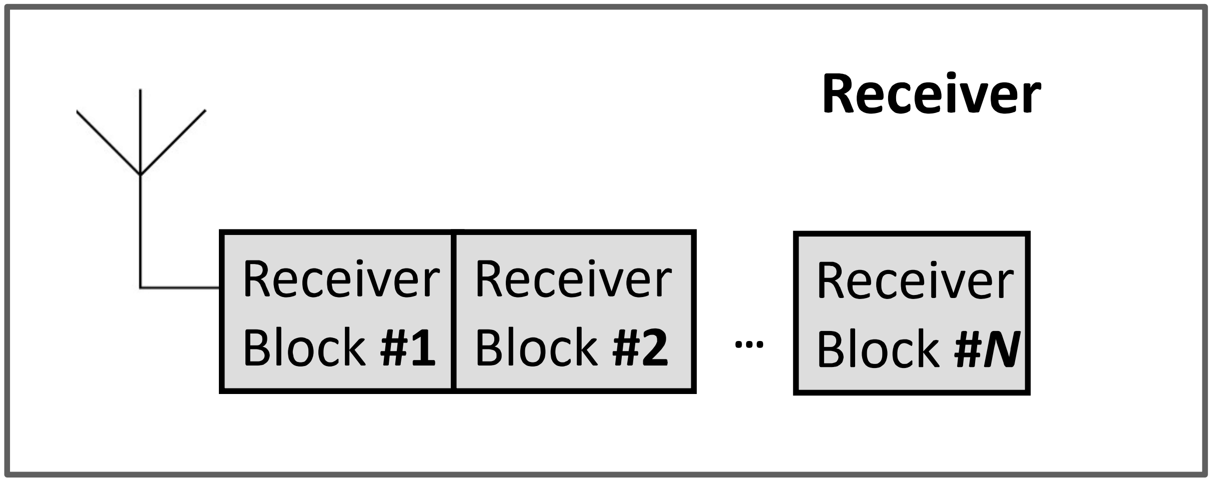
The **Noise Factor (F)** of a block is a measure of the degradation of the SNR caused by the noise added by that block.

$$F = \frac{SNR_{in}}{SNR_{out}}$$

The **Noise Figure (NF)** is the dB expression of the Noise Factor.

$$NF = 10\log_{10}(F) = 10\log_{10}\left(\frac{SNR_{in}}{SNR_{out}}\right)$$

Noise Analysis

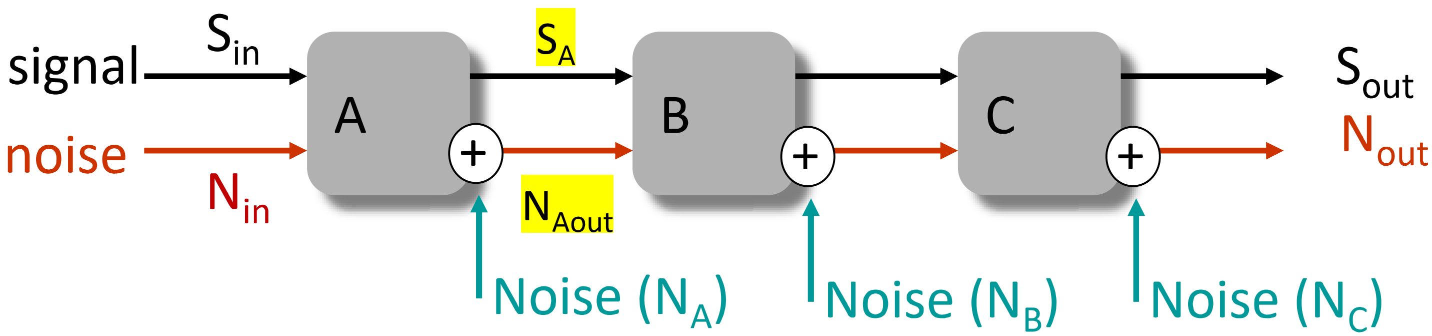


In a typical receiver system **the input signal travels through a cascade of many different components** or blocks of components, each of which may degrade the signal-to-noise ratio to some degree.

If we know the noise figure of the individual stages, we can determine the noise figure of the cascade connection of stages.

Noise Analysis

Imagine each block adds a certain amount of **gain**, let's calculate the change in SNR:

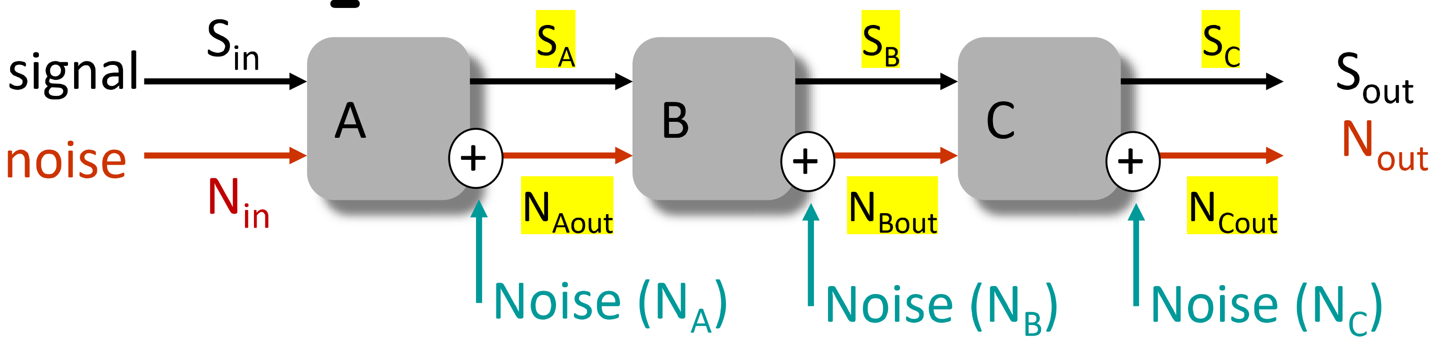


At the input of block **A**, the signal contains both the "desired signal" and the "unwanted noise". There is no way to separate them and so both get amplified. However the process of amplification adds some noise which must be added to the noise term. So at the output of A we get:

$$S_A = G_A S_{in}$$

$$N_{Aout} = G_A N_{in} + N_A$$

Noise Analysis



$$S_A = G_A S_{in}$$

$$N_{Aout} = G_A N_{in} + N_A$$

$$SNR_A = \frac{G_A S_{in}}{G_A N_{in} + N_A} = \frac{S_{in}}{N_{in} + \left(N_A / G_A \right)}$$

$$S_B = G_A G_B S_{in}$$

$$N_{Bout} = G_A G_B N_{in} + G_B N_A + N_B$$

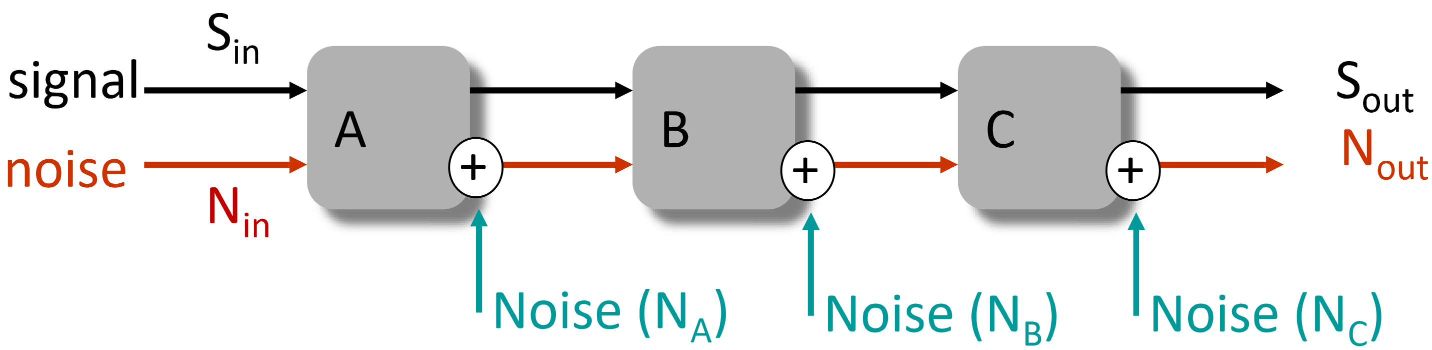
$$SNR_B = \frac{S_{in}}{N_{in} + \left(N_A / G_A \right) + \left(N_B / G_A G_B \right)}$$

$$S_C = G_A G_B G_C S_{in}$$

$$N_{Cout} = G_A G_B G_C N_{in} + G_B G_C N_A + G_C N_B + N_C$$

$$SNR_C = \frac{S_{in}}{N_{in} + \left(N_A / G_A \right) + \left(N_B / G_A G_B \right) + \left(N_C / G_A G_B G_C \right)}$$

Noise Analysis



$$SNR = \frac{S_{in}}{N_{in} + \left({N_A}/{G_A}\right) + \left({N_B}/{G_A G_B}\right) + \left({N_C}/{G_A G_B G_C}\right)}$$

Noise will be introduced at each stage. The SNR **will always get worse**.

However the impact of the noise is divided by the gain of the preceding stages. *So it is critically important that we introduce as much gain as possible as soon as possible while adding the smallest amount of noise.*

Example

We want to transmit a signal with power of 24 dBm at 5.8 GHz. At the transmitter, the signal is amplified by a factor of four. What is the power of the ideal signal as it leaves the transmitter (in dBm)?

Due to losses during transmission, the signal is attenuated by 15 dB.
What is the power of the ideal signal as it reaches the receiver?

At the receiver there is noise of -18 dBm. Calculate the power (in mW) of the combined signal at the receiver (noise + ideal).

What is the SNR (in dB) at the receiver ?

Example - Answer

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Answer

- 30 dBm of power leaves the transmitter
- The ideal signal at the receiver is 15 dBm
- ideal + noise signal at the receiver is $31.64\ mW$
- SNR in dB = 33