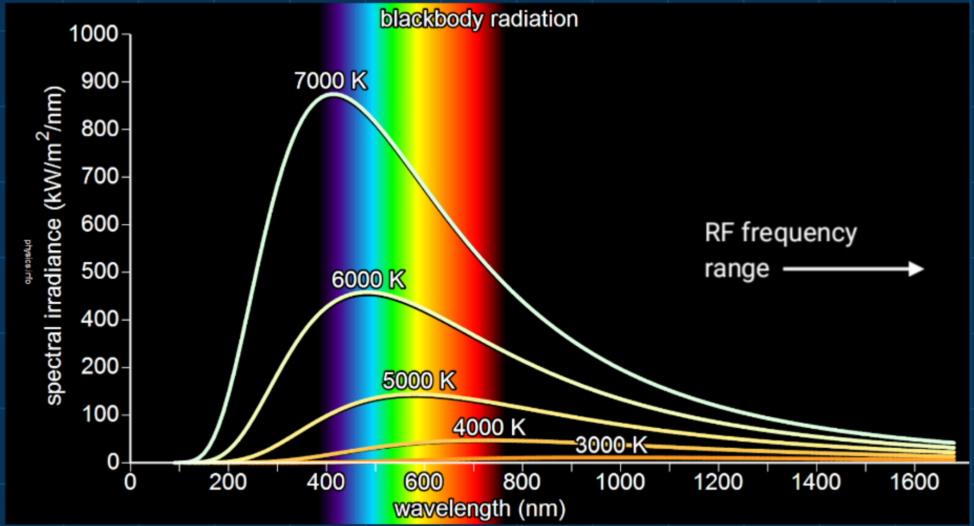
Noise

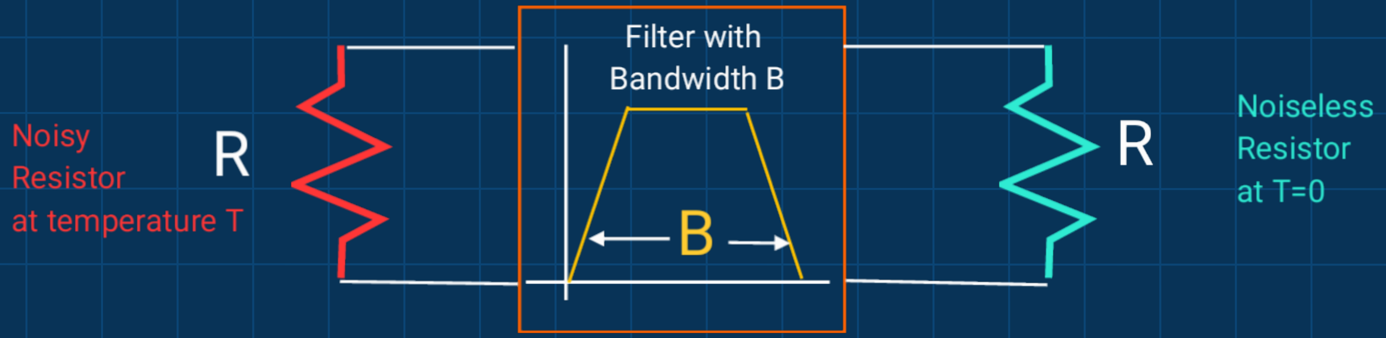
Thermal Noise

Consider a resistor at a temperature T. It will produce photons over a broad spectrum, including the RF frequency range



Band Limited Noise

- Connect a filter with bandwidth B to the hot noisy resistor.
- To collect the noise from the resistor, the filter must be terminated with a matched impedance equal to the source
- Imagine that the matched load is noiseless (ie. at T=0)



Band Limited Noise

From thermodynamics, energy will be transfered from the hot resistor to the cold resistor at an average rate of:

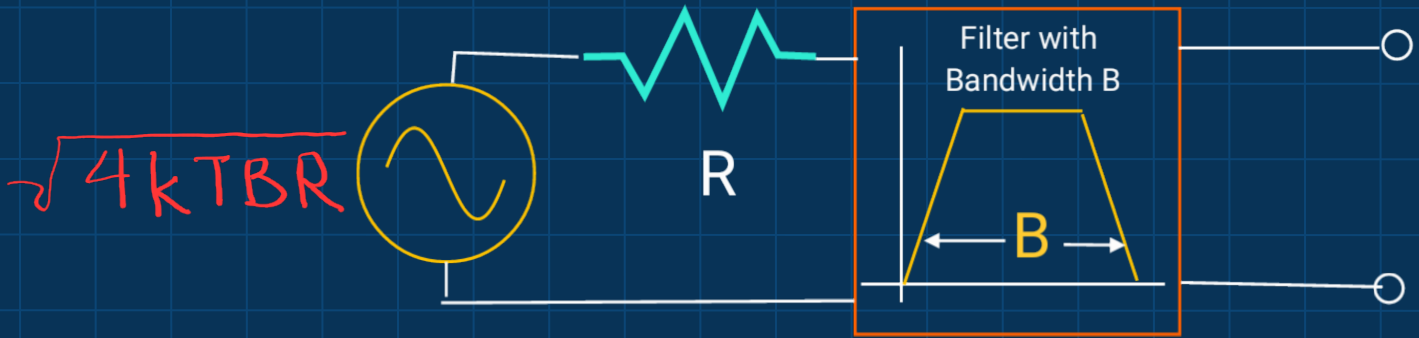
$$\langle P \rangle = kTB$$

$$k = 13.6 \times 10^{-24}\ \mathrm{W/K/Hz}$$

Why not just make R small and have no noise power?
Because to match the source to get the maximum power transfer, the load resistor would have to be made small so you cannot win.

Noise Circuit Model

An equivalent circuit model for the noisy resistor is:



The available noise power density from a resistor is.

$$\boxed{S(f) = kT}$$

No matter what the value of the resistance is!

Noise Power Spectral Density

At T=293K (20C)

$$\boxed{S = 4 \times 10^{-21}\ W/Hz}$$

$$\boxed{S_{dBm} = 10 \log_{10}\left(\frac{4 \times 10^{-21}\ W}{0.001\ W}\right) = -174\ dBm}$$

Easy to remember

$$\boxed{S = -174\ dBm \text{ "per Hz" at Room Temperature}}$$

Noise Power Spectral Density

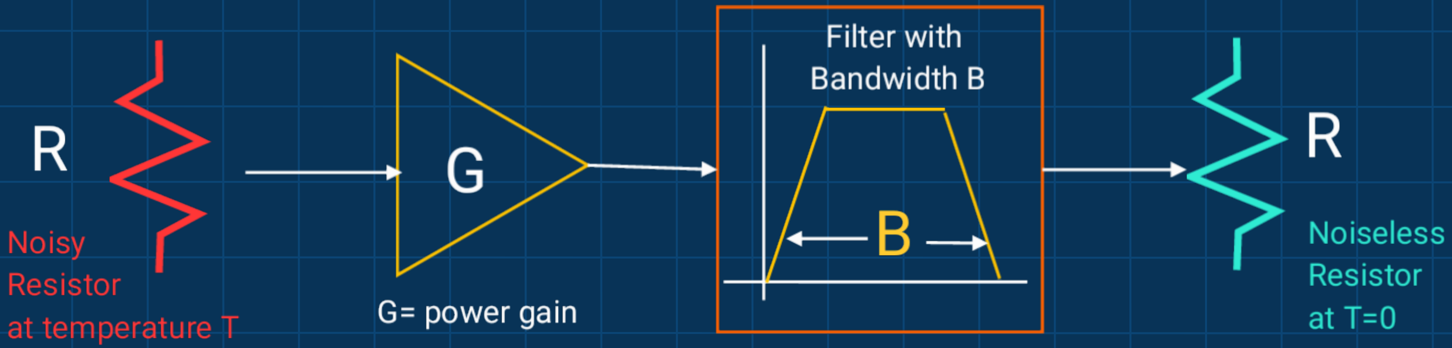
So for a bandwidth of 1 MHz at 293K

$$P_{noise} = -174\,dBm + 10\log_{10}\left(\frac{1\,MHz}{1\,Hz}\right) = -114\,dBm$$

So for a bandwidth of 1 MHz at 77K

$$P_{noise} = -114\,dBm + 10\log_{10}\left(\frac{77K}{293K}\right) \approx -120\,dBm$$

Noise in an Amplifier



A real amplifier will add noise.

For an amplifier, we <u>always</u> define the noise as measured on the output but refered to the input.

$$\boxed{P_o = G(kT_r + S_A)B}$$

Effective Noise Temperature

We can say that the amplifier has an effective noise temperature

$$T_A = S_A / k$$

$$P_o = G(kT_r + kT_A)B$$

We define the noise figure as the ratio:

$$N_f = \frac{T_A + 293K}{293K}$$

Examples

Example 1: An amplifier with a noise figure of 1 dB, what is the noise temperature of the amplifier?

$$1\,dB \Rightarrow 1.26$$

$$T_A = (1.26-1)\,293K = 76\,K$$

Example 2: An passive attenuator of reduces the power by a factor of A. What is the noise figure of the attenuator?

$$P_{out} = \frac{1}{A}\left(kT_A + kT_0\right)B = kT_0B \leftarrow \text{passive}$$

$$N_f = A$$

Examples

Example 3: The noise floor of a spectrum analyzer measured with its input terminated into 50 ohms is -90dBm at a resolution bandwidth of 1MHz.

a). What is the noise figure of the SA

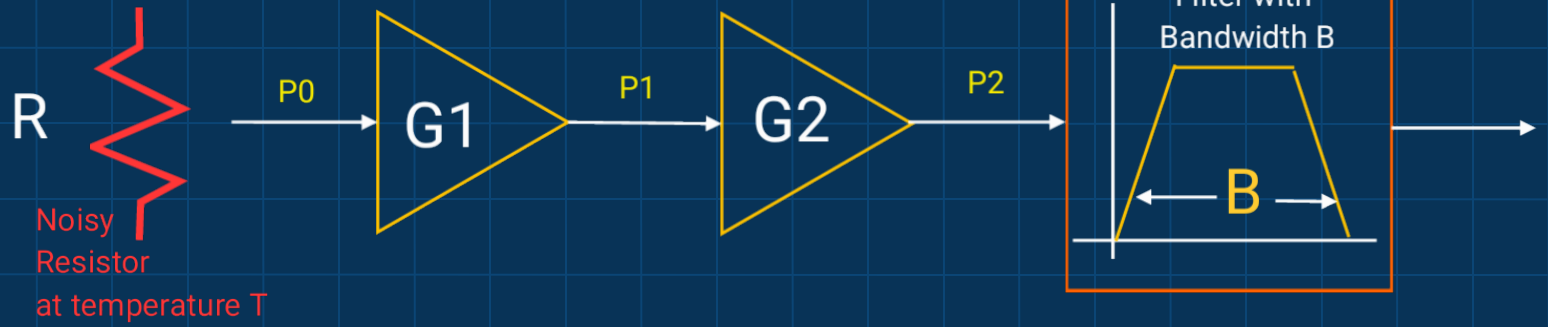
b.) What is the noise temperature?

$$S = -90\,\text{dBm} - 60\,\text{dB} = -150\,\text{dBm/Hz}$$

$$N_f \approx -150\,\text{dB} + 174\,\text{dB} = 24\,\text{dB}$$

$$T \approx 73{,}000\ \text{K}$$

Noise Figure of Systems



$$P_1 = G_1 (kT_0 + kT_{A1}) B$$

$$P_2 = G_1 G_2 (kT_0 + kT_{A1}) B + G_2 kT_{A2} B$$

Noise Figure of Systems

$$N_{F_{Total}} = \frac{P_2}{G_1 G_2} \frac{1}{kT_0} = N_{f_1} + \frac{1}{G_1}\left(N_{f_2} - 1\right)$$

If there was a third amplifier

$$N_{F_{Total}} = N_{f_1} + \frac{1}{G_1}\left(N_{f_2} - 1\right) + \frac{1}{G_1 G_2}\left(N_{f_3} - 1\right)$$

Noise figure of a system is dominated by the first element