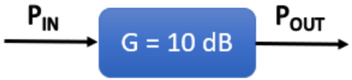
ECE 113: Communication Electronics

Meeting 2: Noise in Communication System

January 18, 2019

Dynamic Range

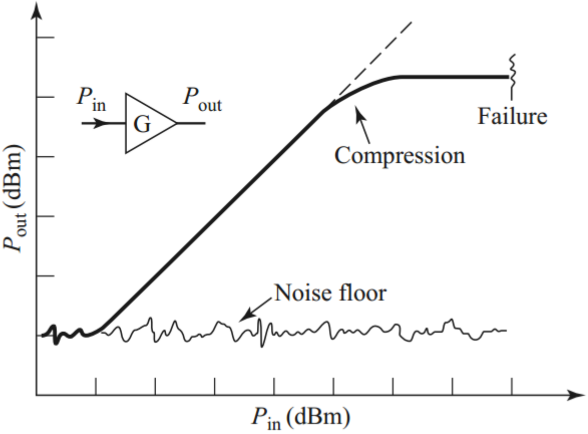
Consider an amplifier having a gain ($G_{dB} = 10dB$)



- Ideally ($P_{out} = G * P_{in}$)
- Reallistically ($P_{out} \neq G * P_{in}$)
  - $P_{out} \neq 0$ when $P_{in} = 0$ due to non-zero noise power
  - $P_{out} \neq G * P_{in}$ for very large P_{in} due to saturation of nonlinear devices

Dynamic Range

Range of signal Levels over which linear relationship between input and output is valid

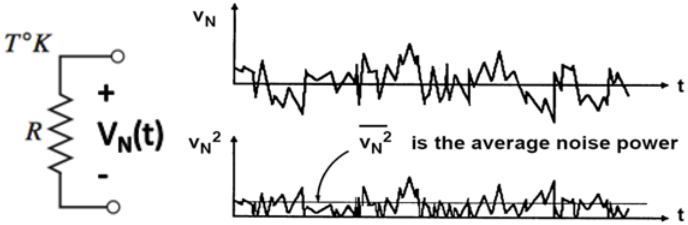


Electronic Noise

- Caused by random motion of charges in devices and materials
- Various sources of noise
  - Thermal Noise (Johnson or Nyquist Noise)- caused by thermal vibration of bound charges
  - Shot Noise - applicable to electron tube and solid-state devices
  - Flicker Noise - $\frac{1}{f}$ noise that occurs in most electronic devices
  - Plasma Noise, Quantum Noise, etc.

Thermal Noise in Resistors

Consider a resistor at a temperature (T) degrees Kelvin (K).



- Planck's black body radiation law.

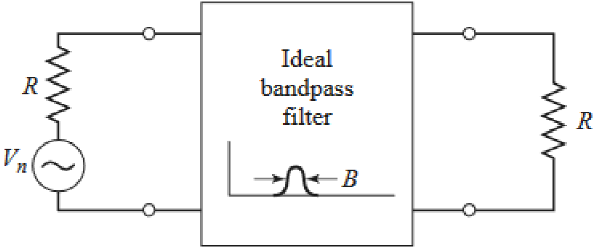
$$v_n = \sqrt{\frac{4hfBR}{e^{hf/kT} - 1}}$$

Thermal Noise at RF

- At microwave frequencies, $hf << kT$.

$$v_n = \sqrt{4kTBR} \qquad \textit{Rayleigh-Jeans approximation}$$

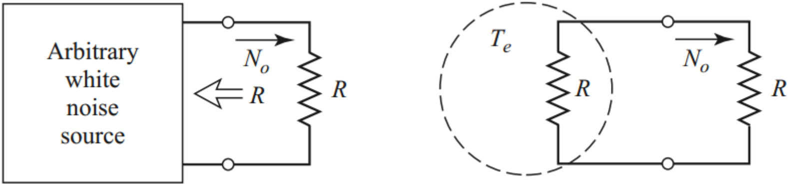
- Equivalent circuit for a noisy resistor



$$P_n = kTB$$

Equivalent Noise Temperature

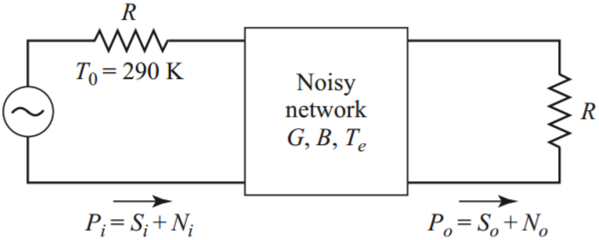
- A white noise source can be replaced by a noisy resistor of value R at temperature T_e so that the same noise power is delivered to the load.



$$T_e = \frac{N_o}{kB}$$

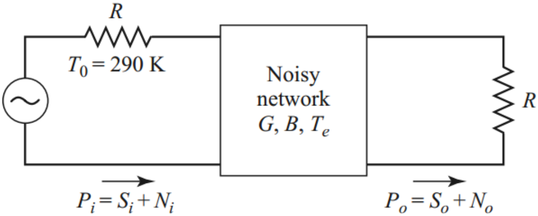
Noise Factor (F)

- Measure of degradation of the signal-to-noise ratio between input and output of the component
- When noise and a desired signal are applied to the input of a **noiseless network**, both noise and desired signal will be amplified/attenuated by the same factor



- If the network is **noisy**, the output noise power will be **increased more than** the desired signal power

Noise Factor



- Input noise power results from a matched resistor at $T_o = 290K$
  - $N_i = kT_oB$
- $N_o = kG(T_o + T_e)B$
- With $S_o = GS_i$

$$F = \frac{S_i}{kT_oB}\frac{kG(T_o + T_e)B}{GS_i} = 1 + \frac{T_e}{T_o} \geq 1$$

Noise Figure (NF)

- Identical with Noise Factor, except that it is given in **dB**

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

$$NF = 10log(F) = 10log(\frac{SNR_{in}}{SNR_{out}})$$

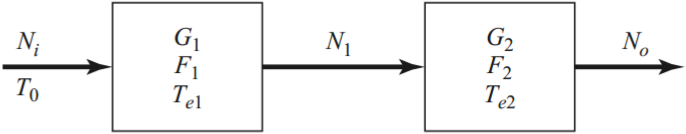
- Noise figure and equivalent noise temperatures are interchangeable characterizations of noise properties of component (in practice, NF is used)

- Noise figure for passive components
  - At thermal equilibrium, $F = L$
  - Example: a 6 dB attenuator has a NF of 6 dB

Cascaded Systems

- Typical microwave system consists of multiple stages - each of which can degrade SNR to varying degrees
- Consider a cascade of 2 components

$$N_1 = G_1 k T_0 B + G_1 k T_{e1} B,$$



- The cascaded equivalent noise temperature

$$T_{cas} = T_{e1} + \frac{1}{G_1} T_{e2}$$

- It can also be shown that

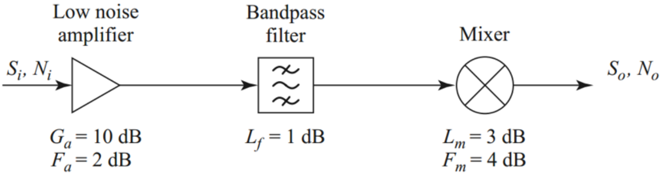
$$F_{cas} = F_1 + \frac{1}{G_1}(F_2 - 1)$$

- Extending it to arbitrary number of stages,

$$F_{cas} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots$$

Examples

- Compute the overall NF of the system



- If the input noise power from a feeding antenna is $N_i = kT_AB$ where $T_A = 150k$, then find the output noise power in dBm. Assume system is at temperature $T_o = 290K$ and bandwidth of 10 MHz
- If SNR $= 20$ dB is required at the output of receiver, what is the minimum input signal power (in dBm)?

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