

Tutorial-1

Basic RF issues & RF Blocks Specifications

Problem-1.1: (Tutorial)

Why to use decibels?

Solution:

- It is more convenient to add/subtract the decibel values rather than to multiply/divide. For example, the amplification factors of two consecutive amplifiers.
- A very large range of ratios can be expressed with decibel scale.

Let's take an amplifier which supplies 3.5 W of output with an input of 20 mW. What is the gain in dB?

$$G = 10 \log \frac{3.5 \text{ W}}{0.02 \text{ W}} = 10 \log 175 = 10(2.24) = 22.4 \text{ dB}$$

Few rules of thumb for easy calculations:

- $10 \log (2) = 3 \text{ dB}$ and $10 \log (1/2) = -3 \text{ dB}$
- $10 \log (4) = 10 \log (2)^2 = 20 \log (2) = 2 \times 10 \log (2) = 6 \text{ dB}$
- $10 \log (100) = 20 \text{ dB}$ and $10 \log (1/100) = -20 \text{ dB}$
- 17 dB?
 - $17 \text{ dB} = 20 \text{ dB} - 3 \text{ dB} = 100/2 = 50$
- 26 dB?
 - $26 \text{ dB} = 20 \text{ dB} + 6 \text{ dB} = 100 \times 4 = 400$

Use of the Decibel with a Defined Reference

The most common "defined reference" use of the decibel is the dBm, or decibels relative to a power level of one milliwatt (mW). It is different from the dB because it uses the same specific predefined power level as a reference.

Let's take an amplifier which supplies 3.5 W of output. What is the power in dBm?

$$P_{out} |_{dBm} = 10 \log \frac{3.5 \text{ W}}{1 \text{ mW}} = 10 \log 3500 = 10(3.544) = 35.44 \text{ dBm}$$

For example, suppose we have a signal source with an output power of -70 dBm, which we wish to connect to an amplifier having 22 dB gain through a cable having 8.5 dB losses. What is the output power level from the amplifier? To find the answer, we just add the gains and losses as follows:

(Signal) (Amp. gain) (Cable loss)

$$\text{Output} = -70 \text{ dBm} + 22 \text{ dB} + (-8.5 \text{ dB})$$

$$\text{Output} = -70 \text{ dBm} + 22 \text{ dB} - 8.5 \text{ dB}$$

$$\text{Output} = -56.5 \text{ dBm}$$

This result only hold for impedance matched conditions.

Prove the expression below. (Assume that source is matched with load, i.e. the source and load resistances are equal)

$$G = 10 \log \frac{P_{out}}{P_{in}} = 20 \log \frac{V_{out}}{V_{in}}$$

Please note the consequence of above equation i.e. power ratio of 2 means 3dB power gain but voltage ratio of 2 means 6dB voltage gain.

Problem-1.2: (Tutorial)

How to convert the voltage in the dBm and vice versa?

$$P_{dBm} = 10 \log \frac{P_{watts}}{1mW} \text{ where } P_{watts} = V_{rms}^2 / R$$

Here R is the load across which the voltage is developed and by definition it should be 50Ω. Also

$$V_{rms} = V_{pp} / 2\sqrt{2}$$

Examples:

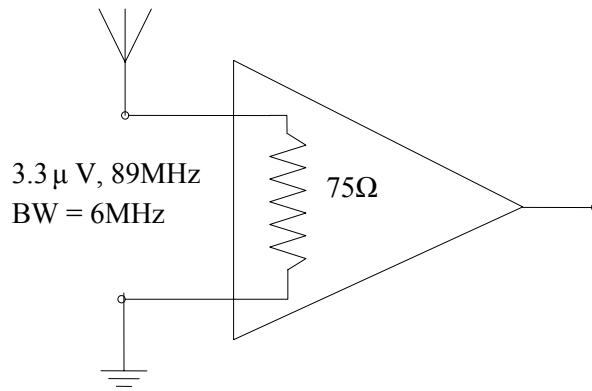
Vpp	Vrms	P _{watts} (50Ω)	P _{dBm} (50Ω)
1 nV	0.35 nV	2.5×10^{-21} W	-176 dBm
1 μV	0.35 μV	2.5 fW	-116 dBm
1 mV	0.35 mV	2.5 nW	-56 dBm
632.4 mV	223.6 mV	1 mW	0 dBm
1V	0.35 V	2.5 mW	4 dBm

Please fill-in the table:

P _{dBm} (dBm)	Vrms (50Ω)	Vpp (50Ω)	Vrms (100Ω)	Vpp (100Ω)	Vrms (500Ω)	Vpp (500Ω)
-176	0.35 nV	1 nV	0.5nV	1.42 nV	1.12 nV	
-56	353.6 μV	1 mV				
0	223.6 mV	632.4 mV				
4	353.6 mV	1 V				
10						

Problem-1.3: (Tutorial)

A video receiver with 75Ω input impedance is matched to antenna having equivalent temperature of 31°C. The received signal applied to the amplifier input has frequency of 89MHz, bandwidth of 6MHz and amplitude of 8.3μV. The NF of the amplifier is 2.8dB.



Calculate

- Input noise power.
- Input signal power and S/N ratio in dB.
- The noise factor F and S/N at the amplifier output.
- The equivalent noise temperature of the amplifier.

Solution:

a).

$$T_{antenna} = 273 + 31 = 304\text{K}$$

$$V_n = \sqrt{4kTBR}$$

$$V_n = \sqrt{4(1.38 \times 10^{-23})(304)(6 \times 10^6)(75)} = 2.75 \mu\text{V}$$

$$P_{n,antenna} = V_n^2 / R = (2.75 \times 10^{-6})^2 / 75 = 0.1 \text{pW}$$

As the voltage attenuation is 1/2, the power attenuation is 1/4.

The noise transferred to amplifier is

$$P_{n,amp} = P_{n,antenna} / 4 = 0.1 \text{pW} / 4 = 0.025 \text{pW}$$

b).

$$P_s = V_s^2 / R = (8.3 \times 10^{-6})^2 / 75 = 0.918 \text{pW}$$

c).

$$S/N = \frac{P_{Signal}}{P_{noise,amp}} = \frac{P_s}{P_n} = \frac{0.918}{0.025} = 36.72$$

$$SNR = 10 \log(S/N) = 10 \log 36.72$$

$$SNR = 15.64 \text{dB}$$

d).

$$NF = 2.8 \text{dB}$$

$$F = 10^{\frac{NF}{10}} = 1.9 \quad \text{noise figure and noise factor}$$

$$F = \frac{(S/N)_{input}}{(S/N)_{output}}$$

$$\begin{aligned} \text{or } SNR_{out} &= SNR_{in} - NF \\ &= 15.64 - 2.8 \\ &= 12.84 \text{dB} \end{aligned}$$

$$S/N_{output} = \frac{S/N_{input}}{F} = \frac{36.72}{1.9} = 19.32$$

$$SNR_{output} = 10 \log 19.32 = 12.86 \text{ dB}$$

Note that SNR_{out} has decreased from 15.64dB to 12.86dB.

e).

$$T_N = 290(F - 1)$$

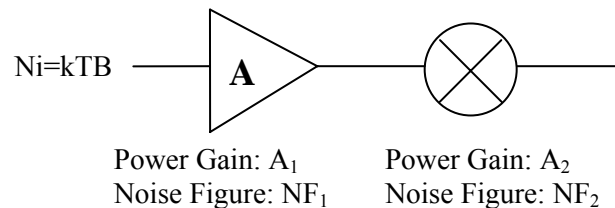
$$T_N = 290(1.9 - 1) = 290(0.9) = 261 \text{ K}$$

F = Noise Factor, NF = Noise Figure

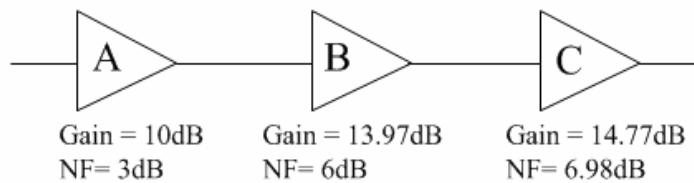
$$NF = 10 \log F$$

Problem-1.4: (Tutorial)

- a) An analog frontend is shown in figure below. Define the noise figure and derive the expression for total NF of the frontend. Assume that all inputs/outputs are matched.



- b) For three stage amplifier, calculate total noise figure and equivalent noise temperature.



- c) Which stage is most critical in determining total NF ? What should be the gain and NF of the most critical stage for overall smaller noise figure?

Solution:

a)

$$F = \frac{(S/N)_i}{(S/N)_o} = \frac{S_i/N_i}{S_o/N_o} = \frac{S_i}{S_o} \times \frac{N_o}{N_i} \quad \because \text{Gain} = A = \frac{S_o}{S_i}$$

$$\text{So, } F = \frac{N_o}{N_i A} \text{ or } N_o = FN_i A \text{ -----(1)}$$

From (1) total equation input noise = $(F)N_i$

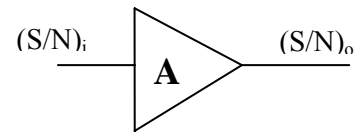
Equivalent input noise generated by Amp

$$N_{eq} = (F)N_i - N_i = (F - 1)N_i$$

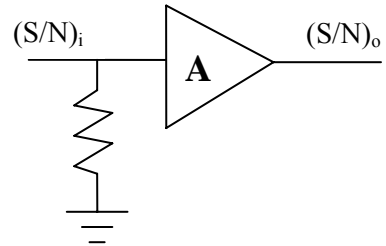
Since $N_i = kTB$

$$N_{eq} = (F - 1)kTB \text{ ----- (2)}$$

Noisy Amp



Noiseless



$$N_{eq} = (F - 1)kTB$$

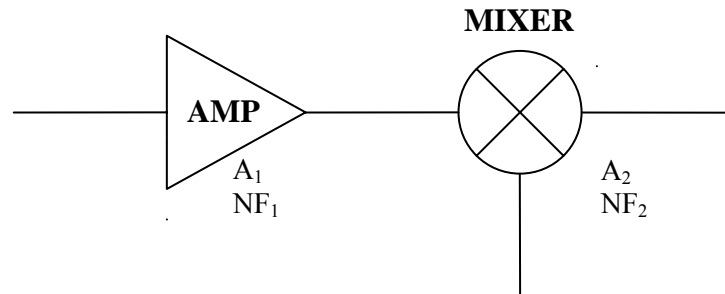
$$kT_{eq}B = (F - 1)kTB$$

$$T_{eq} = (F - 1)T$$

or

$$T_{eq} = (F - 1)290K$$

Now



Let noise power input to the AMP be $N_1 = kTB$

$$(1) N_{o1} = (F_1)A_1kTB$$

This noise appears at the input of mixer and amplified by mixer noise contributed by mixer

$$(2) N_{eq2} = (F_2 - 1)kTB$$

$$\begin{aligned} N_{O2} &= N_{O1}A_2 + A_2N_{eq2} = (F_1)A_1kTBA_2 + (F_2 - 1)kTBA_2 \\ &= kTBA_2(F_1A_1 + F_2 - 1) \end{aligned}$$

The total noise figure of system

$$F_T = \frac{N_{O2}}{N_{i1}A_T} = \frac{kTBA_2(F_1A_1 + F_2 - 1)}{kTBA_1A_2} \quad \because N_{i1} = kTB$$

$$F_T = \frac{F_1 A_1 + F_2 - 1}{A_1}$$

$$F_T = F_1 + \frac{F_2 - 1}{A_1} \quad \text{Called Friis formula}$$

b).

$$A_1 = 10\text{dB} \quad , NF_1 = 3\text{dB}$$

$$A_2 = 13.97\text{dB} \quad , NF_2 = 6\text{dB}$$

$$A_3 = 14.77\text{dB} \quad , NF_3 = 6.98\text{dB}$$

$$A_1 = 10^{\frac{10}{10}} = 10 \quad , F_1 = 10^{\frac{3}{10}} = 2$$

$$A_2 = 10^{\frac{13.97}{10}} = 25 \quad , F_2 = 4$$

$$A_3 = 10^{\frac{14.77}{10}} = 30 \quad , F_3 = 5$$

$$F_T = F_1 + \frac{F_2 - 1}{A_1} + \frac{F_3 - 1}{A_1 A_2}$$

$$= 2 + \frac{4-1}{10} + \frac{5-1}{10 \times 25}$$

$$F_T = 2.316$$

$$NF_T|_{dB} = 10 \log 2.316 = 3.65\text{dB}$$

Noise Equivalent Temperature:

$$T_{eq} = 290(F_T - 1)$$

$$= 290(2.316-1)$$

$$T_{eq} = 382\text{K}$$

c).

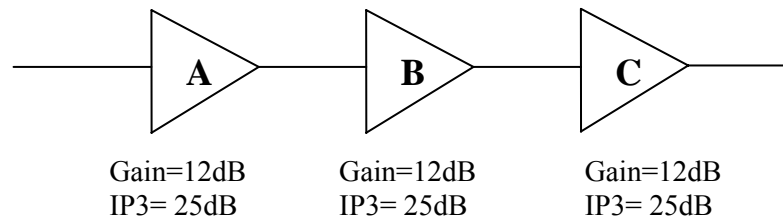
$$F_t = F_1 + \frac{F_2 - 1}{A_1} + \frac{F_3 - 1}{A_1 A_2} + \frac{F_4 - 1}{A_1 A_2 A_3}$$

↑

we can generalize it

Conclusion: Noise figure of 1st stage is most important!!!

Problem-1.5: (Tutorial)



- Estimate the combined $IP3$ for three stage amplifier
- Which of the stages has the most influence in limiting the $IP3$ value?
- How we can improve the NF and $IP3$ in cascade stages at same time?

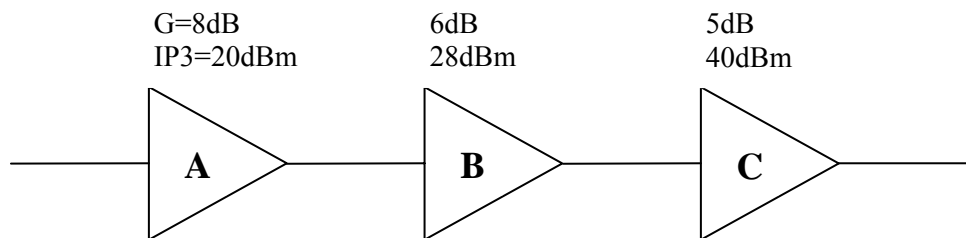
Solution:

$$\frac{1}{IIP_{3,TOT}} = \frac{1}{IIP_{3A}} + \frac{G_A}{IIP_{3B}} + \frac{G_A G_B}{IIP_{3C}} \quad (1)$$

We can directly apply formula or
we can develop the following simple procedure

- Transfer all intercept points to the system input, subtracting gains and adding losses (in dB units)
- Convert $IIP3$ into power (dBm to mW)
- $IIP3_{Total} = \frac{1}{\frac{1}{IIP3_A} + \frac{1}{IIP3_B} + \frac{1}{IIP3_C}}$ mW ($IIP3$ =input referred 3rd intercept point)

First I is for Input



$$IIP3_A = 20\text{dBm} \Rightarrow 100\text{mW}$$

$$\begin{aligned}
 IIP3_B &= 28\text{dBm} - 8\text{dB} \\
 &= 20\text{dB} \Rightarrow 100\text{mW}
 \end{aligned}$$

$$\begin{aligned}
 IIP3_C &= 40\text{dBm} - 8\text{dB} - 6\text{dB} \\
 &= 26\text{dBm} \Rightarrow 398\text{mW}
 \end{aligned}$$

$$IIP3_{Total} = \frac{1}{\frac{1}{100\text{mW}} + \frac{1}{100\text{mW}} + \frac{1}{398\text{mW}}}$$

$$= \frac{398\text{mW}}{3.98 + 3.98 + 1} = \frac{398\text{mW}}{8.9} = 44.42\text{mW}$$

$$IIP3_r = 44.42\text{mW} \Rightarrow 10 \log \frac{44.42\text{mW}}{1\text{mW}}$$

$$= 16.48\text{dBm}$$

Please Note that you can calculate the same answer by putting values directly in eq (1)

b).

By inspection you can see that Later Stages have more influence on total $IP3$.

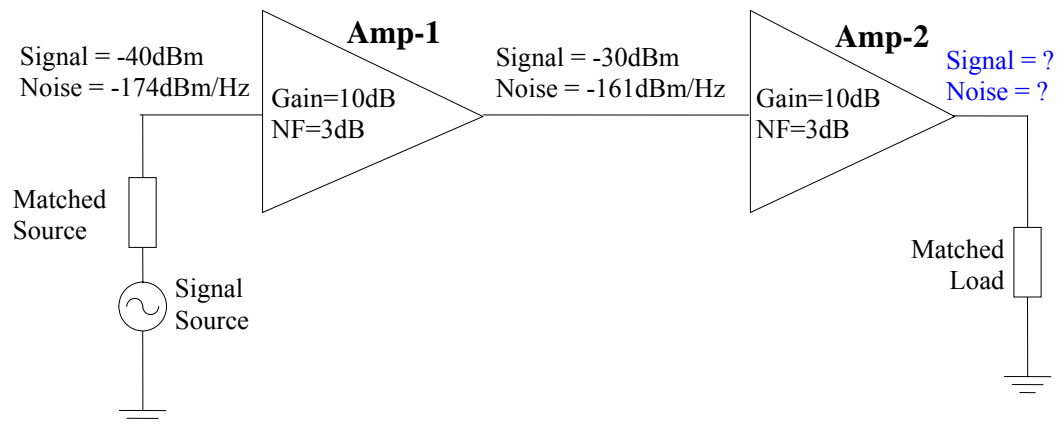
c).

By making stages in Start Low Noise and Later Stage more linear. (Rule of Thumb in RF DESIGN)

Problem-1.6: (HW)

Both amplifiers has 10dB gain and $NF = 3\text{dB}$. The input signal strength is -40dBm and input reference noise floor of the amplifier is kTB (-174dBm/Hz).

- Calculate the signal strength and noise at the output of Amp-2 using the noise/signal level at its input. (6)
- Repeat part a) using Friis formula (4)



Problem-1.7: (HW)

- What is difference between receiver noise floor and reference noise floor?
- The radio receiver shown below requires total $IP3 = 4\text{dBm}$, total $NF = 15\text{dB}$ and total gain anything between 25dB - 30dB . Fill-in the missing details for NF , Gain and $IP3$ for the individual blocks.

Hint: For lossy components the NF and loss have same value, like for BPF Loss = 2dB so $NF = 2\text{dB}$.

Recommendation: Since this problem may have many correct solutions, make a simple spread sheet in Microsoft Excel or Matlab and plug in the values.

