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TSEK02 – Radio Electronics

Tutorial 2

Receiver Noise and Frequency Planning

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Part A – Receiver Noise

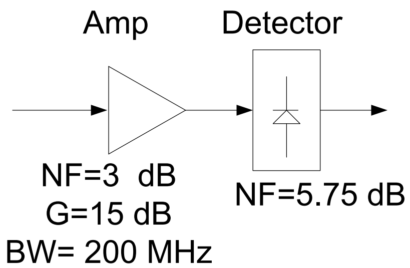
2.1 A receiver is designed for 1 Mbps and 16-QAM modulation with a raised cosine filter (α=0.5). It has a sensitivity of 3μV (rms) for a 50 Ohm input impedance. If the minimum required SNR at the output of the receiver is 12 dB, what is the required receiver noise figure?

Answer: Noise figure = 8.64 dB.

2.2 The AMPS mobile telephone receiver has a noise figure of about 8 dB with an IF bandwidth of 50 kHz. If the required SNR at the output of the receiver is 20 dB, find the minimum detectable signal level at the input of the receiver.

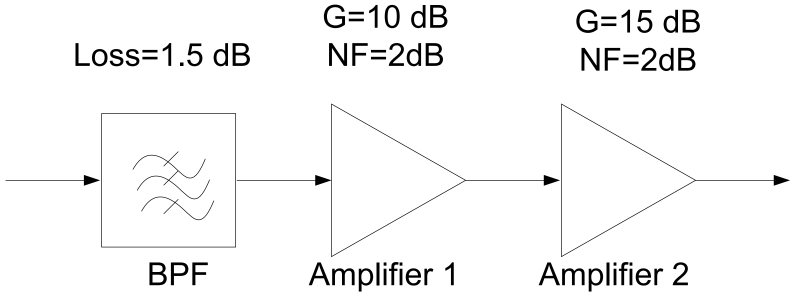
Answer: -99 dBm.

2.3 An amplifier with a gain of 15 dB, a bandwidth of 200 MHz, and a noise figure of 3 dB feeds a detector/demodulator with a noise figure of 5.75 dB. Find the noise figure of the overall system.



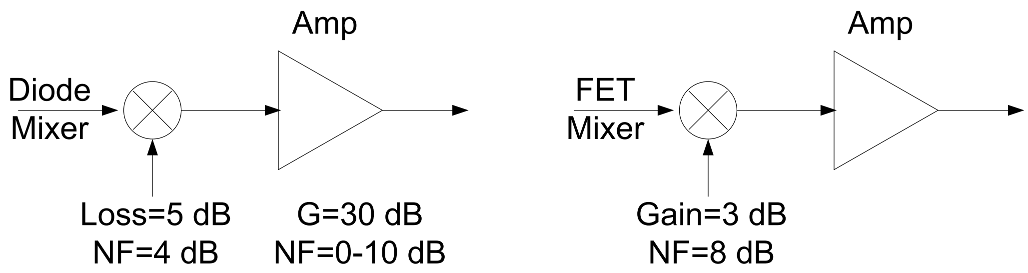
Answer: 3.19 dB.

2.4 Consider the wireless local area network (WLAN) receiver frontend shown below, where the bandwidth of the bandpass filter (BPF) is 150 MHz centered at 2.4 GHz. a) If the system is at room temperature, find the noise figure of the overall system. b) What is the output SNR if the input signal level is -85 dBm? c) Can the components be rearranged to give a better noise figure?



Answer: a) NF= 3.65 dB, b) output SNR = 3.6 dB, c) NF can be as good as 2.05 dB, SNR 5.2 dB.

2.5 Consider a mixer with a conversion loss of 5 dB and a noise figure of 4 dB, and another mixer with a conversion gain of 3 dB and a noise figure of 8 dB. Each of these mixers is followed by an IF amplifier having a gain of 30 dB and a noise figure F_A, as shown below. Calculate and plot the overall noise figure for both the amplifier-mixer configurations for F_A = 0 to 10 dB.



Answer: a) Mixer1: NF varies from 4 dB to 14.9 dB. b) Mixer2: NF varies from 8 dB to 10.3 dB.

2.6 If the noise power N_i=kTB is applied at the RF input port of a mixer having noise figure NF and a conversion loss L, what is the available output noise power at the IF port? Assume a mixer at a physical temperature T_o.

Answer: $N_o = \frac{N_i k T_o B}{L}$

Part B – Receiver Frequency Planning

2.7 A double-sideband signal of the form $v_{RF}(t) = V_{RF}[\cos(\omega_{LO} - \omega_{IF})t + \cos(\omega_{LO} + \omega_{IF})t]$ is applied to a mixer with an LO (local oscillator) voltage given by $V_{LO} \cos \omega_{LO} t$. Derive the output of the mixer after low pass filtering.

Answer: Both the sidebands mix to the same frequency.

2.8 An RF input signal at 600 MHz is down-converted with a mixer to an IF frequency of 80 MHz. What are the two possible LO frequencies and the corresponding image frequencies?

Answer: f_{LO1}= 680 MHz, f_{IM1}= 760 MHz, f_{LO2}= 520 MHz, f_{IM2}=440 MHz.

2.9 A radio receiver is tuned to receive a signal at 880 MHz. It uses an IF frequency of 88 MHz. What is the frequency of the image frequency that could be received by this system?

Answer: f_{IM1}= 704 MHz, f_{IM2}=1056 MHz.

2.10 A multi-user radio system uses three possible channel frequencies of 900 MHz, 910 MHz, and 920 MHz. The channel bandwidth is 1 MHz and the receiver IF frequency is 10 MHz. Assuming the receiver input is band-pass filtered between from 899.5 MHz to 920.5 MHz, will the receiver pick up any image frequencies?

Answer: Yes, for the 900 MHz channel with lower sideband mixing and 920 MHz channel with upper sideband mixing results in images within the channel.

Problems to be solved on your own

2.11 Problem 4.6 of the course book.

2.12 Problem 4.7 of the course book.

2.13 Problem 4.12 of the course book.

Important Note: Always watch out for the scale. Check whether you are in dB scale or the linear scale. This is a very common mistake.

List of Important Formulae

1. Shannon's Channel Capacity Theorem
   $$C = B\times \log_2(1+SNR) = B\times \log_2\left(1+\frac{S}{n_0\times B}\right)\ \left[{}^{b}/_{s}\right]$$

   n_0 is the noise power spectral density in W/Hz, S is the signal power in W, B is the bandwidth, SNR is **NOT** in dB scale. Also note the $\log_2$ which is not the common $\log_{10}$.

2. Bandwidth of a signal shaped by a raised cosine pulse filter is $\frac{1+\alpha}{T_b}$
   α is the roll-off factor, T_b is the original pulse period.

3. Boltzmann's Constant, k = 1.38×10^{-23} J/K.

4. Use a room temperature of 27 °C = 300 K whenever temperature is not specified.

5. Thermal noise power spectral density, PSD=kT. At T=300 K, PSD is -174 dBm/Hz. The PSD is independent of the resistor value. This is true only when the source resistor and the load resistances are matched.

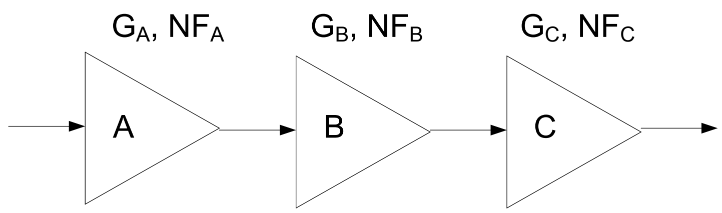
6. Thermal noise power in a bandwidth B: $P_{RS} = kTB$.
   In dB scale at 300 K, the total thermal noise power $P_{RS|dB}$ = 10log(kTB) = 10log(kT)+10log$B$
   => $P_{RS|dB}$ = -174 dBm/Hz + 10log$B$

7. Noise Factor [not in dB] $NF = \frac{SNR_{in}}{SNR_{out}}$

   Noise Figure [dB] $NF_{dB} = 10\log\left(\frac{SNR_{in}}{SNR_{out}}\right) = SNR_{in|dB} - SNR_{out|dB}$

8. Noise figure of a passive lossy component is equal to its loss: NF=L.

9. Effective noise figure of cascaded stages.



$$NF_{total} = NF_A + \frac{NF_B - 1}{G_A} + \frac{NF_C - 1}{G_A G_B}.$$

   This is called Friis' equation. This equation is **not in dB**.

10. $IP3 = P_{1db} + 9.6$.
    in dBm and valid for both input and output referred quantities

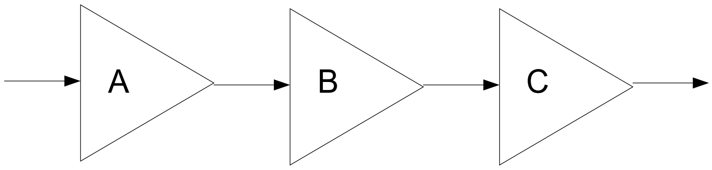
11. Output IP3 of a component can also be calculated from the two-tone test:

$$OIP3\ [dBm] = P_1[dBm] + \frac{\Delta P[dBc]}{2}$$

where P_1 is the power of each of the main tones, ΔP is the power difference between the two tones and the distortion tones.

12. *IP3 = P + ΔP/2.*
in dBm and valid for both input and output referred quantities.
P is the input/output power in each of the main tones, *ΔP* is the power difference between the main tones and the distortion tones

13. IP3 of cascaded stages:



Effective IIP3 (in W, **not in dBm/dB**)

$$\frac{1}{IIP3_{total}} = \frac{1}{IIP3_A} + \frac{G_A}{IIP3_B} + \frac{G_A G_B}{IIP3_C}$$, where G is the gain.

If referred to the output, OIP3 becomes

$$\frac{1}{OIP3_{total}} = \frac{1}{G_B G_C \bullet OIP3_A} + \frac{1}{G_C \bullet OIP3_B} + \frac{1}{OIP3_C}$$

14. At 300 K, the power required at the receiver input in dBm for a given output SNR in a bandwidth B is given by $P_{in|dBm} = -174\ dBm/Hz + 10\log(B) + NF_{dB} + SNR_{out|dB}$. .

15. Dynamic Range Linear (referenced to input) **in dB:** $DR_L = P_{1dB}$(referenced to input) - $P_{sen.}$

16. Spurious Free Dynamic Range, SFDR (referenced to input) **in dB:**

$$SFDR = \frac{2\left(P_{IIP3} + 174\ dBm/Hz - NF - 10\log B\right)}{3} - SNR_{\min}$$

This formula assumes that the input noise is thermal at 300 K.

17. After propagation through an ideal channel of R meters, the received power level is given by
$$P_{receive} = P_{transmit} \times G_t \times G_r \times \frac{\lambda^2}{(4\pi R)^2}$$
G_R and G_T are receive and transmit antenna gains and λ is the wavelength given by $\lambda = \frac{c}{f}$, where c=3*10^8 m/s.