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TSEK02 – Radio Electronics

Tutorial 3+4

Frequency Planning, Receiver Linearity, Sensitivity, dynamic range, BER

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Part A – Receiver Frequency Planning

3.1 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.

3.2 Recommend design parameters for an AM standard broadcast receiver that is to operate with an IF frequency f_{IF} of 455 kHz:

a. Calculate the required LO frequency f_{LO} when the receiver is tuned to a carrier frequency f_C = 540 kHz, assuming that the frequency of the LO is <u>above</u> the frequency of the received signal.

b. Calculate the required LO frequency f_{LO} when the receiver is tuned to carrier frequency f_C = 540 kHz, assuming that the frequency of the LO is <u>below</u> the frequency of the received signal.

NB. In “Lab 2 measurements”, you will measure this on such an AM reciever.

Answer: (a) f_{LO} = 995 kHz, (b) f_{LO} = 85kHz.

3.3 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**.**

3.4 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.

3.5 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.

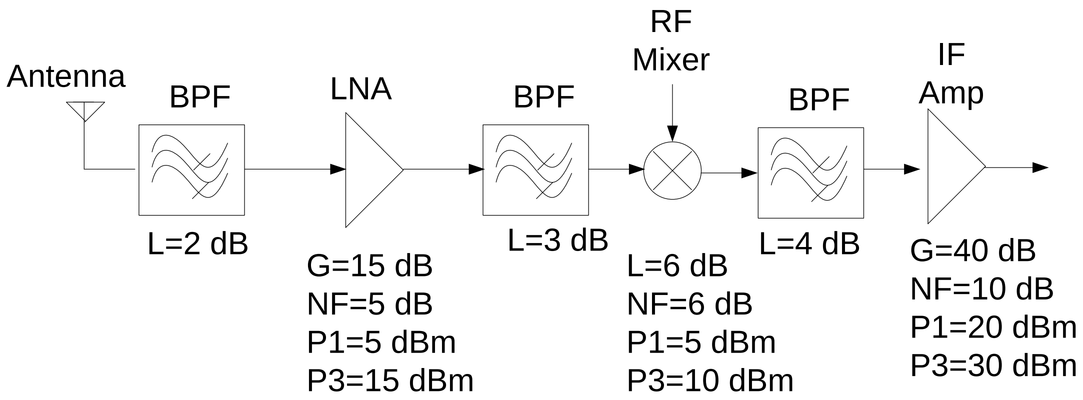
Part B – Receiver Linearity

3.6 Consider the receiver frontend block diagram shown below, with the given parameters for each component. The P1-dB compression points (P1) and the third-order intercept points (P3) are referred to the output of the amplifiers, while for the mixer these quantities are referred to the input.

a) Determine the noise figure of the receiver.

If the required output SNR is 12 dB, find b) the receiver sensitivity and c) the minimum detectable voltage signal, assuming an IF bandwidth of 50 kHz and a receiver impedance of 50 Ω.

d) If two signal power levels of -90 dBm and -30 dBm are used, are P1 and P3 exceeded for any of the component?

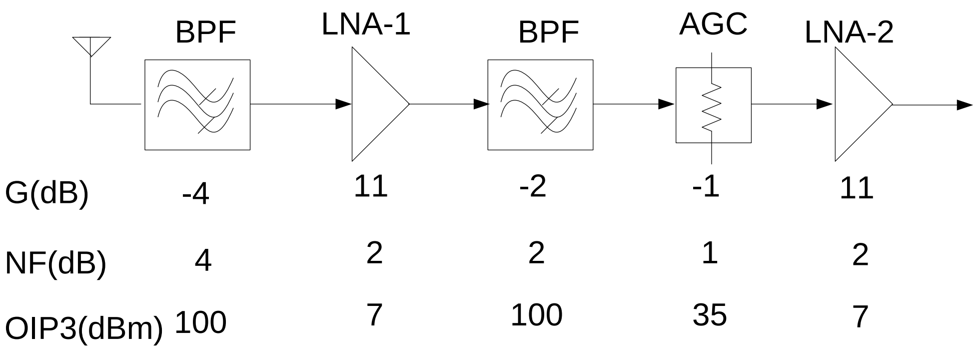


Answer**:** a) Total NF = 11.8 dB, b) minimum detectable signal: 2.2μV_p, c) sensitivity: -103.2 dBm, d) No.

3.7 Consider the IS-54 receiver shown in the figure below.

a) calculate the gain, noise figure, and the third order intercept progressively through the system.

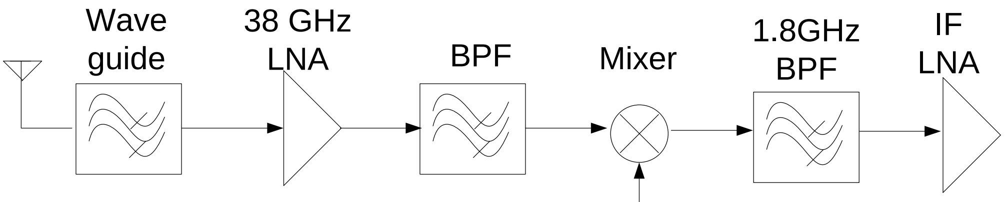
b) A new receiver configuration is now created by moving LNA-2 to a position directly after LNA-1. Compare the performance of this new configuration relative to the original configuration.



Answer**:** a) Total G = 15 dB, NF = 6.4 dB, OIP3 = 6.36 dBm. b) Total G =15 dB, NF = 6.1 dB, OIP3 = 3.7 dBm.

You can see a NF versus OIP3 trade-off in the two configurations and the effect of G on NF and OIP3.

3.8 Calculate the gain, noise figure and the third order intercept point for a 38 GHz receiver shown below.



	Wave guide	38 GHz LNA	BPF	Mixer	1.8GHz BPF	IF LNA
G(dB)	-1	20	-4	-7	0	13
NF(dB)	1	3.5	4	7	0	2.5
OIP3(dBm)	100	15	100	10	100	25

Answer**:** G = 21 dB, NF = 4.6 dB, OIP3 = 15.5 dBm.

Part C – Sensitivity, dynamic range, BER

3.9 A receiver has a noise figure of 6 dB, a 1 dB compression point of 21 dBm (referenced to output), a gain of 30 dB, and a third order intercept point of 33 dBm (referenced to output). If the desired output SNR is 8 dB, find the linear and spurious free dynamic ranges of the subsystem. Assume a system bandwidth of 20 MHz. Assume that the input noise is thermal and a temperature of 27 °C.

Answer**:** Dynamic Range Linear = 78 dB, SFDR = 57.3 dB.

3.10 A cell phone receiver operates at room temperature (T = 20 °C) and has the following specifications: noise figure NF = 20 dB, bandwidth B = 1 MHz, signal-to-noise-ratio SNR = 0 dB. Also, the non-linearity of the receiver circuit can be described by the following output signal *y(x)* function: $y(x) = 2x - 0.267x^3$. The input signal is x = 0.1 sin ωt V

Calculate:

a. the 1 dB compression point.

b. the input intercept point IIP3.

c. receiver sensitivity.

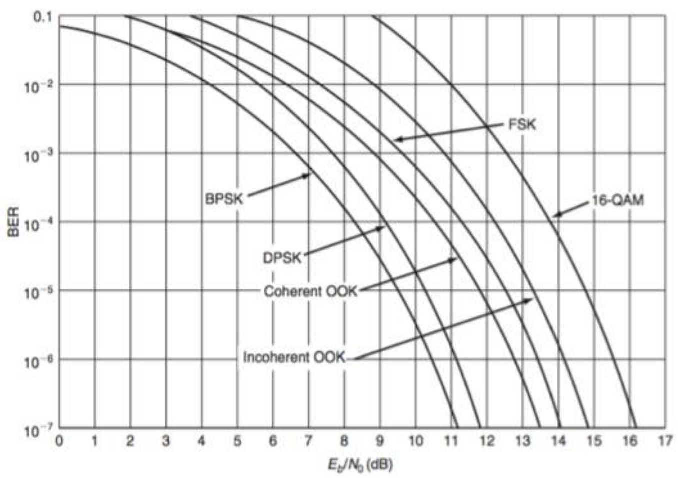
d. dynamic range.

Answers: a. 10 dBm (input-referred), b. 20 dBm, c. -94 dBm (using T=27 °C), d. 104.4 dBm.

3.11 A transceiver is designed for the following system characteristics: Access method is half duplex (TDD). Modulation is QPSK with raised cosine shaping, roll-off factor = 0.3. Channel BW=1.6 MHz. Data rate = 1200 kb/s. BER <1E-5@sensitity of -96 dBm.

What is the maximum acceptable noise figure for the reciever (called “reference noise figure”)?

The relation between BER and SBR is given below.



Answer: 7.2 dB.

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 x 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.

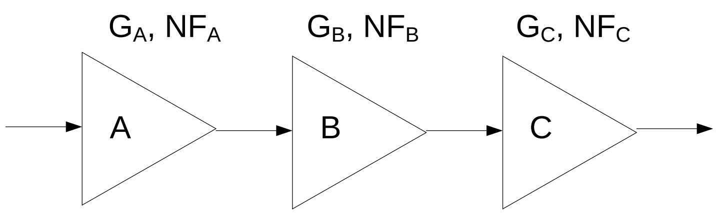
6. Thermal noise power in a bandwidth B: $P_{RS} = kTB$.
   In dB scale at 300 K, the total thermal noise power $P_{RS|dB}$ = 10log(kTB) = 10log(kT)+10log$B$
   => $P_{RS|dB}$ = -174 dBm/Hz + 10log$B$

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

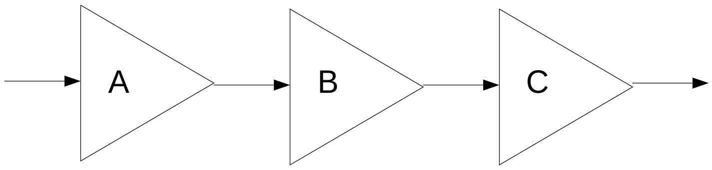
11. Output IP3 of a component can also be calculated from the two-tone test:

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

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.