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TSEK02 – Radio Electronics

Tutorial 3

Receiver Linearity and Dynamic Range

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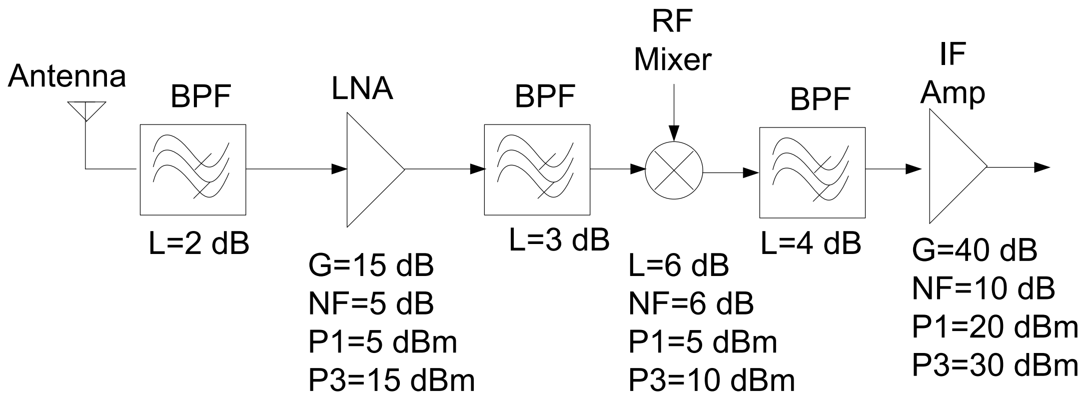
3.1 Consider the receiver frontend block diagram shown below, with the given parameters for each component. The P1-dB compression points (P1) and the third-order intercept points (P3) are referred to the output of the amplifiers, while for the mixer these quantities are referred to the input.

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?

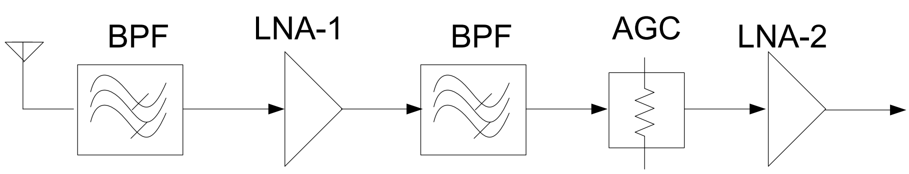


Answer**:** a) Total NF = 11.8 dB, b) minimum detectable signal: 2.2μV_p, c) sensitivity: -103.2 dBm, d) No.

3.2 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.

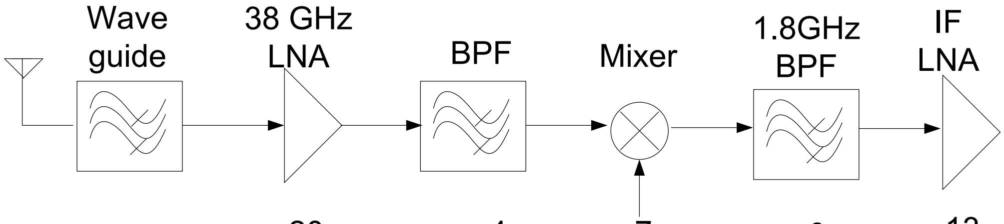


	BPF	LNA-1	BPF	AGC	LNA-2
G(dB)	-4	11	-2	-1	11
NF(dB)	4	2	2	1	2
OIP3(dBm)	100	7	100	35	7

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

3.3 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.

3.4 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.

Problems to be solved on your own

3.5 Problem 2.2 in the course book.

3.6 Problem 2.14 in 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
   $$C = B\times \log_2(1+SNR) = B\times \log_2\left(1+\frac{S}{n_0\times B}\right)\ [b/s]$$

   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.

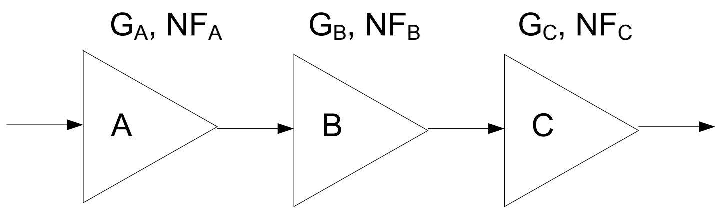
6. Thermal noise power in a bandwidth B: $P_{RS} = kTB$.
   In dB scale at 300 K, the total thermal noise power $P_{RS|dB}$ = 10log(kTB) = 10log(kT)+10log$B$
   => $P_{RS|dB}$ = -174 dBm/Hz + 10log$B$

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

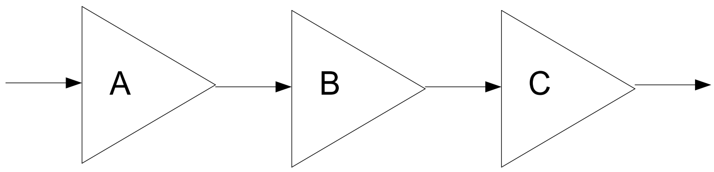
11. Output IP3 of a component can also be calculated from the two-tone test:

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

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.