Institutionen för systemteknik (ISY)

Integrated Circuits and Systems
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TSEK02 – Radio Electronics

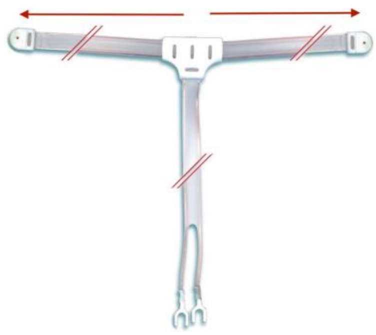
Tutorial 2

Antennas and propagation, transmission/link, receiver noise

2018-11 Updated by Ted Johansson (ted.johansson@liu.se)

Part A – Antennas and propagation

2.1 An FM antenna to hang on the wall is often supplied with commercial audio receivers, it usually looks like this (as sold on Amazon):



This is a dipole antenna. How long would the "arms" on the wall be (red arrows) if intended as an FM antenna? Hint: dipole antenns are usually design with arm lengths in the order of $\lambda/4$.

Answer: 75 cm.

2.2 (a) How long can an antenna 30 m high transmit a signal using a 10 GHz carrier? (b) For a LOS microwave link with two antennas with the heights of 25 m and 30 m, what is the maximum link distance between the antennas? Assume that the transmit power and antenna gains result in a received signal power higher than the sensitivity of the receiver.

Answer: (a) 19.6 km, (b) 37.4 km.

2.3 The highest TV broadcasting mast in the world (according to Swedish Wikipedia) is 628 m high and situated in Fargo, North Dakota, USA. In Sweden there are four almost identical mast constructions at 335 m. One is situated outside Västervik (about 100 km SE of Linköping), the *Fårhult* mast, and it provide radio and TV broadcasting for a wide area.

Assume you have a good outdoor TV antenna and a very sensitive receiver in your TV, can you actually receive any signals from the Fårhult transmitter in Linköping? Does it help to put your TV antenna at the top of your house (antenna is now 10 m above ground)?

Part B – Transmission/link

2.4 Consider a 2 m line-of-sight radio link at 60 GHz which employs QPSK modulation and transmits at a data rate of 4 Gb/s occupying a bandwidth of 2 GHz. Calculate the received power $P_{receive}$ if the transmitter output power $P_{transmit}$ is 0 dBm, and the TX and RX horn antennas each have a gain of 25 dB.

Answer: $P_{receive}$ = -24 dBm.

2.5 A Bluetooth power class 2, a maximal output power of 4 dBm in the 2.4 GHz ISM band is allowed according to the standard. A transmitter with 0 dBm nominal ouptut power using a (almost) non-directional antennas with antenna gain of 1 dB and a similar receiving antenna is used for the link. The mandatory actual sensitive level is -70 dBm with BER<1E-3, also according to the standard.

At what maximum distance can we maintain a link with good data quality for the above specification?

Answer: 48.7 m.

Part C – Receiver Noise

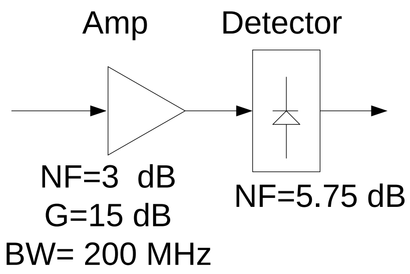
2.6 A receiver is designed for 1 Mbps and 16-QAM modulation with a raised cosine filter (α=0.5). It has a sensitivity of 3μV (rms) for a 50 Ohm input impedance. If the minimum required SNR at the output of the receiver is 12 dB, what is the required receiver noise figure?

Answer: Noise figure = 8.64 dB.

2.7 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.

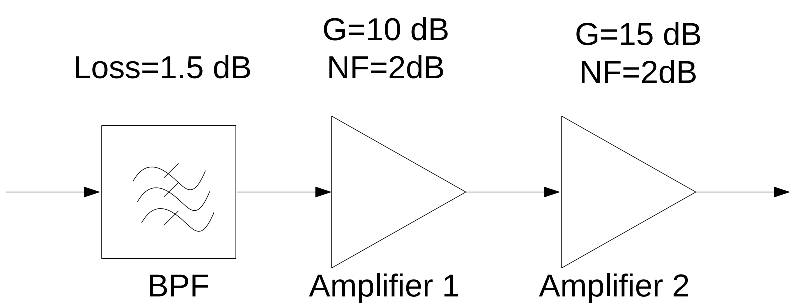
Answer: -99 dBm.

2.8 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.



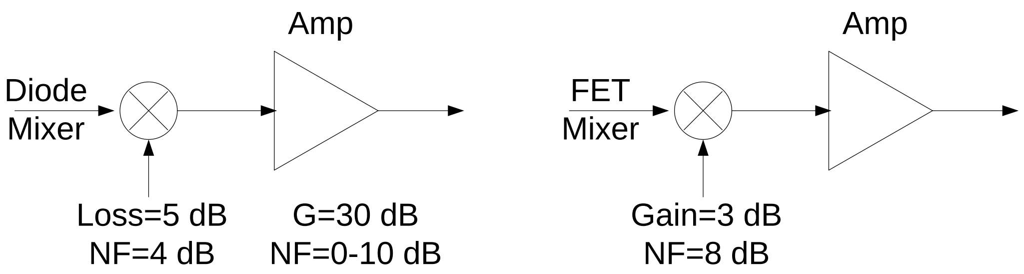
Answer: 3.19 dB.

2.9 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.

2.10 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.

2.11 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:

$$N_o = \frac{NFkT_oB}{L}$$

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.

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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, $k = 1.38 \times 10^{-23}$ 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.

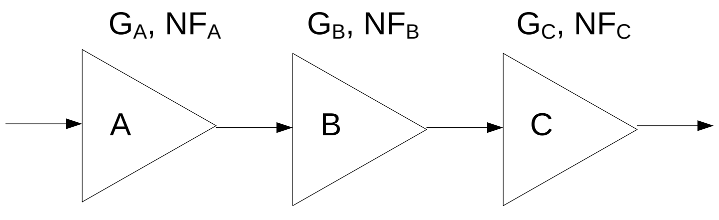
6. Thermal noise power in a bandwidth B: $P_{RS} = kTB$.
   In dB scale at 300 K, the total thermal noise power $P_{RS|dB} = 10\log(kTB) = 10\log(kT) + 10\log B$
   => $P_{RS|dB} = -174$ dBm/Hz + $10\log B$

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

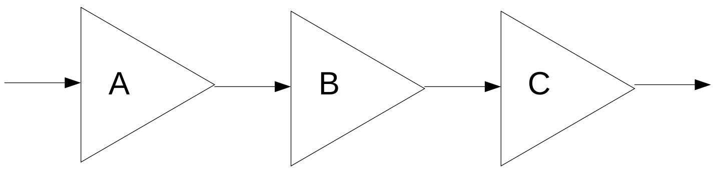
11. Output IP3 of a component can also be calculated from the two-tone test:

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

    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.