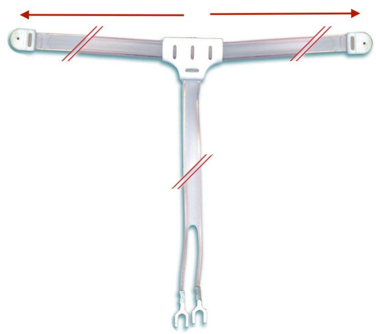
Part A – Antennas and propagation

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.

Solution: One “arm” of an dipole antenna is typically $\lambda/4$ (lecture 6, slide 41 (2018)). FM is broadcasted at 88 – 108 MHz (exact band differs a little bit around the world), so let us calculate $\lambda/4$ using 100 MHz.

$\lambda = c/f$, c = 3e8 m/s, f = 100E6 => $\lambda = 3$ m => $\lambda/4 = 75$ cm.

(The antenna above can be bought at Amazon with a claimed total “span of 6 ft”. This corresponds to a frequency of around 83 MHz, which is maybe not fully optimized, but a reasonable number.)

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.

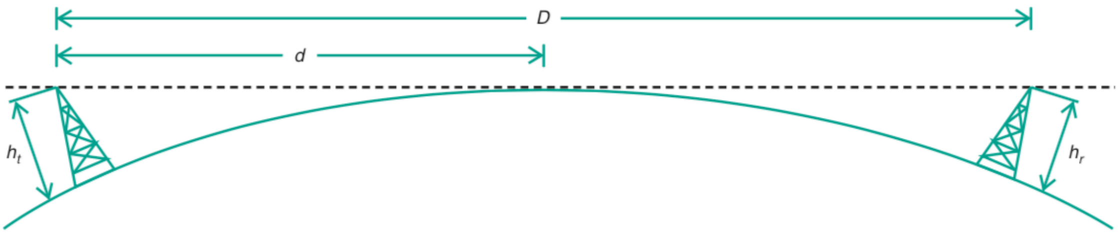
Discussion and solution:

For f > 30 MHz, the radio signals can be transmitted only in "line-of-sight" (LOS). The "Radio Horizon" is the distance at which direct wave signals can no longer be received. It is a function of the height of the transmitting and receiving antennas.

The formula for computing the distance d between a transmitting antenna and the horizon is $d = 3.57\sqrt{h}$, where d is in km and h in meters.

(a) For a single antenna to the horizon: for h = 30 m, d = 19.6 km.

(b) For two antenna with h = 25 m and h =30, the distance is 17.8 + 19.6 km = 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)?

Answer: No, its range (assuming the TV transmitting antenna at the top of the mast and your antenna at the ground) is only 65.3 km. Adding another 10 m will increase the coverage by 11.3 km, but this is still not enough.

Solution: The formula for computing the distance d between a transmitting antenna and the horizon is $d = 3.57\sqrt{h}$, where d is in km and h in meters. For h = 335 m => d = 65.3 km, and for h = 10 m => d = 11.3 km, giving a total of 76.6.

However, the lecturer's house in the archipelago is about 50 km away from Fårhult (grey ring NE on the map), and there it works with a reasonably good antenna (Yagi with + some additional gain from an active antenna amplifier)!

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.

Solution: Use Friis' transmission formula (formula 17).

λ = c/f, c = 3e8 m/s, f = 60E9 => λ = 5 mm. => Link loss = -74 dB.

$P_{transmit}$ = 0 dBm, $G_t = G_r$ = 25 dB

=> $P_{receive}$ (using the logarithmic version of the formula, in dB and dBm) = 0 + 25 + 25 – 74 = -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.

Solution:

We use Friis' transmission equation, eq. (17) in the appendix.

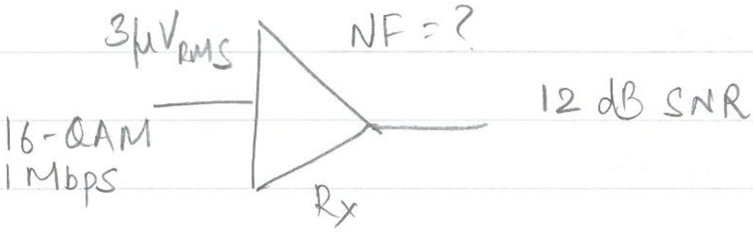
f = 2.4 GHz, c=3E8 => λ = 0.122 m

1 dB ≈ 1.25 x, 0 dBm = 1 mW, -70 dBm = 1E-7 mW

Re-arrange it as: r = λ / 4π * sqrt(1 * 2*1.25 / 1e-7) ≈ 48.7 m.

Tutorial - 2

2.6



Since, data rate is 1 Mbps and QAM is used,
∴ we check the number of bits/symbol.
For, 16 QAM, 4 bits/symbol

$\Rightarrow$ Symbol Rate $= \frac{1\text{Mbps}}{4} = 250$ KHz. i.e. $\frac{1}{T_b} = 250$ KHz

But, Raised Cosine filtering is used with $\alpha = .5$.
Recall from Tutorial 1 that, RCF increases the bandwidth.

$\therefore$ The increased BW $= \frac{(1+\alpha)}{T_b} = (1.5)(250 \text{ KHz})$
$= 375$ KHZ — (1)

$\therefore$ Now the input signal power $= \frac{V_{RMS}^2}{R}$

$= \frac{(3\mu V)^2}{50} = 1.8 \times 10^{-13}$ W

$\Rightarrow P_{sig} = \underline{\underline{-97.44}}$ dBm.

We know that the thermal noise power in a bandwidth $B = KTB$

or $N_{i\,|dB} = 10 \log(KT) + 10 \log(B)$
$= -174 + 10 \log(375e3)$
$= -118.26$ dBm.

$\Rightarrow SNR_{in\,|dB} = P_{sig} - N_i$
$= -97.44 + 118.26 = 20.82$ dB.

We know that

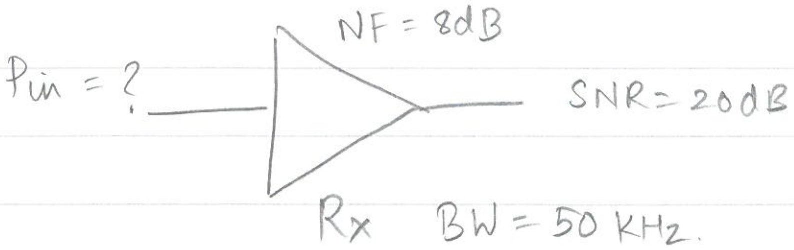
$$NF_{dB} = SNR_{in}|_{dB} - SNR_{out}|_{dB}$$

$$= 20.82 - 12$$

$$= \underline{\underline{8.82\ dB}}$$

2.7

This is similar to the previous problem.



We know that

$$NF_{dB} = SNR_{in}|_{dB} - SNR_{out}|_{dB} \quad -(1)$$

Now, $SNR_{in}|_{dB} = P_{in}|_{dBm} - P_{RS}|_{dBm} \quad -(2).$

We know already that

$$P_{RS}|_{dBm} = -174 + 10\log(B) \quad -(3)$$

[∵ $P = KTB$]
[Convert to dBm]

From (1), (2), (3)., we get

$$NF_{dB} = P_{in}|_{dBm} - (-174 + 10\log B) - SNR_{out}|_{dB}$$

$$NF_{dB} = P_{in}|_{dBm} + 174 - 10\log B - SNR_{out}|_{dB}.$$

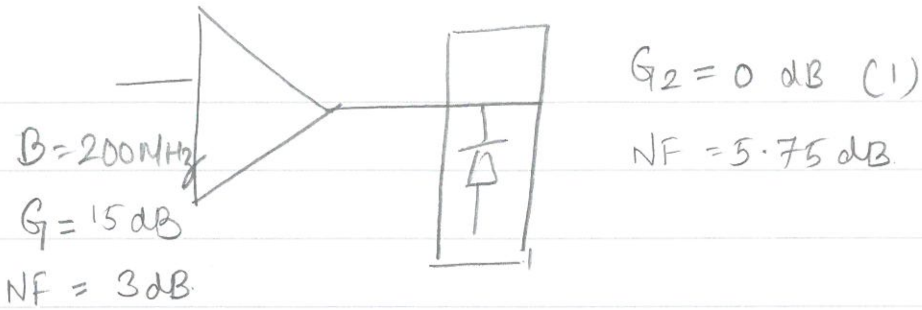
Rearranging,

$$P_{in}|_{dBm} = -174 + 10\log B + SNR_{out}|_{dB} + NF_{dB}$$

$$= \underline{\underline{-99\ dBm}}.$$

Refer to sec 2.4.1 of the textbook.
Remember that this holds good only if antenna matched to receiver.

2.8



This problem is pretty straightforward and a direct usage of the Friis's equation. We have

$G_A = 15\,dB$ $\qquad$ $G_B = 0\,dB$

$NF_A = 3\,dB$ $\qquad$ $NF_B = 5.75\,dB$

$$NF_{TOTAL} = NF_A + \frac{NF_B - 1}{G_A}.$$

$$= 10^{3/10} + \frac{10^{5.75/10} - 1}{10^{15/10}}$$

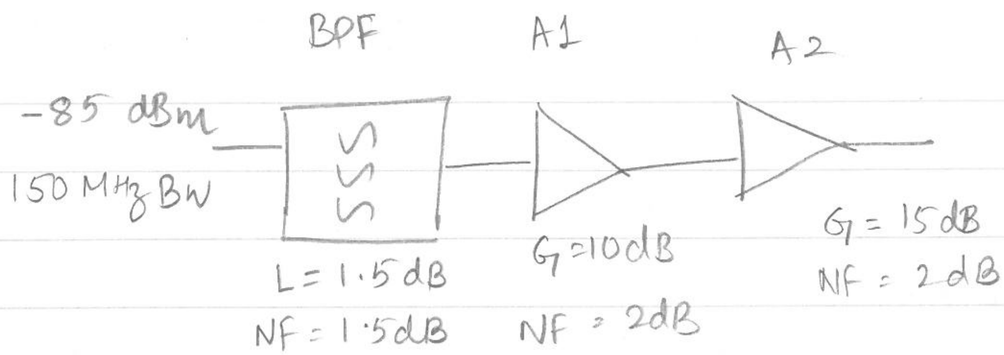
(again Remember that this is not in DB)

$$= 2.082.$$

$$\therefore NF_{total|dB} = 10 \log(2.082)$$
$$= \underline{\underline{3.19\ dB}}$$

(Important to note that the BW information is not relevant in this problem)

2.9



To calculate the overall NF, we use the cascaded NF formula.

$G_A = -1.5\,dB = .708$

$NF_A = 1.5\,dB = 1.412.$

$G_B = 10\,dB = 10$

$NF_B = 2\,dB = 1.585$

$G_C = 15\,dB = 31.62.$

$NF_C = 2\,dB = 1.585$

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

$$= 1.412 + \frac{.585}{(.708)} + \frac{.585}{(0.708)(10)}$$

$$= 1.412 + .826 + .0826$$

$$= 2.32 \Rightarrow \underline{\underline{3.65\,dB}}$$

Assuming $T = 300K$, we know

$$P_{in\,dBm} = -174 + 10\log(B) + SNR_{out}|_{dB} + NF$$

OR

$$SNR_{out}|_{dB} = P_{in\,dBm} + 174 - 10\log B - NF$$

$$= -85 + 174 - 10\log(150e^6) - 3.65$$

$$= \underline{\underline{3.59\,dB}}$$

In order to improve the NF, we must choose high gain and the lowest NF at the preceding stage.

Amp 2 has the highest gain and marginally greater NF than BPF.

and similarly Amp 1 has larger gain but marginally large NF than BPF.

So, intuitively Amp 2 → Amp 1 → BPF combination could potentially improve the NF.

Similarly as before

$G_A = 31.62 \qquad G_B = 10 \qquad G_C = .708$

$NF_A = 1.585 \qquad NF_B = 1.585 \qquad NF_C = 1.412$

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

$$= 1.585 + \frac{.585}{(31.62)} + \frac{.412}{(31.62)(10)}$$

$$= 1.585 + .0185 + 1.3 \times 10^{-3}$$

$$= 1.604 \Rightarrow NF_{total} = \underline{\underline{2.05\ dB}}$$

The new SNR then improves to

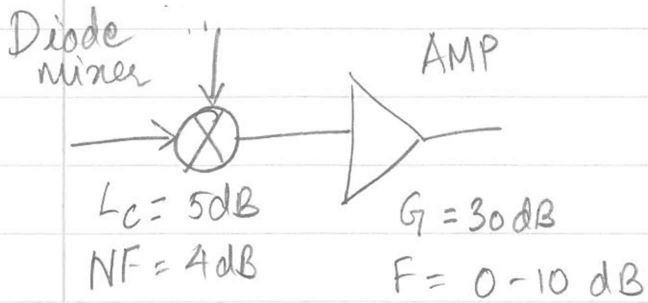
$$SNR_{out}|dB = P_{in}\,dBm + 174 - 10\log(B) - NF$$

$$= -85 + 174 - 10\log(150e^6) - 2.05$$

$$= \underline{\underline{5.18\ dB}}$$

2:10

Case 1



We have $G_A = -5\,dB$ $\quad$ $G_B = 30\,dB$

$NF_A = 4\,dB$ $\quad$ $NF_B - 0 - 10\,dB$

$$NF_{TOTAL} = (10^{4/10}) + \frac{10^{NFB/10} - 1}{(10^{-5/10})}$$

when $NF_B = 0$, $NF_{Total} = 4\,dB$. as expected

when $NF_B = 10$; $NF_{total} = 10^{.4} + \dfrac{10^{10/10} - 1}{(10^{-0.5})}$

$$= 30.97 \Rightarrow NF = \underline{\underline{14.9\,dB}}$$

NF varies from $4\,dB \longrightarrow 14.9\,dB$ as the amplifiers NF moves from $0 \rightarrow 10\,dB$.

Consider Case 2

$G_A = 3\,dB$ $\quad$ $G_B = 30\,dB$

$NF_A = 8\,dB$ $\quad$ $NF_B = 0 - 10\,dB$.

$$\therefore NF_{total} = (10^{8/10}) + \frac{10^{NFB/10} - 1}{(10^{3/10})}$$

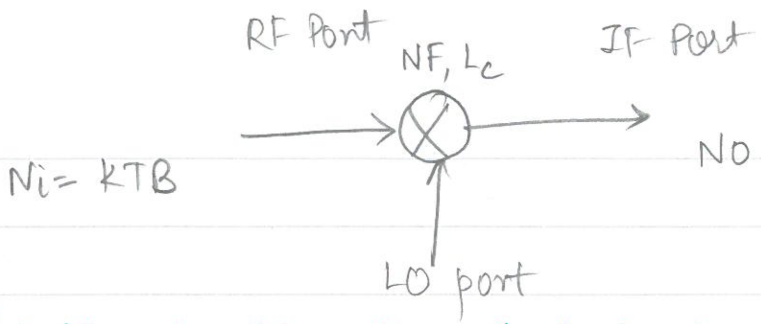
When $NF_B = 0\,dB$, $NF_{total} = 8\,dB$ as expected

$NF_B = 10\,dB$, $NF_{total} = 10.82 \Rightarrow \underline{10.34}\,dB$.

So what are the implications of this?

Noise figure of the second stages determines the overall noise figure to an extent.

2.11



[Briefly describe the 3 ports of a mixer just for clarity]

The gain of the mixer is $1/L_c$ in this case.
We know,

$$NF = \frac{SNR_{in}}{SNR_{out}}$$

$$= \frac{P_{sig\,in}/N_i}{P_{sig\,out}/N_o}$$

$$= \frac{P_{sig\,in}}{N_i} \times \frac{N_o}{P_{sig\,out}} \Rightarrow NF = \frac{P_{sig\,in}}{N_i} \times \frac{N_o}{(P_{sig\,in} \times G)}$$

Since $G = 1/L_c$

$$NF = \frac{L N_o}{N_i} \quad \text{or} \quad N_o = \frac{N_i\, NF}{L}.$$

Since $N_i = KTB$ for a Bandwidth B,
we get

$$N_o = \frac{NF*ktB}{L}.$$