Lab 2

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1 Lab 2.2: Modeling Carrier Phase Uncertainty

1.1 Goal of the lab:

The goal of this lab was to illustrate how wireless multipath channels can be modeled in complex baseband.

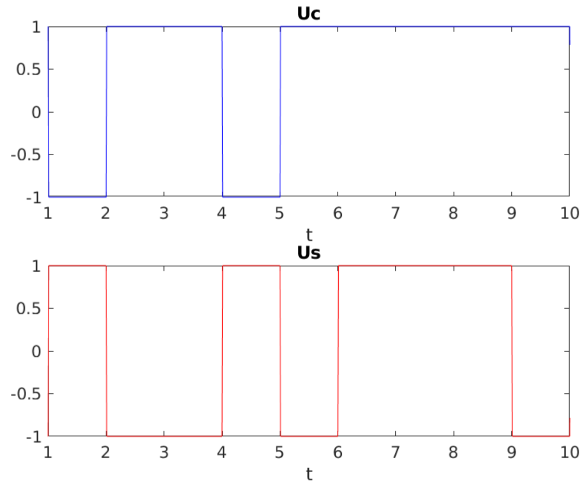
1.2 Laboratory assignment:

For the first part I took a pair of independently modulated signals:

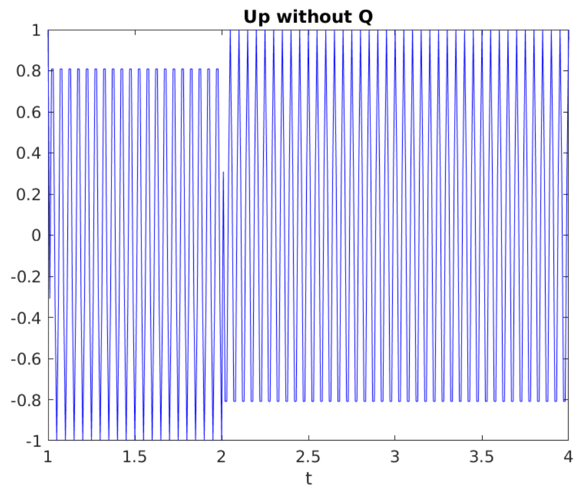
$u_c(t) = \sum_{n=1}^{N} b_c[n]p(t-n)$ and $u_s(t) = \sum_{n=1}^{N} b_c[n]p(t-n)$

where the symbols $b_c[n]$ and $b_s[n]$ are chosen with equal probability to be +1 or -1, and $p(t) = I_{[0,1]}(t)$.

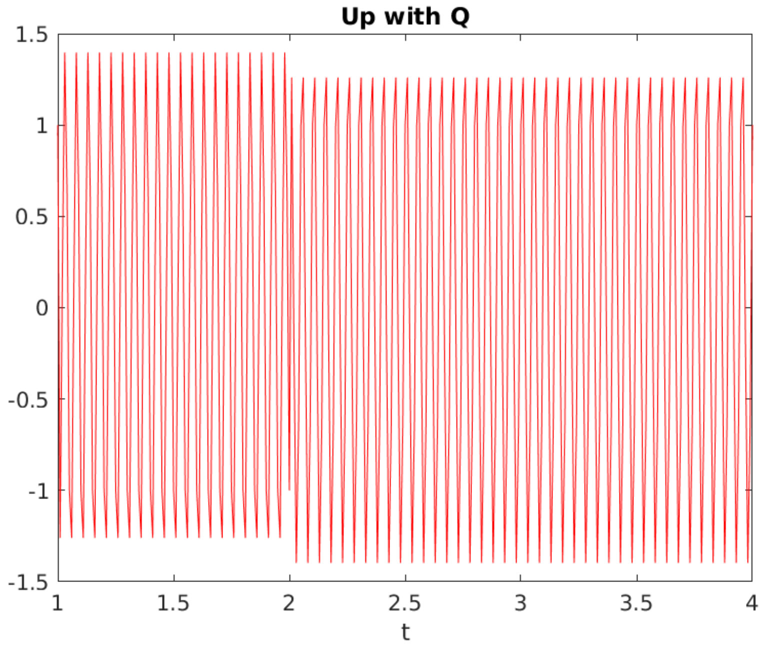
For part 1.1, the plot for these two signals over 10 symbols was:



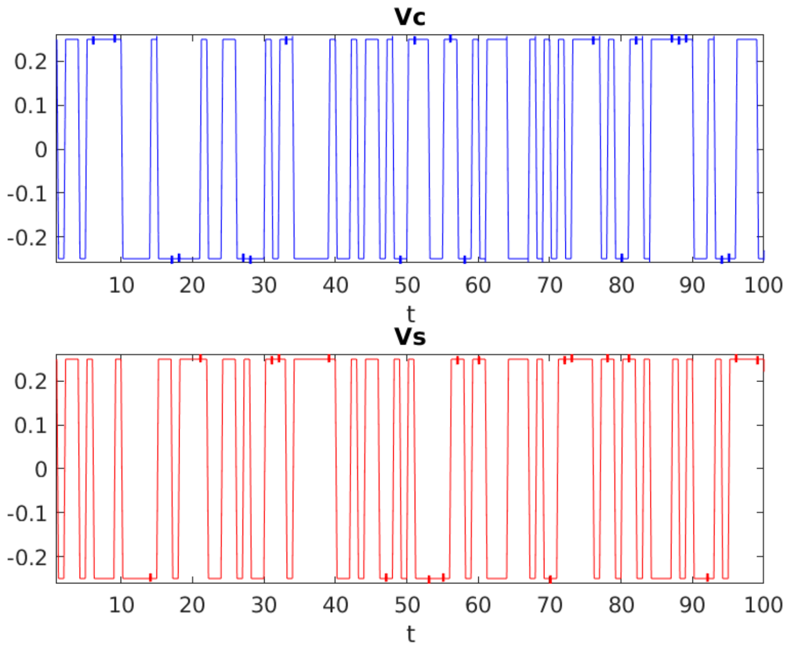
For part 1.2 I upconverted $u_c(t)$ by multiplying it by $cos(40\pi t)$. The graph was a BPSK signal:



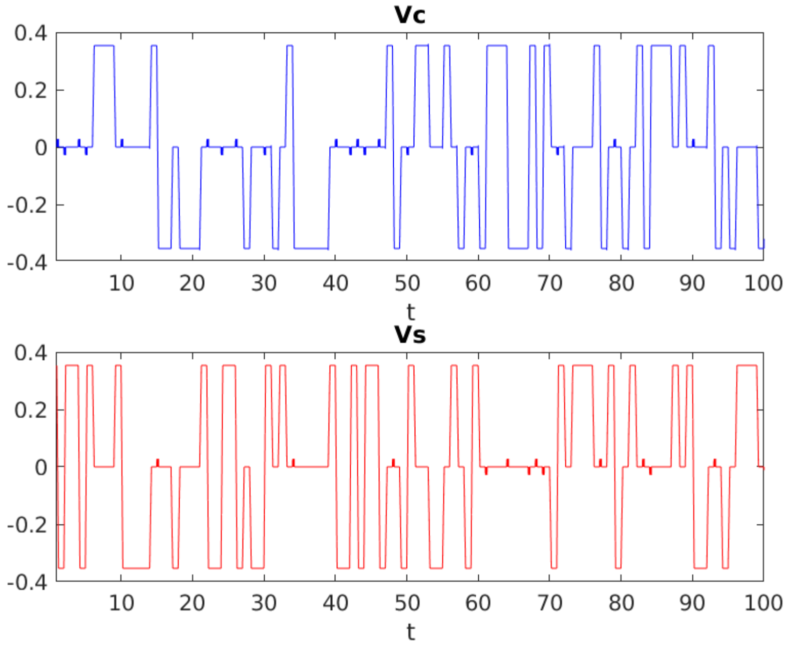
That was the I component. To have the whole passband signal in 1.3, I had to add the Q component, that is, $u_p(t) = u_c(t)cos(40\pi t) - u_s(t)sin(40\pi t)$. The result is a QPSK signal:



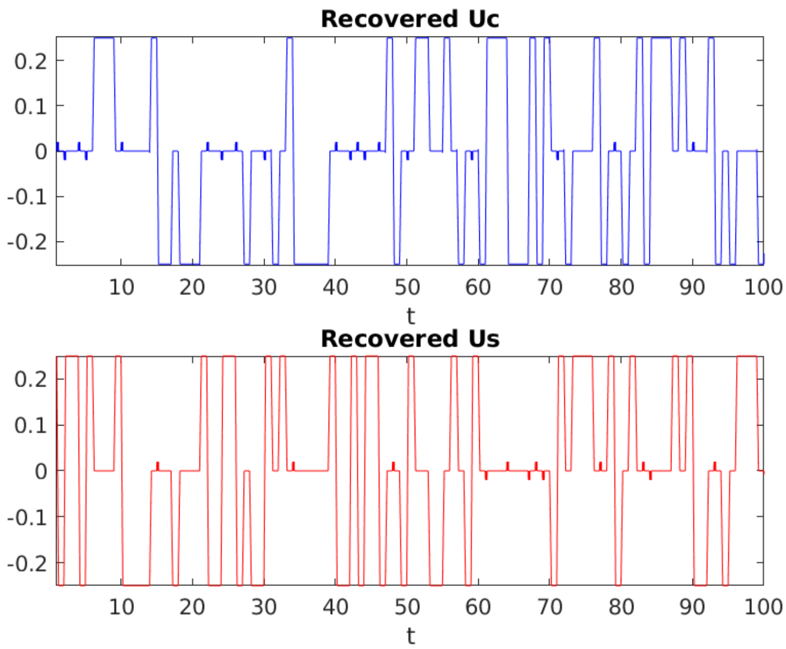
For part 1.4, I downconverted $u_p(t)$ by doing $2u_p(t)cos(40\pi t + \theta)$ and $2u_p(t)sin(40\pi t + \theta)$ and then getting the resulting signals through a low pass filter $h(t) = I_{[0,0.25]}(t)$. When $\theta = 0$, the result was:



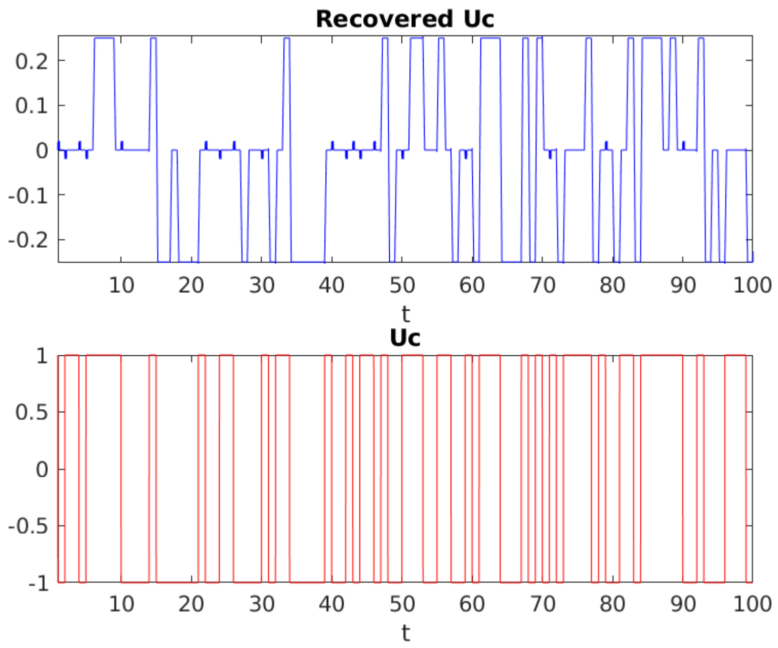
On the other hand, when $\theta = \frac{pi}{4}$, the result was:

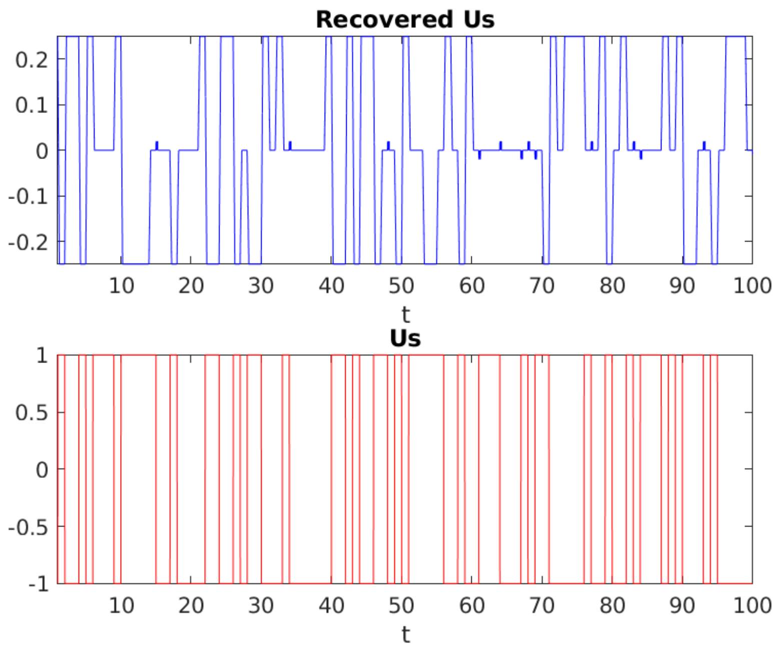


The result from part 2.5 was multiplied by $e^{-j\frac{pi}{4}}$. Then, to recover $u_c(t)$ and $u_s(t)$ I had to multiply the outcome of part 2.5 by $e^{j\frac{pi}{4}}$.



Here there is a comparison between the recovered signals and the original ones. One can see that now there are values in 0 that there weren't before because the possible values were either -1 or +1. Now there are those in the middle because when the phase was added, the QPSK constellation was shifted, adding some values.





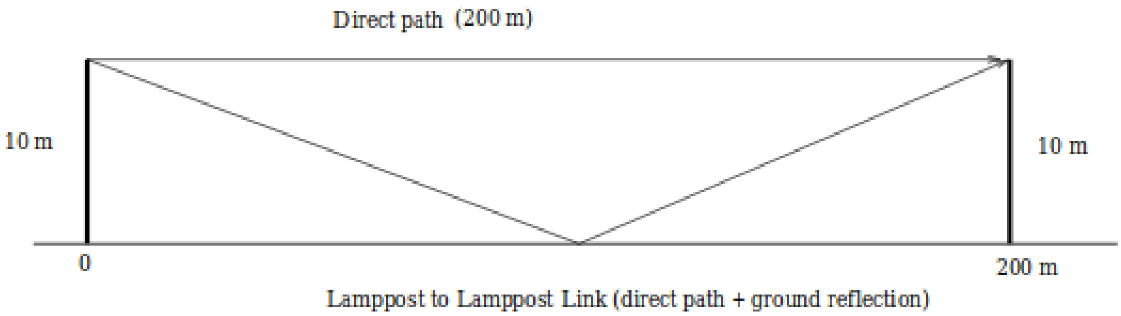
2 Lab 2.3: Modeling a Lamppost based Broadband Network

2.1 Goal of the lab:

The goal of this lab is to illustrate how wireless multipath channels can be modeled in complex baseband, that is, the same as Lab 2.2.

2.2 Laboratory assignment:

The lab presents two lampposts of height 10 meters and separated 200 meters. There is a direct path and an indirect path that works like in the figure:



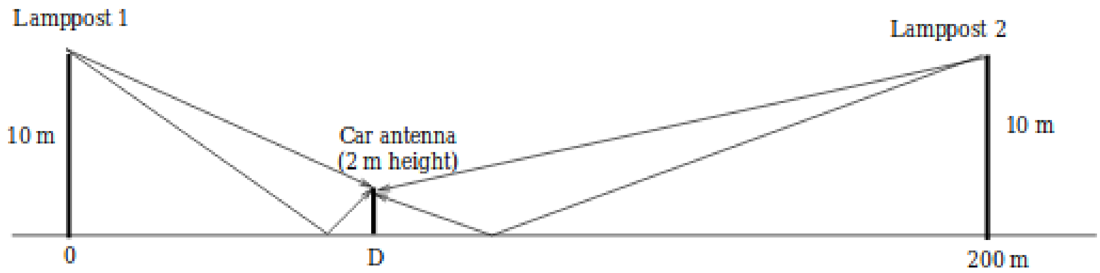
For 2.1, I had to find the delay spread and coherence bandwidth using trigonometric formulas. The code used was:

```
f = 60e9;                                    %Unlicensed spectrum at 5GHz
c = 3e8;                                     %Speed of light
n1 = 1;                                      %Refractive index of air
n2 = 8;                                      %Refractive index of ground
D = 200;                                     %Distance between lampposts
ht = 10;                                     %Height of the first lamppost
hr = 10;                                     %Height of the second lamppost
k = 2*pi*f/c;                                %Wave Number
d1 = sqrt(D.^2 + (ht-hr).^2);                %Trigonometric formula
d2 = sqrt(D.^2 + (ht+hr).^2);                %Trigonometric formula

delay = d2/c - d1/c;                         %Delay spread
bc = 1/delay;                                %Coherence Bandwidth
```

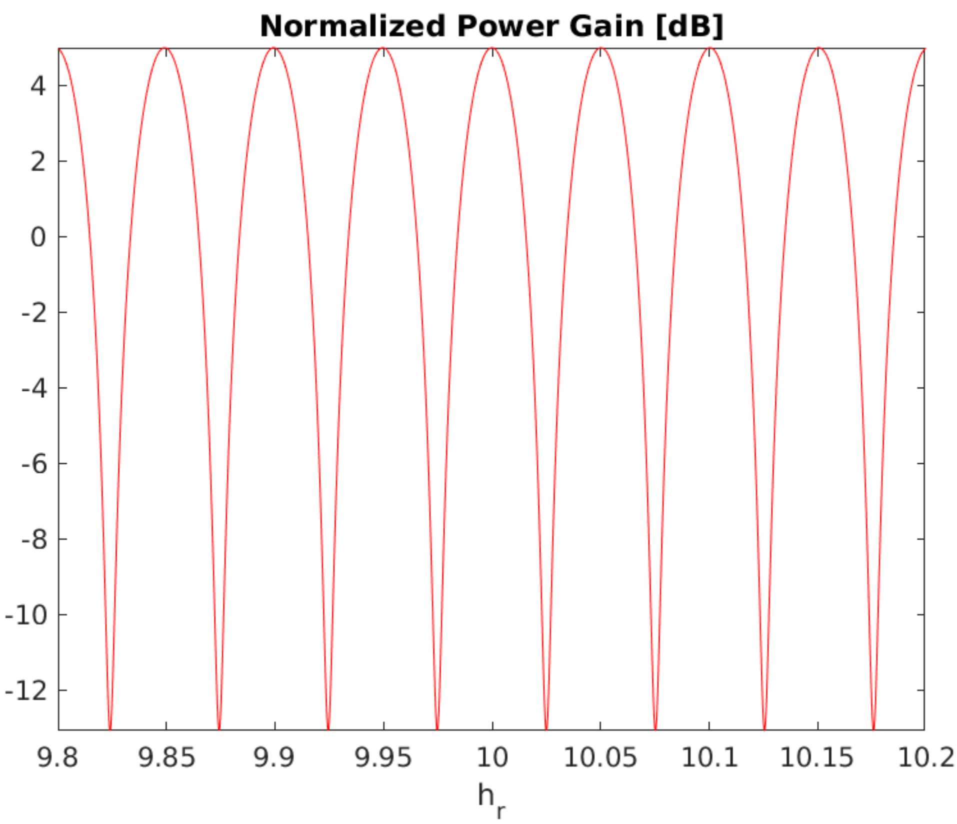
The resulting delay spread was 3.3250e-09, that is, 3.325 nanoseconds. On the other hand, the coherence bandwidth was 3.0075e+08, that is, 0.3 Gigahertz.
If the message signal has 20 MHz bandwidth, the channel's coherence bandwidth is more than 10 times the signal's bandwidth. Therefore, It can be considered narrowband with respect to the channel.

For 2.2 there is a car 2 meters tall and at 100m of the lamppost. The system is modeled like in the figure:



The code used is similar to the one above, so the resulting delay spread was 1.3265e-09, that is, 1.32655 nanoseconds. On the other hand, the coherence bandwidth was 7.5389e+08, that is, 0.75 Gigahertz.

For 2.3 on I explored the sensitivity of the lamppost to lamppost sensitivity to variations in height by varying the height of the receiver from 9.8m to 10.2m in steps of 1mm. I plotted the normalized power gain in dB, that is, $20log_{10}\frac{|h|}{|h_{nom}|}$ with the following result:



The NPG is maximum every 0.05m in multiples of 5, and minimum every 0.05m but right in the middle of all the maximums.

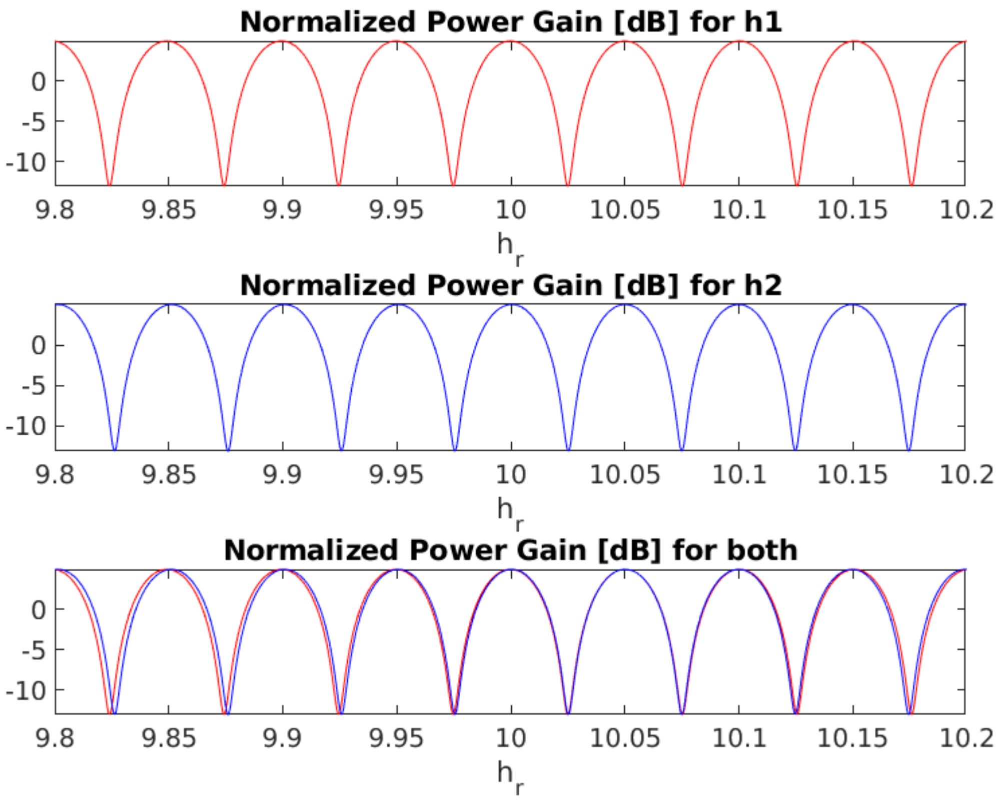
For 2.4 I calculated the probability of the normalized power gain being smaller than -10dB. Since we have an uniform distribution, this could be done by dividing the number of point in which this happens by the total number of points.

```
i = 0;                                  %Counter
for x = 1:length(npg1)                  %Going through npg1
    if npg1(x) <= -10                   %Condition
        i = i+1;                        %Adding counter
    end                                 %End of conditional loop
end                                     %End of for loop

probability = 100*i/length(npg1);       %Probability in %
```

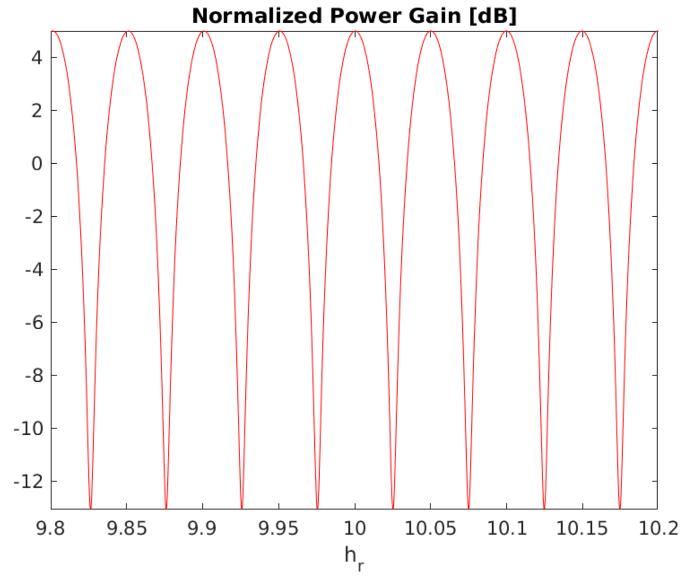
The resulting probability is 8.1480%.

For 2.5 we have to repeat exercise 2.3, but now there are two antennas vertically spaced by 1cm, that is, one at 10m and the other one at 10.1m. Therefore we get two plots for the normalized power gain, one for the lower antenna and one for the upper antenna. The result is:



The peaks look like they are almost at the same time all the time looking at teh two first figures, but as one can see in the third figure, they are not quite at the same time. They are only exactly the same between 10.025 and 10.075 and they have a phase elsewhere.

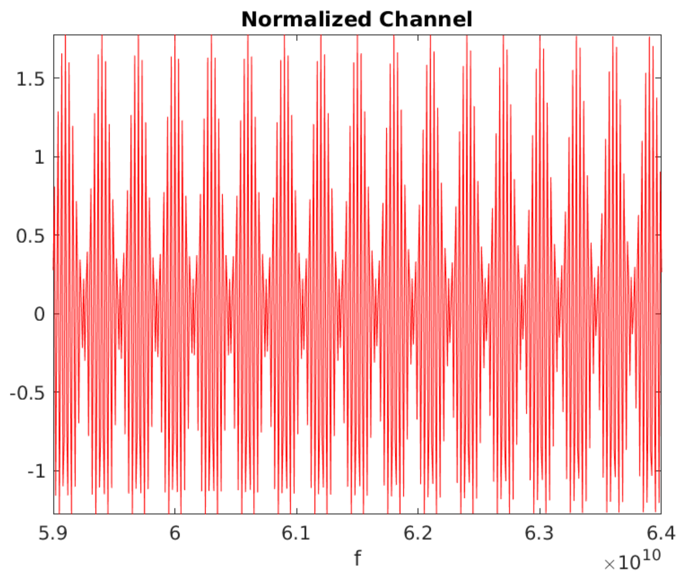
For 2.6 I plotted the normalized power gain for the antenna whose channel is better with $20log_{10}\frac{max(|h_1|,|h_2|)}{|h_{nom}|}$. The result was the plot for the upper antenna:



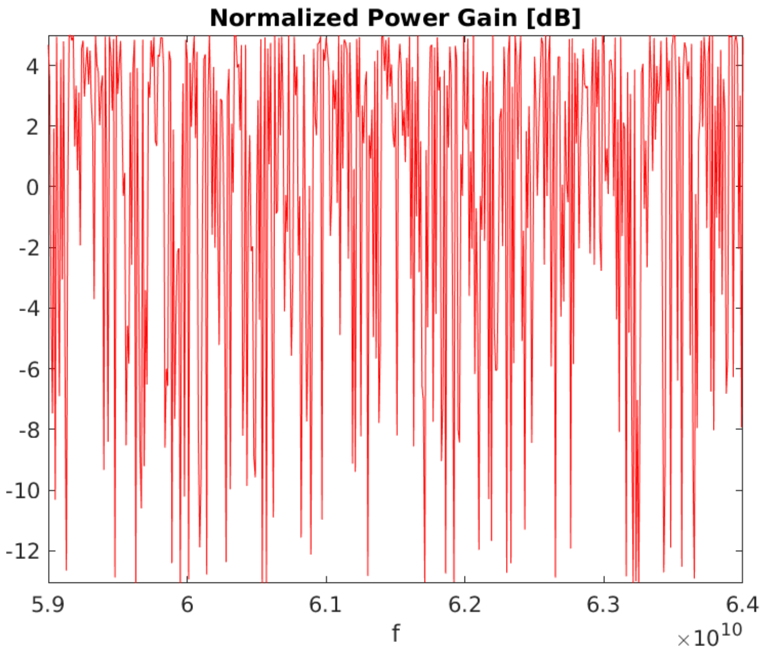
Now the minimum value is -13.06dB.

For 2.7 I had to calculate the probability of the graph in 2.6 being lower than -10dB. I used the same code as in 2.4, with a final probability of 8.0980% of the values dropping under -10dB as opposed to a probability of 8.1480% for the lower antenna, that is, 0.05% higher probability for the lower antenna.

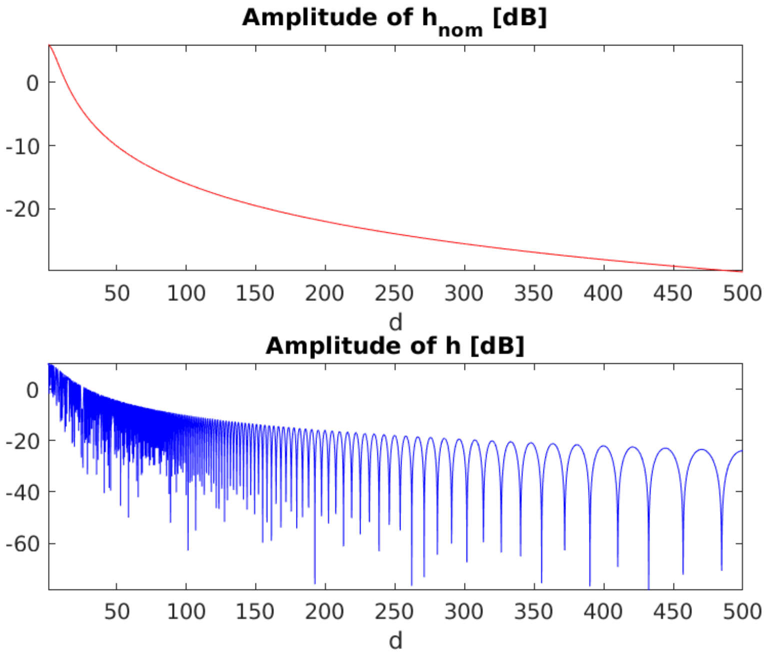
For 2.10 I worked with frequency diversity. I worked with the original heights of the lampposts to get the normalized channel as a function of the carrier frequency using a vector from 59GHz to 64GHz with a step size of 10MHz. The normalized channel plot was:



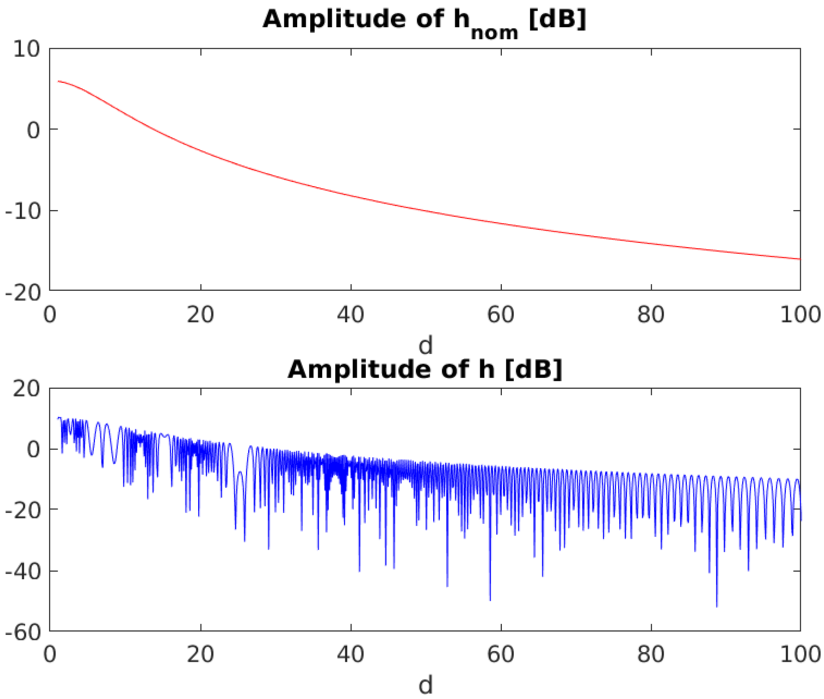
For 2.11 I had to calculate the probability of the normalized channel gain being below -10dB if the carrier frequency is chosen randomly over $[59, 64]$ GHz. I used the same code as in 2.4 and 2.7, with a final probability of 7.3852%. The normalized power gain of this normalized channel with random frequency is the following:



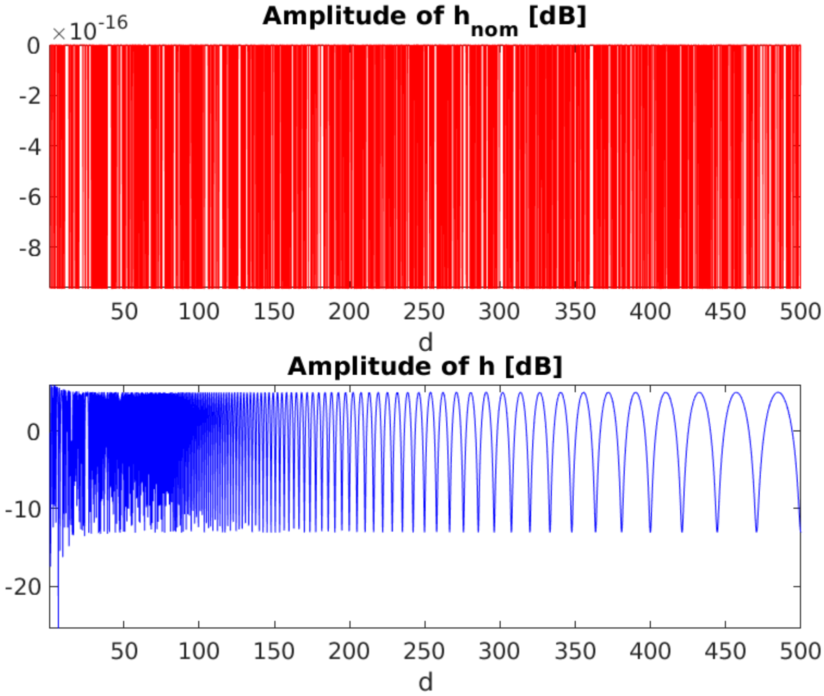
For 2.14 I worked with $|h_{nom}|$ and $|h|$ as functions of the distance, coming back to the access channel from the lamppost to the car. I plotted how the amplitude in dB decays with the distance from 1 to $500m$ with the following result:



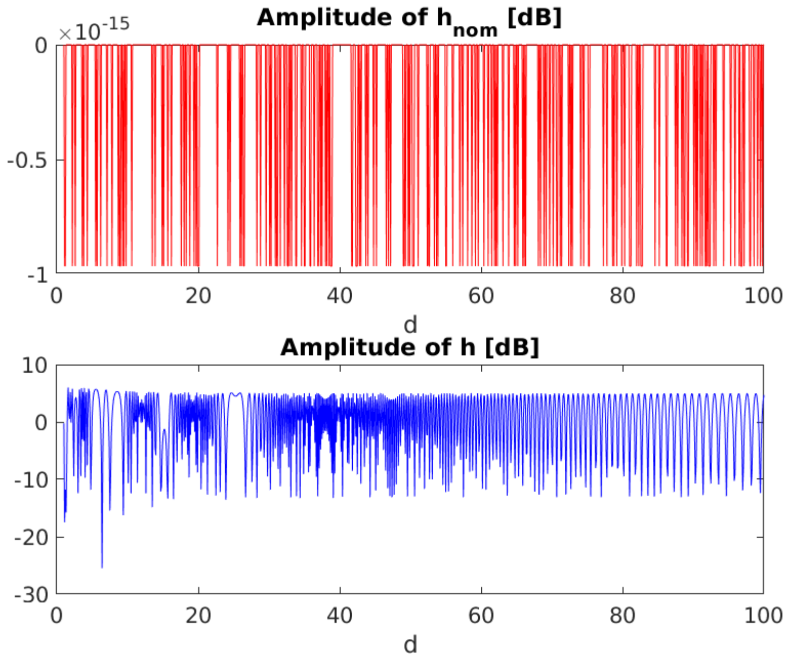
As one can see, it decays faster in the beginning and the the curve smooths. When zooming in to the first values, one can appreciate it:



Finally, 2.15 consists of repeating 2.14 but taking in count the effect of surface roughness, that is, taking $A_r = \alpha_s \rho_s$ with $\alpha_s = e^{-8(\pi \sigma cos(\theta_i/\lambda)^2}$. The plot obtained was:



Here the amplitude stays constant for all the distance. When zooming in to the first values, one can see that they don't change:



3 Conclusion:

In this lab I learned how to use MatLab to work with complex baseband (Lab 2.2) and with multipath channels (Lab 2.3). I felt like Lab 2.2 was a bit smoother to do, partly because it did not involve any trigonometry and it was only working with pure signals. Lab 2.3 was definitely harder, as well as longer. It was really helpful to see how parameters like the amplitude or the sensitivity change with others like the frequency, the distance between two antennas or the distance. Unfortunately, I was not able to finish exercises 2.8, 2.9, 2.12 and 2.13, since I did not understand what was being asked in the question and I could not reach out for help in time to hand it in. Nevertheless, I will ask in the next lab session to make sure I understand everything about multipath channels and how they behave. Overall, I think now I understand better the second half of chapter 2 of the book and I am better prepared to work with problems in this area.