COMM.SYS.450

Multicarrier and Multiantenna Techniques

Exercise 5

Familiarizing with the task before attending the session is strongly recommended, and some work to finalize the code may be needed afterwards. For the exercise bonus, it is required to return the solution script to **Moodle** by the following Tuesday at 23:00. A model solution will be available on Moodle once the submission is closed. For any inquiries regarding the grading of the exercise returns please contact Karel Pärlin (karel.parlin@tuni.fi).

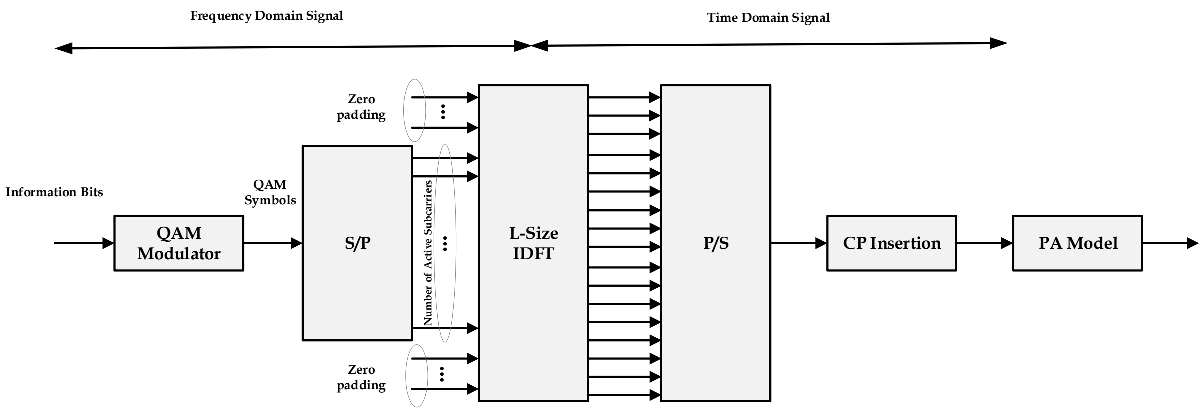
This fifth and last task consists of implementing an OFDM transmitter and analyzing the effect of the power amplifier on the transmitted signal. You have to generate an OFDM signal made up of 1200 active subcarriers, with 15 kHz as subcarrier spacing, CP length of ¼ of the useful symbol duration and 64-QAM symbols as subcarrier modulation. The power amplifier is a nonlinear device that introduces nonlinear distortion, and it can be modeled, among many others, as a memoryless polynomial model of the following form

$$y(t) = \alpha_1 x(t) + a_3 x^3(t) + \alpha_5 x^5(t) + \alpha_7 x^7(t) + a_9 x^9(t)$$

Note that only the odd terms of the polynomial are considered here, since they are the ones producing distortion around the carrier frequency. Even terms lack of interest since they produce distortion around baseband and twice the carrier frequency, and therefore, they are filtered away by the antenna.

The nonlinearities of the power amplifiers introduce inband distortion that deteriorates the inband signal quality degrading the SINR and thus, the system performance. More importantly, the power amplifiers, and in general, any nonlinear device, produce out-of-band emissions, that is, they produce spectral widening of the signal, making the transmitter radiate out of the assigned channel and producing thus harmful interference to the adjacent channels. There are very strict limitations on how much power a certain system can radiate to the adjacent channels, and there are many techniques that seek to reduce such emissions, e.g., digital predistortion.

The transmitter architecture is shown in the figure below:



Since the OFDM signal that we create in this course is very simple is not adequate to observe the effect of the PA on the transmit signal, consequently, an OFDM signal that includes symbol windowing for better spectral containment and PAPR reduction is also provided. The signal is in a mat file called Final_OFDM.

You are provided with a Matlab function called **PA_model_lab(PA_input,backoff)** takes as inputs the OFDM signal that you have created and a certain back-off value, and it generates the signal at the output of the power amplifier following a memoryless polynomial model of the form shown above.

The function **plot_PSD(signal,Fs_final,color)** takes as input a time domain, the sampling frequency and the color that you want for the plot, e.g., 'r' or 'b' and it plots the power spectral density estimation based on the periodogram method considering Welch windowing.

The function **[ACLR_r, ACLR_l] = ACLR_calc(signal,BW,SystemFs)** calculates the adjacent channel leakage ratio of the right and left adjacent channels, which is a figure of metric to quantify the out-of-band quality of the signal. The higher the better. ACLR limit specified by 3GPP for LTE is 45 dBc.

Important note: Since we want to observe/analyze the nonlinear distortion introduced by the power amplifier, that is, the spectral widening of the signal, the IFFT size, and therefore, the sampling frequency of the signal, needs to be selected such that a certain oversampling is provided, otherwise, we will not be able to observe the higher spectral components at the output of the PA. An **IFFT size of 8192** should do the job.

Important note: You will need to generate around 100 OFDM symbols to be able to see a clean spectrum.

Important note: The function **PA_model_lab(PA_input,backoff)** takes as input the signal "PA_input" this signal must be a **COLUMN** vector. Since you have to generate 100 OFDM symbols, a common approach is to work with matrices. You have to transform that matrix into a column vector. You can do it very easily in the following way.

Colum_vector = Matrix(:);

Important note: When plotting the spectrums, the signal at the Input of the power amplifier and the signal output of the power will have different mean power. In order to have them both at the same level, you need to use the function **plot_PSD** in the following way.

plot_PSD(scaling_factor*signal/rms(signal), Fs_final, color)

where scaling_factor = sqrt(18*10^6) ; sqrt(BW)

and signal is the signal that you want to plot.

You have to return a PDF file with the following content

- Plot of the spectrum at the input of the power amplifier and at its output. It is advisable that both spectrums are shown in the same plot. Use the function plot_PSD for this purpose.
- Try with different values of back-off from 4 to and explain the difference utilizing the PAPR of the signals as a reference.
- Calculate the ACLR of the signal at the input of the power amplifier and at the output.
- Plot the AM-AM response of the power amplifier. The AM-AM is the representation of the output signal envelope as a function of the input signal envelope. **scatter(|A_in|, |A_out|)**
- After amplifying the signal, remove the CP and demodulate the OFDM waveform that you have generated. Plot the resulting 64-QAM symbols together with the 64-QAM symbols that were originally generated. This corresponds to the inband distortion.
- Explanation of why the PA introduces inband and out-of-band distortion and how they depend on the power of the input signal.