Lab 3: Transmission through SDR

5ETC0 - Communication 1

Throughout the lab, we will use the ADALM-PLUTO SDR for the wireless transmission of data. Before you can start the Lab, you need to reserve an SDR group. Each group contains 3 SDRs. There are 27 groups (81 SDRs in total). Therefore we encourage you to work in student teams consisting of 3 students. **Per team, you place only ONE reservation per time-slot! Each group reservation gives you access to 3 SDRs**.

The SDR can be reserved through the following link: `https://remoteradio.ele.tue.nl`.

Note: that you must be on the TU/e network to access this page. First, select a date, then select a time-slot. Each time-slot has a duration of one hour. To use the same SDR group for a longer time, please make certain to reserve it for multiple time-slots. The maximum amount of reservations per day is 4. Per reservation, you will receive an email with the login details and the URL to access your specific SDRs.

To sign in, you use the email address that you used for the registration and the password that you received via email! The password does not end with a ".". If you entered the wrong login details then remove your browser history of the last hour to reset the active logins.

Some general remarks about the use of the SDR:

1. Always start the receiver before the transmitter.
2. Sometimes the automatic playback won't work. This is not because you damaged the SDR, but because of occasional issues with the web application.
3. **You must change the center frequency to the frequency given in the reservation email**. This is 2400+[SDR group number] MHz. For example, group number 3 has 2403 MHz. Otherwise, the SDRs will interfere with those of other groups.
4. If you experience any problem with the device check in with a TA to check the device itself.

Exercise 1: Analog transmission AM & FM

The first exercise will focus on AM transmission. The transmission is conducted through the SDR and is therefore digital. The signal is stored with 8 bits per sample, due to the calculation power of the SDR. Therefore, there are only 256 levels to which the signal can be mapped (recall the quantizing exercise from lab 1). Higher gain will enable the use of more levels.

To set up, follow these steps:

1. Reserve the SDR group using the provided link. Follow the instructions in the reservation email to access the SDR.

2. Open **only one** web page for the SDR receiver URL and **one page for each** of the transmitter SDRs.
3. Change the center frequency as specified in your reservation email.
4. On the receiver, start the analog receiver function.
5. At the start of the new hour you need to log in with the new password. It will automatically ask you to login again. Do not use the old password.
6. For the nearby SDR, select ”song1.wav” as the transmitter file and start the transmission.

If all goes well, you will hear the audio playback start on the web page of the receiving SDR. If you have any issues, contact a TA for support.
Note: Starting the transmission or receiving will terminate all background processes. Therefore, we recommend that each student has only one web page open per SDR to avoid accidentally interrupting an ongoing transmission.

Transmit the `song1.wav` file over the SDR in AM mode with the default settings (values that are already present when you open the web application). However, do change the center frequency as mentioned before. Use the base receiver for receiving the signal and start with the nearby transmitter for transmission. Note that you can access these from the reservation email.

1. What do you hear? What happened to the signal while being transmitted over the SDR? (Compare it with the original sound, provided within the .zip file.)
2. Download the received audio and plot the Power Spectral Density plot in MATLAB using `periodogram(signal, [], [], fs, 'centered')`. What does the plot show you? Could it explain what you hear? (Hint: You can load the signal using `[wav, fs] = audioread("song1.wav")`.)
3. How many dB is lost while transmitting through the SDR at this default settings?
4. repeat the same using FM modulation instead of AM. How much dB drop do you notice?
5. How come the FM spectrum is different then that of AM while using the same transmission parameters?
6. Plot the amplitude of the obtained signal against the amplitude of the original signal. What do you see? Can you explain this? (Hint: look at the gain)
7. Try to find values for the variables transmission power and receiver gain for which the SDR has a better spectral output. (Hint: use the ‘sample maximum: x.xxxx’ in the console of the analog receiver to find these values. The sample maximum is related to the gain.)
8. At what transmission power does the system not perform better anymore? Why could this be the case?
9. Listen to the sound and compare the signals in MATLAB. Compare the Power Spectral Density as well as the amplitude. Think about the delay when you plot the amplitude plot (Hint: look at the data and the starting point of the transmission).
10. Now repeat the AM transmission for the Far transmitter which is further away from the receiver. Then plot the spectrum next to that of the near transmitter and original signal. Use the default settings of -10 dBm transmission power, and 30 dB receiving gain. What do you notice?
11. Try the same values for FM transmission as you did for AM transmission (change the SDR from AM to FM). Do you hear a difference?

Exercise 2: Simulink digital data Transmission

1. You will transmit a waveform through a simulation of a noisy channel. In analog transmission, the time taken to transmit a waveform is the time of the audio file being transmitted. You will inspect the effect of levels on digital transmission time.

   You are given several audio files to choose from. You can also upload your own (preferably encoded in unsigned 8 bit integers, with a sample rate of 8000kbps).

   (a) Transmit a chosen audio file with QAM4 as follows:

      i. Open `Lab3_DigitalModulation.m`.

      ii. Run the 1st section of the code. This uploads the audio file to your MATLAB workspace.

      iii. Run the 2nd section of the code. Choose the appropriate amount of `bits_per_symbol` for a 4 level channel (QAM4). `binary` is the vector that you will be transmitting through the noisy channel.

      ```
      binary = audioToBinary(wav, bits)
      ```

      iv. Open `Lab3_DigitalModulation.slx`

      v. Inspect the model. The binary is modulated with QAM, sent through a noisy channel, and decoded before the output. Some useful measurements are given.

      vi. Double Click the Rectangular QAM Modulation block. Choose the "M-ary number", which represents the number of levels in the system. As you click "Apply", you will be able to see what the constellation diagram of the levels looks like in the complex plane by "View Constellation".

      vii. Repeat the same step for the demodulator block placed after the channel.

      viii. Press Run (Ctrl+T), and wait. This will take a while, so be patient. The simulation will be finished once the full message is transmitted.

      ix. Once the simulation is done, note down the BER and the time spent transmitting.

      x. Repeat all previous steps for QAM8. QAM16, QAM32, QAM64, QAM128 and QAM256.

   (b) Plot the transmission time against levels with MATLAB in section 3. What happens to the transmission time as levels increase?

   (c) What trends can you see with increasing levels? How does the transmission time compare to analog transmission?

   (d) When does the increase in BER overshadow the decrease in transmission time.

   (e) Change the SNR of AWGN to 15 dB. What level of quantization is the highest that can be transmitted with a BER lower then 5%?.

Exercise 3: Digital transmission

In this exercise, we will work with the digital function of the SDRs. In the digital transceiver part, note that we have the following options. You select the audio file, the modulation format to use, and the transmission power, next is the forward error correcting code. Note that they have 2 options, which are the inner and outer. See section 9 in the reader for more info. These codes contain additional information to detect and correct bit errors in digital frames. The last option is whether to set the frequency and enable automatic correction, or manually give ppm frequency correction. Keep it always on automatic as the SDR will scan for a known frequency and then calibrate it's own internal transmitter.

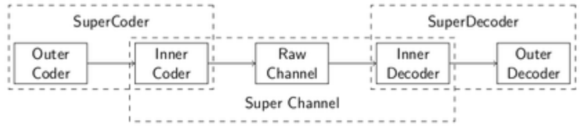

Figure 1: Concatenated coding in digital transmission

1. What is the benefit of using FEC and why would you use double FEC encoding? What is the benefit and the downside?
2. Use the Near Transmitter and set the power on the default of -10 dBm. Pick a song and set modulation format to QAM 4. Put both FEC to noerror-correction. Then first start the receiver and then the transmitter and listen to the results. What do you notice compared to the analog transmission?
3. Now change the transmission power to 0 dBm. Do you notice any difference?
4. Under modulation format, you can find multiple formats. Use QAM 4 up to QAM 256, note down the transmission time and plot it in a figure. What pattern do you see? Describe how the modulation format influences the transmission time. The SDR also has some overhead start time before the actual transmission starts. How long is the overhead time?
5. Transmit with QAM 128 modulation, and transmission power at -10 dBm, and noerror-correction for inner and outer fec. What do your hear? Now repeat the transmission but then select for both inner and outer fec an error correction coding scheme. For example inner: hamming(12,8) and outer SEC-DED(72,64). How does it change transmission time?
6. Add hamming(7,4) blockcode coding for inner FEC, keep the outer FEC on noerror-correction. How long does the transmission now take? Does this time make sense with theory?
7. Now lets compare different modulations. Compare the following modulations which are all 1-bit symbol size using noerror-correction: PSK, ASK2, BPSK, DPSK, and OOK. What is the package success rate and the BER rate? How can it be that the OOK performance is so different?
8. Now repeat with PSK8, DPSK8, ASK8, QAM8, and APSK8. Which performance the worst in package success rate?