

# ETIN85 - Wireless Communication Channels

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## Assignment 2

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### 1 Part 1 - Wideband characterization

#### 1.1 Aim

The aim of this assignment is to analyze the distribution of the received power and amplitudes for an indoor small range wireless system. Furthermore, the aim is to investigate the behavior of the impulse response, and how this relates to the bandwidth of the system. Finally, the PDP, RMS delay spread and time- and frequency correlation will be investigated.

#### 1.2 Measurement setup

Channel measurements are performed with a vector network analyzer connected to two broadband antennas. These antennas can be positioned along a rail by stepper motors and everything is controlled with a laptop running LabView. An overview of the system is found below. The network analyzer measures the transfer function,  $H(t, f)$ , at a number of frequency points. Both the number of points,  $N_f$ , and the frequency band is controlled by the Labview program. Due to frequency regulations we use the 5 GHz band. By moving the antennas between each measurement we can follow the transfer function along a certain line. Since the measurements take some time to perform, we must make sure that the channel is static. If we know the distance between the measurements we can then evaluate the channel response for an arbitrary receiver or transmitter speed afterwards.

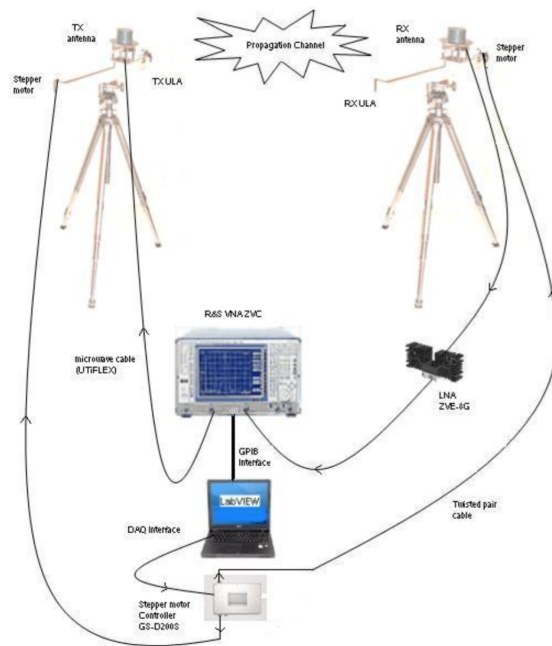


Figure 1: Measurement setup with a VNA, and two rail for positioning the Tx and Rx antennas. Both the VNA and the stepper motrors connected to the rails are controlled through a LabView program. The antennas are broadband antennas for the 5 GHz band.

We have already discussed the measurement setup and the different measurement settings. The transfer function is measured using the following settings:

- Frequency band: 5.4 – 5.6 GHz
- Frequency points:  $N_f = 401$
- Number of positions along the linear rail: 91
- Antenna spacing along the linear rail:  $\Delta d = 0.5$  cm.

### 1.3 Measurement data and assignment

You have access to the data set, which is called `Hcorrected.mat`. Load this measurement data set into Matlab using the `load` command. Then proceed to investigate the following:

- Plot and identify the behavior of the time-dependent (or position-dependent in this case) frequency transfer function  $H(t, f)$ .
- Plot and identify the behavior of the impulse response  $h(t, \tau)$ . Do this for the full bandwidth, as well as for a medium and small bandwidth.
- Investigate the distribution of the amplitude of the frequency transfer function. You do not have to fit the data to a certain distribution, but please discuss possible distributions that could be appropriate and compare what you get to these distributions.
- Investigate the distribution of the amplitude for different taps of the impulse response.
- Derive and plot the measured power-delay-profile (PDP).
- Based on the PDP, calculate the RMS delay spread.
- Optional: Plot the doppler power spectra and investigate the time and frequency correlation behavior of these channels.

## 2 Part 2 - MIMO and Directional Aspects

### 2.1 Aim

For part 2, the aim is to estimate the direction of departure and direction of arrival based on a measured  $8 \times 8$  MIMO system. This is done using a simpler beamforming method, and using *Capon's* beamformer, or the minimum variance method (MVM).

### 2.2 Measurement setup

This measurement setup is similar to that of part 1, but is for an  $8 \times 8$  MIMO system with uniform linear arrays (ULA). The measurements were performed in E:2311 as well. The basic measurement setup is shown in Fig. 2.

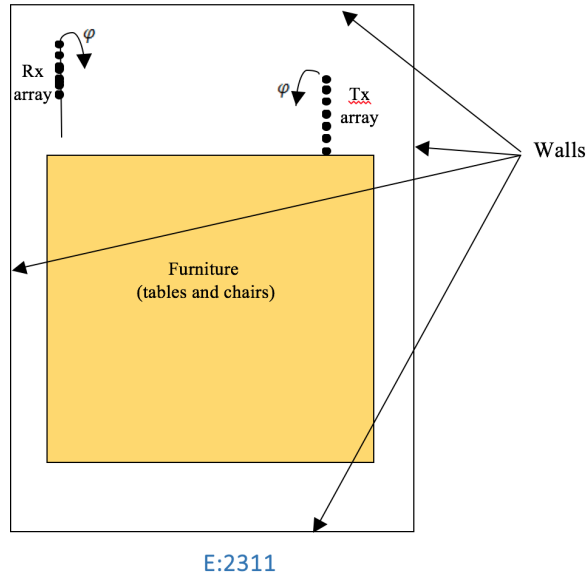


Figure 2: Measurement setup for the  $8 \times 8$  MIMO case.

The transfer function is measured in a similar manner as in part 1, using the following settings on the VNA:

- Frequency band: 5.1 – 5.3 GHz
- Frequency points:  $N_f = 201$
- Number of (virtual) Tx elements: 8
- Number of (virtual) Rx elements: 8
- Antenna spacing for the uniform linear arrays (same at Tx and Rx):  $\Delta d = \lambda/2$ .

### 2.3 Measurement data and assignment

Load the data set `T_MIMO.mat` into Matlab. You should now see a MIMO channel matrix in the workspace. This matrix,  $H(n_{\text{Rx}}, n_{\text{Tx}}, f)$  is of size  $8 \times 8 \times 401$ , where  $n_{\text{Rx}}$  and  $n_{\text{Tx}}$  denote the indices of the receive and transmit antenna elements, respectively. The measured signal can be modelled as

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n},$$

where  $\mathbf{y}$  is the received signal,  $\mathbf{x}$  is the transmitted signal and  $\mathbf{n}$  is a noise vector. The goal is now to estimate the direction of arrival (DOA) of the LOS component. It is optional to also estimate the direction of departure (DOD) for the LOS component. In

order to do this, we need the correlation matrix describing the signal at Rx array for the DOA, which is given by

$$\mathbf{R}_{rr} = \mathcal{E}[\mathbf{r}(t)\mathbf{r}^H(t)],$$

where  $r(t)$  is the array response, i.e., the received signal at all the antenna elements. Since this matrix (of size 8 by 8) is defined as an expected value, we have to estimate it as good as we can. For the measurement we can use the fact that the signal is transmitted from 8 independent positions to get an estimate of the expected value. The beamforming can be performed in either the delay-domain or in the frequency domain.

We also have to define the beamsteering vector, which is a function of the direction of arrival,  $\theta$ , which for an 8 element ULA is given by

$$\mathbf{a}(\theta) = [1 \ e^{-j\frac{2\pi}{\lambda}\Delta d\cos(\theta)} \ e^{-j2\frac{2\pi}{\lambda}\Delta d\cos(\theta)} \ \dots \ e^{-j7\frac{2\pi}{\lambda}\Delta d\cos(\theta)}]^T.$$

Now, we can find the angular spectrum for the conventional beamformer, which is given by

$$P_{BF}(\theta) = \frac{\mathbf{a}^H(\theta)\mathbf{R}_{rr}\mathbf{a}(\theta)}{\mathbf{a}(\theta)^H\mathbf{a}(\theta)}.$$

The MVM beamformer is given by

$$P_{BF}(\theta) = \frac{1}{\mathbf{a}^H(\theta)\mathbf{R}_{rr}^{-1}\mathbf{a}(\theta)}.$$

Use this to estimate the DOA of the LOS component.

## Assignment submission

Submit your assignment no later than on Feb. 19th. Your submission should include the following:

- A technical document, where you discuss and address your findings and present your results using different figures and by giving different experimental parameters estimates that you have derived.
- Submit your code as an appendix in the same document. This should be added as an appendix in the technical document that you provide. Do not submit m-files separately.

Submit your results to the e-mail address given in an email. Make sure to do this *before* the deadline.