**Laboratory 2C:**

Fourier Series and Line Spectrum

In this laboratory you will experiment with non-ideal conditions to approximate the Fourier series using the Fast-Fourier-Transformation (FFT).

Plus you will use the FFT to find out the encoding of telephone dialing system DTMF or “Touch-Tone”.

# Using the FFT in practical cases

So far the approximation we calculated with the fft() function was quite ideal, because we knew exactly the period of the incoming signal and we have adapted the time vector accordingly to match exactly one period of this time signal, plus using a fine resolution in the frequency domain. In practical cases this cannot be done, because the incoming signal is usually unknown, and you do not have the absolute control over the sampling frequency and length of the input buffer (e.g. on the oscilloscope).

What can we expect then in such “real” cases, and how can we optimise the calculated output?

1. Try out the code below and calculate for the different N values the achievable resolution in the frequency domain. Check with the pointer the frequency values for the first harmonic, and determine which ck coefficient does it corresponds to.

% PARAMETERS

N = 2^9; % number of points, try N=128, 512

aux = 0:1:N-1; % auxiliary index vector

Fs = 80e3; % sampling frequency

t = (1/Fs)\*aux;

f = (Fs/N)\*aux;

% FUNCTIONS

x\_t = 2\*square(2\*pi\*1.15e3\*t);

X\_f = (1/N)\*fft(x\_t);

% PLOTS

figure(1)

subplot(121),plot(t,x\_t),grid on

xlabel('t (s)')

subplot(122),plot(f,db(X\_f),'b',f,db(X\_f\_w),'r'),grid on

xlabel('f (Hz)')

1. Leave N=512, and add a second version of the spectrum calculated using a time window of the type Hamming (see code lines below). Superpose this second spectrum to your first plot and comment on the effect of this windowing in the spectrum calculation.   
   Hint: you can better observe the effect of the windowing by zooming in the first 10 harmonics.

window = hamming(N)';

X\_f\_w = (1/N)\*fft(x\_t.\*window);

1. Open the Matlab script *sisy\_fft\_settings\_n\_effects.m* and execute each section, observing the setting and corresponding effects:  
   1. *The basic situation: rectangle window*  
      Is spectral leakage occurring in this plot? (yes/no, and why)  
      Which harmonics can you observe? Why is there a peak around 9.5kHz?
   2. *Increasing window size*  
      Which improvements did you get by increasing the window size? (numerical values are expected)
   3. *Increasing sampling frequency*  
      What has changed here compared to the basic situation (a)?  
       Which harmonics can you observe?
   4. *Adding Windowing (Hanning)*  
      What was done here? Compare to (a).
   5. Zero-Padding  
      What was done here? Compare to (a).

Which of these changes can be done after a measurement is already done and stored as digital data?

# Decoder for DTMF Telephone Ton Dialing

The DTMF or „Touch-Tone“ (dual-tone multi-frequency signaling) is a widespread dialing technics in analog telephony to transmit the dialed number over the network. The corresponding symbols and frequencies are given in the table below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 1209 Hz | 1336 Hz | 1477 Hz | 1633 Hz |
| 697 Hz | 1 | 2 | 3 | A |
| 770 Hz | 4 | 5 | 6 | B |
| 852 Hz | 7 | 8 | 9 | C |
| 941 Hz | \* | 0 | # | D |

Three audio data examples *touchtone\_X.mat (x for A, B, C)* and a Matlab script template sisy\_lab2c\_exer\_DTMF.m are available for this exercise.

1. Load one of the \*.mat file, prepare a plot of the audio signal in the time domain and hear to the audio recording (using the command sound() )
2. Complete the script to process the audio sequence and find out the dialed number.   
   Hints:

* Cut out nine intervals from the audio sequence representing each a digit from the dialed number, and use the fft() to analyse each interval.
* Prepare a plot of the spectrum and either manually or using the findpeaks() function, find out the two frequencies contained in each interval and the corresponding symbol (in the DTMF table).
* The code parts to be completed are marked with   
  ========> HERE COMES YOUR CODE