Experiment 2: Digital Signal Processing

Aims of the experiment

Digital Storage Oscilloscopes are widely used to measure voltage signals. For the correct interpretation of the results it is important to be aware of their properties and possible errors that can occur when the DSO is not used properly. In this experiment you will verify some important properties of the DSO using digital signal processing techniques.

Theoretical Background

Depth of storage and sampling rate

A DSO samples signals with a given sampling rate f_S [unit: samples per second, Sa/s]. When the time base T_B of the DSO is changed, usually the sampling rate changes as well. The shorter the setting of the time base, the higher the sampling rate (until the maximum sampling rate is attained). A typical DSO screen consists of 10 divisions on the time axis (number of divisions n_x = 10, see fig. 1.1). To display the signal for the whole time displayed on the screen the sample points for all n_x divisions need to be stored in the oscilloscope, defining the depth of storage D_{ST} [kSa or MSa]. Hence, the depth of storage describes how many sample points are to be stored to display the full screen of the DSO.

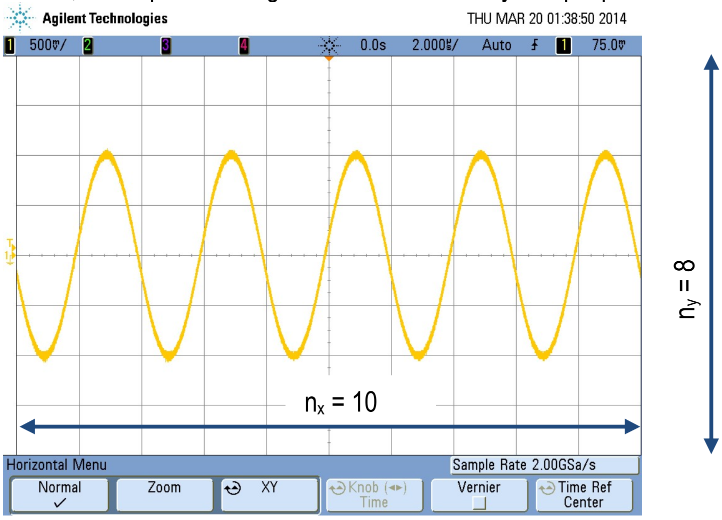


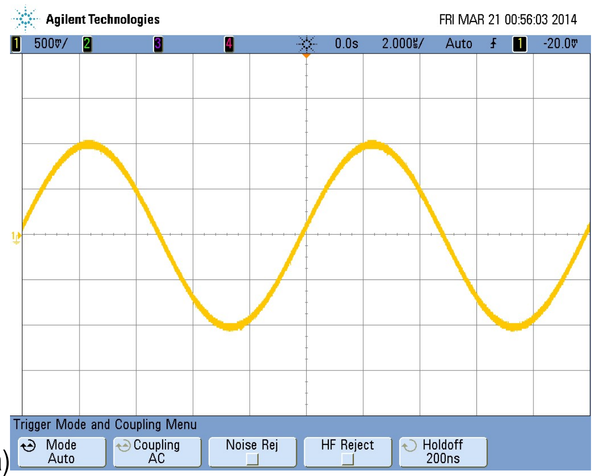
Fig. 1.1: DSO screenshot. TB = 2 µs/DIV, f_S = 2 GSa/s

Resolution of the analogue to digital converter

An analogue to digital converter (ADC) converts analogue values into discrete quantization levels or increments. An 8 bit ADC provides 2^8 = 256 quantization levels or increments. More precisely we have 2^8 -1 increments because the first level is zero. A DSO using an 8 bit ADC has 255 levels available to represent the voltage value for each channel of the DSO. On the voltage axis a typical DSO screen consists of 8 divisions (number of divisions n_y = 8, see fig. 1.1). The full range of voltage to be displayed on the n_y divisions needs to be represented by the 255 quantization levels. Hence, if the voltage sensitivity is set too low and the signal is represented by only a few divisions, only a part of the 255 increments is used to represent the signal. In this way we will loose resolution. To choose an appropriate setting of the voltage sensitivity we have to make sure that the signal uses as much of the screen as possible without being cut off by the limits of the screen.

Leakage effect

The Fourier transform converts a signal from the time domain to the frequency domain by integrating over an infinite period of time. An infinite period of time is not suitable for practical applications. Therefore only a certain time window can be used to calculate a fast Fourier transform (FFT). The restriction to a limited time window causes additional frequency components in the frequency spectrum which are not present in the original signal. This is called leakage effect or spectral leakage. A rectangular time window leads to a significant leakage. Other window functions with a slow rise and decay of the signal amplitude can reduce the leakage effect. An example for such a window function is the "von Hann" window which will be used in our experiment.
The leakage effect can be avoided when the window length is an integer multiple of the period of the signal even when a rectangular time window is used, compare fig. 1.2.

a) 

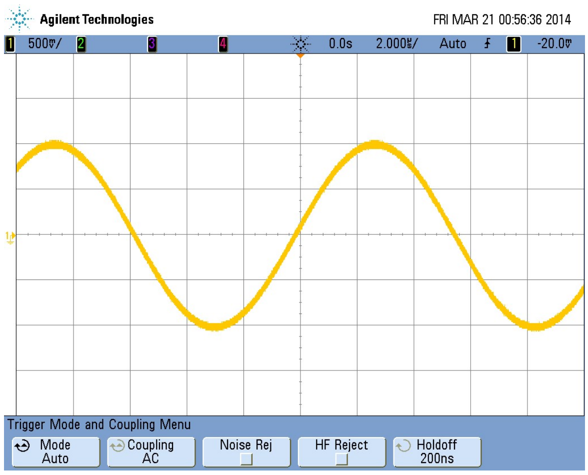
b) 

Fig. 1.2: a) Time window defined by the DSO screen is an integer multiple of the signal period, hence there will be no leakage, b) time window is not an integer multiple of the period, there will be leakage.

Frequency resolution of the FFT

The frequency resolution of the FFT can be increased increasing the window length, which means increasing the number of samples. Therefore, a long setting of the time base of the DSO will lead to a higher resolution of the FFT.

Fourier series of a rectangular signal

A periodic rectangular signal U_R can be described with the following Fourier series.

$$U_R = \frac{4}{\pi} \cdot \sum_{n=0}^{\infty} \frac{1}{2n+1} \cos\left[(2n+1)\omega \cdot t\right]$$

where ω is the basic angular frequency of the rectangle signal and n is a natural number.
Consequently the frequency spectrum of the rectangle consists of the basic frequency and its odd multiples.

Experiments

MATLAB-mess7 is used as an important tool (Please use MATLAB 2011a, set current directory to "D:\gbip", start by typing "mess7"). Read the signals you are working with into the computer and store them with mess7 for later use. Be sure to take notes of the settings of the input voltage of the function generator (amplitude, frequency) and of the settings of the DSO (time deflection setting, voltage setting)

Exercise 1: Determine the depth of storage D_{ST} of the digital storage oscilloscope (DSO)

Disable the anti-aliasing option of the DSO (Utility/Options/Preferences/Antialiasing). Only use channel 1 of the DSO. Using the function generator, apply a sine signal to the DSO (e. g. f = 250 kHz, U_0 = 1 V_{PP}). For two different time settings of the DSO (e. g. T_{B1} = 200 ms/DIV and T_{B2} = 1 s/DIV, these are slow time base settings) find the sampling rate f_S (samples/s). On the Agilent DSO5014, the sampling rate is displayed by pressing the button "Main/Delayed". Is the signal on the DSO-screen a correct representation of the real signal? Consider the aliasing effect. When does aliasing occur?
Calculate the depth of storage D_{ST} of the DSO using the sampling frequency f_S, the time base of the DSO T_B and the number n_x of divisions displayed on the screen of the DSO.

Exercise 2: Determine the resolution of the ADC of the DSO

The ADC of the DSO uses 8 bits. Apply a sine signal to the DSO with small amplitude (e. g. amplitude U_0 = 0.2 V_{PP}). Apply a time base setting that the signal is correctly displayed (no aliasing).For two different voltage settings (e. g. 100mV/DIV and 5V/DIV) calculate the resolution of the ADC using the number n_y of divisions on the DSO screen. By freezing the screen (pressing the Run/Stop button) and adjusting the voltage setting of the DSO you can enlarge the signal and see the incremental steps of the voltage output. Read the signal into mess7 and store it on disk for use in the lab report.

Exercise 3: Study a sine signal without leakage

a) Determine the frequency resolution of the FFT used in MATLAB

Apply a sine signal to the DSO with a frequency that you have no leakage effect and no aliasing. This is achieved using such a frequency that the displayed time window on the DSO screen is an integer multiple of the period of the signal. For two different time settings of the DSO (small and high time base settings) (e. g. f =100 kHz, T_{B1} = 5µs/DIV, T_{B2} = 100 µs/DIV) read the signal into mess7 and determine the frequency of the applied sine signal as well as the frequency resolution in the spectrum using the "spec_1" function of mess 7. Insert the FFT-spectrum into the lab report.

b) Study the influence of a von Hann window on the spectrum

On the signal you read into mess7 in exercise 3a (high time base setting), apply a von Hann window. Describe the changes occurring in the FFT spectrum compared to 3a. Insert the mess7 diagram into the lab report.

Exercise 4: Study a sine signal with leakage effect

Apply a sine signal to the DSO with a frequency shifted by a small amount compared to 3a that you get a spectrum with maximum leakage effect. This is achieved using such a frequency that the displayed time window on the DSO screen no longer is an integer multiple of the period of the signal. Choose the time setting of the DSO to get a good frequency resolution (see 3a) (e. g. period T = 10.6 µs, time base T_B=100 µs). Read the signal into mess 7 and perform an FFT. Describe the influence of a von Hann window on the spectra. Insert the mess7 diagrams into the lab report.

Exercise 5: Measure the phase shift of a low pass filter at the cut-off frequency

a) Sine Signal

Realise an RC low pass filter (LP) and apply a sine signal of the cut-off frequency f_{co} to the low pass (e.g. f_{co} = 1 kHz). Measure the phase shift between input and output of the LP (2 channels) using the phase of the FFT–spectrum ("Spec + phasediff" function in mess7). Insert the mess7 diagram into the lab report.

b) Rectangle Signal

Apply a rectangle signal and determine the frequency response (with phase) of the LP for the frequencies composing the rectangle with the help of the FFT-spectrum. Use the 3 frequency components of largest amplitude.

Optional - Exercise 6: Describe the spectrum of signals produced with different devices

For example you can use a signal from a microphone recording of your voice, or a music instrument (if you want you can bring a music instrument). Insert the mess7 diagram into the lab report.

Experiment 1: Digital Signal Processing

Names		**Lab Protocol**
		Date of Experiment

Type of Oscilloscope used	

Exercise 1: Determine the depth of storage of the digital storage oscilloscope (DSO)

To be done before the lab

- Describe under what condition you will obtain aliasing.
- Calculate the depth of storage D_{ST} for the values given in fig. 1.1.

number of divisions displayed on DSO screen (on horizontal/ time axis) n_x	
signal frequency f (function generator)	
signal amplitude U_0 (function generator)	
time base 1 of DSO T_{B1} [time/DIV]	
sampling frequency 1, f_{S1}	
Calculated storage depth D_{ST1}	
time base 2 of DSO 2 T_{B2} [time/DIV]	
sampling frequency 2, f_{S2}	
Calculated storage depth D_{ST2}	

Exercise 2: Determine the resolution of the ADC of the DSO

signal amplitude U_0 (function generator)	
number of increments of the 8-bit ADC	
number of division on the DSO screen (on vertical/voltage axis) n_y	
voltage setting 1 of the DSO	
calculated voltage resolution 1	
voltage setting 2 of the DSO	
calculated voltage resolution 2	

Exercise 3: Study a sine signal without leakage and without aliasing effect

a) frequency resolution

signal frequency f (function generator)	
signal amplitude U_0 (function generator)	
1st time setting of DSO (time/DIV) T_{B1}	
measured frequency in mess7 for T_{B1}	
measured frequency resolution in mess 7 for T_{B1}	
2nd time setting of DSO (time/DIV) T_{B2}	
measured frequency in mess7 for T_{B1}	
measured frequency resolution in mess 7 for T_{B1}	

b) influence of a von Hann window

signal frequency f or signal period T (function generator)	
signal amplitude U_0 (function generator)	
time setting of DSO (time/DIV) T_B	
changes in the FFT spectrum compared to 3a	

Exercise 4: Study a sine signal with leakage effect but without aliasing effect

signal frequency f or signal period T(function generator)	
signal amplitude U_0 (function generator)	
time setting of DSO (time/DIV) T_B	
changes in the FFT(rectangular window) spectrum compared to 3a	
changes in the FFT spectrum using the von Hann window compared to rectanglar window	

Exercise 5: Measure the phase shift of a low pass filter at the cut-off frequency

To be done before the lab

To obtain a cut-off frequency of 1 kHz calculate the capacitance C when a resistor R = 1 kΩ is used.

a) Sine Signal

signal frequency f (function generator)	1 kHz
time setting of DSO (time/DIV) T_B	
value of resistance R used	
value of capacitance C used	
determined phase shift	

b) Rectangle Signal

signal frequency f_R of the rectangle signal	
time setting of DSO (time/DIV) T_B	
frequency component in FFT spectrum	phase shift

Optional - Exercise 6: Describe the spectrum of signals produced with different devices

type of signal	
observations	

Lab protocol approved