Exercise 2: ALIASING, SAMPLING AND RECONSTRUCTION

Purpose of the lecture is to get familiar with:

- Anti-Aliasing filter;
- Reconstruction filter of D/A converter;
- Sampling rules;

Exercise 1: Anti-Aliasing filter

Determine corner frequency and lowest possible order of anti-aliasing filter with slope of –N*20dB/dec. SNR in the band from 5kHz to 10kHz must be ≥ 100dB.
Additional information:
- fs=1 MHz.
- Bandpass of interest is from 5 kHz to 10 kHz.
- The digital filter is used to remove all out of band components after the sampling

Instructions:

Prepare .m file and Simulink model, where you generate signals with frequencies fs/2-1kHz, fs/2+2kHz, fs+3kHz in fs+7kHz, with corresponding amplitudes (Figure 1). Example of realized model is shown in Figure 2. Compare filtered and non-filtered specter after sampling.
As anti-aliasing filter use function [num,den]=butter(ord,wp,'s'), where you need to determine: filter order, corner frequency wp in rad/s. Result is filter transfer function which should be used in Simulink block "transfer function" Figure 3.

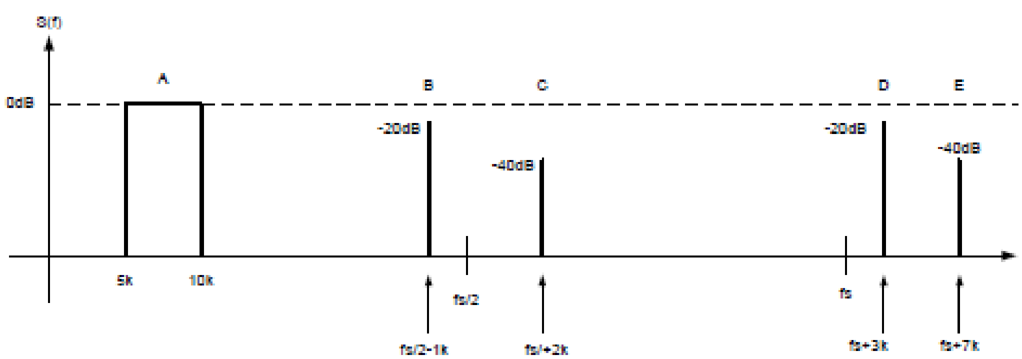

Figure 1: Specter of input signals.

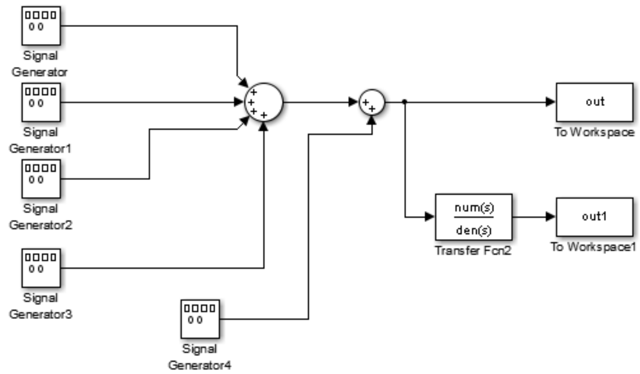

Figure 2: Example of sampling and anti-aliasing filter.

Time continuous signal is sampled by block "To Workspace", where you should determine sampling period (Figure 3). Simulink model is started by sim() function. Example: model "sim_model" is started by sim('sim_model'). Maximal step size "Max step size" in Simulink must be a few times higher than sampling time step.

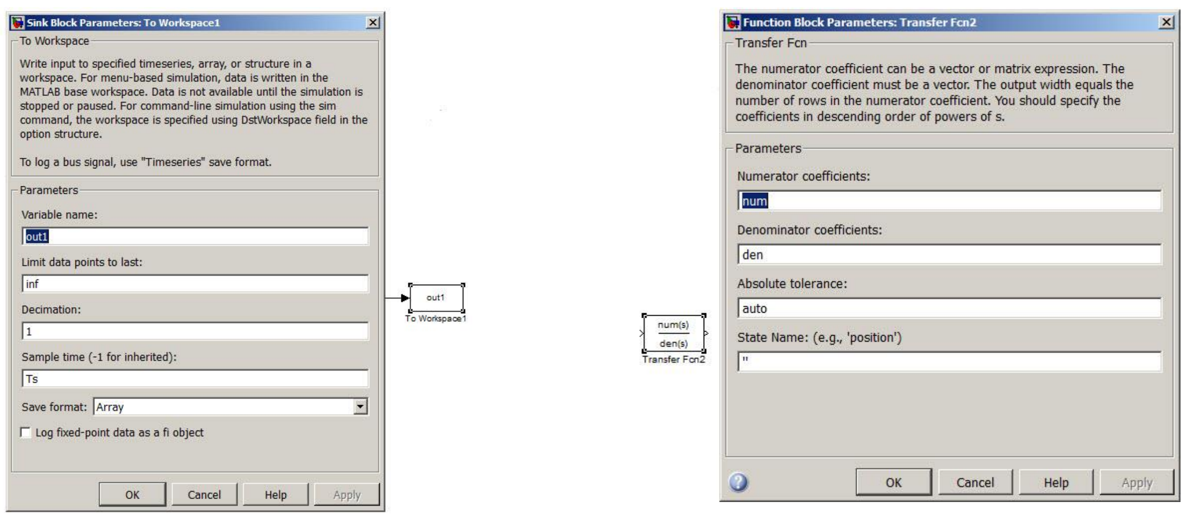

Figure 3: Sampling (left) and preparation of anti-aliasing filter (right) in Simulink environment.

Results: The amplitude of unwanted components at 7 kHz must be attenuated or eliminated with the help of anti-aliasing filter because unwanted components appears in band pass from 5 to 10 kHz (Figure 4 and 5).

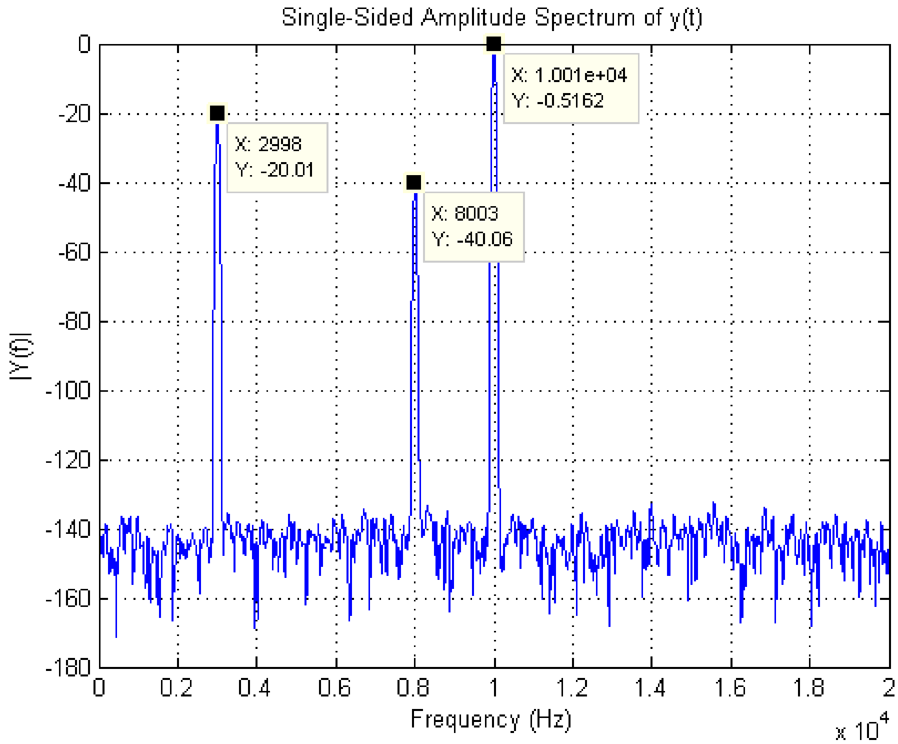

Figure 4: Sampling without anti-aliasing filter with sampling frequency 1MHz.

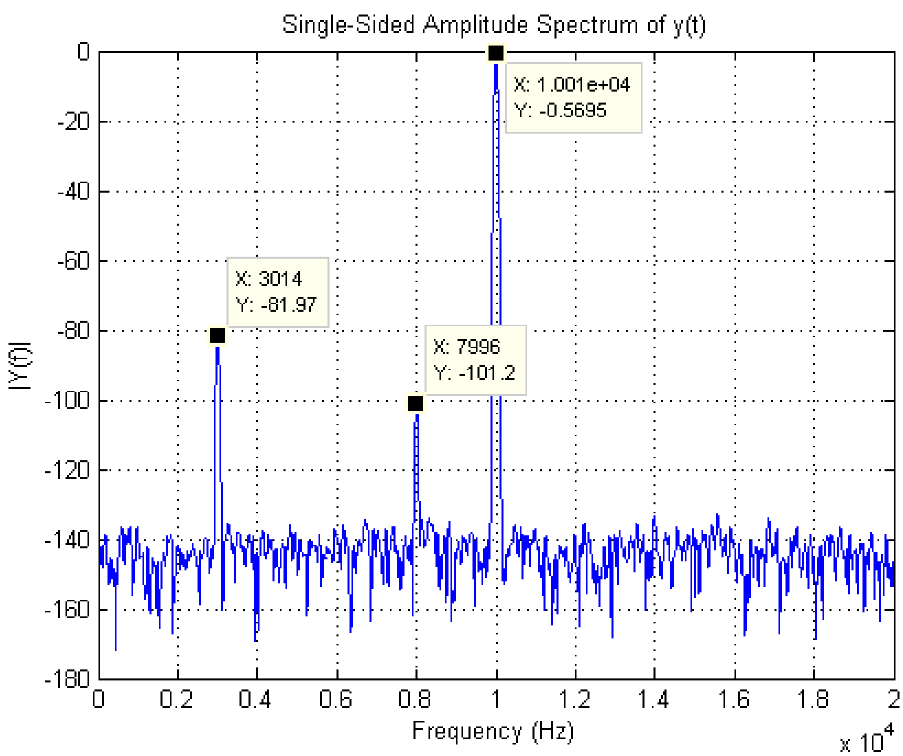

Figure 5: Sampling with anti-aliasing filter with sampling frequency 1MHz.

Exercise 2: Reconstruction filter

12 bit D/A converter converts digital sine signal with $f0=100$ kHz to analog signal with sampling frequency $fs=1$MHz and amplitude $A=1$V.

- Plot the signal spectrum of the D/A output in range from 0 to 3fs,
- Calculate order (N) and corner frequency fp of smoothing filter ($S=-N*20$dB/dec). SNR from 0 to 2fs must be higher than 40dB (sinx/x effect)

Instruction:

Prepare .m file and Simulink model, where you check S/H and reconstruction filter operation.

The example of realized S/H circuit and reconstruction filter is shown in Figure 6. The model consist of signal generator, S/H and analog filter. The Figure 9 shows spectrum without S/H circuit. The figure shows the input signal with frequency f0 and mirrored components over sampling frequency fs. S/H circuit in Simulink environment is described with "Zero-Order Hold" block (Figure 7) with sampling time $Ts=1/fs$.

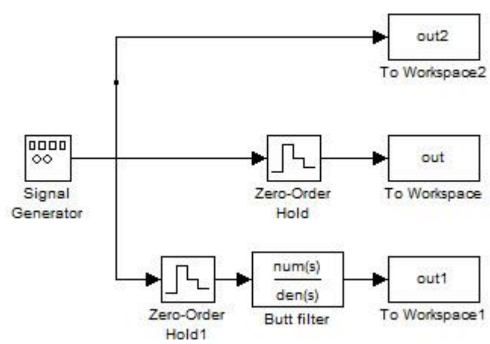

Figure 6: Simulink model of reconstruction filter.

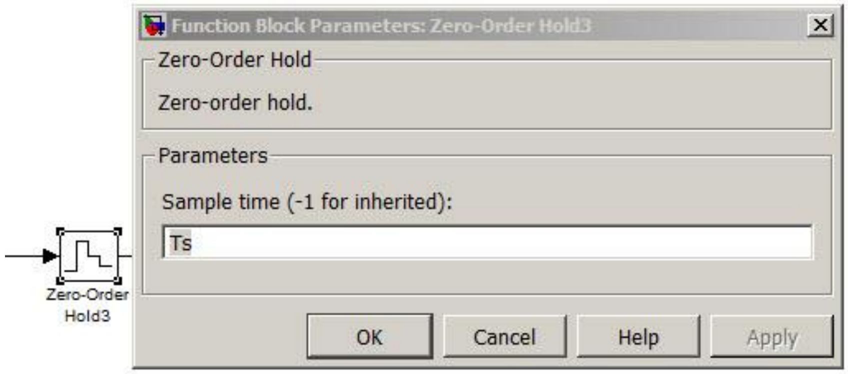

Figure 7: S/H block.

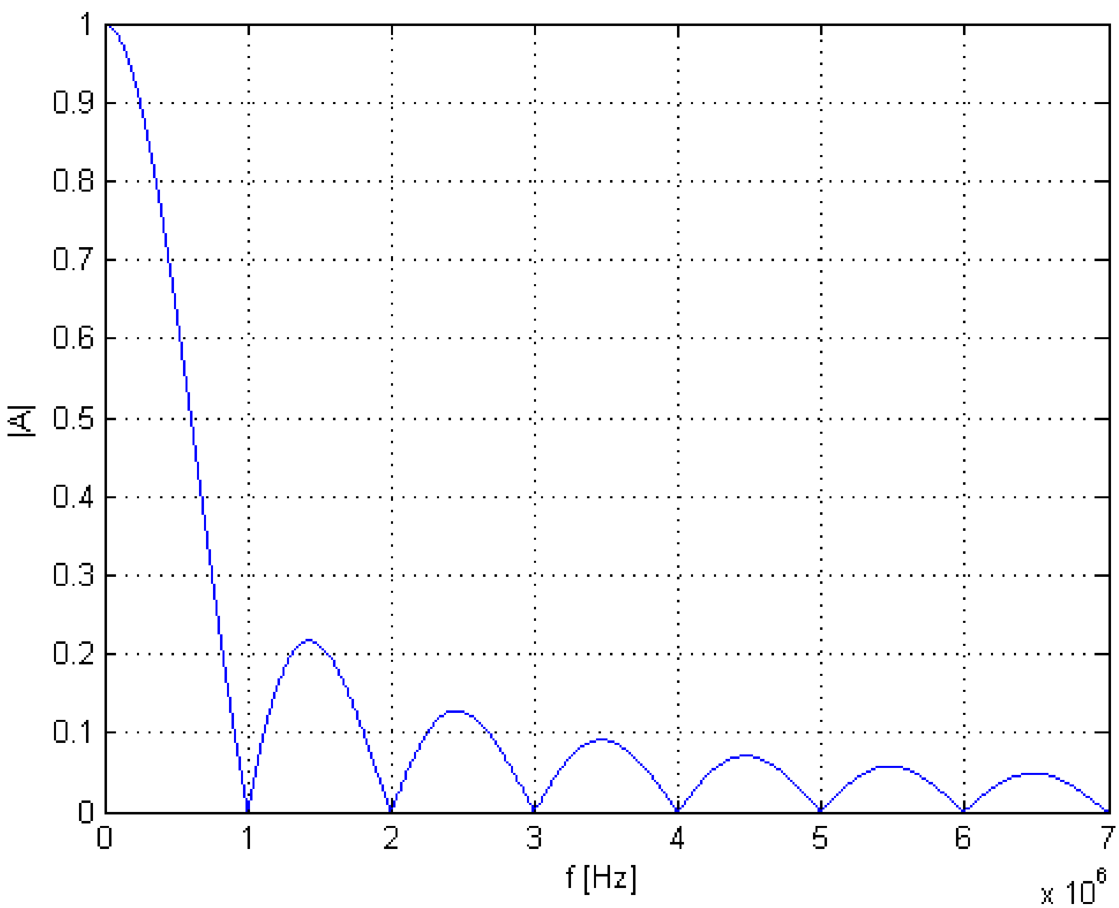

Figure 8: Transfer function of S/H with sampling frequency 1 MHz.

D/A spectrum without S/H from 0 to 3fs:

fft() function calculates Discrete Fourier Transform between f0 and fs/2. Use upsample function to show D/A spectrum without S/H in wider frequency range. Upsample increases sampling rate by inserting N zeroes between samples. With aforementioned function the sampling rate is increased, maintaining same signal spectrum.

For regular result the sampling frequency must be N-times higher (fs_{new}=N*fs). Additional information about upsample() is found with help.

Results out and out1 should be saved with n-times higher frequency as the sampling frequency of S/H.

Results: Figure 9**,** Figure 10 and Figure 11 show spectrum of D/A converter signal without S/H, with S/H and additional reconstruction filter. Figure 11 presents influence of reconstruction filter which attenuates the amplitude of the component at 1,1 MHz

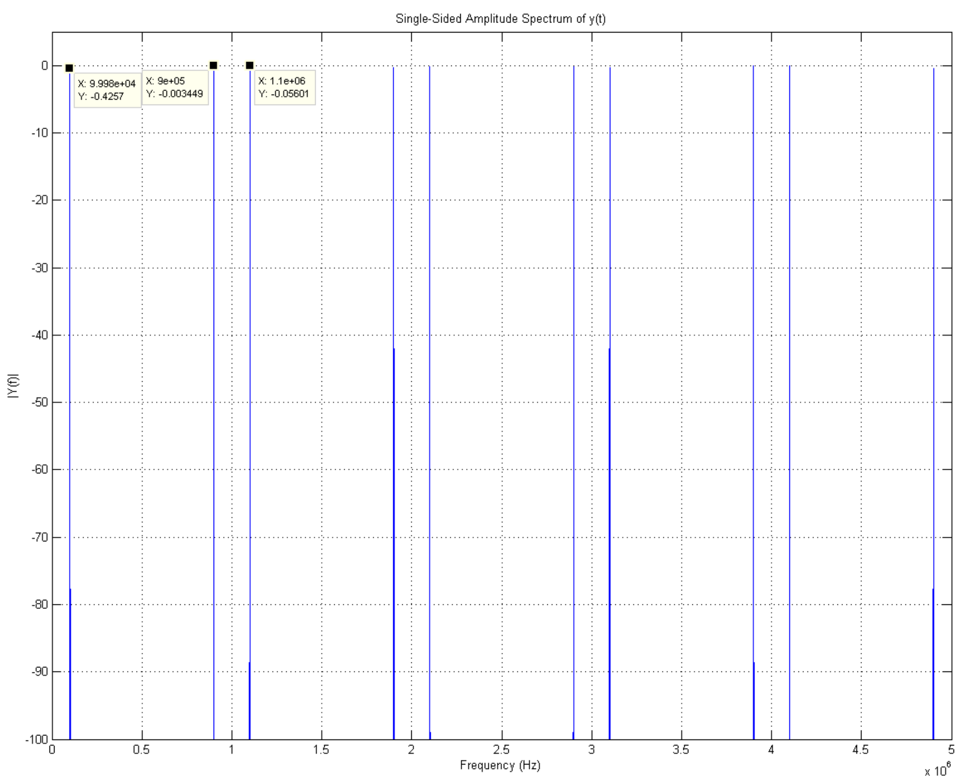

Figure 9: D/A Spectrum without S/H.

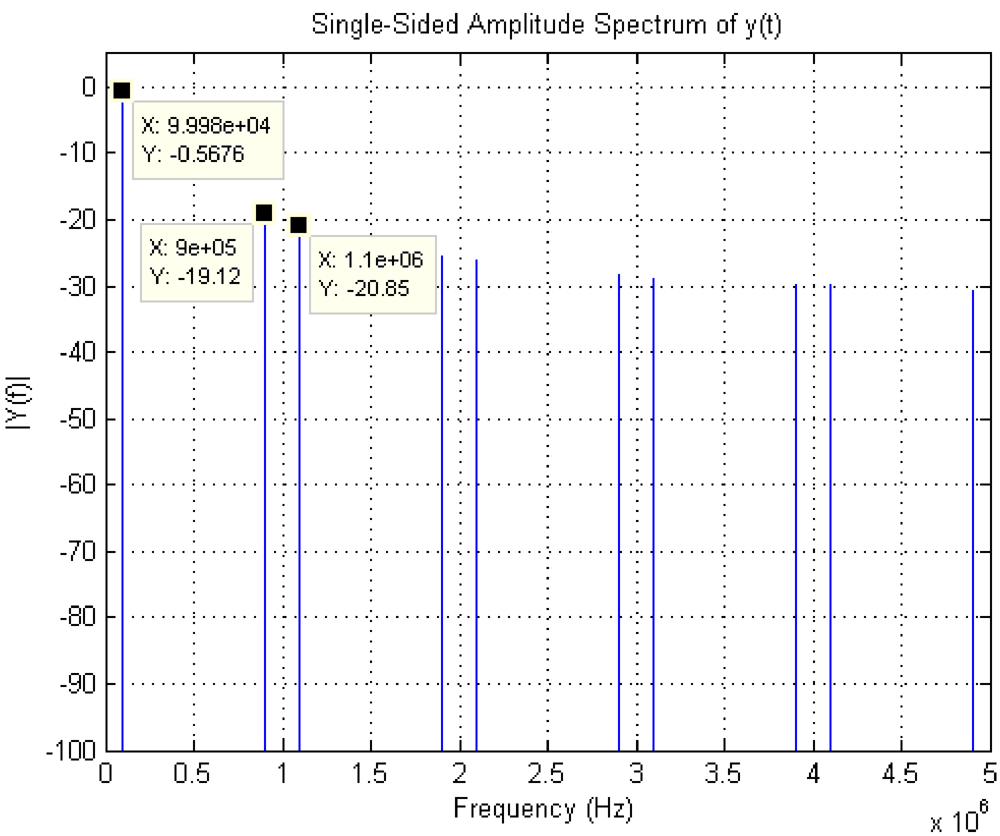

Figure 10: Spectrum of D/A and S/H without reconstruction filter.

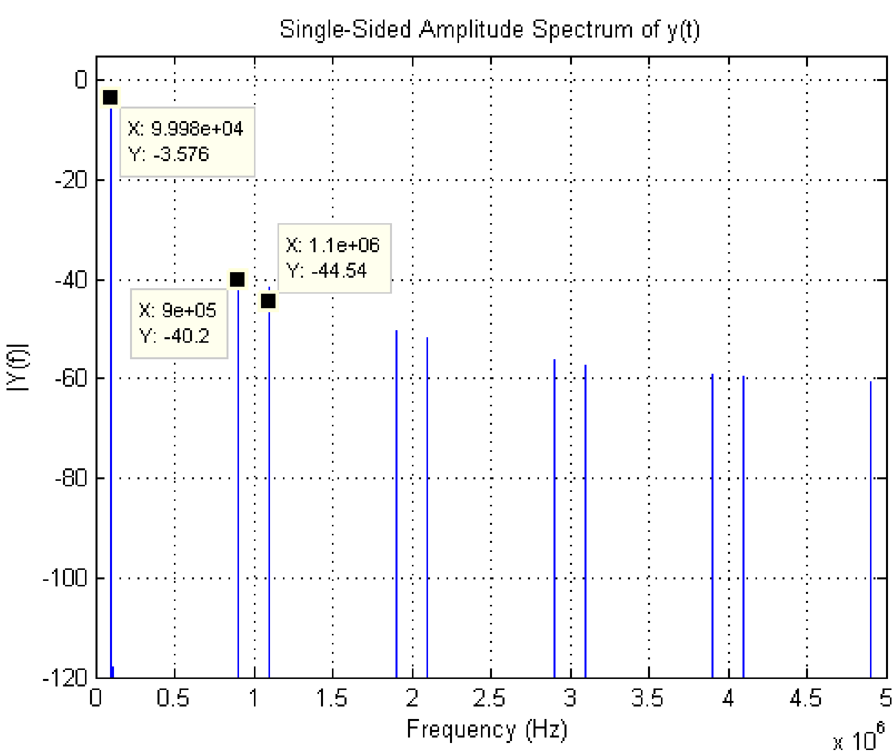

Figure 11: Spectrum of D/A and S/H with reconstruction filter.

Exercise 3: Sampling rule

From fl=10.21 MHz to fh=10.39 is the spectrum before the sampling. Prepare .m file where you calculate the minimal possible sampling frequency and base Nyquist zone before sampling. Plot the spectrum before and after sampling.

$$\frac{2f_L}{n} > f_s > \frac{2f_H}{(n+1)}$$