Embedded Systems Hands-On 1: Design and Implementation of Hardware/Software Systems

Task 5: Analog and Digital Filters

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In this task, analog and digital measurement signals are filtered to remove undesired frequency components. The task is scheduled for two weeks.

Summary

- Simulation of analog filters with [Qucs]
- Observing the behavior of analog filters with waveform generator and oscilloscope
- Simulation and implementation of digital filters

Sensor signals typically consist of a wide range of frequency components, i.e., a superposition of multiple signals with different amplitudes and change rates. For example, an acceleration sensor used to observe the high-frequency vibration of a certain structure will also sample the static (i.e., low frequency) gravity. Furthermore, all non sine-shaped periodic signals are associated with higher order harmonics, i.e., weaker signals swinging at integer multiples of the base frequency.

Analog and digital filters can be used to selectively damp certain frequency ranges of a measurement signal, so only application-relevant frequency components will remain in the filtered signal. For the aforementioned acceleration sensor, a high-pass filter could be used to damp the static gravity, while a low-pass filter has to be employed to get rid of higher order harmonics.

The cutoff frequency (i.e., 3 dB damping point) and filter slopes of analog and digital filters are adjustable to the applications requirements. Steeper filter slopes lead to a larger damping of the undesired frequency bands and a smaller damping of the relevant frequency ranges. However, the edge steepness also effects the resources (i.e., analog components or computation power) required to implement the filters. The goal of this task is thus to learn about different filter implementations and the trade-off between filter performance and resource requirements.

The measurement equipment required for this task will be provided by one of the lab assistants. It has to be returned after finishing the measurement and may not be used outside the lab.

1 Simulation of Analog Filters

Summary

- Use [Qucs] to simulate the behavior of analog low- and high-pass filters

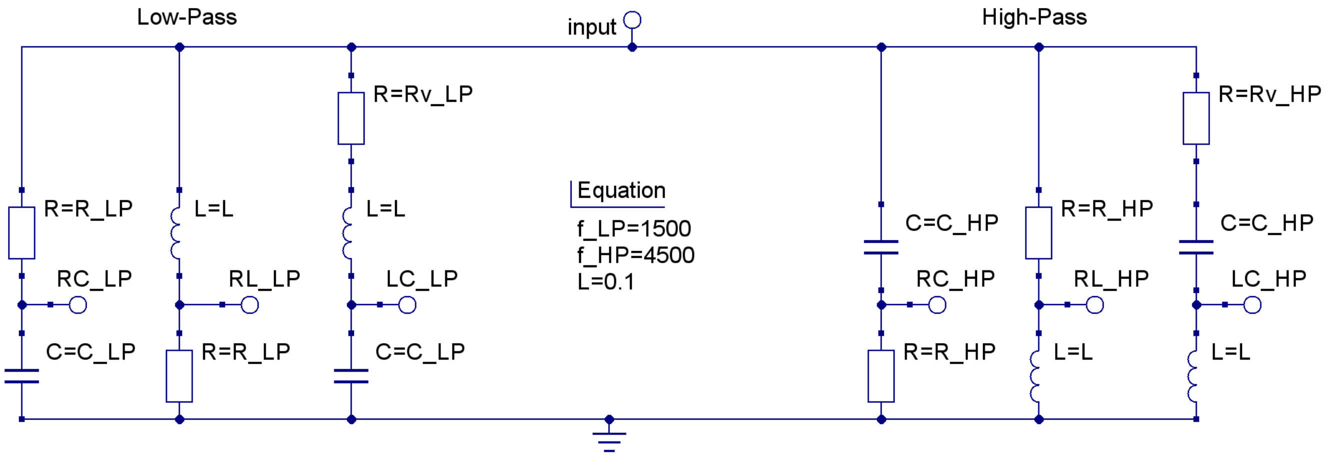

Figure 1: [Qucs] subcircuit with three analog low- and high-pass filters

Analog (passive) frequency filters can be realized by combining resistors (R), capacitors (C) and inductors (L) to RLC elements. Realize a [Qucs] subcircuit with one input and six outputs. As shown in Figure 1, three low-pass (RC_LP, RL_LP, LC_LP) and three high-pass (RC_HP, RL_HP, LC_HP) filters have to be realized, while

- all inductors are equally sized to a nominal value L,
- all low-pass capacitors have the nominal value C_LP,
- all high-pass capacitors have the nominal value C_HP,
- the low-pass resistors RC_LP and RL_LP have the nominal value R_LP,
- the high-pass resistors RC_HP and RL_HP have the nominal value R_HP,
- the series resistor of the LC_LP filter has the nominal value Rv_LP, and
- the series resistor of the LC_HP filter has the nominal value Rv_HP.

The nominal values have to be derived from parameters for the cutoff frequencies (i.e., f_LP $= 1.5\,\text{kHz}$ and f_HP $= 4.5\,\text{kHz}$) by a [Qucs] equation module. The inductor value is also provided as parameter in the equation module as L $= 100\,\text{mH}$.

Generate a linear transient simulation driving the input of the filter subcircuit to

$$t \mapsto \sin(2\pi \cdot 1\,\text{kHz} \cdot t) + \sin(2\pi \cdot 5\,\text{kHz} \cdot t) \qquad \text{for} \quad 0\,\text{ms} \leq t \leq 5\,\text{ms}$$

Generate a linear AC simulation driving the input of the filter subcircuit to

$$t \mapsto \sin(2\pi f \cdot t) \qquad \text{for} \quad 1\,\text{kHz} \leq f \leq 5\,\text{kHz}$$

Generate a data display arranging the results of both simulations. These comprise

- the computed nominal values of all resistors and capacitors
- the input signal and all six filtered output signals from the transient simulation
- the frequency response of all filters as double logarithmic plots
- the damping of all filters at 1 kHz and 5 kHz.

Vary the cutoff frequencies to observe their influence on the frequency response of the filters, the remaining disturbance in the filtered signal, and the phase displacement between the input, and the output of the filters.

Minimum Expected Documentation

- Derivation (or a literature reference) for the calculation of the resistor and capacitor nominal values.
- [Qucs] project with executable simulations and prepared diagrams.

2 Measurement of Analog Filters

An update for this task will follow soon.

3 Simulation of Digital Filters

FIR filters are one possible realization of digital filters. They transfer a discrete signal $(x_k)_{k\in\mathbb{N}_0}$ (e.g., unfiltered sensor samples) into a filtered signal

$$\left(\sum_{i=0}^{\min(N,k)} a_i \cdot x_{k-i}\right)_{k\in\mathbb{N}_0}.$$

N is the order of the filter. The filter coefficients $a_0,\ldots,a_N$ affect the frequency response of the filter. Higher order filters provide steeper damping edges, but also require more memory and processing time.

Summary

- Determine FIR coefficients to realize a low-pass filter

Find coefficients for two FIR filters with a sampling rate of 10 kHz, such that the resulting frequency response matches the `RC_LP` and `LC_LP` from Subtask 1 for `f_LP` = 1.5 kHz and `L` = 100 mH as close as possible. Various filter design tools are available, such as the simple [TFilter]. The filter design tools provided by [MATLAB] are accessible in the lab pool and allow more detailed configurations.

Minimum Expected Documentation

- Filter coefficients and the frequency response of the generated digital filters

4 Realization of Digital Filters

Summary

- Implement a digital filter to improve the signal quality of the acceleration sensor

In Task 4, the acquisition of [LSM303D] acceleration signals has been implemented. Analyse the sensor data to identify undesired disturbance (i.e., noise, static offset). Specify and implement a FIR filter to damp this disturbance. Compare the filtered signal with the original unfiltered signal. Analyzing and filtering the signal of the magnetic field sensor is not expected.

Minimum Expected Documentation

- Documented source code for reading and filtering [LSM303D] acceleration samples
- Diagrams showing the filtered and unfiltered acceleration signals
- Justification for the choice of the filter coefficients

5 Choice of Filter Implementation

Name three advantages of analog filters (over digital filters), and three advantages of digital filters (over analog filters).

Bibliography

LSM303D ST. *Ultra-compact high-performance eCompass: 3D accelerometer and 3D magnetometer module*. 2013. URL: `http://www.st.com/resource/en/datasheet/lsm303d.pdf` (visited on 2018-03-08).

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Qucs *Quite Universal Circuit Simulator*. 2015. URL: `http://qucs.sourceforge.net/` (visited on 2018-03-08).

TFilter Peter Isza. *The free online FIR filter design tool*. 2011. URL: `http://t-filter.engineerjs.com` (visited on 2018-03-08).

Acronyms

FIR Finite Impulse Response