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SIGNAL NOISE REDUCTION AND FILTERING

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Abstract: The paper deals with noise reduction in signal. Normally measured signal very frequently includes noise and data processing includes the activities for its reduction. The best choice is to reduce the source of noise, but often it is not possible to reduce noise source. Filtering is another activity, which helps us to reduce noise in measured signal. Data processing can be executed only with filtered signal.

1 Introduction

Measurement is a set of actions to determine the value of a measurand, which can be performed manually or automatically.

A measuring instrument is a device intended for the conversion of a measured quantity into a quantity holder signal bearing information about its value (data) with possible displaying of the measured value on the indicating device. In most cases, the measuring device is understood to be a ready-to-use compact device. The equivalent term measurement instrument is also often used.

A measuring device is a set of technical means and measuring instruments designed to carry out the measurement of a selected quantity, including all measuring instruments and other auxiliary measuring devices necessary for the application of the given measuring method. The measuring device need not be in a compact state but can be tailored to the application.

The measuring instrument and measuring device are as chains of blocks - a measuring chain in which the measured quantity (input) is transformed into an output quantity i. e. measuring instrument data. A single measuring string may take the form of serially connected blocks (Figure 1).

A signal is a physical quantity that carries added modulated information about the measured quantity with which it is functionally coupled.

The sensor (sensor) transforms a physical quantity into another quantity, so-called quantity holder of information. The sensor transforms information from the physical area of the measured quantity into another physical area, for example a signal to a unified signal, most often to an electrical unified signal.

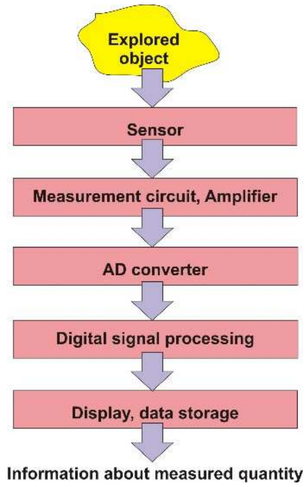

Figure 1 Structure of measurement instrument

Unified signal - moves within a predefined range of the quantity holder variable. eg.:
- 0 to 20 mA or 4 to 20 mA current signal
- 0 to 10 V or -10 to +10 V voltage signal
- pneumatic signal 20 to 100 kPa.

There are two types of signals: according to the nature of information transformation:
- analogue signals (arbitrary value),
- discrete signals, digital signals (finite number of values).

The measurement process can also be controlled by a microprocessor. The microprocessor may perform some activities in a block diagram. However, it is most often used for signal processing and compensation of disturbances. Advantages of microprocessor-controlled measuring instruments:

- the possibility of configuring device features according to user requirements
- possibility to connect several types of sensors
- possibility to modify static characteristic (zero-point shift, change of directive)
- suppression of interferences affecting the measured quantity
- limit state signalization
- the possibility of communicating with the computer
- blocking against unwanted interference
- processing of measured data (average, MAX, MIN, Modus, Median, ...)
- possibility of archiving measured data
- self-diagnosis
- self-calibration
- remote control and data acquisition (GSM, WiFi, ...)

Signal processing is area, which focuses to analysis, to modify and to synthetize the signal captured as sound, image or measurement set. Al activities is used because of a better transferring and storage of the signal.

Mainly analogue signal is damaged with noise. For this purpose are used many additional devices as passive or active filters, mixers, integrators, amplifiers, oscillators etc.

2 Signal noise

Noise reduction is an activity for rejection of noise from signal from measurement and also from sound or image source. Algorithm of reduction depends on character of signal and noise. Noise is characterized as unwanted part of the signal. This unwanted part is as random disturbance (Figure 2).

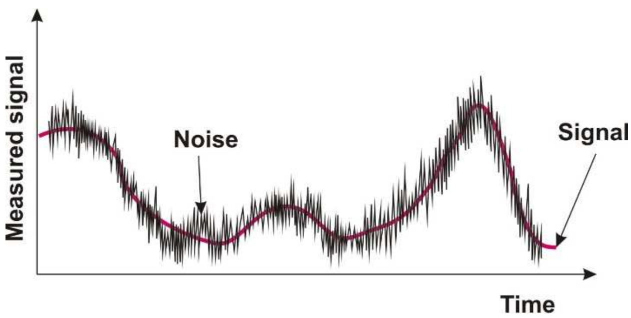

Figure 2 Measured signal with noise

There are several types of noise:

- Short impulse (spikes) and harmonic noise (high-frequency and low-frequency noise)
- White noise
- Impulse, non-stationary noise

Practically, for noise is used colour classification obtained from analogy of sound and light wave spectrum frequencies. White noise (Figure 3) is coming from analogy to white light, which has flat frequency wave spectrum.

Figure 3 White noise

Pink noise (Figure 4) has linearly proportionally wide frequency spectrum in logarithmic scale. Spectral density of pink noise decreases by constant decrement 3 dB per octave.

Brown noise or also called as Brownian noise (Figure 5) has power density which is decreased by 6dB per octave with increasing frequency shown in logarithmic scale.

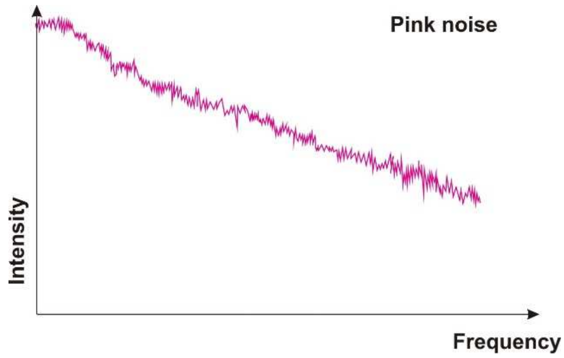

Figure 4 Pink noise

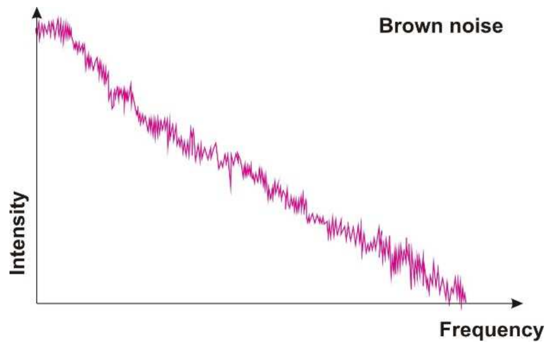

Figure 5 Brown noise

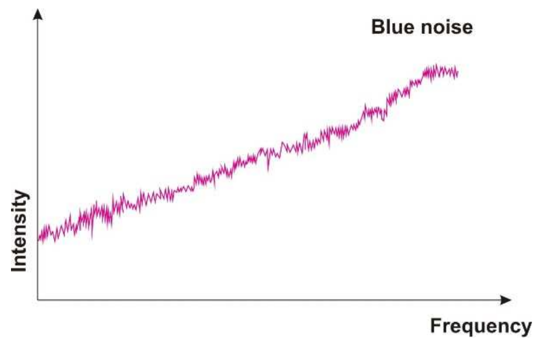

Figure 6 Blue noise

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Blue noise (Figure 6) has power density which is increased by 3dB per octave with increasing frequency shown in logarithmic scale.

3 Noise reduction

There are several ways of noise reduction:

- Faraday cage - is a fully enclosed cage made of an electrically conductive material (e.g. wire mesh). The interior of the cage is protected against the effects of external electric, electrostatic and electromagnetic fields and waves. The principle lies in the characteristic of the electric charge, which concentrates only on the surface of the driver, but not in its volume. The cage as a whole acts as a driver, so there is no charge in its inner volume. Electromagnetic radiation is absorbed by the surface of the cage.
- Shielding cables – electric cable composed from one or more insulated wires in common isolation and covered by conductive layer from foil or braided strands made from aluminium or cooper. Shield should be connected to ground and it works like faraday cage.
- Filtering – electronic circuits, which enable to pass of certain frequencies and to block unwanted frequencies through the filter.

Filters can be divided into two main groups as passive and active filters. Passive filters are composed from combination of passive electric components as resistors, capacitors and inductors. Inductors have ability to block high frequency part of signal and allow to flow low frequency part of signals. Capacitors block low frequency part of signals and allows flow of high frequency part of signals. Resistor has no direct impact to transmitted frequency, but it has influence to value of time constant of filter circuit.

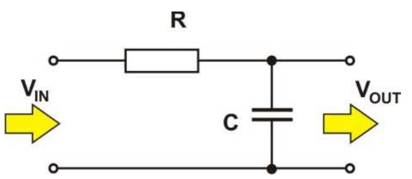

Figure 7 Low-pass frequency passive filter

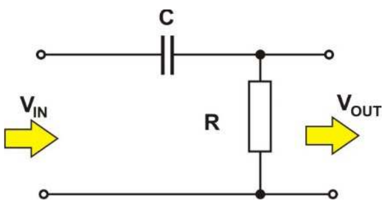

Figure 8 High-pass frequency passive filter

These passive components can be used for building of simple passive low-pass frequency filter (Figure 7), high-pass frequency filter (Figure 8).

Low pass filter is used for removing of high frequency noise. But high pass filter is used for removing of low frequency noise. Beside the mentioned passive filters, there are also Band-pass filter and Band-stop filter. Band-pass filter allows to pass only wanted band of frequencies, but Band-stop filter blocks only frequencies belong to specified bans (Figure 9). Frequency response shown on figure 9 is only ideal case. Real frequency responses of filters have different characteristic. Rising edge and falling edge are not rectangular but there is any slope angle on these responses (Figure 10).

Low-pass filter shown on figure 7 is also called as "first order filter", because it includes only one reactive components (capacitor). For low-pass filters (Figure 7), it is possible derive the equation for cut-off frequency (also called as "break-point"). For low-pass filter it specifies the frequency when input signal amplitude is reduced by value -3dB. For low-pass filter it is defined as:

$$f_{cutoff} = \frac{1}{2\pi \cdot R \cdot C} \quad (1)$$

The same equation for cut-off frequency is valid also for high-pass filter.

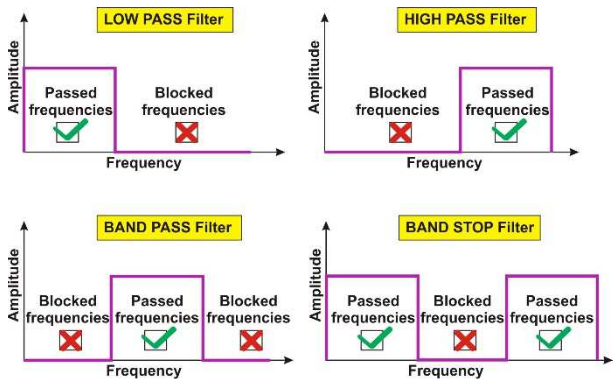

Figure 9 Ideal frequency response of basic types of passive filters

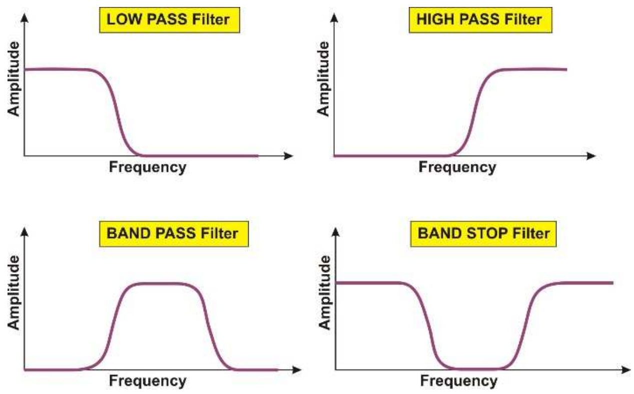

Figure 10 Frequency response of basic types of passive filters

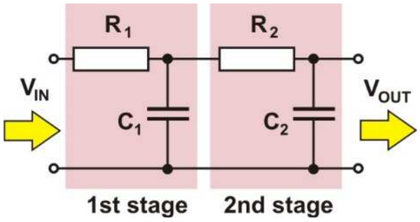

Figure 11 Second order low-pass passive filter

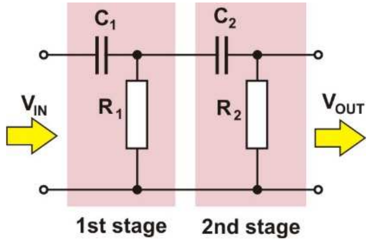

Figure 12 Second order high-pass passive filter

Cutt-off frequency for both second order filters (low-pass and high-pass) is defined as follow:

$$f_{cutoff} = \frac{1}{2\pi \cdot \sqrt{R_1 \cdot R_2 \cdot C_1 \cdot C_2}} \qquad (2)$$

Active filters include also active electronic parts for amplifying of signal intensity. Normally, transistor or operational amplifiers are used for this purpose. For example, non-inverting amplifier can be used as it shown on figure 13 for low-pass active filter and high-pass active filter shown on figure 14. These filters are based on Sallen-Key topology.

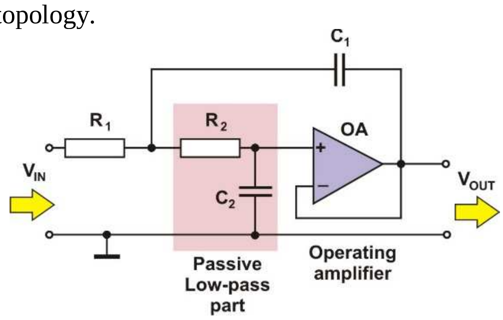

Figure 13 First order low-pass active filter

Natural undamped frequency f_0 is defined:

$$f_0 = \frac{1}{2\pi \cdot \sqrt{R_1 \cdot R_2 \cdot C_1 \cdot C_2}} \qquad (3)$$

Attenuation is defined as:

$$A_T = \frac{1}{2 \cdot C_1} \cdot \frac{R_1 + R_2}{R_1 \cdot R_2} \qquad (4)$$

Analogically, it is possible to build high-pass active filter (Figure 14). Natural frequency is defined with the same equation as before, but attenuanion is defined as:

$$A_T = \frac{1}{2 \cdot R_2} \cdot \frac{C_1 + C_2}{C_1 \cdot C_2} \qquad (5)$$

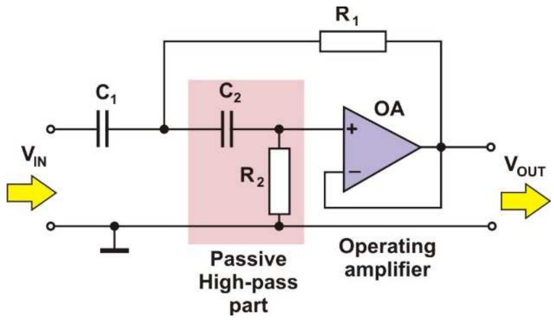

Figure 14 First order high-pass active filter

4 Filtering

Activity of displacement actuator has been measured via using the measurement data acquisition card into PC. Measured signal (Figure 15) is damaged by noise and this signal cannot be used for analysis and for this reason it is necessary to repair it. Noise source was not identified. Therefore, the only possible way is to filter the measured signal. The measured signal was recorded in a file (Figure 15) and its offline processing is thus possible additionally.

Offline data processing can be realized via using of simulation model (Figure 16) with data recorded from real process.

The course of the measured signal (Figure 15) is wavy, and this indicates the presence of higher frequencies in the signal. For this purpose, a frequency analysis was performed (Figure 16), according to which the individual frequencies of the signals present in the measured course were identified (Figure 17).

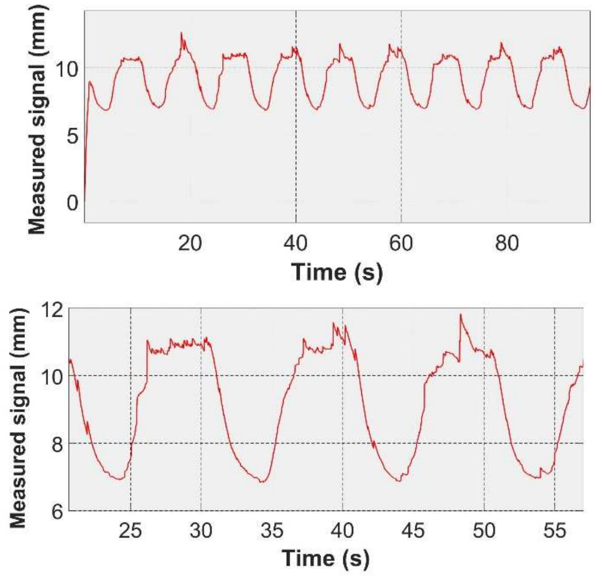

Figure 15 Measured signal and selected detail of noised signal

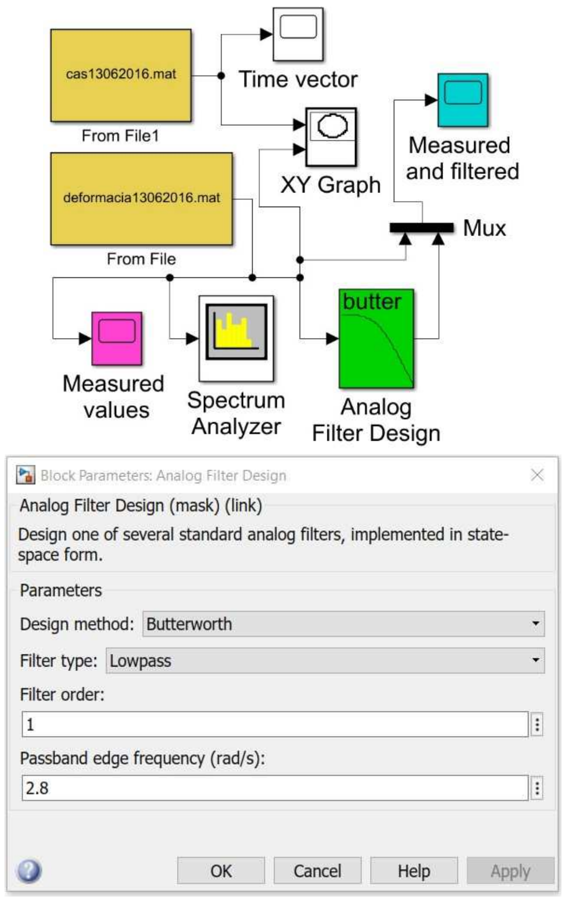

Figure 16 Simulink model for data filtering and setup of filter parameters

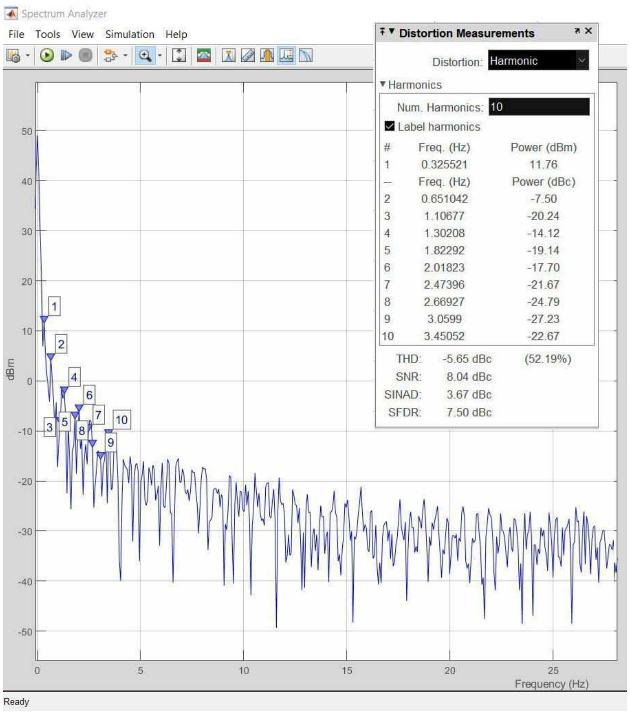

Figure 17 Spectrum analysis in Matlab/Simulink

Result from Spectrum analyser (Figure 17) shows amplitudes of all frequencies. We know that excitation frequency of actuator was 0.3Hz and this signal is the main signal. Other higher frequencies are undesirable, and we would like to reject them from measured signal.

Low pass filter has been proposed into simulation structure (Figure 16) for suppressing of higher frequencies. Result if filtering is visible on Figure 18.

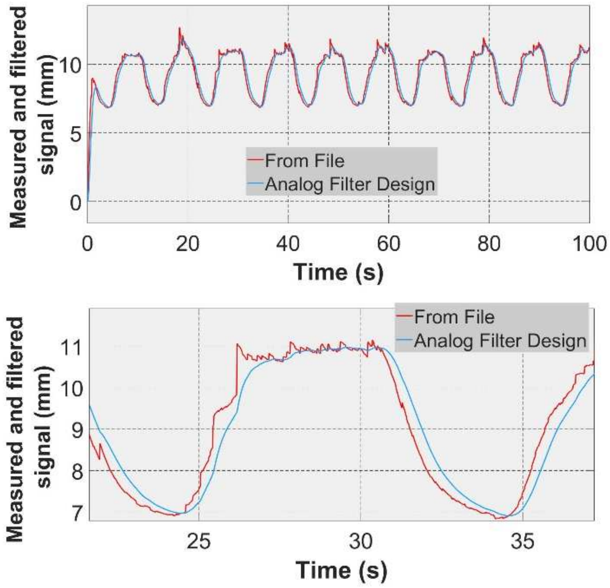

Figure 18 Filtered signal and detail of signal

The filtered signal (Figure 18) is smoothed, and it is possible to make any analysis of actuator dynamic characteristic. As it is visible the filtered signal has also phase shifting as small-time delay of signal.

5 Conclusion

Almost all measurement systems have problems with data processing, because of noise, which is mixed into measured signal. Very frequently measured quantity is lost inside the noise and filtering is inseparable activity during the measuring process [1-23].

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