Optimal filtering for bolometer signals in cryogenic particle detectors

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Signal processing Software implementation







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Signal characteristics

- signals are at low frequencies.
- significant amount of 1/f noise (flicker noise) due to instability in the experiment/hardware conditions
- $1/f^0$ (white noise) due to electronics' noise
- noise from power line/radio frequency/ground loops at "fixed" frequencies (may vary with the configuration)
- unavoideble noise of different nature due to statistical fluctuations in system

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Methods to suppress the noise

- 1/f (flicker)- hardware stabilization (wait a long time before experiment); short accusation time, (filtering?)
- pickup noise- proper power supply and grounding systems; avoiding loops; accurate choosing of experimental time; filtering
- white noise- choosing the low noise electronics; filtering
- unavoideble noise statistical noise filtering

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Signal processing Software implementation

Assumptions for signal filtering

- the pulses D(t) have the same shape $H \cdot S(t)$, H- the amplitude, S(t)- the known pulse shape
- system is linear; S(t) does not depend on H
- the random noise has known staitionar spectrfal power N_f^2 , uncorelated at different f

Signal filtering I

Dan McCammon "Thermal Equilibrium Calorimeters- An Introduction"

Discrete Fourier transform of $D_f = FFT(D(t))$ Root mean square value of the noise N_f Each $D_f \sim H$ and provides an independent estimate for H Then $H = \sum w_f \cdot D_f$ Noise fluctuation $\Delta H_{rms} = \sqrt{\sum (w_f \cdot N_f)^2}$ $\frac{H}{\Delta H_{rms}} = max \Rightarrow w_f = \frac{D_f}{N_c^2} \left(\sum \left(w_f \cdot N_f \right)^2 / \sum w_f \cdot D_f \right)$ remove common scale factor $\Rightarrow w_f = \frac{D_f}{N^2}$ choose phases to maximize the numerator in $\frac{H}{\Delta H_{ms}} \Rightarrow w_f = \frac{\nu_f}{N^2}$ remove common scale factor $H \Rightarrow w_f = \frac{S_f^*}{N_r^2}$ and $H \sim \sum \frac{D_f \cdot S_f^*}{N_r^2}$

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Signal filtering II

A. E. Szymkowiak "Signal Processing for Microcalorimeters"

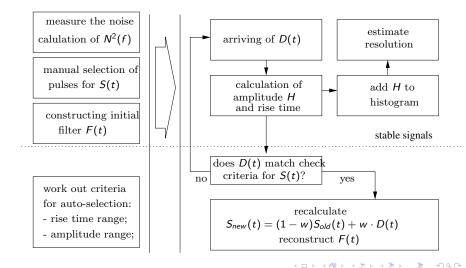
$$\chi^{2} = \sum \frac{|D_{f} - H \cdot S_{f}|^{2}}{N_{f}^{2}} = \sum \frac{(D_{f} - H \cdot S_{f}) \cdot (D_{f} - H \cdot S_{f})^{*}}{N_{f}^{2}}$$
$$\partial \chi^{2} / \partial H = 0 \Rightarrow 2H \sum \frac{S_{f}S_{f}^{*}}{N_{f}^{2}} = \sum \frac{D_{f}S_{f}^{*} + D_{f}^{*}S_{f}}{N_{f}^{2}}$$
ecause of $S(t)$ and $D(t)$ are Real $\Rightarrow H = \sum \frac{D_{f} \cdot S_{f}^{*}}{N_{f}^{2}} / \sum \frac{S_{f}S_{f}^{*}}{N_{f}^{2}}$

because of S(t) and D(t) are Real $\Rightarrow H = \sum \frac{D_f \cdot S_f}{N_f^2} / \sum \frac{S_f \cdot S_f}{N_f^2}$ finally, to avoid FFTs $H = \sum D(t)F(t) / \sum S(t)F(t)$ where filter $F(t) = FFT^{-1}(\frac{S_f^*}{N_f^2})$

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Processing algorithm



Software demands

- fast data taking from digitizer on fly; controlling of acquisition/oscilloscope parameters (sampling rate, coupling etc.)
- data visualization (signal, FFT, energy spectrum)
- data processing on/off fly
- data saving/reading into/from hard disk

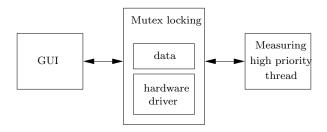
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Software design

- real time multi-thread application with mutex locking synchronization
- MS Visual C++ Net Framework 2
- NI's high frequency digitizer driver
- external OS FFT library- FFTW3, compiled with MinGW

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Software architecture



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Software GUI

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Application example

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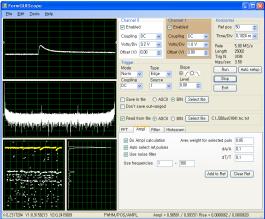
noise power spectrum

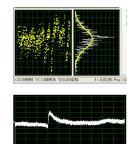
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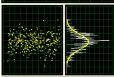
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Application example I

the energy spectrum with using filter







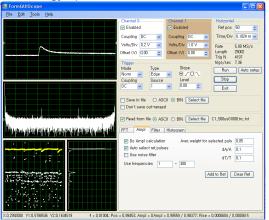
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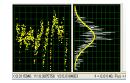
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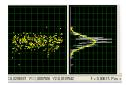
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Application example II

the energy spectrum without filter







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- program support
- implementation new features on demand

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