Optimal filtering for bolometer signals in cryogenic particle detectors

Yury Yuryev

KRISS

International Workshop on Double Beta Decay Searches, 2009.10.16

Overview

1. Signal processing
2. Software implementation

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

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

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 $\Delta H_{rms} = \sqrt{\sum (w_f \cdot N_f)^2}$
$\frac{H}{\Delta H_{rms}} = max \Rightarrow w_f = \frac{D_f}{N_f^2}(\sum (w_f \cdot N_f)^2 / \sum w_f \cdot D_f)$
remove common scale factor $\Rightarrow w_f = \frac{D_f}{N_f^2}$
choose phases to maximize the numerator in $\frac{H}{\Delta H_{rms}} \Rightarrow w_f = \frac{D_f^*}{N_f^2}$
remove common scale factor $H \Rightarrow w_f = \frac{S_f^*}{N_f^2}$ and $H \sim \sum \frac{D_f \cdot S_f^*}{N_f^2}$

Signal filtering II

A. E. Szymkowiak "Signal Processing for Microcalorimeters"

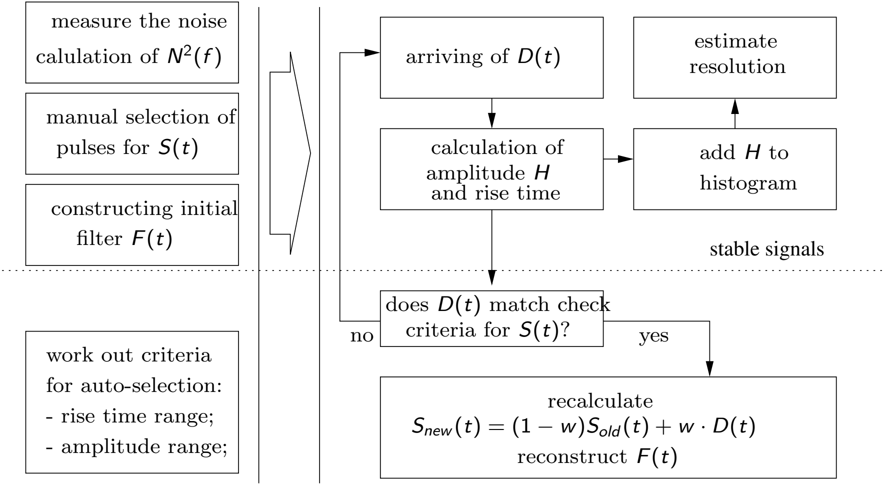
$$\chi^2 = \sum \frac{|D_f - H \cdot S_f|^2}{N_f^2} = \sum \frac{(D_f - H \cdot S_f) \cdot (D_f - H \cdot S_f)^*}{N_f^2}$$

$$\partial \chi^2 / \partial H = 0 \Rightarrow 2H \sum \frac{S_f S_f^*}{N_f^2} = \sum \frac{D_f S_f^* + D_f^* S_f}{N_f^2}$$

because of $S(t)$ and $D(t)$ are Real $\Rightarrow H = \sum \frac{D_f \cdot S_f^*}{N_f^2} / \sum \frac{S_f S_f^*}{N_f^2}$

finally, to avoid FFTs $H = \sum D(t)F(t) / \sum S(t)F(t)$ where filter $F(t) = FFT^{-1}(\frac{S_f^*}{N_f^2})$

Processing algorithm



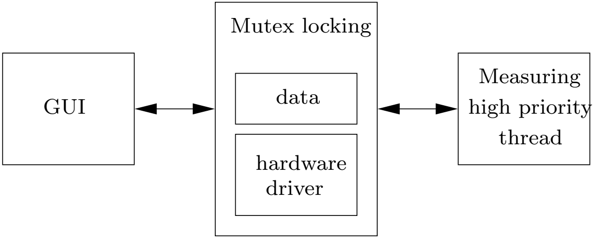
Software demands

- 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

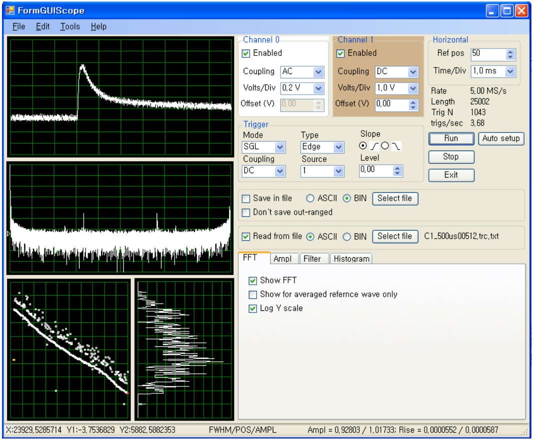
Software design

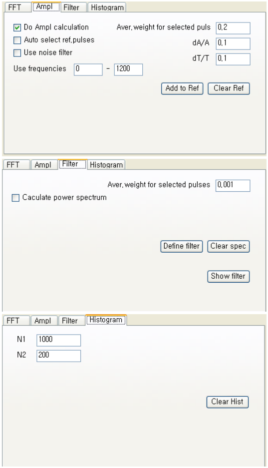
- real time multi-thread application with mutex locking synchronization
- MS Visual C++ Net Framework 2
- NI's high frequency digitizer driver
- external OS FFT library- FFTW3, compiled with MinGW

Software architecture

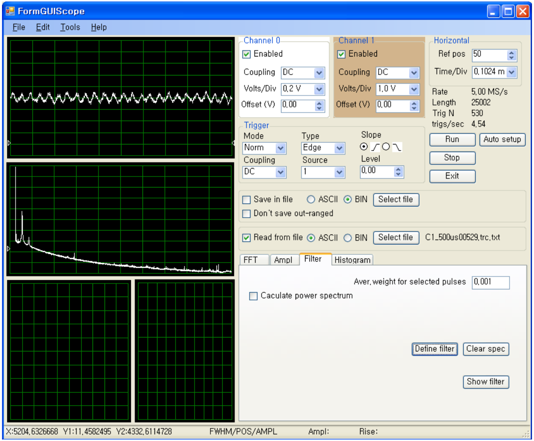


Software GUI





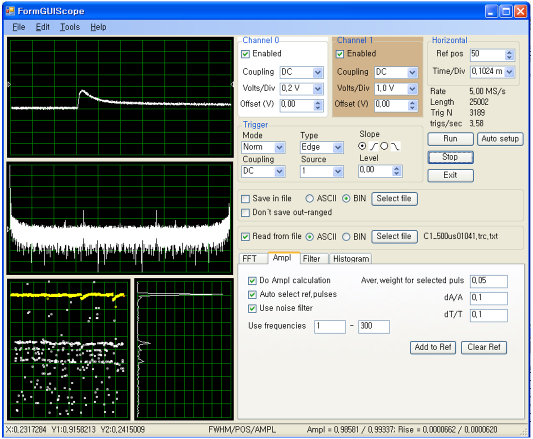
Application example

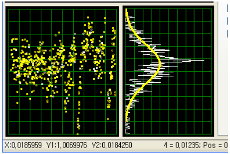


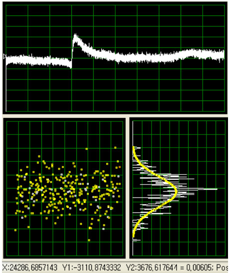
noise power spectrum

Application example I

the energy spectrum with using filter

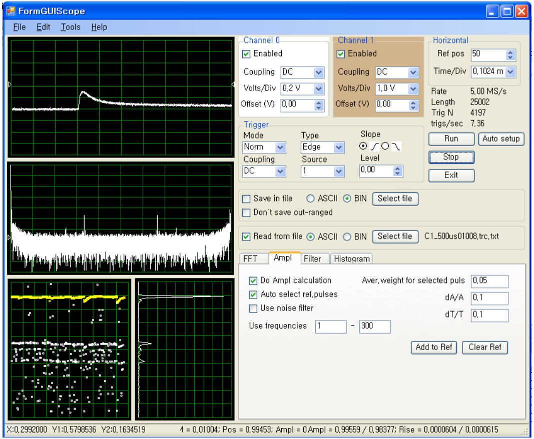


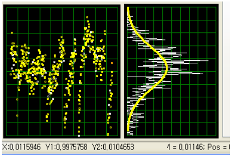


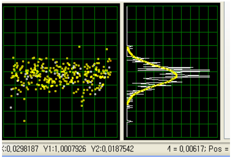


Application example II

the energy spectrum without filter







Plans

- program support
- implementation new features on demand