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Impact of the "non-destructive" multiple-readout on the Lorentzian noise

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Abstract

In this paper, we discuss the effect of "non-destructive" multiple-readout on the Lorentzian noise. To our knowledge, it is the first time that such interaction is investigated. We have studied the peculiarities of the shape of the optimum weighting function for the multiple-readout technique in the presence of Lorentzian noise and other noise sources. The impact of the Lorentzian noise on the resolution achievable with the multiple-readout technique is analyzed in detail with respect to the interaction between the oscillation time and the characteristic time constant of the Lorentzian noise.

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Keywords: Multiple-readout; High-resolution spectroscopy; Lorentzian noise; Radiation damage; Optimum filter

1. Introduction

In the field of X-ray spectroscopy, an accurate readout of the signal charge is essential to be able to detect X-rays even in the low-energy scale. One of the limiting factors of the achievable energy resolution is the noise of the front-end amplifier. The two most common forms of output circuits are floating diffusion (FDA) and floating gate amplifiers (FGA). In the case of the FDA the signal charge is transferred through the device and dumped directly on the output node (the floating diffusion), which is connected to the gate of a FET operated as a source follower. In order to be read, the information brought by the signal charge adds to the charge of the input FET and is no more available. On the contrary, in the case of the FGA the signal charge can be readout multiple times as the signal charge is only capacitively coupled to the output node. By clocking multiple times the signal charge underneath the output node, a periodic current signal is induced at the output electrode. We have analyzed in a previous paper [1] the impact of the "non-destructive" multiple-readout technique on the different noise contributions in order to understand the optimum resolution that can be achieved. This technique allows to reduce the $1/f$ contribution and to eliminate the $qV_{\mathrm{th}}C$ reset noise that is introduced by the reset FET [2]. The optimum weighting function in the presence of different noise sources in the case of the multiple-readout technique was calculated with a novel method. However, in that paper we did not deal with the Lorentzian noise.

It is well known and there are experimental evidences reported in the literature [3] that the exposure to ionizing radiation affects the noise performances of the input transistor of the front-end electronics. In particular, one or more Lorentzian components arise in the noise spectral density of irradiated P- and N-Channels JFETs with characteristic frequencies located in the 1 Hz to 10 MHz range, depending on the channel polarity. The intensity of the Lorentzian terms linearly increases with the absorbed dose. This evidence together with the fact that DEPFET

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devices have been designed to embody the multiple-readout technique in view of the stringent requirements of the Wide Field Imager of the future XEUS mission [4] have stimulated the interest to study the impact of the Lorentzian noise on the "non-destructive" multiple-readout.

To our knowledge, it is the first time that such interaction is investigated. The first time implemented method to derive the optimum signal response in the presence of Lorentzian noise sources in the case of the multiple-readout technique is reviewed in Section 2. In Section 3, we discuss the peculiarities of the shape of the optimum weighting function for the multiple-readout technique in the presence of Lorentzian noise and other noise sources and finally in Section 4, we evaluate the impact of the Lorentzian noise on the resolution achievable with the multiple-readout technique.

2. Description of the method

The optimum weighting function (WF) for a current input signal $i(t)$ is obtained by minimizing the noise-to-signal ratio [5,6]

$$\left(\frac{N}{S}\right)^2 = \frac{\int_{-\infty}^{+\infty} N(\omega)|\Im[\mathrm{WF}(t)]|^2\,\mathrm{d}\omega}{[\int_0^{T_{\mathrm{meas}}} i(t)\mathrm{WF}(t)\,\mathrm{d}t]^2}. \tag{1}$$

The only constraints a priori imposed are the finite time duration T_{meas} of the WF and its zero value at the extremes of this interval and outside it. Other constraints suitable to cope with particular experimental requirements may also be added. All the constraints are imposed as Lagrange constraints:

$$\sum_e \xi(e)A_e + \sum_o \zeta(o)A_o - w = 0. \tag{2}$$

The synthesis algorithm represents the sought WF as a truncated Fourier sine series composed of symmetrical and antisymmetrical harmonics.

$$\mathrm{WF}(t) = \begin{cases} \sum_n A_n \sin(n(\pi/T_{\mathrm{meas}})t), & 0<t<T_{\mathrm{meas}} \\ 0, & \text{elsewhere.} \end{cases} \tag{3}$$

The optimum WF is univocally defined by the coefficients A_n. Any kind of uncorrelated, stationary, additional noises can be taken into account and are expressed as

$$N(\omega) = \sum_k \alpha_k|\omega^k|, \quad k = \ldots,-2,-1,0,1,2,\ldots\ . \tag{4}$$

For sake of simplicity in the case of the "non-destructive" multiple-readout with q signal oscillations, we express the induced current signal $i(t)$ as a series of δ-pulse doublets [1]:

$$i(t) = \sum_{i=1}^{q} Q_{\mathrm{ref}}\left[\delta\left(t+\frac{4i-3}{4}\frac{T_{\mathrm{meas}}}{q}\right) - \delta\left(t+\frac{4i-1}{4}\frac{T_{\mathrm{meas}}}{q}\right)\right]. \tag{5}$$

WF(t) that minimizes

$$\left(\frac{N}{S}\right)^2 = \frac{\int_{-\infty}^{+\infty} N(\omega)|\Im[\mathrm{WF}(t)]|^2\,\mathrm{d}\omega}{Q_{\mathrm{ref}}^2\left[\sum_n A_n \int_0^{T_{\mathrm{meas}}} \sum_{i=1}^{q}\left[\delta\left(t+\frac{4i-3}{4}\frac{T_{\mathrm{meas}}}{q}\right) - \delta\left(t+\frac{4i-1}{4}\frac{T_{\mathrm{meas}}}{q}\right)\right]\sin\left(n\frac{\pi}{T_{\mathrm{meas}}}t\right)\mathrm{d}t\right]^2} \tag{6}$$

is the sought optimum WF.

3. Optimum weighting function calculation in the presence of Lorentzian noise

The method was extended to include also the Lorentzian noise contribution [7]

$$N(\omega) = \frac{A_{\mathrm{L}}\tau_{\mathrm{L}}}{1+\omega^2\tau_{\mathrm{L}}^2}. \tag{7}$$

For the first time in the literature, to the best of our knowledge, we study the impact of the multiple-readout technique on the Lorentzian noise.

The calculus of the shape of the optimum WF in the presence of pure Lorentzian noise shows some numerical difficulties. In fact, at high frequencies the Lorentzian noise power spectral density (PSD) is similar to the one of the white parallel noise and, therefore, a WF similar to a δ function would be required. However, the constant low-frequency component of the Lorentzian PSD forces the low-frequency harmonics to vanish causing the optimum WF to have zero area.

Fig. 1 shows the optimum WF in the time domain in the presence of pure Lorentzian noise for two signal oscillations. The δ function shape of the optimum WF requires a high number of harmonics to be properly described (much higher than in the case of white noises and $1/f$ series noise). Due to the Fourier series truncation imposed by the

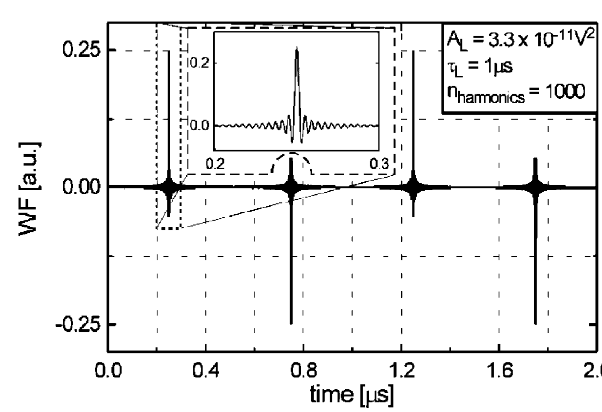

Fig. 1. Optimum WF in the time domain in presence of pure Lorentzian noise for two signal oscillations. The inset shows the increase of the amplitude of the Gibbs' oscillations.