# Measurement of the Power Spectral Density of Noise Produced by a Large Integrated Feedback Resistor for Charge-Sensitive Preamplifiers

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***Abstract*—Charge-sensitive preamplifiers (CSP) require high-valued feedback resistors as continuous-time reset devices: higher resistance values correspond to lower current noise and better spectroscopic performances. Designing integrated multi-channel CSP such resistors are generally left as external components or substituted with active transconductors. The former are bulky and not adequate for situations where a high degree of integration is required, the latter generally suffer from linearity and noise problems. A possible solution could be the use of large integrated polysilicon resistors. These ones, however, suffer from a very high distributed capacitive coupling to bulk, which tends to turn such devices into transmission lines. Simple resistor models are no longer adequate to describe both the impedance and the noise generators of such integrated resistors. A closed-form model was developed which describes the current noise produced by a resistance with distributed capacitance. A 100 MΩ integrated polysilicon resistor was realized and the power spectral density of noise produced by this device has been measured connecting it as a feedback resistor to a low-noise charge-sensitive preamplifier.**

## I. Introduction

In a charge-sensitive preamplifier the feedback resistor has the role of progressively discharge the feedback capacitor avoiding an unbearable pile-up of the signals and providing a precise DC working point to the CSP. Since the parallel current noise generated by this passive device sums up directly with the one produced by the detector, the value of the resistance must be high in order to keep the spectral power noise low. Generally for gamma spectroscopy a 1 GΩ or 2 GΩ resistor is chosen [1]–[8]. They provide respectively a spectral power density of $1.66\dot{1}0^{-29}\frac{\mathrm{A}^2}{\mathrm{Hz}}$ and $8.28 \cdot 10^{-30}\frac{\mathrm{A}^2}{\mathrm{Hz}}$. These values are in agreement with the required spectroscopic resolutions. Traditionally these resistors are discrete thin-film type. Nowadays ASICs are progressively substituting the old discrete-type circuits due to numerous benefits in terms of readout granularity and power consumption. However the physical implementation of a feedback resistor on a standard silicon CMOS chip is absolutely non trivial. Contemporary fabrication technologies provide high-valued resistance modules, but their planar resistivity is only around $1\frac{\mathrm{k}\Omega}{\square}$. If the minimum width of the polysilicon resistor is 1 $\mu$m, the area of a 1 GΩ resistor (without considering the empty areas within the resistance's bends) is 1 mm$^2$. This means that the area occupied by the single feedback resistance can be considerably larger than a complete charge-sensitive preamplifier, feedback and Miller capacitors included. Such large area is responsible for a high capacitive coupling to bulk, which transform the resistance in a transmission line. In the next section a non-approximated closed-form model is presented, which describes the device impedance and its parallel noise generators.

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## II. Closed-form model

The model [9] was written considering the resistance with distributed capacitance as a series of $N$ R-C cells. For a single R-C cell (see Fig. 1):

$$\begin{bmatrix} V_0 \\ I_0 \end{bmatrix} = \begin{bmatrix} 1+sRC & R \\ sC & 1 \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ I_1 \end{bmatrix}. \tag{1}$$

In the limit of $N \to \infty$ the behaviour of the resistance with distributed capacitance is represented by the following equation:

$$\begin{bmatrix} V_0 \\ I_0 \end{bmatrix} = \begin{bmatrix} \cosh\left(\sqrt{sRC}\right) & \sqrt{\frac{R}{sC}}\sinh\left(\sqrt{sRC}\right) \\ \sqrt{\frac{sC}{R}}\sinh\left(\sqrt{sRC}\right) & \cosh\left(\sqrt{sRC}\right) \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ I_1 \end{bmatrix}. \tag{2}$$

Connecting a series of $N$ noisy R-C cells and letting $N \to \infty$ we can determine the spectral noise density of the current noise generator associated to the resistance. When this device is used as feedback resistance in a charge-sensitive preamplifier, the expression of the input-referred spectral power density of current noise is equal to the one in eq. 3.

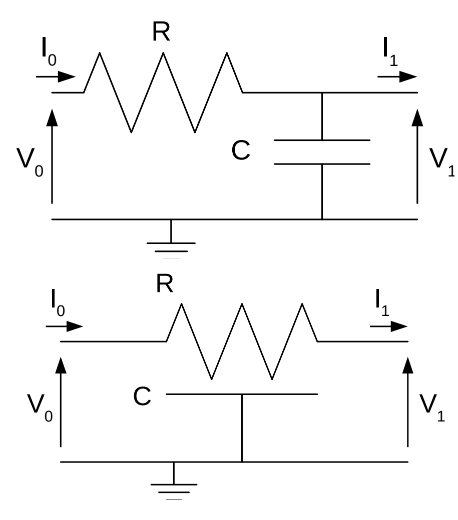


Fig. 1. Top figure: schematic diagram of a single R-C cell. Bottom figure: schematic diagram of a resistance with distributed capacitance to bulk.

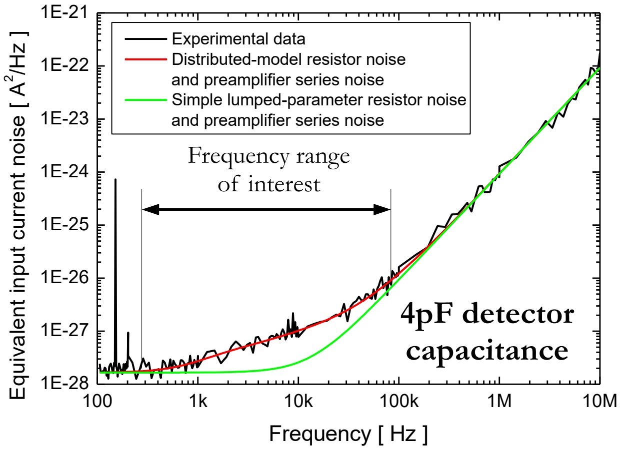


Fig. 2. Input referred current noise of a charge-sensitive preamplifier with the integrated 100MΩ resistor as feedback. The input-referred capacitance is 4 pF. The parallel current noise produced by a resistance with distributed capacitance has a spectral power density that goes like the frequency. The input-referred series preamplifier noise goes like the square of the frequency. This means that the former noise contribution is appreciable only if the preamplifier has a high noise corner frequency.

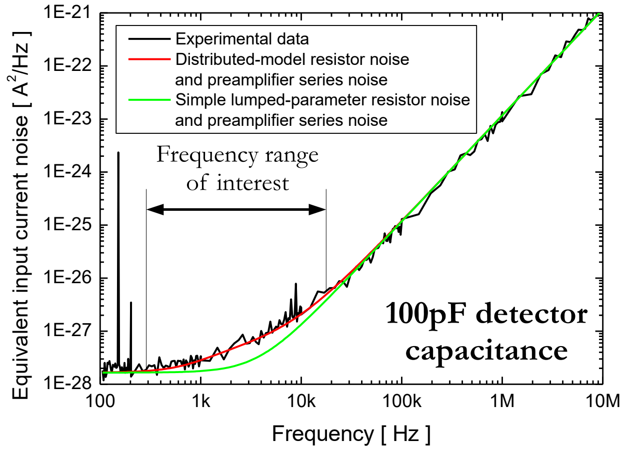


Fig. 3. Input referred current noise of a charge-sensitive preamplifier with the integrated 100MΩ resistor as feedback. For a charge-sensitive preamplifier the noise corner frequency goes like the inverse of the total input capacitance. If either the series noise or the input capacitance are high, the noise corner frequency can become so low that the contribution of the f-like noise component from the resistance with distrubuted capacitance can be considered negligible.

$$i^2_{\text{NOISE}} = 4KT\sqrt{\frac{\pi Cf}{R}} \cdot \left[\frac{\sin\left(2\sqrt{\pi RCf}\right) + \sinh\left(2\sqrt{\pi RCf}\right)}{\cosh\left(2\sqrt{\pi RCf}\right) - \cos\left(2\sqrt{\pi RCf}\right)}\right] \tag{3}$$

Equation 3 shows that the noise produced by a resistor with distributed capacitive coupling to bulk is white only for low frequencies while for high frequencies it goes like the square root of frequency. The characteristic corner frequency of this noise is equal to:

$$f_{\text{CORNER}} = \frac{1}{2\pi\left(\frac{\text{RC}}{2}\right)} \tag{4}$$

that in this case is roughly equal to 300 Hz.

## III. Experimental setup and results

In order to verify the validity of the previous model an integrated 100 MΩ polysilicon resistor was realized (with AMS C35 technology [10]) and connected as a feedback resistance to a low-noise CSP [11]–[13]. The input-referred noise was evaluated using a network spectrum analyser. First of all the output noise of the charge-sensitive preamplifier was measured with the instrument working in "spectrum analyser" mode. Nothing was connected to the input of the CSP. After this step both the input and the output of the preamplifier were connected to the instrument, now working in "network analyser" mode. In this way we measured the response function of the CSP. The data were then processed and the equivalent input referred noise was calculated dividing the output power of noise by the square module of the transfer function. This operation was repeated for two different capacitances connected to the input: 4 pF and 100 pF. The results are reported in fig. 2 and 3. In case of low detector capacitance (4 pF) the noise contribution from the resistance is clearly visible in the range of frequencies between 1 kHz and 50 kHz. At higher frequencies the series noise contribution from the operational amplifier becomes predominant. In case of high detector capacitance (100 pF) the preamplifier noise corner frequency becomes lower and the non-white contribution from the resistor becomes almost negligible.

## IV. Conclusions

The experimental results confirm the validity of the proposed model. The non-white noise contribution generated by the integrated resistor with high capacitive coupling to bulk can be considered negligible if the noise corner frequency of the preamplifier becomes comparable with the characteristic corner frequency of such non-white noise. Further studies will explore the possibility to implement such resistor inside a fully integrated charge-sensitive preamplifier [11]–[14] that can meet the requirements of the new highly-segmented detector arrays like TRACE [15]–[17].

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