NOISE CHARACTERIZATION OF ANALOG DEVICES

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ABSTRACT

In this work, a simple and cheap circuit capable of measuring noise in analog devices has been developed. This circuit allows measuring thermal, shot and flicker noise. Experimental results are shown and compared with theoretical values. The circuit was implemented with discrete components that are easily found in the Brazilian market.

1. INTRODUCTION

Many laboratories do not have equipment to measure noise in analog devices, despite the need for testing them. Equipments with this purpose, generally made by instrumentation companies, are too expensive and seldom used. To bypass the cost of an expensive noise-measuring equipment, we developed a simple circuit that allows measuring noise with reasonable accuracy.

2. SOURCES OF NOISE IN ANALOG DEVICES

The three main types of fundamental noise mechanisms are thermal noise, shot noise and flicker noise.

Thermal noise is caused by the random thermally excited vibration of the charge carriers in a conductor [1]. The rms thermal noise voltage v_t of a resistance R is

$$v_t = \sqrt{4kTR\Delta f} \qquad (1)$$

k: Boltzmann's constant (1.38 x 10^{-23} J/K)
T: temperature in Kelvin
Δf: noise bandwidth in hertz

Shot noise is a noise current mechanism in transistors and diodes. Current flowing in these devices is not smooth and continuous, but rather it is the sum of pulses of current caused by the flow of carriers, each carrying one electronic charge, crossing a potential barrier [1]. The rms shot noise i_{sh} current is

$$i_{sh} = \sqrt{2qI_{DC}\Delta f} \qquad (2)$$

q: electronic charge (1.602 x 10^{-19} Coulombs)
I_{DC}: direct current in amperes

Flicker Noise is a type of noise found in all active devices, as well as in some discrete passive elements. The origins of flicker noise are varied, but it is caused mainly by traps associated with contamination and crystal defects [2].

Flicker noise has a noise spectral density with a 1/f frequency dependence and it is always associated with a flow of direct current. Flicker noise displays a spectral density of the form

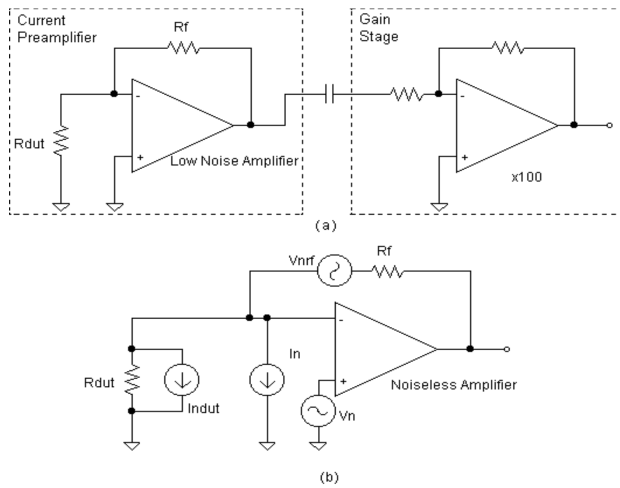

Fig. 1. (a) A schematic diagram of the noise measurement system. (b) The equivalente circuit for noise calculation.

$$\overline{i^2} = K_1 \frac{I_{DC}{}^a}{f^b}\Delta f \qquad (3)$$

K_1: constant for a particular device
a: constant in the range 0.5 to 2
b: constant of about unity

3. CIRCUIT SPECIFICATIONS

The circuit is implemented with discrete components. The noise figure of each component must be as good as possible. In this way, metal film resistor (carbon resistors produces flicker noise), low noise capacitors and low noise operational amplifiers. The prototype must be powered by batteries and allocated inside a metal box to avoid undesired noise from external sources.

The circuit has two basic blocks. The first block is a current preamplifier stage and we have to take care about its layout. The opamp used in the first stage must be a low noise opamp. The second provides voltage gain. It can be built using one or two gain stages, although just one stage is represented in Fig. 1(a). Fig. 1(b) shows the equivalent noise model of the system with the noise sources represented. The noise power spectral density at the output is given by

$$\frac{v_{noise}{}^2}{\Delta f} = i_{ndut}{}^2 R_f{}^2 + 4kTRf + i_x{}^2 R_f{}^2 + v_x{}^2\left(1 + \frac{R_f}{R_{dut}}\right)^2 \qquad (4)$$

Here, R_{dut} is the equivalent resistance of device under test; i_{ndut} is the current noise generated by the DUT; R_f is the feedback resistance of the current preamplifier; i_x and v_x are, respectively, the equivalent input noise current and noise voltage of the operational amplifier.

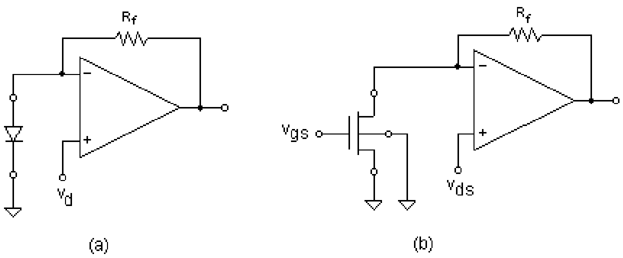

Fig. 2. Adaptations for (a) Shot Noise Measurement (b) Flicker Noise Measurement

The same current preamplifier can be used for measuring shot noise in PN junction as in Fig. 2(a) and flicker noise in MOS devices [3] as in Fig. 2(b).

4. OPERATIONAL AMPLIFIER PERFORMANCE

Using numerical simulations we can compare the performance of different low noise opamps to choose which one will be used in the current preamplifier stage. These simulations were made for thermal noise measurement system. This kind of analysis is necessary because some opamps have a better current noise figure and others a better voltage noise performance. Each of these properties will have a different influence on the final measurement depending on the values of both R_{dut} and R_f. In this way, we can choose a better opamp for a given range of R_{dut} to be measured.

From (4) we can vary R_{dut} and R_f to calculate the noise level introduced by undesirable sources. The values of i_x and v_x are obtained from opamp datasheet.

Fig. 3 illustrates the analysis. For R_{dut} between $10^3\Omega$ and $10^5\Omega$ we have approximately 80% or more of the total noise level coming from R_{dut} using the operational amplifier OPA228 fabricated by Burr Brown. For the resistor R_f, values bigger than $10^4\Omega$ can be used, but we have to choose values that give a gain more than 10 to make the output noise level at this stage much higher than the noise sources of the next stage.

5. MEASUREMENTS AND SIMULATIONS

In the case where spectrum analyzer is not present we can just use an oscilloscope to estimate the noise level. In order to do this we need to take the peak-to-peak value and dividing by 6 ($\pm 3\sigma$) [1]. This approach is very attractive since the motivation of this work is building a low cost measurement system. If accurate values are desired, a spectrum analyzer must be used.

The values showed in Fig. 4 were collected from spectrum analyzer. The resolution bandwidth selected at this instrument was 150Hz at the center frequency of 5kHz.

6. CONCLUSIONS

There are no difficulties to build a circuit like this described in this paper. It is quite easy to find the components and implement the prototype. The cost involved is low. If just an estimation of noise level is needed, spectrum analyzer is not required, so any

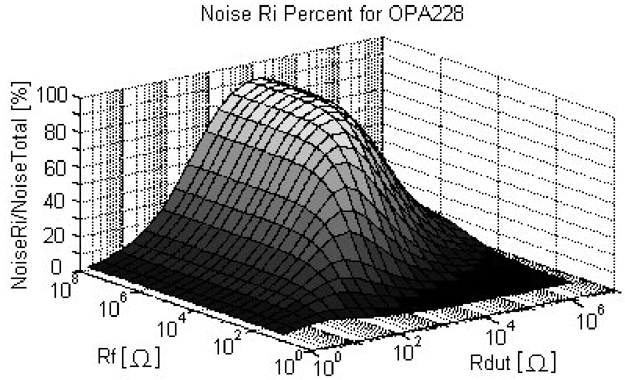

Fig. 3. Percentual noise added by Rdut normalized to total noise

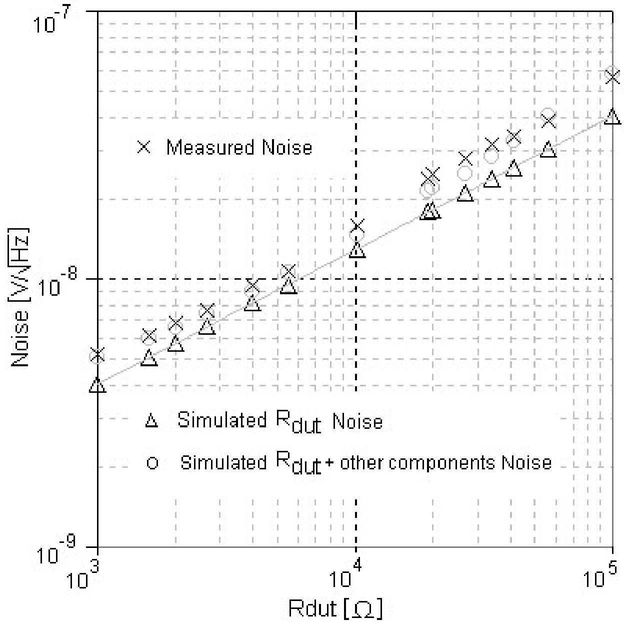

Fig. 4. Noise Simulated and Measured using OPA228

laboratory is able to do these measurements.

Analyzing the results of thermal noise measurements we can validate the good accuracy that this circuit provides.

7. REFERENCES

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[3] A.A. Abidi, "Automated system for the measurement of fluctuation phenomena in FET's," *Rev. Sci Instrum.,* American Institute of Physics, Vol 59, pp. 351-355, February 1988.