IMPLEMENTATION OF CONSTANT COMPONENT FILTER IN MEASUREMENTS OF RANDOM TELEGRAPH SIGNAL NOISE

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Abstract: Noise is generated in all semiconductor devices. The intensity of these fluctuations depends on used elements, manufacturing process, operating conditions and device type. The result noise is a superposition of different kinds of fluctuations like thermal noise, generation-recombination noise, 1/f noise, shot noise and Random Telegraph Signal (RTS) noise. The last one, RTS noise is observed as nonstationary impulse fluctuations. Unfortunately, it is hard to notice and investigate the RTS because of DC component value in contradiction to small amplitude of noise impulses. In the paper a simple filtrating system which removes the DC component without AC signal distortion is presented. Example oscilloscope measurement results and their analysis are also shown.

Keywords: RTS noise, DC filter, active filter

1. INTRODUCTION

RTS noise is also called popcorn noise, impulse noise or bi-stable noise. It belongs to excess noise group. It means, that it is a kind of a fluctuation occurring as a result of faults during the manufacturing processes, materials defects or another external factors like for example harmful radiation [1]. The first observations of RTS noise in semiconductor devices appeared in the 50's of 20th century [2].

In given biasing condition of a device, the RTS is observed as pulses with constant amplitude and random pulse width. In some cases, the RTS noise may have more than two levels [3]. In that case it is called a multi-position or multi-level RTS noise.

The model of two-level RTS noise is presented in Fig. 1. The characteristic parameters of the fluctuations are: the amplitude ΔX, mean time the signal is in down state $\overline{\tau_d}$ and mean time the signal is in up state $\overline{\tau_u}$ .In 1967 Wolf and Holler [4] ascertained, that mean times correspond to Poisson distribution.

$$\overline{\tau_u} = \frac{1}{N} \sum_{n=1}^{N} \tau_{u,n} \qquad (1)$$

where: $\overline{\tau_{u,n}}$, n=1, 2, …, N is a duration of n-th impulse in up state observed in time T [5]

$$\overline{\tau_d} = \frac{1}{M} \sum_{m=1}^{M} \tau_{p,m} \qquad (2)$$

where: $\overline{\tau_{d,m}}$, m=1, 2, …, M is a duration of m-th impulse in up state observed in time T [5]

The characteristic frequency of the RTS noise is defined as follows [5]:

$$f_{RTS} = \frac{1}{\overline{\tau}} = \frac{1}{\overline{\tau_u}} + \frac{1}{\overline{\tau_d}} \qquad (3)$$

Noise spectral density function of the RTS noise is similar to generation-recombination noise:

$$S(f) = C \frac{4 \cdot (\Delta X)^2}{1 + \left(\frac{2\pi f}{f_{RTS}} \right)} \qquad (4)$$

where: ΔX - the amplitude of RTS noise and:

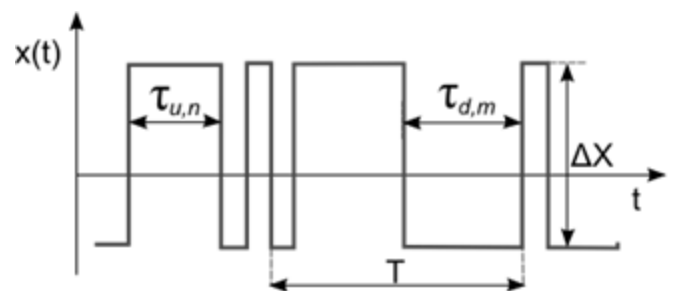$$C = \frac{1}{\left(\overline{\tau_u} + \overline{\tau_d} \right) \cdot f_{RTS}^2} \qquad (5)$$

Fig. 1. Typical two-level RTS noise model

The intensity of RTS noise depends on the location of the trap center with the reference to the Fermi level, because only the centers in the vicinity of Fermi level are able to generate the noise. These trapping centers are usually the result of silicon contamination with heavy metals and lattice structure imperfections [3]. An analysis of RTS noise is typically applied to improve the performance of semiconductor devices, their technology and quality [4].

Important for modern devices is that RTS noise exists in devices with small number of carriers, where single electron can be captured by a single trapping center [**5**].

Typically, the analysis of RTS noise is carried out in the time domain, where signal is observed and the probability density function of the noise signal is calculated. In the frequency domain, usually the power spectral density $S(f)$ is estimated. From the analysis it is possible to assess RTS amplitude ΔX and characteristic frequency f_{RTS}.

2. ANALYSIS AND MEASUREMENTS METHODS

To properly analyze RTS noise, it is necessary to record it properly without any distortions. The measured signal usually consists of AC and DC component. RTS noise is contained in the AC component and its level (amplitude ΔX) is significantly lower than DC component. The high value of DC component requires wide range of measurement system, which in practise gives low resolution, thus low precision of AC component measurement. The easiest way to improve AC component measurement is to eliminate DC component from the measured signal.

To eliminate the DC component of the signal usually a high-pass filter is used, which transmits voltage spikes and blocks the DC component. In a practical approach, to eliminate the DC component a simple RC filter is usually used (Fig. 2). Unfortunately, due to the RTS specific characteristics, the traditional filtration systems do not work properly, because it disorts the input signal. Figure 3 shows deformations of the square wave after transmision by the RC filter with a not correctly chosen time constant.

It can be assumed that constructing a filter with larger time constant could prove to be effective. Unfortunately, increasing the filter's time constant also inceases the measurement time, depending on maximum possible duration time of the RTS impulse. The reason of that is naturally a large capacity applied, which needs a long time to reach a fully recharged state. Only then the filter will correctly reproduce a DC component of the RTS signal. Measurement time of such lenght is in most cases not acceptable. That is why, it is necessary to build a system that will be able to accurately filter the DC component without distorting the RTS noise., regardless of duration of its pulses
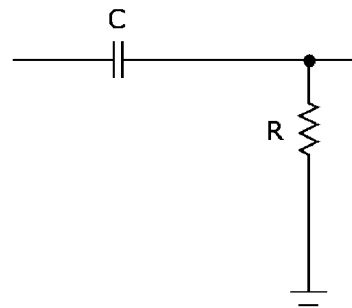

Fig. 2. Typical RC high-pass filter

3. IDEA OF SOLUTION

One of the solutions of the problem described above is to compensate the DC component of the measured signal. It can be done by subtracting the measured signal and DC signal with the value of measured signal DC component. For the measurement simplification, the subtracted DC signal level should be set automatically. Therefore, the solution that should prove effective could be a low pass filter with a very low cutoff frequency. Then it will be possible to isolate the DC component and subtract it from the measured signal of the electronic component. For this purpose, a reverse addition block should be included in the the low-pass filter configuration.

4. PROJECT AND REALIZATION

To design the low-pass filter, Texas Instruments software FilterPro Desktop, version 3.1.0 was used. Design parameters used in the project are presented in Table 1. Figure 4 shows amplitude, phase and filters delay characteristics.
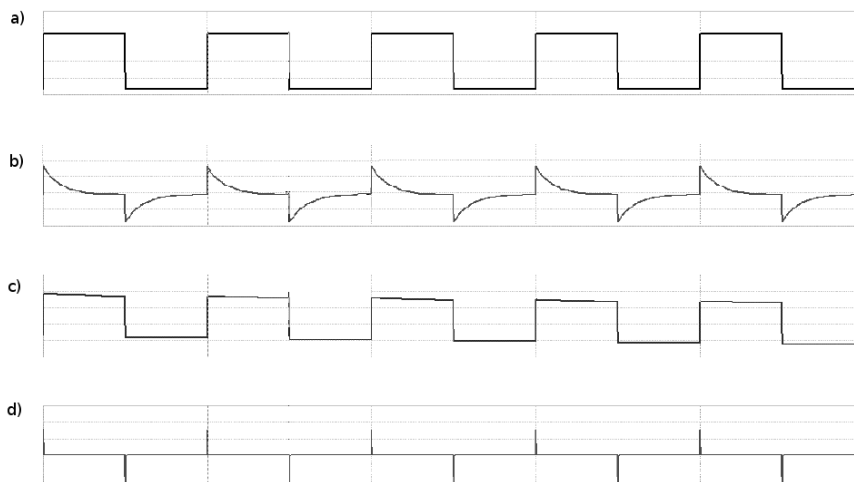

Fig. 3. Result of filtering 10 Hz frequency signal (a) by system of three RC filters with time constant τ_1=10 ms (b), τ_2=1 s (c), τ_3=0,1 ms (d)

The full system includes a reverse addition block, which subtracts extracted DC component from input signal (Fig. 5). For initial tests, the electrical circuit was built on the contact plate SD-24. As operational amplifiers three LM741 were used. The circuit was working properly, thus the printed circuit board was designed, manufactured and mounted. Then several tests were performed to verify system operation for different measurement signal parameters.

Table 1. Design assumptions

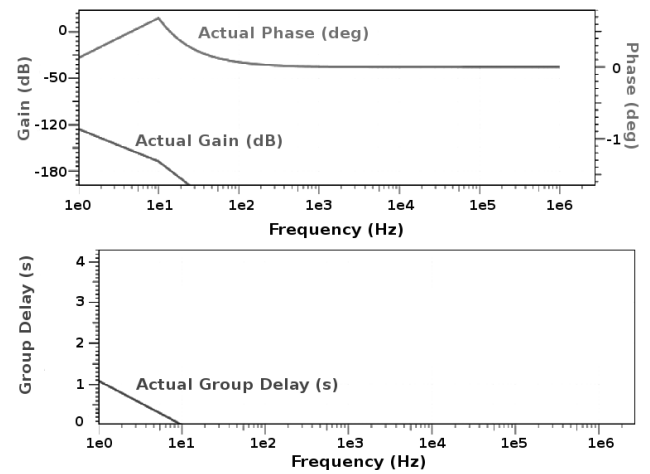| Cutoff frequency	0.5 Hz
Acceptable waving	0.5 dB
Amplification	1 V/V
Row number	2
Filter system	Sellen-Key
Type of filter	Chebyshev
Passband Gain	1
Cutoff Frequency	0 Hz

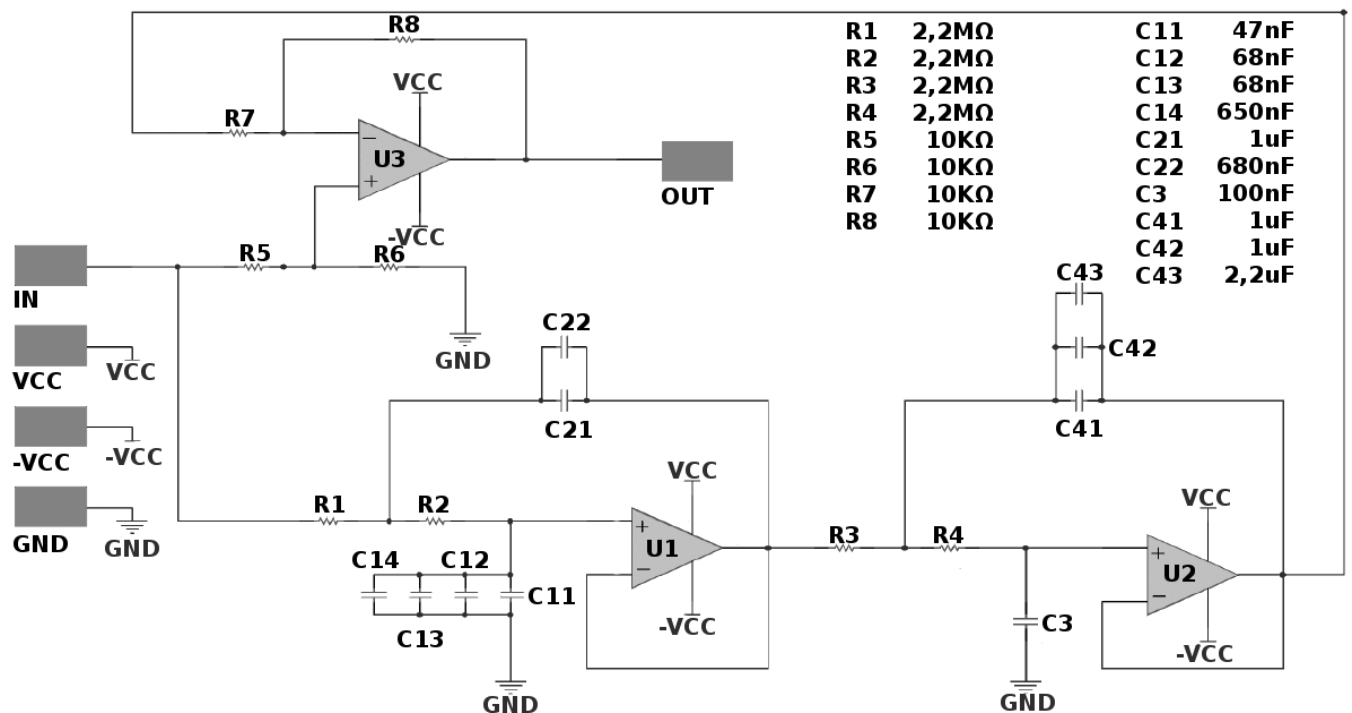Fig. 4. Amplitude and phase characteristic and filter delay

Fig. 5. Schematic diagram of the system

5. SYSTEM TESTS

To analyze the operation of the system a test-bench shown in Fig. 6 was proposed. The test signal is a a square wave (AC component) with DC offset (DC component). A square wave simulate the RTS signal. Its fill factor and frequency can be changed for better simulation of different length of RTS pulses. Test signal parameters are presented in Table 2. The example screenshot of test results is shown in Fig. 7. The square signal in the upper part of Fig. 7 is the input signal, straight line shows the DC component retrieved by low-pass filter. The bottom square signal is the output signal is a result of substraction of the input signal and DC component. As is seen from Fig. 8 the system works properly.

The signal is mapped correctly in the whole testing frequency range. Some signal distortions occurs above 50 kHz and results from frequency band of the system. The fact is practically negligible, because the low frequency noise measurements are not performed for such high values of input signal frequency. Measurements for these values have been carried out to check the limits of correct system functioning. The filter is resistant to the fill percentage factor of the input signal. Change in DC component value require from two to ten seconds for stabilization of the output signal.

Table 2. Testing assumptions

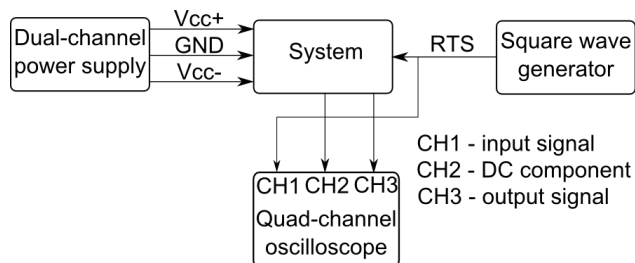| DC component	1 V
AC component	0 ÷ 100 mV
Fill factor percentage	10 % ÷ 90 %
Frequency	0.5 Hz ÷ 100 kHz

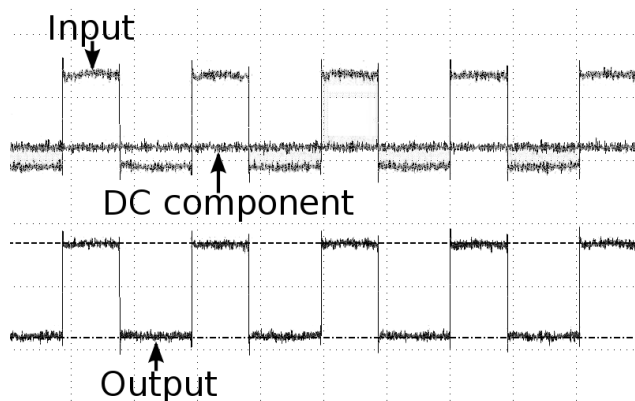Fig. 6. Amplitude and phase characteristic and filter delay

Fig. 7. The result of the test for input AC signal 100 Hz and fill factor 50%

6. CONCLUSIONS

Proposed system allows to increase the measurement accuracy of the RTS noise in low frequency range without observed signal distortions. In comparison with simple RC filtering, the measurement is faster and RTS signal is not distorted by differentiation by the RC filter. In examined frequency range the frequency and fill factor of testing signal doesn't affect the proper operation of the system.

7. REFERENCES

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REALIZACJA UKŁADU FILTRU USUWAJĄCEGO SKŁADOWĄ STAŁĄ W POMIARACH SZUMÓW WYBUCHOWYCH

Słowa kluczowe: filtr, składowa stała, RTS

Szum jest generowany przez wszystkie urządzenia półprzewodnikowe. Szum wynikowy jest zwykle efektem superpozycji różnych rodzajów fluktuacji: szumu termicznego, szumu generacyjno-rekombinacyjnego, szumu 1/f i RTS. Ten ostatni, *Random Telegraph Signal*, jest obserwowany jako pojedyncze, niestacjonarne impulsy w badanym sygnale. Niestety, z powodu małej amplitudy oraz znacznej wartości składowej stałej, szum RTS jest bardzo trudny do obserwacji, co znacząco utrudnia jego badanie. W celu zwiększenia dokładności pomiaru, należy usunąć składową stałą z badanego sygnału. W artykule przedstawiono system odzyskujący składową stałą, a następnie odejmujący ją od sygnału wejściowego. W efekcie w sygnale wyjściowym otrzymuje się sygnał bez składowej stałej, w którym łatwiej jest zaobserwować i zbadać przebieg RTS.