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Noise Resistance of Signal Transformation Methods.

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Introduction

Discrete stroboscopic conversion represents a sequential measurement of instantaneous values of signal by comparison of signals with the known threshold.

The simplest measurement method of instantaneous value of the signal is the “up-and-down” method (hereinafter *ud* method). In accordance with this method measurement of instantaneous value of a signal is done by automatic selection of the threshold of the comparator to be strobed as follows [1]:

$$e_{i,j+1} = e_{i,j} + s * sign(U_{1,i} - e_{i,j}), \tag{1}$$

where

t_i - measurement phase of instantaneous value of the signal,

$e_{i,j}$ - threshold of the comparator in j^{th} time of strobing, where j varies from 1 to n,

n — number of strobings in each phase of the signal,

$U_{1,i} = u_{1,i} + X$ - sum of the value of the signal to be measured $u_{1,i}$ and normally distributed additive noise X with variance $DX = \sigma_1^2$,

s - step of the *ud* procedure.

The measurement result of the instantaneous value of the signal is the last value of the threshold $u_{2,i} = e_{i,n}$.

The development of the *ud* method is the modified “up-and-down” method (hereinafter the *udc* method), according to which changes of the threshold are similar to those in case of the *ud* method, but the result of measurement is determined as follows [1]:

$$u_{2,i} = \frac{1}{n}\sum_{j=1}^{n} e_{i,j} . \tag{2}$$

Noise suppression in case of *ud* and *udc* methods of signal measurement

The discrete stroboscopic converter which is used in case of *ud* method, may be regarded as a relay system of self-adjustment. Suppression of the noise interference in such system of adjustment was studied in the work [2]. Using the results of this work, noise suppression with the *ud* method may be expressed as follows:

$$\sigma_2 = \sqrt{0.625\sigma_1 s + 0.25 s^2}, \tag{3}$$

where

σ_1 - standard deviation of noise at the input of the converter,

σ_2 - standard deviation of noise at the output of the converter.

The main source of the noise is the shot noise of the active elements of the comparator to be strobed. Practically this noise may be regarded as uncorrelated white noise. Then, according to the expression (3) to sufficiently suppress the noise, the step s should be decreased.

In case of the *udc* method the result of noise suppression does not depend on the size of the step s and is determined as [3]:

$$\sigma_2 = 1.25\frac{\sigma_1}{\sqrt{n^*}} . \tag{4}$$

From the expression (4) it follows that in order to sufficiently suppress the noise, it is necessary to increase the number of operations of comparison of the signal with the threshold. During elaboration of highly sensitive stroboscopic converters (in the region of 5-10 µV RMS) it turns out, that the performed theoretical calculations σ_1 of concrete schemes of the comparator and further calculations of corresponding values of σ_2 do not correspond to the experimental results of testing of the converters. It can be explained by impact of electromagnetic pollution of the environment both on the source of the signal to be converted, and the converter itself. In case of application of the discrete stroboscopic converter as the superwideband radar receiver, the input of the converter is affected not only by return signal but also by electromagnetic disturbances in their passband of the receiving antenna. Due to the fact that electromagnetic pollution contains periodic fluctuations, for suppression of the impact of the latter in superwideband radars desynchronization of the converter is introduced by means of connection to the clock generator of the converter of the noise generator [4], [5], [6]. Experimental researches we have carried out have demonstrated that suppression of disturbances with the aforesaid methods in many cases is inefficient. This may be explained by the large correlation distance of the disturbance in comparison with the clock period of the converter (in our appliance the clock period was equal to 1.67 µs). In order to test the hypothesis about impact of the disturbance correlation, as well as testing the eventual way of overcoming this impact, the following experiments were carried out.

Experimental testing of the hypothesis about impact of disturbance correlation

In order to test the hypothesis about impact of disturbance correlation, there was used an experimental appliance of a superwideband radar receiver with the passband of 3.5 GHz, allowing switching operation modes of the converter from the *ud* method to the *udc* method. The appliance also allowed decimation of the selections to be processed with the processor with the *udc* method. For down-scaling of the conversion results at the input of the converter voltage step weakened to 200µV was delivered. Other conditions of the experiment were as follows: strobing frequency (frequency of operations of comparison of the signal with the threshold) $f = 600\,kHz$, increment of the threshold $s = 2.66\,\mu V$, number of points on the scanning-line 300.

Experiment 1:

Input signal - voltage step of 200 µV; *udc* method; number *n* of operations of signal comparison with the threshold in each point is equal to the number averaged selections $n^* = 255$. Thus there are averaged all sequential selections (threshold values). The result of such processing of the signal is given in Fig. 1. The standard deviation of the output noise obtained in this experiment equals to $\sigma_2 = 12.8\,\mu V$.

Experiment 2:

The *udc* method, number n of signal comparisons with the threshold in each point is equal to 10710, number of selections to be averaged $n^* = 255$. Thus every 42nd threshold value is taken for averaging. The result of such processing of the signal is given in Fig. 2. The standard deviation of the noise obtained in this experiment equals to $\sigma_2 = 7.4\,\mu V$.

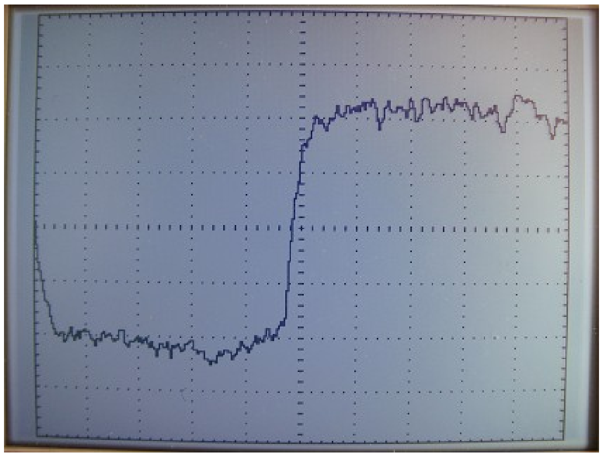

Fig. 1. The result of conversion of 200µV voltage step with the *udc* method. For averaging all selections in succession are taken, output noise $\sigma_2 = 12.8\,\mu V$.

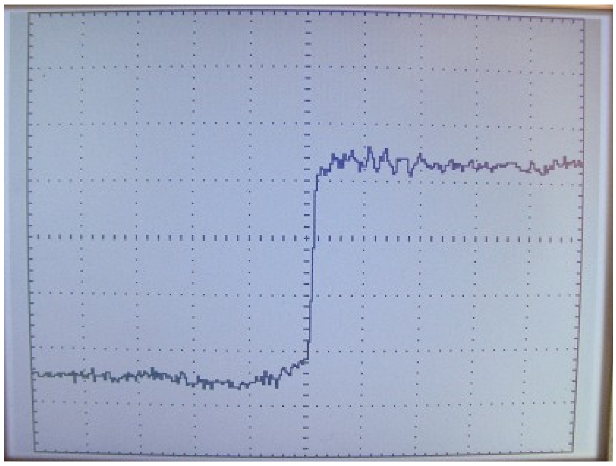

Fig. 2. The result of conversion of 200 µV voltage stap with the *udc* method. For averaging every 42nd selection of the *ud* procedure is taken, output noise $\sigma_2 = 7.4\,\mu V$.

As we see in the second experiment there was obtained almost twice smaller standard deviation of the noise with the same number $n^* = 255$ of selections to be averaged.

Differences of the standard deviation of the noise may be explained by correlation of the selections to be averaged in the first experiment and with significantly smaller correlation between the selections in the second experiment.

For illustration of the dependence of σ_2 from the number of decimations the aforesaid experiment was carried out with different number of decimations. The obtained dependence of σ_2 is given in Fig. 3.

From the obtained results we can see that with the increased number of decimations σ_2 is decreasing, though very slowly because of the long interval of noise correlation. Theoretically, all *n* selections may be averaged, but it is not resulting in great improvement in suppressing the noise influence. So in the given experiment with averaging all 10710 selections $\sigma_2 = 6.2\mu V$ was obtained. Thus, despite the huge amount of averaged selections, the improvement we get is only 16% in comparison with $\sigma_2 = 7.4\mu V$ in case of $n^* = 255$ averaged selections using only each 42nd threshold value. The small improvement of averaging of all selections in succession also supports existence of noise correlation.

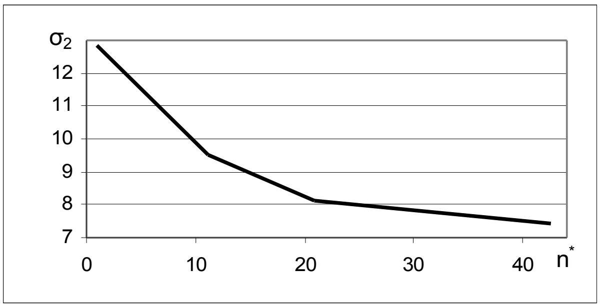

Fig. 3. Dependence of σ_2 from the number of decimations between the selections using *udc* method, in μV.

Suppressing of noise influence by means of selections decimation requires large span time. Therefore for decreasing the noise impact, first it is necessary to use all possibilities of electromagnetic shielding both of the source of a weak signal, and the converter itself.

In addition to the aforementioned researches there was carried out an experiment for determining σ_2 using the *ud* method in the same circumstances of noise impact and with the same step s. In the result of this experiment there was obtained $\sigma_2 = 13.4\mu V$, which differs slightly from the σ_2, obtained with the *udc* method in the mode without decimation between the samples. Obviously, in case of the *ud* method decimation of the selections can't result in any improvement of noise suppression, because the result of the signal measurement is the last value of the comparator threshold. From our previous researches [3] it is known that the results of noise suppression with the *ud* and *udc* methods differ very little, if the step *s* is much smaller than the standard deviation of the masking noise. On the grounds of that we can conclude that in our conditions of the experiments the standard deviation of the disturbance was much greater than the step $s = 2.66\mu V$.

It should be pointed out that application of averagings for improving the sensitivity of stroboscillographs in not new. For instance, in the stroboscopic converter [7] with the bandwidth of 6 GHz, strobing frequency of 250 kHz and 1000 averagings was obtained sensitivity of 30µV RMS. Time of this measurement reached 4 s. In our experiments suppressing of disturbance influence is attained not by means of scanning-line averaging, but by means of sample averaging on each phase of scanning. The aforementioned researches show that with such method of disturbance suppression there should be taken into account the impact of disturbance correlation interval. Therefore in converters with constant number of averagings it is reasonable to envisage the possibility of switching the number of sample decimation.

Conclusions:

1. One of the factors that prevents increasing the sensitivity of discrete stroboscopic converters is electromagnetic pollution of the environment.
2. For suppressing the activity of disturbances, caused by electromagnetic pollution of the environment, there can be used the *udc* method (modified “up-and-down” method).
3. With the aim of more efficient suppression of disturbances by means of the *udc* method, the taking period of samples to be averaged should be set longer than the interval of disturbance correlation.

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The results of experimental studies of noise resistance in case of the discrete stroboscopic conversion of weak (several ten microvolts) signals in conditions of electromagnetic environmental pollution are given. For the transformation of signal “up- and -down” method and the modified “up- and -down” method are used. Modified “up- and -down” method differs in that it contains the averaging of the samples - averaging of threshold values in the assigned phase of signal. This creates some advantages of the method in suppressing interference, created by electromagnetic environmental pollution. It is shown that the suppression of interferences via such averagings in large part is prevented by the correlation of interference. In that case, it is expedient to provide the possibility of switching the duration of the intervals between the averaged samples in the converter. Ill. 3, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

К. Круминьш, В. Петерсонс. Помехоустойчивость методов преобразовании сигналов // Электроника и электротехника. – Каунас: Технология, 20XX. -№ X(XX). – С. XX-XX.
Приводятся результаты экспериментальных исследований помехоустойчивости при дискретно стробоскопическом преобразовании слабых (несколько десятков микровольт) сигналов в условиях электромагнитного загрязнения окружающей среды. Для преобразования сигнала используются “up-and-down” метод и модифицированный “up-and-down” метод. Модифицированный “up-and-down” метод отличается тем, что содержит усреднение выборок – усреднение значений порогов в заданной фазе сигнала. Это создает некоторые преимущества метода при подавления помех, создаваемых электромагнитным загрязнением окружающей среды. Показано, что эффективности подавления действия помех путем таких усреднений препятствует коррелированность помехи. В таком случае в преобразователе целесообразно предусмотреть возможность переключения длительности интервалов между усредняемыми выборками. Ил. 3, библ. 7 (на английском языке; рефераты на английском, руском и литовском яз.).