Stand for Investigating the Measuring Methodical Errors of Microcontrollers Average Energy Power Consumption

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Abstract— **The virtual stand structure is proposed on the basis of the LabView development and simulation environment. The stand allows to investigate the measuring methodical errors of microcontrollers average power consumption and other microchips made using CMOS technology due to the nonlinear dependence of their current consumption on the power supply voltage. A model of the microcontroller current consumption has also been developed for carrying out the research.**

Keywords*— *virtual stand; methodical errors; average power consumption; microcontrollers

I. Introduction

One of the urgent tasks facing the developers of the computer systems with autonomous power is to increase the operating time without recharging the batteries. According to [1], the main ways of solving this problem are: 1) increase of the power supplies intensity; 2) improvement of the microchip manufacturing technology; 3) optimization of power consumption software. The first two ways require fundamental research but the third one needs only the equipment for measuring power consumption.

The difficulty of measuring power consumption of microchips (microprocessors, microcontrollers(MC)) made using CMOS technology, is that they consume power as relatively short pulses. These pulses depend on the edges of the clock generator pulses. The amplitude of these pulses can exceed the constant component of the current in dozens of times. And the frequency of harmonics, which is significant in terms of power consumption, is more than100 MHz.

The first attempts to study the MC power consumption were made in [2]. However, the nature of MC was not taken into account. The average consumption was measured without taking into account the residual charge of the capacitors in the power network. The accuracy of the received models was low (an error was more than ± 10%).

In [3] it is proposed to measure the instantaneous value of the MC power consumption. This eliminated the influence of the capacitor on the measurement result in the power network. To ground the digital oscilloscope, the capacitor in the power network is separated from the MC by a "current mirror". However, the MC, which consumes power from the "current mirror," operates in an abnormal mode. In addition, the supply voltage of the MC changes by 0.2 – 0.3V due to a change in the MC power consumption. This affects the measurement result. In addition, the equivalent input parameters of the measuring device affect the measurement error. Therefore, the error of the constructed models of the MC power consumption reaches ± 7% [1].

In [5], the device for measuring the instantaneous power consumption of MC, which is supplied from a power stabilizer, is proposed. As a power voltage converter, a capacitor is used in the MC power network. At the same time, the MC operates in the normal mode, and the measurement error does not exceed ± 0.75%. Disadvantage of [5] is a weak robustness caused by measurement of instantaneous voltage values. It is also possible to accumulate errors in measuring the MC power consumption when executing program fragments.

In [6], a method for measuring the MC average power consumption is proposed, which is based on the method in [5], but it implements a noise immunity of dual-slope analog to digital converter. As it is shown in [6], the conditions for high accuracy of measuring the average power consumption of the MC are the following:

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a) the change in the voltage of the MC power supply capacitor should not exceed the allowable value;

b) the voltage change integral of the MC power supply capacitor should also not exceed the allowable value.

These conditions can be fulfilled if there is a high-capacity capacitor in the power network. However, this prevents high sensitivity while changing the power voltage. Therefore, it is necessary to adjust the stabilizer power and the capacitor capacitance in the MC power network in order to fulfill the two conditions *above a)* and *b)* simultaneously. The fulfillment of the condition *a)* can be monitored throughout the comparators measurement cycle. To fulfill the condition *b)*, it is necessary to measure the capacitor voltage deviations in the MC power network using an analog-to-digital push-pull integrated converter. However, the result of this conversion becomes known when the measurement process is completed, therefore it is necessary to organize a cyclic iterative process of gradual approximation to the fulfillment of conditions a) and b).

In addition, in order to ensure high robustness of measurement results, the three additional conditions must be satisfied:

c) the time of each measurement cycle must be a multiple of the power supply network period of 50 Hz;

d) the time period of each measurement cycle must be larger than the minimum allowable value and smaller than the maximum allowable value;

e) the measurement process can be completed only if the whole and known number of repetitions of the program under study or its fragment are performed.

The conditions *a) ... e)* above can be easily fulfilled separately. The probability of simultaneous fulfillment of all conditions with high accuracy is not very high. Therefore, it is necessary to try repeated measurements in order to achieve a compromise by expanding the tolerances under the conditions *a) ... d)*. However, this leads to an increase in measuring methodical errors of the MC power consumption. The calculations of these errors are difficult to perform because the measurement error is influenced not only by the allowable values of the tolerances, but also by their combinations. But the study of the mutual influence of the tolerances on the error becomes rather laborious. Therefore, it is advisable to create an appropriate stand.

The purpose of the article is to develop a stand for investigating the methodical errors in measuring the average power consumption of the MC, which implements the method [6].

An experimental research of the methodical errors does not allow us to determine their dependency on the possible parameters of the researched MCs and the components of the circuit. Therefore, simulation method was used. The first stage of the development of such a virtual stand was the creation of a mathematical model of the MC power consumption, taking into account the nonlinearity of the MC as a power consumer.

II. Mathematical Model of MC Power Consumption

The actual nature of power consumption of different types of MCs is determined by the technology of their manufacturing. Therefore, a generalized model of the MC power consumption is required for the research, taking into account the power nonlinear dependence on the supply voltage. Such a simple model is shown in Fig. 1. It refers to a limited number of small changes in the supply voltage of the MC (from U_{MIN} to U_{MAX}) and, accordingly, its power consumption (from I_{MIN} to I_{MAX}). The current power consumption I_{MC} includes the amount of the minimum power I_{MIN}, as well as the linear I_{LIN} and nonlinear I_{NONLIN} components

$$I_{MC} = I_{MIN} + I_{LIN} + I_{NONLIN} \quad (1)$$

In its turn I_{LIN} is determined as

$$I_{LIN} = k \cdot (U_{MC} - U_{MIN}) \quad (2)$$

where U_{MC} – the MC current voltage; k –coefficient calculated as

$$k = (I_{MAX} - I_{MIN}) / (U_{MAX} - U_{MIN}) \quad (3)$$

Nonlinear component I_{NONLIN} is simulated by the quadratic dependency of the power on the supply voltage (if the change U_{MC} is not higher than 1%, the more complex models are redundant). Accordingly,

$$I_{NONLIN} = A \cdot \Delta U_{MC}^2 + B \cdot \Delta U_{MC} \quad (4)$$

where coefficients *A, B, B* can be determined solving a system of equations

$$\begin{cases} A(U_{MAX} - U_{MIN})^2 + B(U_{MAX} - U_{MIN}) = 0 \\ A((U_{MAX} - U_{MIN})/2)^2 + B(U_{MAX} - U_{MIN})/2 = \Delta_{MAX} \end{cases} \quad (5)$$

where Δ_{MAX} – the maximum MC voltage deviation from the linear component.

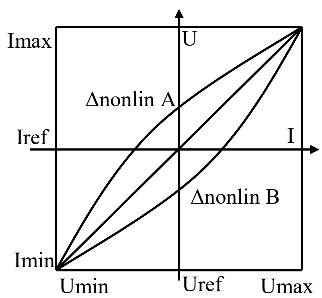

Fig. 1. A generalized model of MC power consumption

It should be noted that the MC value Δ_{MAX} is not normalized, even the sign Δ_{MAX} is not defined in the literature. Therefore, both variants: Δ_{MAX} has a positive value (nonlinearity of A type) and a negative value (non-linearity of B type) are investigated.

III. THE STAND FOR INVESTIGATING THE METHODICAL ERRORS

As the modeling software, the LabView development and simulation environment [8] was chosen, which makes it easy to move from simulation to full-scale experiment. In Fig. 2 the scheme for investigating the methodical error caused by the nonlinearity of the MC power consumption when condition b) is satisfied is shown.

The nine formulas for calculating the methodical error implemented in the LabView environment are shown on the left in Fig 2. The *first* formula enables to determine the nominal equivalent resistance of the MC *Rmk*. It is implemented by the *Inom* and *Unom* task units and the *Rm*k division unit. The results of the calculations of this and other formulas are written into an array (the array driver is denoted by a dashed line in Figure 3). The *second* formula calculates the current random component of the value ΔU_{MC}, it is implemented by the delta task units, 2*delta multiplier, the random number generator (Random) and u2 multiplier. The *third* formula calculates the linear and nonlinear parts of the nonlinear component of the MC voltage. It is implemented by *a, b* units of the *A, B* coefficients defined according to (5), multiplication units Multiply1, Multiply2 and the Power of X squaring unit. The current value of the MC voltage U_{MC} is received due to the *fourth* formula(see Fig.2). It is implemented by the Unom-delta subtraction unit and *u2*, *u3* adders. The current value of the MC power consumption is received due the *fifth* formula. It is implemented by the i division unit. The *sixth* formula determines the current power of the MC (the equivalent of the power consumed by the MC with this combination of parameters during the execution of one command). It is implemented by *p* multiplier unit(see Fig.2). The *seventh* formula calculates the nominal MC power consumption and is implemented by *P* multiplier unit. The received values enable to determine the absolute(the *eighth* formula) and relative(the *ninth* formula) deviations of the consumed power from the nominal value during the execution of a single command.

As it has been already mentioned, the results of the calculations according to all formulas are written to the array for further analysis. In addition, the result of calculating the deviation of the MC consumed power due to the ninth formula is written in a separate array to simplify the graphs building.

Further data processing can also be performed using the LabView development and simulation tools.

IV. RESULTS OF INVESTIGATING THE METHODICAL ERRORS

Firstly, by means of the developed stand, it is shown that the measuring error is being gradually reduced with the increase in a number of repetitions of the program, which is under study or its fragment. However, even if the number of executed commands is not larger than 100, this error will not exceed 0.05%, even with the maximum nonlinearity of the MC (40%).

Secondly, a methodical error caused by inaccurate fulfillment of the condition *b)* above, that is, a change in the integral of the capacitor voltage in the MC power supply network during the measurement of the MC consumption power, was investigated. The graphs of this error dependency are shown in Fig. 3 and 4.

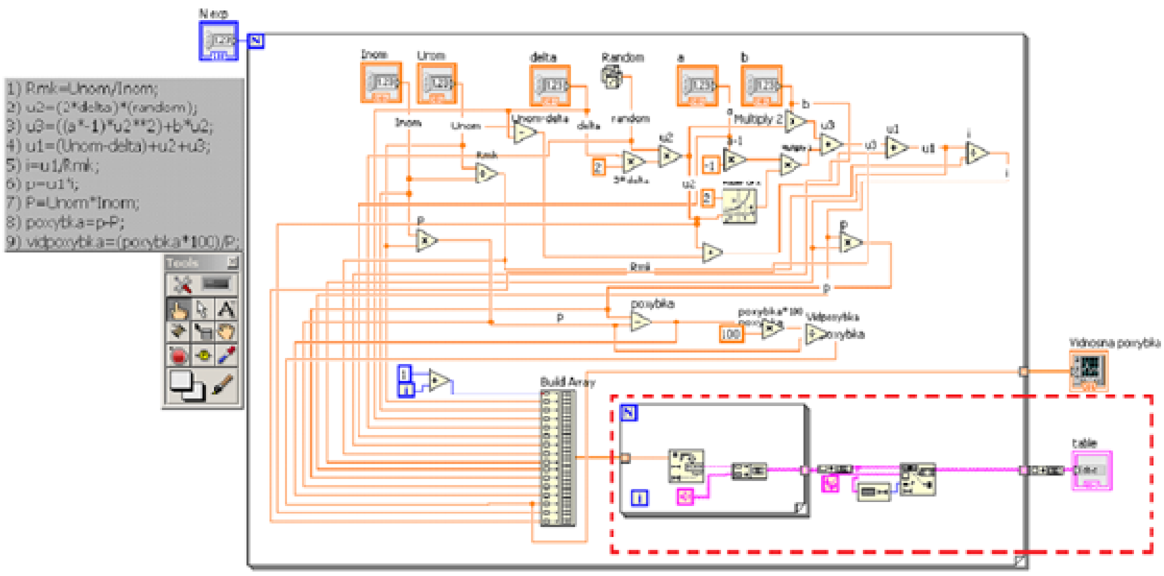

Fig. 2. The scheme of investigating the methodical error caused by nonlinearity of MC power consumption

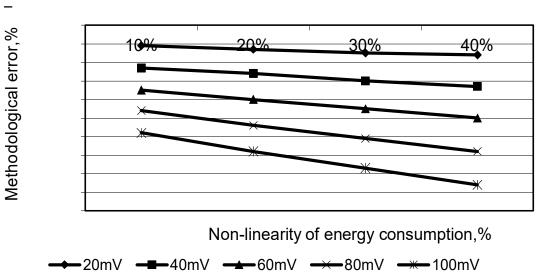

Fig. 3. The dependence of the relative methodological error on maximum voltage change with the nonlinearity type A

Thirdly, a methodical error caused by inaccurate fulfillment of the condition b), that is, a change in the integral of the capacitor voltage in the MC power supply network during the measurement of the MC consumption power, was investigated. The graphs of this error dependency are shown in Fig. 3 and 4.

As it is seen in the Figures 3 and 4, the maximum error does not exceed 0.02% for nonlinearity of A type and 0.01% for B type nonlinearity. In both cases, the maximum errors correspond to the maximum MC voltage change, as it has been expected, that is, ± 100 mV.

Fourthly, the methodical error caused by inaccurate fulfillment of condition *a)* above, that is, a change in the capacitor voltage in the MC power supply network during the measuring the MC power consumption, was investigated.

If the voltage of this capacitor at the end of the measurement is higher than at the beginning, then, the result of measuring the MC power consumption will be higher, that is, a certain amount of the measured power will be fed into the capacitor.

If the voltage of this capacitor at the end of the measurement is lower than at the beginning, then, the result of measuring the MC power consumption will be lower, as a certain amount of power will be fed into the MC from the capacitor. The results of the methodical error investigation are shown in Fig. 5.

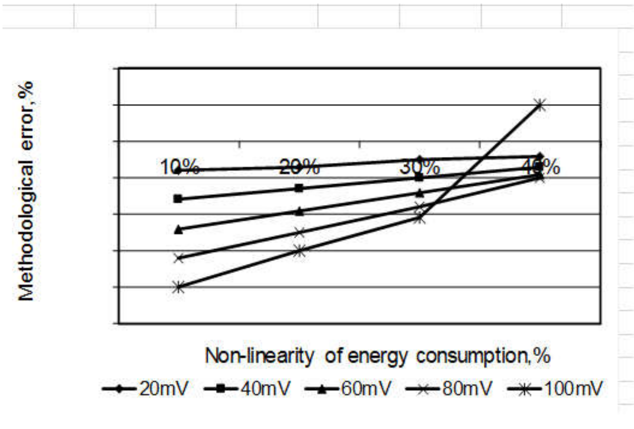

Fig. 4. Dependency of the relative methodical error on maximum change in voltage under B type nonlinearity

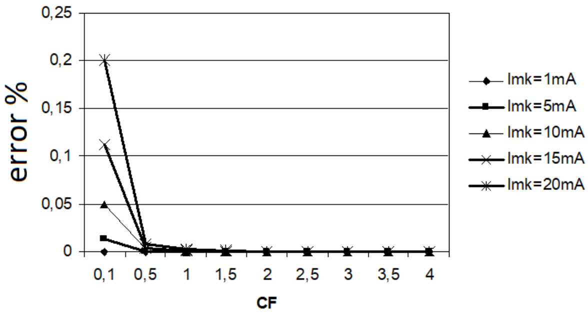

Fig. 5. Dependency of the methodical error on MC power consumption and the creation of capacitor capacitance in the MC power network at clock speed

This investigation shows it's the most convenient to determine this methodical error as a function of creating the MC clock generator speed on the capacitor capacitance in the MC power supply network. As it can be seen in Fig. 5, even if the MC power consumption is rather high, the methodical error rapidly decreases. At the same time, as it has been already mentioned, the capacitor capacitance in the MC power supply network should be the minimal because of a decrease in sensitivity when measuring the average power consumption according to the method proposed in [6].

CONCLUSIONS

Investigation of measuring methodical errors of microcontrollers average power consumption with the developed virtual stand implementing the method of microprocessors average energy consumption measurements showed that an inaccurate compliance with the condition *b)* above for A type nonlinearity (the second derivative of the power dependency on the supply voltage is negative) causes an error, which is not higher than 0.02% even with a significant change in the supply voltage of the MC (up to ± 100 mV, which corresponds to 4%). With a nonlinearity of B type (the second derivative of the power dependency on the supply voltage is positive) the error is twice as low.

The methodical error caused by inaccurate fulfillment of the condition a) causes an error, which is not higher than 0.02% even with a significant MC power consumption and a relatively small capacitor capacitance in the MC power supply network, that is, the sensitivity of the method is high.

Thus, the developed stand made it possible to prove that the proposed method of microprocessors average energy consumption measurements allows measuring the average MC power consumption with high accuracy.

It should be noted, that the estimation of MC power consumption using the developed method of microprocessors average energy consumption measurements can be important for praxis, e.g. in the control system of the profile of temperature field situations when difficult programs are executed rarely.

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