Low-Frequency Digital Phase Meter

Ján Hribik[1], Peter Novák[2], Peter Fuchs[3]

[1] *Dept. of Radio Electronics, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, Ilkovičova 3, 812 19 Bratislava, Slovak Republic, Phone: +421 2 60291 353, Fax: +421 2 6542 9683, E-mail: jan.hribik@stuba.sk*
[2] *Nemetschek Slovensko, s.r.o., Za kasárňou 1, 831 03 Bratislava, Slovak Republic, E-mail: novakpeto@gmail.com*
[3] *Dept. of Radio Electronics, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, Ilkovičova 3, 812 19 Bratislava, Slovak Republic, Phone: +421 2 60291 775, Fax: +421 2 60291 213, E-mail: peter.fuchs@stuba.sk*

Abstract-A microcomputer-controlled measuring instrument for phase angle measurement in low frequency range is described. It is based on the digital measurement of the time shift between input signals. To avoid the necessity of calculation of the measured phase shift, measurement of the time shift is repeated during a constant time interval to get the average value of the phase shift independent on the period of the input signals. The measured results are displayed on the display of the instrument and can be transferred into a personal computer (PC) which can process and display these results and control the instrument via USB serial interface. The method of the average value of the phase angle measurement is described and the error sources are briefly mentioned. The construction of the instrument and the software in the instrument and in the PC are briefly described. Measured results show sufficient accuracy of the instrument.

I. Introduction

Digital methods of phase shift measurement are based on the digital measurement of the time difference between input signals (counting method), [1], [2]. This time interval is then related to the period of the input signals to display it in terms of the phase angle. The recent development of fast real-time data acquisition systems makes it possible to use also sampling methods to compute wave parameters, like phase shift and many others, [1], [3], [4].

Problems arise if a measuring instrument is unable to calculate the resultant phase angle or, if a very short time interval must be measured (small phase angle, higher frequency of the input signals). A method of measurement where the resulting count is independent on the period of the input signals must be used. One of these methods uses a phase-locked loop to get the frequency of the counted pulse signal 360 times the frequency of the input signals, [1], [3]. Another method is sometimes called a method of measurement of the average phase angle value, [2], [5], [6]. In this method the measurement is repeated during a constant time interval to get the average value of the phase shift independent on the period of the input signals. This also increases the measurement accuracy in case a very short time interval must be measured. A comparison of different sampling methods of phase difference measurement from the point of view of their sensitivity to sampling during non-integer number of signal periods (non-coherent sampling) is in [7].

II. Measurement of the Average Value of the Phase Angle

Block diagram of the method of measurement of the average phase angle value is in Figure 1, [2], [5], [6]. The total time interval of measurement, T_m, is specified by a frequency, f_n, of a pulse generator and by a division coefficient, n, of a frequency divider

$$T_m = \frac{n}{f_n} \tag{1}$$

During T_m a signal from a control circuit 2 keeps an AND gate 2 opened. Signal shapers shape the input signals to short pulses, v_i, (e. g. in the instants of zero crossing) separated by a time interval t_1 which is equal to the time difference of the two input signals. A control circuit 1 generates a rectangular pulse, v_o, with the same time duration, t_1, which keeps an AND gate 1 opened during the time interval t_1. This is repeated in every period of the input signals during the time interval T_m. During the time interval t_1 a counter counts N_1 pulses

$$N_1 = f_n t_1 \tag{2}$$

The total number of counted pulses, N, during the time interval T_m is

$$N = \frac{T_m}{T_x} N_1 = n\frac{t_1}{T_x} = \frac{n}{360}\varphi \tag{3}$$

where (1), (2) and the well known expression for the phase angle, φ,

$$\varphi = \frac{t_1}{T_x} 360 \tag{4}$$

were used.

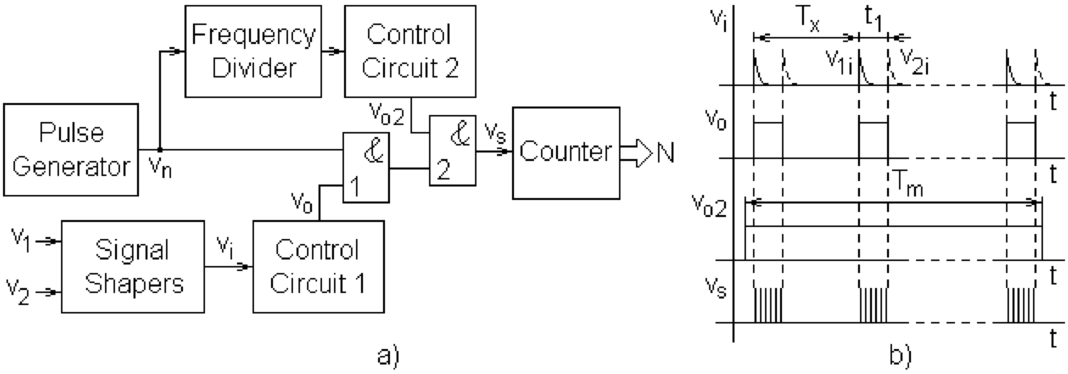

Figure 1. Measurement of the average phase angle value: a) block diagram, b) time diagrams

Equation (3) shows that it is not necessary to know the period T_x. If now the division coefficient n = 3.6x10^k, equation (3) takes the form

$$N = 10^{k-2}\varphi \tag{5}$$

From (5) it is evident that the count, N, is linearly proportional to the measured phase angle, φ, independently of the period, T_x, of the input signals. The division coefficient, n, or the coefficient k, can be used to select the measuring ranges.

III. Designed Instrument Description

A low-frequency digital phase meter based on the method in Figure 1 was designed and constructed. It is controlled by a microcomputer and can communicate with a personal computer (PC) via a serial communication line. Block diagram of the designed instrument is in Figure 2, [8]. The analogue part consists of protection circuits, an amplifier and a comparator in each of the two channels. The protection circuits are simple diode circuits with fast diodes in anti-parallel connection. The amplifier must amplify the input signal to the sufficiently high level not to cause a phase error in the comparator due to possible level shift error. From this point of view the best choice of the comparation level is zero, because the slope of the input signal is the highest just at the zero crossing. The comparator shapes the input signal to the square wave signal with the edges in the instants of zero crossing.

The digital part consists of logic circuits, two AND gates, a quartz oscillator, two counters and a microcomputer with a display, a keyboard and communication means. The logic circuits contain three edge-sensitive D flip-flops. Two of them shape the rectangular pulses v_o of the duration t_1, proportional to the measured phase angle. These pulses make the AND gate 1 open in every period of the input signal and counted pulses from the quartz oscillator can propagate to the input of the Counter 2. The AND gate 2 is kept open during the whole time interval of measurement, T_m, by the control signal generated digitally in the microcomputer by the help of the Counter 1. In the Logic Circuits block this control signal is used in the third D flip-flop which is also controlled by the shaped signal v_o to insure the start and the end of the time interval of measurement, T_m, exactly at the rising edges of the shaped signal v_o. This is necessary to avoid possible errors due to counting during only a part of the time interval t_1 at the beginning and at the end of the time interval of measurement, T_m. The duration of T_m is user-selectable.

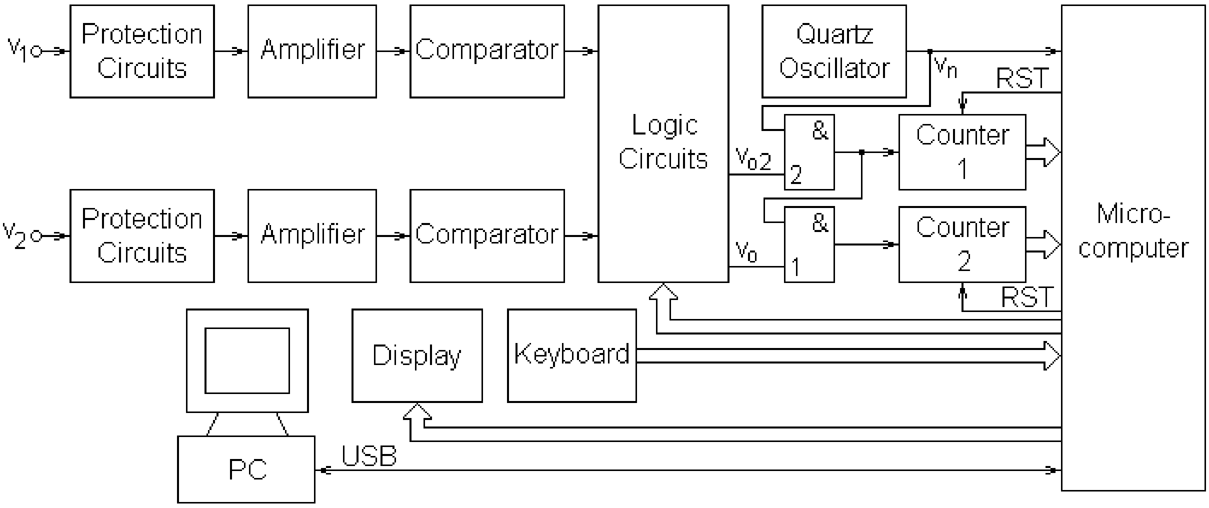

Figure 2. Block diagram of the designed low-frequency digital phase meter

Both counters consist of 4-bit counters (Counter 1, Counter 2) (lower 4 bits of the resulting counts) and of a 16-bit counters in the microcomputer (higher 16 bits). This solution overcomes the problem with the limited counting speed of the counters in the microcomputer. The frequency of the clock signal for the microcomputer (from the quartz oscillator) can be also reduced, if necessary, by a frequency divider. The resulting phase angle, φ, is proportional to the ratio of the counts in the Counter 2 and in the Counter 1 together with the corresponding counts in the microcomputer.

The microcomputer makes necessary calculations, displays the results (phase angle, φ, in degrees and radians, $\cos\varphi$, evolution graph of the repeated phase angle measurements with two cursors and digital display of the values at the cursors positions) and communicates with the PC via USB serial communication line. The result of measurement is corrected to minimize the measurement error. This error correction is based on the simple compensation of zero value error. It is accomplished in the microcomputer by means of a relay connection of one input signal to both inputs and by measurement of such error phase shift at the initialization of the instrument after its switching on.

The designed instrument also contains a communication part Ethernet for LAN. It is realized by an integrated circuit intended for this application, which has a transformer isolation of the output for a transmission line consisted of a pair of twisted conductors. The microcomputer operates this integrated circuit by means of a simple web-page created for this purpose. The web-page can be opened by a commonly used internet explorer after connecting into this network and entering an address and a password. It is also possible to connect the instrument into the Internet, but this possibility has not been verified.

IV. Error Considerations

There are a few error sources mainly in analogue signal handling circuits: phase shifts in input coupling circuits, in the amplifiers, and time delays in the comparators. The phase errors may occur also in the logic circuits and in the AND gates as a result of their time delays. In digital processing the main source of errors may be a low clock frequency for time intervals measurements which may cause large quantization errors. In addition to these error sources, another possible error source is a distortion of the input signals.

The errors in the input coupling circuits and in the amplifiers can be eliminated by a selection of proper values of components (long time constants of the coupling RC circuits) and fast operational amplifiers with high input impedances and low input voltage offsets and drifts. Even if these parameters are not suitable, matching of properties of both input analogue channels may lead to the resulting low error phase shift.

The time delays in the comparators are of two origins: time delays of the output responses caused by the properties of the comparators (response time, output slew rate) and time delays caused by uncertainties of input comparation voltage levels (error bands of the voltage levels of the comparators true responses, input voltage offsets). The first kind of the time delays can be overcome by a proper selection of the comparator circuits. The second kind of the time delays may be partially eliminated by the input offset compensation. But there is another source of similar phase errors – if the comparation voltage level is not zero and the two input signals have different levels. In this case even the same comparation levels in both comparators fail to avoid the significant time and phase error, as shown in Figure 3.

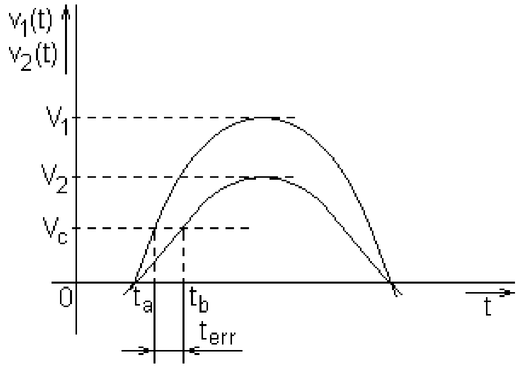

Figure 3. Time error caused by different signal levels

The time error of the comparator responses in case of different input voltage levels (amplitudes), V_1, V_2, and nonzero comparation level, V_c, equal in both comparators, can be expressed by the equation, [8]

$$t_{err} = t_b - t_a = \frac{1}{2\pi f}\left[\sin^{-1}\left(\frac{V_c}{V_2}\right) - \sin^{-1}\left(\frac{V_c}{V_1}\right)\right] \qquad (6)$$

or the corresponding phase error

$$\varphi_{err} = \varphi_b - \varphi_a = \sin^{-1}\left(\frac{V_c}{V_2}\right) - \sin^{-1}\left(\frac{V_c}{V_1}\right) \qquad (7)$$

Equations (6) and (7) are valid also in case both comparators have different comparation levels, V_{c1} and V_{c2}, respectively, which must be used instead of V_c. The worst case is, if one input voltage has minimum and the second one maximum level.

The errors in the logic circuits and the AND gates can be again overcome by the proper selection of the components (short response time, short rise time and fall time). The clock frequency must be high enough to get the desired measurement resolution.

There are, of course, errors inherent to all digital methods of time interval measurement. In every measurement of the time interval t_I the error of ±1 pulse can occur. In the most critical case, when the error of +1 pulse (or -1 pulse) in every measurement of the time interval t_I is observed, the maximum relative error of measurement will be

$$\delta = \frac{T_m}{T_x}\frac{1}{N} = \frac{1}{N_1} \qquad (8)$$

It means that the maximum total error of measurement (only this kind of errors considered) is the same as the error of measurement of the single time interval t_I. This error depends on the measured phase angle, on the frequency of the input signals, and on the frequency of the counted pulses. But, usually, the total error of measurement is much lower due to the averaging effect of the measured time intervals t_I.

The error caused by the distortion of the input signals is high if the distortion causes a shifting of the zero crossing time instants. In this case the time duration, t_1, of the pulses, Figure 1b, will differ from the correct value and the phase measurement error can be high. This error can be partially overcome by measurement of the time interval, t_1, twice per period, taking into account that the probability of the shifting of both zero crossing instants is relatively low. Another possible way to overcome the error caused by the distortion of the input signals is to use filters, but the filters can cause some extra phase shifts which increase the measurement error.

V. Experimental Results

The realization of analogue input circuits and the logic circuits contains commonly used components. The microcontroller is of the type ATMEL AVR ATmega128. USB serial communication line makes use of the integrated circuit FT232RL isolated from the microcontroller by optocouplers. The Ethernet for LAN is based on the integrated circuit ENC28J60. Its connector is isolated from the cable by a transformer. The instrument displays the necessary information on an LCD display with the resolution 128 x 64 pixels. The display BG12864 with two controllers KS0108 has been used.

The software has been developed for the microcontroller and for the PC. The software for the microcontroller has been written in the environment WinAVR GCC.

Measurements of the parameters of the constructed instrument showed very low delay of both comparators in case the same signal was connected to both inputs. The error of the preliminary phase shift measurement in the range from 0.1 V to 3 V and in the frequency range from 30 Hz to 3 kHz has been less than 0.8°. New measurements were carried out using new analogue shaping circuits and a RIGOL DG1022 2 Channel Function/Arbitrary Waveform Generator with the possibility to set a phase shift between the two output signals. The measured results for four values of the signals frequencies, namely 50 Hz, 500 Hz, 3 kHz, and 5 kHz are in Figure 4 to Figure 7, respectively. The values of the input signals were all four combinations of 30 mV and 2 V.

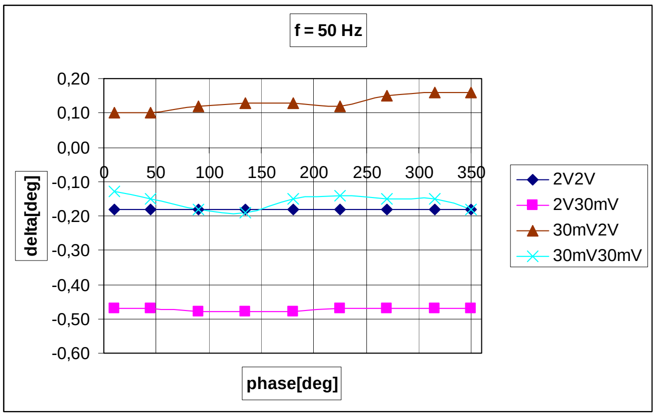

Figure 4. Phase measurement error, f = 50 Hz

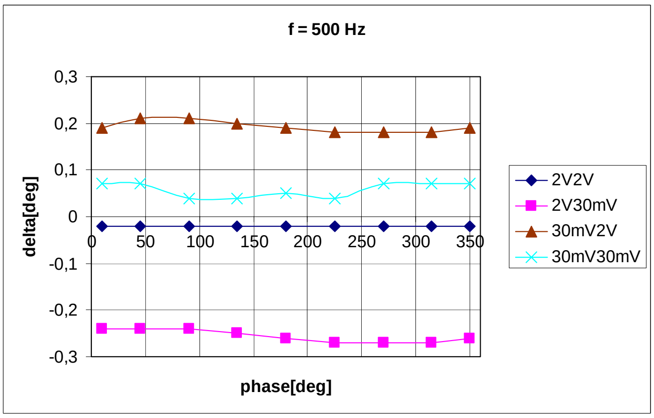

Figure 5. Phase measurement error, f = 500 Hz

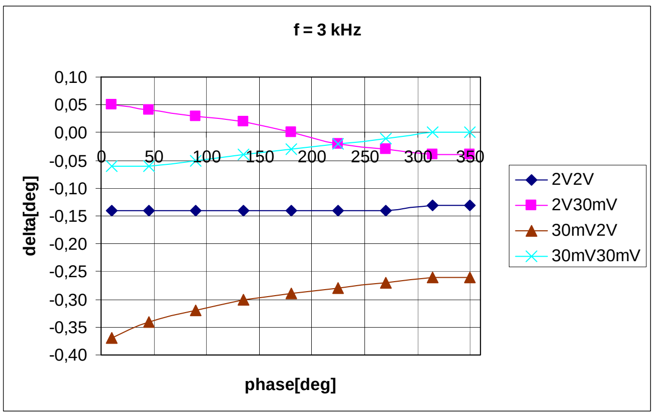

Figure 6. Phase measurement error, f = 3 kHz

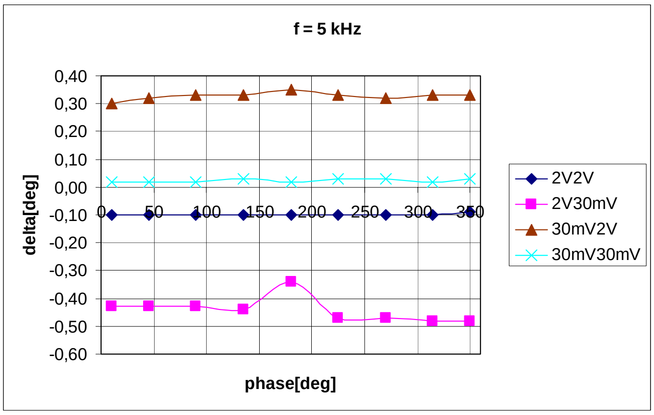

Figure 7. Phase measurement error, f = 5 kHz

These figures show the accuracy of the phase meter better than 0.5°. The best results have been obtained if both input signals have had equal values.

VI. Conclusions

The designed and constructed microcomputer-controlled measuring instrument for phase angle measurement in low frequency range is based on the digital measurement of the time shift between input signals. To avoid the necessity of calculation of the measured phase shift, measurement of the time shift is repeated during a constant time interval to get the average value of the phase shift independent on the period of the input signals. The time interval of measurement is user selectable. The measured results are displayed on the display of the instrument and can be transferred into a personal computer (PC) which can process and display these results and control the instrument via USB serial interface. The instrument can be viewed also as a web-page by commonly used internet explorers in LANs or in the Internet but this second possibility has not been verified yet. The software in the instrument and in the PC is briefly described. The measurements of the parameters show that the error of the phase shift measurement in the input signals levels from 0.03 V to 2 V and in the frequency range from 50 Hz to 5 kHz has been less than 0.5°. The best results have been obtained if both input signals have had equal values.

VII. Acknowledgement

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References

[1] Webster, J. (ed.), *Wiley Encyclopedia of Electrical and Electronics Engineering Online. Instrumentation and Measurement.* John Wiley & Sons, New York, 1999. http://www.mrw.interscience.wiley.com/emrw/9780471346081/eeee/topics

[2] Hribik, J., *Elektronické meranie* (*Electronic Measurements*). Vydavateľstvo STU, Bratislava, 2002. (In Slovak)

[3] Sedláček, M., Haasz, V., *Electrical Measurements and Instrumentation*. Vydavatelství ČVUT, Prague, 2000.

[4] Landis, G. P., Galysh, I., Petsopoulos, T., „A New Digital Phase Measurement System“, In: *Proc. 33rd Annual Precise Time and Time lntewal (PTTI) Systems and Applications Meeting,* Hyatt Regency Hotel, Long Beach, California, November 27-29, 2001, pp. 543-552.

[5] Matyáš, V., *Elektronické měřicí přístroje* (*Electronic Measuring Instruments*). SNTL/ALFA, Prague, 1981. (In Czech)

[6] Antoška, Ľ., Ostrovský, M., *Elektronické meranie III* (*Electronic Measurements III*). AOS M. R. Štefánika, Liptovský Mikuláš, 2007. (In Slovak)

[7] Krumpholc, M., Sedlacek, M., „Measurement of Phase Difference Using DSP Algorithms by Non-Coherent Sampling”. In: *Proc. 14th International Symposium on New Technologies in Measurement and Instrumentation and 10th Workshop on ADC Modelling and Testing*, Gdynia/Jurata (Poland), September 12-15, 2005, Volume I. 2005 IMEKO and GMU, Gdansk, Poland, pp. 229-234.

[8] Novák, P. – Hribik, J.: *Low-Frequency Digital Phase Meter*. Dept. of Radio Electronics FEI SUT Bratislava, May 2008. (In Slovak)