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Phase Angle Measurements Based on Universal Sensors and Transducers Interface (USTI-MOB) IC

Javier CAÑETE and * Sergey Y. YURISH
Excelera, S. L., Parc UPC-PMT, Edificio RDIT-K2M,
c/ Esteve Terradas, 1, 08860, Castelldefels, Barcelona, Spain
Tel.: +34 93 4137941
E-mail: javier.canete@excelera.io, sergey.yurish@excelera.io

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Abstract: An experimental investigation of metrological characteristics of designed Universal Sensors and Transducers Interface (USTI-MOB) integrated circuit working in the phase shift measuring mode is described in the article. The USTI-MOB uses the novel patented method for phase difference (phase shift) measurements between two harmonic (sine wave) or rectangular pulse signals. Experiments have confirmed the high metrological performance in low and inferable frequency ranges up to 0.25 Hz at low power consumption (0.35 mA current consumption at V_{cc} = 1.8 V). The optimal trade-off between accuracy, power consumption and communication speed has achieved. In order to decrease the absolute error in 4 times at least, the standard series of USTI IC is recommended for the usage. Due to the low power consumption, the USTI-MOB is very suitable for various portable measuring instruments, DAQ systems, smart sensor systems, etc. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: Universal Sensors and Transducers Interface, USTI-MOB, Phasemeter, Phase measurement, Phase angle, Phase difference, Phase shift.

1. Introduction

A phase angle measurement between two harmonic (sine wave) or rectangular pulse signals is an important technical task in designing systems of non-destructive testing [1]; in determination of phase frequency characteristics of linear circuits or impedances in various four-terminal circuits [2]; in radio astronomy, radio physics, in measurement of vibrations and displacements, and many other applications areas [3-5]. In various systems of non-destructive testing it is necessary to measure a phase difference of the input signals, the frequency of which is not more than some kHz with an absolute error of no more than a few tenths of a degree [1].

Existing technical realizations of various phasemeters have a complex realization from hardware point of view; they have a high power consumption and limited low frequency range (as usually, > 10 Hz).

In order to eliminate the mentioned disadvantages, a single chip Universal Sensors and Transducers Interface (USTI-MOB) IC with the low power consumption (0.35 mA current consumption at V_{cc} = 1.8 V) and a wide functionality has been designer and introduced on the market by the authors [6, 7]. Like to the previously designed popular USTI IC [8, 9] the USTI-MOB can also to measure a phase angle between two harmonic (sine wave) or rectangular pulse signals.

The article is organized as follow. In Section I the experimental set-up and method for phase difference measurements are described. The obtained experimental results for phase angle measurements are provided and discussed in Section II. The article is concluded in Section III.

2. Method and Experimental Set-Up for Phase Measurements

The aim of this research was to determine limited metrological characteristics of designed USTI-MOB (measuring ranges, absolute errors of measurements and resolution) working in phase measuring mode in order to determine the phase difference between two harmonic (sine wave) or rectangular pulse signals of the same frequency.

The USTI-MOB is using the modified, patented method for phase difference measurements: a direct digital method with an intermediate conversion of phase angle φ_x to time interval Δt and measurement during n periods. As it is known [10], the phase difference φ_x (or $\Delta\varphi$) is the difference of the initial phases φ_1, φ_2 of two harmonic signals of the same frequency: $\varphi_x = \varphi_1 - \varphi_2$. If φ_1, φ_2 are constant in time, then φ_x is independent of time. The phase difference can be expressed in terms of time difference $t_2 - t_1$, in which these signals have the same phase [10]:

$$\varphi_x = \frac{2\pi\left(t_2 - t_1\right)}{T}, \tag{1}$$

where T is the period of signals.

The phase difference definition from the equation (2) can be also applied to two non-sinusoidal periodic signals, if at the moment of transition through zero fluctuations of voltage will have the same direction of change (for example, from negative to positive values). Often, instead of the "phase difference" or "phase angle" the term "phase shift" is used, which refers to the phase difference module [10].

The method's modification consist in the average time interval and average period determination during the conversion time, multiplied to the period of signals T. Due to this, the error by reason of non multiplicity of conversion time and period T is eliminated. Besides, the frequency range of signals is extended up to infralow frequencies, and accuracy has increased for these low and infralow ranges of frequencies.

The phase shift is calculated according to the following equations:

$$N_{\phi x} = 360\frac{N_{\bar{t}}}{N_{\bar{T}}} = 360\frac{\bar{t}}{\bar{T}} = \bar{\phi}_x^{\,0} \tag{2}$$

or

$$N_{\phi x} = 2\pi\frac{\bar{t}}{\bar{T}} = \bar{\phi}_x\left(rad\right) \tag{3}$$

The main component of error is the descritization error. The relative mean root square error can be calculated according to the following formula [1]:

$$\sigma_{\varphi_x} = \pm\frac{T_0}{T\sqrt{6}}\sqrt{360^2 + \varphi_x^{\,2}}, \tag{4}$$

where T_0 is the period of reference frequency f_0. For the USTI-MOB, $f_0 = 1/T_0$= 4 MHz, and T_0= 250 ns.

A prototype of the USTI-MOB development board is shown in Fig. 1. The diagram and photo of experimental measurement set-up for the phase measurements are shown in Fig. 2 and 3 respectively.

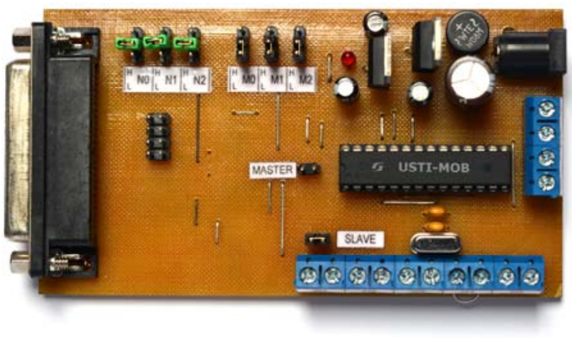

Fig. 1. Prototype of the USTI-MOB development board.

Two harmonic (sine wave) or square waveform pulse signals of the same frequency whose phase shift must be measured, were fed from two channels of Waveform Generator Agilent 33500B to inputs FX1, ST1 and FX2, ST2 (the 1st and 2nd channel of IC respectively) of the USTI-MOB. The Waveform Generator Agilent 33500B was used as an active phase difference reference, which generates two signals with known phase angle and various waveforms.

The supply voltage of the evaluation board was +14 V dc, provided by the Promax FA-851 power supply. The phase shift of signals generated by the waveform generator were measured by: the USTI-MOB, the Universal Frequency Counter/Timer Agilent 53220A with the ultra high oven stability internal time base, working in phase measurement mode and Precision Phasemeter 6620A (Krohn-Hite), which has the absolute error ± 0.05^0 for sinewave signal from 10 Hz to 50 kHz rage of frequencies, and typical absolute error in twice less for other waveforms. The Universal Frequency Counter has the absolute error ± 0.01^0. The Waveform Generator Agilent 33500B has the high-stability OCXO timebase (frequency reference ±0.1 ppm of setting ±15 pHz) [12], and the Universal Frequency Counter/Timer Agilent 53220A-010 has the ultra high-stability OCXO timebase (±50 ppb) [13].

The two-channel digital oscilloscope Promax OD-591 monitored the signals waveforms. Before measurements, the USTI-MOB and phasemeter were calibrated manually in the working temperature range: +23.0 …+ 26.0 ºC at 39-55 % RH. The measurands were sent from USTI-MOB to a PC via an RS232 interface implemented with the ST202D IC on the development board. The user interface was realized with the help of terminal software Terminal V1.9b running under Windows XP or Windows 7 operation systems.

According to the Waveform Generator's indicator, the phase angles with the interval of 30 ° were set up, and after, the phase shift readings from the USTI-MOB have been taken. Every measurement was consisted of 100 values (sample size). The absolute measurement errors of USTI-MOB were evaluated by comparison with the phase shift readings of phasemeter and Universal Frequency Counter/Timer Agilent 53220A [11].

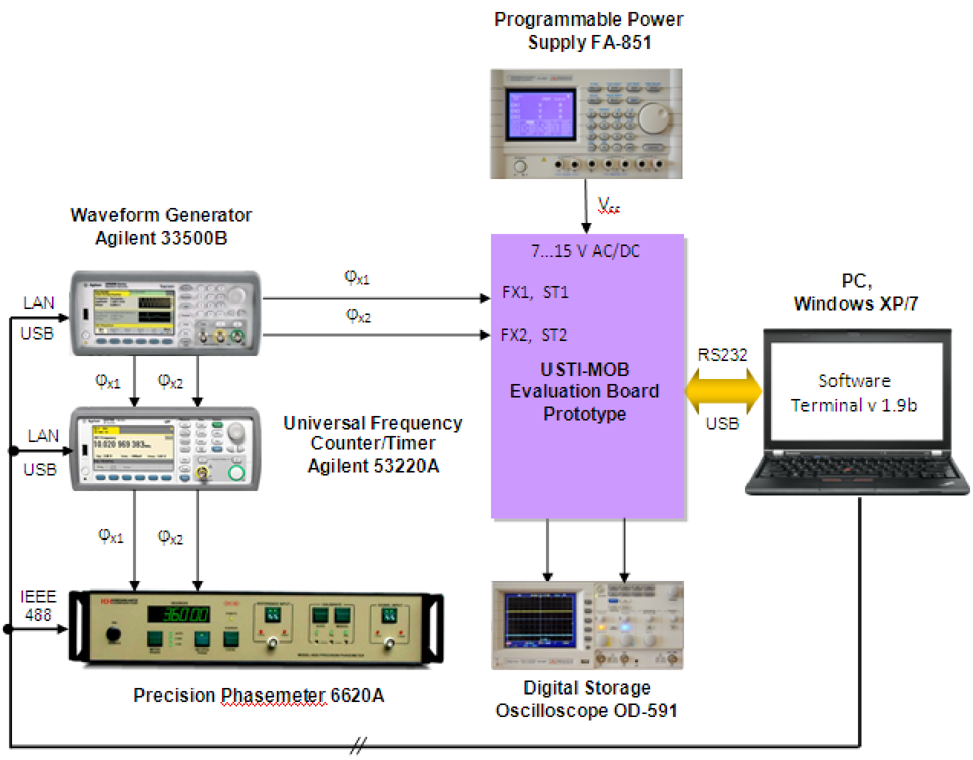

Fig. 1. Diagram of experimental measurement set-up for phase difference measurements.

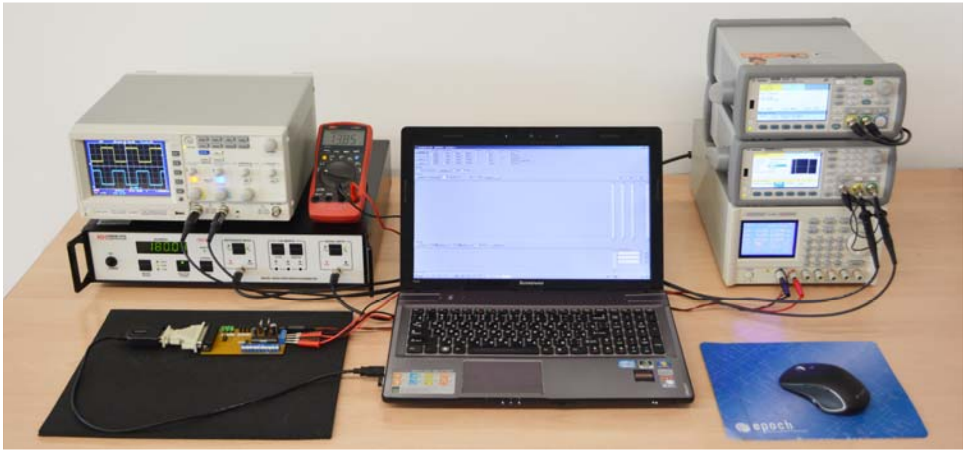

Fig. 2. Experimental measurement set-up.

3. Experimental Results

3.1. Phase Shift Measurements Between Two Rectangular Pulse Signals

The rectangular and sine waveform input signals oscillograms are shown in Fig. 3 and Fig. 4 respectively The phase angle measurements for 30, 60, 90, 120, 150, 180, 210, 240, 270, 300 and 330 degrees at 10 Hz, 100 Hz, 1 kHz and 4 kHz each have been performed and compared with the active reference.

The frequency range at phase shift measurements for USTI-MOB is from 0.25 Hz to several kHz. The absolute error for the phase shift measurement is dependent on the signal's frequency: the higher the frequency, the higher the error.

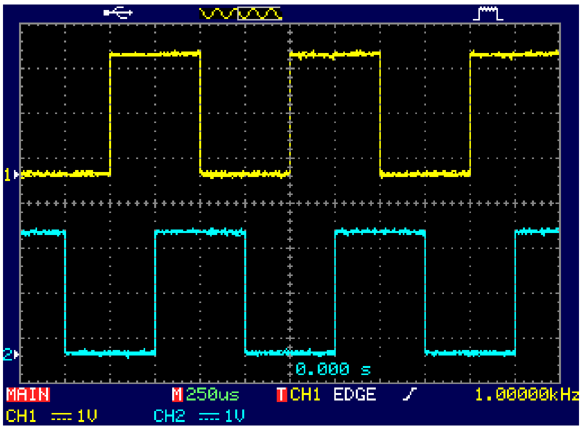

Fig. 3. Rectangular waveform input signals (120^0 phase shift, at 1 kHz).

The experimental results of phase shift measurements are shown in Fig. 5-8.

3.2. Phase Shift Measurements Between Two Harmonic Signals

The phase angle measurements were performed for the same degrees at 100 Hz and 1 kHz frequencies, as for rectangular waveform signals. The experimental results of phase shift measurements are shown in Figs. 9-10.

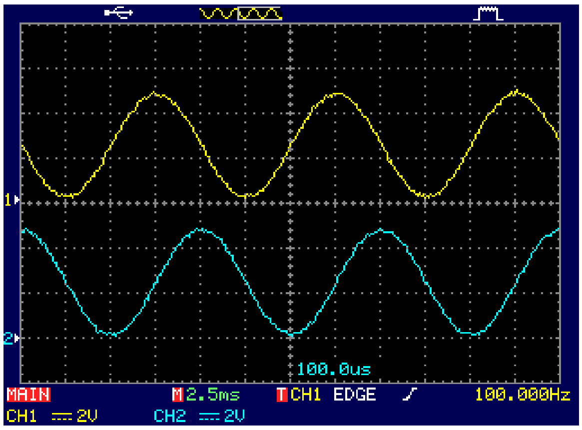

Fig. 4. Sine waveform input signals (90^0 phase shift, at 100 Hz).

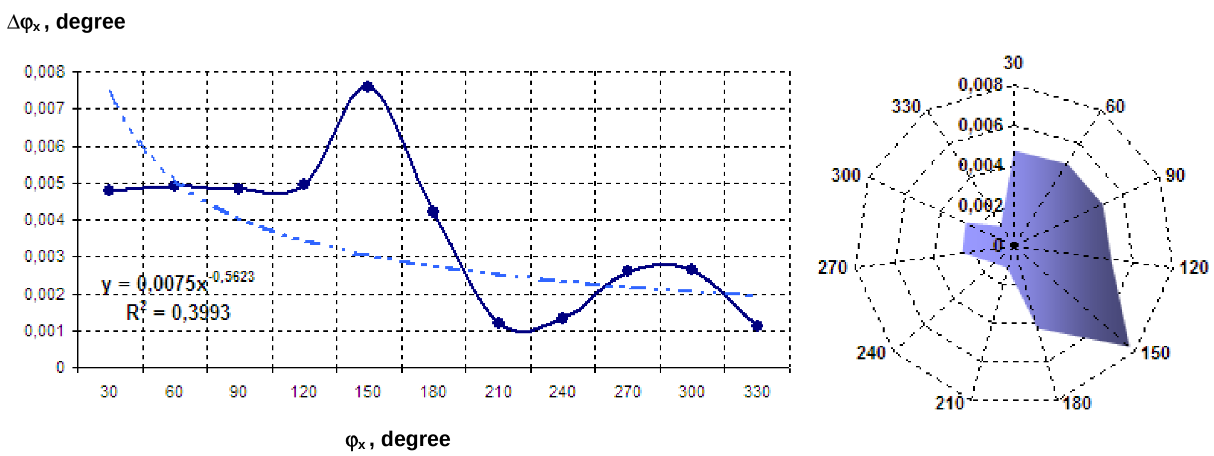

Fig. 5. Phase shift measurement absolute error (10 Hz, rectangular waveform input signals).

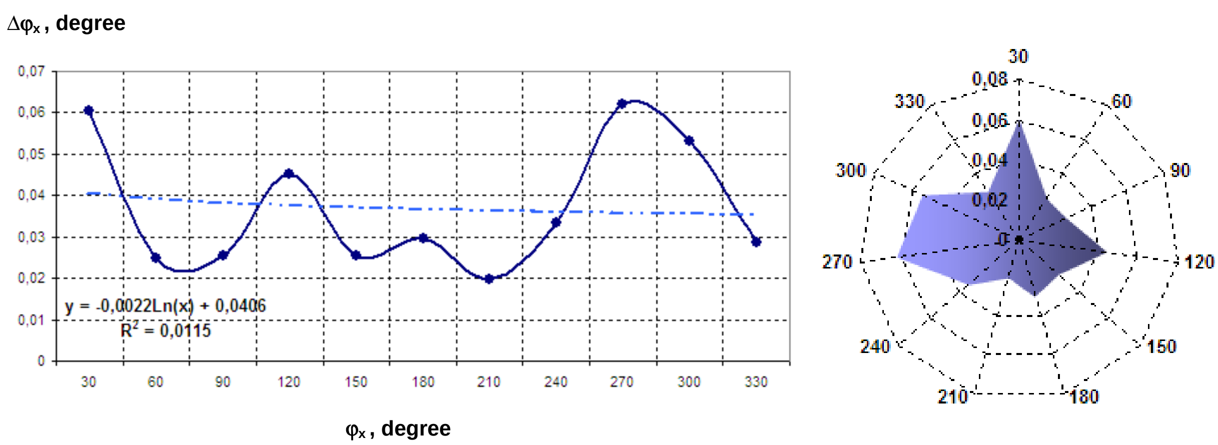

Fig. 6. Phase shift measurement absolute error (100 Hz, rectangular waveform input signals).

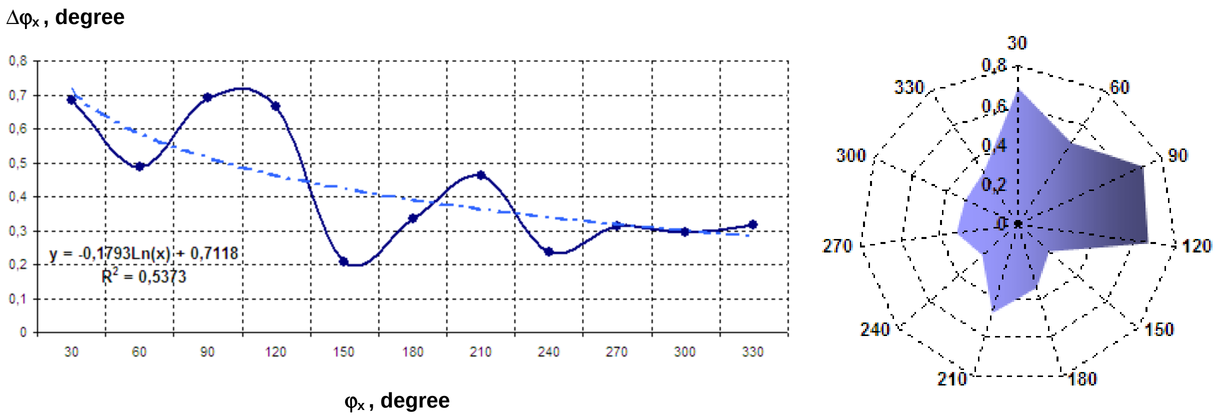

Fig. 7. Phase shift measurement absolute error (1 kHz, rectangular waveform input signals).

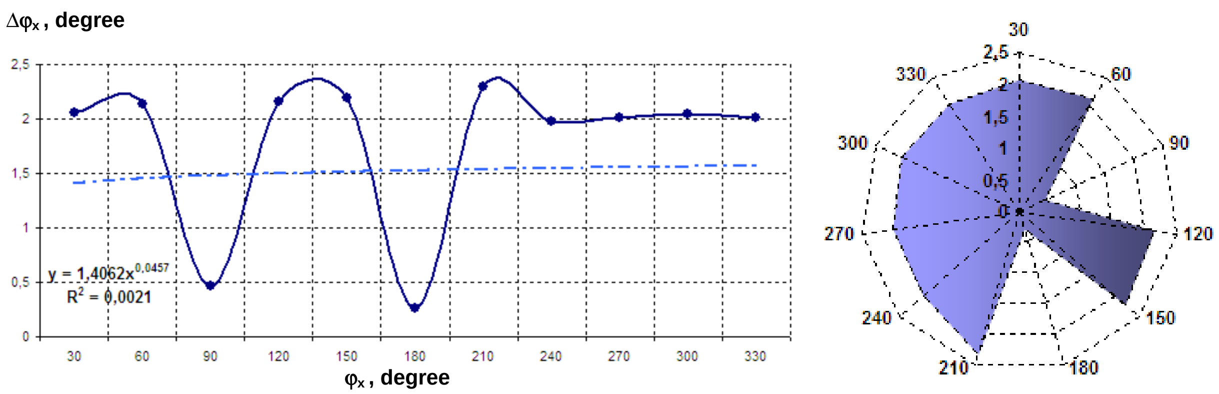

Fig. 8. Phase shift measurement absolute error (4 kHz, rectangular waveform input signals).

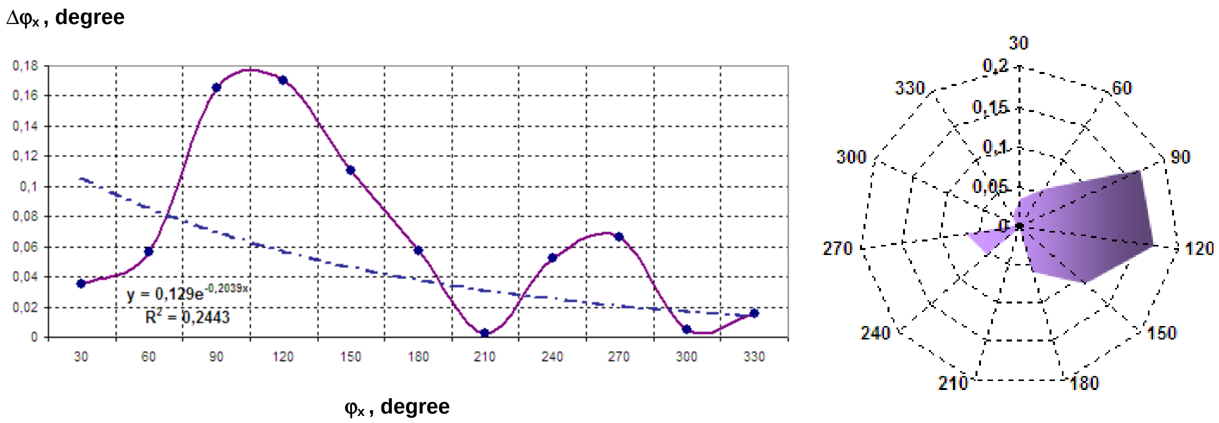

Fig. 9. Phase shift measurement absolute error (100 Hz, sine waveform input signals).

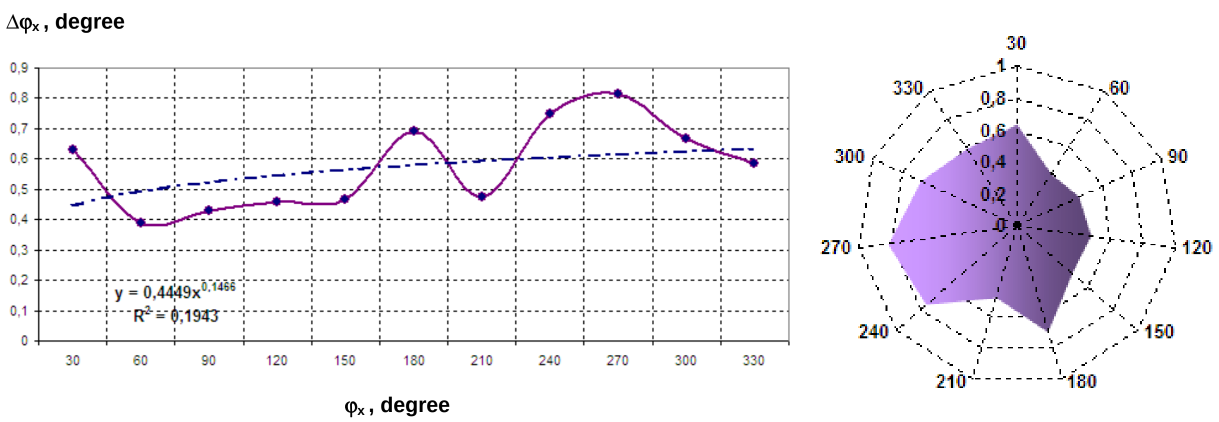

Fig. 10. Phase shift measurement absolute error (1 kHz, sine waveform input signals).

Maximum possible absolute errors for phase difference measurements between two sine and rectangular waveform signals at different frequencies are adduced in Table 1.

Table. 1. Maximum absolute error.

Waveform	Frequency, Hz	Max. absolute error, ⁰
Sine	100	± 0.17
	1 000	± 0.8
Rectangular	10	± 0.008
	100	± 0.06
	1 000	± 0.7
	4 000	± 2.3

4. Communication Modes

Similar to the standard USTI IC, the USTI-MOB IC can work in three communication modes: RS232, I2C and SPI, which can be selected by a circuitry configuration [8]. The commands for RS232, I2C and SPI communication modes at phase shift measurements are shown in Fig. 11 (a-c).

```
M02     ; Select phase shift measurement mode
S       ; Start measurement
C       ; Check result status: 'r' if ready or 'b if busy
R       ; Get result in BCD ASCII format
                                                        (a)

<06><02> ; Select phase shift measurement mode
<09>     ; Start measurement
<03> ; Check result status: '0' if ready or not '0' if busy
<07> ; Get measurement result in BCD format
                                                        (b)

<06><02> ; Select phase shift measurement mode
<09>     ; Start measurement
<03><FF> ; Check result status: '0' if ready or not '0' if busy
<07><FF> ; Get measurement result in BCD format
                                                        (c)
```

Fig. 11. Commands for RS232 (a), I2C (b) and SPI (c) communication modes at phase shift measurements.

In the phase shift measurement mode it is not necessary to set up the appropriate relative error by the 'A' command. It is selected automatically as minimum as possible for current measurement conditions.

The command 'C' is strictly recommended especially in the case of low and infralow frequencies. The command for selection of measurement mode should be executed only once and to be outside of an algorithm's cycle. In addition to the BCD format, the USTI IC can also return the result of measurement in BINARY format for I2C and SPI interfaces, and in BCD HEX, BIN HEX and BIN for the RS232 interface.

5. Conclusions

The experimental investigation of the designed USTI-MOB integrated circuit working in the phase shift measuring mode confirms its high metrological characteristics in low and infralow frequency ranges at low power consumption (0.35 mA current consumption at V_{cc} = 1.8 V). The optimal trade-off between accuracy, power consumption and communication speed has achieved. It makes the USTI-MOB suitable not only for mobile devices but also for other low power consumption applications such as portable measuring instruments, etc.

In case if a power consumption is not a critical parameter, it is recommended to use the standard Series of USTI [8, 9]. It lets to decrease the absolute error of phase shift measurements at least in four times (at < 9.5 mA current consumption and V_{cc} = 5 V) and significantly to extend the range of frequencies.

The USTI-MOB IC will be introduced on the modern market in the current year by *Technology Assistance BCNA 2010, S .L. (Excelera),* Barcelona, Spain (http://www.excelera.io).

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