

## A Study on the Potential Use of Commercial Digital Two-Phase Generators in Impedance Comparison Bridges

Krzysztof Musiol, Andrzej Met, Marian Kampik

*Institute of Measurement Science, Electronics and Control, Silesian University of Technology,  
 ul. Akademicka 10, 44-100 Gliwice, Poland, phone +48 32 2371064, fax +48 32 237 2064,  
[krzysztof.musiol@polsl.pl](mailto:krzysztof.musiol@polsl.pl), [andrzej.met@polsl.pl](mailto:andrzej.met@polsl.pl), [marian.kampik@polsl.pl](mailto:marian.kampik@polsl.pl)*

**Abstract**-Two commercial two-phase digital AC voltage sources, WW2572A from Tabor Electronics and SYS-2722 from Audio Precision, were tested for their potential use in impedance comparator bridges. The mutual relative stability of magnitudes and phase shifts of their output voltages were evaluated. Results of relative amplitude and phase shift stability measurements prove that it is possible to obtain uncertainty of impedance comparison at  $10^{-5}$  level using the WW2572A or SYS-2722 as the two-phase AC voltage source in the balanced comparator bridge.

### I. Introduction

In the classical impedance comparator bridge composed of two AC voltage sources and compared impedances  $Z_X$  and  $Z_N$  (Fig. 1a) the impedance ratio of calibrated and reference standard is determined directly by measuring the complex voltage ratio of the sources supplied to the comparator bridge [1]. Due to a lack of technical possibilities of precise and stable voltage source realization, a impedance elements or a strong magnetic coupling elements (creating transformer bridge [2, 3, 4]) were commonly used in the impedance comparator circuits. Availability of high performance direct digital synthesizers (DDS) has made possible the return to the concept of the impedance comparator bridge in configuration with two AC voltage sources shown in Figure 1. Digital generators have several advantages over conventional analog sinusoidal voltage sources. For example amplitudes of their output voltages and phase shift between them are very stable and can be adjusted with high resolution [1, 5]. Unfortunately currently commercially available DDS generators cannot be used as calibrated sources in high-accuracy comparator bridges. However, the complex voltage ratio of their output voltages can be measured with a sampling voltmeter [6].

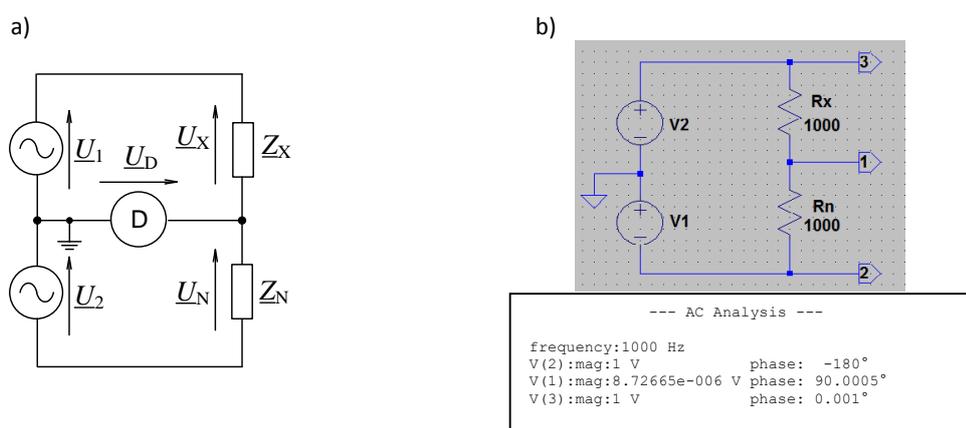


Figure 1. Comparator bridge with calibrated AC sources: a) general circuit, b) comparison of lossless resistors

The two-phase generator for the impedance comparator bridge shall possess first of all very good short-time stability of amplitudes of the both voltages and phase shift between them. The second important requirement is high resolution of adjustment of those both quantities. The analysis of the circuit with calibrated AC sources, shown in Fig. 1a, leads to the conclusion that when the calibration of impedances of similar modulus is

performed in connection with interchange procedure [7], the comparison resolution depends mainly on the short-term magnitude and phase stability of the both voltages supplying the bridge. A resolution, in turn, is essential for achieving balance conditions with appropriate accuracy, based on assumed calibration uncertainty. An effect of a finite resolution of magnitude and phase can be easily explained taking the comparison of 1 k $\Omega$  lossless resistors as an example, shown in Figure 1b. Considering independently influence of finite resolution of magnitude and phase, impedance calibration with uncertainty 10  $\mu\Omega/\Omega$  requires resolution of magnitude at  $1 \cdot 10^{-5}$  level. In turn, the finite resolution of phase shift adjustment results in the complex (instead of the real) ratio of impedance standards compared:

$$Z_X/R_N = 1e^{j0,001}. \quad (1)$$

Hence the resistance of calibrated standard:

$$R_X = \text{Re}\{Z_X\} = 999,9999998 \Omega, \quad (2)$$

differ from the real value about 0,2  $\mu\Omega$ . It gives negligibly small comparison error at the level of  $10^{-9}$ .

## II. Results

The stability of the magnitude ratio of modern commercially available digital two-phase AC sources, may be assessed at the level of  $10^{-5}$ , and the stability of the phase at the level of mrad. Using such stable sources allows to compare impedance standards with accuracy at the level of tens  $\mu\Omega/\Omega$ . Therefore, two commercial two-phase generators:

- 1) generator Tabor Electronics WW2572A with DDS technology, possessing 16-bit magnitude resolution adjustment and phase shift resolution adjustment at the level of mrad ( $0,0015^\circ$  for  $f = 1$  kHz),
- 2) Audio Precision SYS-2722 measuring system with digital two-phase generator of 10  $\mu\text{V}$  resolution of voltage adjustment (for 1 V range) and  $0,01^\circ$  phase shift adjustment,

were tested regarding their potential use in high-precision impedance comparison bridges. Measurements of the relative magnitude and phase shift stability of signals generated by these two generators were performed in electromagnetically screened and temperature conditioned environment (Fig 2).



Figure 2. Research station in the electromagnetically screened room

### A. Magnitude stability

Stability of magnitude ratio for two-phase generator can be determined by the measurement of very small difference of two nominally equal output voltages generated by the both channels [8]. The measurements were performed with Agilent 3458A voltmeter (Figure 3). To increase the common-mode rejection ratio a transformer was used at the input of the voltmeter. Several measurements were performed at  $25^\circ\text{C}$  for frequencies from 50 Hz to 2 kHz and magnitudes from 0.1 to 1 V. Duration of each measurement was about 1 hour which corresponds to the duration of a real impedance comparison process. The results presented in Figure 4 refer to the worst case which occurred at 1 kHz and 1 V. The obtained results prove the short-term magnitude stability of the WW2572A at 15  $\mu\text{V}/\text{V}$  level and the stability of the AP SYS-2722 better than 10  $\mu\text{V}/\text{V}$ .

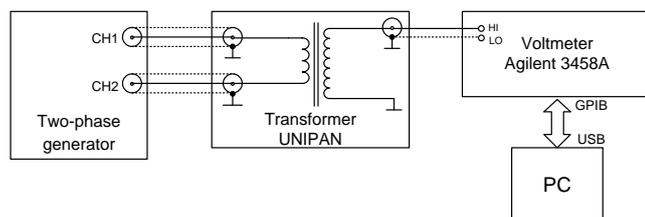


Figure 3. Measuring circuit for investigation of magnitude stability

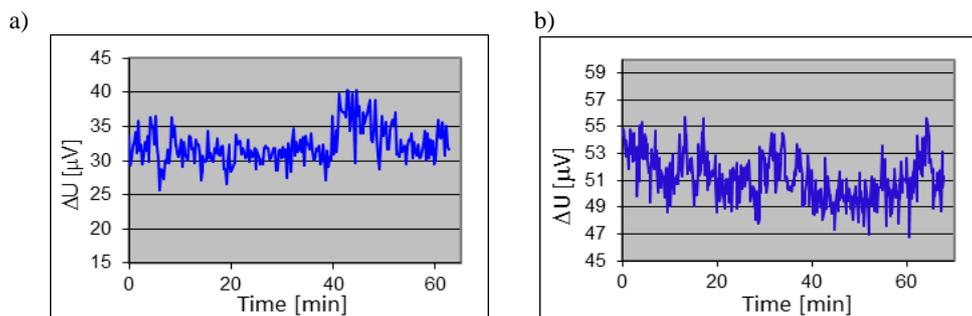


Figure 4. Results of magnitude stability: a) for WW2572A generator, b) for AP SYS-2722 source

## B. Phase stability

Stability of the phase shift was tested using the Stanford Research System SR830 lock-in amplifier. The measurements were performed for four different phase shifts  $\Delta\varphi = \varphi_{CH1} - \varphi_{CH2}$ :  $0^\circ$ ,  $-90^\circ$ ,  $+90^\circ$ ,  $180^\circ$  between output voltages of Channel 1 and 2 and for magnitudes from 0.1 to 1 V. Selected results are presented in Figures 5 and 6. The worst cases occurred when  $\Delta\varphi = -90^\circ$  for WW2572A and when  $\Delta\varphi = 90^\circ$  for SYS-2722. The relative short-term stability of phase shift is equal to 4 mrad for the WW2572A and 6 mrad for the AP SYS-2722.

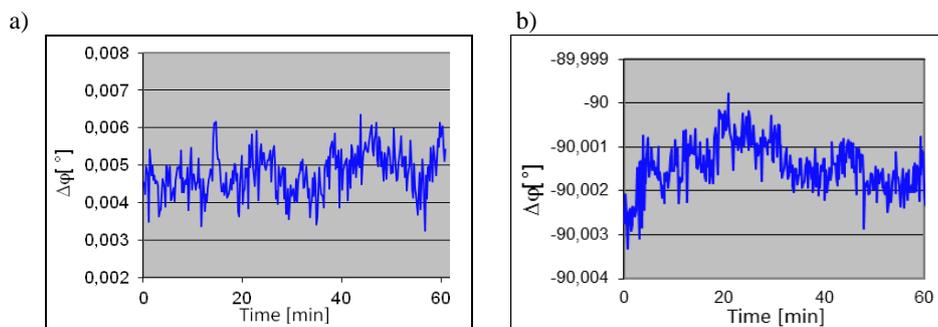


Figure 5. Stability of the phase shift for WW2572A: a) at  $\Delta\varphi = 0^\circ$ , b) at  $\Delta\varphi = -90^\circ$ ,

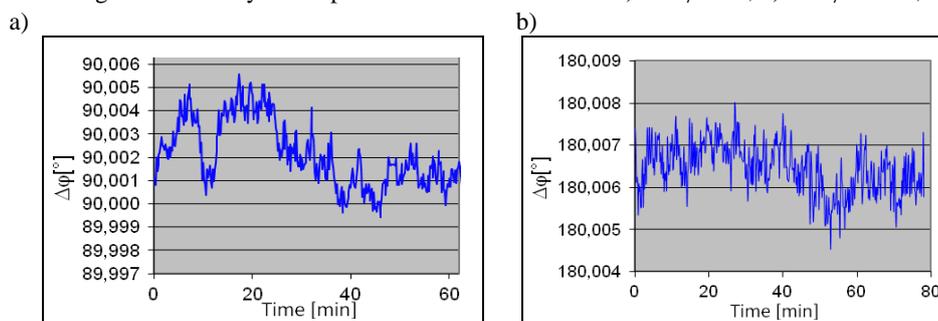


Figure 6. Stability of the phase shift for AP SYS-2722: a) at  $\Delta\varphi = 90^\circ$ , : a) at  $\Delta\varphi = 180^\circ$ ,

### III. Spectral purity

Spectral purity investigation of the considered sources was conducted using the Harmonic Distortion Analyzer which is included to computer-controlled multi-device Audio Precision SYS-2722. The Harmonic Distortion Analyzer uses FFT techniques to isolate and measure each harmonic. The FFT bins are very narrow, and measurement of residual noise is almost entirely excluded. In the THD+N function of the 2700 series Harmonic Distortion Analyzer, the selected channel signal is passed through a tunable bandreject filter in order to reject the fundamental component of an applied single sine wave test signal before the amplitude of the remaining distortion and noise components is measured and displayed. The filter is continuously adjusted for maximum rejection of the highest-amplitude frequency component of the signal. The bandreject filter center frequency can be set in the range between 10 Hz and approximately 204 kHz. The center frequency may be fixed, or may track one of several parameters. In their THD+N Ratio function, the 2700 series Analog Analyzer and DSP Audio Analyzers, like all other commercially available THD+N analyzers, refer the distortion product measurements to the raw input signal that includes fundamental and harmonics.

Spectral purity tests were performed successively for each output of WW2572A and SYS-2722 sources. The outputs were monitored for a period of one hour and every second distortions were recorded. The measurement results of average, minimum and maximum value of THD+N for each generators' channel are shown in Table 1. The results indicate a very high spectral purity of tested sources. Especially noteworthy are the results obtained for the SYS-2722 where the THD is at the level of -100 dB. Such a high spectral purity was obtained by the manufacturer due to the use of high quality digital-to-analog converters on the outputs of the channels.

Table 1. THD for considered two-phase sources

THD+N	Tabor Electronics WW2572A		Audio Precision SYS-2722	
	CH1	CH2	CH1	CH2
Avg.	0,070%	0,072%	0,001%	0,001%
Max.	0,072%	0,073%	0,001%	0,001%
Min.	0,068%	0,070%	0,001%	0,001%

### IV. Conclusions

Results of relative amplitude and phase stability obtained for the two examined commercially available two-phase sources prove that it is possible to obtain resolution of impedance comparison at  $10^{-5}$  level using the WW2572A or AP SYS-2722 generators. Maximum instability of the magnitude ratio for SYS-2722 is at  $10 \mu\text{V/V}$  level and instability of phase shift is below 6 mrad what allows impedance comparison with relative resolution of  $10^{-5}$ . Concluding, these commercial two-phase generators can be used in impedance calibrations performed at  $10^{-5}$  level of uncertainty.

### References

- [1] R. Rybski: "Impedance comparison in a circuit with two digital sinewave generators", *Metrology and Measurement Systems*, vol. 11, no 2, 2004, pp. 131-145.
- [2] A. Muciek:"System for calibration of inductance standards based on a simple unbalanced transformer bridge", *IEEE Trans. Instrum. Meas.*, Volume: 45, Issue: 1, Feb 1996, pp. 306 – 309.
- [3] K. Musiol, A. Met, T. Skubis: "Automatic Bridge for Comparison of Inductance Standards", *Measurement*, Volume 43, Issue 10, December 2010, pp. 1661 – 1667.
- [4] A. Met, T. Skubis, R. Hanke, A. Kölling, Musiol.: "Dissemination of the Unit of Inductance with a New Automatic 1:1 Comparator", *Proceeding of Regional Metrology Conference*, Nairobi, Kenya, 19 – 24. 09. 2005.
- [5] M. Kampik: "Comparison of Non-Quantum Methods for Calibration of the Digital Source of Very-Low-Frequency AC Voltage," *IEEE Trans. Instrum. Meas.*, CPEM'12 special issue, in press
- [6] L. Callegaro, V. D'Elia, and E. Gasparotto: "Impedance comparison at power frequency by asynchronous sampling" in *Proc. CPEM Dig.*, 2010, pp. 322–323.
- [7] K. Musiol, A. Met: "Coherence of Comparison Results Obtained by New Inductance Comparator Bridge", *Przegląd Elektrotechniczny* Nr 9a/2011, str. 298-301.
- [8] R. Rybski, J. Kaczmarek, and M. Krajewski: "Accurate measurement of complex voltage ratio with a sampling voltmeter", *Metrology and Measurement Systems*, vol. 11, no. 2, 2004, pp. 147–158.

*Research work financed by the Polish government (project Iuventus Plus nr IP2011 037571)*