THE COMPLEX AC RESPONSE MEASUREMENT WITH USB CONNECTIVITY TO PC

L. Svilainis, V. Dumbrava

Signal processing department, Kaunas University of Technology
Studentu str. 50, LT-51368 Kaunas, Lithuania
T, +370 37 300532; F, +370 37 753998;E, linas.svilainis@ktu.lt / vytautas.dumbrava@ktu.lt

Abstract

Design of the portable acquisition module for AC parameters measurement is presented. Module has USB connectivity and is operated by host PC. The application of sine wave correlation technique for complex amplitude measurement together with direct digital synthesis for excitation signal and same reference clock allow for significant accuracy improvement and processing simplification. The availability of two simultaneous ADC channels enables complex impedance and gain and phase measurements. Application examples for insertion gain and phase, power stage output amplitude and complex impedance measurement are presented.

1. INTRODUCTION

The AC response is one of the essential parameters of an electronic system [1]. The frequency response of the electrical properties of material is used in medicine [2], biosensors [3] development. Electrical impedance spectroscopy is used even in food industry [4] and the ionic conductivity studies [5].

Numerous publications [1-7] indicate the need for such systems. The performance of commercially available equipment is sufficient but the price is high and such devices are bench instruments which are dedicated for particular tasks. Therefore researchers have turned to customized equipment design. The analog-to-digit (ADC) converters [1] are applied for amplitude and phase measurement. Sine wave fitting technique is used for amplitude, phase and frequency extraction [6]. This technique have inherent error source since the test and ADC sampling frequency ratio is not exactly known. Therefore fitting procedure requires the frequency estimation. Uncertainty in frequency estimation is causing the magnitude and phase error.

In this paper we present the design of the portable AC parameter measurement system which is free from the mentioned shortcoming. A direct-digital-synthesis (DDS) is used for excitation signal generation. Same reference frequentcy source is used for DDS and ADC clocking. Such combination eliminates the excitation and sampling frequencies ratio estimation error. Module has the USB connectivity and is dedicated for ultrasonic equipment amplitude and phase AC response measurement.

2. AC PHASOR ESTIMATION

The frequency response of device under test (DUT) at certain frequency can be determined by probing the system input with a single frequency sine signal while measuring the input/output amplitude ratio and phase difference.

The application of the sine-fitting techniques [6] can largely reduce the influence of noise in the final results. If harmonic signal is used for excitation, the resulting waveform can to be fit as:

$$u(t) = U_c \cos(2\pi f t) + U_S \sin(2\pi f t) + U_{DC}, \quad (1)$$

where U_c and U_s are the orthogonal harmonic signal components of the sine wave, U_{DC} is the DC component and f is the excitation signal frequency (Figure 1).

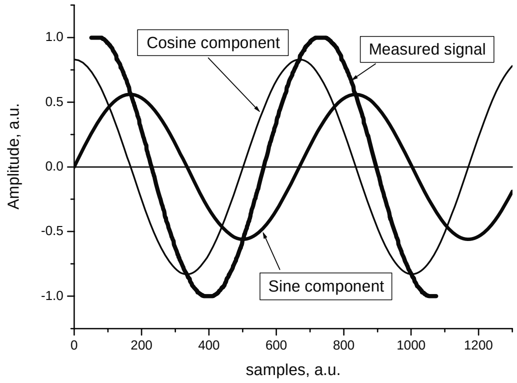

Figure 1. Phasor approximation

Fitting this function to the sampled signal $y_1 \ldots y_M$, acquired at a frequency f_s at time instances $t_1 \ldots t_M$, is accomplished by minimising:

$$\varepsilon_{RMS} = \sqrt{\frac{1}{M}\sum_{m=1}^{M}\left[y_m - u(t_m)\right]^2}\ . \qquad (2)$$

The procedure is iterative, e.g. consuming a lot of computational time and has the inherent error related to frequency estimation. Sine wave correlation (SWC) technique is proposed for signal amplitude and phase measurement [7]. It is suggested to use common reference frequency source for excitation generator and sampling. Then frequency instability errors can be disregarded. In such case non-iterative fitting is used:

$$U_c = \frac{\sum_{m=1}^{M}\left[\cos(2\pi f t_m)\cdot y_m\right]}{\sum_{m=1}^{M}\left[\cos(2\pi f t_m)\right]^2}, \qquad (3)$$

$$U_s = \frac{\sum_{m=1}^{M}\left[\sin(2\pi f t_m)\cdot y_m\right]}{\sum_{m=1}^{M}\left[\sin(2\pi f t_m)\right]^2}, \qquad (4)$$

$$U_{DC} = \frac{\sum_{m=1}^{M} y_m}{M}\ . \qquad (5)$$

Then the magnitude and phase:

$$U = \sqrt{U_c^2 + U_s^2}\ , \varphi = \arctan\left(\frac{U_s}{U_c}\right). \qquad (6)$$

The SWC technique has been implemented for measured signal amplitude and phase estimation in data acquisition module.

3. EXCITATION GENERATOR

In order to have fixed ratio of excitation signal and ADC sampling frequency DDS technique was proposed.

The DDS structure is presented in Figure 2. The DDS output frequency depends upon three parameters: tuning word value ($0<D<2^{N-1}$), clock frequency (F_s) and accumulator capacity 2^N. Output frequency can be expressed as $f=d\varphi/dt$. Time step dt is dependant upon clock frequency and can be expressed as $dt=1/F_s$.

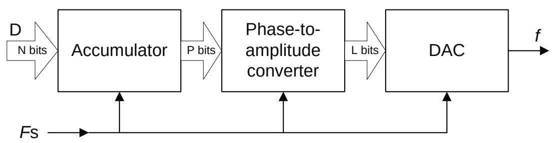

Figure 2. DDS generator structure

The phase increment dφ is the angle which is accumulated at every clock dt. The value dφ is the ratio of the tuning word D and accumulator capacity. Then the output frequency:

$$f = \frac{F_s \cdot D}{2^N}\ . \qquad (7)$$

Only P accumulator bits are used for phase-to-amplitude conversion. The amount of P bits defines the jittering of output signal. Furthermore, only L bits of phase-to-amplitude converter output are used for DAC. The DDS generator output signal frequency, amplitude and phase can be controlled digitally. It was decided to use DDS as it is getting more popular for its simplicity, flexibility and good performance results. Essential, that using DDS the ratio of DDS reference frequency and the harmonic signal output signal is fixed. This fixed ratio is demanded for SWC technique implementation.

4. ACCURACY ESTIMATION

The SWC processing of the signal can be treated as narrowband signal filtering and leads to improved processing gain thanks to significant signal oversampling [8]:

$$PG = 10\log_{10}\left(\frac{f_S}{2\cdot B}\right), \qquad (8)$$

where f_S is a sampling frequency and B is digital processing filter bandwidth. Digitization noise RMS:

$$U_{ADCnRMS} = \frac{U_{FS}}{2^K\sqrt{12}}, \qquad (9)$$

where K is ADC bits number, U_{FS} is the ADC full-scale range.

Treating the reference signal as gated sine wave corresponds to a *sinc* filter in frequency domain. The filter bandwidth expressed as function of length M of the sampled array obtained using frequency f_S

$$B = \frac{f_S}{M}. \qquad (10)$$

Then resulting digitization noise RMS value

$$U_{nRMS} = \frac{U_{\mathrm{Re}f}}{2^K\sqrt{12}}\cdot\sqrt{\frac{2B}{F_s}} = \frac{U_{\mathrm{Re}f}}{2^K\sqrt{12}}\cdot\sqrt{\frac{2}{M}}. \qquad (11)$$

The theoretical analysis, numerical simulation and experimental results have been presented in [7].

5. MEASUREMENT SYSTEM

The system (Figure 3) contains both the excitation and the receiving units.

The excitation channel and the receiving part are connected DUT according to the needed measurement scheme. The driving channel is built using the DDS generator AD9851 from Analog Devices. The AD9851 contains a reference clock multiplier which eliminates the need for a high speed reference oscillator. The DDS's output waveform phase is time-continuous in case of the frequency change. The output signal after filtering and amplification is attenuated by smooth attenuator and two fixed 20dB attenuation blocks. The receiving part consists of the high input impedance preamplifier (optional) and the programmable gain amplifier (PGA), controlled via I2C interface which in turn is tied to a host PC via USB core. The PGA is AD8367 from Analog Devices with 45 dB of variable gain with a linear-in-dB gain. Gain control voltage is derived from AD5321. The AD5321 is a single 12-bit buffered voltage-output DAC. It uses a I2C interface that is derived from the USB controller core. The conditioned signal is supplied to the acquisition unit. The high speed dual channel data acquisition consists of two high speed 10-bit ADC AD9214 operating at 100MS/s conversion rate. The DAC output data is streamed to the high speed SRAM IS61LV25616 from Integrated Silicon Solution, Inc. organized as 256k words by 16 bits. The latching, synchronization and control state machine is organized by 3 Complex Programmable Logic Device (CPLD) chips M4A3-128/64 from Lattice. The CPLD also performs the PC104 bridge functions. PC104 bus is used for main control. It is emulated by the low-power USB2.0 microcontroller EZ-USB FX2LP IC CY7C68013A from Cypress Semiconductor Corporation's. The GPIF bridge, mimicking the PC104 bus is used for connection to USB.

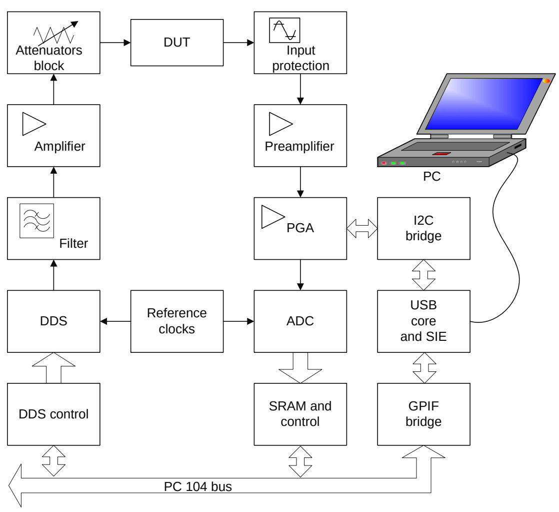

Figure 3. Measurement system

Acquisition module PC-104 stack photo is presented in Figure 4. The top PCB is the excitation DDS with optional RMS detector channel. Middle PCB is the dual channel ADC card. The bottom card is the USB interface and PC104 bridge.

Figure 4. PC-104 stack

Such configuration ensures that up to 256k samples of analog signal can be captured on two acquisition channels at highest 100Ms/s rate.

6. APPLICATION

Figure 5 presents the conventional setup of the module for the DUT AC response measurement. Gain and phase can be calculated since complex signal amplitudes for circuit input and output are available thanks to dual ADC channel acquisition capability.

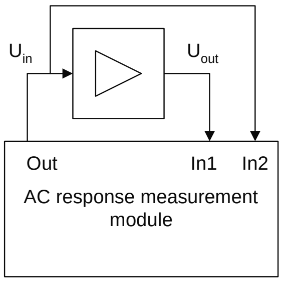

Figure 5. Amplifier AC response

The obtained insertion loss can be stored in a computer memory for compensation of results obtained using the investigated amplifier. The diagram presented in Fig 6 demonstrates the result of ultrasonic preamplifier AC response measurement. Obtained results are presented as gain in dB and phase in degrees.

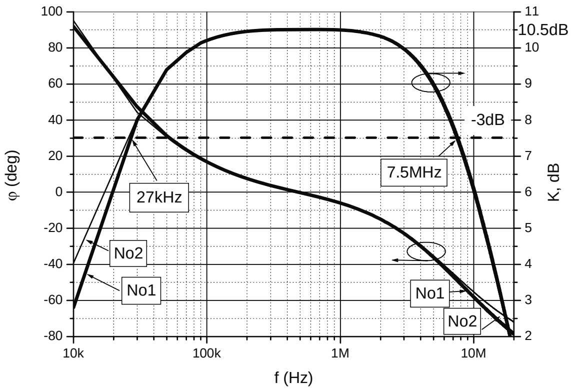

Figure 6. Two channels AC response

Results for high voltage amplifier several configurations measurement are presented in Figure 7.

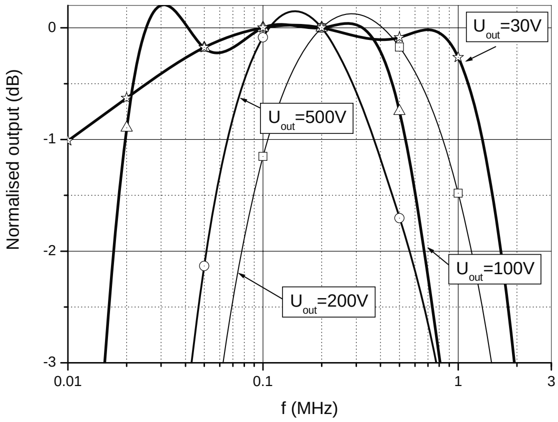

Figure 7. High voltage AC response

The module can be configured for electrical impedance measurement [19]. Necessary setup, using I-V method is presented in Figure 8. The since single-ended implementation is offering the lowest complexity of implementation.

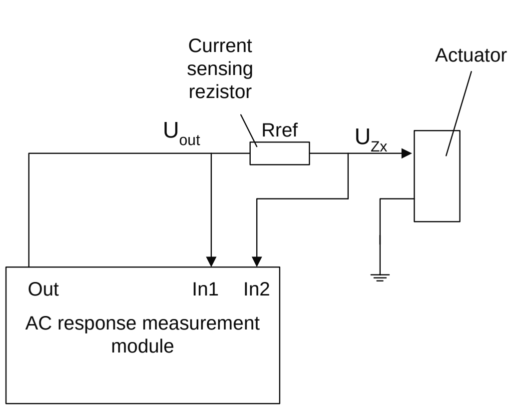

Figure 8. Impedance measurement

Current is calculated using the voltage measurement across an accurately known resistor, R_{ref}.

$$Z_x = \frac{U_{Zx}}{I} = \frac{U_{Zx}}{U_{out} - U_{Zx}} R_{ref} . \quad (12)$$

The complex impedance can be presented as real and imaginary parts or as magnitude and phase. As an example of the dynamic range available, ultrasonic actuator impedance was examined. Actuator impedance investigation results example is presented in Figure 9.

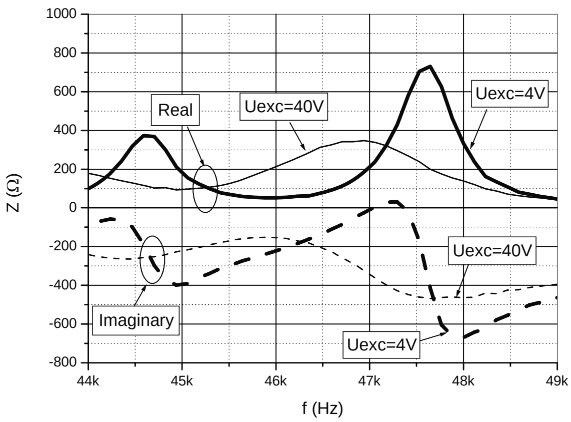

Figure 9. Impedance vs. excitation

The real and imaginary of parts of electrical impedance variation when actuator excitation voltage is changing can be observed. More experimental results of ultrasonic transducers measurement can be found in [9].

7. CONCLUSIONS

The presented module for AC parameters investigation is universal. It can be applied for various AC parameters investigation. It has USB connectivity and is operated by host PC. The application of sine wave correlation technique for complex amplitude measurement together with direct digital synthesis for excitation signal and same reference clock allow for significant accuracy improvement and processing simplification. The availability of two simultaneous ADC channels enables complex impedance and gain and phase measurements.

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