32nd URSI GASS, Montreal, 19-26 August 2017

The Realization and Calibration of Active Simulation Impedance

First A. Yan Xiaojun (1), Second B. Li Yalu (1), Third C. Wu Kang (1), and Fourth D. You Li (1)
(1) Beijing Oriental Institute of Measurement & Test, Beijing, China, 10086

Abstract

This paper introduces the realization and calibration of complex impedance standard which is a kind of active simulation impedance. As a new calibration equipment for digital bridge, complex impedance standard can simulate any amplitude or angle of complex impedance by generating voltage and current to calibrate digital bridge in the whole complex plane, which can make up for deficiency in the calibration of digital bridge at present. At the same time, in order to ensure the calibrated environment of physical impedance, complex impedance standard is needed to track the frequency and lock the phase of digital bridge. In this paper, the realization and calibration of active simulation impedance are analyzed, and the experimental data is given in the end.

1. Introduction

The high precision physical impedance standards such as capacitance, inductance and resistance are used in the verification of RLC digital bridge by direct measurement in the metrological work now [1]. But the method can only calibrate function of capacitance, inductance, resistance, but other functions, especially AC impedance amplitude Z and angle θ are unable to calibrate [2].

In this paper, the active simulation impedance can calibrate RLC digital bridge by simulating AC impedance that has any amplitude and angle [3], which based on adjusting voltage and current waveforms, tracking frequency and phase locking loop. Therefore, the active simulation impedance can simulate capacitance, inductance, resistance and AC impedance, which will play an importance role in the calibration of RLC digital bridge.

2. Calibrated Object

As the calibration object of active simulation, RLC digital bridge is widely used at present. RLC digital bridge can calibrate electrical parameter such as capacitor C, inductor L, resistor R, amplitude Z, angle θ, dissipation factor D, admittance Y and so on.

As shown in Figure 1, the principle of digital bridge is different from traditional bridge, whose balance is based on negative feedback of amplifier but not to adjust. And when bridge is in balance, the bridge can detect zero current automatically and does not need auxiliary of algorithm. Thus, using virtual short principle of amplifier, when anode is connected to ground, cathode is in the state of virtual ground. At the same time, the current through calibrated object and internal resistor R_r is equal:

$$I_x = I_r \quad (1).$$

Then sample the voltage U_x and U_r of Z_x and R_r and the calibrated impedance is:

$$Z_x = \frac{U_x}{U_r} R_r = \frac{a+jb}{c+jd} R_r \quad (2).$$

So Z_x is equal to the product of standard impedance Z_s in the bridge and ratio coefficient K, and digital bridge can achieve high accuracy measurement by using proportional relation.

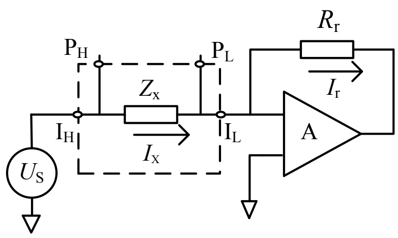


Figure 1. Schematic Siagram of Calibrated Object.

3. Design and Realization

The design of active simulation impedance is as follows:

1) Using the ohm theorem $Z=U/I$, the active simulation impedance can be simulated through regulating voltage waveform and current waveform.

2) To stay the same calibration environment, active simulation impedance need to track the frequency of bridge and lock its phase.

3) Two DAC chips generate sinusoidal voltage waveforms, whose reference voltage is the same voltage.

4) According to the work level of RLC digital bridge, the output waveforms need to convert with resistance divider and resistance shunt.

According to the design of active simulation impedance which can be called complex impedance standard [4], the principle is shown in figure 2. AC impedance information can be inputted by user through man-machine interface which will calculate amplitude and phase of voltage and current waveforms. At the same time, through tracking frequency and locking phase of calibrated digital bridge, pulse signal is produced to be the clock of digital to simulation converters. Then two 16 bit [5] DAC generate sinusoidal voltage waveforms and turn to voltage and current that we need after V/V and V/I transform, so the simulation impedance is generated.

Thus, the simulation impedance of complex impedance standard is:

$$Z_x = \frac{U}{I} = \frac{U_1 \times K}{U_2 / G} = \frac{U_1}{U_2} \times K \times G \qquad (3).$$

In equation (3):

Z_x ---- The actual amplitude of calibrated AC resistance.

U_1 ----The amplitude of sinusoidal waveform outputted by DAC1.

U_2 ---- The amplitude of sinusoidal waveform outputted by DAC2.

K ---- The modulation ratio of V/V transform.

G ---- The modulation ratio of V/I transform.

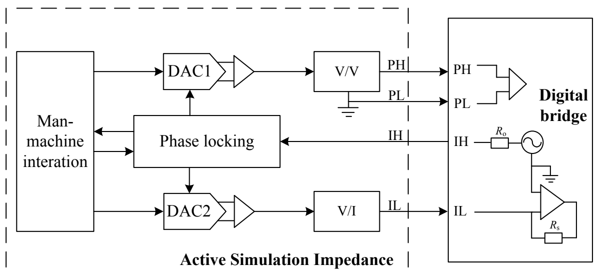


Figure 2. Schematic Diagram of Active Simulation Impedance.

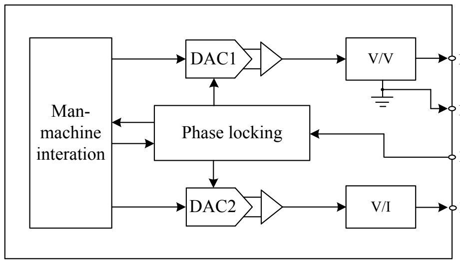
It should be noted that:

1) Lack of locking phase will make inaccuracy in the calibration of digital bridge. Therefore, it is necessary to simulate the environment of digital bridge and make sure the same phase of output current in active simulation impedance and digital bridge.

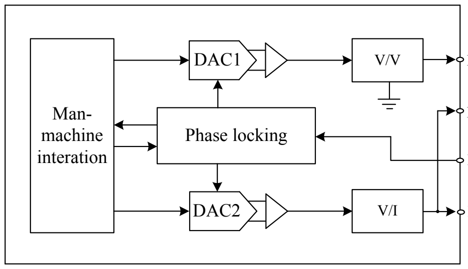
2) The V/I transform can use resistance shunt, which means that a resistor can be connected to DAC2 directly. As the figure 2 shown, the port of current waveform of active simulation impedance will be connected to cathode of amplifier in digital bridge. Because of the anode of amplifier is connected to ground and cathode is in the state of virtual ground, the voltage of DAC2 can be converted to current with a resistor directly.

3) For satisfying the accuracy of angle of active simulation impedance, the DAC must to be 16 bit at least. Otherwise, the angle of active simulation impedance cannot meet the requirment of angle indicator.

4) Active simulation impedance calibrate five terminal digital bridge and four terminal pair digital bridge is difference of the port PL, the principle is shown in figure 3.



(a) Schematic diagram when calibrating five terminal bridge



(b) Schematic diagram when calibrating four terminal pair bridge

Figure 3. The Difference of Port PL in Schematic Diagram.

4. Calibration Method

The method for evaluating measurement uncertainty of AC impedance is as follows:

A. Substitution measurement method

Active simulation impedance can output capacitance, inductance and resistance and can be calibrated by substitution measurement method. As Figure 4 shown, active simulation impedance is calibrated, digital bridge as substitution device and physical impedance as calibrated standard. The actual value of the simulation impedance is:

$$Z_x = Z_0 + (Z_2 - Z_1) \qquad (4).$$

In equation (4):

Z_0---- the actual value of physical impedance.

Z_1---- the reading of digital bridge when measuring physical standard.

Z_2---- the reading of digital bridge when measuring active simulation impedance.

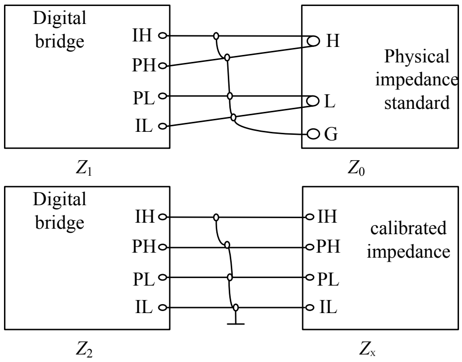


Figure 4. Schematic Diagram of Substitution Measurement Method.

B. Equal potential measurement

Active simulation impedance will use equal potential measurement to trace to voltage ratio standard and phase standard when output AC impedance. As figure 5 shown [6], through regulating dual channel signal source and trimming circuit, equal potential measurement can form mirror current which means current of AC impedance is equal to physical impedance's. Then voltage and phase difference are sampled by digital sampling. Therefore, simulation impedance can be traced to voltage ratio standard K and phase standard θ.

The amplitude of calibrated AC impedance is:

$$\left|\dot{Z}_x\right| = K \times \left|\dot{Z}_0\right| \qquad (5).$$

The angle of calibrated AC impedance is:

$$\theta_x = \theta_0 + \theta + \pi \qquad (6).$$

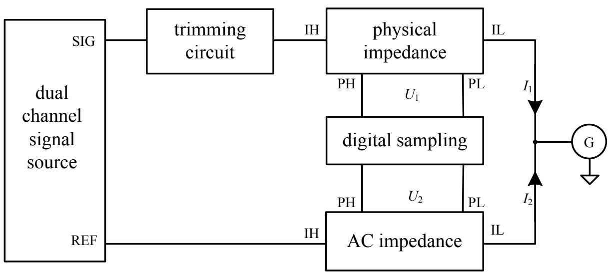


Figure 5. Schematic Diagram of Equal Potential Measurement.

5. Experimental Data

In the laboratory environment, the active simulation impedance output inductance which is calibrated through standard inductance and digital bridge. The experimental data at 1kHz is shown in Table 1. The active simulation impedance output AC impedance which is calibrated through dual channel signal source, digital sampling system, and so on. The experimental data at 1kHz is shown in Table 2.

Table 1. The Experimental Data of Calibrated Inductance at 1kHz.

test point	Z_2	Z_1	Z_0	Z_x
100μH	108.86	108.57	99.97	100.27
1mH	1.00853	1.00835	0.99976	0.99994
10mH	10.0091	10.0074	9.9991	10.0008
100mH	100.010	99.996	99.990	100.004
1H	1.00022	1.00057	1.00054	1.00019

Table 2. The Experimental Data of Calibrated AC Impedance at 1kHz.

indication of AC impedance standard		traceability data		measured quantity value of AC impedance	
Z/Ω	θ/°	K	φ /°	Z_x/Ω	θ_x/°
100.000	0.00	0.628441	0.01	100.003	0.01
100.000	30.00	0.628475	30.02	100.009	30.02
100.000	60.00	0.628466	60.02	100.007	60.02
100.000	90.00	0.628450	89.98	100.005	89.98
100.000	180.00	0.628474	180.02	100.009	180.02
100.000	-30.00	0.628475	-30.02	100.009	-30.02
100.000	-60.00	0.628479	-59.97	100.009	-59.97
100.000	-90.00	0.628450	-89.97	100.005	-89.97

6. Conclusion

As a kind of active impedance simulation, complex impedance standard can realize calibration in the whole complex plane by controlling the amplitude and angle of voltage and current waveforms. Based on digital simulation impedance technology, active impedance simulation uses DDS, phase lock loop technology to make digital regulation of amplitude and angle of simulation impedance. Meanwhile, active simulation impedance can replace 0.02 grade physical impedance standard to calibrate 0.05 grade RLC digital bridge. Thus, the active simulation impedance in this paper will play an important role in the field of metrology.

7. References

1. GJB/J5412-2005 Vertification regulation for wide range digital RLC measurement instrument.

2. Frederic Overney, Blaise Jeanneret, Impedance Simulator for Automatic Calibration of LCR Meters over The Entire Complex Plan, IEEE, 2012:684-685.

3. Liu Min. The digital simulative impedance standard instrument, China patent number: ZL200510082928.X .

4. Yan Xiaojun, Li Yalu and You Li, Design and Analysis of Complex Impedance Standard, ICEMI, 2013, Vol.I, pp:486-489.

5. Li Yalu, Liu Min. The effect on total harmonic distortion by DAC in digital wave synthesis technique. Measurement and Test Committee of Chinese Society of Astronautics Academic Symposium in 2006.

6. You Li, Li Yalu and Yan Xiaojun, Calibration method and device of complex impedance standard, China application patent number: 201410538905.4.