A Virtual Impedance Measuring Instrument Based on a Quasi-Balanced Bridge

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Abstract- The paper presents a virtual instrument based on a quasi-balanced bridge designed to measure the parameters of an inductor, a capacitor or a resistor. The unknown element, in series with a reference resistor, forms the real half of an ac bridge, while the software model of a resistive potentiometer shapes the virtual half. Actually, one acquires the supplying voltage and the voltage across the reference resistor respectively, after which these signals are digitally processed according to the quasi-balanced bridge algorithm. Both the hardware and the software of the prototype model are described. The experimental results and the error analysis are also presented.

I. Introduction

Impedance is one of the most measured quantities in the whole field of electrical measurements. The conversion methods imply the transformation of the unknown impedance into other quantity like voltage, current, period of time, frequency, phase shift, and digital word. [1-3]. These methods allow high measurement rates, are simple, but usually offer modest accuracy, Accordingly, they are widely used in measurements of non-electrical quantities by mediation parametric sensors.

In many component meters the device under test is modelled in terms of quotient of voltage across and the current through itself [4-6]. Their amplitude and phase are gauged by synchronous detection and equivalent circuit model can be established through computation. The accuracy of this method is directly dependent on the voltage and current measurement accuracy.

The most precise impedance measurements are still achievable by applying bridge methods. Digital bridges based on iterative methods and computer control are automatic test systems compatible and provide high accuracy (10 – 100 ppm), reproducibility, reliability and flexibility [7,8].

In the paper, a virtual impedance measuring instrument based on a quasi-balanced bridge is proposed. The instrument is composed by a precise resistor in series with the measuring impedance, which form the real half-bridge. The voltage across the resistor is acquired along with the supplying voltage by means of a dual-channel simultaneous sampling acquisition board. On the other hand, the virtual half of the bridge is achieved by dividing the supplying voltage by a certain factor according to the quasi-balanced bridge algorithm. The use of only one fixed resistor as reference confers accuracy in measurement and the two independent quasi-balances obtained by modifying the same virtual potentiometer setting permit facile and fast automatic balancing.

II. Quasi-balanced bridge principle

The operating principle of the ac quasi-balanced bridge is shown in Fig.1 [9]. The excitation source is an accurate sine-wave generator witch supplies a sinusoidal voltage $\underline{V}_s$ at the required frequency, ω. The voltage drops on the bridge arms are: $\underline{V}_x$, $\underline{V}_r$, $p\underline{V}_s$ and $(1\text{-}p)\underline{V}_s$, where p defines the position of the variable point on the virtual potentiometer. The output voltage $\underline{V}_d$ can be computed as:

$$\underline{V}_d = p\underline{V}_s - \underline{V}_r \quad (1)$$

Vr and V_s are acquired by using the ACh0 and ACh1 analog input channels of a digital acquisition board (DAQB).

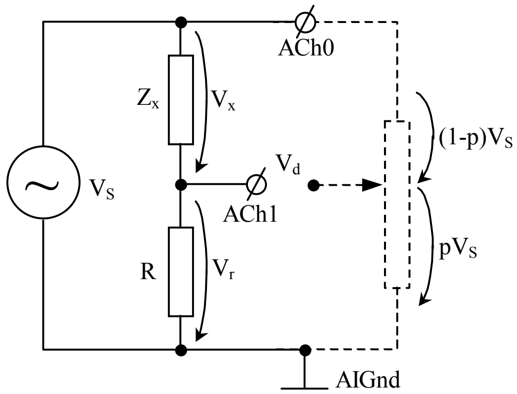

Fig. 1. The quasi-balanced bridge circuit

Two independent and separate quasi-balances of the bridge are performed by varying the position p of the potentiometer. These operations are specific for inductive and capacitive character of the impedance under test, as it follows.

If the impedance character is inductive, the first quasi-balance is obtained by adjusting p so that $\underline{V}_d$ and $\underline{V}_r$ are in quadrature. Let be m this particular position of p. The second quasi-balance implies modifying p in such manner that $\underline{V}_d$ and $\underline{V}_s$ are in quadrature, so their dot product is minimum, in which case n is the particular position of p. Practically, for both quasi-balances, the quadrature point is sensed when two quantities, M_{1L} and M_2 are less than a required accuracy, ε_b, M_{1L} and M_2 are computed as:

$$M_{1L} = \sum_{i=0}^{N-1} v_{di} \cdot v_{ri} = \sum_{i=0}^{N-1} (pv_{si} - v_{ri})v_{ri} \qquad p = m \;\; for \;\; M_{1L} \le \varepsilon_b \tag{1}$$

$$M_2 = \sum_{i=0}^{N-1} v_{di} \cdot v_{si} = \sum_{i=0}^{N-1} (pv_{si} - v_{ri})v_{si} \qquad p = n \;\; for \;\; M_2 \le \varepsilon_b \tag{2}$$

In the above relations, v_{di}, v_{ri} and v_{si} are the values of the i-th sample of the corresponding voltage and N is the total number of samples acquired.

If the impedance character is capacitive, the first quasi-balance is obtained when the voltage $\underline{V}_d$ is in quadrature with the voltage drop across the unknown impedance, $\underline{V}_x$ whereas the second one is obtained in the same manner as in inductive case. The only parameter that is different in this case is:

$$M_{1C} = \sum_{i=0}^{N-1} v_{di} v_{xi} = \sum_{i=0}^{N-1} (pv_{si} - v_{ri})(v_{si} - v_{ri}) \qquad p = m \;\; for \;\; M_{1L} \le \varepsilon_b \tag{3}$$

After which the two quasi-balances are performed, the unknown impedance components are evaluated using the two particular values of p and the known value of the reference resistor, R.

According to the above algorithm, the following sets of relations result for each kind if impedance [9]:

$$\omega L_x = R\frac{\sqrt{m-n}}{m\sqrt{n}}\;; \quad R_{Lx} = R\frac{1-m}{m}\;; \quad Q = \sqrt{\frac{m-n}{n}}\frac{1}{1-m} \tag{4}$$

for an inductor, and

$$\omega C_x = \frac{1}{R}\sqrt{\frac{n-m}{1-n}}\frac{1}{1-m}\;; \quad G_{Cx} = \frac{1}{R}\frac{m}{1-m}\;; \quad \tan\delta = m\sqrt{\frac{1-n}{n-m}} \tag{5}$$

for a capacitor.

The above equations were deduced considering the series equivalent schema for the inductor and the parallel equivalent schema for the capacitor. Hence, good quality components are considered.

III. The virtual instrument

The signal generator employed, Tektronix AFG310, supplies the series circuit formed by the unknown impedance, Z_x, and the precision resistor R, with an accurate sinusoidal waveform. The voltage supplied, V_s along with the voltage drop across the resistor, V_r, are acquired using the two analogue channels of a simultaneous sampling DAQB type PCI6111 manufactured by National Instruments. The maximum sampling frequency allowed is 5 MHz. The software part of the virtual instrument is entirely built in the graphical programming environment, LabVIEW 6.1. The operations performed by this instrument are: i) driving the acquisition process of the voltages V_s and V_r on the simultaneous sampling analogue channels of the DAQB, ii) performing the two quasi-balances of the bridge in order to obtain the values of m and n with the imposed error, iii) calculating and displaying the inductor and capacitor parameters in Cartesian and polar coordinates and iv) saving the information at request. The algorithm of the quasi-balancing process is illustrated on the flow chart in figure 2.

The acquisition of the two voltages, V_s and V_r, is made by their simultaneous sampling on exactly one period, by setting the number of samples/period on the front panel of the instrument. The acquisition is triggered so that each time it begins with approximately the same sample value. For every measurement one takes 50 sequences after which they are averaged for reducing the inherent noise. Once obtained the $\{v_{si}\}$ and $\{v_{ri}\}$ sequences, one determines the impedance nature by calculating the dot product of the Hilbert transform of V_s and V_r. Positive value of this quantity means inductive nature of impedance, whilst negative value signify its capacitive nature. Independently of the impedance nature, the 2nd quasi-balance is then performed, after which the n parameter is obtained. In parallel the 1st quasi-balance is also realised, which depends on the quantities M_{1L} or M_{1C}. m is obtained as a result of this action. Finally, L_x, R_x and Q or C_x, G_x and tanδ are computed.

In figures 3 and 4, the front panel and the diagram of the virtual instrument are presented. One can set from the front panel the acquisition parameters like signal frequency and number of samples per period, from which the sampling frequency is automatically computed. One can also fix the value of the reference resistor that was previously precisely measured using a 4-wires bridge or the value of the standard resistor utilised as reference. The value of the balancing precision, ε_b, might be also established on the front panel. The instrument automatically realises the two quasi-balances as well all the computations for finding the final values of the measured impedance. The values of m and n are also displayed.

The instrument allows saving information when desired. One saves the values of L_x or C_x, the losses, the corresponding impedance and the value of frequency at which the impedance was measured.

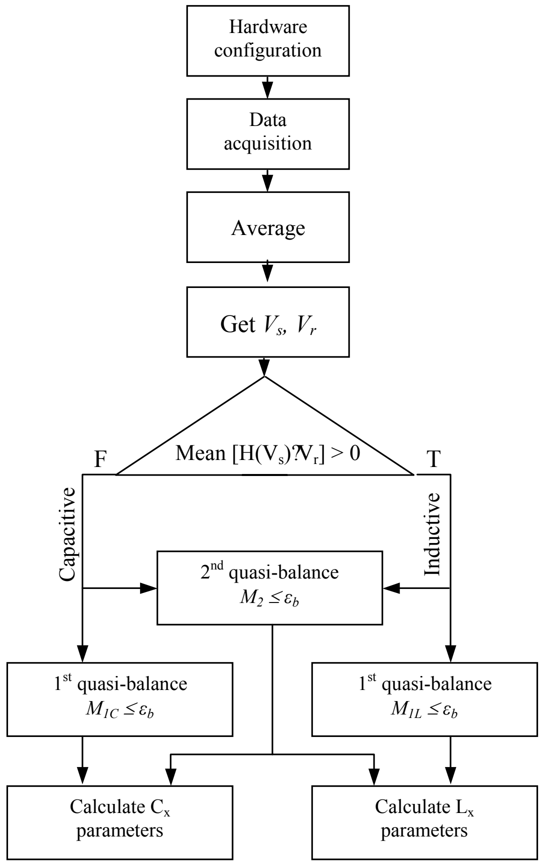

Fig. 2. Flow chart of the quasi-balancing process

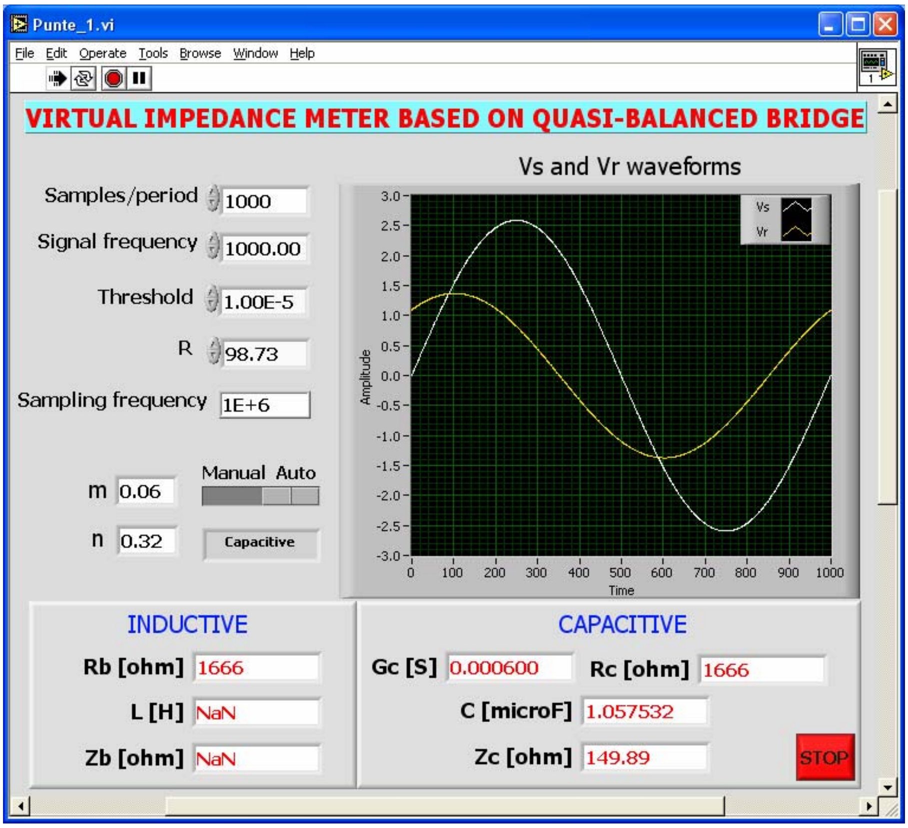

Fig. 3. Front panel of the virtual instrument

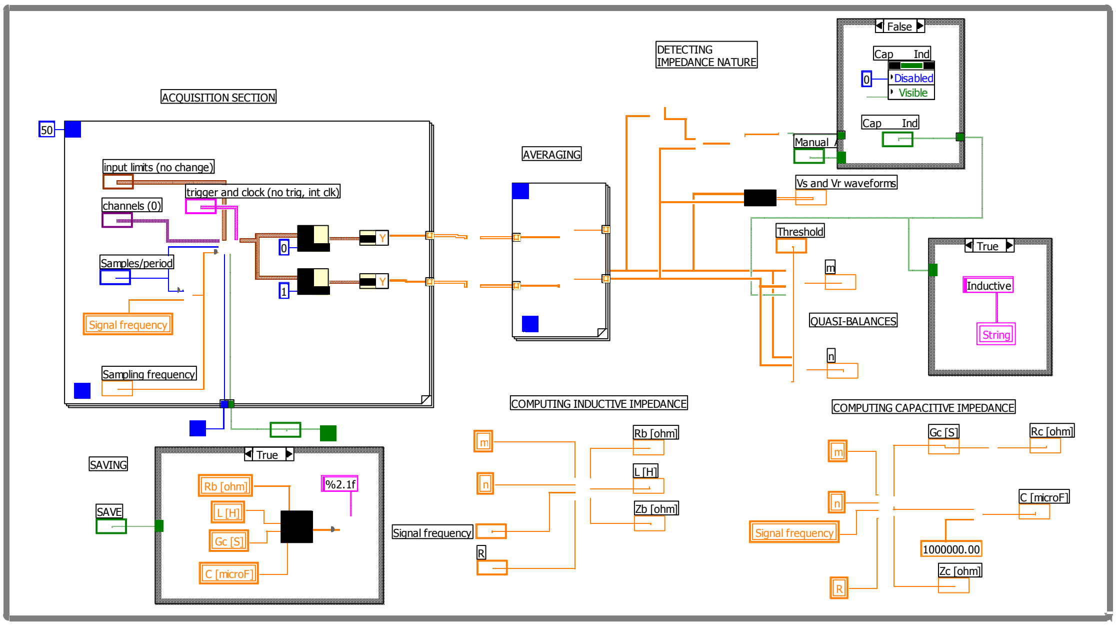

Fig. 4. Diagram of the virtual instrument

IV. Results and errors

Starting from the relation sets (4) and (5) and applying the maximal error propagation law, one obtains the limit error for inductive impedances as:

$$\left|\varepsilon_{L_x}\right| = \left|\varepsilon_R\right| + \left|\varepsilon_f\right| + \left|\frac{(2n-m)}{2(m-n)}\varepsilon_m\right| + \left|\frac{m}{2(m-n)}\varepsilon_n\right| \tag{6}$$

and for capacitive ones as:

$$\left|\varepsilon_{C_x}\right| = \left|\varepsilon_R\right| + \left|\varepsilon_f\right| + \left|\frac{m(2n-m-1)}{2(n-m)(1-m)}\varepsilon_m\right| + \left|\frac{n(1-m)}{2(n-m)(1-n)}\varepsilon_n\right| \tag{7}$$

where $|\varepsilon_R|$ is the relative error of the reference resistor R (less than 0.1 %), $|\varepsilon_f|$ is the signal generator error for frequency (less than 50 ppm), ε_m and ε_n are the quasi-balancing errors when finding m and n (less than ε_b).

First, we observe that the overall errors does not depend on the acquisition parameters, nor on the quality of signal acquisition. The only condition is to simultaneously sampling the two quantities, V_s and V_r. In the case of inductive impedances, the errors are minimal when $R = |Z_x|$ and the inductance has a high quality factor. In this case, $n = 0.5$, whereas $m \to 1$ and thus $2n - m \to 0$ whilst $n - m$ is not very small. For example, for $Q = 5$, $m = 0.84$, and for $Q = 10$, $m = 0.91$.

Conversely, for capacitive impedances, when high quality capacitors are measured, $n = 0.5$ and $m \to 0$. However, increasing capacitance's losses does not affect too much the error since increasing tgδ, m does not increase very much (e.g., for tg$\delta = 0.1$, $m = 0.09$).

Regarding the error of loss resistance measurements, in both cases the relation is:

$$\left|\varepsilon_{R_x}\right| = \left|\varepsilon_R\right| + \left|\frac{1}{1-m}\varepsilon_m\right| \tag{8}$$

As can be observed, for minimising this error, m must be as close to 0 as possible, which corresponds to precise measurements of condensers and bad measurements of inductors. Accordingly, a trade-off between precise measurements of inductance value and its losses has to be made, whereas the capacitors are very accurately measured both for active and reactive parts.

A large amount of experimental measurements was performed for inductors varying in the span of 0.1 mH to 500 mH and for capacitors from 0.1 nF to 10 μF, in order to prove the theoretical suppositions. The system performances were assessed by using precise inductors and capacitors of 0,1

% accuracy as etalons. Some of these results are displayed in Tables 1 and 2. These values were obtained with 500 samples/per.

Table 1

	1 kHz		5 kHz	
L_e [mH]	L_x [mH]	error [mH]	L_x [mH]	error [mH]
10	10.022	0.022	10.034	0.034
20	20.041	0.041	20.065	0.065
40	40.084	0.084	40.094	0.094
60	60.116	0.116	60.121	0.121
80	80.126	0.126	80.135	0.135
100	100.125	0.125	100.140	0.140

Table 2

	1 kHz		5 kHz	
C_e [nF]	C_x [nF]	error [nF]	C_x [nF]	error [nF]
0.1	0.10021	0.00021	0.10035	0.00035
1	1.0018	0.0018	1.0027	0.0027
10	10.022	0.022	10.03	0.03
100	100.185	0.185	100.261	0.261
1000	1001.255	1.255	1001.324	1.324

As can be observed, in both cases the total error does not exceed 0.22 % at 1 kHz and 0.34 % at 5 kHz. For the rest of measurements carried out, the errors did not exceed 0.5 %.

The experiments were also realised for different numbers of samples per period (s/per), from 50 s/per to 5000 s/per. We have found that, between 50 s/per and 200 s/per and for 5 kHz signal frequency, the errors decreased non-linearly from 0.5% to 0.25 % and remained approximately constant up to 5 ks/per.

V. Conclusions

A virtual instrument designed for impedances measurements based on a quasi-balanced bridge method has been described in the paper. It might be a very good alternative to the commercial RLC bridges and even for impedance analysers, since its functionality can be extended to frequency spanning. Its best behaviour is with any kind of capacitors, when accurately measurements can be done both for capacitance and losses measurements. For inductors, one has to make a trade-off between the accuracy of inductance measurement and the loss resistance. Using a DAQB of 5 Msamples/s with simultaneous channel sampling, one can measure impedances in the frequency range of 10 Hz to 100 kHz, the errors not exceeding 0.5 %.

Acknowledgments

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