

PC Based RLC Meter

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Abstract –This paper presents method that convert resistance, capacitance or inductance values into corresponding time intervals - frequency. Virtual RLC meter, based on a PC with a DAQ and external relaxation oscillator is used for measurements. The fair accuracy of the Virtual RLC meter is verified by experimental results for resistance and capacitance measurements.

Keywords – Virtual RLC meter, DAQ, relaxation oscillator

I. INTRODUCTION

Most of the methods and techniques for measuring resistance, capacitance and inductance are very complicated. RLC meters are specialized laboratory equipment, dedicated in measuring the component's resistance, inductance and capacitance, and are typically expensive. In recent years is used one popular method that converts resistance, capacitance or inductance into corresponding voltage, time intervals or frequency. Two basic techniques for R, L and C measurement are called "Step response" and "Frequency domain" methods. Both methods are based on a resistor – capacitor circuit and a resistor – inductor circuit.

By using a PC with a DAQ board, and developing an interface with relatively reduced complexity, we were able to build a medium performance RLC meter at an exceptionally reduced cost.

This paper describes how we developed a Virtual RLC meter, based on a PC with a DAQ board (National Instruments PCI 6221) and an external relaxation oscillator, using Lab VIEW as the development software, and our results and conclusions are presented.

II. STEP RESPONSE

The RC circuit and the RL circuit have some very similar properties that can be used to determine the value of either the inductor or capacitor in the circuit. If the input (U_i) of the circuit is abruptly stepped from 0 volts to some positive value, the output voltage (U_0) rises in an exponential manner (Fig. 1).

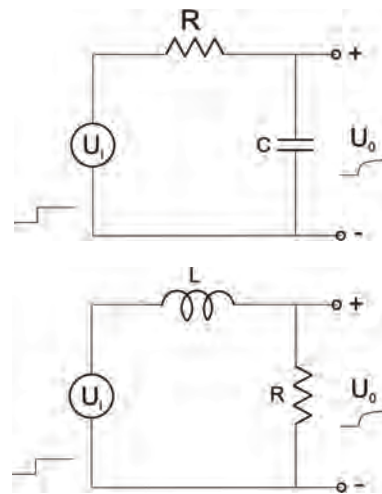


Fig. 1. RC and RL circuits

These circuits can be used to determine C and L values by measuring the time constant of the circuit.

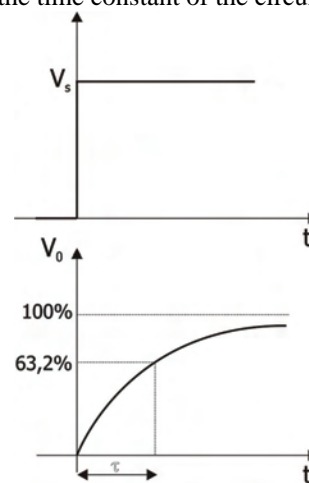


Fig. 2. The step response input (U_i) and output (U_0) waveforms for the RC and RL circuits shown in Fig. 1.

The output voltage that results from a voltage step at the input is called the step response. The mathematical expression for the step response of the circuit shown is

$$U_0(t) = U_i(1 - e^{-t/\tau}), \quad t \geq 0 \quad (1)$$

In one time constant, the step response reaches 63,2% of its final value.

$$U_0(\tau) = U_i(1 - e^{-1}) = 0,632 \cdot U_i \quad (2)$$

The time constant can be computed from the circuit values.

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$$\begin{aligned}\tau &= RC && \text{for the RC circuit} \\ \tau &= L/R && \text{for the RL circuit}\end{aligned}$$

An unknown capacitor or inductor whose value is to be determined can be connected to a known resistor in the appropriate circuit. The time constant of the circuit can be measured and the unknown component value computed.

$$\begin{aligned}C &= \tau / R && \text{for the RC circuit} \\ L &= \tau \cdot R && \text{for the RL circuit}\end{aligned}$$

III. SINUSOIDAL RESPONSE

These same circuits, with voltage sine wave as excitation, can be used in the frequency domain to measure the value of a capacitor or inductor (Fig. 3). The frequency response of these two circuits is the same.

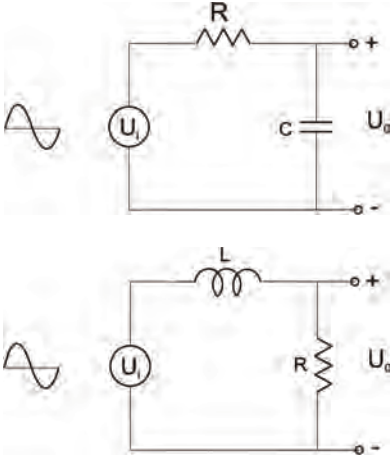


Fig. 3. The frequency response of the RC and RL circuits can be used to measure a capacitor or inductor

Low frequency signal are passed from the input to the output with a little or no attenuation, while high- frequency signals are attenuated significantly, resulting in a low – pass filter. The point at which the response is under 3dB is used to define the filter bandwidth. A loss of 3dB corresponds to a reduction in output voltage to 70,7% of the original value (Fig.4).

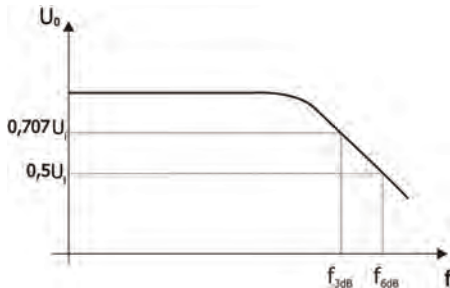


Fig. 4. The frequency response of the RC and RL circuits

$$f_{3dB} = \frac{1}{2\pi\tau} \quad (3)$$

Where τ is the time constant of the circuit.

A 6-dB reduction in voltage corresponds to a 50% reduction in voltage.

$$f_{6dB} = \frac{\sqrt{3}}{2\pi\tau} \quad (4)$$

The 3dB or 6dB frequency can usually be determined from the frequency control of the source, or for more accuracy, a frequency counter can be used to measure the source frequency. After the f_{3dB} or f_{6dB} frequency is measured, the value of the capacitance or inductance is calculated.

IV. RELAXATION OSCILLATOR

A relaxation oscillator is an oscillator in which a capacitor is charged gradually and then discharged rapidly. Relaxation oscillator is a circuit that repeatedly alternates between two states with a period that depends on the charging of a capacitor. The capacitor voltage may change exponentially when charged or discharged through a resistor from a constant voltage. With exponential charging, the timing is expressed in terms of time constants RC. In a basic circuit, the capacitor will charge with time constant τ_1 from a starting voltage U_1 towards a supply voltage U_u for a time t_1 . When it reaches some voltage U_2 , it will then discharge with time constant τ_2 towards a lower voltage U_d for a time t_2 , when the cycle will repeat. The period of the oscillator is $T = t_1 + t_2$, and its frequency $f = 1/T$. In terms of these parameters,

$$t_1 = \tau_1 \ln[(U_2 - U_1)/(U_u - U_2)] \quad (5)$$

$$t_2 = \tau_2 \ln[(U_2 - U_d)/(U_1 - U_d)]. \quad (6)$$

A classic op-amp relaxation oscillator is shown on Fig. 5. The noninverting input is biased at $\lambda \cdot U_0$, where U_0 is the output voltage. The inverting input chases this value and when it reaches it, the output voltage changes from one saturation level to the opposite one from $+V_{cc}$ to $-V_{cc}$.

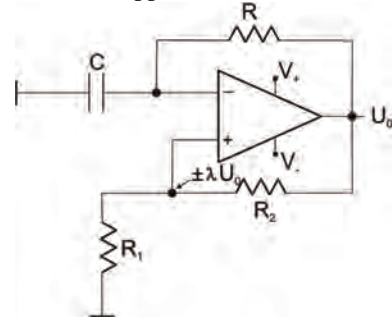


Fig. 5. Relaxation oscillator

This square wave generator is like the Schmitt trigger circuit where the reference voltage for the comparator action depends on the output voltage.

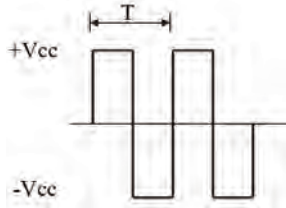


Fig. 6. Square waveform

$$T = 2RC \ln \left[\frac{1 + \lambda}{1 - \lambda} \right], \quad \lambda = \frac{R_1}{R_1 + R_2}$$

$$\text{If } R_1 = R_2 \Rightarrow \lambda = 1/2$$

$$f_{out} = \frac{1}{kRC} \quad (7)$$

The output voltage is a square wave (Fig.6), with a frequency of $f_{out} = 1/1.22RC$, and duty cycle of 50% if the saturation levels are symmetrical. Using expressions for R-L circuit it is possible to achieve that if R is replaced by L and C by R the output frequency will be:

$$f_{out} = \frac{R}{kL} \quad (8)$$

For measurement of R, C or L the unknown component is connected in an R-C or R-L circuit as appropriate. For example for measurement of C, the resistor is known or can be accurately measured and vice versa.

V. HARDWARE AND SOFTWARE REALIZATION

The designed virtual RLC meter consists of the following blocks: the relaxation oscillator, switching block, data acquisition system, personal computer and Labview software.

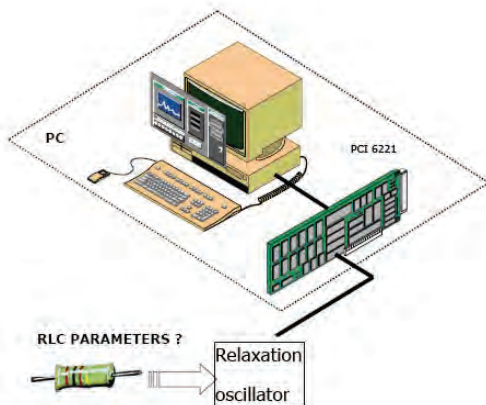


Fig. 7. The block diagram of virtual RLC meter

The designed virtual RLC meter has three operation modes for R, L and C measurement respectively. The oscillator circuit consists of a comparator with a positive feedback loop, which converts the time – varying signal into a square wave with a varying time period. This signal can be counted and digitized into a value that is proportional to the oscillator frequency and in turn proportional to R, C or L measured.

The software of the RLC meter was entirely developed using Lab VIEW. Programming an application in Lab VIEW is very different from programming in a text based language such as C or Basic. Lab VIEW uses graphical symbols (icons) to describe programming actions. Data flow is “wire” into a *block diagram*. This software provides an extensive library of functions and tools for data analysis, report generation, data acquisition and file input/output.

The choice of this development software was mainly due to its easy-of-use in communicating with the DAQ board for data generation and acquisition, and the extreme simplification in the processing and visualization of the data.

The created programming code made in Lab VIEW is shown on the Fig. 8.

For frequency measurement is used one counter on a Counter Input Channel. The edge, minimum value and maximum value are all configurable (Fig.9).

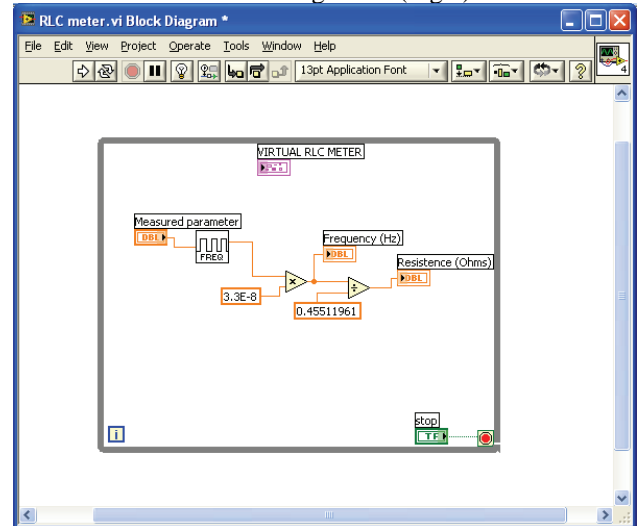


Fig. 8. The block diagram of the frequency measurement

The measurement edge is used to specify the edge on which the counter has started measuring.

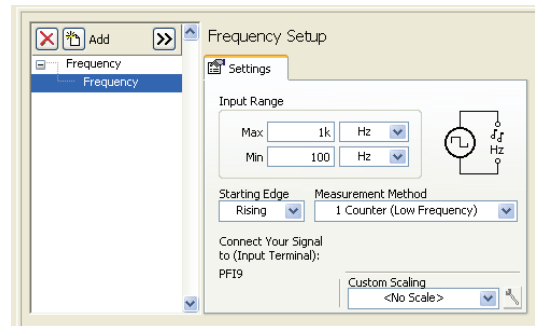


Fig. 9. Frequency setup

The starting edge parameter is used to determine if the counter will begin measuring on a rising or falling edge. It is important to set the maximum and minimum frequency values as accurately as possible so the best internal timebase can be chosen to minimize measurement error. The default values specify a range that can be measured by the counter using the 20 MHz Timebase.

The user interface of the created virtual system is shown on Fig. 10.

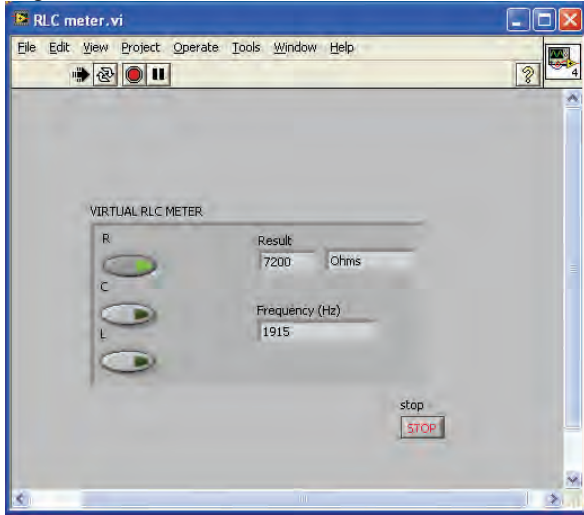


Fig. 10. The block diagram of the frequency measurement

The front panel consists of basic parts. The first one is placed in the left corner and is related to the selection of measurement parameter. In the example shown above, the button that is switch on means that the measurement parameter is resistance. The numeric indicators show the measured value and the current frequency.

VI. EXPERIMENTAL RESULTS

In order to define the measurement accuracy of the realized virtual system a set of arbitrary selected resistors and capacitors are measured. The measured results are summarized into Table I (for resistance), Table II (for capacitance).

	$R_{ref}(\Omega)$	$R_{cal}(\Omega)$	$C_{ref}(nF)$	$(\delta_1\%)$	$(\delta_2\%)$
1	1M	1,23M	0,133	22,87	12
2	47k	40k	10	0,6	-14,8
3	33k	35,3k	10	1	2,7
4	22k	20,7k	10	1,8	-6
5	10k	10,4k	10	4	-2
6	4,7k	5,36k	10	14,28	10
7	2,2k	2,45k	100	4,54	9
8	1k	1,084	100	12,5	8,4
9	680	765	100	17,6	12,5
10	470	604,2	100	28,78	15

Table I Resistor measurement results

	$C_{ref}(F)$	$C_{cal}(F)$	$R_{ref}(k\Omega)$	$(\delta_1\%)$	$(\delta_2\%)$
1	680p	660p	105	10	-11,7
2	1n	1,067n	105	6,7	-5
3	3,3n	3,35n	105	1,5	-4
4	6,8n	7,1n	10	4,4	1,5
5	10n	10,3n	10	3	-2
6	22n	22,7n	10	3,2	-4,5
7	33n	33,9n	10	2,7	-6
8	100n	112n	1	12	8
9	470n	530n	1	12,7	-1
10	1 μ	1,3 μ	0,1	30	-8

Table II Capacitor measurement results

The calculated errors are shown in the Tables I and II. The first error δ_1 is calculated using the operational amplifier TL, while δ_2 is calculated by using higher performance comparator OP27. As it can be seen errors can be lower using OP27.

VII. CONCLUSION

In this paper, a design and development of virtual RLC meter is presented using a low-cost general-purpose DAQ board from National Instruments (PCI 6221, 16 bit, 250kSamples/s) and simple external hardware.

This approach offers a simple solution for an application that needs the low cost measurement of resistors, capacitors and inductors. The realized virtual system can be used to any applications where frequency-time parameters have to be measured with highest resolution and programmable accuracy.

Using a relaxation oscillator with higher performance comparator would significantly improve the performance and precision of this RLC meter.

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