Impedance Measurement Basics

I. Measurement of component impedance

The passive components we usually use or produce (including inductance, capacitance, resistance) are marked with some values. And component's vale (nominal value) is sure, so, in fact, the component is measured in the following three factors:

1. Component produced by factory is marked with some error, so it needs measuring to get the accurate value to know whether the component meets the error requirement.
2. Component is produced under some special condition (including test frequency, test level, bias level, etc.), which is different with operating condition. So component's parameter situation in practical operating condition should be known.
3. In fact, there aren't ideally pure inductors, resistors and capacitors. All components aren't ideal devices, having parasitic parameters. Therefore, component's parasitics should be measured. It's very important for component's correct application.

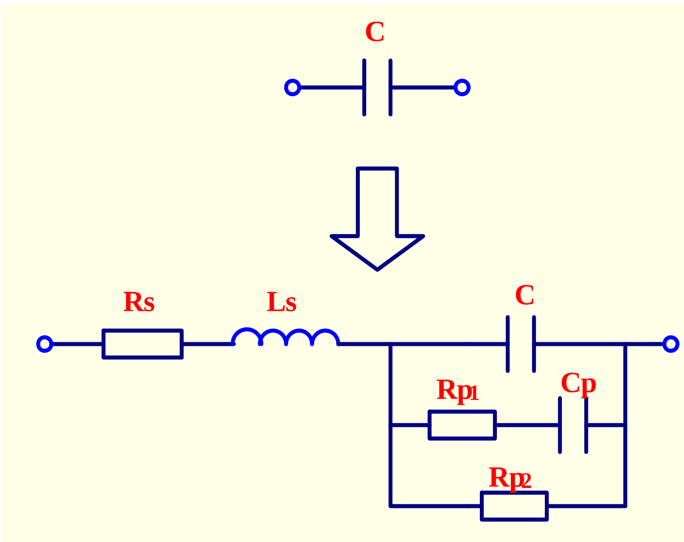
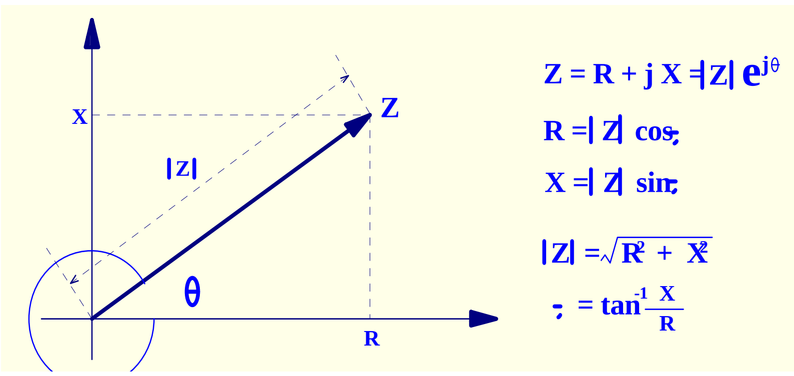


Figure 1 Distribution of real-world capacitor's parasitic parameters

Take capacitor C as example (in Figure 1). Parasitic parameters include lead resistance R_S and inductance L_S, material's insulation resistance R_{P2}, distributed capacitance at two terminals of capacitor C_P and resistance R_{P1}. Some of them can be neglected under operating condition, but some of them can't.

For example in the above capacitor, when capacitance C is big, lead resistance R_S is the main heating component. If the value is too big, the serious result of exploding to split will happen at big current with high frequency.



Impedance Z (referring to Impedance Measurement Basics) is defined as the total opposition a device or circuit offers to the flow of an Figure 2 Impedance's vector expression and conversion alternating current (AC) at a given frequency. It is represented as vector on complex quantity plane, or reciprocal of impedance, admittance Y (Y=1/Z), as shown in Figure 2.

Component's impedance is a complicated quantity, and it's dependent on signal frequency and voltage on it. LCR meter not only measures inductance L, capacitance C, and resistance R, but describes component's parameters: impedance Z, reactance X, admittance Y, conductance G, susceptance B, dissipation D, quality factor Q, and phase angle θ.

The instrument doesn't directly measure some single parameter, but complex impedance. Then needed measurement parameters will be converted according to relationship between each other.

II. Brief Introduction of Impedance Measurement Methods

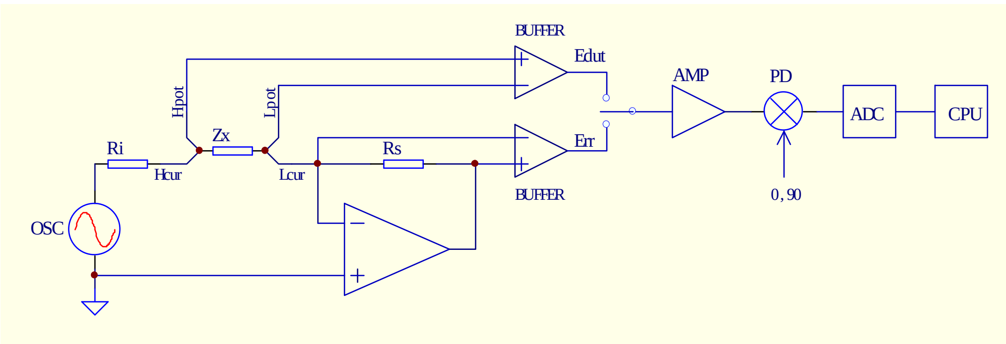


Figure 3 Low-frequency impedance measurement

Impedance measurement process can be understood in a rough through Figure 3. OSC is pure sine signal source with definite signal source and level. The signal source is energized on the DUT Zx through singal source resistance; Hpot and Lpot samplings are energized on the DUT's voltage Edut; Hcur is singal source output terminal; Lcur is current dectection terminal. Current Ix flowing though the DUT is transferred to voltage Err through Lcur, I-V convertor and standard resistance Rs. Edut and Err are sent to CPU through convertor ADC of PD and AD. And needed impedance parameters are respectively calculated.

Impedance measurement is a vector test process.

Impedance Zx consists of a real part Rx and an imaginary part Xx: $Zx = Rx + jXx$ ---- ---- (1)

And accoring to Ohm's law, $Zx = \frac{Edut}{Ix}$ -- (2)

I-V convertor can be described as $Err = - Ix \times Rs$, then $Ix = -\frac{Err}{Rs}$ -------------------------- (3)

From equations (3) and (2), $Zx = -\frac{Edut}{Err} \times Rs$ --- (4)

Here, Err and Edut are both vectors.

Suppose $Edut = V0 + jV1$, $Err = V2 + jV3$ -- (5)

From euqations (5) and (4), $Zx = -\frac{V0V2 + V1V3}{V2^2 + V3^2}R_s + j\frac{V0V3 - V1V2}{V2^2 + V3^2}R_s$ ---------------- (6)

Compare equations (6) and (1),

$$R_x = -\frac{V0V2 + V1V3}{V2^2 + V3^2}R_s \text{ -- (7)}$$

$$X_x = \frac{V0V3 - V1V2}{V2^2 + V3^2}R_s \text{ -- (8)}$$

Equations (7) and (8) are needed impedance parameters.

Instruments have different configurations to measure circuit. I-V convertor, consisting of complicated null detector, phase dector, integrator and vector modulator, is used in wide-bandwidth and precision LCR meter and impedance analyzer to ensure high accuracy at wide frequency range.

III. Dependencies of component value and special factors

Generally, every LCR meter gives special measurement conditions, such as measurement frequency, signal level, DC bias, etc. These conditions regulate the instrument's application range. Because component under test has different characteristics under different operating conditions, it's very important to correctly realize mutual orderliness between component and operating conditions, and relativity is important. The instrument's measurement condition should reflect component's operating condition as factually as possible.

1. Test signal frequency dependency

All the components are related to signal frequency. Its change is dependent on component's parasitic parameters. Series and parallel equivalent modes are only considered at the time of operating instrument, but the real component equivalent mode is much more complicated than them. Figure 3 approximately shows frequency response of resistors, inductors, and capacitors of some type.

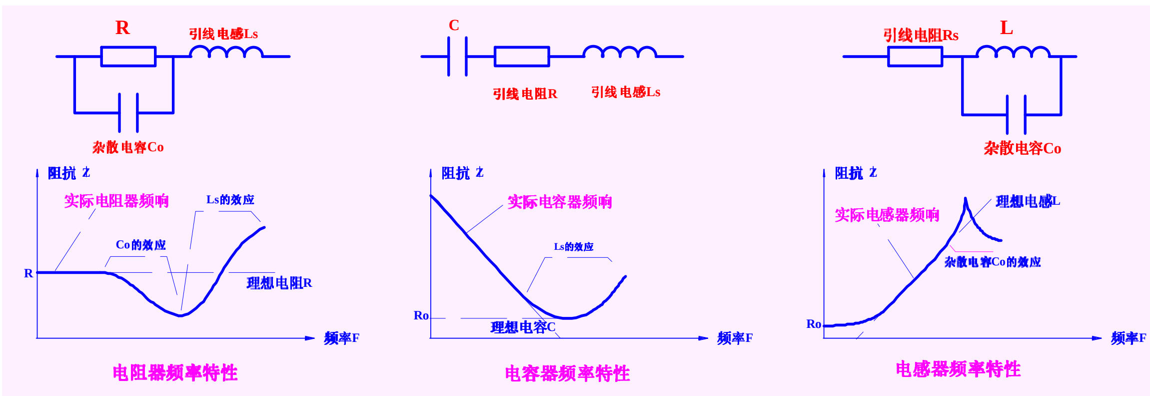


Figure 3 L, C, R components' frequency characteristics

2. Test Signal Level Dependency

All the components are related to signal level. Component's value varies depending on signal level at set frequency. Some components values are not sensitive to signal level, but some are, such as high-K (high dielectric constant) ceramic capacitor, high-magnetoconductivity inductor, etc. Therefore, it's very important to regulate test signal level (voltage or current) for component of this type, as shown in Figure 4.

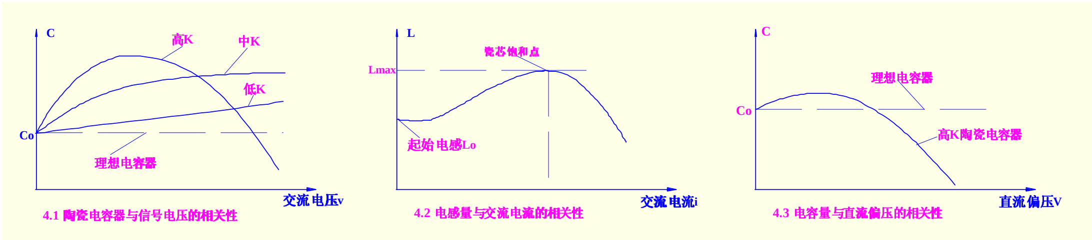


Figure 4 Dependencies of component and signal level

3. DC bias dependency

Components are related to DC bias voltage or current on them. It's very common to add AC and DC signals to use, such as tied capacitance of diodes and transistors, high-K ceramic capacitors, electrolytic capacitors, cored-inductors or transformers, etc. In the case of cored-inductors or transformers, the parameter varies according to the DC voltage or current flowing through the coil. Figure 4.3 shows change of high-K ceramic capacitors energized on DC bias voltage.

4. Other Factor's Dependency

Component parameters are mainly above conditions dependent. But other physical and electrical environments, e.g., time, temperature, humidity, pressure and magnetic fields may change the impedance value.

Therefore, not only needed measurement parameters are considered, but also the operating conditions. Sometimes wrong result will be had just because inappropriate measurement condition is selected.

IV. Selecting the Best LCR Meter

1. Purposes of selecting LCR meter

Generally, LCR meter is used for three purposes:

A) Accurately evaluate component's performance, and ensure that component meets requirement under operating condition. It's necessary for instrument to provide high accuracy and powerful functions to correctly evaluate relativity of component and many conditions, such as R & D of new component, inspection, etc.

B) Fast inspection on production line or incoming inspection, which needs particular measurement conditions. For example, fast sorting to improve efficiency, particular frequency, level and other needed functions, etc.

C) Estimate the component's performance in a rough. The requirement is less than that of B. It only needs to know component's general performance, without fast sorting.

Tonghui divides LCR meters basically according to the three requirements.

2. Several aspects of selecting LCR meter

A）Measurement accuracy

Measurement accuracy is one of the main specifications that show instrument's performance. It's key for component's accurate evaluation to exactly know instrument's accuracy. In general, instrument's accuracy should be 3 to 5 times as high as component's specifications. What's more important, the highest accuracy at some condition is usually given in sample or some introduction materials, which confuses customers. It should be known whether impedance the component under test shows at measurement frequency and instrument's accuracy at corresponding measurement condition meet the measurement requirement.

It's very important to adequately comprehend instrument's measurement accuracy. What's more, accuracy has close relationship with given test conditions, such as level, speed, temperature, etc.

We'll take TH2818 and TH2828 as examples to show that even the given basic accuracies on samples are the same, there is big difference actually.

TH2818: frequency 20Hz – 300kHz, basic accuracy: 0.05%

TH2828: frequency 20Hz – 1MHz, basic accuracy: 0.05%

Suppose the instruments test capacitors of 100pF, 10nF at the condition of slow speed, 1Vrms level and 20°C, measurement accuracies at different frequencies are evaluated, shown in Table 1.

Table 1 Typical frequency accuracy comparison

Capacity	model	100Hz	1kHz	10kHz	40KHz	100kHz	200kHz	300kHz	500kHz	1MHz
100pF	TH2818	4.06	0.59	0.13	0.11	0.10	0.25	0.65	------	------
	TH2828	0.3	0.15	0.05	0.05	0.05	0.05	0.05	0.10	0.10
10nF	TH2818	0.08	0.05	0.05	0.10	0.10	0.25	0.65	------	------
	TH2828	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.10

Table 1 shows instruments with the same basic accuracy have different accuracies while measuring devices under test with different values at different frequencies.

B）Test signal frequency and level

Being the principal parameters that are needed to perform component measurement, and the most important contents to reflect relativity of component's elements, test frequency and level are very important to correctly select LCR meter.

C） Instrument accessories & options

Standard configuration of instrument accessories is given when Tonghui instruments leaves factory. Sometimes components under test have different shapes and sizes with those of standard configuration. So it's necessary to select test fixture that meets requirement or make test fixture by ourselves. Reasonable and suitable test fixture can ensure accurate component measurement to be performed.

D） Instrument's price

Before purchasing instrument, you should make a budget of the instrument which has the performance and functions you need. In general, the instrument's price is dependent on its main factors, such as frequency, accuracy, performance, etc.

Through many years' effort, Tonghui's low-frequency (≤2MHZ) LCR meter has modern technique and it can replace advanced products abroad which are expensive as 2 to 6 times as homemade instruments.

So we suggest that you should choose famous homemade instruments with advanced performance, strong technical guarantee, and good reputation and service.

V. Other Functions of LCR Meter

Generally, LCR meter still has other functions. Especially with fast development of measurement technology and micro processing technology, various new performances and functions are developed. It will have better effect to use these functions correctly and neatly.

1. Open and short correction

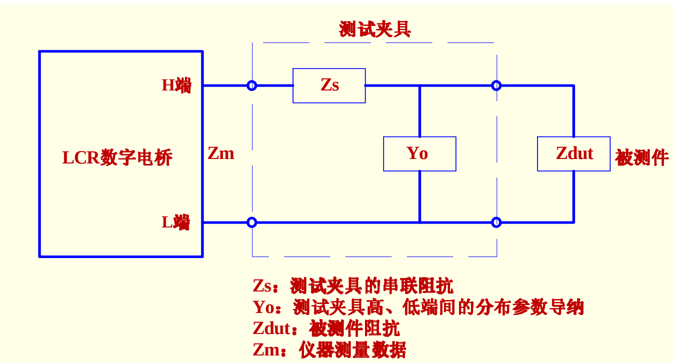


Figure 5 Equivalent figure of test terminal

As we describe in Section III, component's distributed parameter must be considered when component is measured, and test fixture also has many distributed parameters. These parameters will affect measurement accuracy. Open/short correction can solve the problem. Consider test fixture's distributed parameters as a linear network, and its existing distributed parameters synthetically as concentrative parameter analysis. They are: a) parameters brought about by test lead, which should be corrected using short correction; b) distributed parameters between test terminals, which should be corrected using open

D) Load calibration

Being an advanced calibration method, load calibration can make instrument measure component at the higher accuracy than instrument's original one. It is mainly used in the following two situations:

a) There's component with higher accuracy and the component with the same specifications needs to be performed higher-accuracy measurement.

b) Unify all the measurement data of LCR meters on spot.

3. Test signal monitoring

As we have discussed in III.2, level energized on the device under test is very important. Level (voltage or current) actually energized on the DUT is related to instrument's signal source impedance. So the actual level is different if signal source impedance is, even with the same level. Tonghui has many kinds of products which have the function of monitoring the DUT's current and voltage.

4. Auto level control

According to III.2, it's very important to keep on energizing constant test signal level (voltage or current) on some components which have strong relativity with signal level. TH2818, TH2819, and TH2828/A/S have the function of auto level control which is very useful to measure components with strong relativity.

5. Signal source output impedances

Traditional LCR meter's signal source impedance differs with range. So actual level changes a lot when different components are measured, which is not reasonable for some component's measurement. International advanced and approbatory output impedance method is 100Ω, such as Agilent4284A, Agilent4980A, Agilent4263B, etc. Considering the consistency with traditional instruments, most of Tonghui products provide keyboards through which user can select output impedance.

6. List sweep

Since component is related to frequency, level, DC bias voltage, and DC bias current, Tonghui has some kinds of instruments performing list sweep for the above parameters (referring to Tonghui LCR Meters Guide). The instrument scans many frequency points (or level, bias voltage, bias current) to measure, displays measurement value at the same time, and compares and judges measurement values. List sweep of bias current should be performed with the cooperation of Tonghui's inductance bias current source.

7. Test terminal configuration

Traditional LCR meter provides 5-terminal configuration, which efficiently solves lead resistance's effect on measurement result and distributed capacitance between test terminals and ground. However, impedance measurement low-limit of 5-terminal configuration is 10mΩ, and mutual electromagnetism coupling between test cables can't be solved. Measurement result will differ with move of test lead when Kelvin test cable is used at the time of low-impedance measurement. TH2828/A/S's 4-terminal pair configuration not only has the impedance measurement low-limit of 1mΩ, but also efficiently solves the effect of electromagnetism coupling between test cables. Refer to Terminal-connection Used for Component Measurement.

8. Component's graphics analysis ability

TH2818/TH2828S provides some analysis functions, such as frequency response analysis, AC voltage characteristics analysis, DC bias voltage/current characteristics analysis, etc.

Based on frequency resolution of 10mHz/1mHz, TH2818/TH2828S automatic component analyzer provides strong function of component frequency response analysis. The instrument can perform frequency response analysis of primary and secondary parameters at random frequency range, and display in graphics mode, which is significant for component's R&D and performance evaluation, especially for piezoelectricity component's analysis. Refer to the article of Perfect Solutions of Piezoelectric Component Measurement.

9. Measurement range, Max. display range, Display digits

It's very difficult to accurately describe some parameter's measurement range in technical manual or product sample of component test instrument with multi measurement frequencies and parameters. Instrument's measurement range is mainly dependent on the following factors:

a) resistance of the device under test, the main reason affecting measurement range;

b) actual measured level;

c) resolution of A/D converter. Acceleration of instrument must decrease resolution, which will affect measurement range;

d) electromagnetism disturb, temperature, humidity.

In these situations, the measurement range in specifications isn't applicable in all conditions, and sometimes it's expressed as max. display range. And measurement range and max. display range are different. Display digit shows instrument's ability of providing stable readings.

So it's nonsensical at all to be of multi digits but with unstable reading.

10. Transform measurement function

Transformer is an electronic component with multi parameters, including primary/secondary inductance, mutual inductance, leakage inductance, turns ratio, primary/secondary capacitance, DC resistance, and etc. Tonghui has many kinds of LCR meters providing transformer measurement function, and, as particular automatic transformer test system, TH2818XA/XB/XC provides complete solution of transformer measurement.

11. Interface function

Instrument's interface has its important function. Generally interface is divided into two kinds:

a) Communication interface

There are mainly two kinds: IEEE-488 general-purpose parallel interface and RS-232C general-purpose serial interface. Currently LAN communication interface and USB communication interface have become new selection of instrument's communication capability. Tonghui's products don't have the two capabilities now.

Communication interface helps to realize data exchange, instrument's remote control, auto measurement system's composing, and measurement data's statistics and analysis. Tonghui can provide computer operation control interface targeting communication interface and also develop customized statistics and analysis software.

b) Sorting interface, also called HANDLER interface

HANDLER interface can make instrument and component's mechanical process system cooperate to be used, such as component's automatic sorting system. HANDLER interface should have result output port which had better be isolated with instrument's electric circuit and contacting signal which includes START signal, EOC signal, BUSY signal. HANDLER interface without contacting signal isn't a perfect one.

c) USB data interface

Tonghui has many instruments equipped with USB interface through which instrument's parameters could be saved into USB disk. And customer can conveniently transfer data or edit them on computer.

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