Measurement Technique of High-level Dissipation Factor

I. Negative dissipation D

Many users have the following problem when using LCR meter or capacitance meter to measure low-dissipation capacitor: why is dissipation is negative value?

Dissipation physically means the ratio of the energy dissipated (resistance) to the energy stored in the capacitor, and the resistance can’t be negative, such as dissipation factor in equivalent series connection $D = 2\pi f R_s C_s$, and in parallel connection $D = 1/(2\pi f R_p C_p)$.

The reasons why negative dissipation is caused will be described in the following aspects, and how to correctly use the instrument to understand and solve these problems will be discussed.

II. The reasons why negative dissipation is caused

Generally speaking, the reasons why negative dissipation is caused are as follows:

A. Limit accuracy of instrument
B. Excessive compensation (excessive short correction)
C. Effect of contact resistance
D. Complex residual parameter existing between test cables and test terminals

A. Limit accuracy of instrument

Any component parameter meter has limit accuracy, which causes measurement to be uncertain. Theatrically, capacitor’s dissipation is represented on impedance plane as tangent of angle δ between impedance vector and imaginary axis, as shown in Figure 1. When capacitor is described in equivalent series mode, dissipation can be calculated using the following equation:

$$D = \frac{R}{|Xc|} = \omega RC = 2\pi fRC$$

At the time of low dissipation, D’s accuracy mainly depends on R’s measurement accuracy (R<<1/ωC)

Generally, if Ae is defined as impedance’s basic accuracy (as in Figure 1, suppose Ae=0.001), the following equations exist: Xce(capacitive’s accuracy)=±Ae(1+ $|Z - Xc|$ /Xc)， Re(resistance’s accuracy)=±Ae(1+$|Z - R|$ /R), then D’s accuracy is

$$D_e = \frac{R(1 \pm Ae(1 + |Z - R|/R))}{|Xc|(1 \pm Ae(1 + |Z - Xc|/Xc))}$$

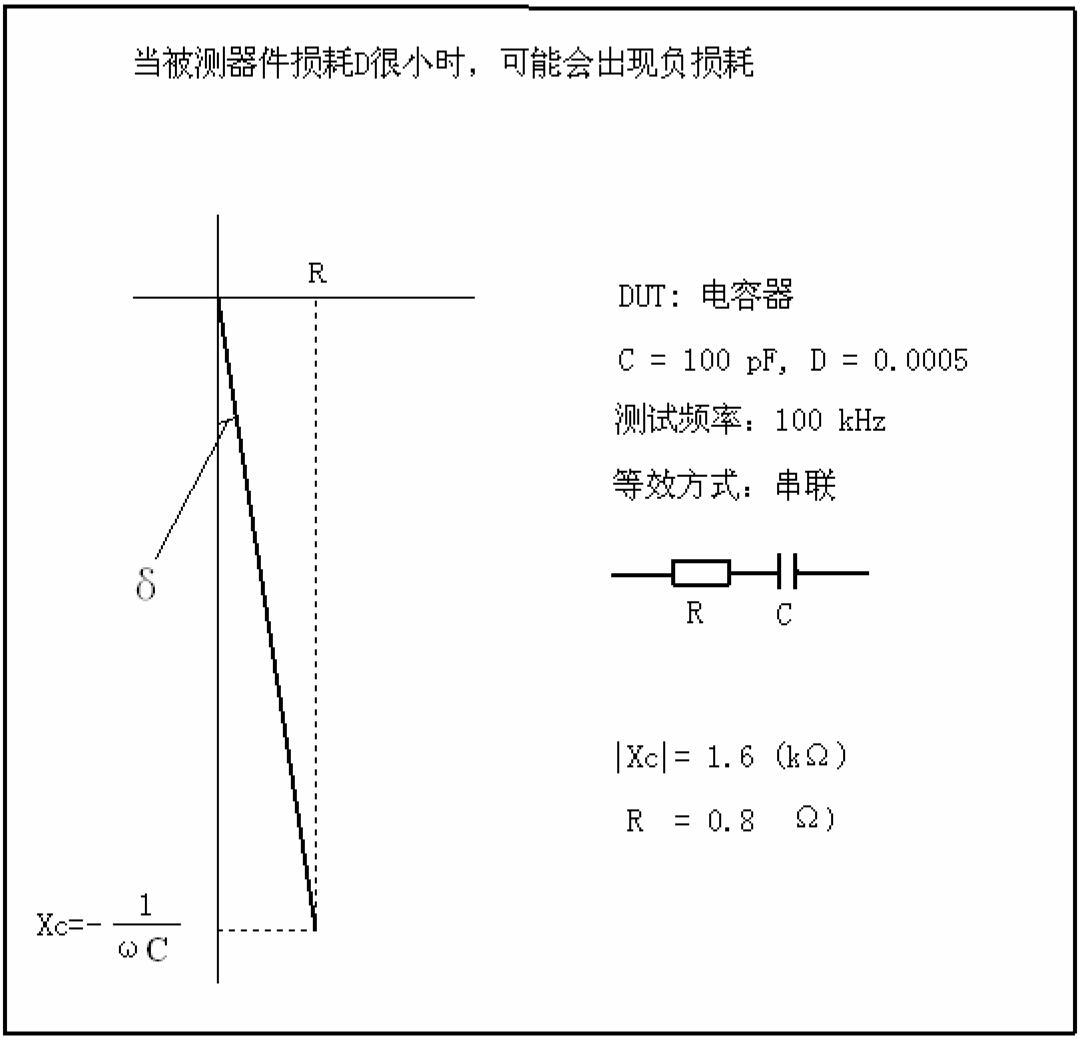
And use the values in Figure 1 to calculate, then D’s accuracy range is -0.0005—0.0015.

Or D’s range can be approximately calculated using the following expression: Dx±De.

So Dx=0.0005, De=0.001, $Dx \pm De = -0.0005 — 0.0015$

It means that negative dissipation is caused by limit measurement accuracy at the time of measuring low-dissipation capacitor, which is normal. The following methods can be used to correctly understand and approximately calculate. On the one hand, the instrument's dissipation accuracy in basic range should be less than 1/2 of given error (not for all instruments); on the other hand, error presented by dissipation is fixed, and it can be eliminated by man-made operation at the time of measurement.

And some manufacturers make special treatment for LCR meter's calculation software, which makes user not see negative dissipation. In fact, while being calculated, dissipation has been made treatment of absolution value. So even negative dissipation exists, it is displayed as positive number, for example, -0.0002 is displayed as 0.0002. But it is very harmful. Then how could we identify whether the treatment of absolute value has been made? Select parameter display to series resistance Rs display. If Rs is negative, and D is displayed as positive, it shows that the treatment has been made.



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B. Performing excessive compensation (excessive short correction)

When LCR meter is performing open or short correction, short correction probably mainly causes D's error.

When shorting plate is used to perform short correction, the shorting plate itself has residual inductance and contact resistance. So negative dissipation is caused because of over correction.

Suppose shorting plate has residual parameters Ls=26mH, Rs=2mΩ at 1MHz, then Rs+jXs=2mΩ+j163mΩ. When measuring capacitor with Cs=100nF, D=0.0005, and performing short compensation, Z = R+jX = D/(ωCs)+j1/(ωCs) = 0.8mΩ+j1.6Ω, and finally D is displayed as

$$\frac{R - Rs}{X - Xs} = \frac{0.8m\Omega - 2m\Omega}{1.6\Omega - 0.163\Omega} = -0.000835 .$$

It is recommended that the following shorting materials should be used when capacitor with large capacitance and small impedance, to reduce negative dissipation:

1) Shorting plate with small residual parameter (gilded one is better);
2) Thick multi-section low-resistance copper wire;
3) Direct short circuit of test fixture. Connect high and low terminals of voltage and current, as shown in Figure 2.

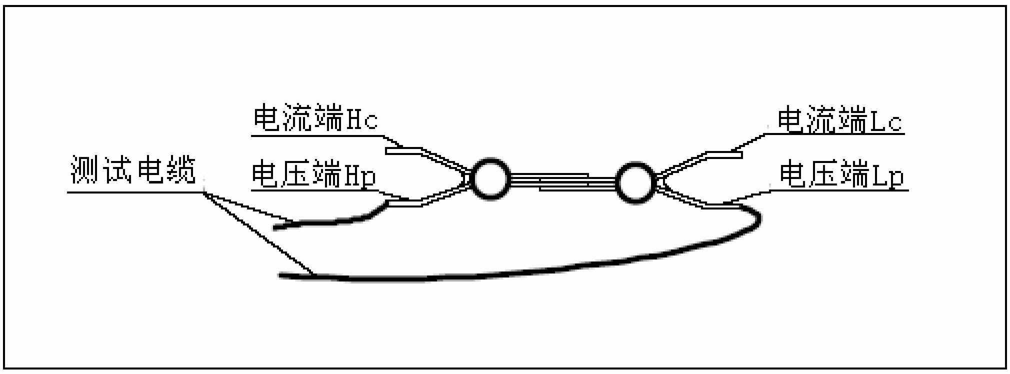

Figure 2 Correct short compensation connection of test cables' terminals

C. Effect of contact resistance

Any contact resistance between electrodes of the DUT and test fixture or test cable causes dissipation error. And the effects of contact resistances of the DUT's 2-terminal configuration and 4-terminal configuration are different.

In the case of 2-terminal connection, contact resistance is added to the DUT's impedance in series way, which causes positive error of D reading. Generally, this error can be eliminated by short compensation.

In the case of 4-terminal connection, contact resistances of different terminals Rhc, Rhp, Rlc and Rlp have different effect on dissipation. Rhc reduces test signal level on the DUT, but it doesn't cause error directly. Rlp generally ignores the effect. Rhp and Chp (distributed capacitance of coaxial test cable) make up of lowpass which can cause attenuation and phase shift of Hp input signal to cause measurement error. Rlc and Clc also make up of lowpass and cause error when measuring the DUT's current and phase angle. Because finally it is in direct ratio with -ωRhp×Chp and -ωRlc×Clc, D's error is negative, and increases with frequency.

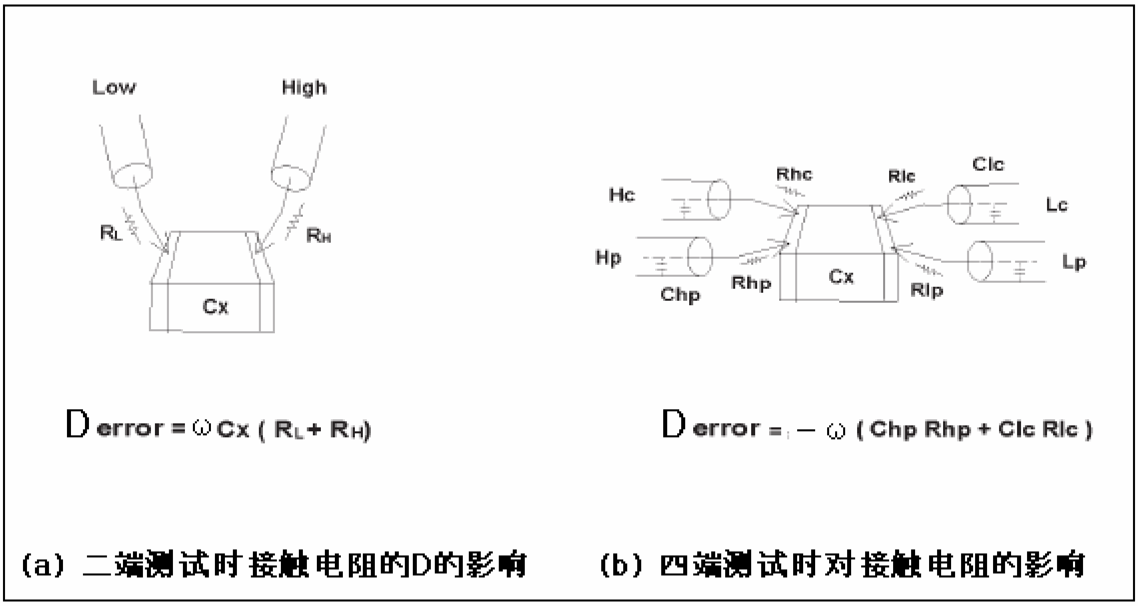

Figure 3 Contact resistance of test cable affecting dissipation

D. Complicated residual parameters between test cables and test terminals

In many measurement conditions, complicated residual parameters can't be modeled as the simple series or parallel equivalent circuit. In terms of using long cable, multi-channel scanner or machine processor, complicated network is added between the DUT and test terminals, as shown in Figure 4. Just because of this network, error is caused in measured impedance and phase parameters, which can't be eliminated through open/short correction.

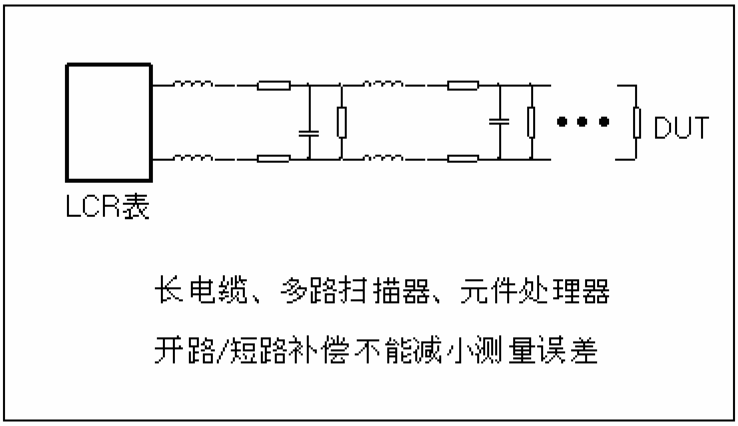

Figure 4 Complicated dissipation affecting measurement

III. General methods to solve negative dissipation measurement

The most efficient method to solve problems described in A, C, D is to use technique of open/short/load compensation.

Open/short/load compensation is an advanced compensation technique that is applicable to solve limit measurement accuracy, contact resistance and complicated residual parameter.

To perform open/short/load compensation, three measurements are required before measuring the DUT, with the test fixture opened, shorted, and with a reference DUT (with known accuracy) connected.

Please refer to related manual for how to perform load correction.

The open/short/load compensation should be used in the following situations:

1) An additional passive circuit or component (e.g. external DC bias circuit, balun transformer, attenuator and filter) is connected.
2) A scanner, multiplexer or matrix switch is used.
3) A long cable is used.
4) An automatic component tester is used.
5) A custom-made test fixture is used.
6) Accuracy higher than instrument's is used.

(Note: Standard DUT should correctly read standard data on instrument with higher accuracy.)

It is not necessary to use open/short/load compensation for simple measurement, like measuring an axial leaded component.

Open/short compensation is adequate for such measurements.

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