THE TREND TOWARDS LOWER ESR IN CAPACITORS

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INTRODUCTION

The rise in the use of portable electronic devices and performance improvements in personal computers, have placed increasing demands upon the passive components used in these products. The additional supply current requirement that accompanies increased microprocessor speed and consumer demand for extended battery life in portable electronics, contribute to the need for capacitors with lower equivalent series resistance (ESR). This paper will explain what ESR is, discuss the trend towards the development of capacitors with lower equivalent series resistance, and describe the test challenges these devices can present.

TECHNOLOGY DRIVERS

In any digital design, particularly in microprocessor based systems, switching currents place great demands upon the power distribution system. As the system frequency increases and as the system supply voltage decreases, the demands become even greater. Modern systems require power supplies with much higher current capabilities than in the past with load change transients typically from 30 to 80 A/μS.[1] Resistance and inductance in power cables and traces prevent the power supply from delivering the peak currents required. The purpose of the bypass capacitor is to store energy and to supply the high instantaneous currents during switching and to prevent the supply from drooping. Any losses within the capacitor limit its ability to supply this current. The losses also cause heat to be dissipated within the capacitor contributing to reduced system efficiency. In portable electronic devices, lower system efficiency reduces battery life or requires the use of physically larger batteries. In order to provide adequate supply decoupling and maintain low loss, the capacitor must have low impedance at high frequencies. This requires a capacitor which has low ESR.

TRENDS

Over the past 3.5 years, microprocessor current has increased by a factor of 5 and ESR requirements have dropped by a factor of 7. Next generation microprocessors will have lower voltages and increased supply currents. They will require higher value capacitors with lower ESR. To meet the changing requirements, capacitor manufacturers must cut ESR in half every 1.5 years.[2] Future microprocessors will require capacitors with equivalent series resistance of less than 10 mΩ.

Improvements in battery technology have allowed for smaller battery sizes without compromising capacity. To meet consumer demand for portable electronics with extended battery live, designers have been making systems more efficient. This trend will continue and will necessitate further reductions in ESR.

To meet present system decoupling requirements, designers parallel capacitors to obtain the needed capacitance and ESR values. The disadvantages to using multiple capacitors are increased circuit area, increased material cost, and increased assembly cost. Capacitor manufacturers have helped to solve these problems by developing technology to reduce ESR and to increase volumetric efficiency.

WHAT IS ESR?

Equivalent Series Resistance is a frequency variable measure of the total lossiness of a capacitor. It is sometimes referred to as R_S. ESR is the real part of Z and the unit of measure is ohms (Ω). It can be calculated from the real part of admittance (G_P) and susceptance (B_P) according to the equation: $ESR = G_P / (G_P^2 + B_P^2)$. The measured ESR consists of several different phenomena:

1. **The actual series resistance (R_{as})**: The ohmic resistance of the leads or plates. This value is typically very low. It causes a power loss of $I^2 R_{as}$. Its contribution to the total dissipation factor is $D_1 = \omega R_{as} C$

2. **The leakage resistance (R_L)**: A parallel resistance due to leakage current in the capacitor. This value is typically very high. It causes a power loss of V^2/R_L. Its contribution to the total dissipation factor is $D_2 = 1 / (\omega R_L C)$.

3. **The dielectric loss (R_D)**: A parallel resistance arising from two phenomena; molecular polarization and interfacial polarization (dielectric absorption). Dielectric loss is a complex phenomenon that can change with frequency in most any manner that is not abrupt. Its contribution to the total dissipation factor can be approximated by $D_3 \approx 1 / (\omega R_D C_B)$. One model is a frequency variable resistor (R_D) in series with a large blocking capacitor (C_B).

A model depicting the three contributing elements to ESR is shown in Figure 1. How the three phenomena relate to dissipation factor is shown in Figure 2.
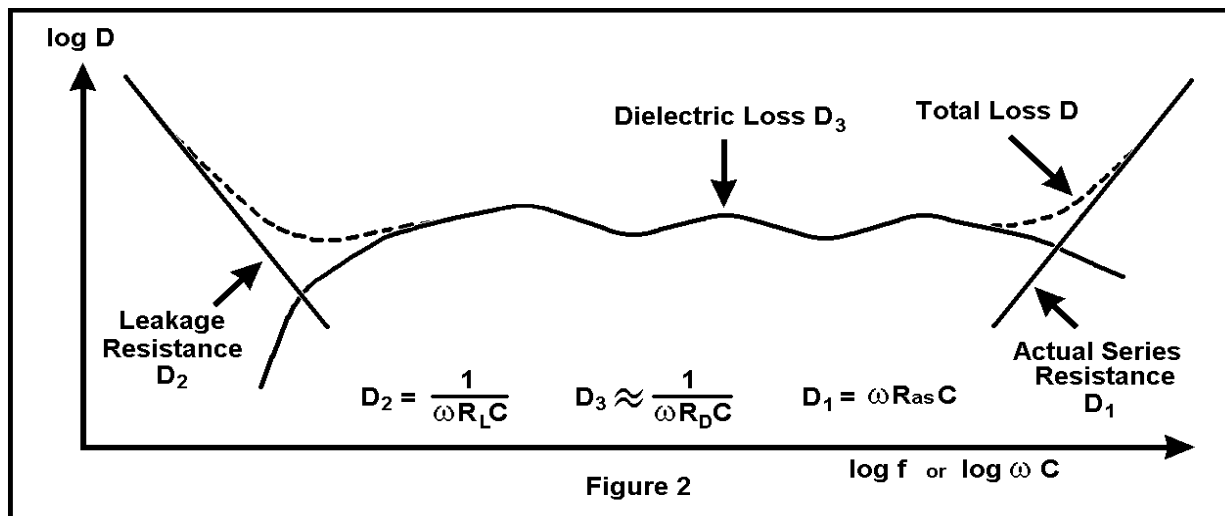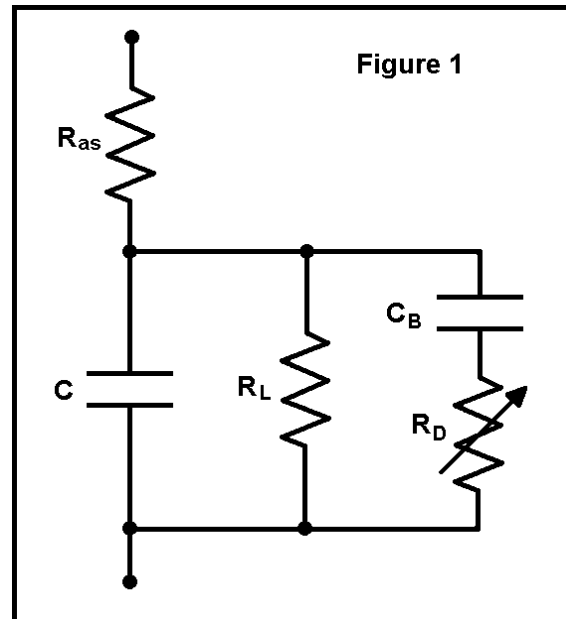

Figure 1

Figure 2

HOW IS ESR MEASURED?

Historically, the most common way to measure impedance was to use a nulling type bridge as shown in Figure 3. When no current flows through the detector (D), the value of the unknown impedance (Z_X) can be obtained by the relationship to the other bridge elements, where $Z_X = (Z_1/Z_2) Z_3$.
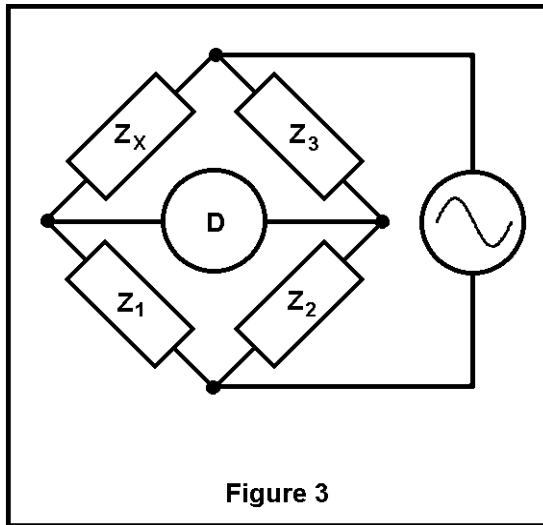
Figure 3

Modern instrument used to measure impedance generally use digital techniques for signal generation and detection. The elementary measurement circuit is shown in Figure 4.

Figure 4
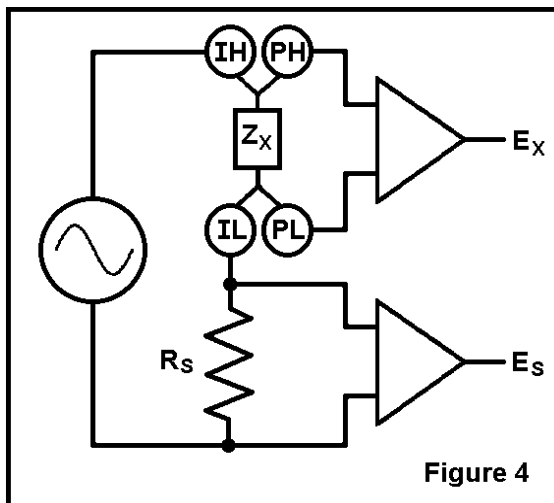
A sine wave is applied to the unknown impedance (Z_X) through IH. The current flows through Z_X and reenters the instrument at IL. The same current flows through a reference resistor (R_S). A differential amplifier across PH and PL generates E_Z, which is proportional to the voltage across the unknown device. Similarly, E_S, a voltage proportional to R_S is generated.

E_S and E_X are sampled many times per cycle of the applied sine wave and digitized. Digital signal processing is used to compute the real and imaginary components of both E_S and E_X. The real and imaginary components of E_X and E_S are by themselves meaningless. These components are combined with each other and with the known characteristics of the reference resistor. Calibration constants are factored in to calculate the complex impedance Z_X, from which the ESR value is obtained.

Some factors that can lead to errors in low ESR measurements are the instrument's ability to resolve small amplitude and phase differences, incorrect calibration factors, and uncompensated fixture and cabling effects.

MAKING ACCURATE MEASUREMENTS

The capacitor manufacturers have been successful at meeting the market requirements for low ESR capacitors. However, as the ESR values go down, making reliable measurements becomes more difficult. As with any type of measurement, accuracy and repeatability suffers as the measured parameter becomes very small or very large.

It is possible to make good measurements if proper techniques are followed. Low ESR measurements require the same attention to error sources as any other very low impedance measurement. A good four terminal (Kelvin) connection to the device to be measured is required. Cables and fixtures must be of high quality to insure repeatable measurements.

In order to make accurate ESR measurements, it is important to reduce external electrical interference. Differential coupling of noise and coherent signals will affect the quality and repeatability of the measurement. Common mode coupling into signal pairs is rejected by the instrument, therefore, common routing of pairs of signals (current or voltage) will reduce differential signals. Magnetic coupling of the stimulus current into a measurement channel will sum with the desired signal to alter the measurement. Maintaining a constant geometry of cabling will allow the instrument's short circuit correction to cancel this effect. If the geometry of the cabling and contact system changes after the short circuit correction is applied, the measurement can have additional errors.

At lower ESR values, it is important to use available instrument features such as open and short circuit compensation, the reduction of measurement speed, the use of averaging, and if a known standard is available, the use of load correction. All of these methods can help to maximize measurement accuracy.

SUMMARY

Advances in microprocessor technology and the need to extend battery life have been the technology drivers requiring the development of low ESR capacitors. Capacitor manufacturers have introduced new technology and refined processes to meet the new requirements.

There are instruments that are capable of measuring capacitors being manufactured now. However, as the trend toward lower ESR continues, new instruments will be required to meet the measurement challenges of tomorrow.

REFERENCES

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