IMPEDANCE ANALYZER MEASUREMENT OF PASSIVE COMPONENTS

Inas Abuetwirat
Doctoral Degree Programme (2), FEEC BUT
E-mail: xabuet00@stud.feec.vutbr.cz

Supervised by: Karel Liedermann
E-mail: liederm@feec.vutbr.cz

ABSTRACT

The frequency dependences of a 100 nF ceramic capacitor, a 1 MΩ resistor and a 100 Ω resistor have been measured at room temperature at frequencies from 20 Hz to 1 MHz by using a HP4284A impedance analyzer, and at frequencies from 75 kHz to 1 MHz with the HP4285A impedance analyzer, with four-terminal-pair (4TP) connections to the device under test (DUT) and auto-balancing bridge system.

1. INTRODUCTION

The impedance is an important parameter used to characterize electronic circuits, components and materials used to manufacture components. All AC circuits, however complex, can be analyzed into resistance in series with reactance (inductive / capacitive). The impedance describes a measure of opposition to alternating current (AC), so that it extends the concept of resistance to AC circuits, describing not only the relative amplitudes of the voltage and current, but also their phase shift. The value of this angle normally ranges from -90° (capacitive reactance only) through 0° (resistance only) to +90° (inductive reactance only), as shown in Fig. 1.

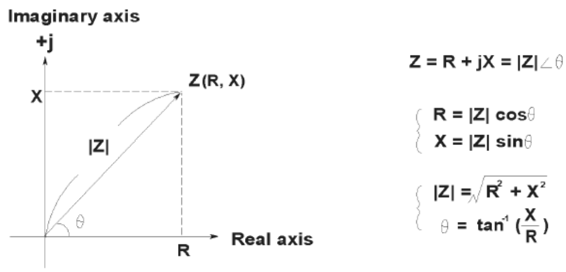

Fig 1: Impedance consists of a real part (R) and an imaginary part (X)

The dissipation factor (D) serves as a measure of a reactance's purity, and is defined as the ratio of the energy stored in a component (resistive component) to the energy dissipated by the component (inductive / capacitive reactance). D is the tangent of the complementary angle of θ.

This paper describes the challenges of measurements of passive components (resistors and a ceramic capacitor,) and how to extend their capability to have the measured value as close as possible to the real value, by using commercial impedance analyzers HP4284A, and HP4285A with partially overlapping frequency ranges 20 Hz – 1 MHz and 75 kHz – 1 MHz, respectively, and it shows their ability to meet accurately measured value.

Impedance analyzer 4284A can adequately characterize the 1 MHz resistor, and high accuracy can be achieved. But for the 100 nF ceramic capacitor, their limitations in the frequency range can become problematic. Neither analyzer completely characterizes the device for all applications. Thus the correct characterization requires testing with the HP4285A. These effects are reported.

2. MEASUREMENT

The measured high-value 1 MΩ resistor has parasitic-unwanted capacitance. With the combination of primary and parasitic elements, each component will be like a complex circuit model as shown below.

Fig 2: Real-world high value resistor

$$Z_T = R \times X_C \Big/ \sqrt{R^2 + X_C^2} \qquad (\Omega) \qquad (1),$$

where Z_T is the total impedance, *R* is the resistance value and X_c capacitive reactance.

$$\theta = \arccos(Z_T / R) \qquad \text{(degrees)} \qquad (2)$$

The measured ceramic capacitor 100 nF has a parasitic resistance and a parasitic inductance, as shown below:

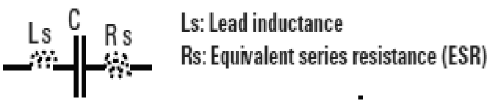

Fig 3: Real-world ceramic capacitor

$$Z = R_S + j\left(2\pi f L_s - 1/(2\pi f C)\right) \qquad (\Omega) \qquad (3)$$

$$\theta = arctg((X_L - X_C)/R_S) \qquad \text{(degrees)} \qquad (4),$$

where Z is total impedance, R_s is the resistor value, X_c capacitive reactance and X_L inductive reactance. The measured low-value resistor 100 **Ω** has parasitic-unwanted inductance, as shown below

Fig 4: Real-world low value resistor.

$$Z_T = \sqrt{R^2 + X_L^2} \qquad (\Omega) \qquad (5),$$

where Z_T is total impedance, R is the resistor value and X_L inductive reactance.

$$\theta = arctg(X_L / R) \qquad \text{(degrees)} \qquad (6)$$

Impedance analyzer 4284A can adequately characterize the 1 MHz high-value resistor, and high accuracy can be achieved. Because the capacitive reactance is inversely proportional to the frequency, and as shown in the mathematical derivations, $X_C = 1/(2\pi fC)$.

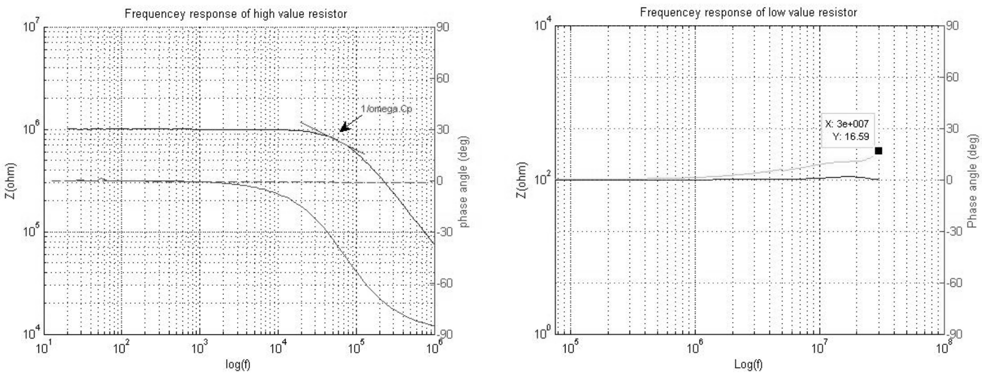

Fig 5: Frequency response of high value resistor by using 4284A impedance analyzer, Frequency response of low value resistor by using 4285A impedance analyzer

The parasitic capacitance is the prime cause of the frequency response as shown above. The measured high-value resistor behaves as capacitor at frequencies above 10^5 Hz; the phase angle changes to a negative value around -90◦ at 1 MHz. The 100 **Ω** resistor behaves as inductor at frequencies above 10^6 Hz; the phase angle changes from 0° to a positive value around +17° at 30 MHz.

For the ceramic capacitor, the prime cause of the frequency response is parasitic inductance. At low frequencies, the phase angle of impedance is around -90° ($X_C > X_L$), so the reactance is capacitive. The capacitor frequency response has a minimum impedance point at a self-resonant frequency, which is determined from the capacitance and parasitic inductance (L_S) of a series equivalent circuit model of capacitor. At a self-resonant frequency (SRF), the capacitive and inductive reactance values are equal, $1/(\omega C) = \omega L_S$, and, as a result, the phase angle is 0° and the device is resistive. Above the resonant frequency, the measured capacitance exhibits a negative value, the phase angle changes to a positive value around +90° ($X_L > X_C$) and the inductive reactance due to the parasitic inductance is dominant. Ceramic capacitor behaves as a resistive device at SRF, because the impedance is purely resistive. At frequencies above SRF it behaves as an inductive device, as a result it cannot be used as a capacitor.

The inductive reactance is directly proportional to the frequency as shown above, and as shown in the mathematical derivations, $X_L = 2\pi f L_S$, where X_L is the inductive reactance, f is frequency, L_S parasitic inductor. At SRF, $f = 1/(2\pi.\sqrt{(L_S C)})$, the values of reactances are equal and, hence, cancel each other. The impedance is then equal to the resistance.

The quality factor Q of a capacitor is derived from the relation

$$Q = |X_C / R_S| \qquad (7)$$

Both R_S and Q are frequency dependent and the characteristics of the dependence are affected by the proximity of the frequency to f_s (lowest SRF). The values of R_S and f_s are directly measurable; the first resonance is defined as the maximum in loss as shown below.

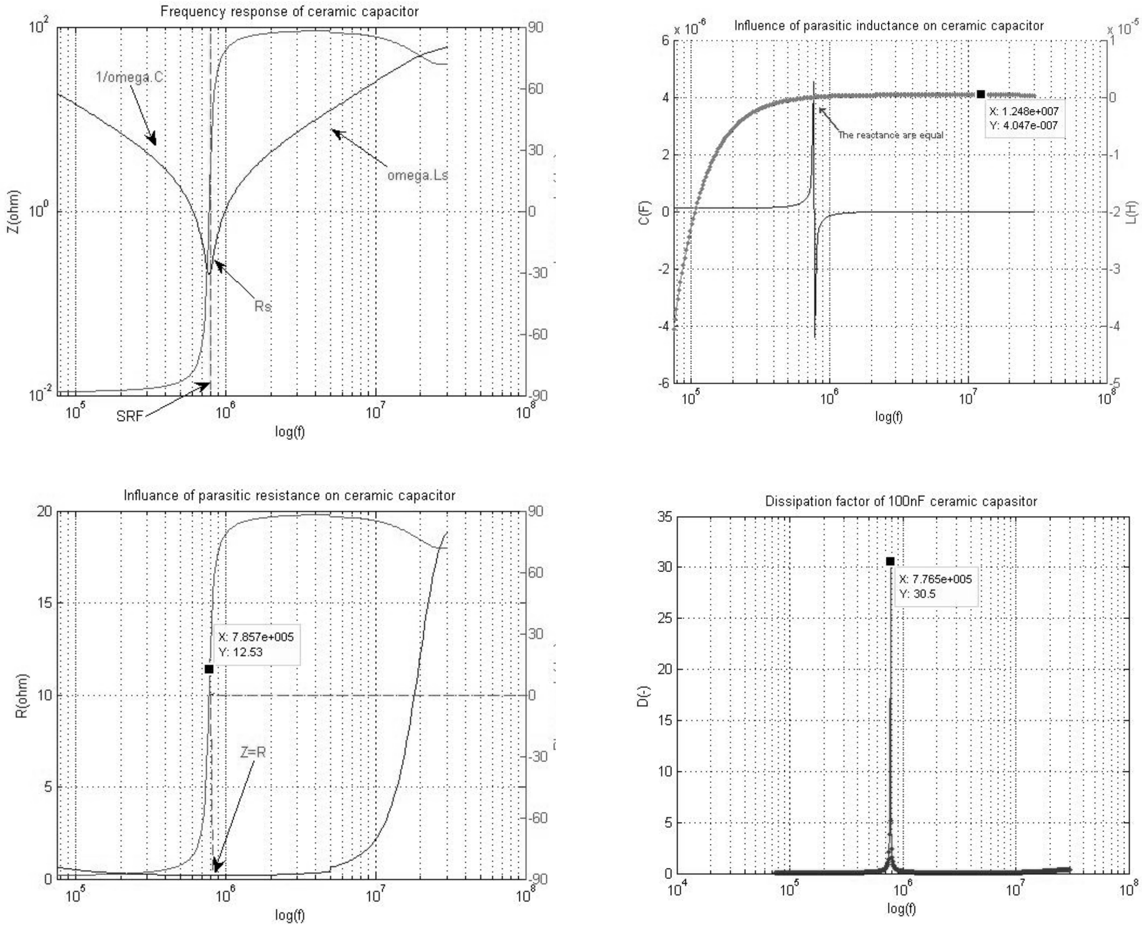

Fig 6: Frequency response of ceramic capacitor by using 4285A impedance analyzer

3. CONCLUSION

The HP4284A low-frequency analyzer 20 Hz – 1 MHz is convenient for high-value resistors as high accuracy can be achieved. For ceramic capacitor, the values of C_p and R_S do not completely characterize the device for many applications. The HP4285A analyzer is convenient for the 100 nF ceramic capacitor and high accuracy can be achieved. In all components studied, significant parasitic effect appear.

ACKNOWLEDGEMENTS

This research has been supported by the CME in the framework of MSM 0021630503 Research Intention MIKROSYN and also by the GAČR with project 102/09/H074 "Diagnostics of material defects using the latest defectoscopic methods". This support is gratefully acknowledged.

REFERENCES

[1] Agilent Impedance Measurement Hand Book, Application Note, 5950-3000, http://www.home.agilent.com

[2] Veley, F., S., S.: Basics of Electricity 2, McGraw-Hill, 2001.

[3] Prabkaharan, S., Sullivan, C., R.: Impedance-Analyzer Measurement of High-Frequency Power Passive: Techniques for High Power and Low Impedance, IEEE Industry Applications Society Annual Meeting, October 2002, pp. 1360 – 1367.

[4] Mark, I., Gordon, K., Measurement of the Characteristics of High-Q Ceramic Capacitors, IEEE, please add the complete citation.