BE1M13VES

Manufacturing of Electrical Components

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CTU in Prague

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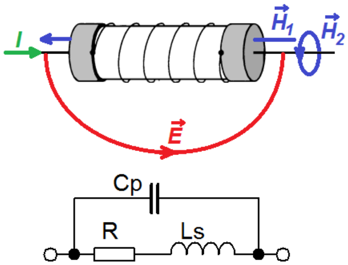
Overview

TOPIC

Equivalent Circuit

For AC circuits the parasitic serial inductance and parallel capacity must be taken into account. The frequency dependence of the resistors is caused especially by its construction.



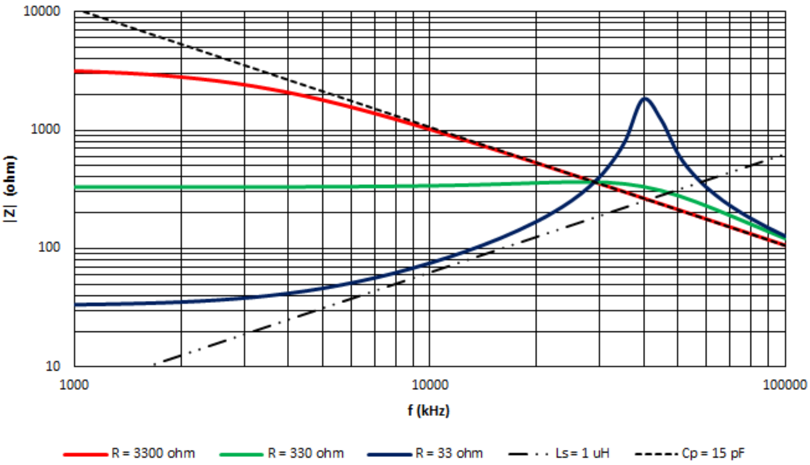
- H_1, H_2... magnetic field from resistive track and leads.
- E... electric field (capacitance) between opposite sides of package and leads.

Technology Overview

- Parasitic capacitance is dominant for higher values of resistance ($>$kΩ).
- Parasitic inductance is dominant only for small values of resistance ($<100\Omega$) and frequencies smaller than resonant frequency.
- Larger packages have larger parasitic inductance
  - power resistors (resistive wire) - worst
  - small smd thin film resistors - best



Impedance Plot Example



Equivalent Circuit Analysis

Impedance:

$$\hat{Z} = \frac{R - \frac{j}{\omega C_p} \cdot \left(\omega^2 L_s C_p \cdot \left(\omega^2 L_s C_p - 1\right) + \left(\omega C_p R\right)^2\right)}{\left(1 - \omega^2 L_s C_p\right)^2 + \left(\omega C_p R\right)^2}$$

Low frequencies ($\omega \to 0$): resistivity

$$\hat{Z} \approx R$$

High frequencies ($\omega >> \omega_{REZ}$): parasitic capacitance effect

$$\hat{Z} \approx \frac{1}{j\omega C_p}$$

Equivalent Circuit Analysis - Resonance

Resonance frequency:

$$\omega_{REZ} = \sqrt{\frac{1}{L_s C_p} - \left(\frac{R}{L_s}\right)^2}$$

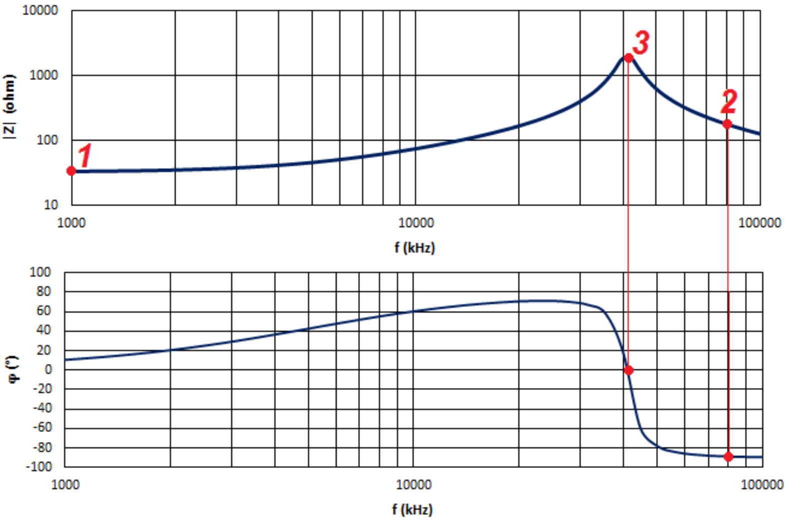
Impedance at ω_{REZ}

$$\hat{Z}_{REZ} = \frac{Z_0^2}{R}$$

Where Z_0 has the same definition as wave impedance:

$$Z_0 = \sqrt{\frac{L_s}{C_p}}$$

Analysis Example



Analysis Example

1. Resistance:

$$R = 33\Omega$$

2. Capacitance **(15 pF)**:

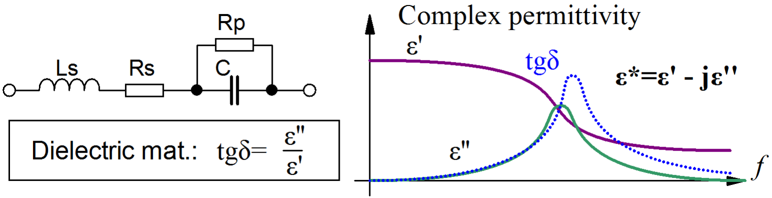
$$C_p \approx \frac{1}{\omega \cdot |Z|} = \frac{1}{503 \cdot 10^6 \cdot 180} = 11pF$$

3. Inductance **(1 μH)**:

$$L \approx Z_{REZ} \cdot R \cdot C_p = 1900 \cdot 33 \cdot 15 \cdot 10^{-12} = 940\mu H$$

TOPIC

Equivalent Circuit



Frequency dependence due to package properties:

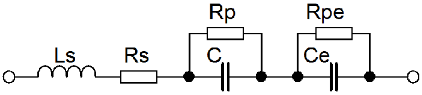
- Parasitic inductance of the leads and electrodes L_s.
- Parasitic resistance of the leads R_s.

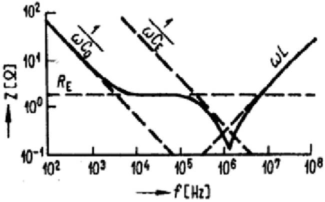
Frequency dependence due to material properties (complex permittivity):

- Change in dielectric power dissipation R_p (ϵ'') - dissip. factor (D).
- Change in capacity C (ϵ').

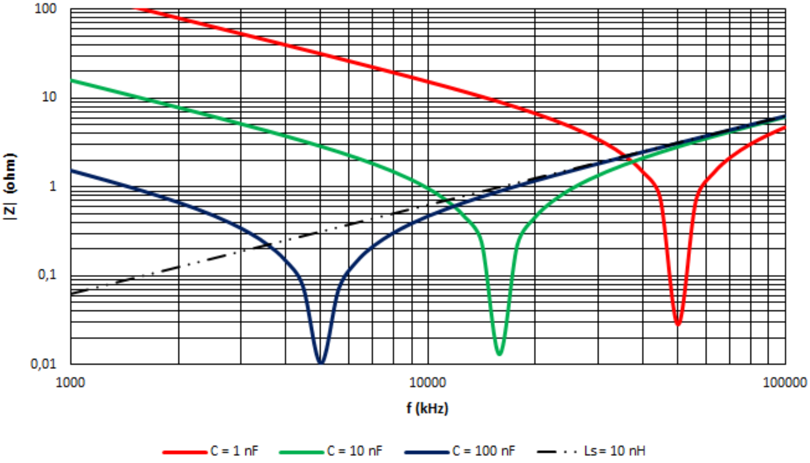
Technology Overview

- Capacitors with higher capacitance have lower resonant frequency.
- Foil capacitors have larger parasitic inductance L_s.
- Electrolytic capacitors have higher serial parasitic resistance R_s due to electrolyte presence.
- Equivalent scheme of electrolytic capacitor:





Impedance Plot Example



Equivalent Circuit Analysis

Impedance:

$$\hat{Z} = R_s + \frac{R_p}{(1 + (\omega C R_p)^2)} + j\left(\omega L_s - \frac{1}{\omega C} \cdot \frac{(\omega C Rp)^2}{(1 + (\omega C R_p)^2)}\right)$$

Low frequencies ($\omega << \omega_{REZ}$): capacitance

$$\hat{Z} \approx \frac{1}{j\omega C}$$

High frequencies ($\omega >> \omega_{REZ}$): parasitic inductance

$$\hat{Z} \approx j\omega L_s$$

Equivalent Circuit Analysis - Resonance

Resonance frequency:

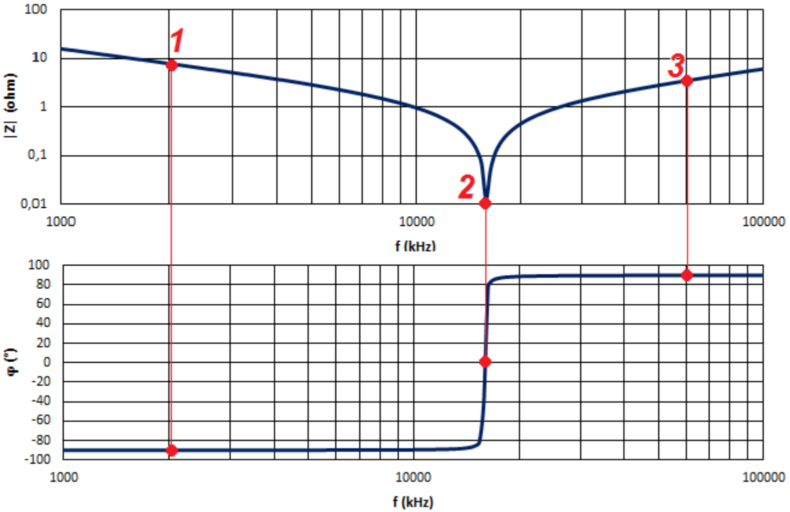
$$\omega_{REZ} = \sqrt{\frac{1}{L_s C} - \left(\frac{1}{R_p Cp}\right)^2} \approx \sqrt{\frac{1}{L_s C}}$$

Impedance at ω_{REZ}

$$\hat{Z}_{REZ} = R_s + \frac{Z_0^2}{R_p} \approx R_s$$

- The approximation is made for capacitors with high resistance R_p and value of capacitance $C > 1\ nF$
- The higher resistance at the resonance is caused by the factor $\frac{Z_0^2}{R_p}$ or by **skin-effect**.
- The parasitic resistances can change due to frequency dependence of complex permittivity.

Analysis Example



Analysis Example

1. Capacitance **(10 nF)**:

$$C \approx \frac{1}{\omega \cdot |Z|} = \frac{1}{12.6 \cdot 10^6 \cdot 7.85} = 10.1nF$$

2. Serial resistance **0.01** Ω**)**:

$$R_s \approx Z_{REZ} = 0.01\Omega$$

3. Inductance **(10 nH)**:

$$L \approx \frac{|Z|}{\omega} = \frac{3.65}{376 \cdot 10^6} = 9.7nH$$

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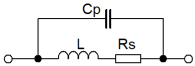
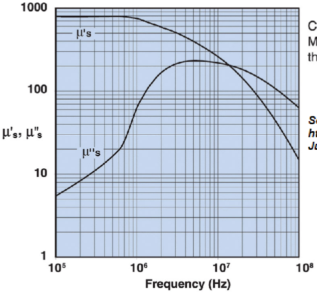
Equivalent Circuit



$$\mu^* = \mu' - j\mu''$$

Magnetic mat.: $\mathrm{tg}\delta = \frac{\mu''}{\mu'}$

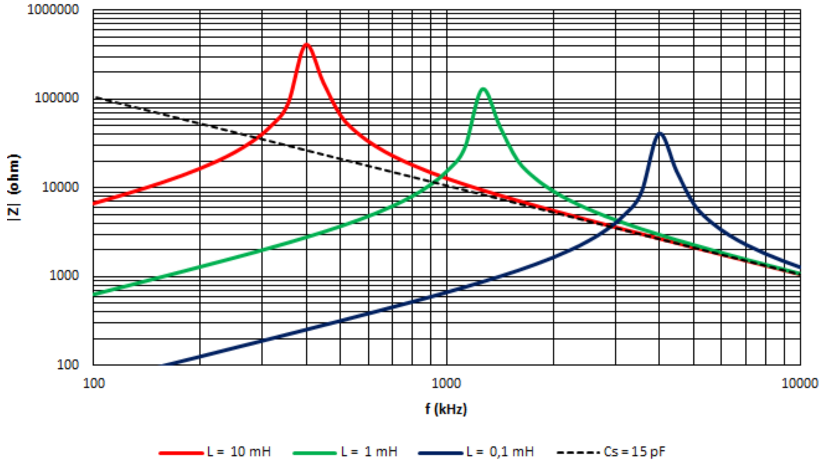


Complex Permeability vs. Frequency Measured on a 17/10/6mm toroid using the HP 4284A and the HP 4291A.

***Source:* http://www.nutsvolts.com/magazine/article/July2015_HamWorkbench**

- The same equivalent circuit as in case of resistors.
- The frequency dependence strongly affected by core material properties and skin-effect.
- Coils with high impedance have lower resonant frequencies.

Impedance Plot Example



Equivalent Circuit Analysis

Very low frequencies ($\omega \to 0$): parasitic resistivity

$$\hat{Z} \approx R_s$$

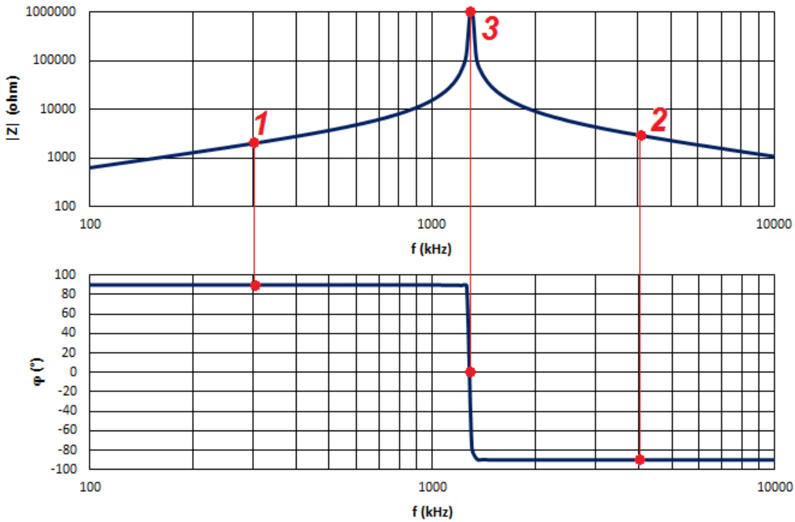
Low frequencies ($\omega << \omega_{REZ}$): inductance

$$\hat{Z} \approx j\omega L$$

High frequencies ($\omega >> \omega_{REZ}$): parasitic capacitance effect

$$\hat{Z} \approx \frac{1}{j\omega C_p}$$

Analysis Example



Analysis Example

1. Inductance **(1 mH)**:

$$L \approx \frac{|Z|}{\omega} = \frac{2050}{1885 \cdot 10^3} = 1.1mH$$

2. Parallel capacitance **(15 pF)**:

$$C \approx \frac{1}{\omega \cdot |Z|} = \frac{1}{25.1 \cdot 10^6 \cdot 2970} = 13pF$$

3. Serial resistance **10 Ω)**:

$$R_s \approx \frac{Z_0^2}{Z_{REZ}} = \frac{10^{-3}}{1510^{-12} \cdot 10^6} = 6.67\Omega$$

- **NO!** ... better to find out the serial resistance from DC measurement.

TOPIC

NOTES

- In case of impedance plot use logarithmic scale for both axis.
- In case of phase plot use logarithmic scale only for frequency.
- $$\hat{Z} = R + jX$$
- $$|Z| = \sqrt{R^2 + X^2}$$
- $$\varphi = arctg\frac{X}{R}$$
- resonance: $X = 0$, $\varphi = 0$, parallel $\Rightarrow$ high $|Z|$, serial $\Rightarrow$ low $|Z|$