High-frequency characteristics of resistors

§0 Abstract

Resistors have a variety of impedance characteristics in the high frequency range depending on the resistance value, the structure, and the size, which can cause unexpected problems in high-speed electronic circuits. This technical note explains the parasitic capacitance and inductance of resistors and their effects on the high-frequency characteristics of resistors.

§1 Parasitic capacitance and inductance of resistors

1.1 Enhancing the performance of devices

Various electronic devices such as automotive electronics and smartphones are becoming more sophisticated. This performance enhancement has been benefitting mainly from the high-speed information processing, supported by the electronic components with superior high-frequency characteristics. Though the ideal characteristic for resistors is the constant impedance regardless of the frequency, the impedance changes in the high frequency region. Figure 1 shows the frequency characteristics of the flat chip resistors (0603 inch size). The horizontal axis represents the frequency, and the vertical axis represents the impedance change rate based on the direct current. For this series of products, the impedance of the 2.2 Ω and 100 kΩ products is completely far from the ideal cheracteristics in the range over several tens MHz.
The high-frequency characteristics of resistors clearly vary depending on the structure and the size as well as the resistance value of resistors. Accordingly, high frequency characteristics of resistors must be taken into account when designing high-speed electronic circuits.

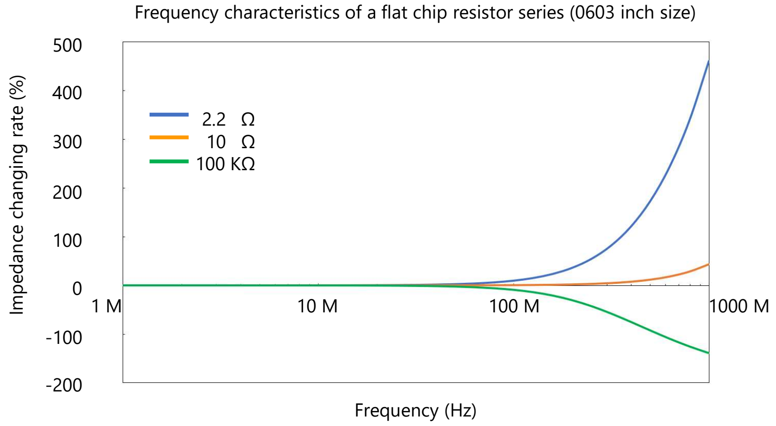
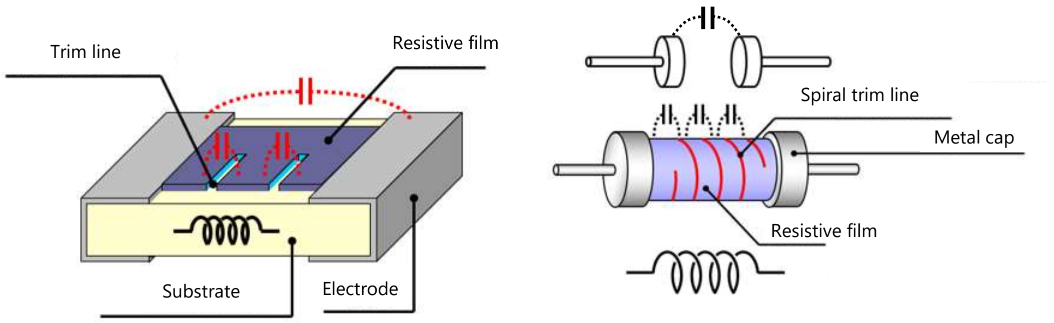


Fig.1 Frequency characteristics of the resistors

1.2 Structure of resistors

This section explains the reason why capacitance and inductance exist in resistors. Figure 2 shows the typical structures of flat chip resistors and resistors with leads.



(a) Flat chip resistor (b) Resistor with leads

Fig. 2 Structure of resistor

The flat chip resistor (Fig. 2 (a)) has the inductance proportional to the length of resistor, and the capacitance in between the electrodes and between the resistive films separated by the trim line. The resistor with leads (Fig. 2 (b)) has the similar inductance and capacitance composition. But, the inductance of resistive film is especially large because a coil is formed by this spiral trim line.
These capacitance and inductance that exist due to the structure of the resistor are called parasitic capacitance and inductance.

1.3 Equivalent circuit of resistors

It is beneficial to utilize the equivalent circuit in order to consider the effect of the parasitic capacitance and inductance of the resistor in the circuit designing process. Commonly, the three-element equivalent circuit shown in Fig. 3 (a) is used. The capacitance indicated in the figure is called equivalent parallel capacitance (C_P), the inductance is called equivalent series inductance (L_S), and these are collectively called equivalent circuit parameters. In order to more accurately model the impedance characteristics of a resistor in the high frequency region the five-element equivalent circuit shown in Fig. 3 (b) or one with more elements in combination is used.

(a) Three-element equivalent circuit (b) Five-element equivalent circuit

Fig. 3 Equivalent circuit of resistors

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KOA provides the equivalent circuit parameters calculated based on the frequency characteristics measured by an impedance analyzer on its website. Table 1 and 2 show the three-element equivalent circuit parameters for flat chip resistor RK73 series and wide terminal type flat chip resistor WK73R series. The equivalent circuit parameter distinctly vary depending on the dimensions of the resistor. The inductance increases as the length of the resistor increases and decreases as the width of the resistor increases. L_S is more sensitive to the length according to the fact that L_s tends to increase with the size as shown in the table below. On the other hand, the capacitance decreases as the distance between the electrodes increases, but increases as the width increases because the opposing surface area of the electrodes increases. C_P is more sensitive to the width according to the fact that C_P also tends to increase with the size as shown in the table below. For the same reasons, when comparing RK73series (Table 1) and WK73R series (Table 2) in the same size, L_S is larger for RK73 series and C_P is larger for WK73R series due to the difference in structure.

Table 1 Equivalent circuit parameters for RK73 series

Inch Size Code	L_S [nH]	C_P [fF]
01005	0.37	12
0201	0.6	23
0402	0.7	30
0603	1.1	50
0805	1.1	65
1206	1.67	65
1210	1.3	115
2012	2.1	70
2512	2.3	80

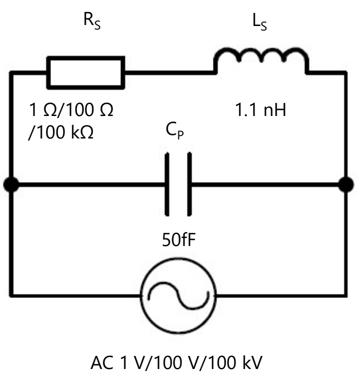
Table 2 Equivalent circuit parameters for WK73R series

Inch Size Code	L_S [nH]	C_P [fF]
0204	0.36	82
0306	0.33	95
0508	0.49	115
0612	0.47	200
1020	0.65	230
1218	0.90	190
1225	0.50	190

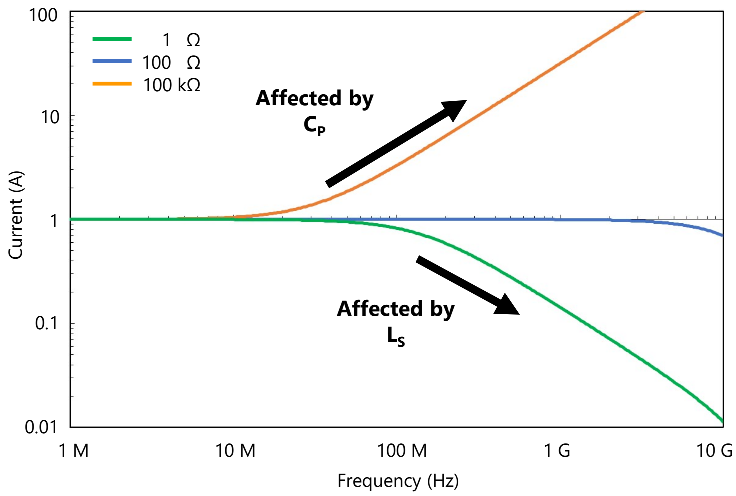
The resistance values are not included in the table of the equivalent circuit parameters for the flat chip resistors provided on KOA's website. The equivalent circuit parameters (L_S and C_P) are virtually constant regardless of the resistance values since the structures of resistors vary only slightly by the resistance value. Thus, the values in the tables are the typical values calculated from the measurement results of each size. For resistors with leads, as the pitch width between the spiraling trim line varies greatly depending on the resistance value, the equivalent circuit parameters vary greatly depending on the resistance value. Moreover, since resistors with leads are large and their resistive film is in coil form, their L_S is extremely high compared to that of flat chip resistors. While the L_S of the flat chip resistors indicated in table 1 and 2 is 2.3nH at the maximum, that of the resistor with leads in Fig. 2 (b) is several tens nH to several hundred nH. Additionally, as for wire wound resistors, the Ls will be several tens nH to several µH.

§2 Effect of resistance value on frequency characteristics

Attention must be paid to the fact that even if the L_S and the C_P are constant, the frequency characteristics of the impedance vary significantly depending on the resistance value. Figure 4 shows the simulation results of frequency characteristics using L_S and C_P values of RK73 series flat chip resistors in 0603 inch size from table 1 with the resistance values of 1 Ω, 100 Ω and 100 kΩ. Figure 4(b) shows changes in current when the AC voltage with the constant amplitude and different frequencies are applied.



(a) Three-element equivalent circuit



(b) Frequency characteristics

Fig. 4 Simulation results

Using the 100 kΩ resistor, the current increases at over 10 MHz; using the 100 Ω resistor, the current does not change much even in the high frequency region; using the 1 Ω, however, the current decreases at over 100 MHz. In the high frequency region, the impedance decreases at the high resistance value because C_P is dominant. As a result, the current increases. On the other hand, the L_S is dominant at low resistance value and increases the impedance in the high frequency region, which decreases the current. Note that even with a constant L_S and C_P, the different resistance values show different characteristics in the high frequency region. In addition, the resistors with extremely low resistance value, such as metal plate resistors used for current sensing, require special attention to the effect of L_S from a lower frequency. For these resistors, two-element equivalent circuit can be used as shown in Fig. 5 since the C_P hardly gives an effect on the impedance characteristics. For the details on metal plate resistors, please refer to the technical note “Effect of parasitic inductance of current sensing resistor".

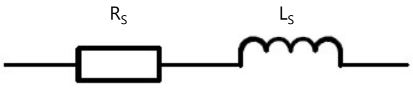


Fig. 5 Equivalent circuit of metal plate resistor (two-element)

§3 Factors affecting frequency characteristics

Table 3 summarizes the factors that affect the frequency characteristics of resistors. Smaller chip resistors receive less effect of the frequency. This would help when designing an electronic circuit that operates in high frequency region.

Table 3 Factors affecting frequency characteristics

Factor	Description
Structure of the resistor	L_S is larger for resistors with leads than for flat chip resistors Wirewound resistors require special attention because of the high inductance C_P varies depending on the shape of trimming and the type of resistive film
Size of the resistor	Smaller sizes have both smaller C_P and L_S (Table 1)
Resistance value	L_S has greater impact for low resistance values, and C_P has greater impact for high resistance values

Note that the parasitic capacitance and inductance exist in the pattern of printed-wiring board (PWB) as well as in the resistor, which may affect the circuit operation more than C_P and L_S of the resistor do. Therefore, it is necessary to consider the characteristics by the entire circuit, not by the individual components, in the high frequency region.

§4 Summary

Because resistors have the parasitic capacitance and inductance, the impedance of the resistor varies with the frequency. As the variation depends on the product series, the size, and the resistance value, please carefully select a resistor suitable for its application when using in the high frequency region.
Regarding the equivalent circuit parameters offered on KOA's website as a reference for simulation analysis and product comparison, please be aware that the actual circuit will be affected by the parasitic capacitance and inductance of the PWB besides those of electronic components. The circuit operation should be tested sufficiently using the actual PWB and device when using a resistor in the high frequency region.