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ANALYSIS OF CERAMIC CHIP CAPACITORS AT HIGH FREQUENCY

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The dimensions of monolithic ceramic capacitors today becomes very small and they presents good performance at high frequency. It is used in various high frequency circuits for impedance matching, DC block, filter, bypass and decoupling functions. For the best performance in these applications , low equivalent series resistance and equivalent series inductance is required. This parameters are analyzed in the paper for multilayer ceramic chip capacitors. Using an impedance analyzer and SPICE simulations the impedance of capacitors at high frequency is presented.

1. INTRODUCTION

The frequencies of electronic circuits have increased rapidly in the last time. The movement to higher frequency requires the improvement of the high frequency performance of the components used in the circuit, as well as in the circuit design itself. The multilayer ceramic capacitors are used in various high frequency circuits for impedance matching, DC block, filter, RF coupling, bypass and decoupling. The parasitic equivalent series inductance (ESL) of the capacitors becoming more and mare important in this applications. On the other hand, for different applications, for decoupling, for example, the equivalent series resistance (ESR) becoming very important parameters. For this reason, ESL, ESR, resonant frequency and the impedance of ceramic chip capacitors was analyzed, measured and simulated. A methodology to obtain an equivalent capacitor with a low impedance in a big bandwidth is proposed.

2. PARASITICS AND EQUIVALENT CIRCUITS FOR CAPACITORS

Every electronic component has parasitic effects, which may modify the good function of components. An ideal capacitor should only have a capacitive component, but in reality also has resistive and inductive components. The resistive components of capacitor are: electrodes and terminals resistance (R_e), AC dielectric loss (R_d), the DC dielectric leakage or insulation resistance (R_i). It also has an inductive component due to electrodes and terminals. Having in mind this parasitic components and the structure of capacitors it results the equivalent circuit shown in figure 1. At high frequency, the equivalent circuit can be simplified as in figure 2. The resistance R is called ESR and the inductance L is called ESL.

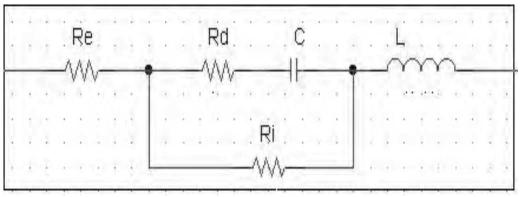

Fig. 1 Equivalent circuit of capacitor

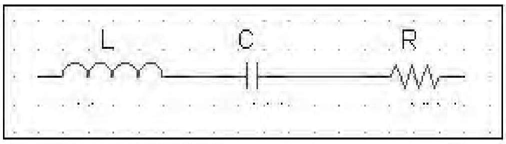

Fig. 2 Simplified equivalent circuit of capacitor at high frequency

In general, the quantities C, ESR and ESL are frequency dependent. For most applications, C and ESL can be regarded as frequency independent below 1 GHz. The inductance L is independent of the dielectric material and is dependent on the size of capacitor. The inductance of chip capacitor increase with the distance between terminations, the height and the number of dielectric layers. ESR is determined by energy dissipation mechanisms and is dependent of the dielectric material, electrodes and terminations. At high frequency, for chip capacitor, the electrodes resistance becomes very important, because this resistance increases with $f^{1/2}$, due to skin effect. The resistance of electrodes increases with the distance between terminations and is dependent to the type of material and the thickness of electrodes. ESR depends also of frequency and capacitance.

$$R = R_e + R_d = R_e + \tan\delta /(\omega \cdot C) \quad (1)$$

where, tanδ is the dielectric loss factor.

The resonant frequency is calculated from the simple equation,

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (2)$$

3. CHARACTERISTICS OF CERAMIC CHIP CAPACITORS AT HIGH FREQUENCY

For measurement the impedance analyzer type HP 4396B was used, with a frequency range from 100 kHz to 1.8 GHz and the SMD fixture type HP 16192A.

Ceramic chip capacitors have several dielectric types: NP0, X7R, X5R, Y5V. The NP0 capacitors have the lowest ESR and best temperature and voltage properties, but are only available up to a few nF. X7R capacitors have reasonable voltage and temperature coefficients and are available from several nF to several μF. X5R is similar to X7R, but capacitance may be to 100 μF. Y5V capacitors have high capacitance values, but have very poor voltage and temperature characteristics. Depending on dimensions, ceramic chip capacitors may be classified in standard, cube and modified. Standard capacitors have EIA dimension: 0504, 0603, 0805, 1206. 1210, et al. These capacitors have a big ESR and L. Typical ESR at resonant frequency is shows in figure 4. ESR and L have a small variation with dimension. Typical L is shown in table 1. Cube capacitors have the same length, width and high and have a medium ESR and L. Modified capacitors have terminations on the larger sides, see figure 3.

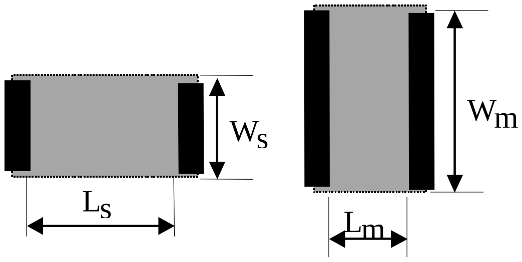

Fig. 3. Standard and modified chip capacitors

By comparing standard with modified chip capacitor at the same capacitance and electrode areas, it results, [8],

$$R_m = R_s / k^2 ,\ L_m = L_s / k \quad (3)$$

where R_m, R_s, L_m, L_s are resistance, respectively inductance of modified and respectively standard capacitor; factor k is:

$$k = L_s / L_m = W_m / W_s \quad (4)$$

So, these capacitors have a low ESR and L.

Using SPICE simulation, the impedance versus frequency for different capacitors is shown in figures 4 - 9. For every type of capacitor the impedance at high frequency is depending on ESR, see figure 4 and inductance, see figure 5. A solution to obtain a capacitor with low ESR and ESL is the parallel connection. The impedance of identical capacitors parallel connected is reduced by a factor of two every time the quantity is doubled, see figure 6. The ESR of *n* identical capacitors in parallel – ESR_p- at the resonance frequency is

$$ESRp = ESR / n \quad (5)$$

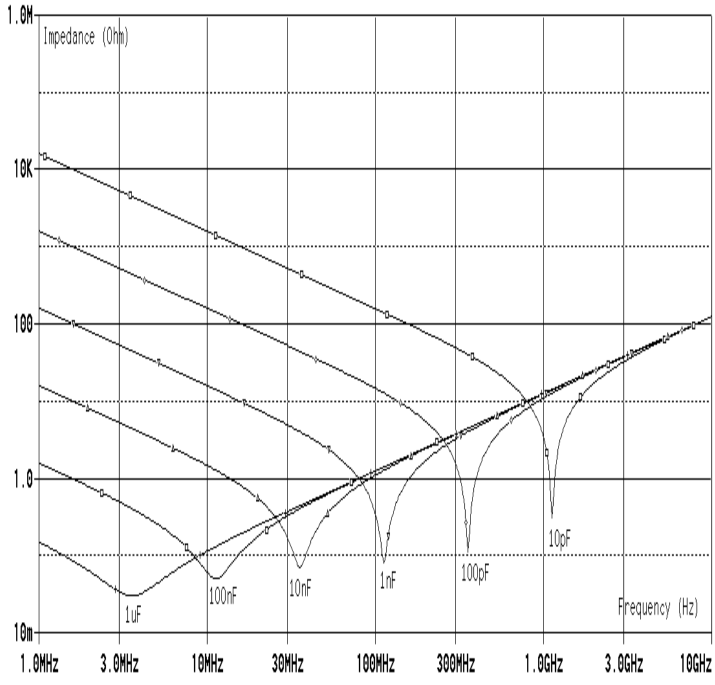

Fig. 4. Impedance versus frequency for several standard X7R and NP0 capacitors

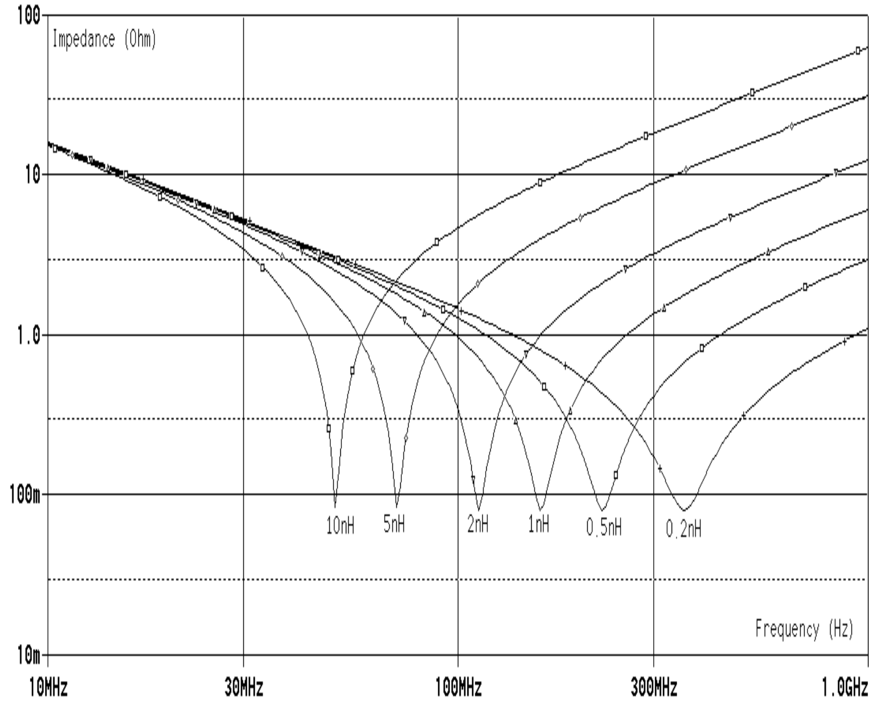

Fig. 5. Impedance of capacitor for different inductance values

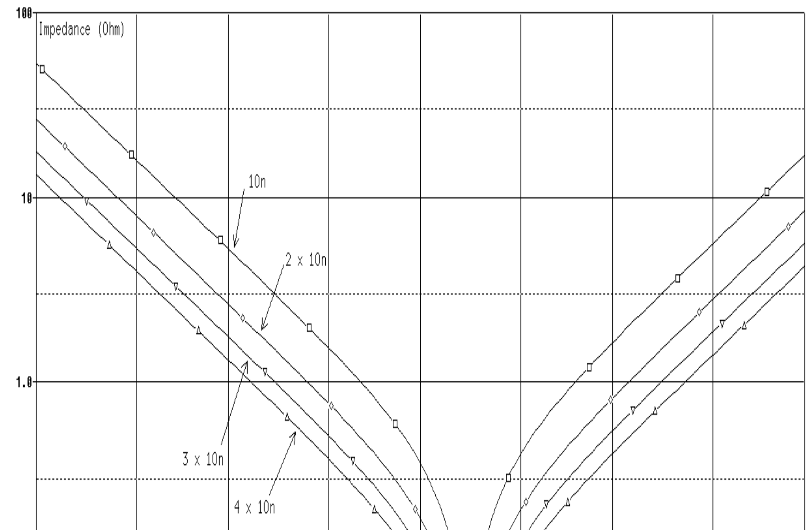

Fig. 6. The impedance versus frequency for identical capacitors in parallel

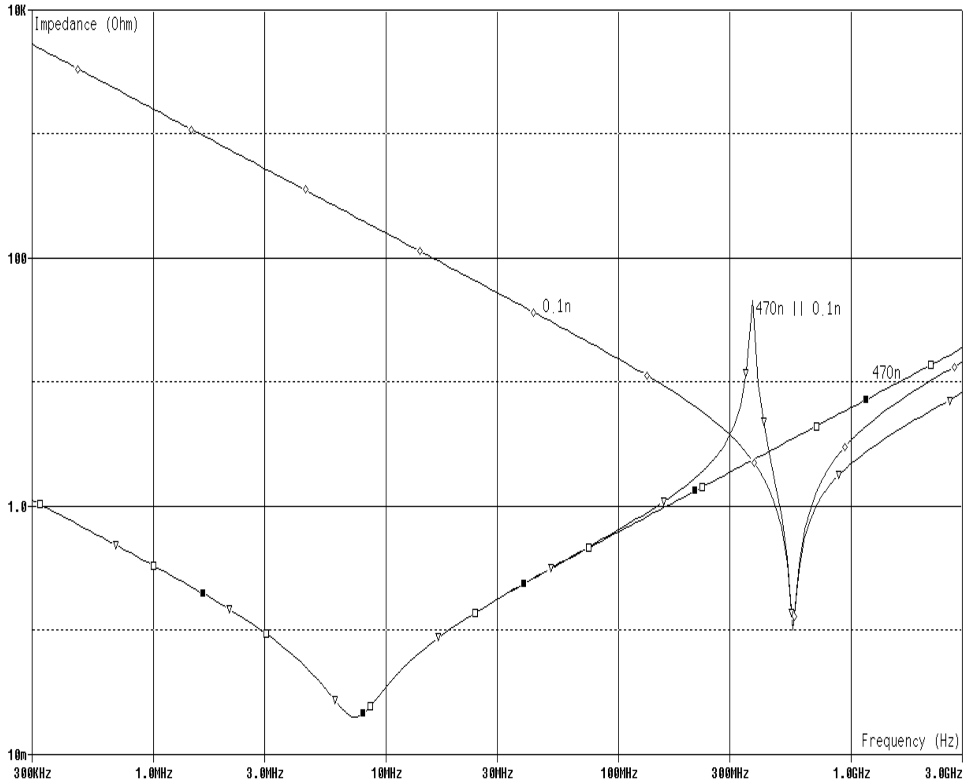

Fig. 7. Impedance for two standard ceramic chip capacitors in parallel

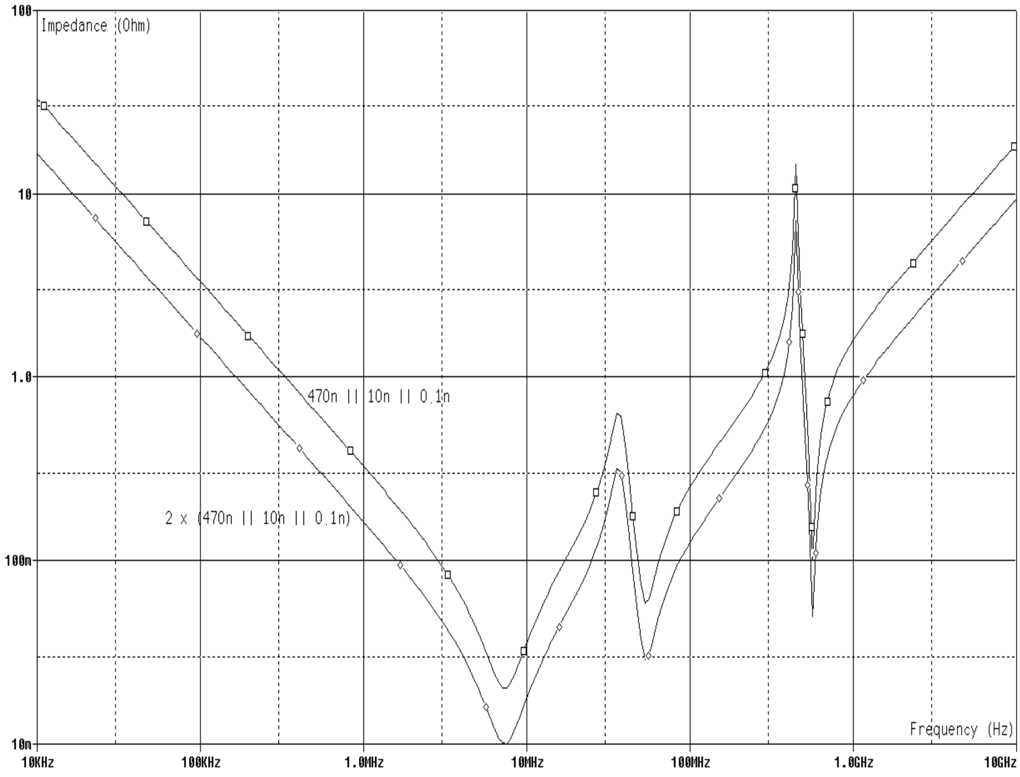

Fig. 8. Impedance for three and six standard ceramic chip capacitors in parallel

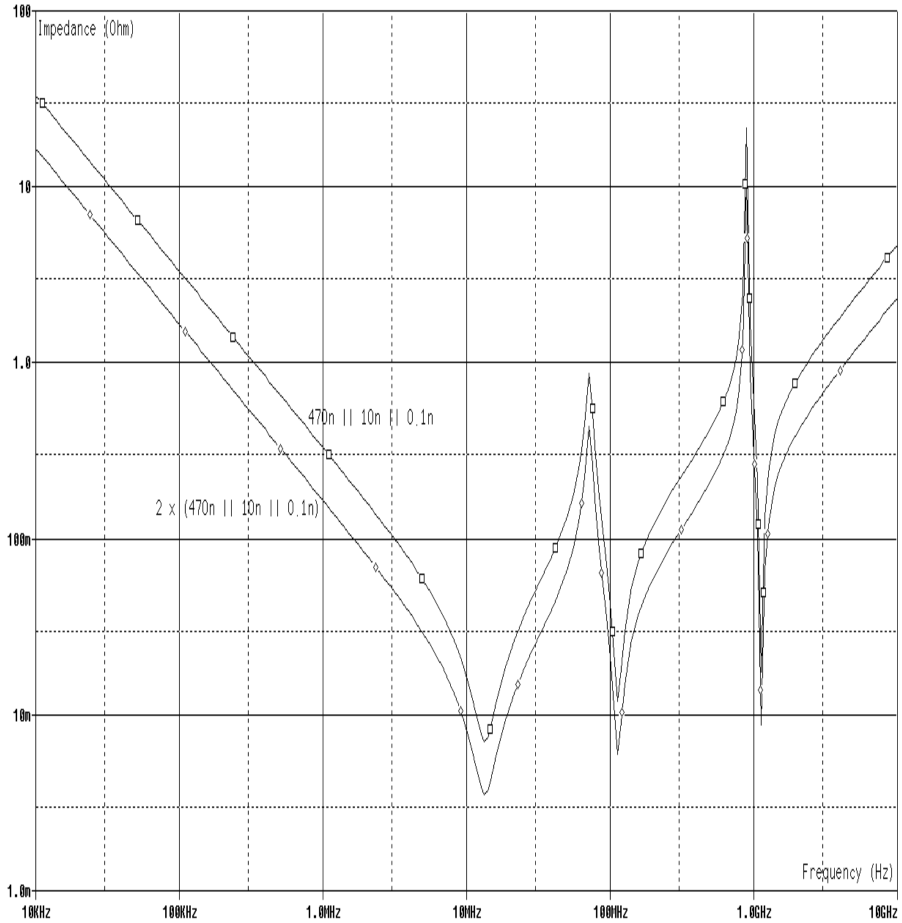

Fig. 9. Impedance for three and six chip capacitors with low ESR and L in parallel

From figures 7 - 9 results that to obtain a low impedance in a wide bandwidth it is necessary to connect in parallel some capacitors with different capacitance and low ESR and ESL. The capacitor parameters, which are used for SPICE simulation in figures 7 - 9, are presented in table 2. C_{MD} is capacitor with maximum capacitance, C_{mD} is capacitor with minimum capacitance, C_{iD} is capacitor with medium capacitance.

Table 1

Equivalent series inductance for some chip capacitors

Chip type	L (mm)	W (mm)	L/W	ESL (pH)
1210	3.2	2.5	1.28	1020
1206	3.2	1.6	2	1280
0805	2	1.25	1.6	1070
0603	1.6	0.8	2	900
0612	1.6	3.2	0.5	620
0508	1.25	2	0.625	600

Table 2

The capacitor parameters, which are used for SPICE simulation in figures 7 - 9

Figure	Capacitor	C (nF)	ESR (mΩ)	L (nH)
6	C_{MD}	470	20	1
	C_{mD}	0.1	100	0.8
7	C_{MD}	470	20	1
	C_{iD}	10	60	0.9
	C_{mD}	0.1	100	0.8
8	C_{MD}	470	7	0,3
	C_{iD}	10	12	0.2
	C_{mD}	0.1	15	0.2

4. CONCLUSIONS

The frequencies of electronic circuits have increased rapidly in the last time. For the best performance in these applications, low equivalent series resistance and equivalent series inductance, high resonant frequency, low impedance of capacitor is required. Thiese parameters are analyzed in the paper for multilayer ceramic chip capacitors. A solution to realize a capacitor with low ESR and ESL is connection in parallel of some identical capacitors. A methodology for realize a capacitor with low impedance in a broad bandwidth is the connection in parallel of some capacitors with different capacitance.

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