ELECTRONIC PASSIVE COMPONENTS TRAINING ACTIVITY-DEMAND FOR PERFORMANCE ELECTRONIC PACKAGE DEVELOPMENT

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Abstract: Beside the active electronic components the passive ones are subject of continuing developments. It is difficult to imagine the dynamics of electronic products without the proper "support" of passives. In a way it is possible to say: "Today the passives are very active!". More and more requirements are coming from end users, the equipment developers. In the same time new electronic packaging technology ask for new feature of components. These features must be seen in a large approach that includes electrical, mechanical, thermal, technological and other points of view. This huge amount of knowledge must be appropriate for the packaging engineers. It is expected that in the near future the demand of such specialists will dramatically increase.

Today's exciting new products - including cell phones, laptop computers and personal data assistance - will change the way we live. These products are known for their portability, ease of use, small size and continuing increased performance. Every one of such products uses passive components in one form or another. In fact it is difficult to nominate an electronic product without electronic passive components insides. With many different capabilities and unique performance characteristics available, design engineers can use passive components to address their design challenges like: power handling, ultra high stability, current sensing, low thermal deviation, pulse handling, influence of frequency, etc. By matching the right passive component technology to the design requirements, during the development, the engineer can optimize the overall product.

The paper will be analyzing some aspects of electronic packaging education focused on the most usual electronic passive components. It will be highlighted the influence of parasitic to impedance of passive components at high frequency. One of the main problems for engineer takes into account the proper behavior of the passive components included in the electronic circuits. The impedance of passive components will be analyzed according with technology, material, structure and geometry. The computed results will be comparing with the experimental one.

Potrebne aktivnosti šolanja na področju pasivnih elektronskih komponent, ki zagotavljajo kvaliteten razvoj tehnik zapiranja

Ključne besede: tehnologije zapiranja, aktivne elektronske komponente, pasivne elektronske komponente, ohišje, izobraževanje za tehnologije zapiranja

Izvleček: Ne samo aktivne, tudi pasivne komponente so podvržene hitremu in stalnemu razvoju. Težko si predstavljamo razvoj elektronskih sistemov brez ustrezne podpore pasivnih komponent. Na nek način bi lahko rekli : » Dandanes so pasivne komponente zelo aktivne » ! Vse več zahtev prihaja od končnih uporabnikov, razvijalcev elektronske opreme. Obenem tudi nove tehnologije zapiranja zahtevajo komponente z novimi lastnostmi. Pod lastnostmi razumemo električne, mehanske, termične, tehnološke in druge. Zaradi tega morajo inženirji, ki delujejo na področju montaže komponent obvladovati vsa ta različna znanja. Pričakujemo, da bo v bližnji prihodnosti močno narasla potreba po takih strokovnjakih.

Že danes obstoječi elektronski izdelki, kot so prenosni telefoni, prenosni računalniki in dlančniki, bodo kmalu spremenili način našega življenja. Gre za izdelke, ki so prenosni, majhni in jih odlikuje enostavnost uporabe kljub stalno naraščajočemu številu funkcij. Vsak od teh izdelkov uporablja pasivne komponente, oz. težko najdemo izdelek, ki ne bi imel vgrajenih pasivnih komponent. Načrtovalci lahko danes uporabijo mnoge pasivne komponente v primerih, ko je potrebno zadostiti zahtevam po moči, izredni stabilnosti delovanja, zaznavanju toka, termični stabilnosti, obvladovanju pulznega delovanja, vplivu frekvence ipd.. Z uporabo ustreznih pasivnih komponent lahko načrtovalec že v razvojni fazi optimizira elektronski sistem.

V prispevku obravnavamo določene poglede na izobraževanje za tehnologije zapiranja in za uporabo ustreznih pasivnih elektronskih komponent. Posebej bomo poudarili vpliv parazitnih pojavov na impedanco pasivnih komponent pri visokih frekvencah delovanja. Le-to bomo analizirali glede na tehnologijo, material, strukturo in geometrijo. Izračunane rezultate bomo primerjali z eksperimentalnimi.

1. INTRODUCTION

It is important for engineers to know and understand the technology and the science of passive components and material in order to develop the best overall product designs. With many different capabilities and unique performance characteristics available, engineers can use passive components to address many of their design challengers: power handling, current sensing, ultra high stability, low thermal deviation, thermal sensing, frequency response.

In literature there are many papers about these components, but most of them analyze the technologies, materials, precision and stability, dissipated power, thermal deviation, noise, integrated structures and applications. Only a few papers present the frequency response, respectively characteristics at high frequency .Having in view the increasing of electronic circuits' frequency, this aspect become very important for the users. For this reason in the paper will be presented some aspects of this subject.

2. PARASITIC ELEMENTS AND EQUIVALENT CIRCUITS FOR RESISTORS

Any electronic component has different parasitic elements, which may modify the good function of component. For resistors, considering the parasitic effects, the results of the equivalent circuit are shown in figure1. By neglecting the skin effect and losses in the dielectric at high frequency, the resistor can be represented by the equivalent circuit diagram shown in figure 2:

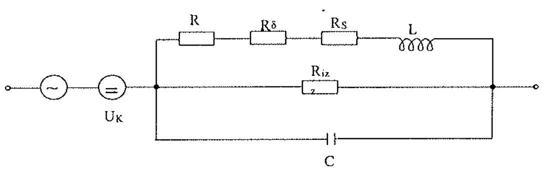

Figure 1. General equivalent circuit for resistors

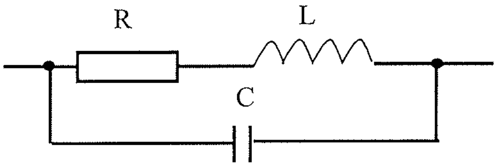

Figure 2. Equivalent circuit of resistor at high frequency

So, for high frequency, the inductance and capacitance of the resistor become important parameters and they must be smaller if the working frequency is high. The inductance is dependent on the structure of the resistor and can be approximated with the inductance of the terminals together with the inductance of the resistive element. The inductance of the terminals is function of the terminals type, dimension and the distance between them. It can be approximated with 10nH/cm for THD (Through Hole Devices) and with 0.2...0.3nH for SMD (Surface Mounted Devices). The inductance of the resistive element depends on its geometry. From this point of view, the resistive elements can be classified in: wire round- with very high inductance, spiraled film-with high inductance and plane film-with small inductance.

The resistor capacitance is dependent on the structure and the dielectric material. Predominant, resistor capacitance is determinate by the "capacitor" formed by the dielectric substrate and the contacts between the resistive element and terminals. So, the capacitance is directly proportional with the substrate dielectric constant and the area of contact between the sensitive element and terminal, and inverse proportional with the distance between contacts. For wire rounded and spiraled film resistors, the capacitance increase due to the parasitic capacitance between the spirals.

3. EXPRESSIONS FOR FREQUENCY RESPONSE OF RESISTORS

The impedance, Z, of the resistor is given by the following equation:

$$Z(\omega) = \frac{R + j\omega L}{1 - \omega^2 LC + j\omega RC} = \mathrm{Re}\{Z\} + j\,\mathrm{Im}\{Z\} \quad (1)$$

The resistive and reactive parts of the impedance will be:

$$\mathrm{Re}\{Z\} = \frac{R}{(1-\omega^2 LC)^2 + (\omega RC)^2},$$

$$\mathrm{Im}\{Z\} = \frac{\omega L(1-\omega^2 LC) - R^2 C}{(1-\omega^2 LC)^2 + (\omega RC)^2} \quad (2)$$

The admittance, Y, of the resistor is:

$$Y = \frac{1}{R + j\omega L} + j\omega C = \mathrm{Re}\{Y\} + j\,\mathrm{Im}\{Y\} \quad (3)$$

It results the conductance and susceptance,

$$\mathrm{Re[Y]} = \frac{1}{R[1+(\frac{\omega L}{R})^2]}, \ \mathrm{Im[Y]} = \omega[C - \frac{1}{L\omega^2(1+(\frac{R}{\omega L})^2)}] \quad (4)$$

The resistor has the resonance frequency, f_r, only if

$\frac{1}{R}\sqrt{\frac{L}{C}} > 1$,

and is $f_r = \frac{1}{LC}\sqrt{1 - \frac{R^2 C}{L}}$ (7)

By using the expressions (1), (2) or (3), (4) the impedance or the admittance of the resistor can be calculated. In figure 3 is shown the characteristic Im{RY}-Re{RY}. At high frequency the impedance of resistor may be capacitive or inductive in function of R,L,C values. From figure 3 results:

For $\sqrt{\frac{L}{C}} < R$ the impedance is capacitive at high frequency; the maximum working frequency decrease with the increasing of the resistance value;

For $\sqrt{\frac{L}{C}} = R$ at high frequency the impedance is capacitive, but the resistor has the biggest maximum working frequency;

For $\sqrt{\frac{L}{C}} > R$ (for small value of R), at high frequency the impedance is inductive; the maximum working frequency decreases with the decreasing of the resistance value;

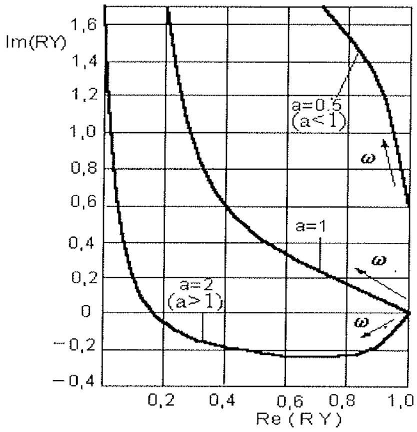

Figure 3 Characteristics Im{RY}-Re{RY} for resistors

The voltage transient response to a current step pulse of magnitude I_0 can be estimated by solving the equation:

$$\frac{d^2u}{dt^2} + \frac{R}{L}\frac{du}{dt} + \frac{1}{LC}u = \frac{RI_0}{LC}$$

The solution of the equation depends on the nature of the roots of characteristic equation. These roots have the form

$$p_{1,2} = -\alpha \pm \beta \text{ where } \alpha = \frac{R}{2L} \qquad (5)$$

So, we distinguish three cases for β real values, imaginary values or β equal to zero.

1) β is real, or equivalent $R > 2\sqrt{\frac{L}{C}}$

In this case the characteristic equation has two different real roots and the solution is:

$$u(t) = R \cdot I_0 \left[1 - \frac{e^{-\alpha t}}{\beta \cdot R \cdot C} \sinh(\beta t + k) \right] \qquad (6)$$

with k a constant given by $\tanh k = \frac{\beta}{\alpha - \frac{1}{RC}}$

2) β is equals to zero or $R = 2\sqrt{\frac{L}{C}}$

In this case the characteristic equation has one double root and the solution can be written as :

$$u(t) = R \cdot I_0 \left[1 - \left[1 - \left(\alpha - \frac{1}{RC} \right) \cdot t \right] e^{-\alpha t} \right] \qquad (7)$$

3) β is complex, or $R < 2\sqrt{\frac{L}{C}}$. We note $\beta = j \cdot \omega_p$

$$u(t) = R \cdot I_0 \left[1 + \frac{e^{-\alpha t}}{\omega_p \cdot R \cdot C} \sin(\omega_p t + k) \right]$$

$$\text{with } \tan k = \frac{\omega_p}{\alpha - \frac{1}{RC}} \qquad (8)$$

So, the pulse behavior of the resistor is somehow similar as in AC current.

Case 1 of above, $R = 2\sqrt{\frac{L}{C}}$ describes the so called damped regime. In this case the response of the resistor increase practically exponential to the final value. The rise time increases with the resistance value.

Case 2 is the critical regime and is obtained if $R = 2\sqrt{\frac{L}{C}}$, In this case the response of the resistor is similar as in case 1. The rise time in this case is lower as in case 1. In a similar way, the rise time increases with the value of C.

In case 3, for $R < 2\sqrt{\frac{L}{C}}$ the response of the resistor has oscillations. The frequency of these oscillations is ω_p which is very close to the resonance frequency of the resistor ω_0. The amplitude of the oscillations increases when R values decreases and the transition time increases with the decreasing values of resistance.

So, the behavior of resistor at current pulses depends on the parasitic elements value in a similar way as in alternative current.

4. THE INFLUENCE OF PARASITIC INTERCONNECTIONS TO THE RESISTOR

The resistor works in an electronic circuit and for this it is necessary to be connected with other components. The parasitic elements of the interconnection line modify the impedance of resistor. In this case the equivalent circuit is shown in figure 4.

In figure 4 L_1, L_2 respectively C_1, C_2 are the inductance, respectively the capacitance of the interconnection lines. The resistance of the line was neglected because it has a small value. This resistance may influence the resistance of resistor only for precision and very low resistance resistors. L_1, L_2, C_1, C_2 depend on the type and length of the interconnection lines.

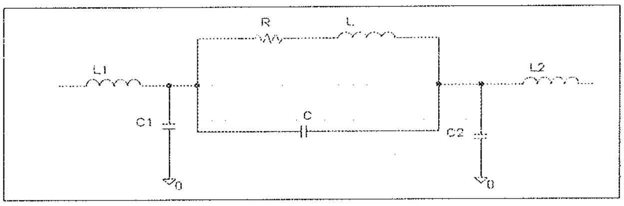

Fig.4. The equivalent circuit of resistor in interconnection environment.

At high frequency, when clock speeds in excess of 5..10MHz, or when rise times faster than 5ns exist, should be used a multilayer board and the lines should be of type microstrip and stripline.

For a microstrip line the inductance and capacitance are:

$$L_0 = 2 \ln \frac{5.98\,H}{0.8W + T}$$
(nH/cm) for 0.4mm<W<1mm (9)

$$L_0 = 1.64 \ln \frac{5.98\,H}{0.8W + T}$$
(nH/cm) for 0.1mm<W<0.4mm (10)

$$C_0 = \frac{0.264(\varepsilon_r + 1.41)}{\ln \frac{5.98\,H}{0.8W + T}} \text{ (pF/cm)} \quad (11)$$

For strip line the inductance and capacitance are:

$$L_0 = 1.998 \frac{\left(\ln \frac{1.98}{0.8W + T}\right)^2}{\ln \frac{3.81\,H}{0.8W + T}} \text{ (nH/cm)},$$

$$C_0 = 0.555 \frac{\varepsilon_r}{\ln \frac{3.81\,H}{0.8W + T}} (pF/cm) \quad (12)$$

All dimensions in the expressions (9)-(12) are in cm. In table 1 are presented some values for inductance and capacitance of microstrip and strip lines with FR-4 material and T=17 μm, in function of W/H.

5. SIMULATION AND COMPUTATIONAL RESULTS FOR RESISTORS

For the impedance computation and for the transient behavior of the resistor were made PSPICE simulations and also the impedance was computed using the given relations. In figures 5 - 12 are presented the computed and simulated results of impedance resistor in different cases. The results sustain the observations presented in the second paragraph. For low values of resistance the influence of inductance is strong, see figure 7; the working frequency decreases with the increasing inductance; for higher resistance values the influence of inductance can be neglected (fig.8). The influence of capacitance is high for high resistance values (fig. 9) and low for low resistance values (fig. 10). The inductance and capacitance of interconnection lines produce series resonant frequency and can reduce considerably the maximum working frequency of resistor.

In figures 13 - 18 are presented the computed and simulated results of the transient voltage across the resistor as response to a current step transition of 1 mA.

W/H		0.1	0.2	0.3	0.4	0.5	0.8	1	1.5	2	2.5	3
Microstrip line	L0 (μH/cm)	7.2	6	5.4	4.9	4.5	3.7	3.36	3.2	2.7	2.22	1.85
Microstrip line	C0 (pF/cm)	0.34	0.4	0.46	0.5	0.55	0.66	0.73	0.92	1.12	1.34	1.62
Strip line	L0 (μH/cm)	7.7	6.3	5.52	4.94	4.5	3.56	3.11	2.3	1.73	1.28	0.42
Strip line	C0 (pF/cm)	0.57	0.7	0.8	0.9	0.98	1.25	1.42	1.93	2.58	3.46	4.48

Table. 1 Inductance and capacitance for strip and microstrip line:

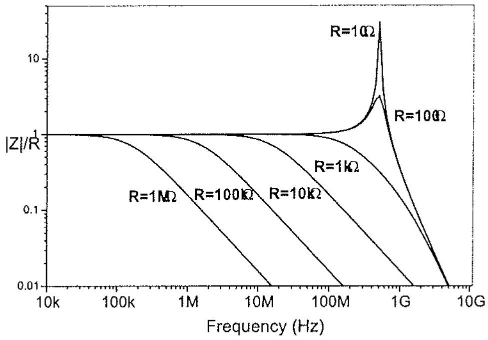

Fig. 5. Normed impedance of resistor for C=1pF, L=100nH, R=(10Ω; 100Ω; 1kΩ; 10kΩ; 100kΩ; 1MΩ)

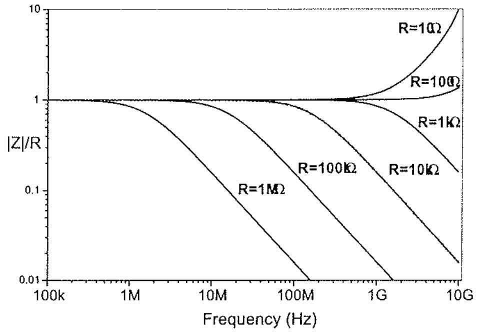

Fig. 6. Impedance of resistor for C=0.1pF, L=1nH, R=(10Ω; 100Ω; 1kΩ; 10kΩ; 100kΩ; 1MΩ)

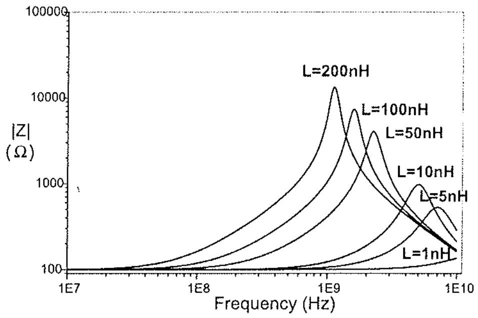

Fig. 7. Impedance of resistor for R=100Ω, C=0.1pF, L=(1; 5; 10; 50;100; 200)nH

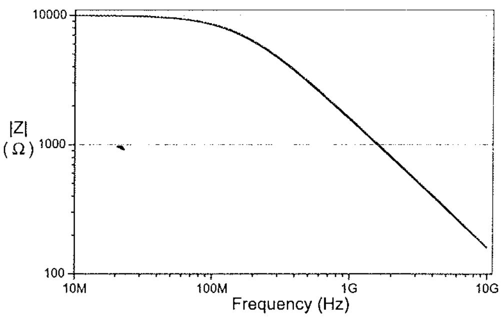

Fig. 8. Impedance of resistor for R=10kΩ, C=0.1pF, L=(1; 5; 10; 50;100; 200)nH

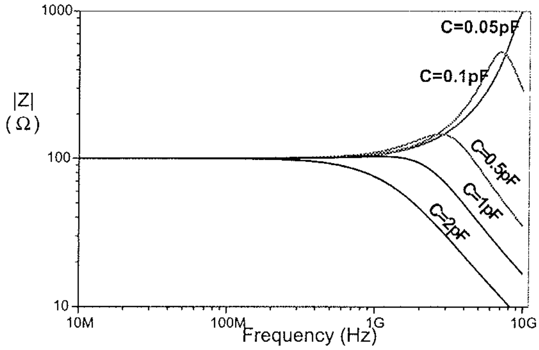

Fig. 9. Impedance of resistor for R=100Ω, L=5nH, C=(0.05; 0.1; 0.5; 1; 2) pF

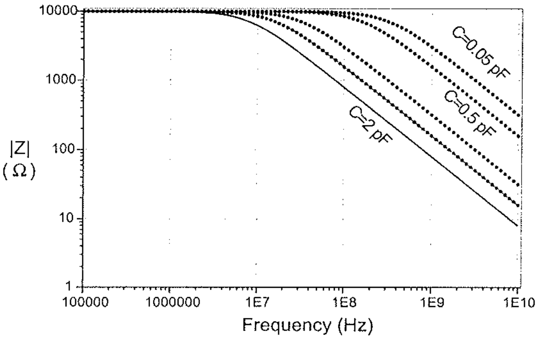

Fig. 10. Impedance of resistor for R=10kΩ, L=5nH, C=(0.05; 0.1; 0.5; 1; 2) pF

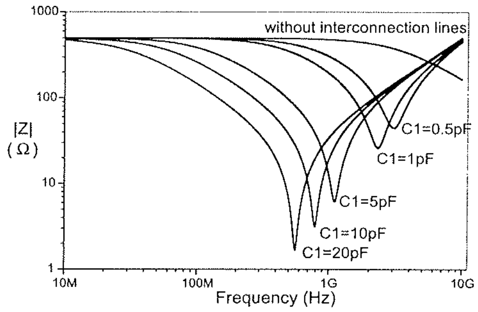

Fig. 11 Influence of the line to resistor impedance for R=500Ω, L=2nH, C=0.1pF, L_1=L_2=4nH, C_1=C_2=(0.5;1;5;10;20)pF

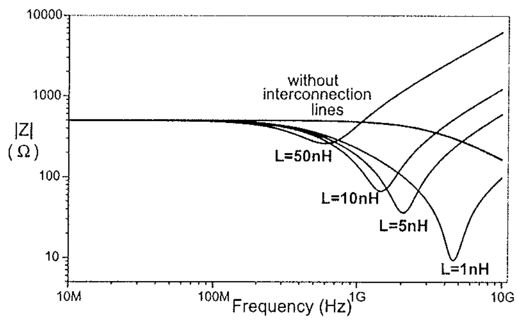

Fig. 12 Influence of the line to resistor impedance for R=500Ω, L=2nH, C=0.1pF, C_1=C_2=1pF, L_1= L_2=(1;5;10;50)nH

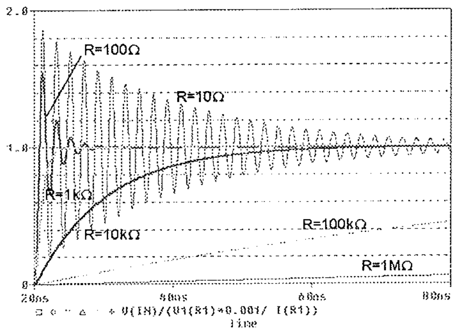

Fig. 13. Normed transient response of resistor for C=1pF, L=100nH, R=(10Ω; 100Ω; 1kΩ; 10kΩ; 100kΩ; 1MΩ)

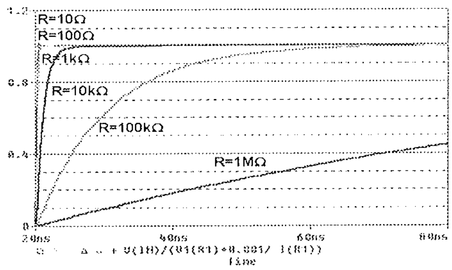

Fig. 14. Normed transient response of resistor for C=0.1pF, L=1nH, R=(10Ω; 100Ω; 1kΩ; 10kΩ; 100kΩ; 1MΩ)

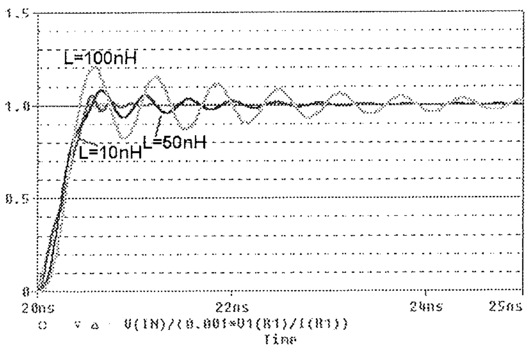

Fig. 15. Normed transient response of resistor for R=100Ω, C=0.1pF, L=(1; 5; 10; 50;100)nH

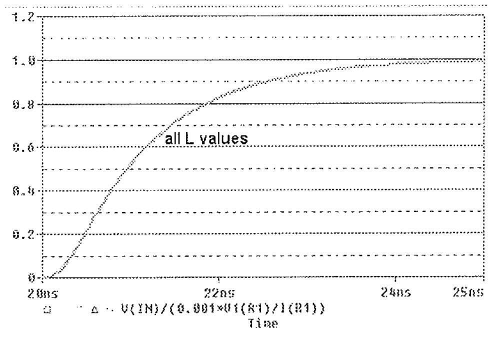

Fig. 16. Normed transient response of resistor for R=10kΩ, C=0.1pF, L=(1; 5; 10; 50;100)nH

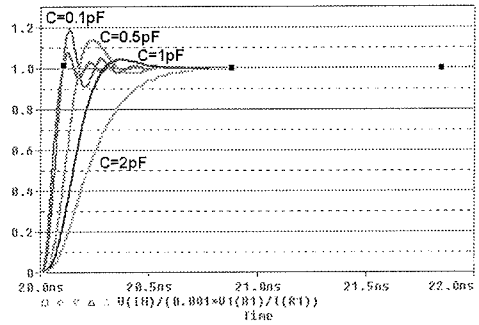

Fig. 17. Normed transient response of resistor for R=100Ω, L=5nH, C=(0.05; 0.1; 0.5; 1; 2) pF

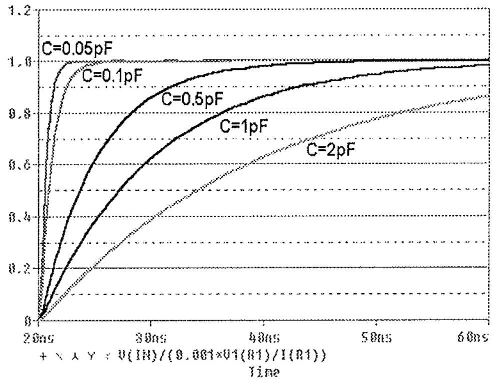

Fig. 18. Normed transient response of resistor for R=100Ω, L=5nH, C=(0.05; 0.1; 0.5; 1; 2) pF

6. PARASITIC COMPONENTS AND EQUIVALENT CIRCUITS FOR CAPACITORS

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. Have in view this parasitic components and the structure of capacitors results the equivalent circuit shown in figure 19. At high frequency, the equivalent circuit can be simplified as in figure 20. R is called ESR and L is called ESL.

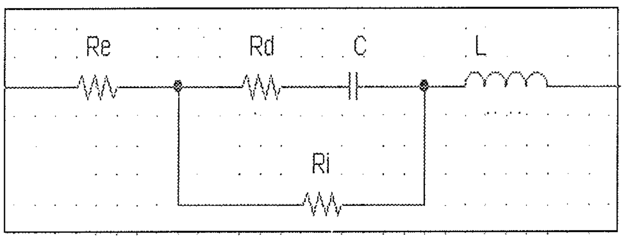

Fig. 19 Equivalent circuit of capacitor

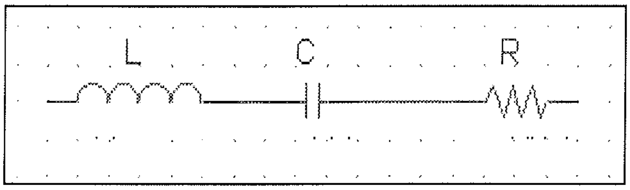

Fig. 20 Simplified equivalent circuit of capacitor at high frequency

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 high and the electrodes number of capacitor. ESR is determined by energy dissipation mechanisms and is dependent of the dielectric material, electrodes and terminations. At high frequency, for chip capacitor, is very important the electrodes resistance, because this resistance increase with $f^{1/2}$ due to skin effect. The electrodes resistance increases with the distance between terminations and is dependent to the type of material and the thickness of electrodes. ESR is also dependent from frequency and capacitance,

$$R = R_e + R_d = R_e + \tan\delta/\omega C \quad (13)$$

$\tan\delta$ is the dielectric loss factor.

The resonant frequency is important for high frequency, a decoupling capacitor, as the resonant point will give the most signal attenuation. The resonant frequency is calculated from the simple equation,

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (14)$$

7. CHARACTERITICS OF CERAMIC CHIP CAPACITORS AT HIGH FREQUENCY

For measurement was utilized the impedance analyzer type HP 4396B 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: NPO, X7R, X5R, Y5V. The NPO 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. In function of 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 shown in figure 22. ESR and L have a small variation with dimension. Typical L is shown in table 1. Cube capacitors have the same length, width and height and have a medium ESR and L. Modified capacitors have terminations on the larger sides, see figure 21.

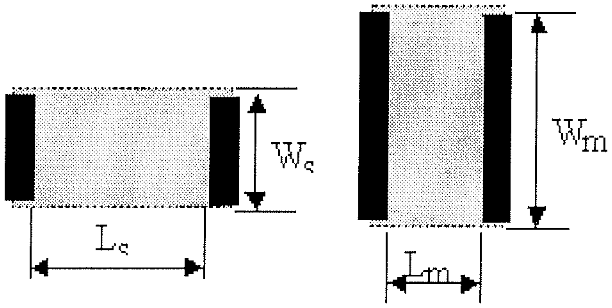

Fig. 21. Standard and modified chip capacitors

Compare standard and modified chip capacitor for the same capacitance and electrode areas, results, /8/,

$$R_m = R_s/k^2, \quad L_m = L_s/k \quad (15)$$

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

$$K = L_s/L_m = W_m/W_s \quad (16)$$

So, these capacitors have a low ESR and L.

Using SPICE simulation the impedance versus frequency for different capacitors is shows in figures 22 - 27. For every type on capacitor the impedance at high frequency is depending of ESR, see figure 22 and inductance, see figure 23. A solution for to obtained a capacitor with low ESR and ESL is connection in parallel. The impedance of identical capacitors in parallel is reduced by a factor of two every time the quantity is doubled, see figure 24. The ESR of n identical capacitors in parallel - ESR_p- at the resonance frequency is

$$ESR_p = ESR/n \quad (17)$$

From figures 25 - 27 results than for to obtain a low impedance in a big 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 25 - 27, 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.

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

Table. 2 The capacitor parameters, which are used for SPICE simulation in figures 25-27.

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 3 Equivalent series inductance for some chip capacitors

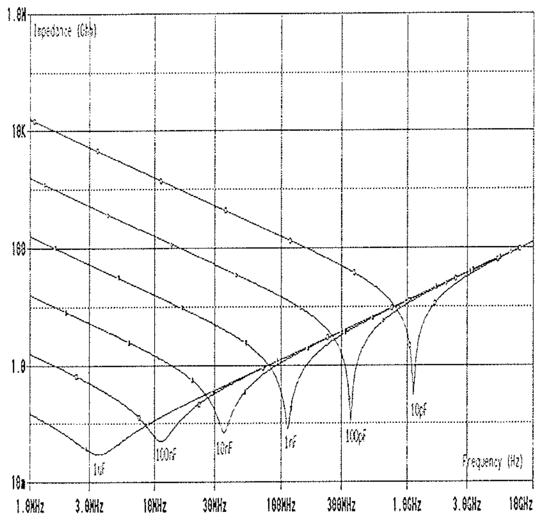

Figure 22. Impedance versus frequency for several standard X7R and NPO capacitors.

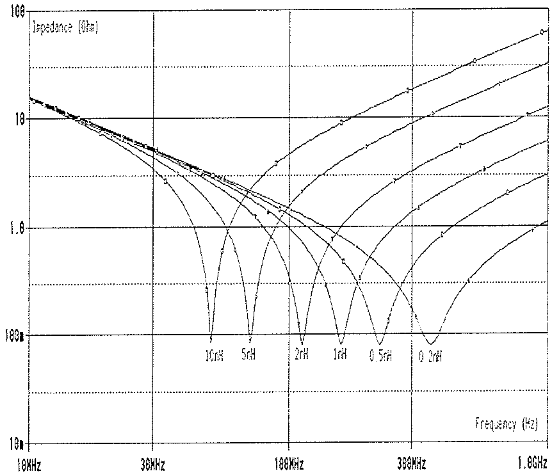

Figure 23. Impedance capacitor for different inductance values.

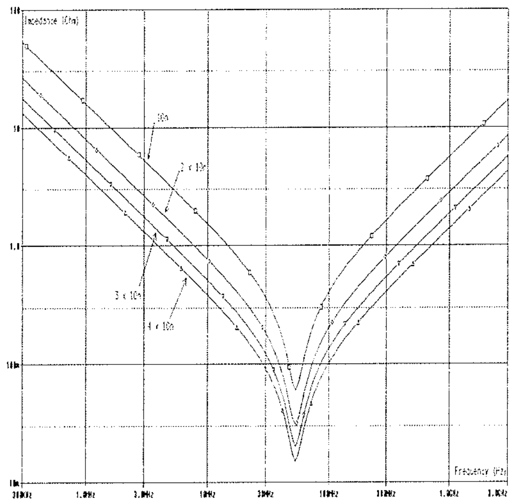

Figure 24. The impedance versus frequency for identical capacitors in parallel.

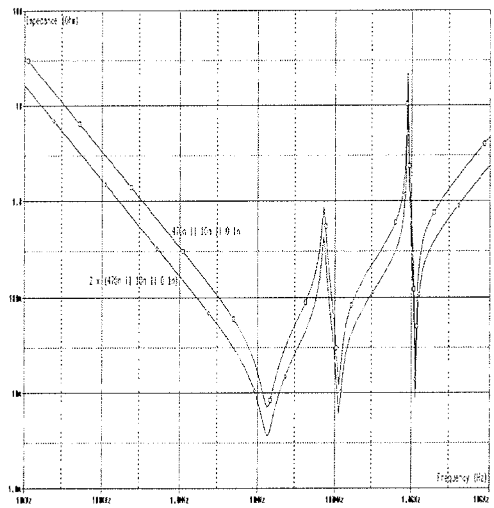

Figure 25. Impedance for three and six chip capacitors with low ESR and L in parallel.

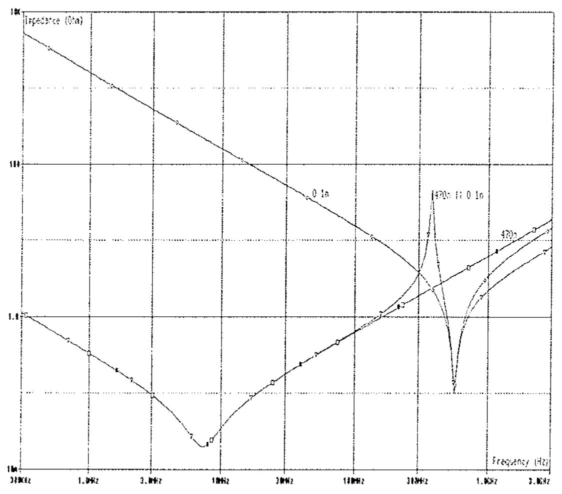

Figure 26. *Impedance for two standard ceramic chip capacitors in parallel.*

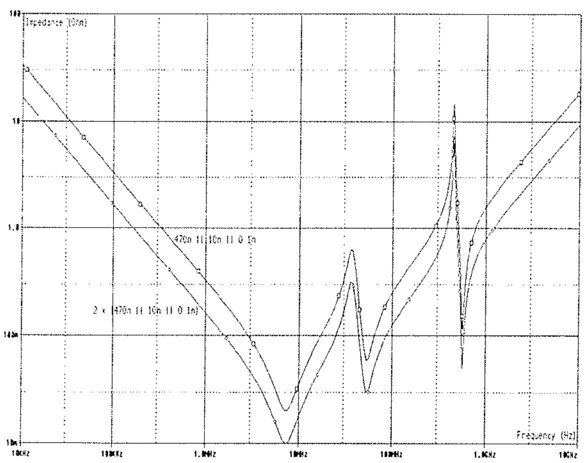

Figure 27 *Impedance for three and six standard ceramic chip capacitors in parallel.*

8. THE INFLUENCE OF THE RESISTOR PARASITICS ON THE BODE PLOT FOR A RC LOW-PASS FILTER

In figure 32 is shown the influence of the resistor parasitics, with the measured impedance presented in figure 29 - 31, on the Bode plot for a RC low-pass filter with a ceramic capacitor which has the measured impedane presented in figure 28.

9. CONCLUSIONS

At high frequency the impedance of resistor may be capacitive or inductive in function of R, L, C values. For big values of resistance the impedance is capacitive at high frequency and the maximum working frequency decrease with the increasing of the resistance value. For medium values, the impedance is capacitive, but the resistor has

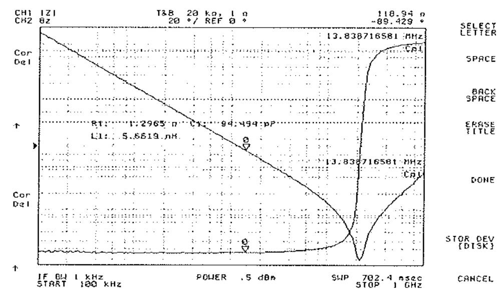

Figure 28. *The impedance versus frequency for a ceramic type I capacitor (100pF)*

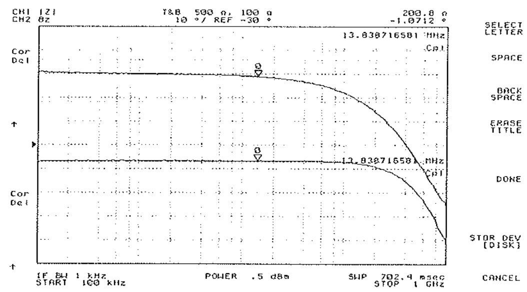

Figure 29. *The impedance versus frequency for a thick film resistor- R1 (200Ω*

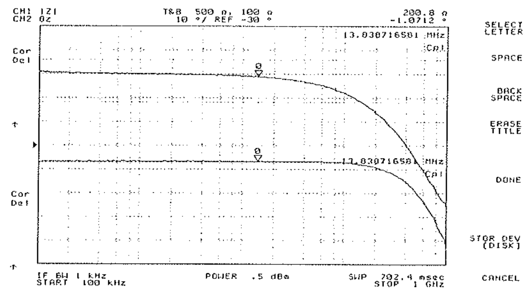

Figure 30. *The impedance versus frequency for a carbon film resistor – R2 (200Ω/0.25W))*

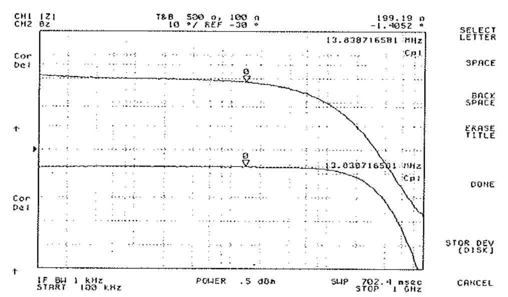

Figure 31. *The impedance versus frequency for a carbon film resistor – R3 (200Ω/0.1W)*

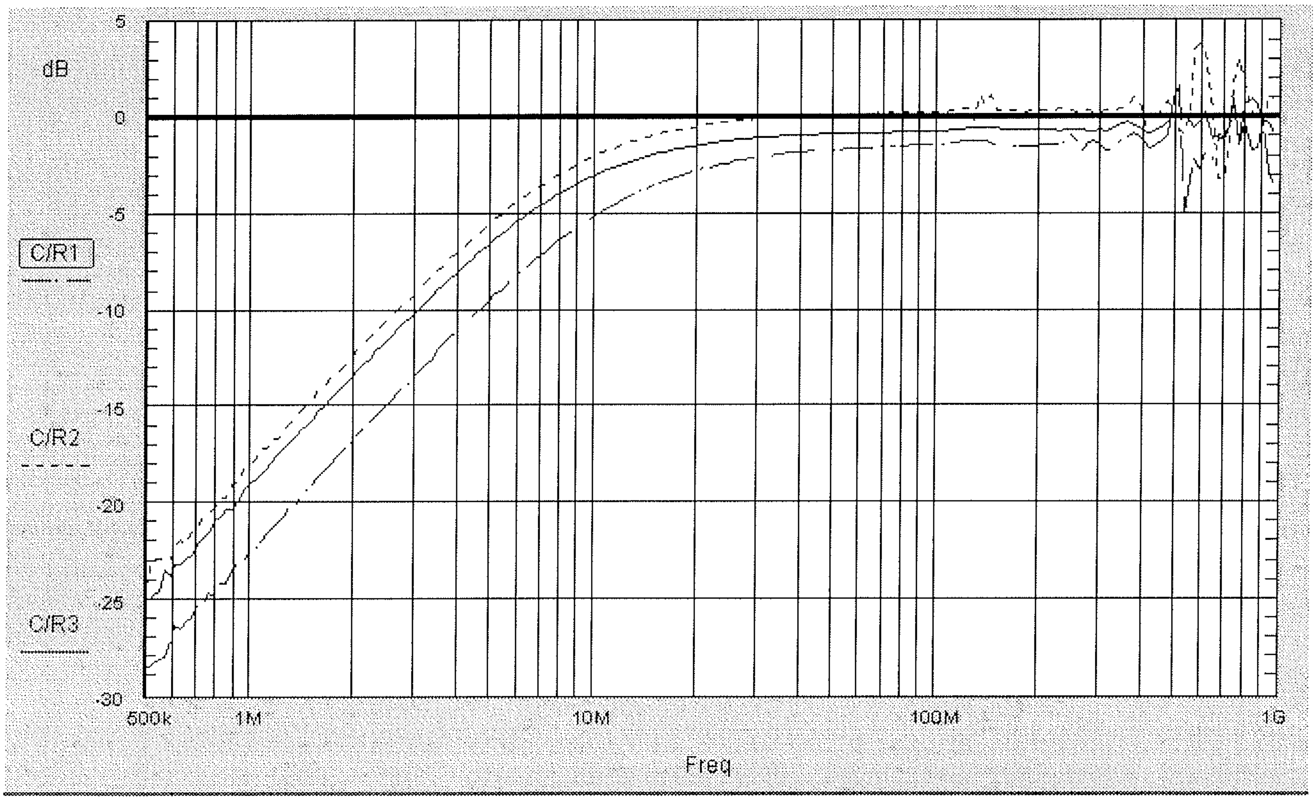

Figure 32. The influence of the resistor parasitics on the Bode plot for a RC low-pass filter

the biggest maximum working frequency. For small values, at high frequency the impedance is inductive and the maximum working frequency decreases with the decreasing of the resistance value.

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. These parameters are analised 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 capaacitors. A methodology for realize a capacitor with low impedance in a broad bandwith is connection in parallel of some capacitors with different capacitance.

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