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# Parasitic capacitances of converters and EMC

[1]*Irena KOVÁČOVÁ*

[1] Department of Theoretical and Industrial Electrical Engineering, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Slovak Republic

[1]irena.kovacova@tuke.sk

***Abstract* — Main attention of the paper is focused on implications of parasitic capacitance and capacitive coupling existence in converters.**

***Keywords* — EMC, converter, parasitic capacitances, capacitive coupling**

## I. Introduction

The importance of the electromagnetic compatibility (EMC) of all electrical products is rapidly increasing during the last decade. The environment is increasingly polluted by electromagnetic energy. The interference output into own surroundings, is doubled every three years, and covers a large frequency range.

## II. Converters parasitic capacitance calculation

Capacitive coupling is typical for galvanically separated circuit nodes, between which exists mutual influence by individual intensity vectors $\overline{E}_i$ of electrostatic field, Figure 1. In such case the influence value is given by rising or decreasing slope of potential in described nodes, electrode area dimensions, space dielectric property and wire geometrical ordering in described nodes.

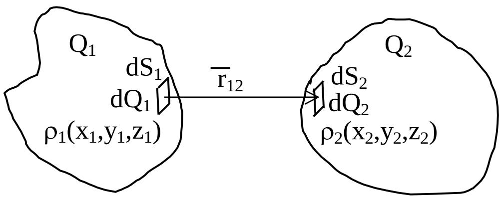


Fig. 1 Capacitive coupling

For predictive investigation of capacitive coupling implications we will come out from well-known Maxwell's equations valid for electrostatic field:

$$rot\,\overline{E} = 0 \tag{1}$$

$$div\,\overline{D} = \rho \tag{2}$$

where the vector of electric induction $\overline{D}$ is given as

$$\overline{D} = \varepsilon.\overline{E} \tag{3}$$

Based on physics knowledge we can state the force acting between two elementary charges Q1 and Q2.

$$\bar{F} = \frac{1}{4\pi\varepsilon_0} \int_{S_1} \int_{S_2} \frac{\bar{r}_{12}}{r_{12}^3} .\rho_1 .dS_1 .\rho_2 .dS_2 \tag{4}$$

where $\rho_1 = dQ_1/dS_1$ and $\rho_2 = dQ_2/dS_2$. One element $\bar{E}_{1i}$ of electrostatic intensity vector $\bar{E}_1$ can be expressed as:

$$\bar{E}_{1i} = \frac{\bar{F}_{1i}}{Q_{2i}} = \frac{\frac{Q_{2i}}{4\pi\varepsilon_0} \int_{S_1} \frac{\bar{r}_{12}}{r_{12}^3} .\rho_1 .dS_1}{Q_{2i}} = \frac{1}{4\pi\varepsilon_0} \int_{S_1} \frac{\bar{r}_{12}}{r_{12}^3} .\rho_1 .dS \tag{5}$$

Total electrostatic intensity vector $\bar{E}$ at investigated place will be given as sum of vectors $\bar{E}_1$ and $\bar{E}_2$ induced by both charged volumes. Existing voltage between these volumes is possible to express by next equation.

$$U_{12} = \varphi_1 - \varphi_2 = \int_1^2 \left(\bar{E}_1 + \bar{E}_2\right). d\bar{r}_{12} = \int_1^2 \left( \frac{1}{4\pi\varepsilon_0} \int_{S_1} \frac{\bar{r}_{12}}{r_{12}^3} .\rho_1 .dS_1 + \frac{1}{4\pi\varepsilon_0} \int_{S_2} \frac{\bar{r}_{21}}{r_{21}^3} .\rho_2 .dS_2 \right) .d\bar{r}_{12} \tag{6}$$

If we will suppose that $Q_1 = Q$ and $Q_2 = -Q$, so we can to write the equation for created capacitance.

$$C_{12} = \frac{Q}{U_{12}} \tag{7}$$

In many cases the engineers must state mutual parasitic capacitance of two wires, which have optional routing as it is shown in Figure 2.

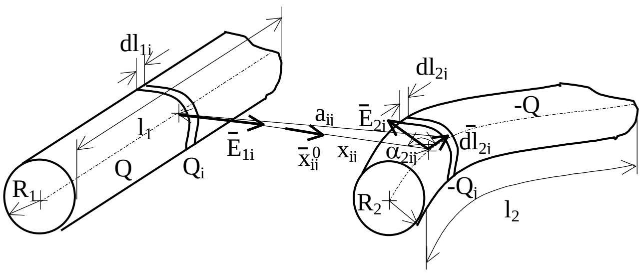


Fig.2 Capacitive coupling

The analytical expression of resulting capacitance is very difficult in such case and in due to they are utilizing analytic-numerical method consist in differential form utilizing. For all that the following basic assumption must be done.

$$l_1 = \sum_{i=1}^{m\to\infty} dl_{1i}, \quad l_2 = \sum_{j=1}^{k\to\infty} dl_{2j} \tag{8}$$

The potential at the second wire place we can express by next equation.

$$\varphi_2 = \sum_{i=1}^{m} \frac{Q_i}{2\pi\varepsilon dl_i} .\ln \frac{x_{ij} - R_2}{R_1} .\sin(\alpha_{2ij}) = \sum_{i=1}^{m} \frac{Q_i}{2\pi\varepsilon dl_i} .\ln \frac{x_{ij} - R_2}{R_1} . \sqrt{\left(1 - \left(\frac{x_{ij}^2 + \left(\frac{dl_{2j}}{2}\right)^2 - a_{ij}^2}{x_{ij} .dl_{2j}}\right)^2\right)} \tag{9}$$

Similar we can state the potential for first wire position.

$$\varphi_1 = \sum_{j=1}^{n} \frac{-Q_j}{2\pi\varepsilon dl_j}.\ln\frac{x_{ji}-R_2}{R_1}.\sin(\alpha_{1ji}) = \sum_{j=1}^{n} \frac{-Q_j}{2\pi\varepsilon dl_j}.\ln\frac{x_{ji}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ji}^2+\left(\frac{dl_{1i}}{2}\right)^2-a_{ji}^2}{x_{ji}.dl_{1i}}\right)^2\right)} \tag{10}$$

Voltage between both wires will be given as:

$$U = \frac{Q}{2\pi\varepsilon}\left(\sum_{i=1}^{m}\frac{\ln\frac{x_{ij}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ij}^2+\left(\frac{dl_{2j}}{2}\right)^2-a_{ij}^2}{x_{ij}.dl_{2j}}\right)^2\right)}}{dl_{1i}} + \sum_{j=1}^{n}\frac{\ln\frac{x_{ji}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ji}^2+\left(\frac{dl_{1i}}{2}\right)^2-a_{ji}^2}{x_{ji}.dl_{1i}}\right)^2\right)}}{dl_{2j}}\right) \tag{11}$$

Searched value of parasitic capacitance is possible to state by Coulomb's law.

$$C_{12} = \frac{2\pi\varepsilon}{\left(\sum_{i=1}^{m}\frac{\ln\frac{x_{ij}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ij}^2+\left(\frac{dl_{2j}}{2}\right)^2-a_{ij}^2}{x_{ij}.dl_{2j}}\right)^2\right)}}{dl_{1i}} + \sum_{j=1}^{n}\frac{\ln\frac{x_{ji}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ji}^2+\left(\frac{dl_{1i}}{2}\right)^2-a_{ji}^2}{x_{ji}.dl_{1i}}\right)^2\right)}}{dl_{2j}}\right)} \tag{12}$$

Expressing of individual equation members for 3-D Cartesian system shown in Figure 3 is possible to do by the following equations.

$$dl_{1i} = \sqrt{(x_{1i}-x_{0i})^2+(y_{1i}-y_{0i})^2+(z_{1i}-z_{0i})^2} \tag{13}$$

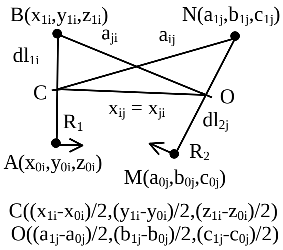


Fig. 3 3-D Cartesian system

$$dl_{2j} = \sqrt{(a_{1j}-a_{0j})^2+(b_{1j}-b_{0j})^2+(c_{1j}-c_{0j})^2} \tag{14}$$

$$a_{ij} = \sqrt{(a_{1j}-(x_{1i}-x_{0i})/2)^2+(b_{1j}-(y_{1i}-y_{0i})/2)^2+(c_{1j}-(z_{1i}-z_{0i})/2)^2} \tag{15}$$

$$a_{ji} = \sqrt{(x_{1i}-(a_{1j}-a_{0j})/2)^2+(y_{1i}-(b_{1j}-b_{0j})/2)^2+(z_{1i}-(c_{1j}-c_{0j})/2)^2} \tag{16}$$

$$x_{ij} = x_{ji} = \sqrt{((a_{1j}-a_{0j})/2-(x_{1i}-x_{0i})/2)^2+((b_{1j}-b_{0j})/2-(y_{1i}-y_{0i})/2)^2+((c_{1j}-c_{0j})/2-(z_{1i}-z_{0i})/2)^2} \tag{17}$$

Only such wire length elements $dl_{1i}$ and $dl_{2j}$ must be taken for total parasitic capacity calculation, are fulfilling the next conditions.

$$x_{ji}^2+\left(\frac{dl_{1i}}{2}\right)^2 = (x_{1i}-(a_{1j}-a_{0j})/2)^2+(y_{1i}-(b_{1j}-b_{0j})/2)^2+(z_{1i}-(c_{1j}-c_{0j})/2)^2 \tag{18}$$

$$x_{ij}^2+\left(\frac{dl_{2j}}{2}\right)^2 = (a_{1j}-(x_{1i}-x_{0i})/2)^2+(b_{1j}-(y_{1i}-y_{0i})/2)^2+(c_{1j}-(z_{1i}-z_{0i})/2)^2 \tag{19}$$

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Correctness verification of obtained results can be done by simulation and measuring. For this purpose is possible to utilize the connection of DC impulse converter shown in Figure 4.

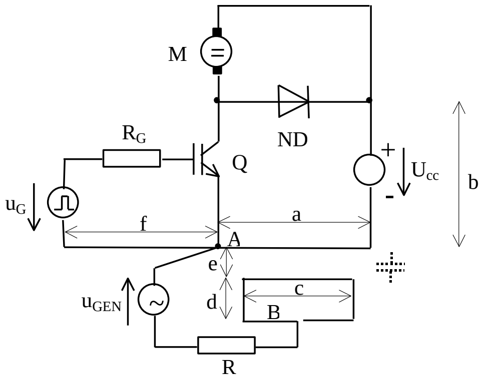


Fig. 4 Investigated circuit

We will try to state the value of parasitic capacitance between the node A of impulse converter and node B of sense loop. Space dielectric material is created by air. Geometrical dimensions of investigated circuits are a = f = 0,2 m, b = 0,3 m, c = 0,1 m, d = 0,05 m, e = 0,00135 m. Wires are made from cooper with the radius R = 0,0006 m. Based on above mentioned parameters it is possible to calculate the individual partial parasitic capacitances.

$$C_{ace} = \frac{1}{\frac{1}{2\pi\varepsilon_0 a}\ln\frac{e-R}{R} + \frac{1}{2\pi\varepsilon_0 c}\ln\frac{e-R}{R}} = 16{,}63\,pF \quad (20)$$

$$C_{aced} = \frac{1}{\frac{1}{2\pi\varepsilon_0 a}\ln\frac{(d+e)-R}{R} + \frac{1}{2\pi\varepsilon_0 (c-0{,}001)}\ln\frac{(d+e)-R}{R}} = 0{,}8306\,pF \quad (21)$$

$$C_{fce} = \frac{1}{\frac{1}{2\pi\varepsilon_0 a}\ln\frac{\sqrt{e^2+a^2}-R}{R} + \frac{1}{2\pi\varepsilon_0 c}\ln\frac{\sqrt{e^2+a^2}-R}{R}} = 0{,}6391\,pF \quad (22)$$

$$C_{fced} = \frac{1}{\frac{1}{2\pi\varepsilon_0 a}\ln\frac{\sqrt{(d+e)^2+a^2}-R}{R} + \frac{1}{2\pi\varepsilon_0 (c-0{,}001)}\ln\frac{\sqrt{(d+e)^2+a^2}-R}{R}} = 0{,}6314\,pF \quad (23)$$

$$C_{bda-c} = \frac{1}{\frac{1}{2\pi\varepsilon_0 \frac{b}{2}}\ln\frac{\sqrt{\left(\frac{b}{4}+e+\frac{d}{2}\right)^2+\left(\frac{a}{2}-\frac{c}{2}\right)^2}-R}{R} + \frac{1}{2\pi\varepsilon_0 d}\ln\frac{\sqrt{\left(\frac{b}{4}+e+\frac{d}{2}\right)^2+\left(\frac{a}{2}-\frac{c}{2}\right)^2}-R}{R}} = 0{,}3989\,pF \quad (24)$$

$$C_{bda+c} = \frac{1}{\frac{1}{2\pi\varepsilon_0 \frac{b}{2}}\ln\frac{\sqrt{\left(\frac{b}{4}+e+\frac{d}{2}\right)^2+\left(\frac{a}{2}+\frac{c}{2}\right)^2}-R}{R} + \frac{1}{2\pi\varepsilon_0 d}\ln\frac{\sqrt{\left(\frac{b}{4}+e+\frac{d}{2}\right)^2+\left(\frac{a}{2}+\frac{c}{2}\right)^2}-R}{R}} = 0{,}3658\,pF \quad (25)$$

$$C = C_{ace} + C_{aced} + C_{fce} + C_{fced} + 2.C_{bda-c} + 2.C_{bda+c} = 20{,}26\,pF \tag{26}$$

Based on calculated capacitance the simulation analysis is possible to do now by PSPICE program and circuit connection shown in Figure 5.

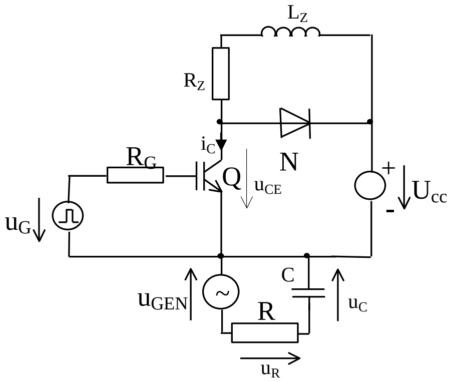


Fig. 5 Simulation circuit

Parameters of individual elements are $U_{CC}$ = 70 V, $R_Z$ = 11,66 Ω, $L_Z$ = 400 μH, R = 1 MΩ, $u_{GEN}$ = 2 sin (ωt) V. Simulation results for frequency f = 10 kHz are pictured in Figure 6.

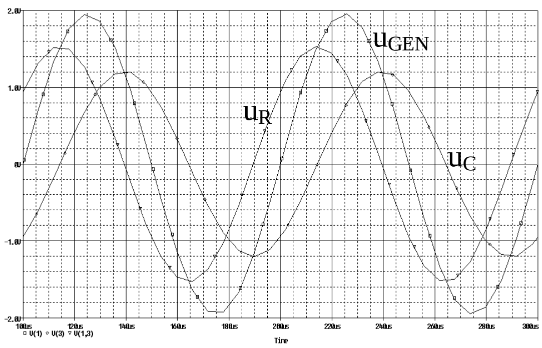


Fig. 6 Simulation results for f = 10 kHz

The same output values obtained by simulation, but for frequency f = 50 kHz are shown in Figure 7.

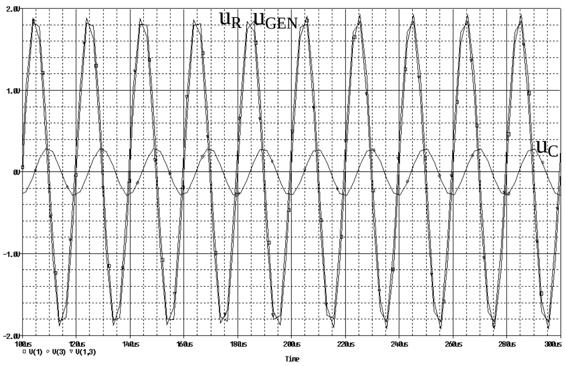


Fig. 7 Simulation results for f = 50 kHz

Measured values of $u_{CE}$, $u_{GEN}$ and $u_C$ are shown in next figures Figure 8 till to Figure 11.

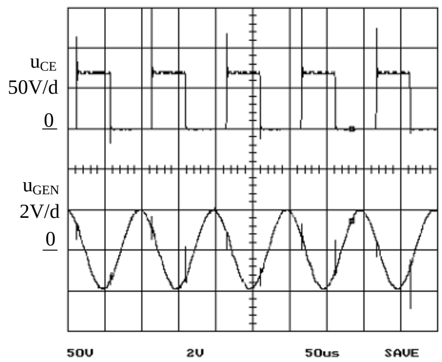


Fig. 8 Measured results for f = 10 kHz

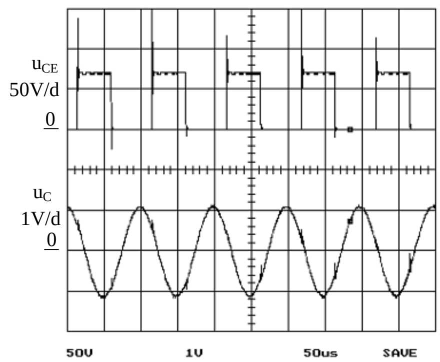


Fig. 9 Measured results for f = 10 kHz

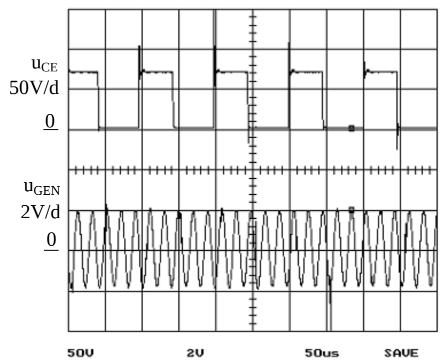


Fig. 10 Measured results for f = 50 kHz

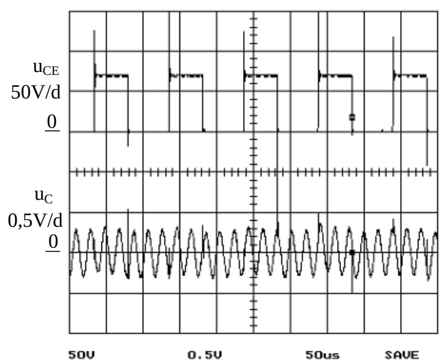


Fig. 11 Measured results for f = 50 kHz

By comparing of simulated and measured results one can see that obtained results are identical and it means that derived analytical formula for parasitic capacitance calculation is valid.

In due to additional verification requirement the same problem is possible to analyze also by numerical, finite element simulation method of electrostatic field. Obtained result is shown in Figure 12.

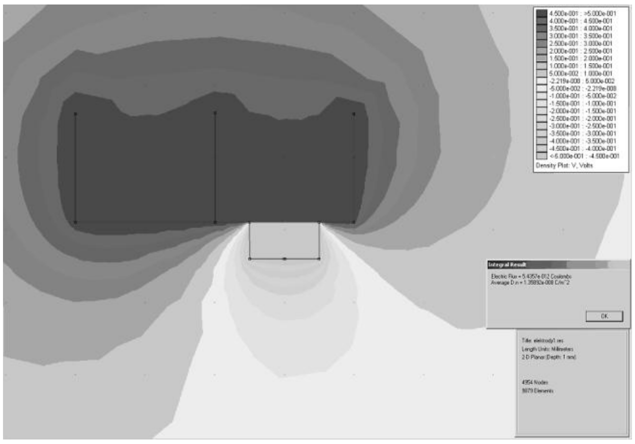

Fig. 12 Finite element method simulation

From data window is possible to state that the value of electrical flux between both nodes is 5,4357.10$^{-12}$ C. Based on the program property we must multiple this value by value of wires perimeter $l = 2.\pi.R = 2.\ \pi.0{,}6 = 3{,}76$ mm. Total electrical flux is then 20,4382 C. In due to fact that the voltage between nodes have value 1V, so the resulting parasitic capacitance is C = 20,4382 pF.

By comparing of all results we can state that difference is only 0,879% and it means that the correctness of derived formula for parasitic capacitance calculation is satisfy.

## III. Conclusion

Obtained formula for parasitic capacitance calculation enabling predictive EMC investigation. Although such converter capacitances seem to be negligible so performed analyze show to us that it can have important influence. Mainly in the case when the switching frequency is high or one of the both nodes belong to the circuit with great impedance. It is obviously in the case of capacitive coupling existence between CMOS integrated circuits and power converter circuit when EMC quality can be very fundamental for right equipment operation.

## References

[1] Kováč, D. Simulation Models of Power Elements in PSPICE Program. In *Proceedings of Conference on Power Electronics and Motion Control*, PEMC´94, Warsaw, 1994,

[2] Kováčová, I. Optimal Procedure for the Design of Power Converter Connection with Unipolar Transistors. In *Proceeding of 9th International Scientific Conference*, Žilina, 1993, pp.117-120

[3] Kováčová, I. The Influence of Individual Parameters of Power and Control Circuits on the Switching Process of Power MOSFETs. In *Proceedings of International Conference Electrical Drives and Power Electronics*, Košice, 1992, pp. 268-270

[4] Kováčová, I. Switching Simulation Models of Power MOSFET and IGBT. In *Proceeding of International Conference*, Ostrava, 1995, pp.191-196

[5] Gallová, Š. Tools to Model Uncertainty in Knowledge-based System. In *Transactions of the Universities of Košice*, No. 2, 2000, pp. 1 - 4.

[6] Kováčová, I. Function Simulation of Converters and Inverters in PSPICE Program. In *16th International Symposium of Teachers of Electrical Drives and Power Electronics*, Brno, 1996, pp. 75-80

[7] Kováč, D. Simulation Models of Power MOSFET and Power Diode Switching. In *Journal of Electrical Engineering*, No.8, 1994