Minimization of Noise Current on a printed Circuit Board

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***Abstract*—The modern society is mainly influenced by the latest high-tech innovations and devices. Especially in terms of Covid-19, digitization has made progress and is more than ever indispensable for our daily life. The majority of smart devices (e.g. laptops, smartphones) are using printed circuited boards to connect the different working elements. The minimization of power losses on those circuited boards, is one key element to optimize smart devices. This paper investigates the minimization of noise current on a printed circuit board and the effectiveness of a decoupling capacitor.**

***Index Terms*—Circuit board, noise current, Student Contest**

I. Introduction

A printed circuit board is mostly used in high tech devices to connect the used elements on the board on an easy way. Moreover, it is low cost and easy to manufacture. The printed circuit board is powered by an ideal current source and the task is to minimize the noise current at a special spot. The solution for that issue is a decoupling capacitor, which is placed near by the source. The reason for that is discussed later in this paper. The printed circuit board has a length of $200\,\mathrm{mm}$, a width of $150\,\mathrm{mm}$ and a height of $1.5\,\mathrm{mm}$. The substrate is *FR-4* with $\epsilon_r = 4.3$ and $\tan\delta = 0.025$. There are no specification about the sickness of the copper layer, because of that the sickness is set to $35\,\mu\mathrm{m}$. In terms of the IEEE Student Contest, the task is to design a decoupling capacitor to achieve the lowest noise current on a specific spot at the board, which is called sink.

II. Solution of the Problem

The solution of the complex problem is separated into some simple preliminary considerations and a complex full wave simulation of the setup, solved by the finite integration technique (FIT).

A. Preliminary Considerations

The complex problem, to minimize the noise current at the sink, can generally be expressed by a simple equivalent circuit diagram Fig. 1. This equivalent circuit does not cover the whole problem, but represents some of the main elements of the described task. Obviously, the decoupling capacitor is the most important component to solve the issue. This real capacity is a series oscillating circuit, including an inductance, a capacity and a resistance. The specific values are $L = 4\,\mathrm{nH}$, the capacity between $1\,\mathrm{pF} \leq C \leq 1\,\mu\mathrm{F}$ and the resistance among $10\,\mathrm{m}\Omega \leq R_\mathrm{D} \leq 10\,\Omega$. This series can be expressed

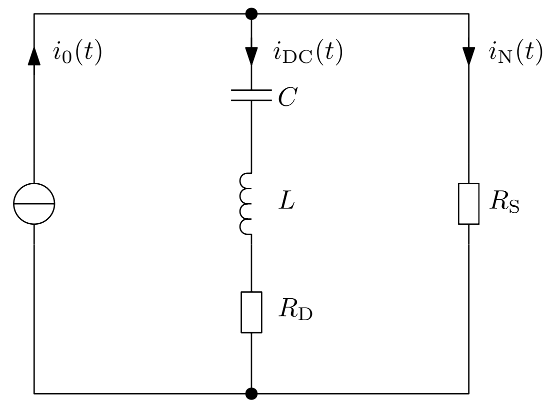

Fig. 1. Equivalent circuit diagram of the series oscillating circuit

as a complex impedance $\underline{Z}(\omega)$ and the absolute value $|\underline{Z}(\omega)|$ is determined by (1).

$$|\underline{Z}(\omega, R_\mathrm{D}, C)| = \sqrt{R_\mathrm{D}^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} \tag{1}$$

The stimulated current $i_0(t)$, represented by (2), has two frequencies $f_1 = 355\,\mathrm{MHz}$ and $f_2 = 472\,\mathrm{MHz}$, causing two different impedances $\underline{Z}(\omega_1)$ and $\underline{Z}(\omega_2)$.

$$i_0(t) = 1\,\mathrm{mA}\left(\sin\left(2\pi \cdot 355\,\mathrm{MHz} \cdot t\right) + \sin\left(2\pi \cdot 472\,\mathrm{MHz} \cdot t\right)\right) \tag{2}$$

The impedance of the series oscillate circuit has to be minimized, that the majority of the current flows through this component ($i_\mathrm{DC}(t)$ maximized). The impedance depends on two variables, R_D and C, but in case of that simple model the resistance has to be as low as possible, to reach the smallest impedance. Because of that the resistance has the value $R_\mathrm{D} = 10\,\mathrm{m}\Omega$ in this specific investigation. Note, that this simplification is just because of the general consideration of the complex problem. Now, the determination of $|\underline{Z}_1(\omega_1, C)|$ and $|\underline{Z}_2(\omega_2, C)|$ can be done and the results are presented in Fig. 2. The impedance has a significant minimum for a specific value of the capacity. The final result of C, which is presented later, should be in between the minimums of the two separated frequencies $2.9 \cdot 10^{-11}\mathrm{F} \leq C \leq 5.0 \cdot 10^{-11}\mathrm{F}$. Thus preliminary considerations lead to a simple solution of the problem, which is helpful for later explanations. Of

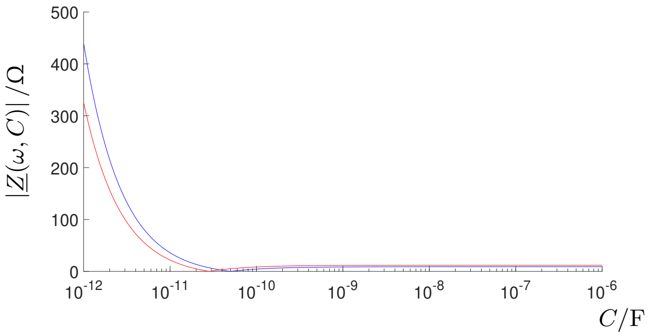

Fig. 2. Absolute Values of the impedances $|\underline{Z}_1(\omega_1, C)|$ (blue) and $|\underline{Z}_2(\omega_2, C)|$ (red) with $R_\mathrm{D} = 10\,\mathrm{m\Omega}$

course, there are too many physical effects missing, like wave propagation and reflection on the board and the capacity of the two copper layers. Therefore, the full wave simulation is done, including all physical side effects.

B. Simulation Setup

The geometry of the circuit board is implemented in a simulation software [1] and the current source, the decoupling capacitor and the sink are handled as different ports. The problem is transformed to a three port network Fig. 3, characterized by an $\underline{\mathbf{S}}$-matrix. The different parameters $\underline{s}_{ij}$, with $i \in 1, 2, 3$ and $j \in 1, 2, 3$, are calculated by a full wave simulation with an FIT. [1]. This method has a performance advantage compared to a time or frequency domain solution.

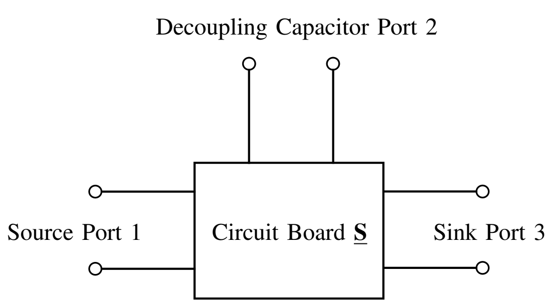

Fig. 3. Three port network of the Circuit Board

The first port is connected to the ideal current source, which delivers the current $i_0(t)$ (2). The stimulation of the current (at port one) is done by an AC - sweep at the two frequencies $f_1 = 355\,\mathrm{MHz}$ and $f_2 = 472\,\mathrm{MHz}$. The second port is connected to the decoupling capacitor. The third port is the sink, there is a resistance with $R_\mathrm{S} = 50\,\Omega$ and the amp meter to measure the noise current. The described setup is shown in Fig. 4.

C. Parameter Sweep and Post Processing

The adjustment of the resistance R_D and the capacitor C is calculated with a parameter sweep. That means the selection of different values for capacity, resistance and the calculation of the noise current for each configuration. It is necessary to compare the noise current for every combination of R_D and C. Therefore, the RMS value I_RMS is used. The RMS value

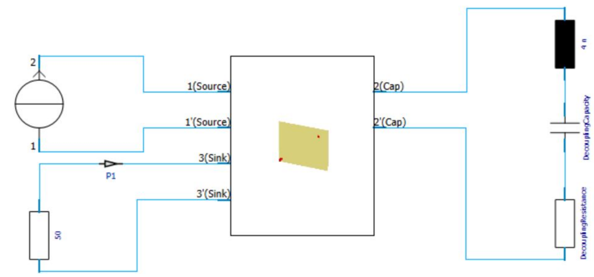

Fig. 4. Simulation Setup of the three port network

is calculated by the magnitudes $\hat{i}_1$ and $\hat{i}_2$, which belongs to the two stimulated frequencies (3).

$$I_\mathrm{RMS} = \frac{1}{\sqrt{2}}\sqrt{\hat{i}_1^2 + \hat{i}_2^2} \qquad (3)$$

The first parameter sweep covers the entire interval of C and R_D and each element has 50 samples. In total there are 2500 different configurations, which are shown in Fig. 5, where every node is one configuration.

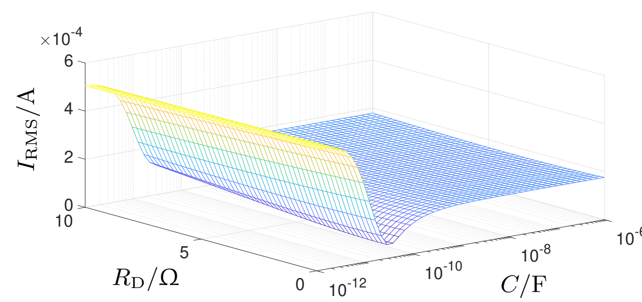

Fig. 5. Parameter Sweep covering the entire interval for R_D and C (logarithmic scale)

The solution is the minimum of that three dimensional surface, because there is the lowest noise current. In order to specify the data, the capacitor is restricted to $10\,\mathrm{pF} \leq C \leq 0.1\,\mathrm{nF}$ and the interval of the resistance is $10\,\mathrm{m\Omega} \leq R_\mathrm{D} \leq 2\,\Omega$. The repetition of the parameter sweep is done with thus new boarders, specifying the result. Again, there are 50 samples for capacitor and resistance. The results are presented in Fig. 6 and the final solution for R_D and C can be determined. At the minimum point of that surface the values are:

- $R_\mathrm{D} = 0.3755\,\Omega$
- $C = 33.932\,\mathrm{pF}$

III. Effectiveness of the Decoupling Capacitor

The result of the capacity is in between the interval, considered in section A, which leads to the following explanation. The series oscillating circuit has the minimum possible impedance (for the overlapping two investigated frequencies), with the configuration of $R_\mathrm{D} = 0.3755\,\Omega$ and $C = 33.932\,\mathrm{pF}$, leading to a maximum current flowing to the decoupling capacity. Note, that the resistance R_D has not the smallest

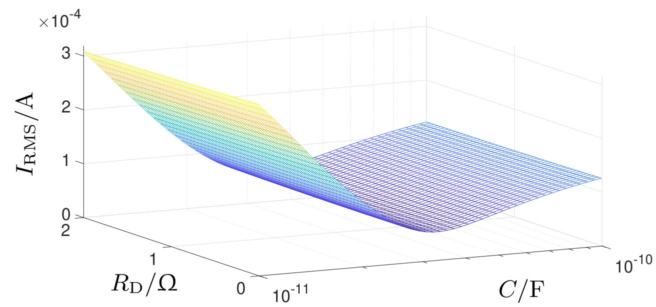

Fig. 6. Parameter Sweep covering a specified interval for R_{D} and C (logarithmic scale)

possible value, considered at the beginning, because the result is determined by a full wave simulation. The considerations in the beginning are very simplified and do not cover wave propagation, reflection, adaption and edge effects. Moreover, the minimal impedance of the series oscillating circuit can not be reached, for both frequencies. The current at the sink is minimized, because it is parallel connected to the decoupling capacity. Consequently, the majority of the current flows through the much smaller impedance of the decoupling capacitor. Because of that, the noise current is minimized, if the impedance of the decoupling capacitor reaches the smallest value.

References

[1] CST Microwave Studios 2020