Radiated emission of various PDN designs

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Abstract— Several solutions to decrease the propagation of simultaneous switching noise (SSN) in power distribution network (PDN) were evaluated for boards with active components. Radiated emission of the boards using power track, 2 cell symmetric power island (or one-cell Electromagentic Band Gap (EBG)) with square patches or asymmetric EBG was measured using a Reverberation Chamber, and the results were compared to a standard power plane design. The effect of the various EBG structures on the noise in PDN, and the radiated emission due to printed circuit boards was investigated.

Keywords—EMC, PDN, EBG, VIRC, noise, radiated emission, common mode current

I. Introduction

Power–ground plane pairs are the conventional structure in modern printed circuit boards (PCB) for creating a low impedance power distribution network (PDN). The main disadvantage of the power-ground plane pair in a power distribution network is that it creates a channel for noise propagation. Noise generated by different components of a PCB propagates via the power plane and may affect the sensitive circuitry. Several solutions have been proposed to eliminate this problem. If the power is carried by a plane, discrete decoupling capacitors can be placed between power and ground plane close to noisy components [1]-[5] or high capacitor material embedded between power and ground plane couple can be used. The combination of bypass capacitors and ferrite beads [6] or resistive edge termination of PCB [7]-[8] are also well known techniques. A good approach is to carry power using a power line or track instead of plane [9]-[12]. There are a lot of different designs of Electromagnetic Band Gap structures (EBG) which eliminate the noise in one particular frequency band creating a (frequency) band gap [13]-[15]. Most of the authors are investigating the influence of EBG on SSN, in [16] it was shown that common mode currents can be reduced by means of partial EBG structures, based on the concept described in [17].

It also has been proposed to combine EBG and high capacitance material [18]-[19] or EBG and magnetic material [20]. By using one single element EBG, and combine it with other, but different sized single-element EBGs a much wider frequency range is achieved [22]. The single-element EBG can be considered as a power island, which has the objective to mitigate noise over the planes. In [22]-[24] the efficiency of the concept of segmentation was shown. At the same time the use of EBG structures with different cell size can create a low pass filter behavior [21].

Many authors investigated the influence of EBG and power islands on propagation of simultaneously switching noise and not on common mode current and radiated emission. In addition, some studies considered passive boards only. To comply with electromagnetic compatibility (EMC) regulations, the common mode currents and radiated emissions of the product shall be minimized. In [25] the influence of different PDN designs on noise reduction of the board with active components was studied.

In this work the effect of power plane, power track and power island, which represents a single-cell Electromagnetic Band Gap structure (EBG) on the noise reduction and radiated emission of printed circuit boards (PCB) with active components is analyzed.

II. Power isolation

In [25] four identical digital hardware circuits which generated noise have been used. Each board was 50mm wide, 160mm long and 1.6mm thick employing FR4 dielectric covered with 0.035mm copper layer on both sides. The photo of the boards and schematic are shown in Fig. 1 and 2 respectively. The noise generator consists of a 24 pin SOIC line driver fed by a 10MHz crystal controlled oscillator. The line driver`s signal rise-times was approximately 0.3 ns/V, resulting in harmonics into the GHz range. The 8 outputs were loaded with eight 47pF capacitors to ground. The clock generator and driver were supplied with 5V via a 9V battery stabilized by a LM7805CV regulator in a TO220 package. Four board configurations were designed with PDN configuration as listed in Table 1.

TABLE I. Overview of boards designed for a study

N	PDN configuration	Figure
1	Power/gnd plane	Fig. 1a
2	Power trace	Fig. 1b
3	Two patches & trace for power	Fig. 1c
4	Asymmetrical EBG	Fig. 1d

Fig. 1a Power distribution network employing power plane

Fig. 1b Power distribution network employing power line

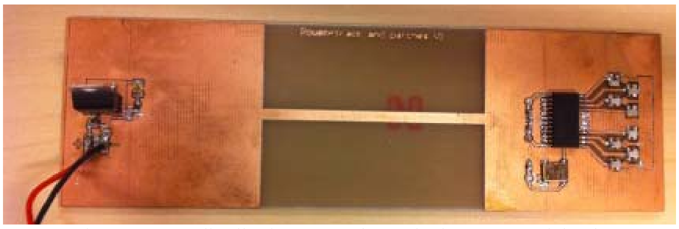

Fig. 1c Power distribution network employing a power island, i.e. two single-cell EBG

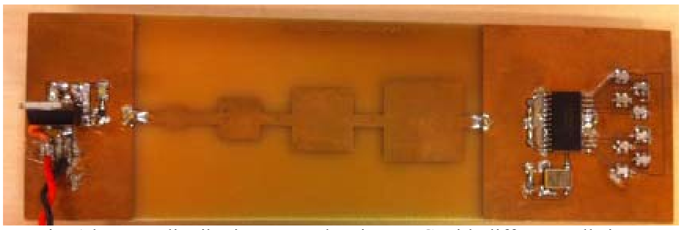

Fig. 1d Power distribution network using EBG with different cell sizes

III. Measurements using VIRC

One of the ways of estimating the radiated emission is to conduct the measurements inside a Reverberation Chamber (RC) [26]. A RC consists of an electromagnetic resonant cavity featuring some kind of mode-stirring process to create changing boundary conditions in order to obtain a statistically uniform electromagnetic field. This is conventionally accomplished by introducing a mechanical tuner into a shielded room.

By rotating the tuner, the boundary conditions within the chamber are changed. Once the tuner has been moved to a sufficient number of positions the field at any point is statistically uniform [27].

A particular non-conventional reverberation chamber available at the University of Twente is the Vibrating Intrinsic Reverberation Chamber (VIRC), as shown in Fig. 3[28]. The VIRC is a made of conductive cloth. By vibrating the walls inside the VIRC a diffuse, statistically uniform electromagnetic field is created without the use of a mechanical, rotating, mode stirrer. The results regarding the VIRC lead to a better homogeneity and increased field strength compared to a conventional mode stirred chamber [28][29]. Each board was placed inside the VIRC as depicted in Fig.3. For our measurements the discone antenna was used [30]. The main advantage of application of this antenna for VIRC measurements is its compact size and large frequency operation band (0.35 – 3 GHz). The Rohde and Schwarz FSH3 Spectrum Analyzer was connected outside the reverberation chamber. Comparative measurements were done: the boards under the test (Figs 1b-1d) were each compared against the board with conventional power plane(Fig 1a).

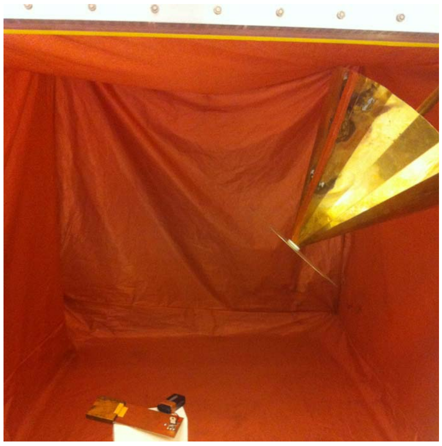

Fig.3 Position of board inside the VIRC

Fig. 4 depicts the comparison of the radiation emission measurements of the board with the conventional design of a power distribution network using a power plane and alternative board with power track or line in PDN. The track was 3mm wide and 100mm long. It can be seen that the design with a line radiates more than the reference board. This is due to fact that this is an open structure.

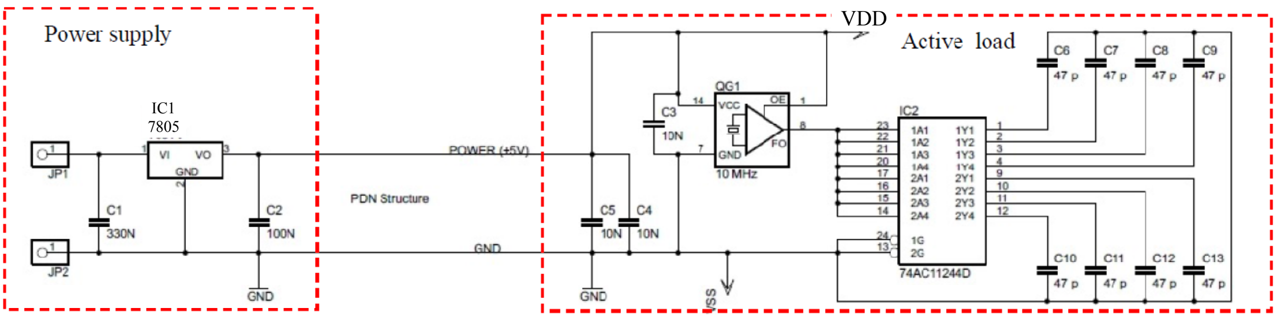

Fig. 2 Circuit of the test board

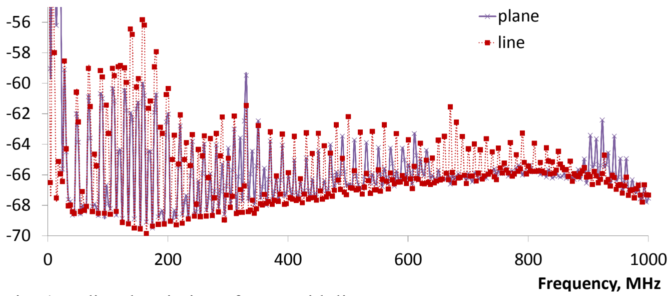

Fig. 4 Radiated emission of PDN with line

In our earlier work [16] it was demonstrated that a two single-cell EBG can reduce resonances and decrease common mode current. Because of the finite velocity of propagation the charge is only used when located within a finite radius of the devices being supplied, and large planes are often not needed as PDN for a single device. On this demonstrative board the power islands, which are actually two cells of an EBG structure of 50x50mm, were interconnected by a 60mm long and 3mm wide line. The active components were placed on each island. The objective is that the decoupling currents are handled locally on the power island and are not propagating over the board. Fig.5 shows the measured radiated emission of this board.

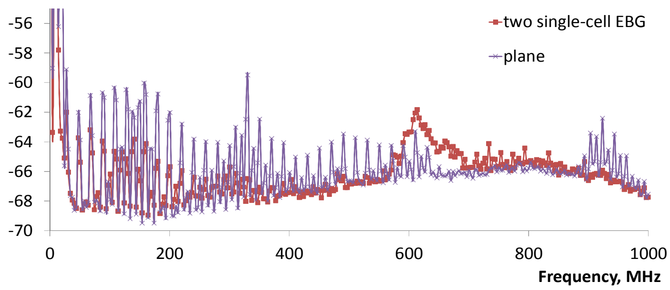

Fig. 5 Radiated emission of PDN with two single-cell EBG

It can be seen from these measured results that the reference board radiates more due to the parallel-plate configuration corresponding to resonant frequencies. Around 600 MHz the board with EBG cells has its pass band which increases the radiated emission. These characteristics indicate that a 2 cells-EBG power plane can exhibit low radiation in the measured frequency band.

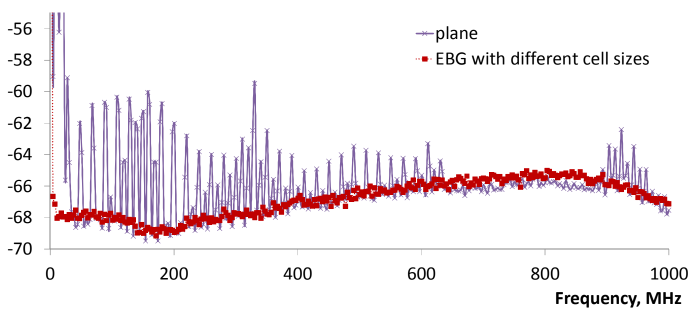

Fig. 6 Radiated emission of EBG with different cell sizes

The last design configuration is shown on Figure 1d. This board contains cells with different size (50x50mm, 20x20mm, 15x15mm, 10x10mm, 5x5mm, 50x25mm) interconnected with 3mm wide traces. This structure forms an EBG, by employing a periodic structure (of different cell, or patch, size) which forms a low-pass filter with a low frequency cut-off. The trace is used as inductive decoupling, while each patch itself can be considered as a capacitor. This creates a wide-frequency band stop filter, while each of the cells has a different resonance frequency. Fig.6 demonstrates the measurement of radiated emission of this board. These measured results demonstrate that the reference board radiates more due parallel plate configuration corresponding to resonant frequencies. The radiation of the EBG board is much less than the reference board. EBG with different cell sizes can significantly reduce the radiated emission.

IV. Conclusions

The effect of PDN structured power-ground plane pair, 2 single cell EBG (power island) structures and different sized EBG for creating a wide-band filter has been shown. Instead of many authors, not the passive behaviour, but a design with active components was used. The creation of a wide-frequency band EBG showed to be effective on the radiated emission of PCB with active components.

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