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Estimation of Radiation Limit from a Huygens' Box under Non-Free-Space Conditions

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Abstract – **The recently studied Huygens' box method has difficulties when radiation of an electronic module is to be determined under non-free-space conditions, i.e. with an enclosure. We propose an estimate on radiation limit under such conditions based only on the Huygens' box data from free-space measurements. Numerical experiment shows that the limit is valid everywhere except the resonance frequencies. Consequently, it is argued that knowledge of the inner structure of the module is in fact necessary also for the limit estimation.**

1 INTRODUCTION

One of the challenging problems in the field of electromagnetic compatibility (EMC) is the correct prediction of radiated emission from an apparatus while still in its design stage. Electromagnetic simulations are generally used to obtain the desired radiation properties, but it requires that the designer of the apparatus has detailed models of all components available. Finding out all details necessary for the simulation is often impractical, and sometimes even impossible, typically if some parts of the apparatus are provided by external vendors.

When such situation occurs and the apparatus contains one or more modules with unknown parameters, it has been suggested to scan the near fields around the respective module and use these as a virtual source of electromagnetic field, so called *Huygens' box*, in the simulation to replace the module [1]. However, in our earlier work [2,3] we have demonstrated that the proposed method may be accompanied by significant error, if there are objects in the vicinity of the Huygens' box in the simulation. This is almost always the case, because, apart from the involved module, the apparatus contains other modules, bunches of cables and especially the enclosure (chassis) of the apparatus. Radiation can be underestimated in such cases, leading to false conclusion that the apparatus complies with the respective emission standards, whereas it in fact does not.

As a remedy, it has been suggested to include major features of the respective module inside the Huygens' box during the simulation [1,4]. This comes as a result of combining the surface equivalence theorem, which stands behind the Huygens' box method, and the induction theorem. In our study, we have used a simplified printed circuit board (PCB) with three traces as a representative of a typical module. Experiments with cables, metallic planes and enclosures have revealed that including e.g. the ground plane and the substrate of the PCB, as their dimensions are directly observable by the designer, reduces the far-field (radiation) error of the Huygens' box to acceptable levels [2,3]. Work on generalizing these results for everyday use in EMC community is still ongoing.

In this paper, we look at the problem from different perspective – we aim at finding out whether there exists an upper bound for radiation from a given module under non-free-space conditions (typically when the module is inside an enclosure), solely based on the fields measured in free space. We have set up a numerical experiment similar to our previous work observing the peak E-fields at 3m distance, but this time also with an estimate on the radiation limit based on typical antennas.

2 NUMERICAL EXPERIMENT

The numerical setup uses a generic test printed circuit board (PCB) as a typical representative of an electronic module (Fig. 1). It has dimensions 150 × 100 mm, made of 2 mm thick substrate FR4 with relative permittivity 4.35 and conductivity 10^{-3} S/m. The PCB contains three traces on the top layer with only the first trace active and matched to 50 Ω impedance at both ends. The bottom layer of the PCB is formed by a continuous ground plane.

In order to evaluate the influence of an enclosure on radiation, we introduced a metallic box with dimensions 450 × 300 x 40 mm, which is open at one side (Fig. 1). The PCB is then placed in the middle, without any contact with the walls of the enclosure.

The numerical experiment utilizes the established finite-difference time-domain method [5]. We have assumed that all metals (PCB layers and the enclosure) are made of perfect electric conductor (PEC), i.e. without losses.

For both cases, PCB in free space and PCB inside the enclosure, we have calculated the far fields and selected the peak value of E-field at 3m distance, from both polarizations. These values are shown in Fig. 2 for a frequency range from 20 MHz to 1 GHz with 20 MHz step.

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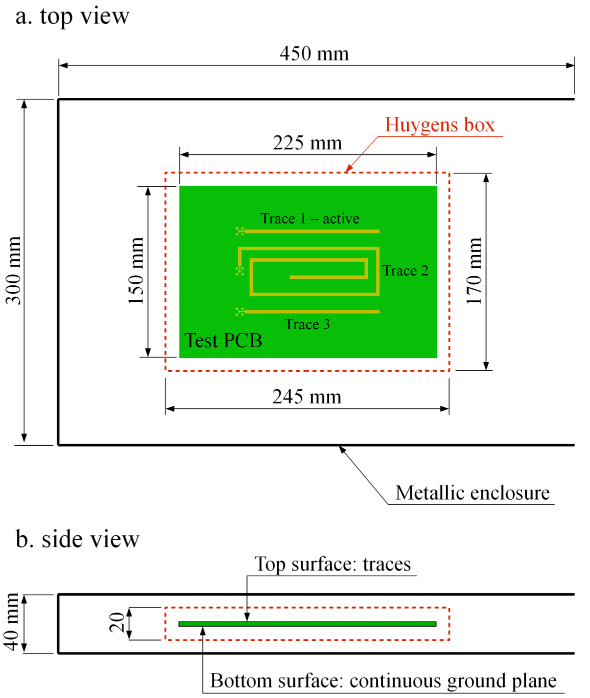

Figure 1: Schematic drawing of the simulated structure: the test PCB inside the metallic enclosure.

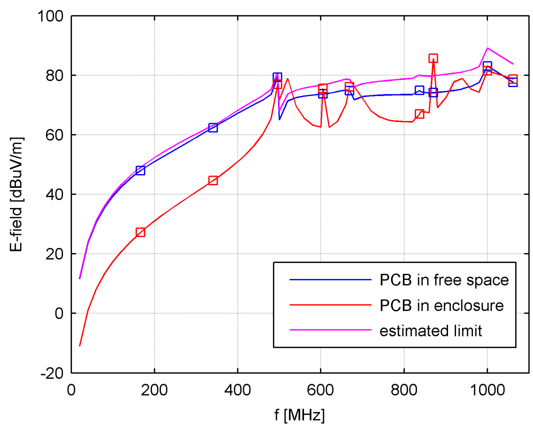

Figure 2: Peak E-field radiated from the PCB at 3m distance (Squares show the resonances).

It can be seen that the radiation from the PCB placed in the enclosure is lower than in free space, except at a few points. These points correspond to resonances that can occur either on the PCB itself, dominantly on its second trace, or in a space between the PCB and the enclosure, basically a parallel plate resonator. At some of the frequencies the PCB becomes strongly coupled to the enclosure and the enclosure then amplifies the radiation.

From this finding it follows that we cannot use the radiation properties of the PCB in free space to estimate the peak radiation from the PCB placed in the enclosure. Doing so we would underestimate the radiation at some frequencies where the coupling is strong and the enclosure works as a good antenna.

In order to get a rough estimate on how much the PCB is capable of radiating in the enclosure, we have assumed that 1) all the power radiated from the PCB in free space is coupled to the enclosure, and 2) the enclosure radiates this power without any losses and with directivity of an antenna corresponding in size to the enclosure. In particular, the directivity is considered to be the higher of the values of a dipole and a uniformly excited aperture.

The length of the dipole is chosen to be the diagonal of the enclosure, 540 mm, possibly the worst case. Likewise, the size of the aperture is chosen to be the largest dimensions of the enclosure, 450 × 300 mm. The power level is calculated by integrating over the Huygens' box.

The estimated limit for the radiation level obtained this way is shown in Fig. 2 as the magenta line. The E-field is larger than for the PCB in free space, which demonstrates that the PCB itself is a suboptimal antenna. The same could be said about the PCB placed in the enclosure, however there are still points around the resonances at 496 MHz and 870 MHz where the proposed limit is broken. This may indicate that the power transferred from the PCB to the enclosure is actually higher than the power radiated from the PCB alone, which we used for the estimate. It also means that the Huygens' box method described in [2,3] *must* depend on the knowledge of the inner structure of the PCB, because it influences the magnitude of the coupling.

In analogy with electrical circuits, the maximum delivered power to the load depends on the source impedance, where the equivalent of the source impedance is the internal structure of the module with sources excluded. We acknowledge that obtaining the internal structure of the module would solve the estimation problem entirely, yet the exact scattering approach would be prohibitively expensive – by second order with respect to the near-field scan alone. It turns out that the knowledge of the internal structure of the module may in fact be crucial even for the upper bound estimation.

4 CONCLUSION

We have shown that the radiation limit based on the Huygens' box data obtained in free space is valid even under non-free-space conditions everywhere except a few points at the resonances. This is in concordance with our recent findings about the Huygens' box method for predicting the actual radiation levels [6]. It indicates that at least some information about the internal structure of the investigated module, however difficult to obtain, is necessary for setting up the radiation limit.

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