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Estimate on the uncertainty of predicting radiated emission from near-field scan caused by insufficient or inaccurate near-field data

Evaluation of the needed step size, phase accuracy and the need for all surfaces in the Huygens' box

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***Abstract*—Near-field scan on a Huygens' box can be used in order to predict the maximal radiated emission from a Printed Circuit Board. The significance of step size and phase accuracy, and the importance of a full Huygens' box are investigated by simulation of two different models with two different numerical methods. The prediction of maximal radiated emission is quite robust but the results also show that a full scan on all six surfaces is probably needed.**

Keywords-component; near-field scan; Huygens' box; predicting radiated emission; simulation

I. Introduction

In the antenna society, near-field scan has been used to determine the far-field radiation from antennas since the 1960s[1]. In the EMC society, the aim of near-field scan has more been to find EMI hotspots on Printed Circuit Boards (PCBs), but in recent years, attempts to predict radiated emission using near-field measurement have also been carried out.

Near-field to far-field transformation based on antenna near-field scan is often done by plane- or spherical wave spectrum[2], but in EMI/EMC related problems, nearby PCBs, chassis, cables or other structures complicate the prediction of radiated emission, and therefore, numerical methods as MoM or FDTD/FIT are often used[3,4,5]. From a theoretical point of view, it is straight forward to make the near-field to far-field transformation if the complex tangential electrical and magnetic fields on a closed surface are known based on Huygens' principle. But in practice, a lot of difficulties arise when you want to measure unintentional emission in a large frequency span from a PCB.

We must measure close to the PCB to get highest SNR of the often weak fields, and, as a side effect, this is usually in the reactive field. This requires a fine measurement grid and since the EMC requirements cover a broad frequency spectrum, the measurement time can be overwhelming and the phase measurement itself represents a challenge.

Connected cables also make it difficult to measure the near-field on all 6 surfaces.

The objective of the work presented in this article is to estimate the importance of the issues mentioned above, i.e. measurement step size, the need of all 6 surfaces and accuracy of the phase representation. Section II gives a very short introduction to the surface equivalence principle, also called Huygens' principle. The objective with the simulations and a description of the models and simulations methods are given in section III. The results are presented and discussed in Section IV and finally Section V draws the conclusions.

II. Huygens' Box

In Figure 1a a PCB is enclosed in a surface S. $\{\boldsymbol{E_1}(\boldsymbol{r})\ \boldsymbol{H_1}(\boldsymbol{r})\}$ represents the electric and magnetic fields on this surface. The Huygens' principle states that an arbitrary structure containing sources of electric and magnetic fields can be represented by electric and magnetic currents on a surface that encloses the structure such that they produce the same field outside the surface while producing null field inside [6,7]. Such a rectangular box with equivalent currents on the surface is often denoted as Huygens' box. This is illustrated in Figure 1a and 1b where the equivalent electric and magnetic currents are given by $\boldsymbol{J}_s(\boldsymbol{r}) = \boldsymbol{n} \times \boldsymbol{H}_1(\boldsymbol{r})$ and $\boldsymbol{M}_s(\boldsymbol{r}) = -\boldsymbol{n} \times \boldsymbol{E}_1(\boldsymbol{r})$. These current densities can be deduced from the tangential electric and magnetic field on the closed surface, which in practice may be found using near-field measurements.

A near-field scan with a finite number of points gives only an approximation of the equivalent currents on the Huygens´ box surfaces so the question is how many measurements points is needed as illustrated in Figure 1c.

Advanced contemporary PCB´s will often have a lot of cable connections that go through the Huygens' box. These cables will make it very difficult to measure the sides of the

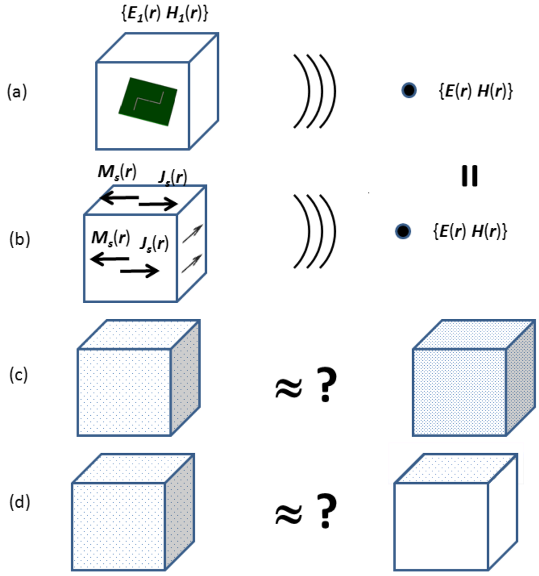

Figure 1: The surface equivalence principle and its representation by measured near-fields on a Huygens' box.

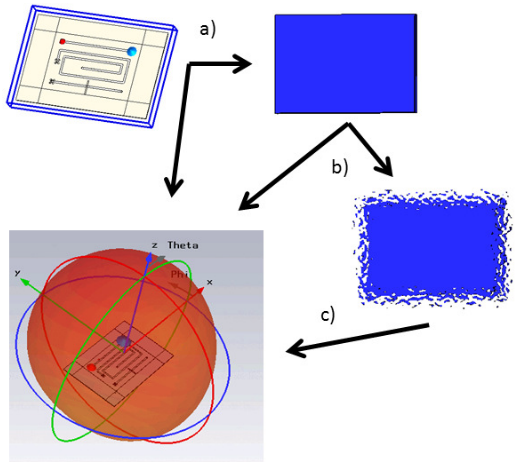

Figure 2: The simulation workflow

Huygens' box, where the cables go through. In addition, measuring the side of the Huygens' box requires an advanced robot or special perpendicular probes. It is therefore of interest how much accuracy is lost if only the field on the surface above the active part of the PCB is measured as illustrated in Figure 1d.

III. Test Setup

A. *The objective of the experiments*

As mentioned in the introduction, there are a lot of issues regarding the accuracy of the predicted radiated emission from a near-field scan.

The near-field measurement technics is still in embryo, so this paper will investigate the issues by means of simulations. With the purpose to increase the credibility of this investigation's conclusions a cross verification with two different structures simulated with two different numerical tools was carried out.

The work flow in the simulation is described in Figure 2.

a) A full model of the structure was simulated and the tangential components on a Huygens' box were exported. In addition, the maximal electric far-field in 3 m distance was calculated for reference as representative for a radiated emission test like CISPR 22.

b) The exported Huygens' box was now manipulated in different ways

c) and the maximum far-field in 3 m distance was simulated based on the manipulated Huygens' box. The different data manipulations are listed below:

- Reduction of the number of data points be equivalent to different step sizes in a near-field scan (see Figure 1c).
- Removing data from the sides and bottom of the Huygens' box in order to represent the situation, where only the surface above the PCB is measured (see Figure 1d). This was done for different scan heights and different scan areas.
- Random phase noise added to the data representing a random measurement uncertainty. For each field component and each frequency a random angle in different intervals was added (see Figure 3a).
- The H-field was unchanged but the phase of the E-field was shifted in order to equate a probe calibration, where the relative phase between the E-field probe and H-field probe was not considered and thereby random.
- A systematic phase error across the PCB. As mentioned before, the probe is in the reactive near-field in EMI near-field scan and hence complex interactions can take place. For example the probe could interact with the PCB and change the impedance of the traces and hence change the phase of the reference signal depending of the measurement probe position. Worst case is probably a case where the phase change is continuous across the scanned surface as illustrated in previous conducted near-field scan of one of the test PCBs (see Figure 3b).

B. *The models*

The two simulated models are shown in Figure 4. Model 1 was a simple 150 x 225 mm PCB with three 50 ohms traces on the top layer with a full ground plane on the bottom layer. Only one trace was excited and terminated. Both source impedance and load was 50 Ω. The simulations were carried out in CST Microwave Studio with the transient solver (Finite Integration Technique) [8].

Model 2 was a scaled IC consisting of two printed-circuit boards and ten vertical pin-headers, which were used to mimic the die substrate, the lead-frame package and foot print of an IC. There are few loads applied within the scaled IC. It was placed right on an infinite ground plane, which is in general

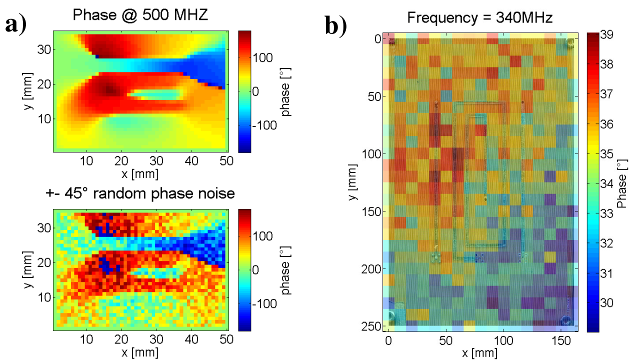

Figure 3: a) Introduced random +- 45° phase noise error., b) a real near-field scan of the PCB where the phase of the reference probe is plotted vs. the measurement probe position. The phase should be independent of the measurement probe position, but it looks like the phase decrease linearly across the PCB.

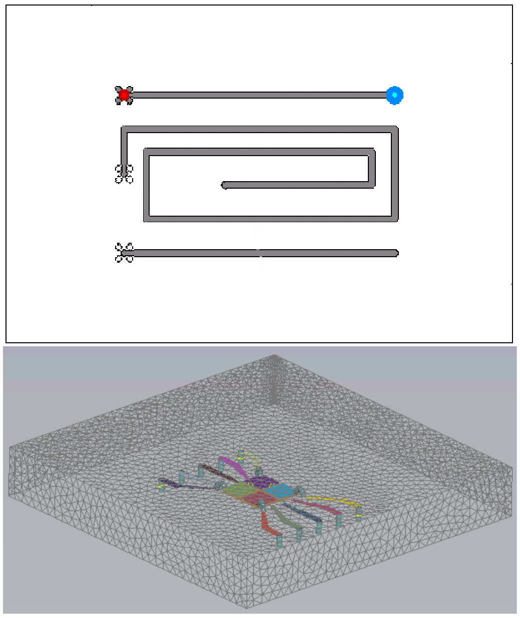

Figure 4: Model 1 (top), Model 2 (bottom)

similar to normal IC placed on PCB. The simulations were carried out in EMCos based on MoM [9].

In model 1 the radiated emission was evaluated on a sphere with a radius of 3 m (see Figure 2). In model 2 the maximal electric field was evaluated on a cylinder with radius 3 m simulating a 3 m semi anechoic chamber measurement.

IV. Results and Discussion

In most cases, the cross validation was successful. The trends in model 1, simulated with FIT, and the trends in model 2, simulated with MoM, was similar and for reason of space only result from one model is shown.

A. *Stepsize*

Figure 5 gives an indication of the necessary step size in near-field scan. Different step sizes were used on a full Huygens' box (all 6 surfaces) 10 and 20 mm from the PCB. For low frequencies (<50 MHz), the full model and the Huygens' box model differs some dB even for the smallest step size, which probably is caused by insufficient distance to the boundary in the FIT simulation. Above 50 MHz, the difference is below a few tenths of dB as long as the step size is less than or equal to the scan height divided by 2. With higher scan height, less number of measurements points is necessary, but in practice the dynamic range is also reduced due to weaker signal. It is likely that a smaller step size is needed if the simulation also must take interaction with nearby structures into account.

B. *Top only scan*

As mentioned in section II, it is often difficult and very time consuming to measure all 6 surfaces of the Huygens' box. Figure 6 compares the predicted radiated emission from model 2 based on the full model, a full Huygens' box (i.e. equivalent sources on all 6 surfaces) and the top only Huygens' box where the equivalent currents on all sides except the dominating top surface was set to 0. Three different step sizes were used for two different scan heights. The scan area was constant 20 x 20 cm. There is no visible difference between step size at given height – curves are matching each other in agreement with the step size result.

The full Huygens' box matches the full model within 0.1 dB (see Figure 6.a). The 10 mm scan height, top only box was within 0.8-2.5 dB and the 20 mm scan height, top only box was within 1.2-3.8 dB. Figure 6.b shows that all kinds of sources become better at higher frequencies, especially above about 600 MHz.

Figure 7 shows the top only results for different scan areas. Model 1 was used and the scan areas exceeded the PCB in both x- and y direction with 10 mm up to 100 mm. Unfortunately the result show that using the equivalent sources on top only is not sufficient and in addition there is no clear relation between the deviation from the direct solution and the scan area.

C. *Random phaise noise and no phase information*

In Figure 8, different phase noises was added to the full Huygens' box of model 1. For each frequency and each field-component a random angle +- "max error" was added to the Huygens' box data. In addition no phase information (i.e. only amplitude) and completely random phase was tested. The results show that the prediction of maximal radiated emission is quite indifferent for random phase noise. Even +- 45° random noise introduced only a deviation about 1 dB. The maximal deviation increased to 5 dB for +- 90° random phase noise. Completely random noise was far away and if only the amplitude data is present the simulations overestimate the maximal radiated emission by several dBs although the deviation decreased with frequency.

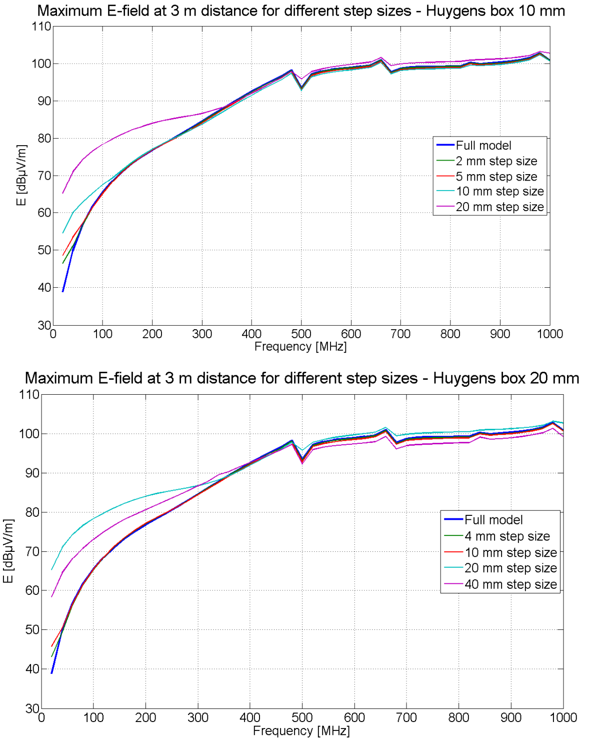

Figure 5: Evaluation of the needed step size vs. scan height, model 1.

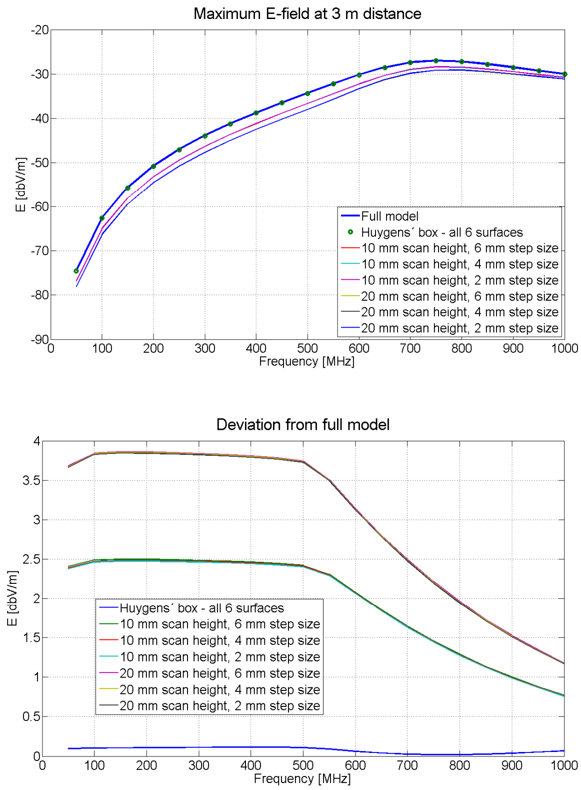

Figure 6: Evaluation of the need of a full Huygens' box with different scan heights and different step sizes, model 2.

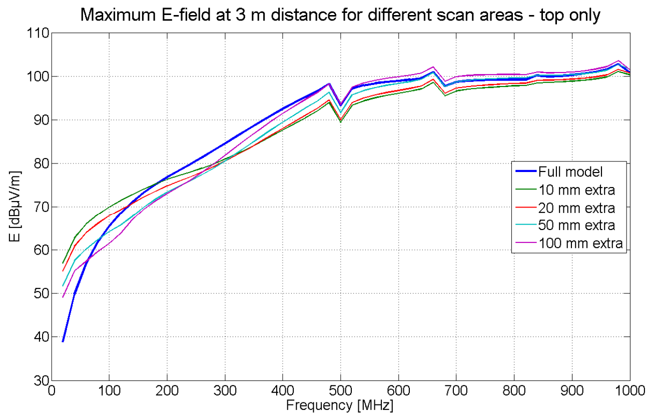

Figure 7: Evaluation of the need of a full Huygens box with different scan areas, model 1.

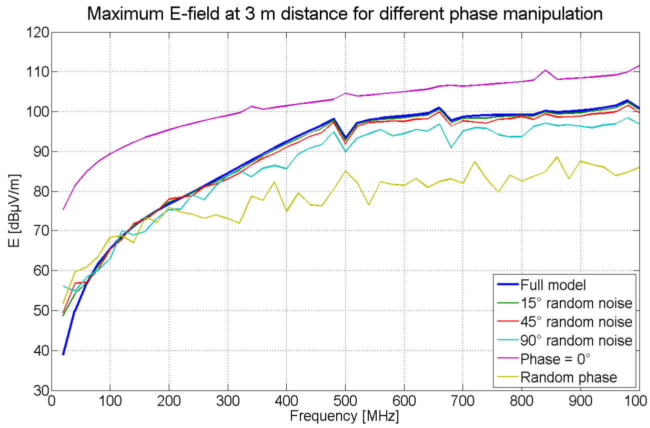

Figure 8: Evaluation of different phase manipulations, model 1.

Model 2 gave similar results. In Figure 9 +- 45° and +- 90° was added to the top only scan and the procedure was repeated three times. Figure 9.b shows the deviation caused by this random phase error. Again up to +- 45° the deviation was almost within 1 dB while +- 90° caused larger deviation. As for the other introduced errors the deviation decreased with increasing frequency.

D. Systematic phase shift between E- and H-field probe

In Figure 10, the phase of the H-field was unchanged while the phase of the electric field at all frequencies and all components was added a certain value. For model 1 the phase shift introduced a small deviation up to 3 dB while for model 2 the deviation was below 0.5 dB.

Beforehand, we had expected that this phase shift be equivalent to an insufficient probe calibration was very critical. At least mathematically, field produced by J and M are vector-summed at observation point, so it was expected that the phase relation between E- and H-field was critical. If the radiation is dominated by either J or M in model 2, the unexpected robustness can possible be explained by that.

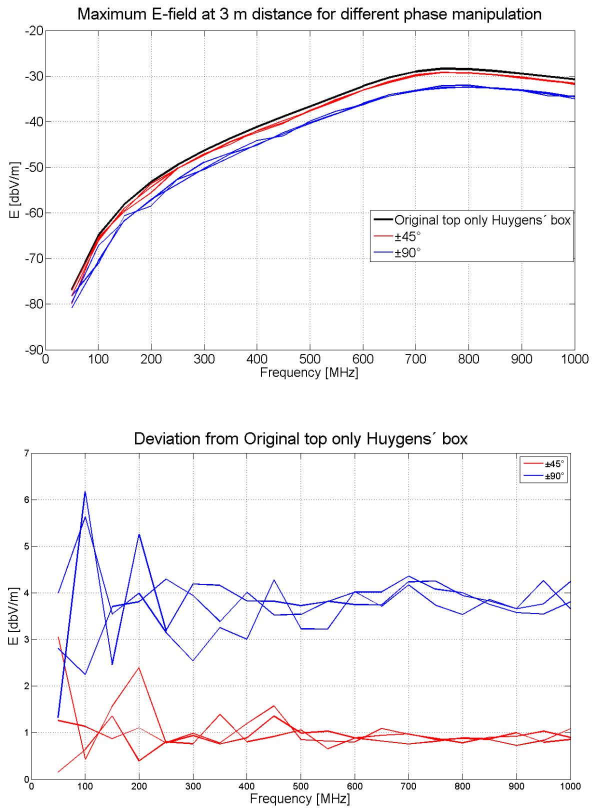

Figure 9: Evaluation of random phase error, model 2.

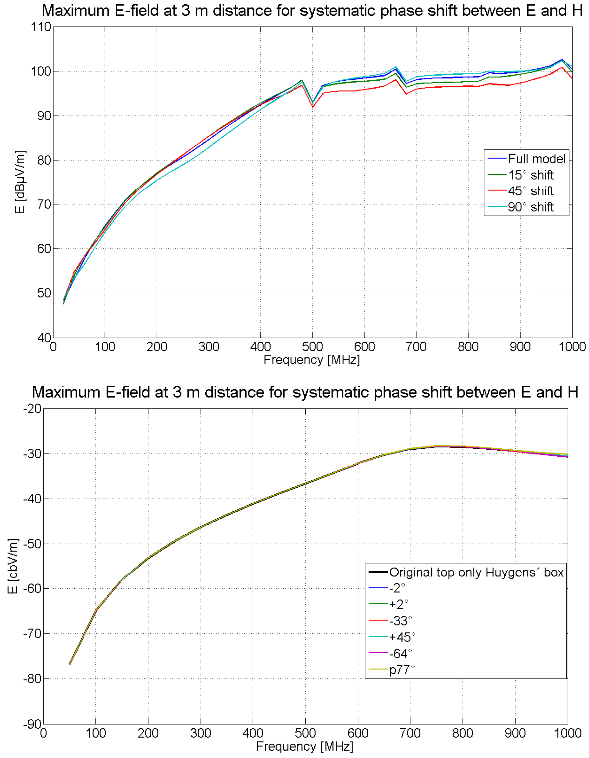

Figure 10: Systematic phase shift between E- and H-field probes, top model 1, bottom model 2

E. Systematic Phase shift across the PCB in one direction

In Figure 11, a phase gradient was added for all frequencies and components. From y_{min} to y_{max} a linearly decreasing phase error was added. The maximal far-field was quite robust to this systematic phase shift, even 30° phase error caused only a deviation up to 1 dB except for the low frequencies.

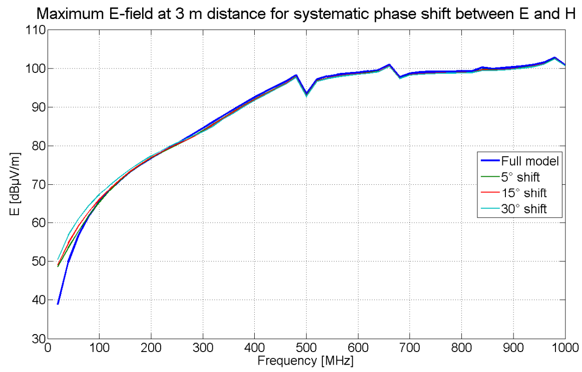

Figure 11: Systematic phase across the PCB, model 1.

V. CONCLUSIONS

In this paper, we have studied the significance of different near-field scan issues by simulating to different structures with two different numerical methods. The conclusion is summed up in the table 1.

Predicting of the maximal radiated emission seems to be quite robust against different kind of phase errors. Perhaps counterintuitive it appears that the high frequency prediction of maximal far-field radiation is more robust to insufficient data set or manipulated data set than low frequency.

Unfortunately, the study also showed that the equivalent sources on all six surfaces are needed. Because of practical difficulties like cables, this issue can be one of the largest challenges.

The conclusions are based on a simple near-field to far-field transformation without nearby structures. The needed accuracy may be higher in this case.

TABLE I. CONCLUSION

Issue	Conclusion
Step size	Step size < scan height / 2
Full Huygens' box needed?	Yes. Otherwise risk of several dB´s underestimation of the maximal radiated – especially for frequencies below 300 MHz
Random phase noise	Very robust. +- 15° causes less than 1 dB error.
Phase shift between E- and H-field probes.	Can cause up to 5 dB error in the predicted maximal radiated emission.
Systematic phase shift across the PCB.	Very robust. 30° across the PCB causes less than 1 dB error.

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