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# Perturbation of near-field scan from connected cables

Morten Sørensen[#1], Ondrej Franek[#2], Gert Frølund Pedersen[#3], Knud A. Baltsen[*4], Hans Ebert[#5]

[#]Antennas, Propagation and Radio Networking, Department of Electronic Systems, Faculty of Engineering and Science, Aalborg University,
Niels Jernes Vej 12, 9220 Aalborg, Denmark

[1] mos@es.aau.dk, [2] of@es.aau.dk, [3] gfp@es.aau.dk, [5] heb@es.aau.dk

[*] Bang & Olufsens a/s, Peter Bangs Vej 15, 7600 Struer, Denmark

[4] kbl@bang-olufsen.dk

***Abstract*—The perturbation of near-fields scan from connected cables are investigated and how to handle the cables is discussed. A connected cable induced small but theoretical detectable changes in the near-field. This change can be seen in Huygens' box simulations (equivalent source currents on a box) at the cable resonance frequencies while there is no change away from the resonance frequencies.**

## I. Introduction

Near-field scanning has become a popular measurement technique in the field of EMI/EMC. For some years near-field scan has been used in the development phase in order to find EMI hotspots on PCBs (Printed Circuit Boards), but in recent years attempts to predict radiated emission using near-field measurement have also been carried out.

There are two different dominating approaches to far-field prediction. One approach uses the near-field as basis for source reconstruction by help of an equivalent set of dipoles [1,2] and one approach uses the tangential electrical and magnetic fields on a closed surface often named a Huygens' box [3,4].

The very ambitious idea is that an apparatus´ radiated emissions in the far-field can be simulated based on near-field scan of the modules comprising the apparatus and the influence of the architecture (module's relative position, cables, chassis and other environments).

The work with predicting far-field radiated emission from near-field scan is still in embryo and the attempts until now have been carried out on very simple structures without long cables and often only for a single frequency.

If near-field scanning shall become an effective tool for engineers in R&D, it is necessary to be able to near-field scan advanced PCBs with (galvanically) connected cables. But no one has yet investigated how connected cables can be handled in the near-field scan and the subsequent simulations. Do the cables perturb the near-field significantly? Is it best to establish fixed common mode impedance for connected cables? Is it possible to predict common mode currents on connected cables from near-field scan? It is many questions and they are not yet answered in the literature.

The objective of the work presented in this article is to start the investigation and discussion about this important topic by studying a simple PCB with connected long cables. Mainly based on simulations we will find the absolute and relative perturbation caused by a cable on the near-field.

Section II gives a very short introduction to the surface equivalence principle (the Huygens' box) and the challenges we face in using the principle for predicting far-fields based on measured near-field for real PCBs and apparatuses. In section III the test setup and simulations are described. Then the results are presented and discussed in Section IV. Finally Section V draws the conclusions.

In Fig. 1.a a PCB is enclosed in a surface S. The electric and magnetic fields on this surface are denoted $\{\boldsymbol{E_1}(\boldsymbol{r})\ \boldsymbol{H_1}(\boldsymbol{r})\}$ According to the surface equivalence principle an arbitrary structure containing sources of electric and magnetic fields is equated with electric and magnetic currents on a surface that encloses the structure so that the fields within the surface all are 0, while outside the surface the fields are identical to the fields caused by the initial sources provided that the outer region is homogeneous and source free [5,6]. A rectangular box with equivalent currents on the surface is often denoted a Huygens' box. This means that electric and magnetic fields at a general observation point outside S in Fig. 1.a, denoted $\{\boldsymbol{E}(\boldsymbol{r})\ \boldsymbol{H}(\boldsymbol{r})\}$, are equal to the electric and magnetic fields at the same

## II. Huygens' Box

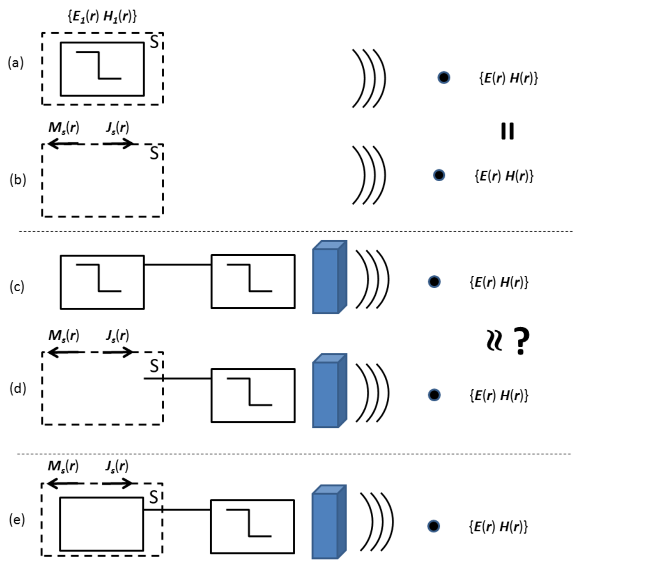


Fig. 1. Representation of the Huygens' box: (a) Original problem for a single radiating PCB, (b) equivalent sources on a Huygens' box, (c) original problem for a more complicated system with 2 PCBs, a cable and a scattering surface (the blue box), (d) an approximation of the surface equivalence principle where the region outside the surface is not homogenous nor source free, (e) a probably better solution where a ground plane approximates the coupling between the PCB and devices outside S.

observation point in Fig. 1.b 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.

In real apparatuses configured of several PCBs, chassis, cables etc. the region outside the surface is not homogenous nor source free. This is indicated in Fig. 1.d. If we use the equivalent sources from Fig. 1.a in order to predict the electric and magnetic fields in Fig. 1.d, we do not know how well the electric and magnetic fields in a general observation point in Fig. 1.c and 1.d are in agreement.

As long as the coupling between devices outside the Huygens' box and the radiating device is weak, good results can probably be achieved by this approximation. To improve the results of a simulated model, one can approximate the first order effects of the coupling by replacing the radiating device inside the Huygens' box by an approximate model, e.g. the ground plane of a PCB (Fig. 1e). This is possible because the equivalent sources acting alone produce a null field inside the box.

Connected cables, e.g. LVDS cables or power cables represent a distinct challenge for the prediction of the radiated emission, because the coupling between the near-field scanned radiating device and the cables is strong and cables often have lengths comparable with the wavelength of the unintended radiated emission and hence common mode current on cables becomes the dominant emitter. In addition the cables go through the walls of the Huygens' box.

## III. Test Setup

### A. The objective of the experiments

It emerges clearly that the model for predicting radiated emission based on near-field measurements described in section II violates the surface equivalence principle when cables are connected. Does that mean that near-field measurements are useless if cables are connected or is the deviation small or can we perhaps compensate for the violation?

In order to answer these questions some simple setup were simulated and measured with and without connected cables. In each setup the approach was as illustrated in Fig. 2.

*a) Physical models* of the PCB alone and the PCB with a cable connected to the PCB ground plan. The PCB alone model represents a near-field scan where all connected cables have been terminated with perfect ferrites in order to remove the effect of the cables. The near-fields of the two models were compared with the objective to estimate whether it is possible to measure the differences with a near field scanner or the differences are below the measurements uncertainty.

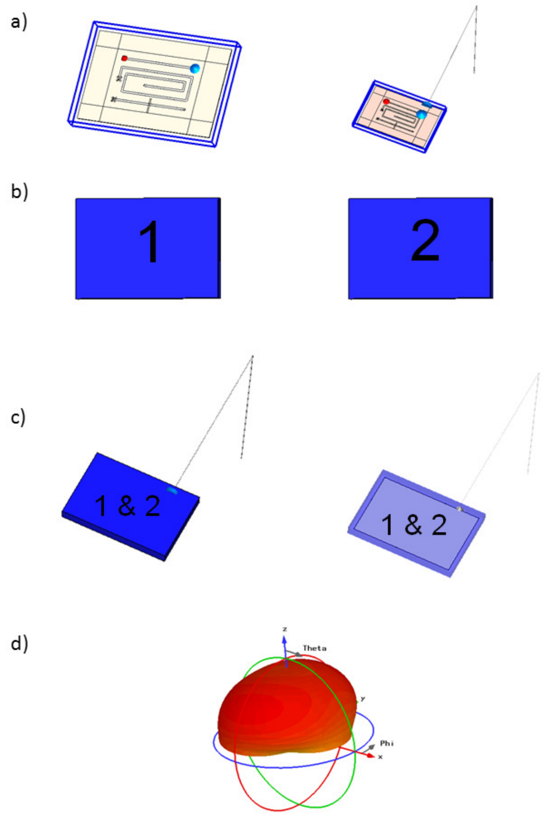


Fig. 2. Simulation workflow.

*b) Huygens' box extraction:* The tangential near-fields on a Huygens' box surrounding each model (i.e. with and without cable) were extracted. The Huygens' box exceeded the PCB by 10 mm in all directions and hence included a part of the cable (10 mm).

*c) Huygens' box source simulations:* The two Huygens' boxes were used as source for simulations of a 3 m semi-anechoic chamber (3 m SAC) measurement. For both cases a cable was added and in another simulation a ground plane inside the Huygens' box was also added in order to approximate the coupling between the PCB and the cable.

*d) Comparison of far-fields:* The predicted maximum far-fields from the physical models (reference) and the two different Huygens' boxes models were compared.

### B. Simulations

The simulated PCB is shown in Fig. 3. A simple 150 x 225 mm PCB with three 50 ohms traces on the top layer and full unbroken ground plane were chosen. Only one trace were 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).

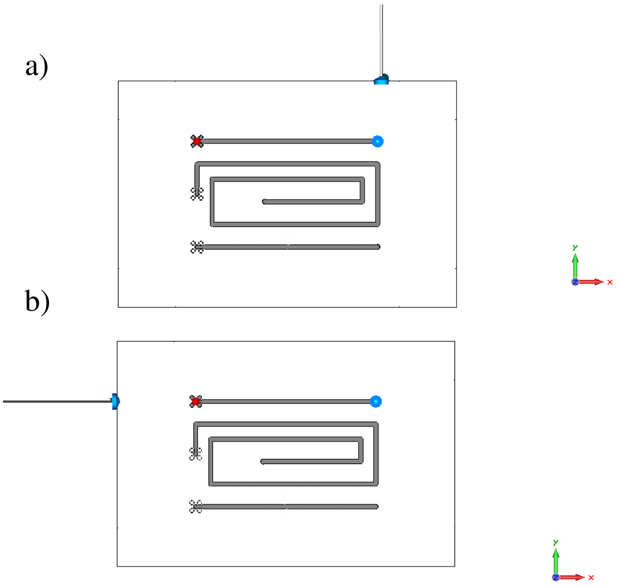

Fig. 3. Layout of the test PCB and position of the connected cables.

Three different cables setups were simulated. In all setups an infinite ground plane was placed 80 cm below the PCB in order to simulate a 3 m SAC.

1) An 80 cm long cable was connected 5 cm from the edge (Fig. 3.a). After 40 cm the cable made a 90° bend towards the ground and hence the cable end is 40 cm above the ground plane.

2) A 100 cm long cable was connected at the same position (Fig. 3.a). After 20 cm the cable made a 90° bend towards the ground and the end is connected to the ground plane 80 cm below the PCB.

3) A 100 cm straight cable was connected at another side of the PCB (Fig. 3.b).

The cable setups was chosen so that they represent a variety (floating vs. terminated cables) of typical setups in apparatus.

### C. *Measurements*

With the purpose to perform a basic validation of the simulations, a near-field scan and a 3 m SAC measurement were carried out on setup 1. A comb generator (a signal generator that produces multiple harmonics of its input signal) with fundamental frequency of 20 MHz was mounted on the back of the PCB and used as a noise generator. The output voltage from the generator measured across 50 Ω was about 85 dBμV up to 1 GHz.

The near-field scanner was a home-made scanner consisting of a robot that moves a Langer RF 50-1 near-field probe across the PCB. Through an Agilent 8447D pre-amplifier the probe was connected to a Rohde Schwartz ZVB8 VNA acting like a spectrum analyser. In other words it was only the amplitude that was measured. The step size in the measurement was 5 mm and the scan height was 10 mm.

## IV. RESULTS AND DISCUSSION

The simulation results from all 3 setups were similar and therefore we will only present the results from setup 1. The simulation results will be presented in a way that represents a hypothetical state-of-the-art near-field scanner, which means that all data are plotted with a dynamic range of 60 dB. The input power in the simulation is scaled to 0 dBm.

### A. *Near-field comparison metric*

In the next section we will compare the near-field on the Huygens' box for two different frequencies. Two different metrics for the difference between near-fields are chosen. In the "absolute difference" the near-fields (in linear scale) for with- and without cables are subtracted and then plotted in a dB-scale, e.g.:

Absolute diff. = 20*log10(abs($H_{x\ \mathrm{without\ cable}}$ (linear) - $H_{x\ \mathrm{with\ cable}}$ (linear)).

This gives an absolute measure of the perturbation from the cable.

In the "relative difference" the near-fields in dB scale are subtracted, e.g.:

Relative diff. = abs($H_{x\ \mathrm{without\ cable}}$ (dB) - $H_{x\ \mathrm{with\ cable}}$ (dB)).

If the near-field in a point is below the dynamic range the field value is set to the lowest value in the dynamic range in order to represent a real near-field scan where the field value is in the noise floor. It is reasonable to assume that a state-of-the-art near-field scanner would have a log-scaled measurement uncertainty and hence this relative difference will indicate whether it is possible to measure the difference, or whether it is below the measurement uncertainty. The color bar scale in the relative plots are set to 0-4 dB, which means that with this state-of-the-art scanner, the cable perturbation surely will be measurable in areas, where the difference is over 4 dB (the dark areas), while it goes below the measurement uncertainty when the difference come close to 0 dB (the blue areas).

### B. *Near-field comparison*

In the simulations there was a cable resonance at 118 MHz and at 286 MHz. The results for 118 MHz and 286 MHz are similar and only the results for 286 MHz are shown. As a representative for a non-resonance frequency 800 MHz was chosen.

In Fig. 4.a the magnetic near-field at 286 MHz 10 mm above the PCB (xy-plane) is shown. The PCB is 225x150 mm and we have plotted the field 10 mm extra in both x- and y-direction (see PCB layout and coordinate systems in Fig. 3). In Fig. 4.b the H-field at 286 MHz on the xz-plane (at the cable side) 10 mm from the PCB is shown. The PCB was 1.6 mm thick and the ground plane is placed in z = 0 mm. The near-field data was exported with 1 mm resolution.

With the naked eye it is difficult to see any difference in Fig. 4a while even though the H-field level is weaker at the y-normal surface the cable emerge clearly in Fig. 4b (the dark spot at x = 175 mm, z = 0 mm).

In Fig. 5 the difference is plotted according to section IV A. At the xy-plane the absolute differences show that the cable resonance causes currents to run in the ground plane (especially at the edge on the cable side) although these are small compared to the currents running on the microstrip.

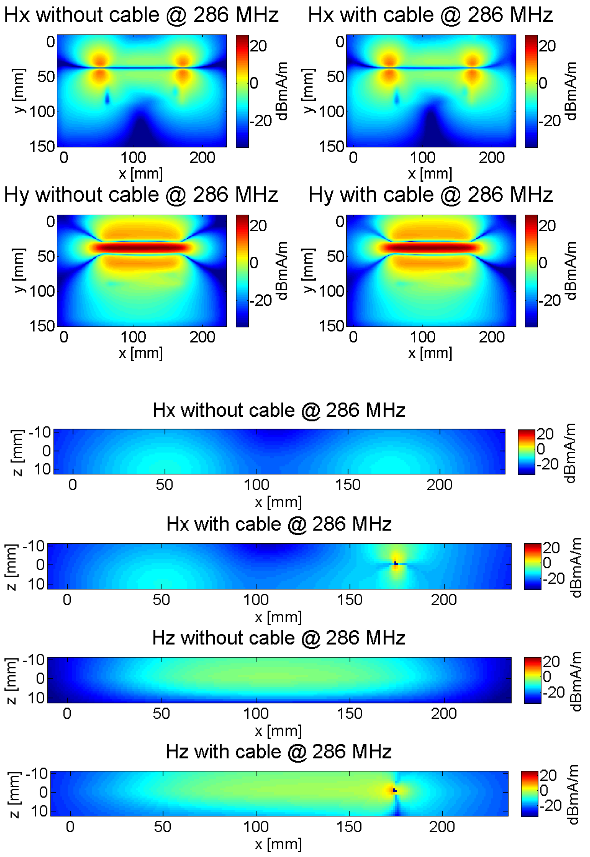


Fig. 4. The magnetic near-field at the top surface and the cable surface. See Fig. 3 for PCB layout and cable position.

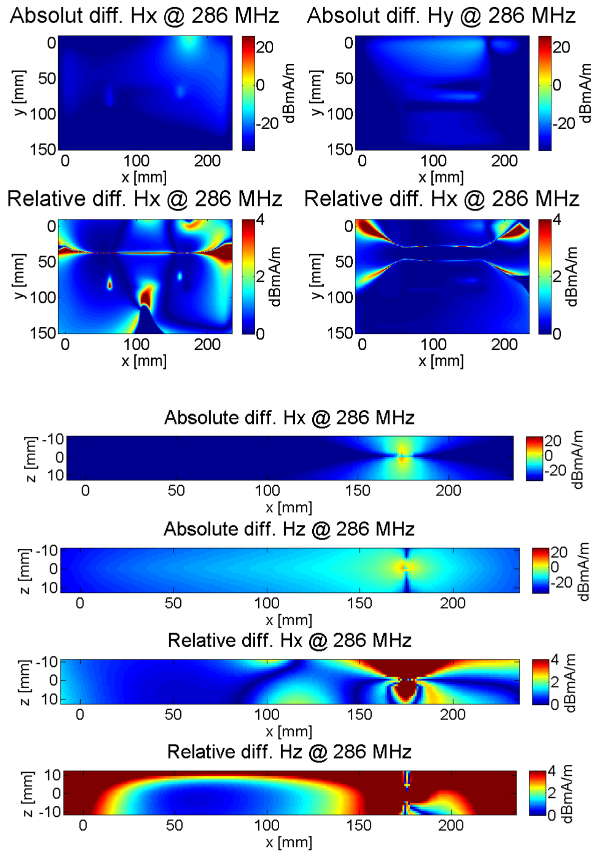


Fig. 5. The difference in magnetic near-field at the resonance frequency 286 MHz. See Fig. 3 for PCB layout and cable position.

The relative difference plot shows that with a measurement uncertainty of 1 dB and a dynamic range of 60 dB it is only possible to measure the difference at some low radiating spots. At the xz-plane the difference is larger - both absolute and relative. The common mode current on the connected cable is mainly induced by the fields on this plane.

The difference plot for the E-field at 286 MHz in figure 6 shows that the cable causes a voltage difference across the PCB´s ground plane. It also shows that the electric field caused by this voltage is small compared to the electric field from the microstrip.

In Fig. 7 the difference plot for the H-field at 800 MHz is shown. Even though the 800 MHz is not a resonance frequency, the perturbation of the near-field is at the same level as at the resonance frequencies.

### *C. Prediction of 3 m SAC measurement*

In Fig. 8 the validity of the Huygens' box method is tested. In the simulation the full model of the PCB without cable is replaced by the Huygens' box and the radiated emission in 3m SAC is simulated. We have used two different mesh cell sizes, 2.5 mm and 5.0 mm (representing two different step sizes in a near-field scan), and both simulated Huygens boxes are in very good agreement with the full model simulation.

Fig. 9 shows the simulation of the maximum E-field in a 3 m SAC for the two different Huygens' boxes. When we added only a cable to the Huygens' box extracted from the model without cable connected and simulated the far-field, the simulations did not predict the resonances at 118 MHz and 286 MHz. When we inside the Huygens' box added a ground plane connected to the cable, the resonances was predicted but the amplitude of the resonance was far below the full model resonance.

Above 450 MHz the PCB itself was the dominating radiator and the connected cable did not change the far-field significantly. When we used the Huygens' box extracted from the model with cable connected (Fig. 9.b) and made the same simulations of the far-field, the simulations predicted the correct resonance frequencies at the right amplitude for both cases, i.e. only cable and cable plus ground plane.

For both Huygens' boxes a weak but wrong resonance at 190 MHz was also predicted (the enlarged part of Fig. 9) if only the cable and not the ground plane was added to the Huygens' box.

It is outside the scope of this paper to give a detailed explanation, but it is obvious that the cable alone in the 3 m SAC has another resonance than the cable together with the PCB ground plane.

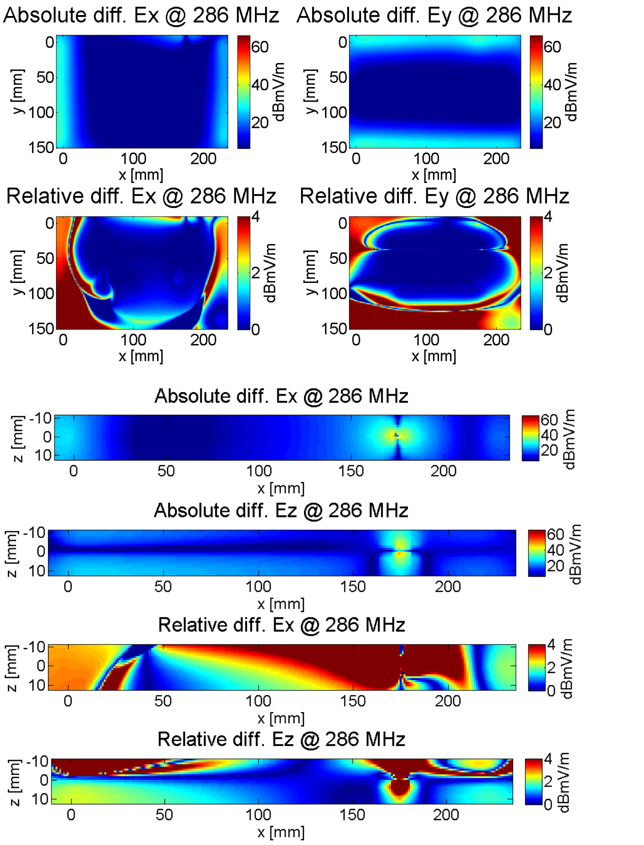

Fig. 6. The difference in electric near-field at the resonance frequency 286 MHz. See Fig. 3 for PCB layout and cable position.

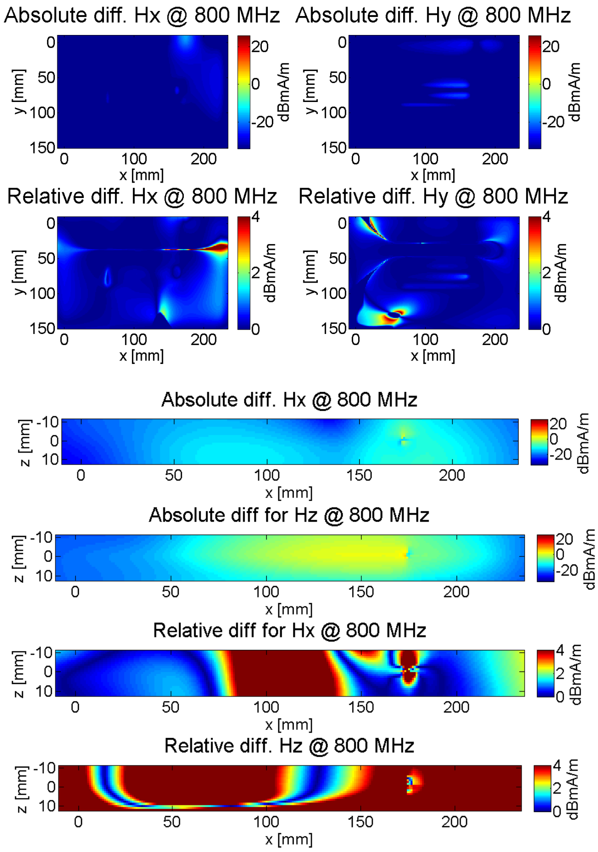

Fig. 7. The difference in electric near-field at the non resonance frequency 800 MHz. See Fig. 3 for PCB layout and cable position.

The field on top of the PCB (xy-plane), which does not change much with the cable attached, is able to induce a small current on the cable (with resonance frequency of 190 MHz) and cable plus ground plane (with resonance frequency of 118 and 286 MHz), but only the fields on the y-normal side of the Huygens' box are able to induce a large current. In practice it will be very difficult physically to make a near-field scan in the area close to cables which seems to be necessary in order to measure the near-field that induced the common mode current on cables.

### *A. Comparison between simulation and measurement*

In Fig. 10 the measured and the simulated near-field is compared. The simulated near-field is scaled to the output power of the comb generator. The plot shows that our measurement did not have 60 dB dynamic range. The maximal amplitude in the simulation was 3.3 dBmA/m and –0.5 dBmA/m in the measurement. The step size in the measurement was 5 mm while data is extracted with a resolution of 1 mm from the simulation.

Beside that there is not used probe compensation in the measurement. At the scanned surface it was not possible to measure a systematic difference between the PCB without cable and the PCB with a cable connected, i.e. the difference was below the measurement uncertainty or the areas with relative large difference was in the noise floor.

Fig. 11 shows the full model simulated E-field inside the 3 m SAC compared with the 3 m SAC measurement - with and without cable. Here it must be pointed out that an EMC 3 m SAC measurement carried out after the CISPR standard does not give the correct E-field. Nevertheless simulation and measurement predict the same cable resonances and almost the same amplitude level.

The sharp resonances at approximately 500 MHz and 660 MHz are not reflected in the measurement but it is possible that the resonances were between two comb frequencies.

## V. Conclusion

In this paper we have investigated the perturbation of near-field scan from connected cables. In order to measure the perturbation a very good near-field scanner with large dynamic range and small measurement uncertainty is needed. If we hypothetically assume that such a state-of-the-art scanner is available and it is physically possible to measure the near-field close to cables, it should be possible from the surface equivalence principle to predict the radiated far-field if we measure the near-field on a Huygens' box enclosing the PCB when the cable is present and connected and if we include a ground plane inside the Huygens' box in the simulations.

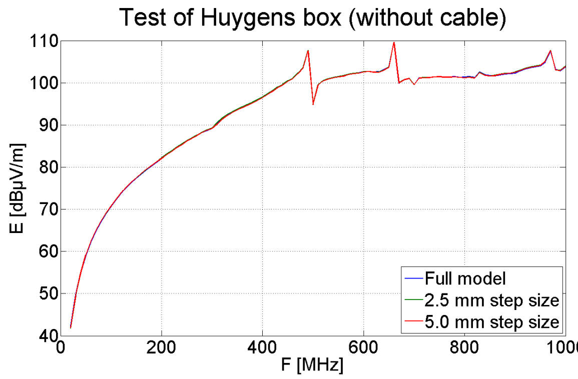


Fig. 8. Simulations of the E-field in a 3 m SAC chamber for the full model, a Huygens' box model with coarse mesh and fine mesh reflecting the step size in a near-field scan. The differences is within a few tenths dB and hence the curves overlap.

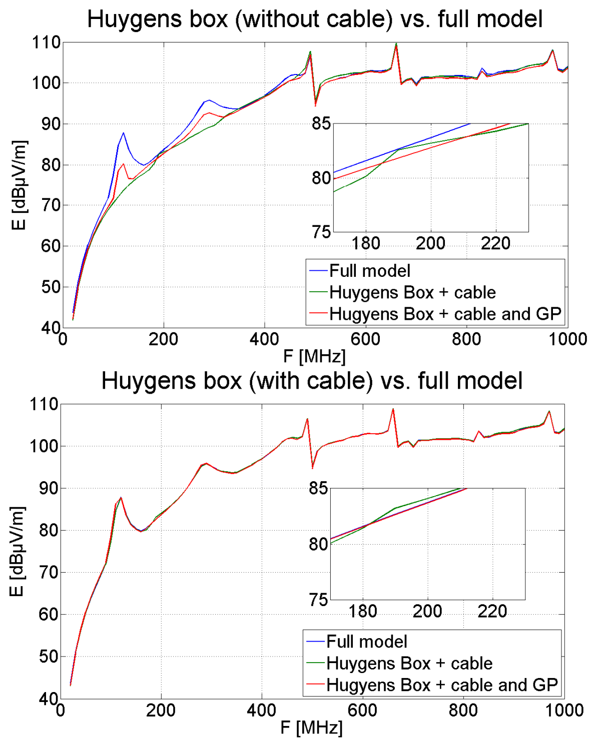


Fig. 9. Simulations of the E-field in a 3 m SAC chamber: (a) for the Huygen box source simulated without cable, (b) for the Huygne box source simulated with cable. In (b) the differences is within a few tenths dB and hence the curves overlap. The plot in a frequency span around 190 is enlarged in order to show the weak but wrong cable resonance at 190 MHz.

But this will require that the cable common mode impedance is the same in the near-field scan than in the final apparatus.

Away from the cable resonance frequencies a connected cable also causes perturbation of the fields, but the perturbation of near-field does not influence the far-field prediction. To be on the safe side one could of course add ferrites on the cables in the near-field scans.

In other words the near-fields on Huygens' boxes are useful for predicting radiated fields from the PCB itself even though cables are connected, but it could be difficult in practice to predict the radiation from common mode currents on cables based on near-field scan.

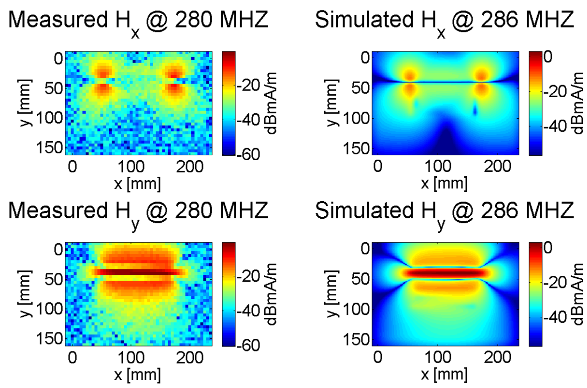


Fig. 10. Comparison between measured and simulated near-field at 286 MHz. See Fig. 3 for PCB layout.

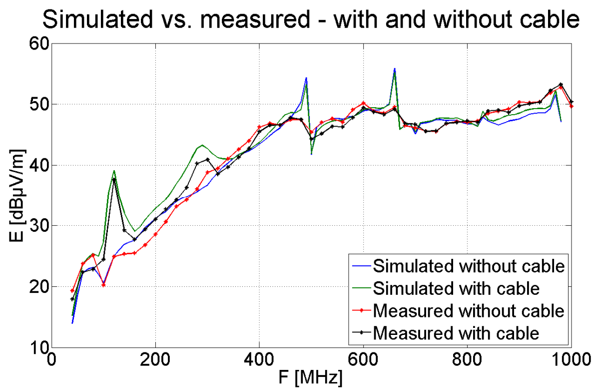


Fig. 11. Comparison between measured and simulated 3 m SAC measurement.

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