Practical Implementation of a Sequential Sampling Algorithm for EMI Near-Field Scanning

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Abstract—**In this paper, a practical implementation of a recently proposed automatic and sequential sampling algorithm for the near-field scanning of printed circuit boards and/or integrated circuits is presented. The sampling algorithm minimizes the required number of sampling points by making a balanced trade-off between 'exploration' and 'exploitation'. Moreover, at every moment analytical models for the complete near-field pattern can be computed by means of Kriging. By comparing successive models, an automatic stopping criterion can be implemented. The performance and effectiveness of the proposed sampling algorithm is tested on a number of simple printed circuit boards and compared with that of the traditionally used uniform sampling.**

Keywords – near-field scanning, surrogate modeling, sequential sampling, Kriging

I. INTRODUCTION

Nowadays, printed circuit boards (PCBs) and integrated circuits (ICs) are combining more and more functionalities working at high frequencies in an ever more confined space. As a consequence, the risk for electromagnetic interference (EMI) issues is increasing and this for both inter- and intra-system. Knowledge of the electromagnetic behavior of PCBs and ICs is therefore essential. Testing the radiated emission of electronic systems is usually done in a (semi-)anechoic chamber, a reverberation chamber or at an open area test site. Access to such certified test facilities can be expensive. Consequently, physical testing is most often only done near the end of a development cycle, i.e., when the range of available low-cost solutions to reduce emissions is rather limited.

To address these difficulties, a low-cost pre-certification test method that provides an in-depth insight on the real root-cause of excessive emissions would be very useful. Electromagnetic near-field (NF) scanning could be a very useful alternative to characterize possible EMI problems at PCB and/or IC level very early in the design cycle [1]. Unfortunately, one of the main draw-backs of NF scanning is the time required to scan the complete device-under-test with a sufficient resolution to capture all relevant phenomena. To overcome this bottleneck, the use of e.g. neural networks has been proposed in the past [2]. However, the technique proposed in [2] still relies on near-field samples that reside on a uniform grid. A major problem is that it is not known a priori how dense this uniform grid has to be.

Recently, a novel sequential sampling and modeling algorithm for the near-field analysis of electronic devices was proposed [3]. This technique combines a sequential sampling algorithm based on a balanced trade-off between 'exploration' (*Voronoi Tesselations*) and 'exploitation' (*Local Linear Approximations*) with analytical approximation models based on Kriging. The main advantages of this technique are that it (*i*) minimizes the number of sampling points required to capture the NF pattern with a given accuracy and (*ii*) allows to check at every moment the convergence of the measured NF data allowing to implement an automatic stopping criterion. In [3], the theoretical background of this algorithm is given in full detail. Its effectiveness was demonstrated by applying it on the simulated near-fields of a printed circuit board.

In this paper, the technique proposed in [3] is applied to the in-house built near-field scanning system available at the University College KHBO – Belgium. The performance of the algorithm is tested on a set of simple PCBs and compared to that of the traditionally used uniform sampling. Finally, the use of 2D Feature Selective Validation (FSV) [4][5] as a possible stopping criterion is investigated.

This paper is organized as follows. Section II gives some more details about the near-field scanner, the near-field probe and the PCBs under test. Section III gives a short overview of the theoretical background of the proposed sampling. Section IV is devoted to the measurement results. Section V gives a brief discussion on the use of 2D FSV as a stopping criterion. Finally, Section VI draws concluding remarks.

II. MEASUREMENT SET-UP

A. *Near-field scanning system and probe*

Figure 1 shows the NF scanning system available at the University College KHBO. It comprises a CNC milling machine that was rebuilt into a NF scanning system. To do this, the miller and its suspension were removed and replaced by a head to which a near-field probe can be attached. The head can be moved automatically in three dimensions above the device under test to make a NF measurement.

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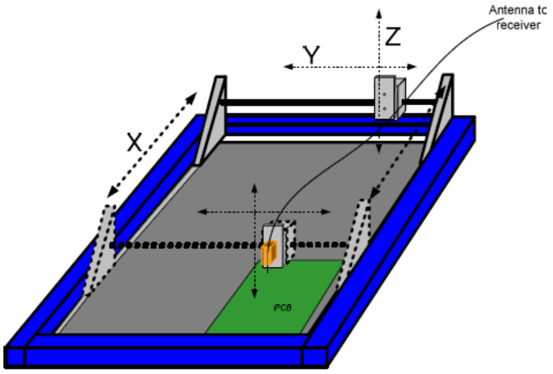
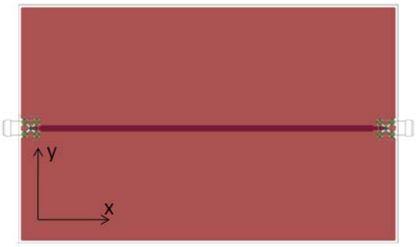
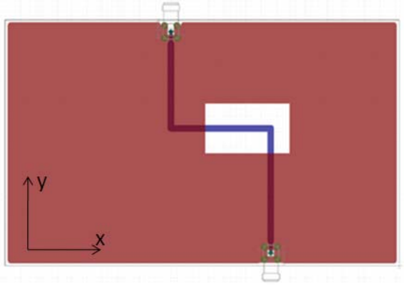


Figure 1: Near-field scanning system

The near-field probe used for the measurements is a magnetic near-field probe from Langer EMV-Technik (RF-U 2.5-2) with a resolution of about 0.5 mm in the frequency range of 30 MHz up to 3 GHz. This probe is connected to a Rohde&Schwarz EMI receiver. Only the magnitude (and not the phase) of the tangential magnetic fields is measured and this at a height of 2 mm above the PCB under test. All measurements are done at 200 MHz.



(a) Straight microstrip



(b) Bent microstrip over slot

Figure 2: PCBs under test

B. *PCBs under test*

In order to test the performance of the proposed sampling algorithm, a set of simple PCBs was manufactured. These PCBs all comprised 50 Ohm microstrips on a 15 cm by 9 cm FR4 substrate of 1.5 mm thickness. To create sufficient radiation, some basic EMC rules were violated on the test PCBs (like e.g. routing the microstrip over a slot in the ground plane). In this paper, the measurement results will be shown for the two PCBs shown in Fig. 2. The first PCB is a simple straight microstrip line. The second PCB is a bent microstrip which is routed over a slot in the ground plane.

III. SEQUENTIAL SAMPLING ALGORITHM

The sequential sampling algorithm starts by computing a small number of initial scan points according to a Latin hypercube design [6]. In successive steps, additional sampling points are selected in a sequential way until the overall variation of the NF pattern is characterized. In order to sample the NF pattern as efficiently as possible, the robust sampling strategy from [7]-[9] is applied to determine the optimal coordinates of the sampling points in a sequential way. It makes a balanced trade-off between exploration and exploitation criteria :

- Exploration is the act of exploring the design space in order to detect key regions that have not yet been identified before. It does not involve the actual pattern of the near-fields, but only the coordinates of the sampling points and their coverage of the design space. It ensures that all the scan points are spread as evenly as possible.
- Exploitation ensures that additional scans are performed in regions of the design space where the amplitude of the near-field component that is being measured is changing more rapidly. These regions often require a finer sampling density than regions with little variation.

For the exploration criterion, the density of data samples is quantified by computing a Voronoi tessellation of the data samples and by calculating the volume of each Voronoi cell. For the exploitation criterion, the dynamic variation of the near fields is quantified by computing simple local linear approximation models that are compared with the sampled NF pattern. Both criteria are combined into a unified metric that can be used to identify undersampled regions of the design space, and to determine the optimal location of additional sample points. The reader is referred to [9] for an in-depth discussion of the theoretical background of the new sampling algorithm.

IV. MEASUREMENT RESULTS

A. *PCB 1: Straight microstrip line*

Figures 3 and 4 show the measured tangential magnetic fields at a height of 2 mm above the PCB under test and this for a uniform sampling with a resolution of 2 mm. This means that there are in total 3375 sample points. The total measurement time for one component is 15 minutes.

Figures 4 and 6 show the measured tangential magnetic fields at a height of 2 mm above the PCB under test and this for the new sequential sampling algorithm. The algorithm was stopped after 350 sample points. A very good agreement with the uniformly sampled field patterns is observed.

Note that the sequential algorithm preferably chooses sampling points in the regions where the NFs vary the most (which are not necessarily the regions with the strongest fields).

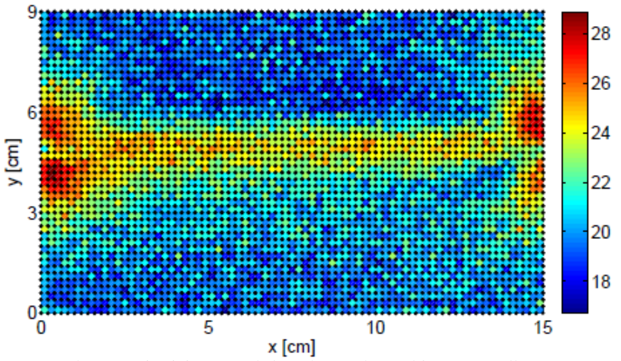


Figure 3: |H$_x$| for a straight microstrip, uniform sampling (2 mm resolution, 3375 samples)

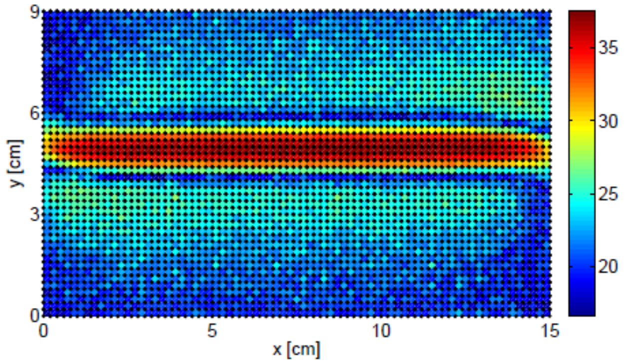


Figure 4: |H$_y$| for a straight microstrip, uniform sampling (2 mm resolution, 3375 samples)

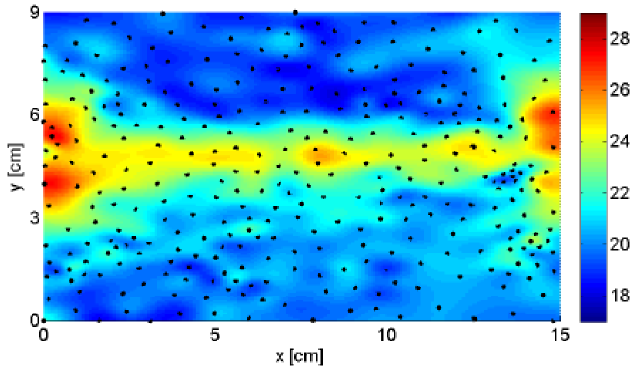


Figure 5: |H$_x$| for a straight microstrip, sequential sampling (350 samples)

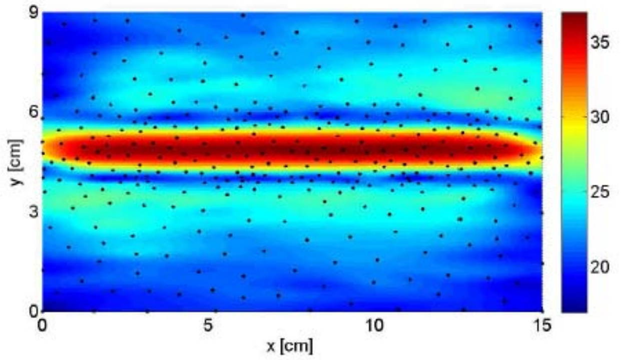


Figure 6: |H$_y$| for a straight microstrip, sequential sampling (350 samples)

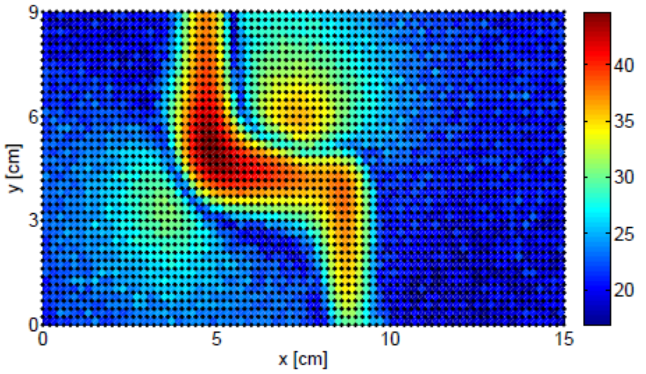


Figure 7: |H$_x$| for a bent microstrip over a slot, uniform sampling (2 mm resolution, 3375 samples)

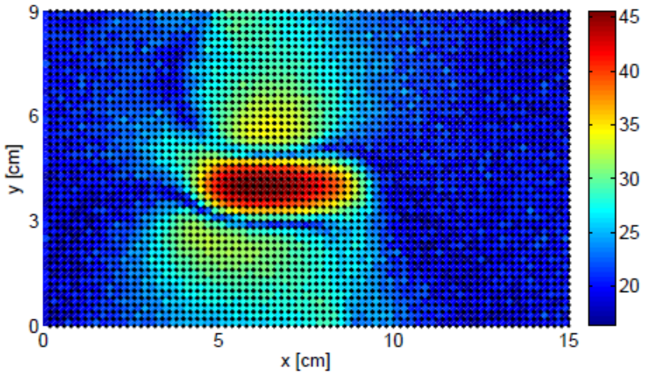


Figure 8: |H$_y$| for a bent microstrip over a slot, uniform sampling (2 mm resolution, 3375 samples)

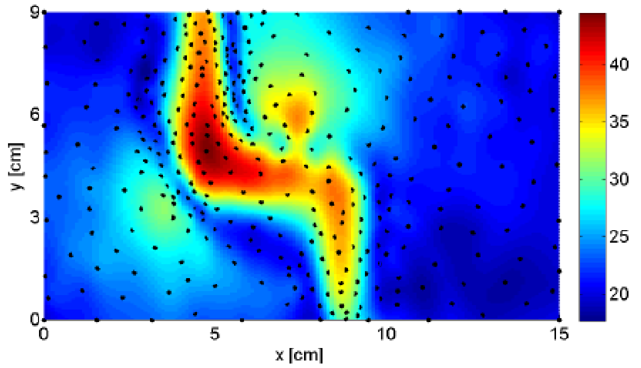


Figure 9: |H$_x$| for a bent microstrip over a slot, sequential sampling (356 samples)

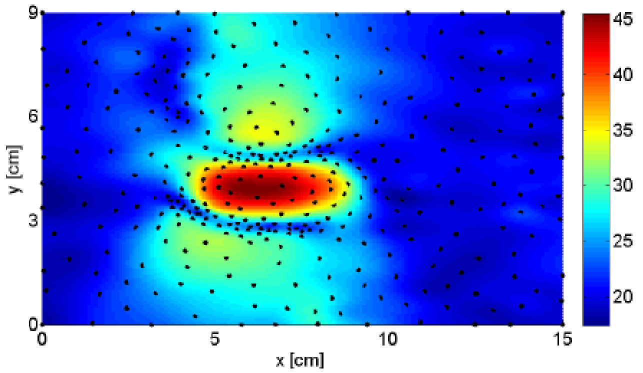


Figure 10: |H$_y$| for a bent microstrip over a slot, sequential sampling (356 samples)

For the sequential sampling algorithm with 350 sample points the total measurement time is about 13 minutes per component. Some extra time is lost due to the extra time needed to move the NF probe between at first sight random positions which can be far away from each other. Hence, a possible improvement could be to let the sampling algorithm propose more than one, e.g. ten, sampling points which can then be measured in a optimal way with respect to the movement of the NF probe.

B. PCB 2: Bent microstrip line over slot

Figures 7 and 8 show the measured tangential magnetic fields at a height of 2 mm above the PCB under test and this for a uniform sampling with a resolution of 2 mm. This means that there are in total 3375 sample points.

Figures 9 and 10 show the measured tangential magnetic fields at a height of 2 mm above the PCB under test and this for the new sequential sampling algorithm. The algorithm was stopped after 350 sample points. Again, a very good agreement with the uniformly sampled field patterns is observed.

The same conclusion for the measurement time applies to this example.

V. TWO-DIMENSIONAL FSV AS STOPPING CRITERION

One of the major advantages of the proposed sequential sampling algorithm is the fact that it allows to check on the fly the convergence of the measured NF pattern. One question that arises is how to compare consecutive models. The most obvious error criteria are the absolute or relative error in a large number of predefined points on a (uniform) grid. However, in practice, it is seen that the absolute or relative error between two consecutive models might be quite high due to very local differences while the two models are very similar for the human eye.

As an alternative, the FSV algorithm [4][5] could be used to compare consecutive models. The FSV algorithm tries to quantify the comparison between two datasets as it would be undertaken by human beings. When comparing two datasets, FSV decomposes both datasets into two parts, trend and feature data. The trend data can be seen as the slow variations, while the feature data can be seen as the fast variations. Analysing the slow varying part gives a measure of similarity of the trend (ADM or Amplitude Difference Measure). Analysing the fast varying part gives a measure of the similarity of the feature (FDM or Feature Difference Measure).These figures combine to a global goodness-of-fit value (GDM or Global Difference Measure). Figure 11 shows how the value of the GDM has to be interpreted.

Figure 12 shows the GDM of two consecutive Kriging models versus the number of samples used to obtain that model and this for the magnetic field components for the bent microstrip over a slot. It is seen that already after 100 samples the comparison between two consecutive models can be seen as ‘Very Good’. After 150 samples this is even “Excellent”.

FSV value (quantitative)	**FSV interpretation (qualitative)**	**FSV Visual six point scale**
Less than 0.1	Excellent	1
Between 0.1 and 0.2	Very good	2
Between 0.2 and 0.4	Good	3
Between 0.4 and 0.8	Fair	4
Between 0.8 and 1.6	Poor	5
Greater than 1.6	Very poor	6

Figure 11: FSV interpretation table [4]

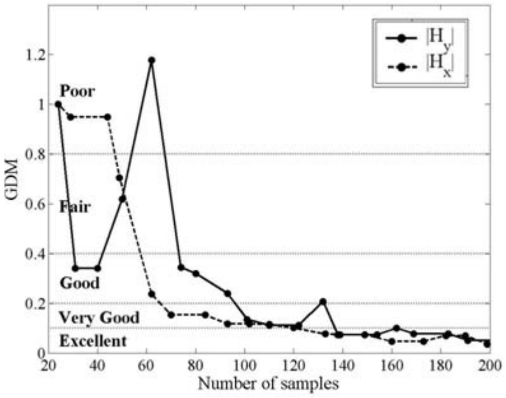


Figure 12: Global Difference Measure between two consecutive models versus the number of samples

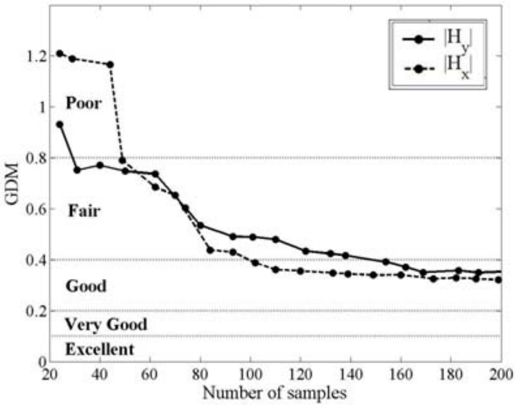


Figure 13: Global Difference Measure between the Kriging model and the very densely uniformly sampled pattern versus the number of samples

Figure 13 shows the GDM of the last Kriging models compared to the (final) NF pattern obtained with a very dense uniform sampling (which can be seen as the exact solution) and this for the magnetic field components for the bent microstrip over a slot. Although there is a correlation with the data of Fig. 12, this GDM only indicates a “Good” comparison, even after 200 samples.

Although these results show that FSV can be used as an objective comparison between models, it is clear that a blind application of the standard interpretation table of FSV is not sufficient and that further research is needed to calibrate the FSV method towards this application.

VI. CONCLUSIONS

The sequential sampling algorithm proposed in [3] was applied in practice to the in-house built near-field scanning system available at the University College KHBO – Belgium. The performance of the algorithm was tested on a set of simple PCBs and compared to that of the traditionally used uniform sampling. Finally, the use of 2D Feature Selective Validation (FSV) as a possible stopping criterion was investigated. Although promising, using the FSV for 2D data needs further investigation.

An open source MATLAB implementation of the modeling techniques in Section III is made publicly available for non-commercial, personal and academic use (AGPLv3 license) [10]. It can be downloaded as “SUMO Toolbox”from [11].

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