Accelerated Implementation of the Power Method for Analysis of Electromagnetic Fields

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1. The collaborative Project
2. The work of research partner
3. Our algorithm/computing contribution

ICT COST Action IC1407

Advanced characterisation and classification of radiated emissions in densely integrated technologies (ACCREDIT) – 20 partners

http://www.cost.eu/COST_Actions/ict/IC1407

ICT (InformationCommunicationTechnology)
COST (COoperationScienceTechnology) – a framework supporting trans-national cooperation among researchers, engineers and scholars across Europe

The Topic here:

Electromagnetic interference (EMI) + ubiquitous computing devices → !?

The electromagnetic interference will increase with the anticipated **increase of clock speeds, frequency of operation and circuit density**.
(mobile technologies, remote control, Internet of Things, ...)

Immunity levels will also decrease due to lower supply voltages and lower signal power levels.

Traditionally the potential EMI sources were assessed in the frequency domain **assuming static emissions. This is not valid for** multifunctional devices with many operating modes and wideband digital receivers.

New approaches that fully account for time dependence and uncertainty are needed.

- modelling approaches to include efficient behavioural models, propagation and interaction of stochastic field distributions
- experimental methods including wideband near field probes and efficient time or frequency domain EMI measurement

A coordinated international research programme

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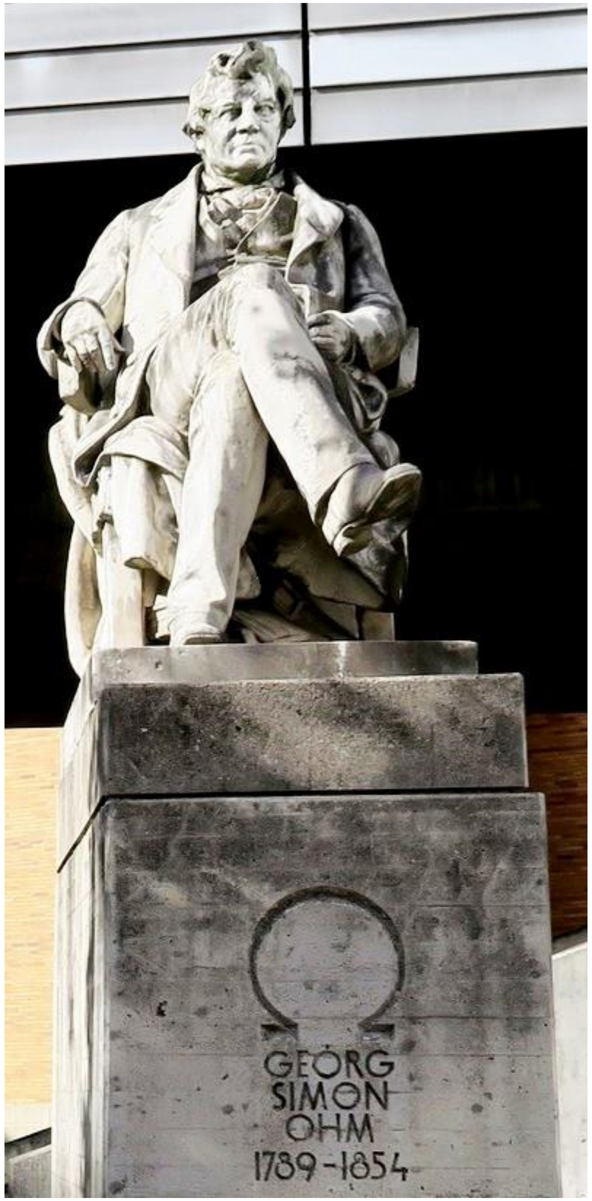
WEB: http://www.nano.ei.tum.de

- Stochastic electromagnetic fields can be described by the correlation function of the field amplitudes in all pairs of space points.

- A description of stochastic electromagnetic fields by correlation matrices.



What the research partner is doing

1. making the measurement

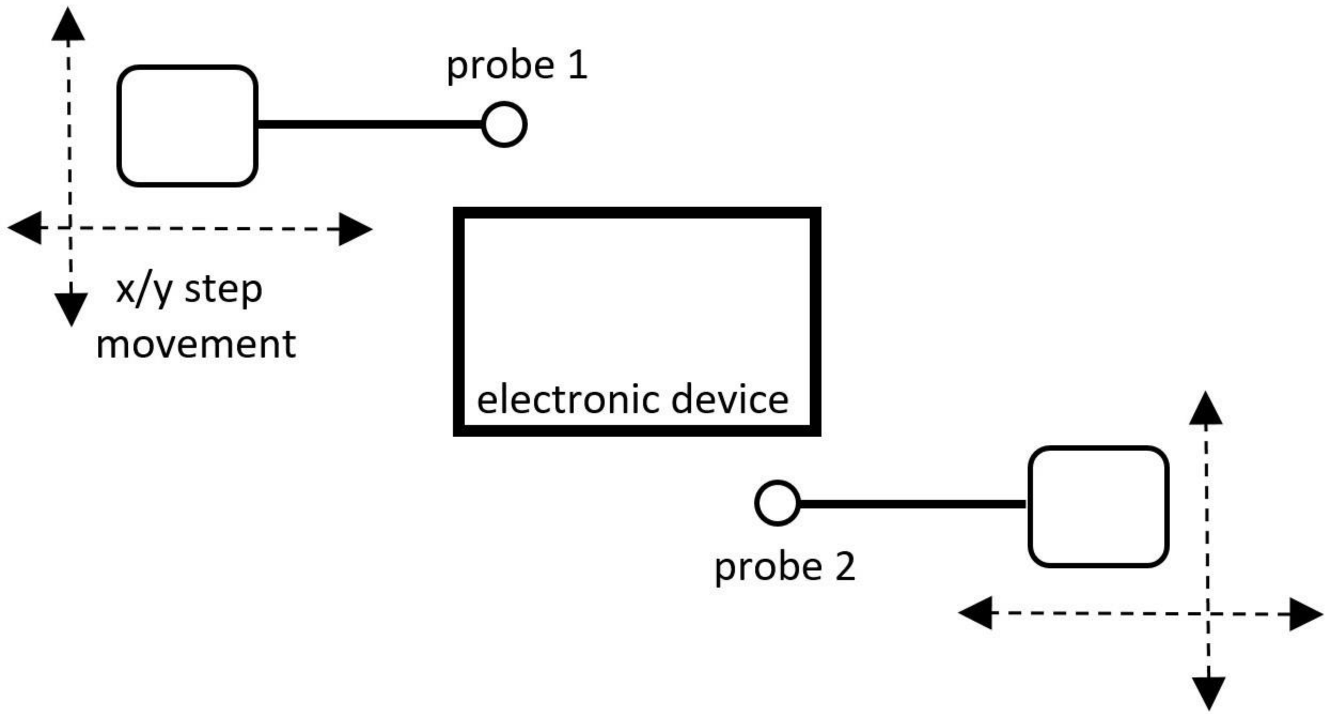
The 2-probe scanning system on a rectangular grid of measurement points.

2. making a description of stochastic electromagnetic fields by correlation matrices

the cross correlation functions for every pair of sampling points is evaluated and from this, by numerical Fourier transformation the correlation matrix is computed.

3. matrices can be simplified using the principal component analysis (PCA) for eigenvalue decomposition.

The problem is in the practical aspect of the data analysis, where tens of thousands of realizations of random field measurement over thousands of frequencies must be processed, and the enormous unnecessary redundancy must be eliminated.



The grid of size 6 × 6 requires measurement of 1260 point pairs (36x36 -36).
The uniform grid has 10mm spacing just above a PCB containing a test structure.
Correlation spectra are obtained by Fourier transformation
and yield data from DC to 1.2 GHz resolved in about 32 000 frequency bins.
The large correlation matrix dimensions imply the size of the dataset.

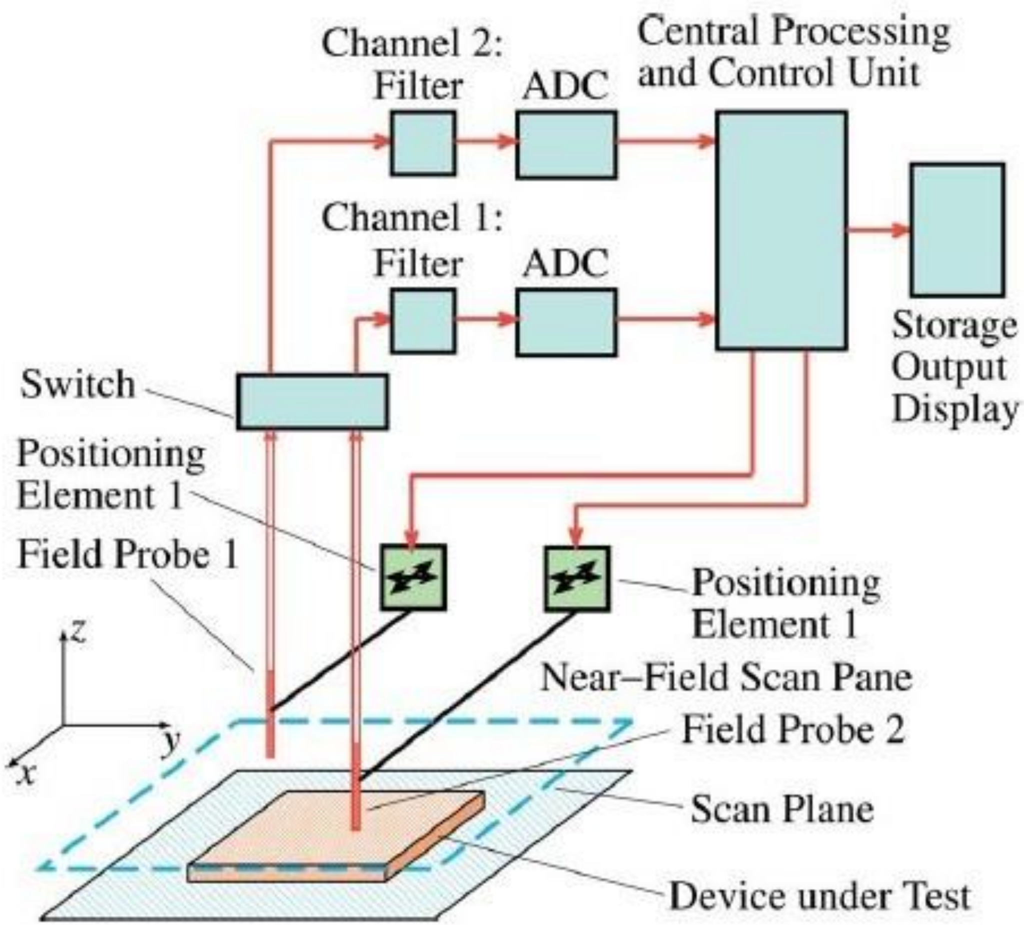


Fig. 16. Schematic drawing of the near-field scanning system.

In: Johannes A. Russer, Member, IEEE, and Peter Russer, Life Fellow, IEEE:
Modeling of Noisy EM Field Propagation Using Correlation Information.
IEEE Transactions On Microwave Theory And Techniques, Vol. 63, No. 1, January 2015

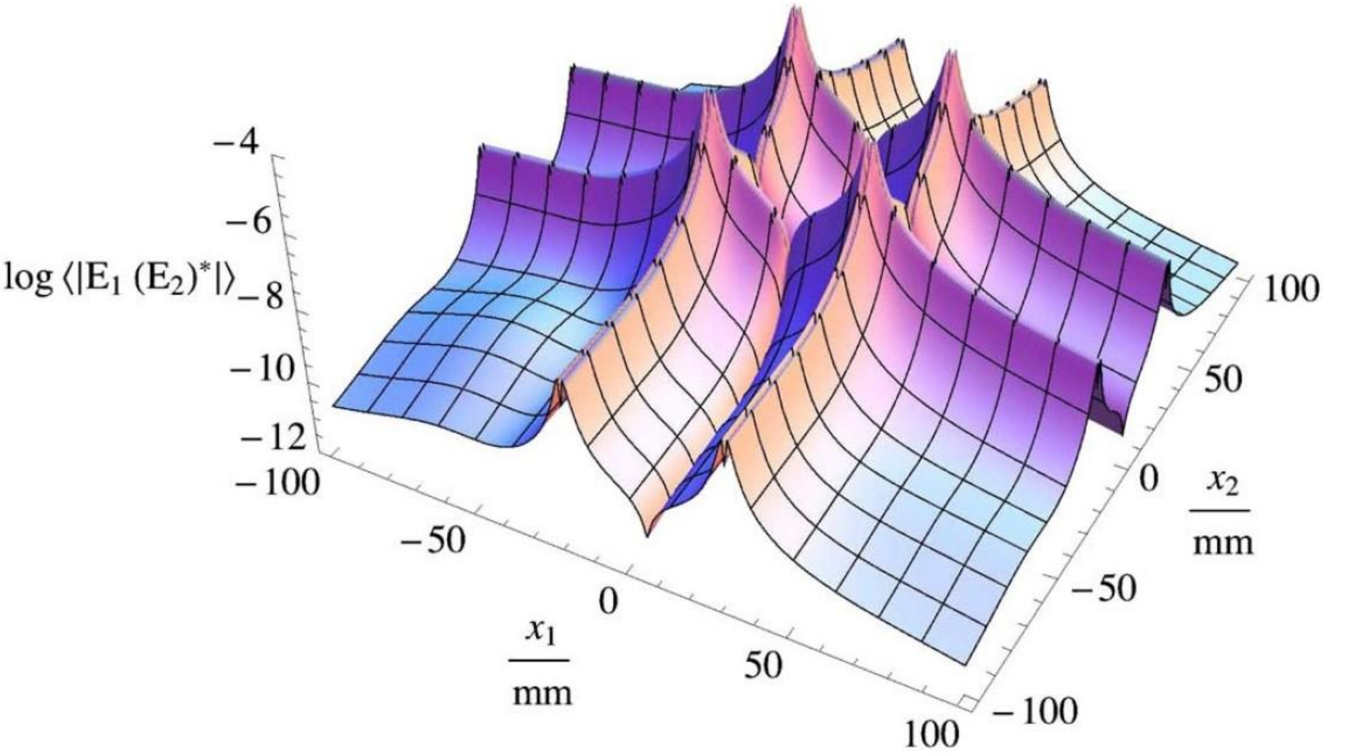


Fig. 8. Three-dimensional logarithmic plot of the magnitude of the electric-field correlation density $\Gamma_E(\boldsymbol{x}_1', \boldsymbol{x}_2', \omega)$ for fully correlated in-phase sources of

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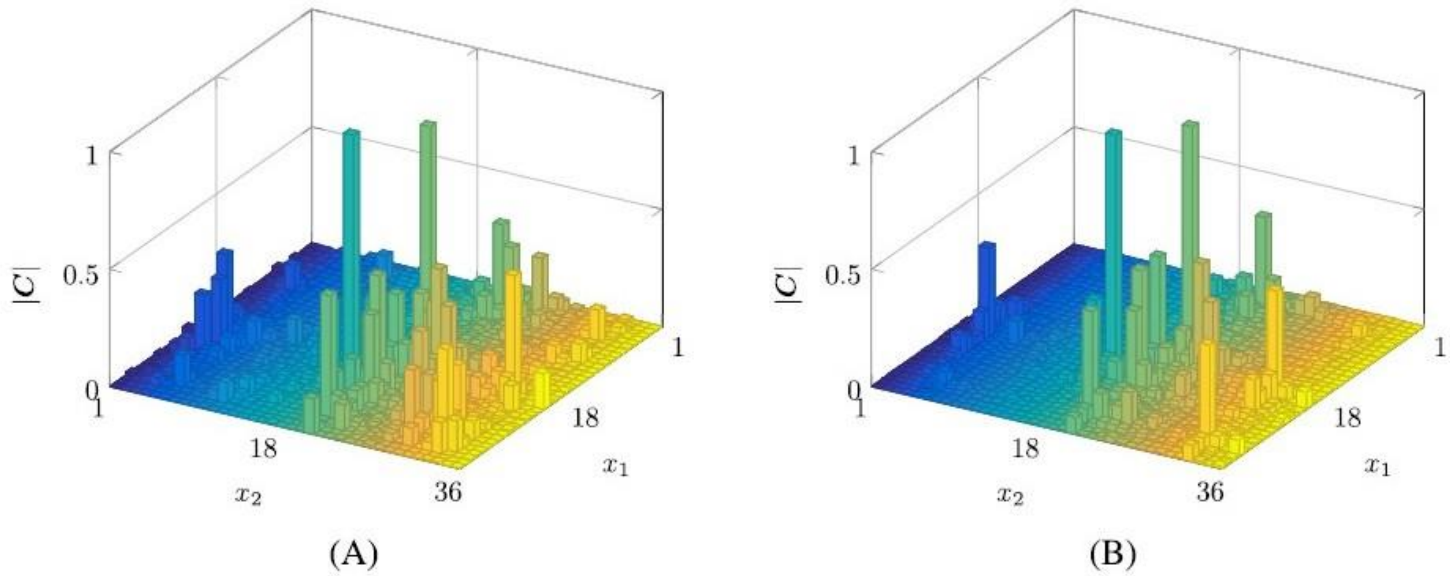


FIGURE 4 Visualized A, original and B, reconstructed correlation matrix at 635.99 MHz

In: M. Haider, J. Russer: Principal component analysis for efficient characterization of stochastic electromagnetic fields. Wiley, 2017. DOI: 10.1002/jnm.2246.

1. The collaborative Project
2. The work of research partner
3. **Our algorithm/computing contribution**

Our article presents two kinds of optimizations to the well known power iteration method for finding dominant eigenvalue of matrices (Principal Component Analysis), with regard to special matrices often used in EM field measurement and processing.

Two optimizations

1. improving the convergence of the power iteration algorithm (PCA analysis)

2. the acceleration of the power method is implemented by means of modern vector processing features of the x86-64 architecture, (various implementations using different parameters are evaluated by using the Intel MKL library)

1st attempt for optimisation (Principal Component Analysis)

The original PI method is iterating using a single vector estimate converging slowly to the actual eigenvector.

The closer this estimate points into the direction of the actual dominant eigenvector to be found, the less iterations of the algorithm will be necessary.

The modification provides vector of several estimates. Out of these several estimates only one value - the one with the minimal distance to previous iteration is selected.

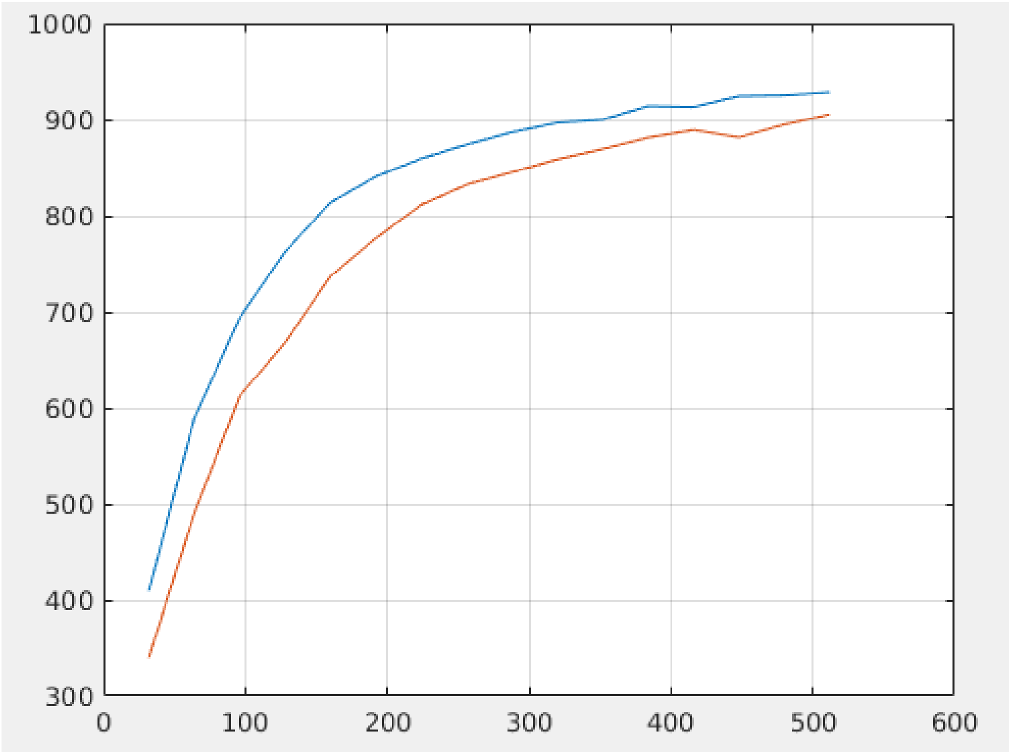
Experimental analysis

random matrices of varying size between N = 32 and 512

resulting number of iterations from averaging over 10000 random matrices

The improvement in convergence is around 20%.
A set of 8 parallel starting vectors seems too small to bring substantial improvement.

More suitable for matrices smaller than approximately N = 200, but these are of limited practical use when analyzing real measurement data.



Average number of iterations (y) for various matrix sizes (x),
upper blue (interpolated) line shows the standart implementation results,
lower red line shows the parallelized implementation results

2nd attempt for optimisation (Principal Component Analysis)

The other method is focused on optimized implementation in C++
with the powerful Single Instruction Multiple Data (SIMD) vector processing capabilities of modern processors.

two lower-level implementations in C++

- standard ISO C-libraries and language constructs only
- sophisticated optimizations by advanced vectorization features of modern processors

a tool was selected – the Intel MKL library, that provides a set of standardized mathematical interfaces for various scientific areas

64-bit Linux Ubuntu LTS 16.04.1 system, with minimal background services running on a four-core 3.6 GHz Intel Core I7-4790 CPU capable of running up to 8 threads simultaneously.

These different computing conditions were compared

1. Type of matrix A
    a. PI (Power Iteration) for generic matrix A
    b. PI for special case symmetric matrix A

2. Precision of the floating point arithmetic
    a. double precision
    b. float precision

3. Libraries used
    a. Standard C++ libraries only
    b. Intel MKL **SIMD** optimized libraries

4. Number of threads
    a. Single threaded implementation
    b. Four threads
    c. Eight threads

	implementation	runtime [ms/call]	speedup factor
1	C++ std. gen. double	19.20	1
2	**C++ std. sym. double**	9.949	1.9
3	C++ std. gen. float	19.13	1
4	C++ std. sym. float	9.762	2
5	C++ MKL gen. double	4.320	4.4
6	**C++ MKL sym. double**	2.574	7.5
7	C++ MKL gen. float	2.214	8.7
8	C++ MKL sym. float	1.429	13.4
9	C++ MKL gen. double, 4 threads	1.348	14.2
10	**C++ MKL sym. double, 4 thr.**	0.9539	20.1
11	C++ MKL gen. float, 4 thr.	0.7928	24.2
12	C++ MKL sym. float, 4 thr.	0.5326	36
13	C++ MKL gen. double, 8 thr.	1.278	15
14	**C++ MKL sym. double, 8 thr.**	0.9518	20.2
15	C++ MKL gen. float, 8 thr.	0.8317	23.1
16	C++ MKL sym. float, 8 thr.	0.5314	36.1

A potential for improvement **not only by vectorization, but also by multithreading**. This is demonstrated by lines 5 and 9 and the four-thread implementation easily outperforms the already optimized single threaded one by 68.8 %.

The **limited positive effect of multithreading** when using the MKL library

- the thread count 4 provides impressive improvement
- number of threads 8 doesn’t really brings much improvement (by result on lines 9 and 13: only 5.2 % improvement)

MKL library really proves being **effective, even in the single thread** scenario. When comparing lines 1 and 5 in Table 1, the improvement brought by MKL implementation is 77.5 %, or in other words, the optimized code runs less than one fourth of the time comparing to the implementation using just standard libraries.

Conclusion

In this paper we presented two kinds of optimization to the well-known power iteration method for finding dominant eigenvalue of matrices, with regard to special types of matrices often used in EM field measurement and processing.

1. method: for large matrices is provided **a limited benefit**

2. method: an **interesting overview on the effects** of various parameters of implementation, with or without usage of the optimized MKL library for general and also specific matrices that are important in the EM field measurement and processing.