Reduced order multiport modelling via Laguerre-SVD and its application to FDTD

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ABSTRACT

In this contribution we first briefly introduce a new Reduced Order Modelling (ROM) algorithm based on the decomposition of the system transfer matrix into orthogonal scaled Laguerre functions. This new technique overcomes the difficulty of unstabilities at low frequencies often experienced with other ROM techniques. Next, we propose a new approach to automatically derive subcell models for 2D FDTD problems. This approach is based on the state-space description of Maxwell's equations for the subcell problem space followed by the application of the new ROM technique to obtain a compact description. We illustrate this with an example of scattering by an array of dielectric wires.

A NEW REDUCED ORDER MODELLING ALGORITHM

A specific branch of research called Reduced Order Modelling (ROM) or in more recent publications also called Model Order Reduction (MOR), takes a state space description of a system as its starting point, together with a number of input and output variables (port variables) of that system. The variables used in the state space description are termed "internal variables". A state space description is essentially a (often very large) set of first order differential equations. It is the business of ROM to develop techniques to come up with a "reduced" state space description using fewer internal variables but leaving intact the relationship between input and output variables (at least over a certain frequency range). This way of treating a system originates from control systems theory and involves concepts such as observability and controlability.
Maxwell's equations are continuous in space and time. Through the discretisation of the space derivatives, as e.g. in FDTD or TLM, these equations can be transformed into a state space description. Other approaches also lead to such a description e.g. the well-known PEEC method. By solving an electrostatic and magnetostatic problem, a SPICE circuit description is obtained which can readily be rewritten as a state space description.

A problem which arises with many of the ROM-algorithms that have been proposed in literature, is that they experience late-time instabilities which make them less suited for broadband problems such as e.g. DC-coupled digital interconnects. To tackle this difficulty a new reduced order multiport modeling algorithm based on the decomposition of the system transfer matrix into orthogonal scaled Laguerre functions was developed [1]. A subsequent singular value decomposition leads to a simple and stable implementation of the algorithm. Stability remains intact at low frequencies. For reciprocal structures the algorithm preserves reciprocity while passivity also remains assured. An additional advantage of the new method is that the degree of reduction can be chosen as a function of the bandwidth over which the reduced model must remain valid. We refer the reader to [1] for more details.

APPLICATION TO SUBCELL MODELLING IN FDTD

As an application we discuss a new and automatic subcell generation technique for FDTD. This technique takes advantage of interpreting the FDTD-equations as a state space description. The starting point is shown in Fig. 1. The original coarse FDTD-grid is subdivided into a subcell part and a remaining part. This remaing part is treated in the classical FDTD way. The subcell region will typically contain a problem feature which requires a much finer grid, as also suggested in Fig. 1. In this finer grid, a state space description of the subcell region is obtained based on the way space (i.e. the curl operator) is discretised in the FDTD-method. In this way a state space description is obtained of the subcell region. Fields at the boundary of the subcell are used as input and output variables while fields internal to the subcell are considered to be the internal variables. Next, our new ROM algorithm is invoked to derive a state space description with fewer internal variables. Finally, when time is discretised, the time-stepping algorithm consists of an explicit algebraic equation for the subcell region and the explicit scalar FDTD-equations in the surrounding region (the "remainder" region of Fig. 1). A leapfrog time-stepping algorithm is finally used to solve the combined subcell-remainder region problem. One of the problems involved is the communication between the remaining FDTD-grid and the reduced state space description description of the subcell region. We will not go into detail here but refer the reader to [2][3]. Up to now our technique is restricted to the 2D case. Work is underway to extend this work to 3D.

EXAMPLE: SUBCELL MODELLING FOR A GRID OF DIELECTRIC WIRES

As an example consider the dielectric wire depicted in Fig. 2. Its radius is 0.9 mm and ε_r=10. The subcell consists of 2 by 2 coarse FDTD grid cells. A coarse cell measures 1.3mm x 1.3mm while the finer grid in the subcell measures 0.1mm x 0.1mm. In that case, the state space description of the subcell takes 4408 internal variables. Applying our ROM-technique, this is reduced to either 36, 24 or 12 internal variables.

Next, the subcell model for the wire is used in the FDTD-simulation of the problem depicted in Fig. 3, which shows a 3 by 3 array of dielectric wires. The problem is excited by a line current source as shown in the figure, while the electric field is recorded at the opposite side of the array. Fig. 4 shows the final result (the amplitude of the transfer function) as a function of frequency. The result of an FDTD simulation which does not use the subcell technique, but an overall fine FDTD-grid of 0.1mm x 0.1mm is displayed as a reference result. Furthermore, the figure shows three other curves obtained through the combination of an FDTD-simulation on the coarse 1.3mm x 1.3mm grid in conjunction with the ROM-models of the dielectric wires. The accuracy of the ROM-FDTD modelling depends on the amount of reduction enforced on the subcell model. Fewer internal variables clearly imply that the ROM-model will only yield good results over a limited frequency range. The stability of the ROM-technique at the lower frequency end is clearly seen.

REFERENCES

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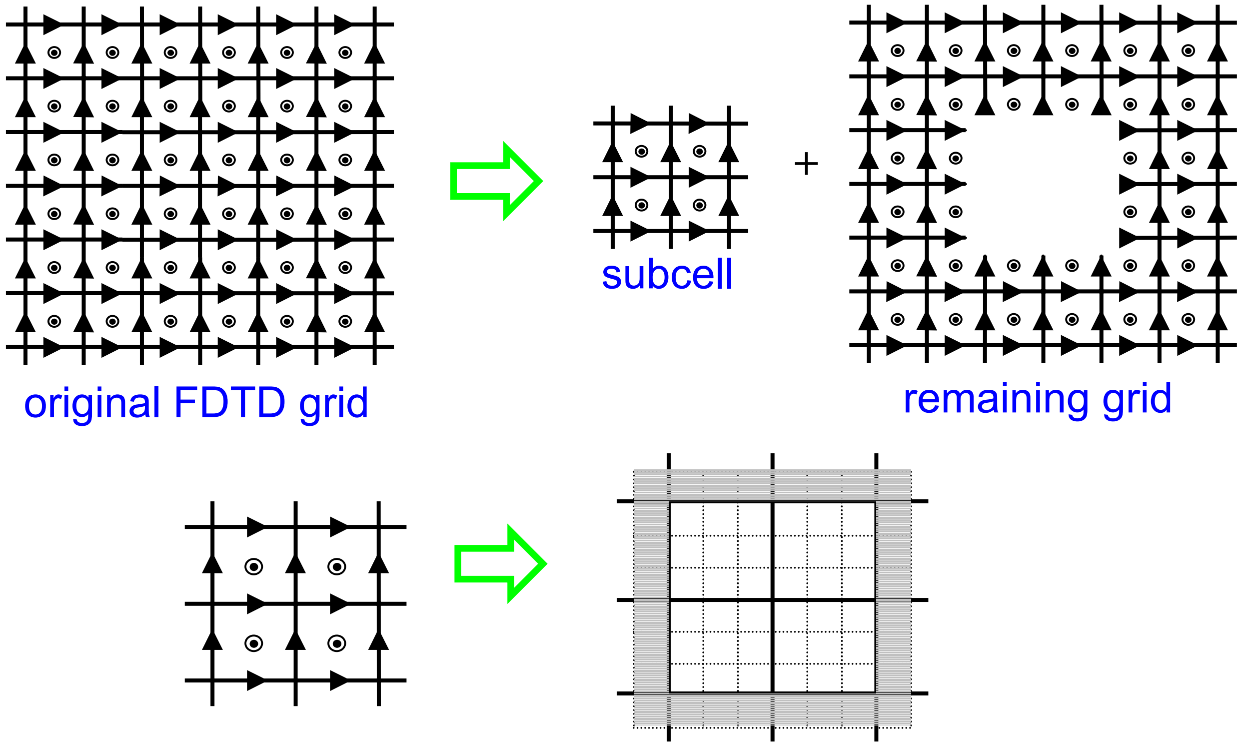

Fig. 1: the principle of subcell modelling in FDTD

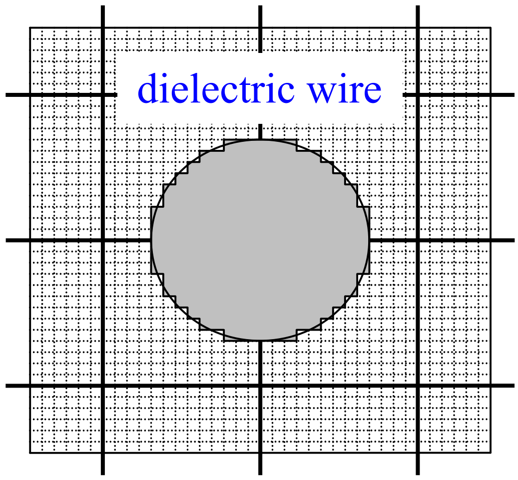

Fig. 2: dielectric wire of radius 0.9 mm and ε_r=10 embedded in a subcell region

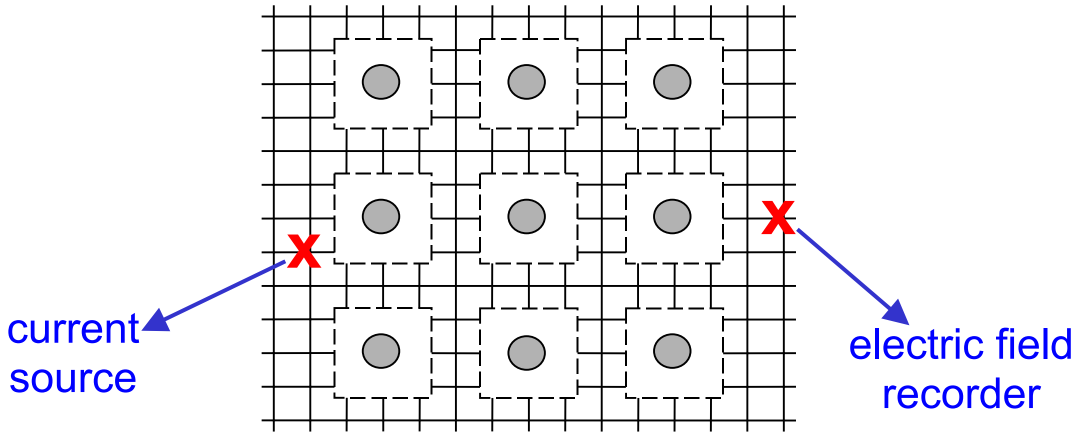

Fig. 3: array of dielectric wires excited by a line current

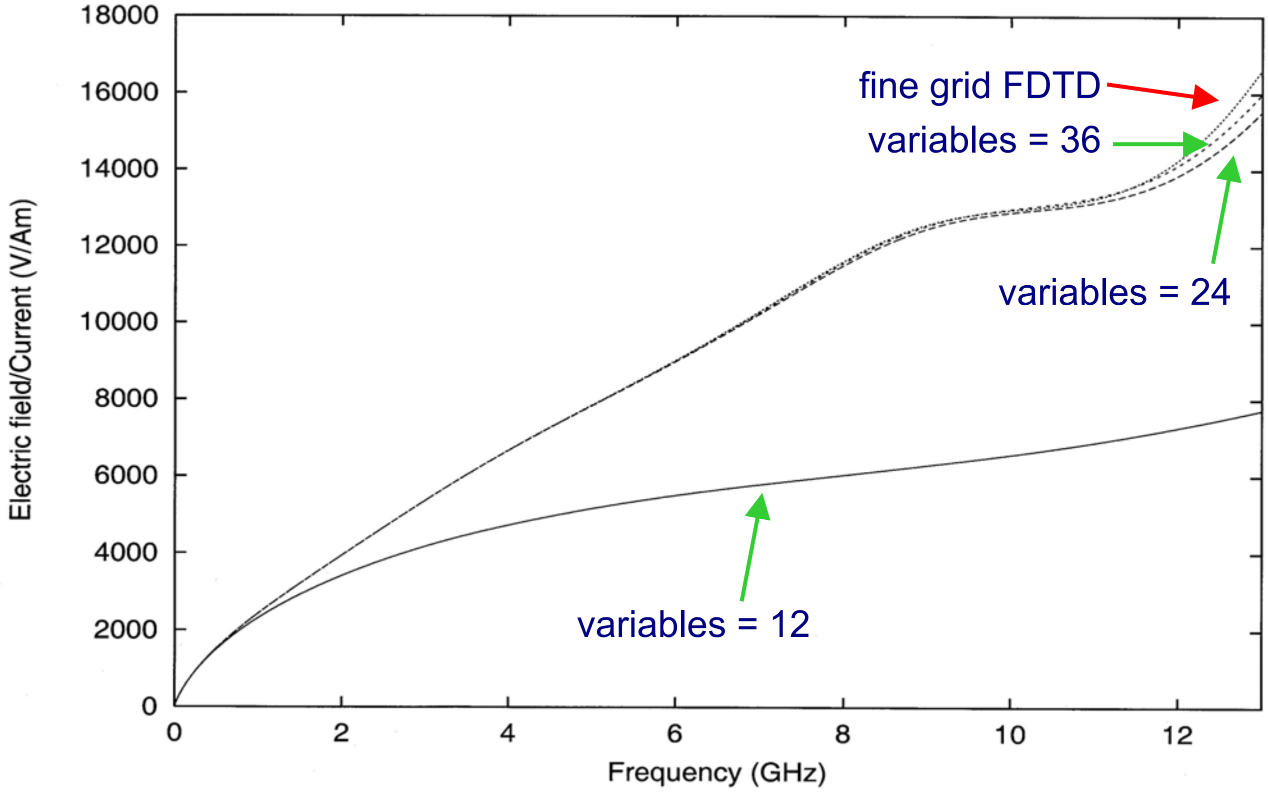

Fig. 4: amplitude of the transfer function between current and recorded electric field. Comparision between exact fine grid FDTD result and reduced order model subcell-FDTD combination for different degrees of reduction of the model.