Simulation of EM-Wave Propagation from an Antenna Element

Maksims Abalenkovs   Luis Cebamanos   Dr Fumie Costen

School of Electrical and Electronic Engineering
University of Manchester

MANSKADS-3
Manchester, United Kingdom

Outline

SKADS Context

- SKADS Position: 2-PAD
- SKADS Activity:
  - numerical simulation of EM-wave propagation
  - various UWB antenna elements (geometric shape and material)
  - excitation source $\rightarrow$ antennas
- COTS $\rightarrow$ commercial software (MATLAB, CST Studio ++):
  - not enough precision, small-scale (up to 4 elements)
  - little parallelisation capabilities $\rightarrow$ in-house software
  - might be competitive in 5 years

Working procedure

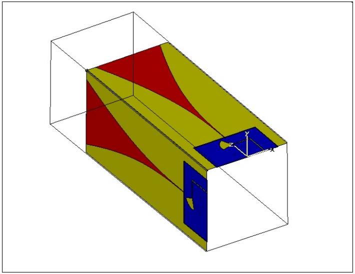
- Strong coupling:
  - David Zhang $\rightarrow$ element geometry, shape
  - Ahmed El-Makadema $\rightarrow$ array geometry, placement
- Input: shape + placement
- pattern of EM-field distribution and coupling
- new shape + new placement
- $\ldots$

Antenna Element Design

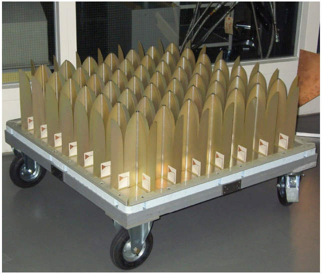
Vivaldi Antenna – antenna best suited for transmission of broad spectrum signals.

Validation of a new antenna:

- Analysis of radiation pattern around the antenna

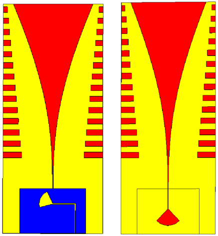


(a) Vivaldi Antenna Scheme

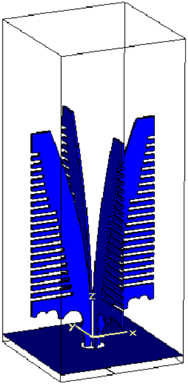


(b) Vivaldi Antenna Array

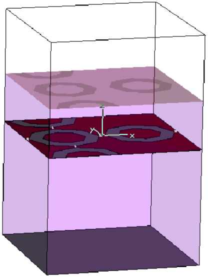
Perspective Antenna Designs



(c) CLVA



(d) BECA



(e) ORA

- Comb-Line Vivaldi Antenna (CLVA)
- Bunny Ear Comb-Line Antenna (BECA)
- Octagon Rings Antenna (ORA)

Finite Difference Time Domain (FDTD)

Kane S. Yee, 1966, FDTD classical approach:

- Initial EM-field values
  - Maxwell's Equations (ME)
  - system of hyperbolic PDE
  - unique solution
- Second order finite centred approximation to derivatives in ME
- Explicit algorithm
  - current values = function of previous values in time
- Simulation
  - CPU, memory, I/O-intensive

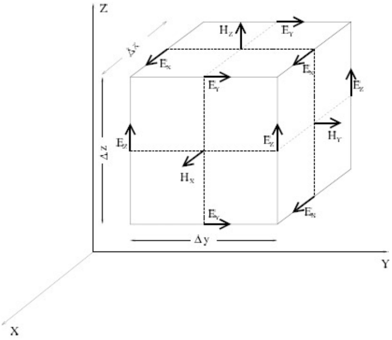


Figure: Yee Unit Cell

Frequency Dependent – FDTD (FD-FDTD)

- Reflects medium and material properties
- Permittivity ϵ and conductivity σ are frequency dependent

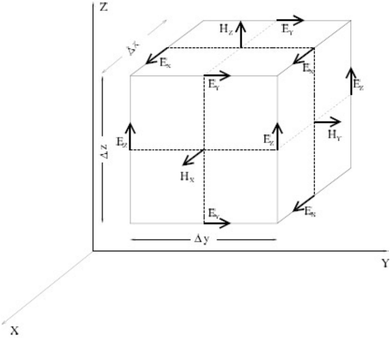


Figure: Yee Unit Cell

Method Implementation

- Set antenna geometry and material for the FD-FDTD calculation
- FD-FDTD simulation software $\rightarrow$ Fortran, MPI
  - Workload division $\rightarrow$ z-axis
  - Data output $\rightarrow$ textual ASCII and binary formats
- Real-world simulation:
  - 5000 time steps $\times$ 16 CPUs $\times$ 250 MB data files $\approx$ 19.07 TB
  - Single file production time: 3-58 min
- Data post-processing $\rightarrow$ shell scripts, Fortran, MPI
  - Point plotting
  - Plane visualisation
- CPU frequency and RAM size are vital
- Conclusion $\rightarrow$ optimisation of data production and post-processing

Produced Data: Structure and Character

One file for each time step for each processor,
e.g. 100 time steps $\times$ 2 processors = 200 files

- File:
  - Name: `<timestep>_<rank>.<format>`
  - Structure:

Spatial Coordinates			Field Values		
x	y	z	E_x	$\cdots$	H_z
1	1	96	-0.15396E+10	$\cdots$	-0.15041E+12
$\vdots$					$\vdots$
189	467	100	0.13878E+08	$\cdots$	0.13895E+10

Achievements

- Achievements up to date:
  - simulation of specific pre-defined antenna shape
    - normal Vivaldi antenna design, specified by David, 1 element
  - developing the functionality for automatic radio environment setting
    - antenna shape recognition
  - improving the simulation efficiency (load-balancing)
    - non-dedicated I/O-server $\rightarrow$ data collection and output

Current Research Activities

- improving the efficiency of data post-processing
- near- to far-field conversion
- development of subgridding technique
  for the EM-wave propagation problem

SKA Comparison

- international SKA R&D:
  - ASTRON, simulation package
- Approaches for data storage
  - text, binary, scientific format, database
- SKA-ready performance
  - 1 element vs 8×8 element array
- Further challenges:
  - Computation and I/O speed-up
    - subgridding techniques, parallelisation, binary format
  - Data analysis speed-up
    - smarter and faster post-processing tools
- Publication
  - one conference paper submitted (HDF5)
  - journal and conference papers on subgridding expected

Discussion

- Questions
- Answers