Course of COMPUTATIONAL ELECTROMAGNETICS

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ORGANIZATION OF THE COURSE

University of Pavia

DESCRIPTION OF THE COURSE

The course provides an introduction to the most common methods in numerical modeling of **electromagnetic wave** interactions and components.

The use of some commercial codes is also described.

GOALS

- Understand the theory, numerical implementation and applications of the numerical techniques for modeling microwave and mm–wave components
- Evaluate the most suitable numerical technique to solve a given analysis or design problem
- Begin to read the technical literature on computational electromagnetics.

PROGRAM OF THE COURSE

1. Introduction
2. Finite-Difference Time-Domain Method (FDTD)
3. Method of Moments, (MoM)
4. Finite Element Method (FEM)
5. Boundary Element Method (BEM)
6. Other methods for electromagnetic simulation.
7. Mode Matching Method (MM)

ORGANIZATION OF THE COURSE

REFERENCE TEXT

M.N.O. Sadiku, *Numerical techniques in Electromagnetics*, CRC Press, 2000.

USEFUL READINGS

FEM: Jianming Jin,
The finite element method in electromagnetics
John Wiley & Sons, 1993

MoM: R. F. Harrington,
Field Computation by Moment Methods
IEEE Press, 1993.

MM: R. Mittra and S.W. Lee,
Analytical Techniques in the Theory of Guided Waves
The Macmillan Company, 1971.

Notes of the lectures available at http://microwave.unipv.it/

Organization of the Course

PREREQUISITES

Basic knowledge of electromagnetic fields and wave propagation in guided structures is recommended.

EXAMINATION

The final exam consists of the presentation and discussion of a project based on one of the topics of the course.

Organization of the Course

The course of Computational Electromagnetics is organized in lectures and practical classes:

Lectures: 36 hours

Practical class: 18 hours

corresponding to 6 credits (ECTS).

Lecture 1

INTRODUCTION TO CEM

WHY NUMERICAL METHODS

Analytical methods provide exact solutions to a limited number of problems in electromagnetic problems.

They can be applied for a preliminary study of the problem, under some simplifying hypotheses.

Experimental methods (cut-and-try techniques) permit to validate a design and to optimize it by an iterative approach.

Nevertheless, they are slow and expensive, due to the need of fabricating and measuring several prototypes. Moreover, they do not allow much flexibility in the parameter variation.

WHY NUMERICAL METHODS

Numerical methods provide approximate solutions to large classes of problems in electromagnetic problems.

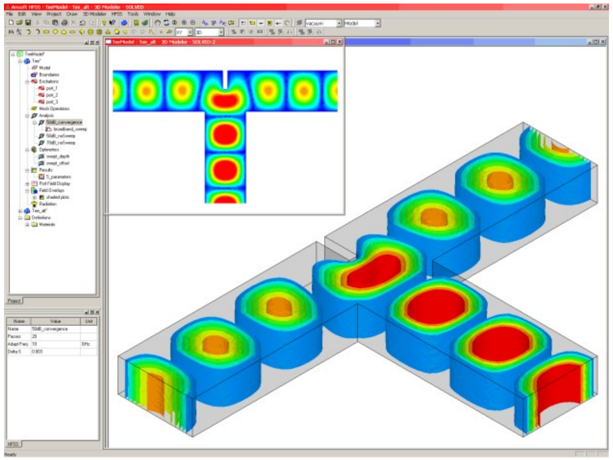
The accuracy of the solution can be typically controlled: longer computing time and memory allocation usually provide better solutions.

They provide good design flexibility and the possibility to investigate unconventional solutions.

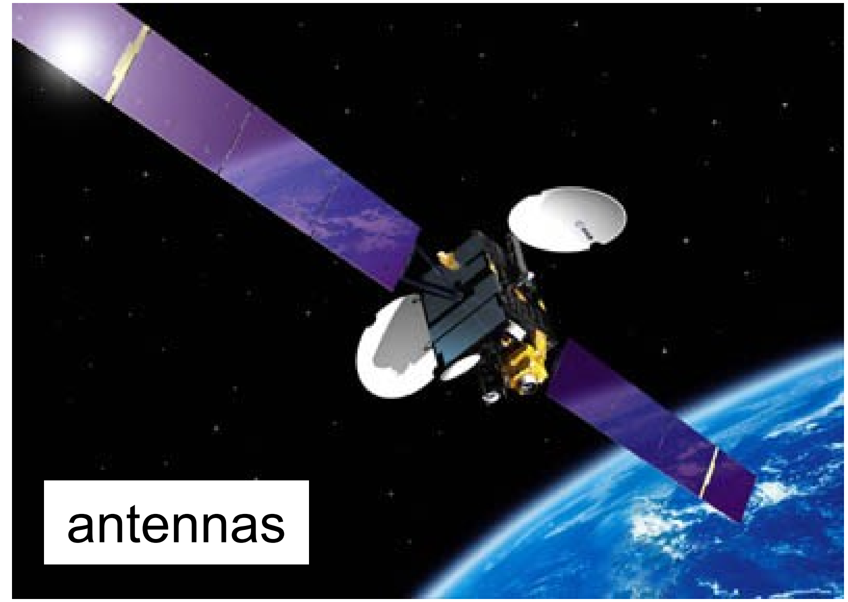
Furthermore, numerical methods guarantee a significant reduction in cost and time, when compared to experimental techniques.

It is noted that numerical methods adopted for electromagnetics also find application in other continuum problems such as fluid, heat transfer, acoustics.

Why Numerical Methods

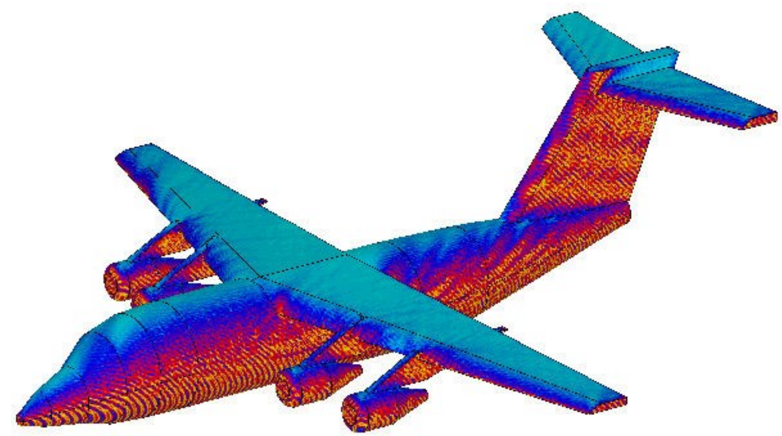


microwave circuits



antennas

bio-eletromagnetics



radar systems

WHY NUMERICAL METHODS

Relevant dates of modern electromagnetics:

1873 Maxwell's equations

1900 Analytical techniques

1940 Equivalent circuit models (Marcuvitz)

1966 FDTD method (Yee cell)

1967 Method of moments (R.F. Harrington)

1969 FEM technique (waveguide analysis, P.P. Silvester)

The development of numerical methods started in the mid-1960s with the availability of high-speed digital computers.

Modeling of the EM Problem

The solution of an electromagnetic problem through a numerical technique is based on three steps:

- Analytical pre-processing of the physical problem, to convert the electromagnetic problem into an algebraic problem;
- Solution of the algebraic equation;
- Interpretation of the result.

When applied to the solution of the same electromagnetic problem, different numerical methods require different analytical pre-processing and exhibit different **computational efficiency**.

MODELING OF THE EM PROBLEM

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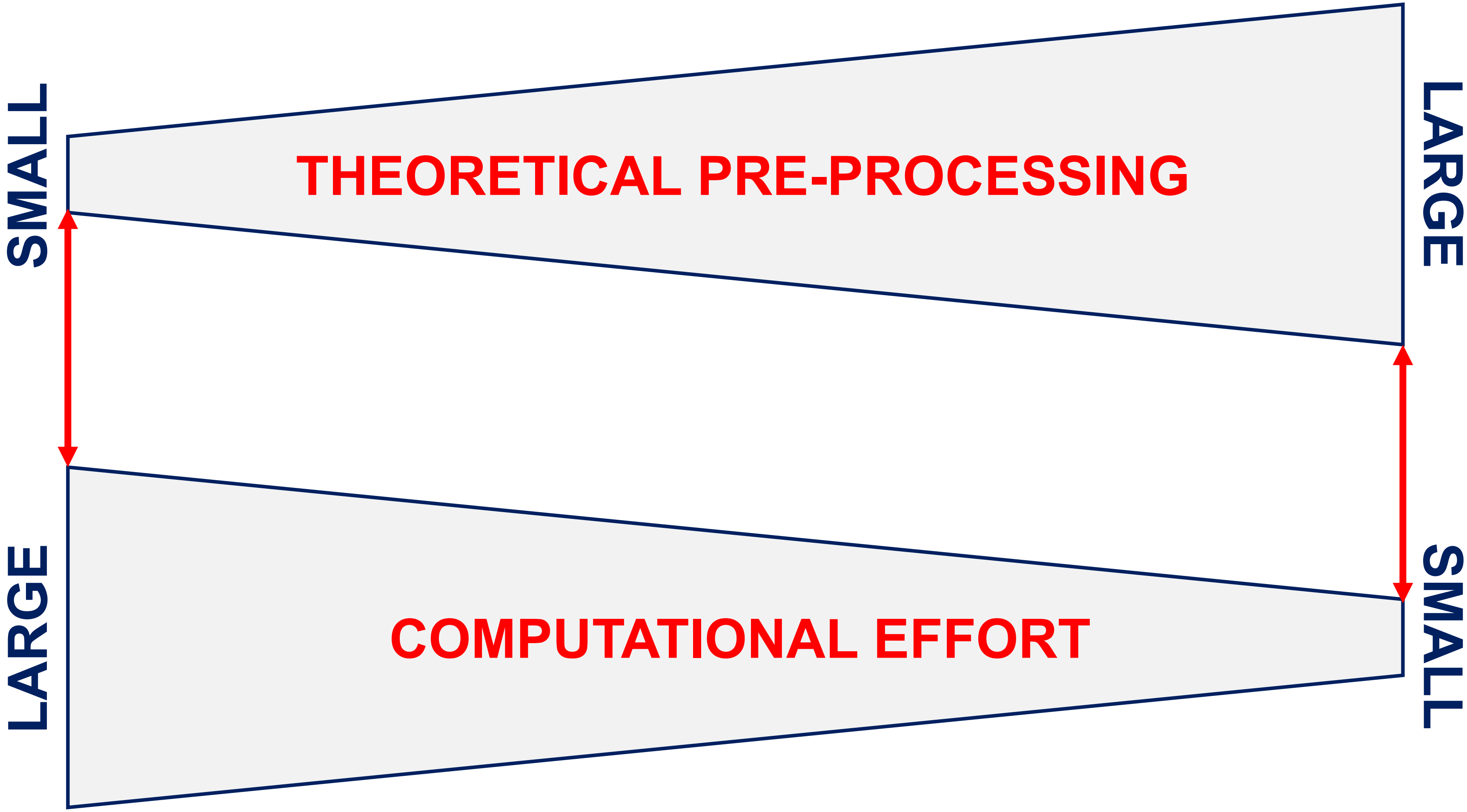
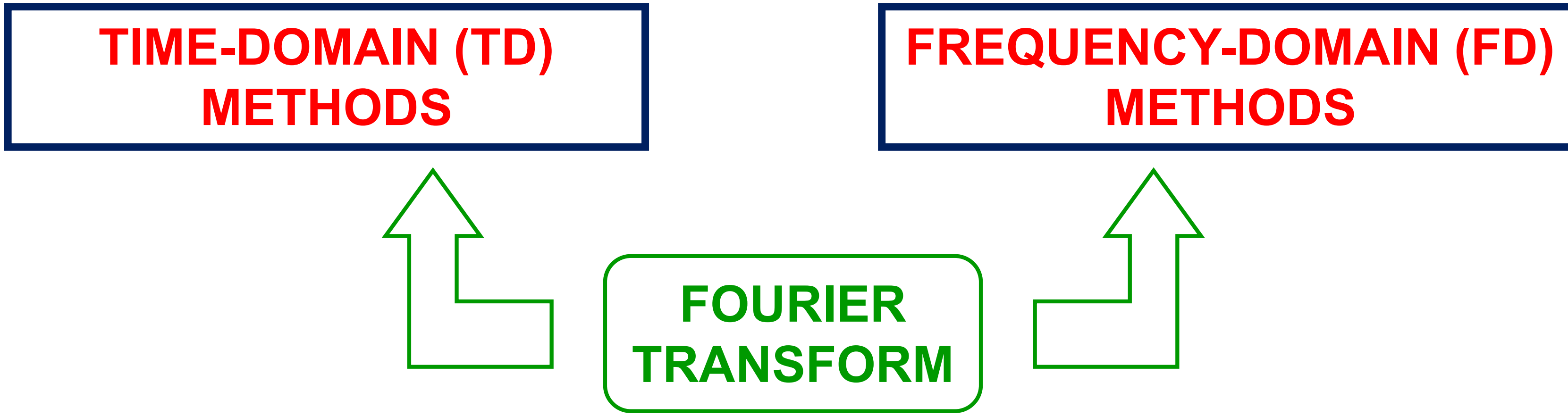


CLASSIFICATION OF NUMERICAL METHODS



Time-domain methods:

- simulations are closer to real world experience
- wide-band analysis performed in one shot
- modeling of transient phenomena and non-linear sistems

Frequency-domain methods

- compact and elegant phasor notation
- design specs are usually given in the FD
- easy description of material properties and boundary conditions

Classification of Numerical Methods

1D METHOD

Fields and currents/voltages vary in one dimension
Example: transmission lines
Commercial codes: SPICE

2D METHOD

Fields and currents/voltages vary in two dimensions
Example: H-plane waveguide components
Commercial codes: MeFiSTo-2D

2.5D METHOD

Fields vary in three dimensions, but current densities vary only in two dimensions
Example: microstrip circuits
Commercial codes: Ansoft Designer, Microwave Office

3D METHOD

Fields and currents/voltages vary in three dimensions (most general case)
Commercial codes: Ansoft HFSS, Microwave Studio, …

Commercial Software

ANSYS
HFSS™
3D Full-wave Electromagnetic Field Simulation

Agilent Technologies

CST

Microwave Office

Comprehensive Electromagnetic Solutions
FEKO

WIPL-D
Electromagnetic and Circuit Simulation

SONNET®

speag
SEMCAD X

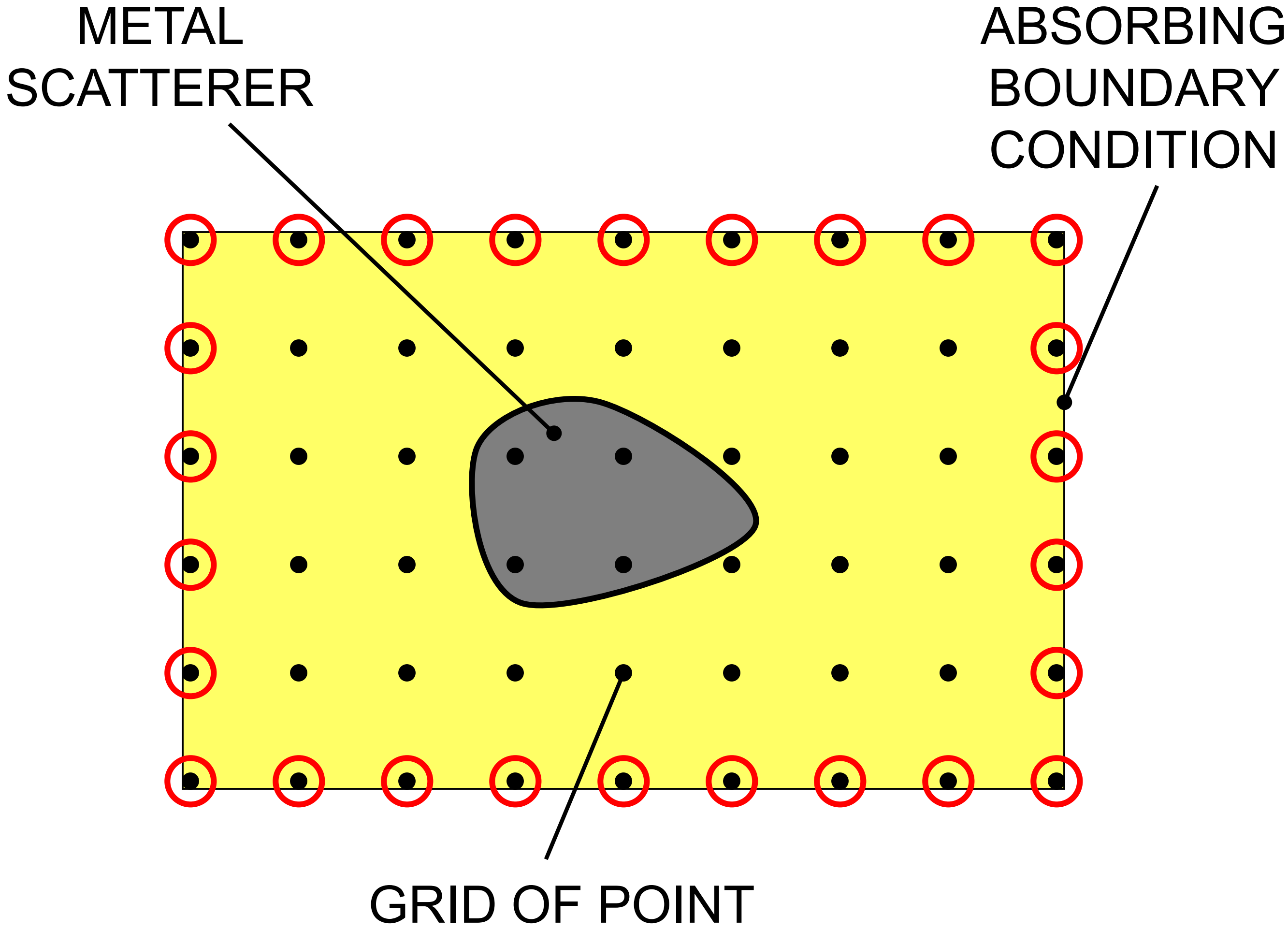
FAUSTUS
Scientific Corporation

MEFiSTo-3D Pro™
3D Time Domain Electromagnetic Simulator

FDTD

- The FDTD method is a time-domain technique, based on the definition of a grid in the considered region and the replacement of the partial derivative with finite differences.
- The method is very flexible: it applies to closed regions filled with inhomogeneous, anisotropic, non-linear media, with complex geometry.
- It permits to study the transient behavior of the system, and the time behavior of the source can be arbitrarily chosen (pulse, sinusoidal, …).
- The application to open regions is not straightforward and requires the use of particular absorbing boundary conditions.
- It requires the mesh defined in the whole domain and a time iterative procedure, which lead to a limited computational efficiency.
- The calculation of the response at a given frequency requires the Fourier transform of the complete time-domain response.

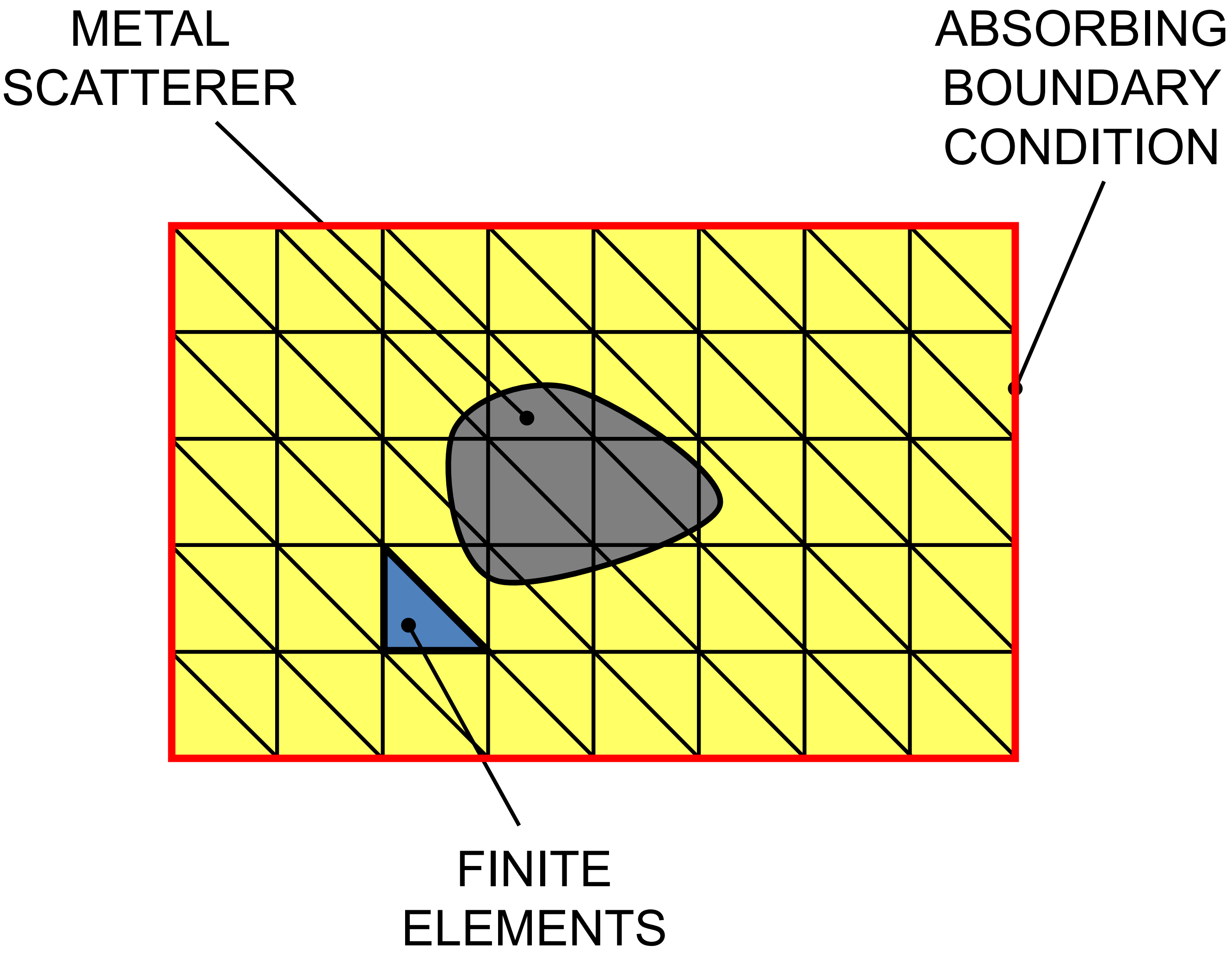
FDTD


METAL
SCATTERER
ABSORBING
BOUNDARY
CONDITION
GRID OF POINT

FEM

- The FEM is usually a frequency domain method, based on the segmentation of the considered region in small sub-domains (“finite elements”), where the unknown field is represented through “interpolating functions”.
- The method is very flexible: it applies to closed regions filled with inhomogeneous, anisotropic, non-linear media, with complex geometry.
- When it is formulated in the frequency domain, the behavior of the source is supposed to be sinusoidal.
- The application to open regions is not straightforward and requires the use of particular absorbing boundary conditions.
- It requires the mesh defined in the whole domain, which lead to a limited computational efficiency.
- It determines sparse matrices.

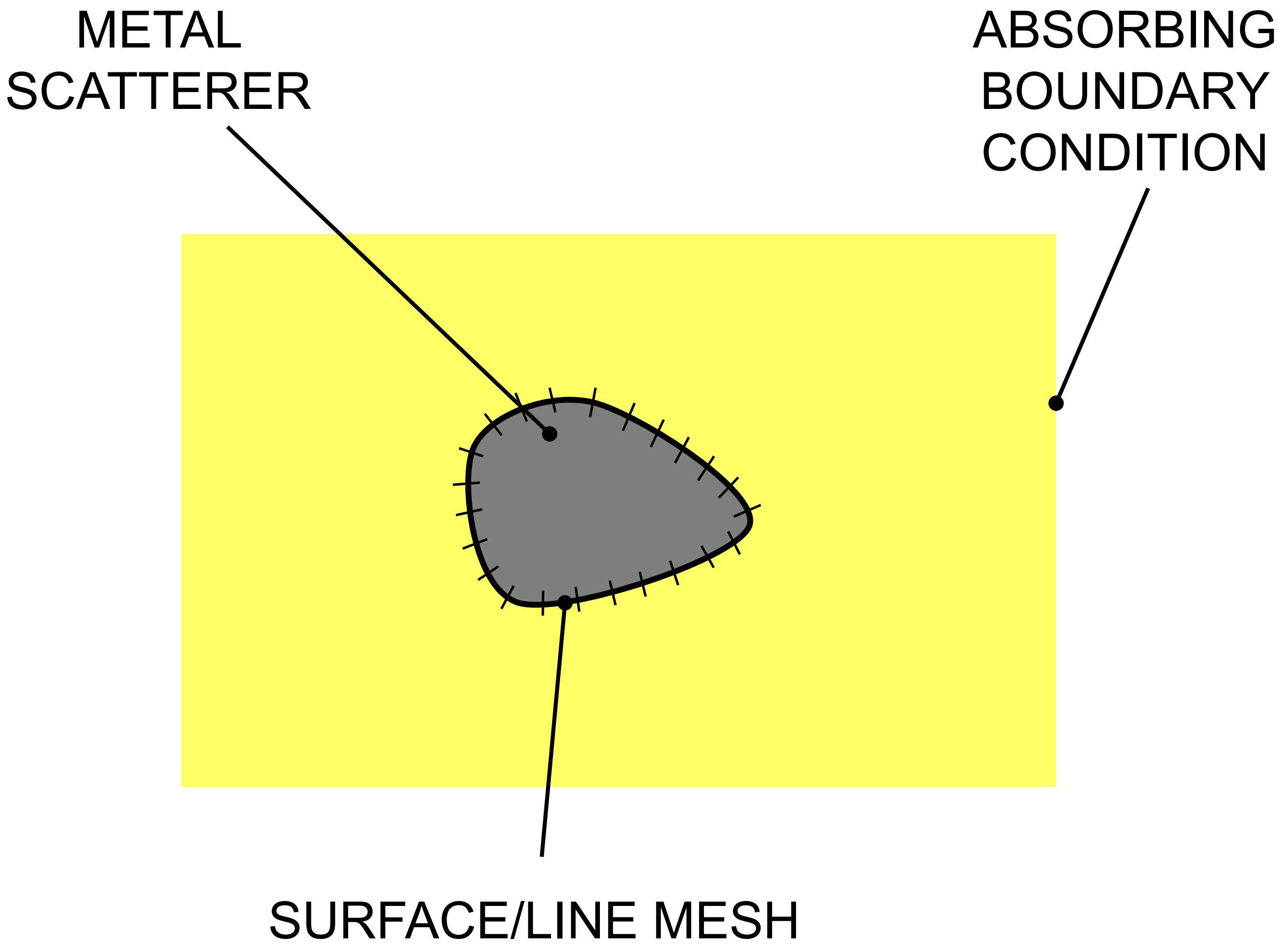
FEM


METAL
SCATTERER
ABSORBING
BOUNDARY
CONDITION
FINITE
ELEMENTS

BEM/MoM

- The BEM is based on the representation of the field as a Green's integral, depending on unknown equivalent sources defined on the surface discontinuities between different media.
- It requires the analytical or numerical determination of the Green's function for the considered domain.
- It applies to both closed and open regions, preferably filled with an homogeneous or stratified medium. The extension to inhomogeneous medium and complex geometry can be critical.
- It is typically formulated in the frequency domain, and therefore the behavior of the source is supposed to be sinusoidal.
- It requires the segmentation only of surface discontinuities where the unknown source is defined, and therefore it leads to small matrices.
- It determines dense matrices.

BEM/MoM


METAL
SCATTERER
ABSORBING
BOUNDARY
CONDITION
SURFACE/LINE MESH