It is rare for real-life EM problems to fall neatly into a class that can be solved by the analytical methods presented in the preceding lectures. Classical approaches may fail if:

- the material is not linear and cannot be linearized without seriously affecting the result
- the solution region is complex (i.e. the various boundaries do not coincide with any well described coordinate system).
- the boundary conditions are time-dependent
- the medium is inhomogeneous or anisotropic

Whenever a problem with such complexity arises, numerical solutions must be employed.

Fortunately there are a large number of very good commercial programs available for solving antenna problems.
Computational Electromagnetics

Rigorous methods

- IE
  - TD
  - FD
- VM
- DE
  - TD
  - FD

High frequency

- Field based
  - FEM
  - MoM
  - FDTD
  - TLM

- Current based
  - GO/GTD
  - PO/PTD
The Universe of Antenna Modeling Methods

![Diagram showing different methods of antenna modeling based on electrical size and complexity of materials. Methods include UTD, GO, PO, MLFMM, MOM, FEM-MOM.](image)

Courtesy of EMSS
Computational Electromagnetics

- **Method of moments (MoM)**
  - A method for solving integro-differential equations such as Hallen’s or Pocklington’s equation at a given frequency
  - Earliest and longest legacy of software codes for antenna modeling
  - BRACT, WIRA, AMP, NEC, NEC-2, NEC-3, NEC-4, MiniNEC, ELNEC, EZNEC, winNECPlus, 4nec2, FEKO, WIPL-D, Zeland IE3D

- **Finite element method (FEM)**
  - Best for design of small antennas of complex structure
  - Ansoft HFSS

- **Finite difference time-domain method (FDTD)**
  - Time-domain method
  - Best for design of small antennas for broadband applications
  - CST Microwave Studio, Zeland Fidelity, Faustus MEFIStO

- **Geometric, physical, and uniform theories of diffraction**
  - Best for electrically large antennas
## Comparison of Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Domain</th>
<th>Generality</th>
<th>Accuracy</th>
<th>Memory (N= number of elements)</th>
<th>Antenna Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoM</td>
<td>Frequency</td>
<td>Homogeneous or discretely homogeneous regions</td>
<td>Very accurate</td>
<td>@(N²)</td>
<td>All but harder for large reflector antennas</td>
</tr>
<tr>
<td>FDTD</td>
<td>Time, (all frequencies in one run)</td>
<td>Very general, inhomogeneous, dispersive, anisotropic</td>
<td>Moderately accurate</td>
<td>@(N)</td>
<td>All but harder for large reflector antennas</td>
</tr>
<tr>
<td>FEM</td>
<td>Frequency</td>
<td>Very general, inhomogeneous, dispersive, anisotropic</td>
<td>Very accurate</td>
<td>@(N log N)</td>
<td>All but harder for large reflector antennas</td>
</tr>
<tr>
<td>High Frequency Methods</td>
<td>Frequency</td>
<td>Only good for structures much larger than the wavelength</td>
<td>Only accurate for large structures</td>
<td>@(N)</td>
<td>Only good for large antennas (mostly used for reflectors)</td>
</tr>
</tbody>
</table>
Goal of all of these methods

Approximate these

\[
\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} - \vec{M} \quad \nabla \times \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J}
\]

\[
\nabla \cdot \vec{D} = \rho \quad \nabla \cdot \vec{B} = \rho_m
\]

With this

\[
[A] \cdot [x] = [b]
\]
The Method of Moments
Equations for Obtaining the Current Along a Wire

- Pocklington’s equation (1897)

\[
\int_{-\frac{1}{2}}^{\frac{1}{2}} I_z(z') \left[ \left( \frac{\partial^2}{\partial z'^2} + k^2 \right) G(z, z') \right] dz' = -j \omega \varepsilon E_z^i (\rho = a)
\]

- Hallen’s equation (1938)

\[
\int_{-\frac{1}{2}}^{\frac{1}{2}} I_z(z') \frac{e^{-jkR}}{4 \pi R} dz' = -j \sqrt{\frac{\varepsilon}{\mu}} \left[ B_1 \cos(kz) + C_1 \sin(k | z |) \right]
\]

- General form

\[ L(f) = g \]
Integro-Differential Equations Made Simple

- Start with an equation. The analysis problem is to find $f$
  \[ L(f) = g \]

- Assume $f$ can be expanded as a weighted sum of basis functions
  \[ L(f) = L\left( \sum_n a_n f_n \right) = g \]

- Set all projections (via test functions) of left and right sides equal
  \[ \sum_n a_n L(f_n \cdot \phi_m) = g \cdot \phi_m \]

- Write as a matrix equation
  \[
  \begin{bmatrix}
  L(f_1 \cdot \phi_1) & \ldots & L(f_N \cdot \phi_1) \\
  \vdots & \ddots & \vdots \\
  L(f_1 \cdot \phi_M) & \ldots & L(f_N \cdot \phi_M)
  \end{bmatrix}
  \begin{bmatrix}
  a_1 \\
  \vdots \\
  a_N
  \end{bmatrix}
  =
  \begin{bmatrix}
  g \cdot \phi_1 \\
  \vdots \\
  g \cdot \phi_M
  \end{bmatrix}
  \]
The Solution

- Solve for the vector of expansion coefficients

\[
\begin{bmatrix}
a_1 \\
\vdots \\
a_N
\end{bmatrix} = \left[ L(f_1 \cdot \phi_1) \quad \cdots \quad L(f_N \cdot \phi_1) \right]^{-1} \left[ g \cdot \phi_1 \\
\vdots \\
g \cdot \phi_M \right]
\]

- Obtain \( f \)

\[
f = \sum_n a_n f_n = [f_1 \quad \cdots \quad f_N] \left[ L(f_1 \cdot \phi_1) \quad \cdots \quad L(f_N \cdot \phi_1) \right]^{-1} \left[ g \cdot \phi_1 \\
\vdots \\
g \cdot \phi_M \right]
\]
Principle MoM Computer Codes

- **BRACT & ANTBRACT** – Developed late 1960’s at MBAssociates, San Ramon
- **WIRA** – Developed early 1970’s by M. Andreasen, F. Harris and R. Tanner at TCI
- **AMP/AMP2** – Developed mid 1970’s by G. Burke at MBAssociates, San Ramon
- **NEC-1** (1979) – Added more accurate current expansions; multiple wire junctions; thick wires
- **NEC-2** (1981) – Sommerfield-Norton ground interaction for wire structures above lossy ground; numerical Green's function allows modifying without repeating whole calculation
- **NEC-3** (1985) – Buried wires
- **NEC-4** (1992) – Improved accuracy for stepped-radius wires and electrically-small segments, end caps and insulated wires, catenary-shaped wires, improved error detection
- **Zeland IE3D** (1992) – Adaptive meshing, developed by Dr. Jian-Xiong Zheng. Company in Fremont, CA
- **WIPL-D** (ca 2000) – Advanced MoM for wires, plates, and dielectrics based on work of A.R. Djordjevic, B.M. Kolundzija, U. Belgrade, Serbia
- **FEKO** (ca 2000) – Hybrid method developed by U. Jakobus at EMSS, Stellenbosch. South Africa
The Development of NEC

- Pocklington’s IE
- Pulse Current
- Point Matching

J. H. Richmond 1965

K. K. Mei 1965

- Hallen’s IE
- 3-term current
- Point Matching

BRACKT 1967

- Point Matching
- Pocklington’s IE
- 3-term current
- RCS

ANTBRACKT 1968

- Antennas
- R.C.A. ground model

AMP 1970

- User Oriented I/O
- Loading, T-lines, Networks
- Large matrices on disk
- Full Documentation

AMP2 1975

- EFIE for wires
- MFIE for surfaces

Albertson et al.
Tech. U. of Denmark

NEC 1977

- Spline expansion for current
- Extended Thin-Wire
- Bicone voltage source
- Evaluation Near E and H

NEC2 1980

- Sommerfeld Integral and Interpolation for wires above ground
- Numerical Green’s Function

NEC3 1983

- Sommerfeld solution for buried wires and wires penetrating the ground interface

NEC4 1990

- Improved numerical precision for low frequencies
- Insulated wires
- Change in radius
EZNEC  http://www.eznec.com/

- Developed by Roy Lewallen, W7EL
- Now in version 5.0
- Six products available
  - EZNEC v.5 demo program  $0 (free)
  - EZNEC-ARRL v.3 & v.4  $45 (on ARRL Antenna Book CD-ROM)
  - EZNEC v.5  $90
  - EZNEC+ v.5  $140
  - EZNEC Pro/2 v.5  $500
  - EZNEC Pro/4 v.5  $650 (sold only to NEC-4 licensees)
- EZNEC includes either the NEC-2 or NEC-4 engines
- NEC-4 license for qualified US academic and noncommercial users can be obtained from Lawrence Livermore National Laboratory for $300. This probably includes you!
  - Form at:  https://ipo.llnl.gov/technology/software/documents/NEC.pdf
Key Parts of EZNEC

- Specifying the antenna model
  - Wire geometry (including radials)
  - Excitation sources
  - Wire loads
  - Transmission lines
  - Ground type and parameters
  - Frequency or sweep range

- Specifying the desired outputs
  - Radiation pattern crosssection at a given frequency
  - Gain in a specific direction
  - Pattern beamwidth
  - Front-to-back ratio
  - Front-to-rear ratio
  - Impedance
  - SWR
  - Output data files for other programs
A free full-featured GUI for NEC-2 and NEC-4
Written and supported by Arie Voors, Netherlands
Runs under Windows 2000 and XP
Includes standard EZNEC models as .nec files
Comes with NEC-2 executables but can use NEC-4 executables
Comes configured for up to 11,000 segments but can be increased by to any number by recompiling the NEC-2 or NEC-source codes

Two versions
- 4nec2 – limited to machine memory
- 4nec2X – uses virtual memory for bigger problems

Has 3D graphics and two optimizers
- Gradient descent optimizer
- Genetic optimizer

Permits writing NEC script, thereby giving access to all NEC-2 and NEC-4 commands
4nec2 Wire-Grid Models of Boeing 747 and Automobile
4 nec2 Screen Displays

Main screen

Geometry screen

Edit screen

Wire tab
4nec2 3D Pattern of Antenna on 747 – Vert Pol
Developed and sold by EM Software & Systems (EMSS), South Africa

Switches automatically among multiple “engines” like a Toyota Prius

Main method is MoM/SIE, but has MoM/VIE, FEM, FMM, and several optics approximations

Capabilities similar to WIPL-D: lossy conductors, dielectric and magnetic materials, near and farfield calculations, optimizer

Curved surfaces are approximated by many flat triangles

Triangle surface meshing and low-order basis functions give heavy computation burden, hence the need for multiple engines

Has infinite Sommerfeld-Norton ground

Limited LITE version of interest to Radio Amateurs

FEKO LITE – Free download from http://www.feko.info/sales
FEKO Model of Global Hawk (RQ-4A)

Figure 2. Finer mesh yields detailed surface contour, as shown on
FEKO Pattern of Horn Antenna in Wing Pod

Figure 8. Pod location, performance of horn array at 90 deg
The Next Step – Modeling the Landscape
### Required Computation

#### Frequency vs. Triangles, Run Time, Memory Used

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>Triangles</th>
<th>Hours</th>
<th>Memory (GB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,900</td>
<td>3,928</td>
<td>0.125</td>
<td>0.53</td>
</tr>
<tr>
<td>3,750</td>
<td>12,834</td>
<td>1.54</td>
<td>5.48</td>
</tr>
<tr>
<td>7,150</td>
<td>38,717</td>
<td>52.1</td>
<td>9.38</td>
</tr>
</tbody>
</table>
Other Useful Antenna Software

- **winSMITH 2.0 by Agilent (formerly Eagleware)**
  - ISBN 1884932908
  - $149 from Amazon.com
  - For interactive design of ladder networks for impedance matching
  - Excellent tool for learning to use the Smith chart
  - Grossly overpriced

- **MultiNEC by Dan Maguire, AC6LA, [http://www.ac6la.com](http://www.ac6la.com)**
  - Excel/Visual Basic program; low cost but currently unavailable
  - Puts NEC, EZNEC, and 4nec2 on autopilot for making a series of runs
  - Inexpensive alternative to a real optimizer
  - Doesn’t work with EZNEC-ARRL
  - Temporarily unavailable
Finite Difference Time Domain
FDTD
Reason for interest in FDTD

In the time domain, Maxwell’s equations give rise to PDEs involving time and spatial derivatives. Some good reasons for dealing with PDE’s are:

- Complex-value materials easily accommodated.
- Computer resources are adequate.
- PDE solutions are robust.
- Time domain PDE methods usually have no matrices.
- Geometries to be solved can be more varied.
Some big advantages

- Broadband response with a single excitation.
- 3D models easily.
- Memory requirement scales linearly with problem size
- Frequency dependent materials accommodated.
- Most parameters can be generated e.g.
  
  Scattered fields
  antenna patterns
  RCS
  S-parameters
  etc.....
How does it work?

Based on the two Maxwell curl equations in derivative form. These are linearized by central finite differencing. We only consider nearest neighbor interactions because all the fields are advanced temporally in discrete time steps over spatial cells.

ie we sample in space & time

embedding of an antenna in a FDTD space lattice (note that the whole volume is meshed!)
Discretize Objects in Space using Cartesian Grid

2D Discretization

3D Discretization

1D Discretization

$z = 0$ $E_x(z, t)$ $z = Z$
Define Locations of Field Components: FDTD Cell called Yee Cell

- Finite-Difference
  - Space is divided into small cells
    One Cell: $(dx)(dy)(dz)$
  - E and H components are distributed in space around the Yee cell (note: field components are not collocated)

3D formulation

\[
\begin{align*}
\frac{\partial H_x}{\partial t} &= \frac{1}{\mu} \left( \frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y} - \rho' H_x \right) \\
\frac{\partial H_y}{\partial t} &= \frac{1}{\mu} \left( \frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} - \rho' H_y \right) \\
\frac{\partial H_z}{\partial t} &= \frac{1}{\mu} \left( \frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x} - \rho' H_z \right)
\end{align*}
\]

\[
\begin{align*}
\frac{\partial E_x}{\partial t} &= \frac{1}{\varepsilon} \left( \frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \sigma E_x \right) \\
\frac{\partial E_y}{\partial t} &= \frac{1}{\varepsilon} \left( \frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \sigma E_y \right) \\
\frac{\partial E_z}{\partial t} &= \frac{1}{\varepsilon} \left( \frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z \right)
\end{align*}
\]

Convert equations like these

To ones like these

\[
\begin{align*}
H_x^{n+\frac{1}{2}}(i, j + \frac{1}{2}, k + \frac{1}{2}) - H_x^{n-\frac{1}{2}}(i, j + \frac{1}{2}, k + \frac{1}{2}) &= \frac{1}{\mu_0 \mu_r(i, j + \frac{1}{2}, k + \frac{1}{2})} \left[ E_x^n(i, j + \frac{1}{2}, k + \frac{1}{2}) - E_x^n(i, j + \frac{1}{2}, k) \right] \Delta z - E_x^n(i, j, k + \frac{1}{2}) \Delta y \\
H_x^{n+\frac{1}{2}}(i + \frac{1}{2}, j + \frac{1}{2}, k + \frac{1}{2}) - H_x^{n-\frac{1}{2}}(i + \frac{1}{2}, j + \frac{1}{2}, k + \frac{1}{2}) &= \frac{1}{\mu_0 \mu_r(i + \frac{1}{2}, j + \frac{1}{2}, k + \frac{1}{2})} \left[ E_x^n(i + 1, j + \frac{1}{2}, k + \frac{1}{2}) - E_x^n(i, j + \frac{1}{2}, k + \frac{1}{2}) \right] \Delta x - E_x^n(i + \frac{1}{2}, j, k + \frac{1}{2}) \Delta z \\
H_x^{n+\frac{1}{2}}(i + \frac{1}{2}, j + \frac{1}{2}, k + \frac{1}{2}) - H_x^{n-\frac{1}{2}}(i + \frac{1}{2}, j + \frac{1}{2}, k + \frac{1}{2}) &= \frac{1}{\mu_0 \mu_r(i + \frac{1}{2}, j + \frac{1}{2}, k + \frac{1}{2})} \left[ E_x^n(i + \frac{1}{2}, j + 1, k + \frac{1}{2}) - E_x^n(i + \frac{1}{2}, j, k + \frac{1}{2}) \right] \Delta y - E_x^n(i + \frac{1}{2}, j + \frac{1}{2}, k) \Delta x \\
E_x^{n+1}(i + \frac{1}{2}, j, k) - E_x^n(i + \frac{1}{2}, j, k) &= \frac{1}{\varepsilon_0 \varepsilon_r(i + \frac{1}{2}, j, k)} \left[ H_y^{n+\frac{1}{2}}(i + \frac{1}{2}, j + \frac{1}{2}, k) - H_y^{n-\frac{1}{2}}(i + \frac{1}{2}, j - \frac{1}{2}, k) \right] \Delta y - H_y^{n+\frac{1}{2}}(i + \frac{1}{2}, j, k + \frac{1}{2}) - H_y^{n+\frac{1}{2}}(i + \frac{1}{2}, j, k - \frac{1}{2}) \Delta z \\
\sigma(i + \frac{1}{2}, j, k) &\left[ E_x^{n+1}(i + \frac{1}{2}, j, k) + E_x^n(i + \frac{1}{2}, j, k) \right] \Delta t
\end{align*}
\]

Convert equations like these

To ones like these
QuickWave (http://www.qwed.eu/)

- Commercial FDTD package with CAD interface
- Uses conformal FDTD mesh
- Many special features for antenna problems
- Written and supported by QWED, Poland
- Runs under 32/x64 bit Windows platforms and Linux
Examples:

Circular Patch Antenna - a circular patch fed by a thin vertical coax line

Radiation patterns versus elevation angle \( \Theta \) with azimuthal angle \( \Phi = 0 \), calculated for two frequencies: 2.65 and 5.575 GHz.

Circular patch antenna model

Radiation patterns versus azimuthal angle \( \Phi \) with elevation angle \( \Theta = 30\degree \), calculated for two frequencies: 2.65 and 5.575 GHz.
Examples:

Consider Standard/Dhmorn/dm_horn.pro, which is an example of dual-mode axisymmetrical horn antenna [43]. Input of the antenna is excited with the fundamental mode TE11 of 10.14 GHz spectrum range. However, as the wave propagates through the tapered section, some of its energy is transformed into TM11 mode. Thus, an appropriate design allows us to equalise polarisation in E and H planes. It makes this horn a good feed for reflector antennas. Additionally, proper choices of flare angle and length of the horn’s tube help suppress the side lobes in the radiation pattern. Changing Gain Reference in the Radiation pattern window from Relative to Directive we see that the gain of this antenna is about 14.5 dB for both E and H planes. The 3 dB beamwidth is 35.4° and 37° for the E and H plane, respectively.

Sinusoidal excitation of the model at the central frequency (f = 12 GHz) confirms that the same radiation levels at both E and H planes are obtained at the end of the antenna.
XFddtd (http://www.remcom.com/)

- Commercial FDTD package with CAD interface
- Probably the most popular FDTD package for antenna problems
- Many special features for antenna problems including full human body mesh
- Written and supported by Remcom, USA
- Runs under 32/x64 bit Windows, Mac OS X and Linux
XFdtd (http://www.remcom.edu/)

Figure 1
A CAD representation of the cavity-backed antenna. The white material represents the metal layers while the green color is the dielectric substrate under the slots.

Figure 5
Mesh representation of EBG reflector.

Figure 6
Full model with spiral antenna and EBG reflector.

Figure 7
Comparison of impedance of antenna over EBG reflector.

Figure 8
Axial ratio of antenna over EBG reflector.

Figure 9
Comparison of peak gain of antenna over EBG reflector.
Lumerical (http://www.lumerical.com/)

- Commercial FDTD package with CAD interface
- Popular FDTD package for the optics folks (i.e. integrated optics, light scattering, plasmonics)
- Large library of materials at optical wavelengths
- Has very nice scripting language for defining large complicated problems.
- Has nice built in optimization
- Runs under 32/x64 bit Windows, Mac OS X and Linux
Finite Element Method
Finite Element Method
Variational Approach

In solving problems arising in physics and engineering it is often possible to replace the problem of integrating a differential equation by the equivalent problem of seeking a function that gives a minimum value of some integral. Problems of this type are called *variational problems*.

The methods that allow us to reduce the problem of integrating a differential equation to the equivalent variational problem are usually called *variational methods*. 
# Variational Approach

<table>
<thead>
<tr>
<th>Name of equations</th>
<th>PDE</th>
<th>Variational principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous wave equation with sources</td>
<td>( \nabla^2 \Phi + k^2 \Phi = g )</td>
<td>( I(\Phi) = \frac{1}{2} \int_v \left[ \left</td>
</tr>
<tr>
<td>Homogeneous wave equation without sources</td>
<td>( \nabla^2 \Phi + k^2 \Phi = 0 )</td>
<td>( I(\Phi) = \frac{1}{2} \int_v \left[ \left</td>
</tr>
<tr>
<td>Diffusion equation</td>
<td>( \nabla^2 \Phi - k \frac{\partial \Phi}{\partial t} = 0 )</td>
<td>( I(\Phi) = \frac{1}{2} \int_t \int_v \left[ \left</td>
</tr>
<tr>
<td>Poisson's equation</td>
<td>( \nabla^2 \Phi = g )</td>
<td>( I(\Phi) = \frac{1}{2} \int_v \left[ \left</td>
</tr>
<tr>
<td>Homogenous Laplace's equation</td>
<td>( \nabla^2 \Phi = 0 )</td>
<td>( I(\Phi) = \frac{1}{2} \int_v \left[ \left</td>
</tr>
</tbody>
</table>
Finite Element Method

The finite element method (FEM) has its origin in the field of structural analysis. However, since then the method has been employed in nearly all areas of computational physics and engineering.

The FEM method, while more difficult to program than either the finite difference (FD) or method of moments (MOM), is a more powerful and versatile numerical technique for handling problems involving complex geometries and inhomogeneous media.
Basic concept

Although the behaviour may be complex when viewed over a large region, a simple approximation may suffice over a small subregion. The region is divided up into finite elements.

Regardless of the shape the field is approximated by a different expression over each element, maintaining continuity at adjoining elements.
Solution Strategy: Variational Approach

The equations to be solved are usually stated not in terms of field the variables but in terms of an integral-type functional such as energy.

The functional is chosen such that the field solution makes the functional stationary.

The total functional is the sum of the integral over each element.
Finite Element Method

The finite element method (FEM) involves basically four steps:

(1) Discretize the solution region into a finite number of subregions or elements
(2) Derive the governing equations for each element based on either a variational approach or Galerkin’s method
(3) Assemble all the elements together in the solution space.
(4) Solve the resulting system of equations
HFSS (http://www.ansoft.com/)

- Commercial FEM package with CAD interface
- Uses adaptive meshing
- Probably the most popular commercial package for antenna applications.
- Written and supported by Ansoft, USA
- Runs under 32/x64 bit Windows platforms, Redhat Linux, Solaris (Sun workstations).
- Has integrated hybrid finite element / boundary integral methods (MoM)
- Kind of expensive!
- Optional optimization package (optimetrics)
HFSS (http://www.ansoft.com/)
CST Microwave Studio (http://www.cst.com/)

- Commercial FEM, MoM and TLM package with CAD interface
- Mature and easy to use interface
- Popular program for microwave circuit applications but also very useful for antennas.
- Written and supported by CST, International
- Runs under 32/x64 bit Windows platforms and Redhat Linux,
- Kind of expensive!
- Has a specific antenna design option called Magus
Installed Antenna Performance

CST Microwave Studio (http://www.cst.com/)
Comsol Multiphysics (http://www.comsol.com/)

- Commercial FEM package with CAD interface
- Is best known for its ability to solve multiphysics problems
- Becoming a very popular program.
- Links nicely with Matlab
- Easy to learn interface
- Runs under 32/x64 bit Windows platforms
- Moderately prices
Comsol Multiphysics (http://www.comsol.com/)
References:

1. Clemson site lists all the free EM modeling tools
   http://www.clemson.edu/ces/cvel/modeling/EMAG/free-codes.html

2. Clemson site lists all the commercial EM modeling tools
   http://www.clemson.edu/ces/cvel/modeling/EMAG/csoft.html