

EMMCAP

**ElectroMagnetic Modeling Computation and Analysis
Program**

***Version 1.6 - May 2003
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Manual for *EMMCAP - Demo*

EMMCAP - Demo 1.6 is "Shareware". This means that we have made the software available to you for free evaluation. You can evaluate the software for an unlimited period of time without obligation to pay.

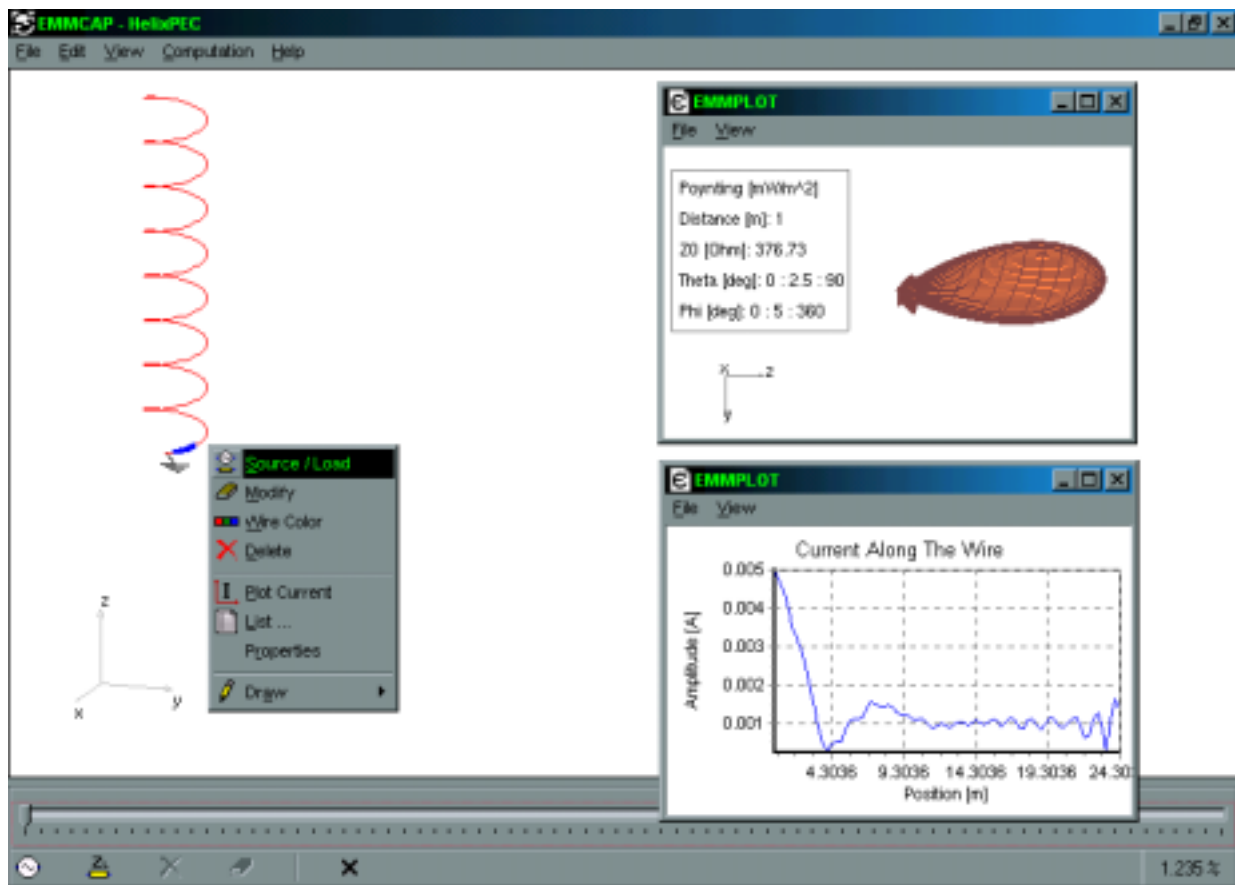
EMMCAP - Demo 1.6 is not a full-featured release. The full version has several capabilities unavailable in the demo version.

For more information visit: <http://www.emmcap.com.ar>

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Abstract

EMMCAP is a program system for the modeling of 3D arbitrarily shaped wire structures and for the computation and analysis of their electromagnetic behavior, including radiation and scattering problems.

The computer code is based on an Electric Field Integral Equation (EFIE) expressed in the frequency domain. The current distribution on thin-wire structures is computed by solving the EFIE using a Method of Moments (MoM) formulation with **curved basis and testing functions**. This means that curved wires are modeled by using **curved segments**, which exactly follow the contour of the structure, instead of the typical approximation with straight wire segments. With this technique, the number of unknown currents and memory space can be reduced, allowing for the simulation of bigger problems.

The wire geometry is easily drawn on the screen using dialog boxes for the input data. All wires are placed in 3D space, and several 3D-tools are implemented in the program.

Lumped impedances representing discrete resistors, inductors and capacitors can be placed at arbitrary locations on the structure. As excitation either discrete sources or an incident plane wave can be used. Current generators for the simulation of impressed current sources can also be taken into account.

In order to plot the computed results a special program, called **EMMPLOT**, has been developed. The current distribution on a selected wire is shown as a 2D plot, and the radiation pattern in the far-field can be viewed either as a rectangular plot, as a polar plot or as a 3D plot.

Also, other parameters of interest, such as input impedances, voltages over lumped loads, radiated power and directivity can be plotted vs. frequency.

Supported platform: PC running Windows 95/NT 4.0 or later.

1. Introduction

EMMCAP is a program system for the modeling of 3D arbitrarily shaped wire structures and for the computation and analysis of their electromagnetic behavior, including radiation and scattering problems.

EMMCAP computes the current distribution on a thin-wire structure operating in the frequency domain. Using a Method of Moments (MoM) approach with **curved segments** simulates the current distribution. This means that the structure is first divided into segments, which exactly follow the contour of the wires, instead of the typical approximation with straight wire segments. The straight wire approximation often requires a large number of segments to adequately approximate the curved wire geometry. Because of this, by using curved segments the number of unknowns and memory space can be reduced, allowing for the simulation of bigger problems.

Next, a basis function is defined on each pair of adjacent segments, representing an unknown current. Then, an Electric Field Integral Equation (EFIE) is converted into a system of linear equations, which has to be solved for the unknown currents. Afterwards field strengths, radiated power and other parameters of interest can be computed.

In using the **EMMCAP** program system, simulating a wire structure is a four-step procedure:

- Defining the program's configuration.
- Drawing the wire geometry.
- Performing the computation.
- Visualizing the computed results.

The program's configuration refers to the definition of the operating frequency or range of frequencies of the system, the permittivity and permeability of the medium, and other options defining the type of simulation, such as a free space computation or a simulation over a perfect electric conductor (PEC) ground plane.

The wire geometry is easily drawn on the screen using dialog boxes for the input data. All wires are placed in 3D space, and several 3D-tools are implemented in the program. The subdivision of the wires into current segments is done automatically, but can also be set manually by the user.

An arbitrary number of voltage and current sources can be placed at any positions and an incident plane wave of arbitrary direction of incidence and polarization can be used for the excitation of the structure.

Lumped loads, representing discrete resistors, inductors and capacitors, as well as discrete sources can be added to a wire by using a special tool-bar.

Once the geometry has been entered the simulation can be performed. The results from the simulation are the currents on the wire structure. Additionally, the far-field in selected angular ranges can be computed.

In order to plot the computed results a special program, called **EMMPLOT**, has been developed. The current distribution on a selected wire is shown as a 2D plot, and

the radiation pattern in the far-field can be viewed either as a rectangular plot, as a polar plot or as a 3D plot.

Other parameters of interest, such as input impedances, voltages over lumped loads, radiated power and directivity are shown as lists in text format, and can also be plotted vs. frequency.

2. Defining the configuration

Selecting "Computation | Configure..." in the main menu can set the program configuration. The "Configuration" dialog box has the following pages: *Frequency*, *Medium*, *Options*, *Far-Field* and *Incident Wave*, Fig. 2.1.

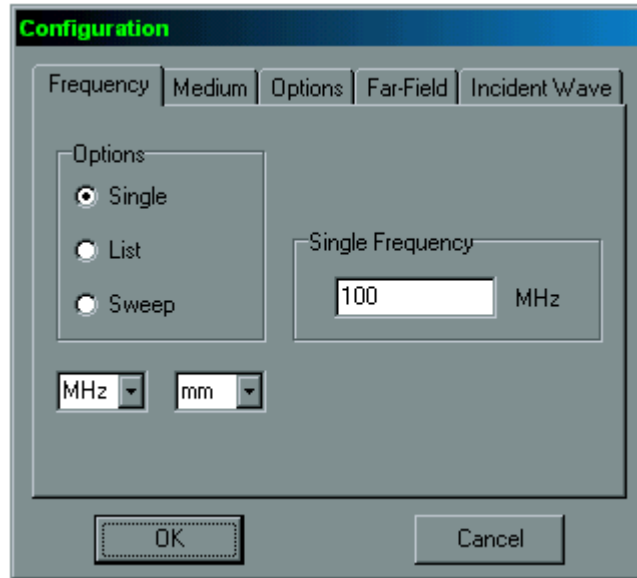


Fig. 2.1: "Frequency" page in the "Configuration" dialog box.

2.1 "Frequency" page

The *Frequency* page has three different options: *Single*, *List* and *Sweep*.

By choosing one option the computation can either be performed for a *single* frequency, for frequencies taken from a *list* or for a frequency *sweep*, Fig. 2.1.

The list of frequencies can either be created in the same dialog box or readied from a text file; it could also be saved to a .txt file.

If *Sweep* is selected it can either be linear or logarithmic. For a linear sweep the start, step and stop frequencies have to be defined. For a logarithmic frequency sweep the start, stop and a multiplication factor must be defined.

Besides this options, a suitable unit system can be selected (frequency scaling in Hz, KHz, MHz and GHz; length scaling in m, cm, mm and um).

2.2 "Medium" page

The relative permittivity and permeability of the medium can be defined in this page, Fig 2.2.

Two sets of values have to be defined, the medium's constants for the computation of currents and the medium's constants for the computation of far-fields. For instance, the first set of values will be used in the determination of the current distribution when a dielectric material is present. The radiated far-field can be computed in free space using the second set of constants, but neglecting the effect of the dielectric material. This is done only for experimentation, and in most cases the currents and the far-field are both computed in free space or in the same medium.

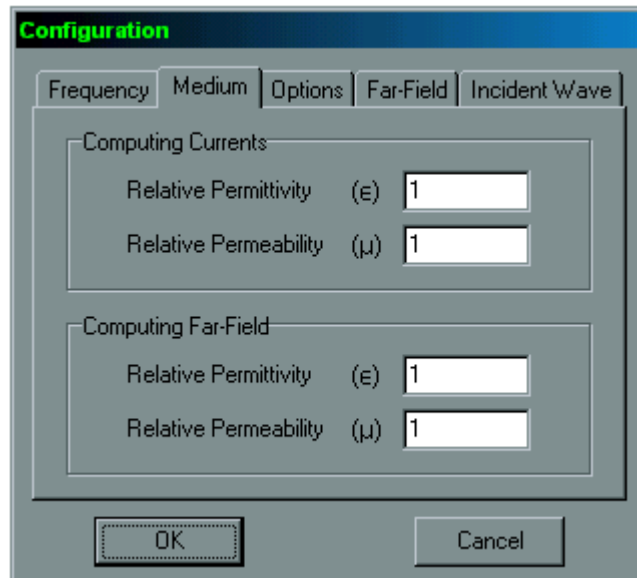


Fig. 2.2: "Medium" page in the "Configuration" dialog box.

2.3 "Options" page

Four options for the type of simulation are available, Fig. 2.3.

If "*Ground Plane*" is checked an infinite PEC ground plane will be placed at the specified height from the xy-plane. Thus, the ground plane is parallel to the xy-plane. If "*Height*" is positive the ground plane will be over the xy-plane, if "*Height*" is negative the ground plane will be under the xy-plane, and if "*Height*" is set to zero the ground plane will be the xy-plane.

If "*Incident Plane Wave*" is checked an incident plane wave will be used as the excitation. All discrete sources, if any, on the wires will not be used. The direction of incidence and polarization of the incoming field can be set in the "*Incident Wave*" page described below.

If "*Load Impedances*" is chosen lumped impedances, if any, will be taken into account in the simulation. With this option all lumped loads can be disabled or enabled at the same time.

If "*Resistivity*" is checked the finite resistivity of the wires will be taken into account in the simulation. Each wire has its own resistivity in [ohm/m]; this value is defined when a wire is drawn. This option allows considering the whole structure as a perfect electric conductor.

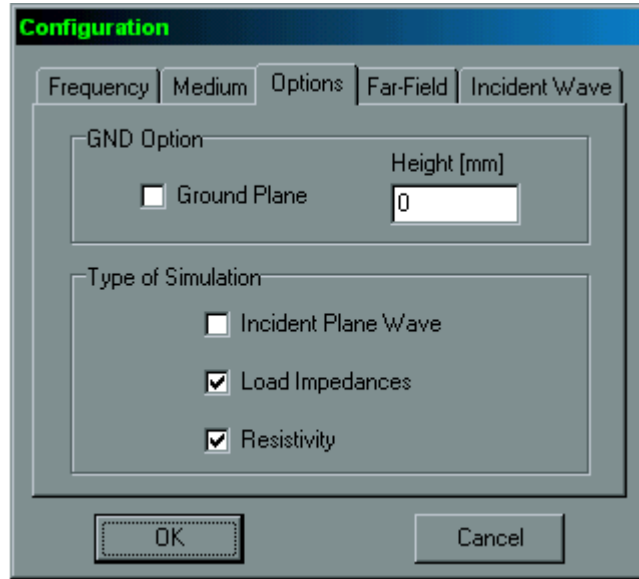


Fig. 2.3: "Options" page in the "Configuration" dialog box.

2.4 "Far-Field" page

The far-field can be computed only when the current distribution has been obtained. Thus, the parameters defined in this page have no effect in the determination of the currents, and can be set after the computation of the current distribution.

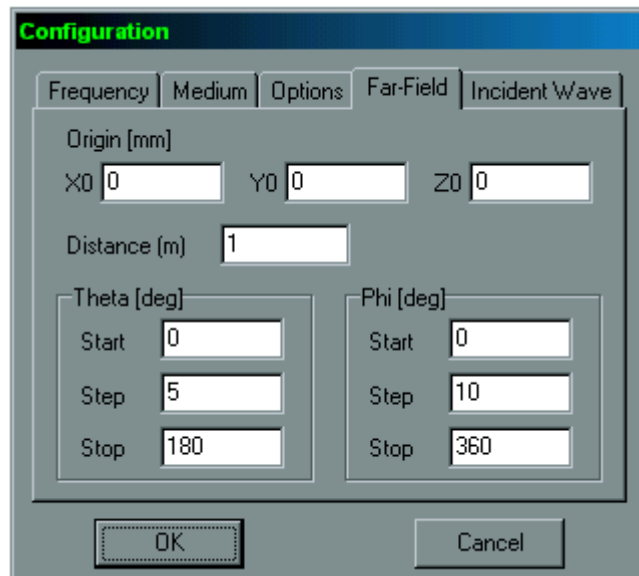


Fig. 2.4: "Far-Field" page in the "Configuration" dialog box.

The far-field is computed on a sphere of radius "*Distance*" and center "*Origin*", in the angular sector defined in the "*Theta*" and "*Phi*" boxes, Fig. 2.4. The values of *Distance*, *Theta* and *Phi* correspond to the spherical coordinates of a field point far from the sources, which are in the neighborhood of the origin point. The definitions of these coordinates are illustrated in Fig 2.5.

Thus, the origin point (X0,Y0,Z0) can be any point on the wire structure, it is used as a phase reference and its coordinates don't affect the shape of the radiation pattern. The "*Distance R*" is the distance from this origin point to an observation point in the far-field region. If "*Distance*" is equal to one meter, then a normalized field is obtained.

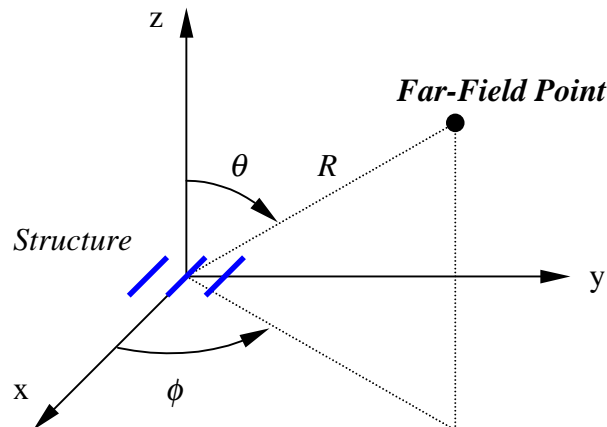


Fig. 2.5: Spherical coordinates of a far-field point.

2.5 "Incident Wave" page

The parameters set in this page are taken into account only if the option "*Incident Plane Wave*" in the "*Options*" page is checked.

When an incident plane wave is used as excitation, all discrete sources, if any, will not be considered in the simulation.

The *Electric Field Amplitude*, the incident direction and polarization for the incident field can be set in this page, Fig. 2.6. The *Theta* and *Phi* angles give the direction of the incoming wave, and its polarization is described by the *Gamma* angle.

When the "*3D View*" button is pressed a special user interface is enabled. With this tool the parameters defining the incident wave can be entered in an easy way, Fig. 2.7. The definitions of these parameters are illustrated in Fig. 2.8.

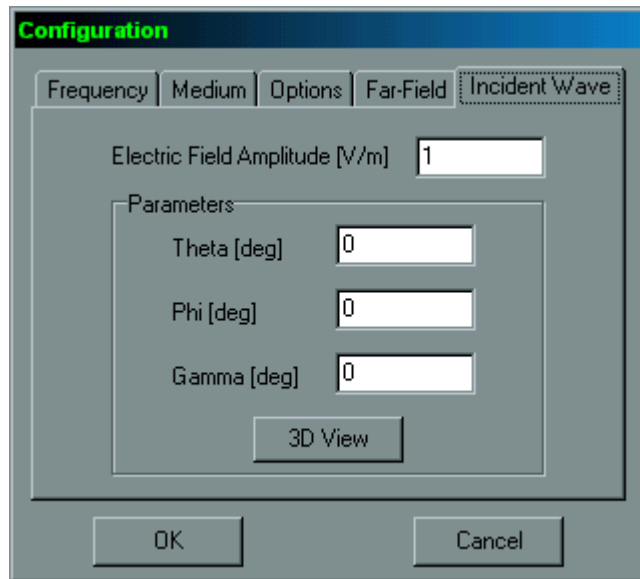


Fig. 2.6: "Incident Wave" page in the "Configuration" dialog box.

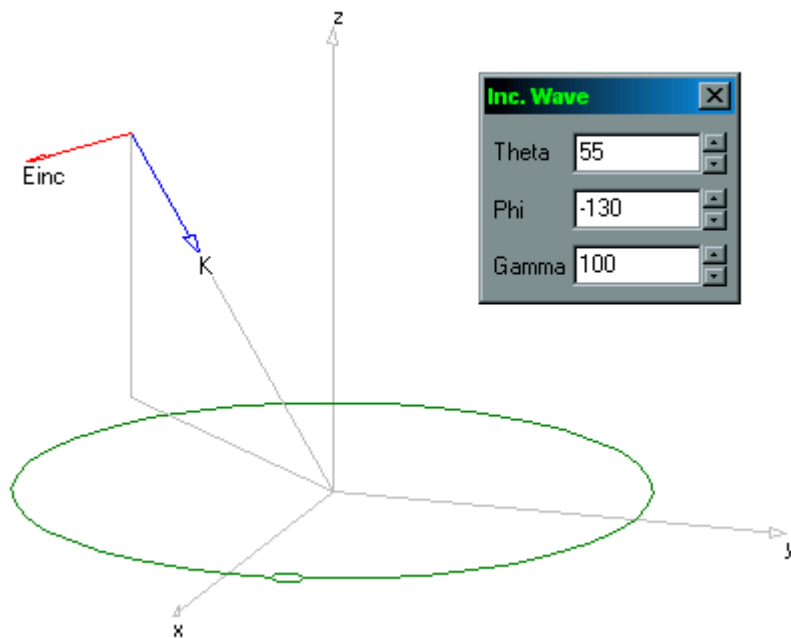


Fig. 2.7: "3D View" user interface for the incident wave definition.

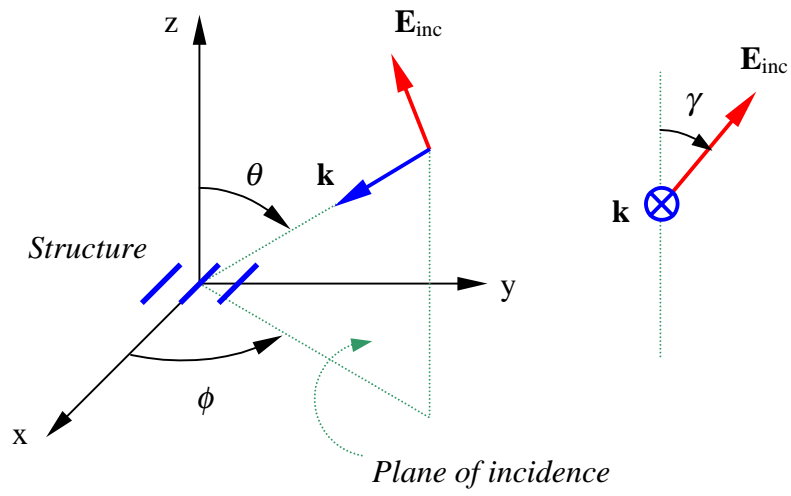


Fig. 2.8: Definition of the incident plane wave.

3. Drawing wires

3.1 "Attributes" page

EMMCAP has different types of wires. Each wire has its own input parameters and attributes that can be set in its specific dialog box. However, all wires share the following common attributes:

- ❑ Number of segments.
- ❑ Resistivity.
- ❑ Cross-section.

Each wire has to be divided into a given number of segments. An unknown current on each segment must be found in the simulation process. This number is set automatically by considering the wavelength and the length of the wire, but can also be set manually by the user.

The resistivity in [ohm/m] (ohm per meter) of a wire is taken into account in the computation if "*Resistivity*" is checked on the "*Options*" page of the "*Configuration*" dialog box. For perfectly conducting structures this option should not be checked.

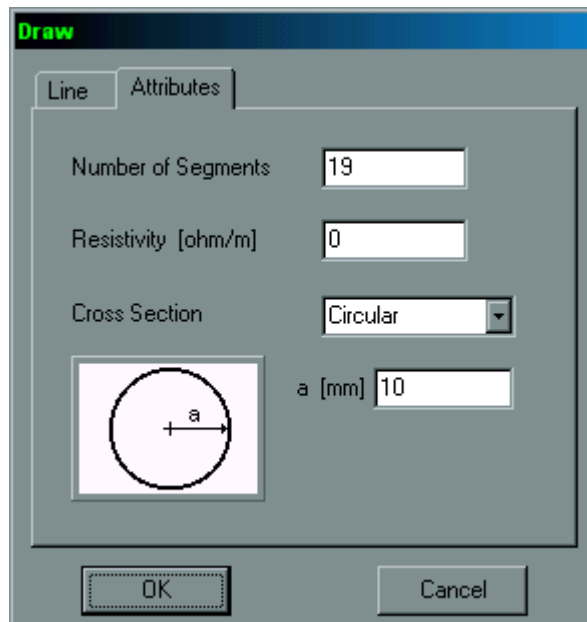


Fig. 3.1: "Attributes" page in the "Draw" dialog box for the wire "Line".

The cross section of each wire can be selected from a list, and there are five options available: *Circular*, *Square*, *Flat*, *Elliptical* and *Rectangular*. Considering the

length of a segment automatically sets a recommended radius for the circular cross section case.

The "Attributes" page in the "Draw" dialog box for the wire "Line" is shown in Fig. 3.1. The "Draw" dialog box for each type of wire has its own "Attributes" page with the same features described above.

3.2 Wire "Line"

Wire "Line" refers to a straight wire. By clicking with the right mouse button in any part of the screen a pop-up menu, where the type of wire can be chosen, will be shown. Selecting "Draw | Edit" in the main menu can also choose the type of wire.

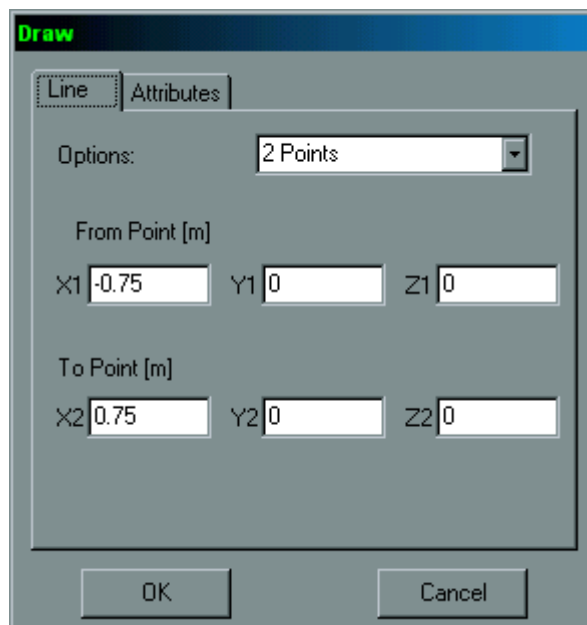


Fig. 3.2: "Line" page in the "Draw" dialog box for the wire "Line". "2 Points" option.

By selecting "Line" the "Draw" dialog box, where the parameters and attributes of the wire can be set, will be shown, Fig. 3.2. On the "Line" page of the "Draw" dialog box there are two options available: "2 Points" and "Start - Direction - Length".

The "2 Points" option allows to enter the straight wire by giving two points: "From Point" and "To Point", Fig. 3.2.

If "Start - Direction - Length" is selected, the line is drawn starting from "Start Point", in the direction defined by the "Theta" and "Phi" angles in spherical coordinates, and ending at a point defined by its "Length" measured in that direction, Fig. 3.3.



Fig. 3.3: "Line" page in the "Draw" dialog box for the wire "Line". "Start - Direction - Length" option.

Once the parameters on the "Line" page have been set, the "Attributes" page can be selected, Fig. 3.1. Default values of the number of segments, resistivity and radius for the circular cross section case will be shown, but these values can be changed.

3.3 Discrete sources and loads

An arbitrary number of discrete sources can be placed at any positions for the excitation of the structure. There are two types of generators: *Voltage sources* and *Current sources*. Current sources serve for the simulation of impressed currents.

Their amplitudes and phases define discrete sources, and they could have inner impedances. These inner impedances can either be resistive, inductive or capacitive.

Lumped loads, representing discrete resistors, inductors and capacitors can be added to a wire at any position. There are two types of loads: *Inductive* and *Capacitive*.

Its resistance in [ohm] and inductance in [uH] define inductive load impedance. An inductive load with a null inductance can define resistors.

Its resistance in [ohm] and capacitance in [pF] define capacitive load impedance.

3.4 Adding sources / loads

By clicking with the right mouse button in any part of a wire a pop-up menu, where the "Source / Load" option can be chosen, will be shown, Fig. 3.4.

The "Source / Load" option can also be chosen by first selecting a wire by clicking with the left mouse button on it, and next selecting " Source / Load " under "Edit" in the main menu, Fig. 3.5.

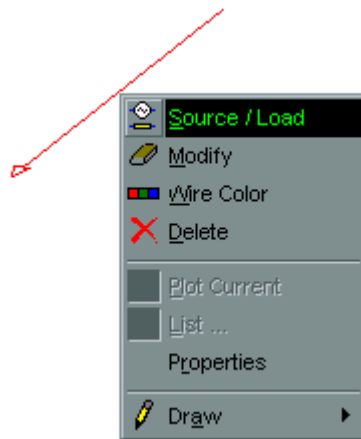


Fig. 3.4: "Source / Load" option in the pop-up menu.

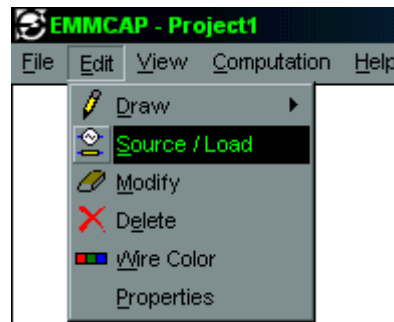


Fig. 3.5: "Source / Load" option in the main menu.

When the "Source / Load" option has been chosen a special tool-bar at the bottom of the screen will be shown, Fig. 3.6.

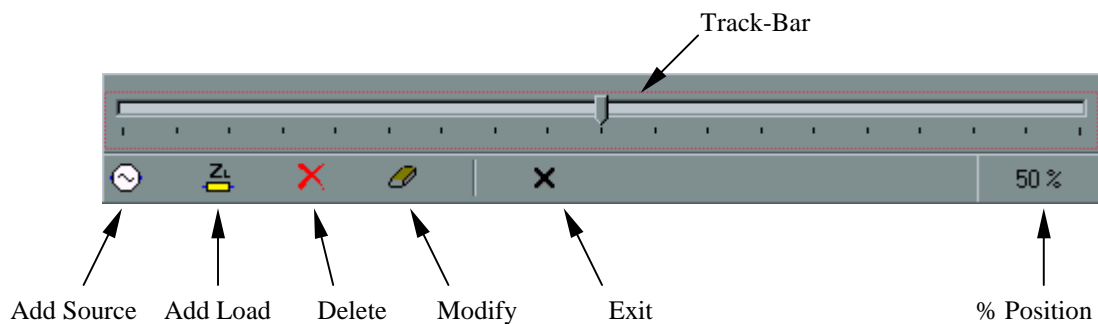


Fig. 3.6: "Source / Load" tool-bar.

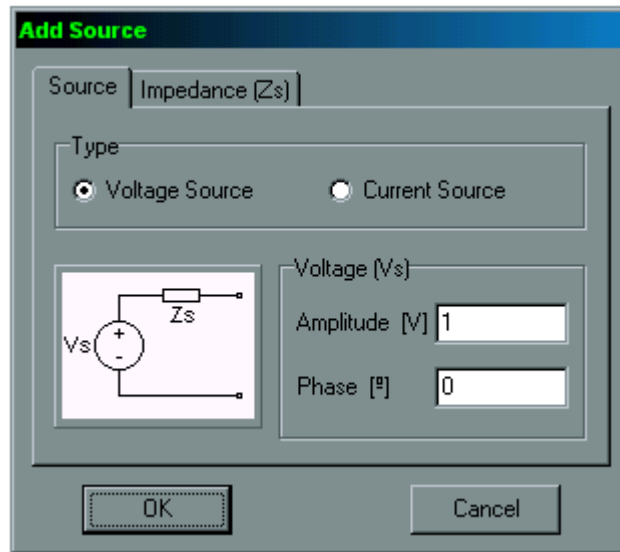


Fig. 3.7: "Add Source" dialog box.

The "Source / Load" tool-bar has a "Track-Bar". Each position of the *Track-Bar* corresponds to the position of a segment in the selected wire. Thus, this *Track-Bar* allows selecting a segment where either a source or a load can be placed.

By clicking on the "Add Source" button a dialog box is shown, Fig. 3.7.

In the "Add Source" dialog box the type of source, its amplitude and phase and its inner impedance can be set.

By clicking on the "Add Load" button a dialog box is shown, Fig. 3.8.

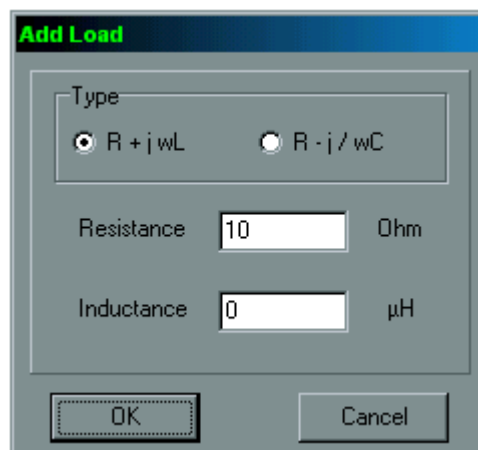


Fig. 3.8: "Add Load" dialog box.

In the "Add Load" dialog box the type of lumped load and its resistance and inductance/capacitance can be set. By selecting the type of impedance a load element can either represent a resistance in series with an inductance or a resistance in series with a capacitance.

With the "*Delete*" and "*Modify*" buttons either a source or a load can be edited. This buttons are enabled when the segment, where a source/load is placed, is selected with the *Track-Bar*.

At the right corner of the "Source / Load" tool-bar the *percent position* at which the selected segment is on the wire is shown. This position is measured from the starting point of the wire to the middle point of the selected segment, and is defined as "*100 * position / wire length*".

The "*Exit*" button allows to close the "Source / Load" tool-bar.

3.5 Modifying / Deleting a wire

The "*Modify*" option, as well as the "*Delete*" option, can be chosen in a pop-up menu by clicking with the right mouse button on a wire, Fig. 3.4.

These options can also be chosen by first selecting a wire by clicking on it with the left mouse button, and next selecting either "Edit | Modify" or "Edit | Delete" in the main menu, Fig. 3.5.

If "*Modify*" is chosen the parameters and attributes of the selected wire can be modified in a dialog box.

If "*Delete*" is chosen the selected wire will be deleted with all sources and loads placed on it.

4. Performing the computation

When the configuration, the geometry and the excitation are defined **EMMCAP** is ready to compute the currents on the segments. Pressing "Computation | Run Currents" in the main menu, Fig. 4.1, can run this simulation.



Fig. 4.1: "Computation | Run Currents" in the main menu.

Once the current distribution on the whole wire structure has been computed, the far-field in the directions defined in the "Configuration" dialog box can be obtained. Pressing "Computation | Run Far-Field" in the main menu, Fig. 4.2, can run this simulation. This option is enabled when the currents have been computed in a previous simulation.

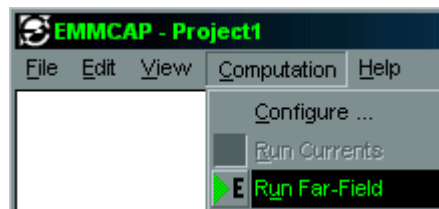


Fig. 4.2: "Computation | Run Far-Field" in the main menu.

5. Visualizing computed results

5.1 Current plot

A 2D plot of the current distribution along a particular wire can be shown by clicking on the wire with the right mouse button, and selecting "Plot Current" in the pop-up menu, Fig. 5.1.

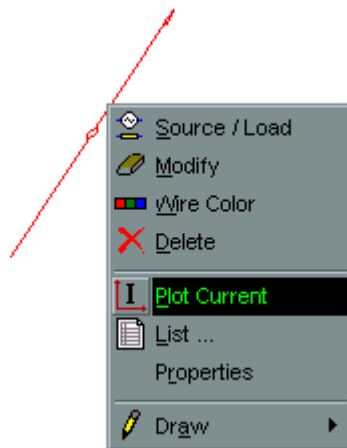


Fig. 5.1: "Plot Current" option in the pop-up menu.

Choosing this option executes the **EMMPLOT** program, where the current is plotted in amplitude vs. position along the wire, Fig 5.2. The current distribution can also be shown in phase, real and imaginary parts by selecting these options under "View" in the **EMMPLOT**'s main menu.

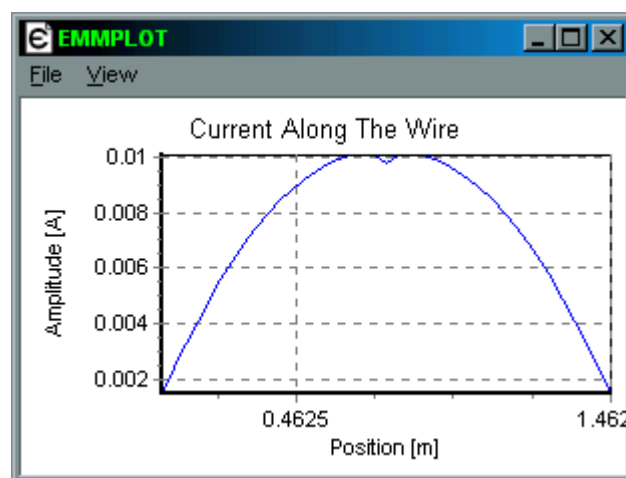


Fig. 5.2: Current distribution plotted by **EMMPLOT**.

5.2 Radiation pattern plot

The computed radiation pattern can be shown as a 2D rectangular plot by selecting "View | Plot Far-Field | 2D Plot" in the main menu, Fig 5.3.

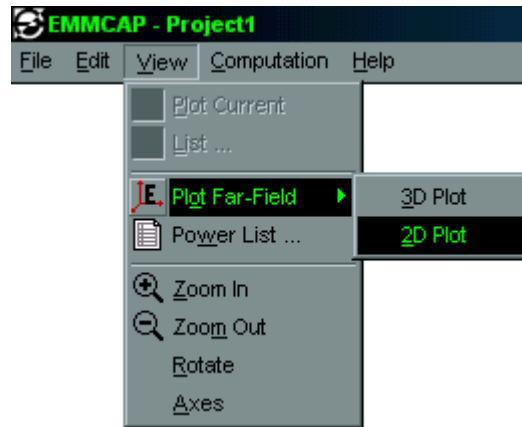


Fig. 5.3: "View | Plot Far-Field | 2D Plot" in the main menu.

Choosing this option shows the "Radiation Pattern Cut" dialog box, where two kinds of plots can be produced: *conical* and *vertical*. Conical plots are for fixed θ with ϕ varying, and vertical plots are for fixed ϕ with θ varying, Fig 5.4.

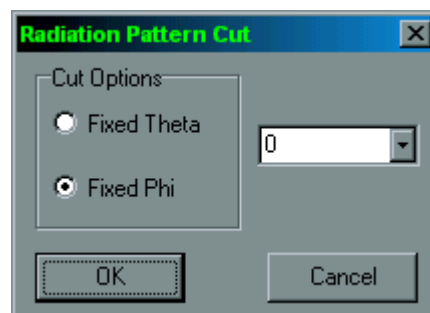


Fig. 5.4: "Radiation Pattern Cut" dialog box. A vertical plot for a fixed $\phi = 0^\circ$ is selected.

Selecting a kind of radiation pattern cut executes the **EMMPLOT** program, where the average *Poynting* vector is plotted vs. ϕ if a *conical* plot was chosen (for fixed θ) or vs. θ if a *vertical* plot was chosen (for fixed ϕ), Fig 5.5. Selecting these options under "View" in the **EMMPLOT**'s main menu can also show the total E-field, the E- θ and E- ϕ field components and the directivity patterns.

The radiation patterns can also be plotted in a 2D polar chart by pressing "Polar/Ortho" under "View" in the **EMMPLOT**'s main menu, Fig 5.6.

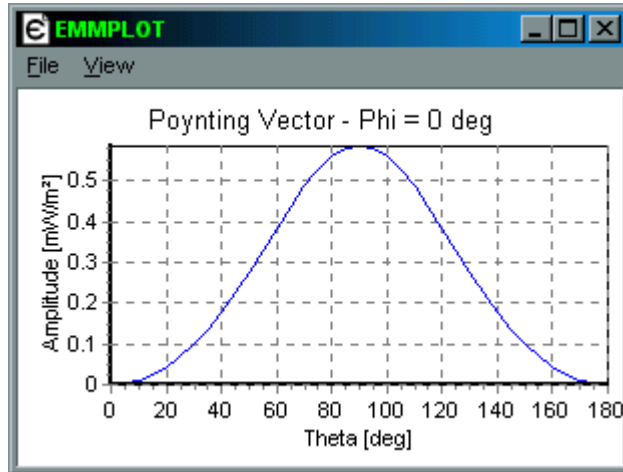


Fig. 5.5: "Radiation Pattern Cut" plotted by the **EMMPLOT** program in an orthogonal chart.

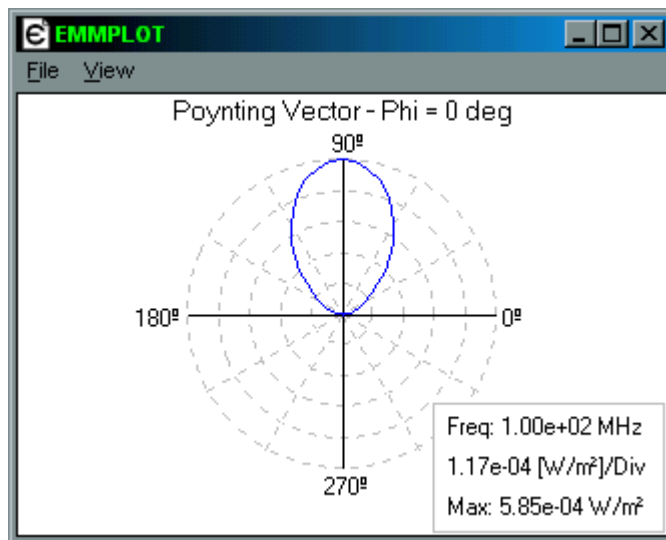


Fig. 5.6: "Radiation Pattern Cut" plotted by the **EMMPLOT** program in a polar chart.

If discrete sources were used as the excitation of the wire structure, the computed and plotted far-field is the *total field*, but if an incident plane wave was used as the excitation, the computed and plotted far-field is the *scattered field*. In the last case, the total field is given by the superposition of the incident field and the scattered field.

5.3 Listing results

There are two kinds of lists: 1) a list associated with a particular wire, 2) a list associated with the whole system.

Clicking with the right mouse button on a particular wire shows a pop-up menu, Fig. 5.7. Pressing "List ..." in the pop-up menu shows a tool-bar, Fig.5.8.

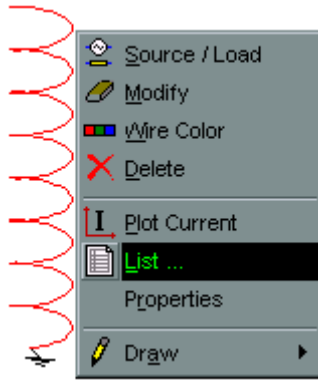


Fig. 5.7: "List ..." option in the pop-up menu.

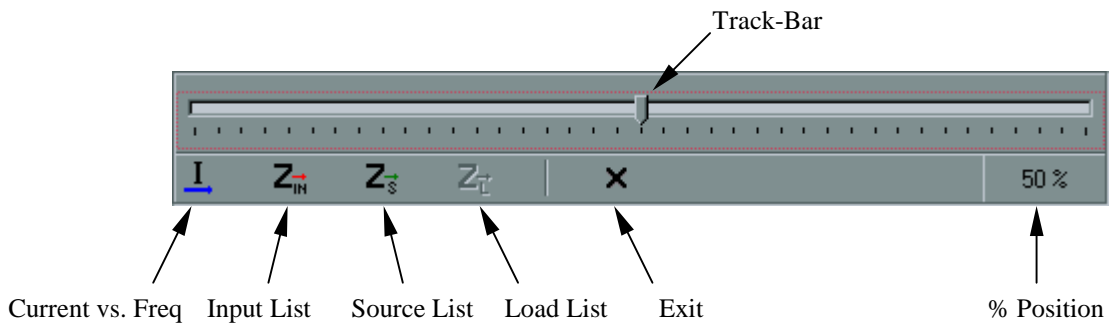


Fig. 5.8: Tool-bar for listing results associated with the selected wire.

Current vs. Frequency			
No.	Frequency [MHz]	Amplitude [A]	Phase [deg]
1	10	0.000427481	89.9904
2	20	0.000877796	89.9191
3	30	0.00137961	89.7028
4	40	0.00197657	89.2015
5	50	0.00274671	88.1395

Fig. 5.9: "Current vs. Frequency" dialog box.

The tool-bar has a "Track-Bar". Each position of the *Track-Bar* corresponds to the position of a segment in the selected wire. Thus, this *Track-Bar* allows selecting a particular segment in the wire.

By clicking on the "Current vs. Freq" button a dialog box with a list of the current in the selected segment is shown, Fig. 5.9. This list shows the current in the segment vs. frequency and pressing the "Plot" button in the dialog box can plot these data.

If the selected segment has a source on it, the "Input List" button is enabled. Choosing this option shows the list of the input impedance vs. frequency that can be plotted by pressing the "Plot" button, Fig. 5.10.

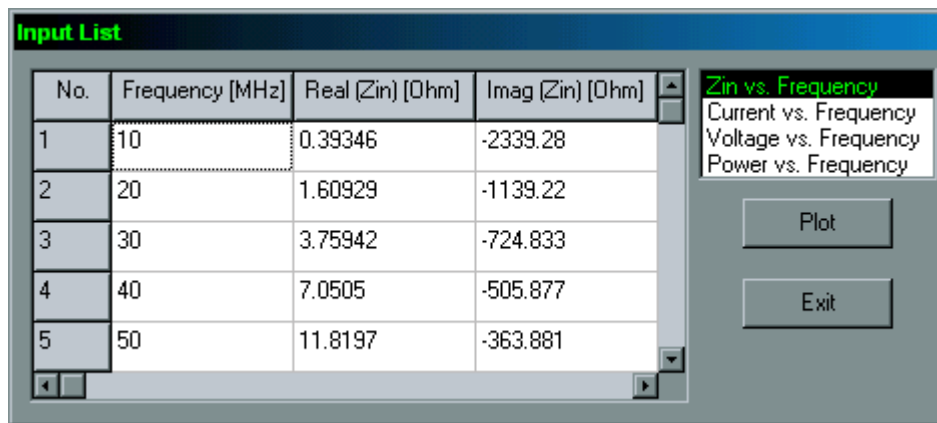


Fig. 5.10: "Input List" dialog box.

The list associated with the whole system refers to the total power radiated by the wire structure, the maximum and average power densities, the directivity and the direction of the maximum radiation. These values are listed vs. frequency.

Selecting "View | Power List..." in the main menu shows the "Power List" dialog box, Fig. 5.11 and Fig. 5.12.

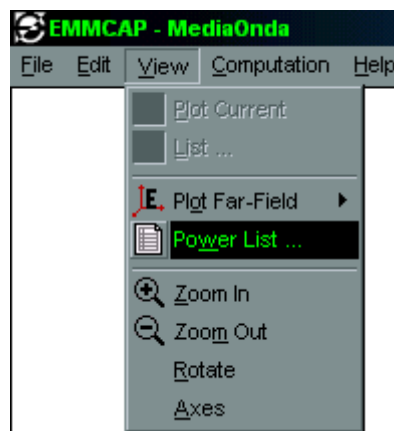


Fig. 5.11: "View | Power List..." option in the main menu.

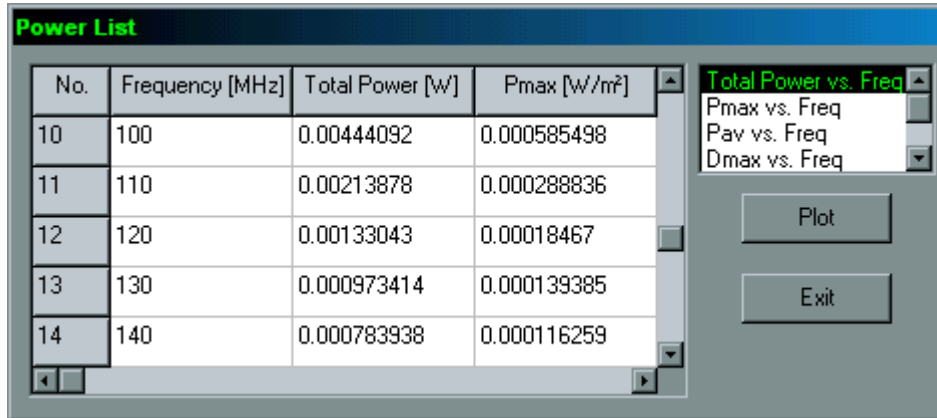


Fig. 5.12: "Power List" dialog box.

The column "*Total Power*" refers to the total radiated power from the structure. If the wire structure was excited by an incident plane wave, this power is the total *scattered power* from the wires.

The column "*Pmax*" is the maximum value of the radiated power density.

The column "*Pav*" is the average power density. This value is computed averaging the power density in all directions.

The column "*Dmax*" is the maximum value of the directivity, and is defined as P_{max}/P_{av} . This value is usually called "*directivity*" or "*directive gain*" of the system. The directivity is also given in decibels in the column "*Dmax [dB]*".

The columns "*Theta*" and "*Phi*" correspond to the direction of the maximum radiation given in spherical coordinates.

6. Examples

6.1 Simulation of a cylindrical antenna

A straight wire with a voltage source at its center can simulate a center-fed cylindrical antenna. Following the steps listed below can perform the simulation.

Step 1: Select "Computation | Configure..." in the main menu. In the "Frequency" page of the "Configuration" dialog box choose "Sweep" and fill the "Frequency Sweep" box as shown in Fig. 6.1.

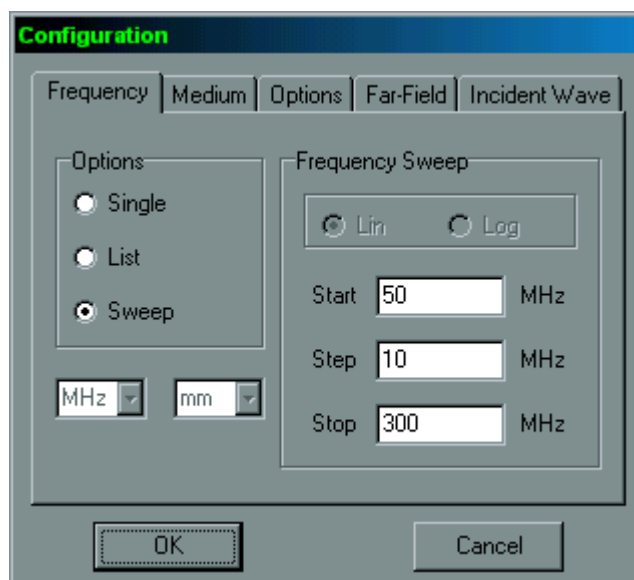


Fig. 6.1: "Frequency" page in the "Configuration" dialog box. The computation will be performed at the frequencies: 50, 60,... ,290, 300 MHz.

Step 2: Select "Edit | Draw | Line" in the main menu. The "Draw" dialog box for the wire "Line" will be shown. Fill the pages "Line" and "Attributes" as shown in Fig. 6.2 and Fig 6.3. A straight wire with 17 segments will be drawn.

Clicking with the right mouse button on the wire shows a pop-up menu, where the "Source/Load" option can be selected. Follow the procedure described in section 3.4 and put a voltage source in the segment no. 9, i.e. at the middle point of the wire. The source voltage can be 1 (0°) V.

Step 3: Press "Computation | Run Currents" in the main menu. Once the simulation has finished press "Computation | Run Far-Field".

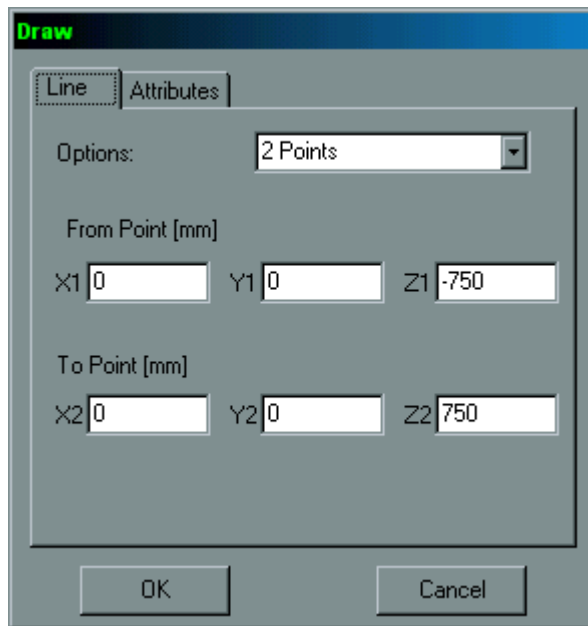


Fig. 6.2: "Line" page in the "Draw" dialog box. The straight wire will be drawn starting from the point (0,0,-750 mm) and ending at the point (0,0,750 mm). Thus it is on the z-axis and is 1500 mm long, corresponding to half-wavelength at 100 MHz. Press "F3" to view the main axes.

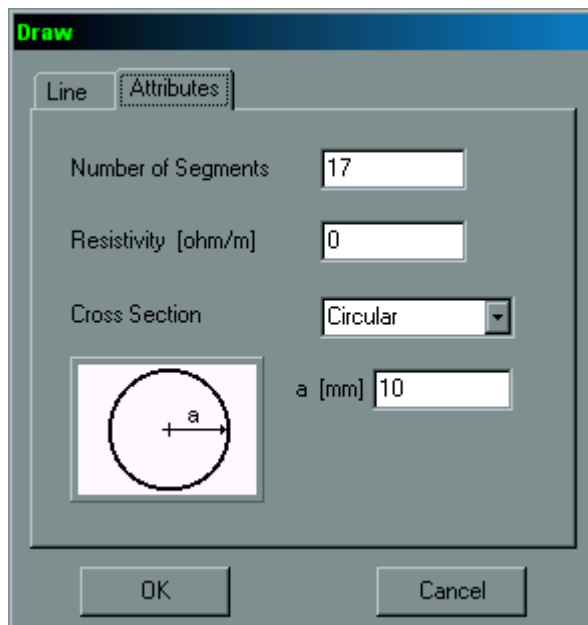


Fig. 6.3: "Attributes" page in the "Draw" dialog box. The wire will be divided into 17 segments, its resistivity is set to zero (perfect electric conductor) and it has a circular cross-section with the radius set to 10 mm.

Step 4: Clicking on the wire with the right mouse button, and selecting "Plot Current" in the pop-up menu can show a plot of the current distribution. Follow the procedures described in section 5 for visualizing other parameters of interest. As an example, the current distribution in amplitude at 200 MHz, the radiation pattern in a 3D diagram at 300 MHz and the input impedance vs. frequency are shown in the following figures.

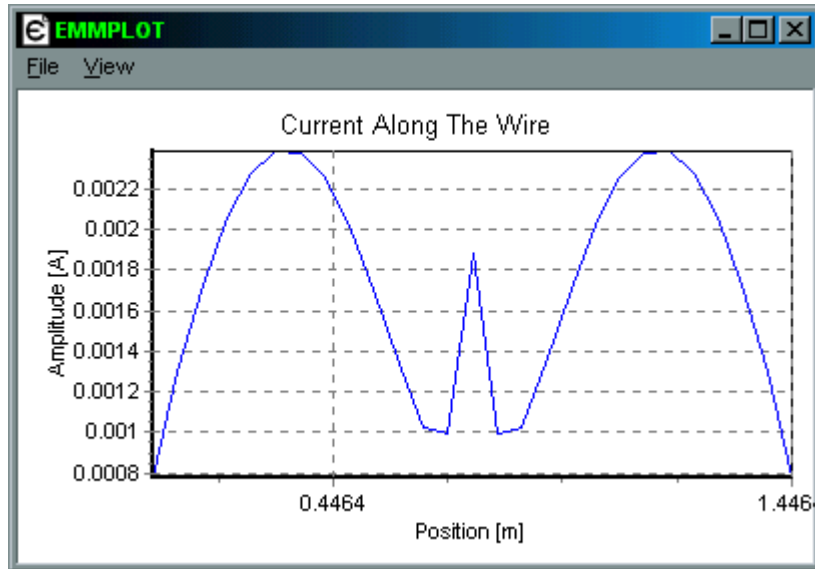


Fig. 6.4: Current distribution in amplitude along the cylindrical antenna at 200 MHz.

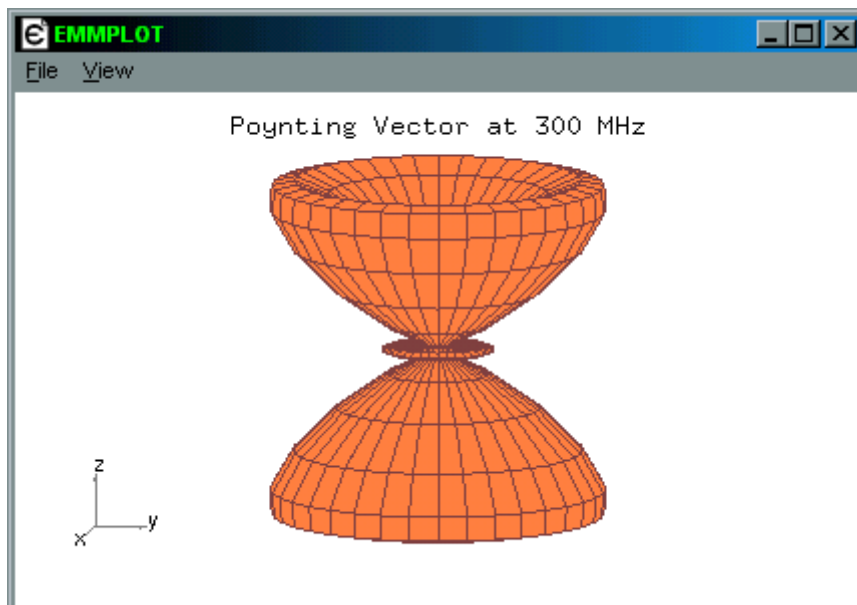


Fig. 6.5: Radiation pattern of the cylindrical antenna at 300 MHz.

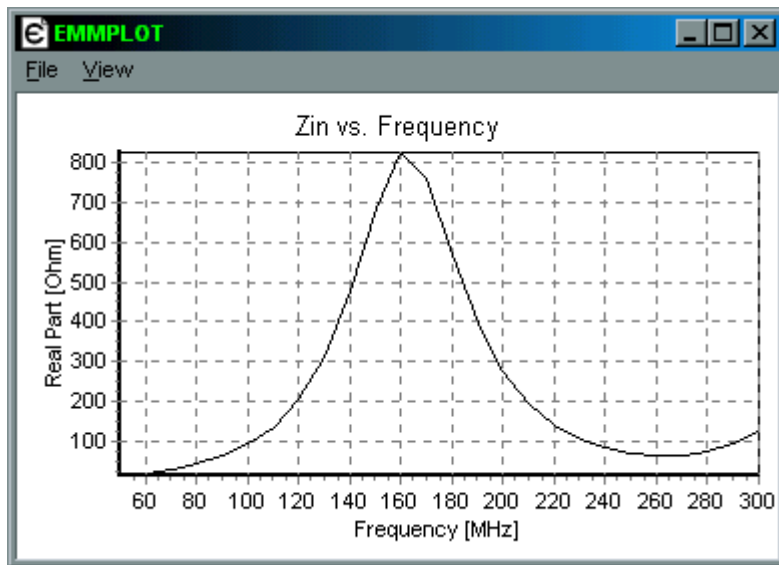


Fig. 6.6: Real part of the input impedance vs. frequency.

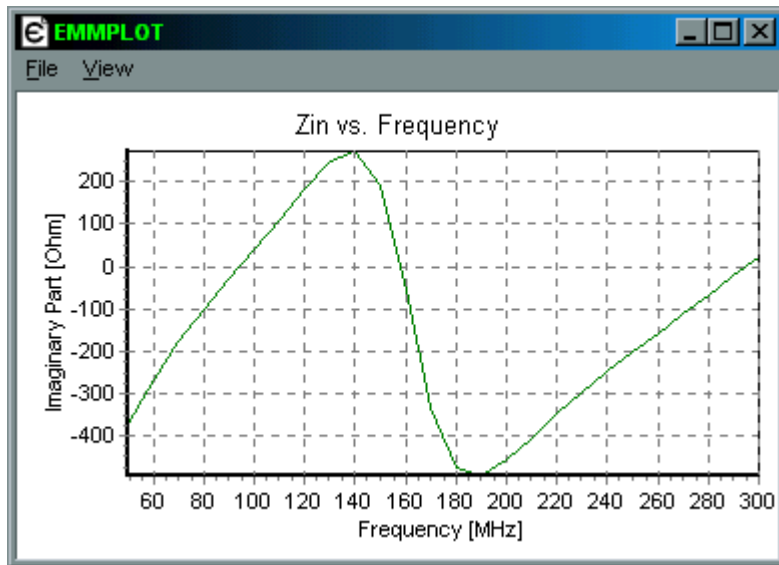


Fig. 6.7: Imaginary part of the input impedance vs. frequency.

6.2 Simulation of a transmission line

A straight wire above a ground plane will simulate a transmission line. The geometry definition is shown in Fig 6.8.

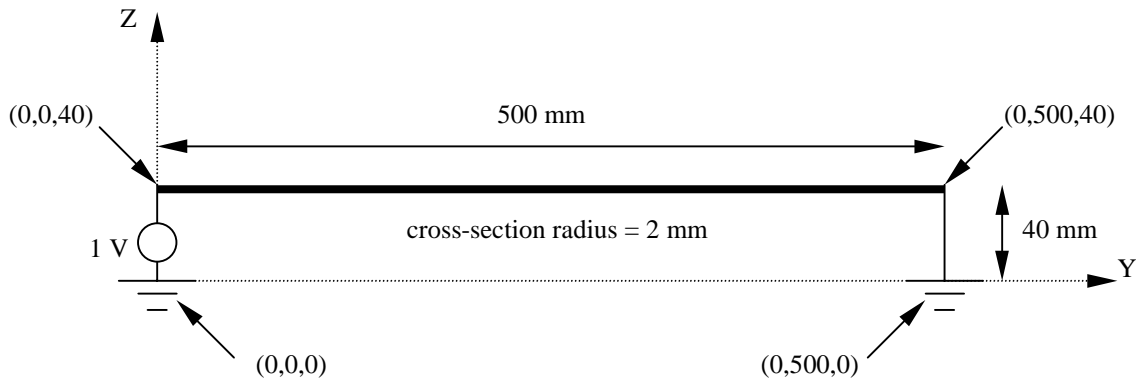


Fig. 6.8: Short-circuited transmission line.

The computation will be performed at 100 MHz. Following the steps listed below can perform the simulation.

Step 1: Select "Computation | Configure..." in the main menu. In the "Frequency" page of the "Configuration" dialog box choose "Single" and fill the "Single Frequency" box as shown in Fig. 6.9. Then, choose the "Options" page and fill it as shown in Fig 6.10.

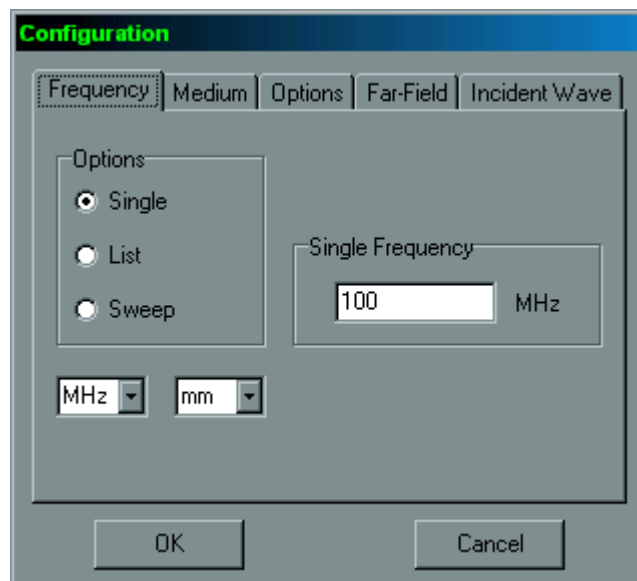


Fig. 6.9: "Frequency" page in the "Configuration" dialog box.

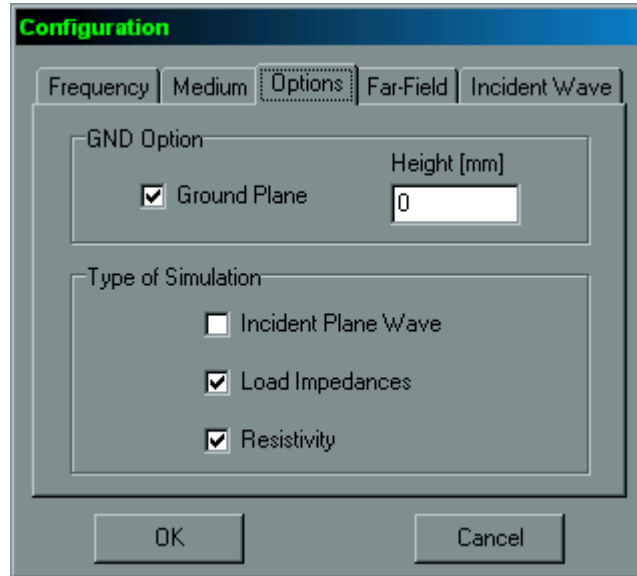


Fig. 6.10: "Options" page in the "Configuration" dialog box.

Step 2: Select "Edit | Draw | Line" in the main menu. The "Draw" dialog box for the wire "Line" will be shown. Follow the procedures described in section 3 for drawing wires to replicate the geometry in Fig. 6.8. The horizontal wire has 9 segments and the vertical short wires only 1 segment. The electrical connections at the points (0,0,40) mm and (0,500,40) mm are done automatically as well as the ground connections.

Step 3: Press "Computation | Run Currents" in the main menu.

Step 4: Follow the procedure described in section 5.3 to obtain the input impedance of the short-circuited transmission line. Delete the right short wire in Fig. 6.8 to simulate an open-circuited transmission line and obtain its input impedance. These values are approximately:

- Z_{in} (short-circuited line) = j 503 Ohm.
- Z_{in} (open-circuited line) = $-j$ 107 Ohm.

Then, the characteristic impedance of the line is given by:

$$Z_c = \sqrt{503 \cdot 107} = 232 \text{ Ohm}$$

On the other hand, the relation for the characteristic impedance of a line above a ground plane is given by:

$$Z_c = 60 \cdot \cosh^{-1}(h/a) = 60 \cdot \cosh^{-1}(40/2) = 221 \text{ Ohm}$$

where a is the wire's cross-section radius and h is the height above the ground plane. As can be seen from these results, the agreement is quite good.

6.3 Simulation of an RLC circuit

The geometry definition of the RLC circuit is shown in Fig 6.11. Resonance is obtained at the frequency:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = 796 \text{ Hz}$$

Thus, this frequency will be verified by a frequency sweep computation. Following the steps listed below can perform the simulation.

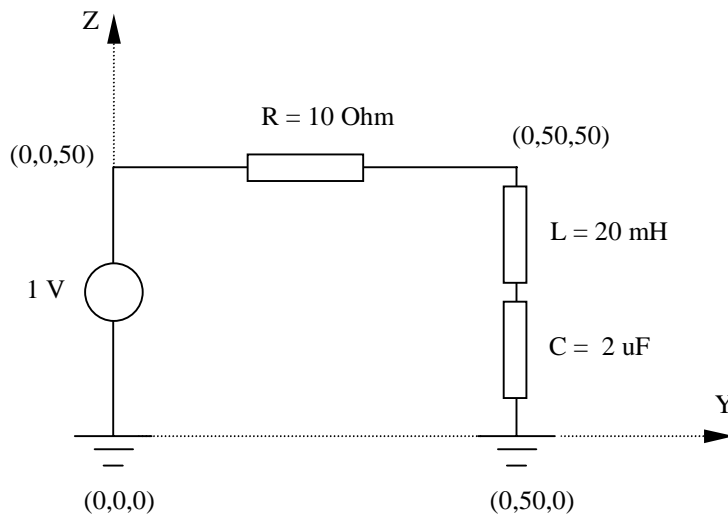


Fig. 6.11: Geometry definition for the RLC circuit.

Step 1: Select "Computation | Configure..." in the main menu. In the "Frequency" page of the "Configuration" dialog box choose "Sweep" and fill the "Frequency Sweep" box as shown in Fig. 6.12. Then, choose the "Options" page and fill it as shown in Fig 6.10.

Step 2: Select "Edit | Draw | Line" in the main menu. The "Draw" dialog box for the wire "Line" will be shown. Follow the procedures described in section 3 for drawing wires to replicate the geometry in Fig. 6.11. The left vertical wire has 1 segment, the horizontal wire has 1 segment and the right vertical wire has 3 segments. The electrical connections at the points (0,0,50) mm and (0,50,50) mm are done automatically as well as the ground connections.

Step 3: Press "Computation | Run Currents" in the main menu.

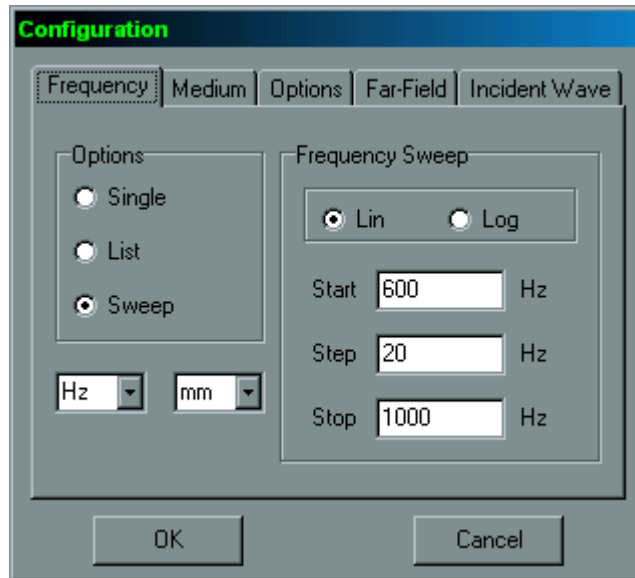


Fig. 6.12: "Frequency" page in the "Configuration" dialog box. The computation will be performed at the frequencies: 600, 620,... ,980, 1000 Hz.

Step 4: Follow the procedure described in section 5.3 to obtain and plot vs. frequency the current in a segment of any wire, Fig 6.13. Because of the circuit topology it must be the same in all wires.

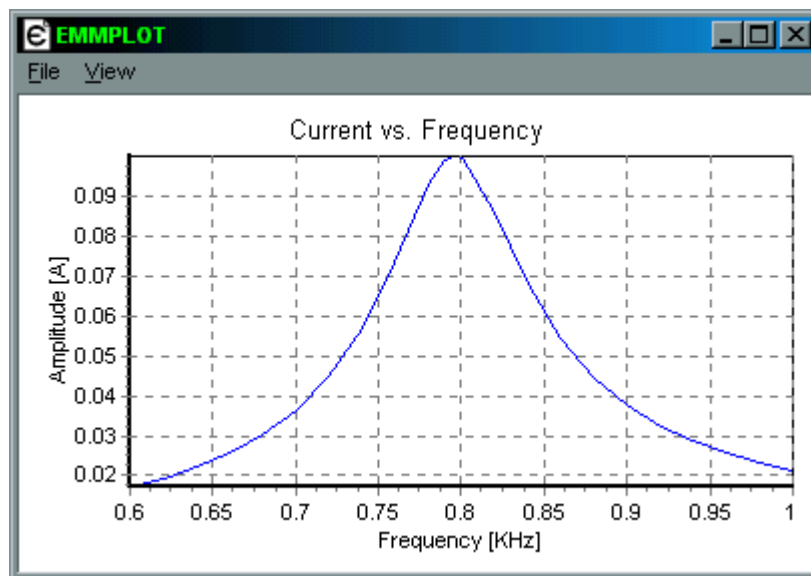


Fig. 6.13: Current amplitude vs. frequency in the RLC circuit of Fig. 6.11. As can be seen, the resonance occurs at a frequency near to 800 Hz. In fact, the value 796 Hz can be verified by simulating at this single frequency.

7. File formats

When a project is saved **EMMCAP** will save six different files. These files will have the same name that the user gave to the project, but with a unique extension referring to the contents in the file. The **EMMCAP** file types are:

File type	Description
*.emm	Main file of the program.
*.wre	File containing geometrical data.
*.cur	File containing currents flowing on wires.
*.phi	E-phi component of the far-field.
*.the	E-theta component of the far-field.
*.pwr	File containing information about the radiation patterns.

8. Shortcut keys

Key	Action
Home	Initial 3D view
Delete	Delete a selected wire
Left Arrow	Select a wire
Right Arrow	Select a wire
Q	Rotate around +X axis
A	Rotate around -X axis
W	Rotate around +Y axis
S	Rotate around -Y axis
E	Rotate around +Z axis
D	Rotate around -Z axis
F3	Show Main/Small axes

9. Background Theory

EMMCAP is written in C++ and it was developed with the aim of improving the accuracy in the modeling of wire structures. Curved wire antennas are usually analyzed using codes based on a straight wire approximation to the geometry [1]. This can be a very inefficient method in terms of unknowns or computer memory. By using curved segments, which describe accurately the contour of the geometry, the number of unknowns can be reduced, thus allowing for the solution of bigger problems.

Here is a brief explanation of the theoretical basis for the **EMMCAP** program system.

9.1 Electric Field Integral Equation for curved wires

The current distribution on metallic surfaces with ideal conductivity can be found by solving an Electric Field Integral Equation (EFIE) expressed in the frequency domain:

$$\mathbf{n} \times \mathbf{E}_i(\mathbf{r}) = \mathbf{n} \times \frac{j}{\omega \epsilon} \iint_S \left[k^2 \mathbf{J}(\mathbf{r}') G(\mathbf{r}, \mathbf{r}') + \text{div}'(\mathbf{J}(\mathbf{r}')) \text{grad}(G(\mathbf{r}, \mathbf{r}')) \right] dS' \quad (1)$$

where:

\mathbf{E}_i : Incident Electric Field on the surface S .

\mathbf{n} : unit vector on the surface S at the point \mathbf{r} .

k : wave number.

\mathbf{J} : unknown electric current density flowing on the surface.

G : Green's function, which in free space is given by:

$$G(\mathbf{r}, \mathbf{r}') = \frac{e^{-jk|\mathbf{r}-\mathbf{r}'|}}{4\pi|\mathbf{r}-\mathbf{r}'|} \quad (2)$$

The EFIE is an expression of a boundary condition on the surface, namely zero tangential electric field.

When we are dealing with a wire structure, the EFIE reduces to:

$$\mathbf{T} \cdot \mathbf{E}_i = \mathbf{T} \cdot \frac{j}{\omega \epsilon} \int_{\Gamma} \left[k^2 I(s') K(s, s') \mathbf{T}' + \frac{dI(s')}{ds'} \text{grad}(K(s, s')) \right] ds' \quad (3)$$

where \mathbf{T} is the tangential unit vector describing the contour of the curve Γ , $I(s)$ is the unknown electric current on the wire, and $K(s, s')$ is the integral equation's kernel defined as:

$$K(s, s') = \frac{1}{4\pi^2} \int_0^{2\pi} \int_0^{2\pi} G(\mathbf{r}, \mathbf{r}') d\phi' d\phi \quad (4)$$

The EFIE is averaged about the wire circumference described by the angle ϕ , resulting in the EFIE (3) with the kernel (4), [2]. The current distribution $I(s)$ is then the average value of the current density \mathbf{J} in the axial direction; the current in the ϕ direction is neglected. This is a good assumption provided that the wire radius is small with respect to the wavelength.

The wire axis Γ is defined by its parametric equations that can be written in the compact form:

$$\mathbf{r}(s) = x(s)\mathbf{i} + y(s)\mathbf{j} + z(s)\mathbf{k} \quad (5)$$

which points from the origin to any point on the wire. The parameter s varies over a real interval.

The tangent unit vector can be obtained from the first derivative of (5):

$$\frac{d\mathbf{r}(s)}{ds} = \frac{dx}{ds}\mathbf{i} + \frac{dy}{ds}\mathbf{j} + \frac{dz}{ds}\mathbf{k}, \quad \mathbf{T} = \frac{d\mathbf{r}}{ds} \left| \frac{d\mathbf{r}}{ds} \right|^{-1} \quad (6)$$

This parametric description is the key for the accurate modeling of the wire structure. A straight wire approximation to the geometry produces a loss of geometrical information that can't be completely restored. However, this information is not lost if a parametric representation is used to describe the wire locus. It is also possible to improve on the straight wire approximation by using quadratic segments to model the geometry [3], [4].

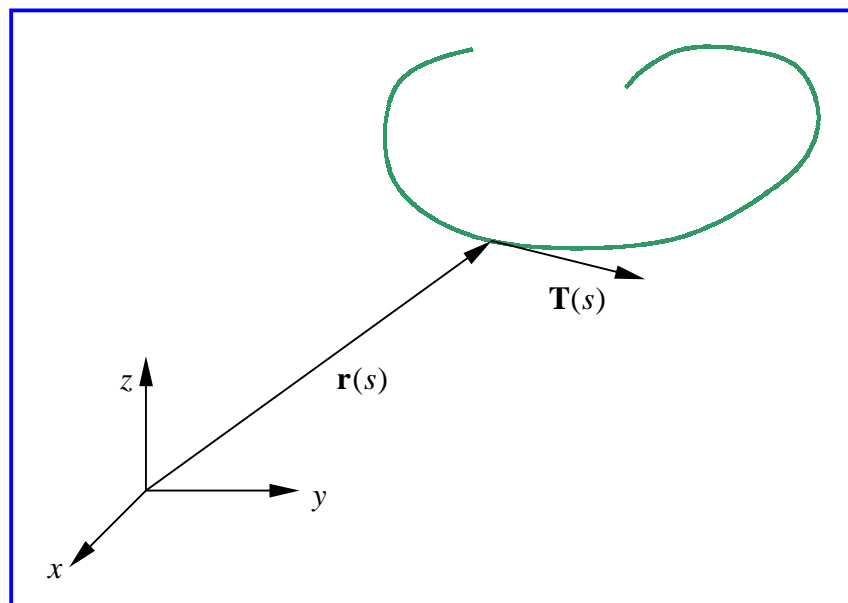


Fig. 9.1: Parametric description of a curved wire. The tangent unit vector is obtained from the first derivative of the position vector $\mathbf{r}(s)$.

Thus, the definition of a wire must include its parametric description and its first derivative if an exact representation of the geometry is required, as shown in Fig. 9.1.

The kernel (4) is approximated by the following *generalized thin-wire approximation*:

$$K(s, s') \cong \frac{e^{-jkR}}{4\pi R}, \quad R = \sqrt{|\mathbf{r}(s) - \mathbf{r}(s')|^2 + a^2} \quad (7)$$

where a is the wire radius.

When the observation point $\mathbf{r}(s)$ and the source point $\mathbf{r}(s')$ are both in the same straight wire, the distance R reduces to the usual thin-wire approximation:

$$R = \sqrt{(s - s')^2 + a^2} \quad (8)$$

Thus, the EFIE and its kernel are also valid for straight wires.

An accurate form of the kernel can be obtained by calculating the integrals in (4), but it requires an extra computational effort for curved wires. A more accurate kernel than the thin-wire approximation for the curved case is under development.

The existence of a PEC ground plane is modeled by means of image currents. This method can be easily implemented by adding an image term to the Green's function, resulting in an additional term for the kernel.

9.2 Method of Moments

The Method of Moments (MoM) [5] is a technique used to convert the EFIE into a system of linear equations that then can be solved by standard methods.

For simplicity, the integral (linear) operator in (3) will be denoted by L , then the EFIE takes the form:

$$L(I) = E_T \quad (9)$$

where E_T is the tangential component of the incident electric field.

The current distribution is approximated by a sum of N *basis functions* with unknown amplitudes I_n , giving:

$$I = \sum_n I_n F_n \quad (10)$$

With this expansion and using the linearity of the operator L , we can write:

$$\sum_n I_n L(F_n) = E_T \quad (11)$$

In order to obtain a set of N equations, the functional equation (11) is weighted with a set of N independent *testing functions* w_m , giving:

$$\sum_n I_n \int w_m L(F_n) ds = \int w_m E_T ds \quad (12)$$

where the integrals are calculated over the domain of L . Now we have as many independent equations as unknowns, so (12) can be written as:

$$[Z] \cdot [I] = [U] \quad (13)$$

where

$[Z]$: impedance matrix with dimension $N \times N$ and the elements $Z_{mn} = \int w_m L(F_n) ds$.

$[I]$: current matrix with dimension $N \times 1$ and the elements I_n .

$[U]$: voltage matrix with dimension $N \times 1$ and the elements $U_m = \int w_m E_T ds$.

This fully occupied equation system has to be solved for the unknown currents I_n . LU decomposition is used in **EMMCAP**.

The MoM is applied by first dividing the wire structure into N segments, and then defining the basis and testing functions on the segments. Triangular basis and pulse testing functions are used in **EMMCAP** as shown in Fig. 9.2.

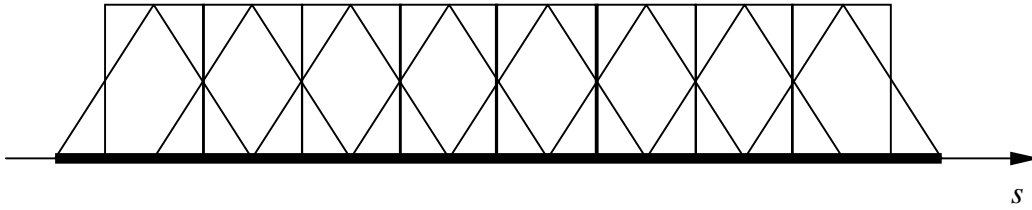


Fig. 9.2: Triangular basis and pulse testing functions.

When a curved wire is described parametrically by a vector function (5), *the basis and testing functions are curved* in the sense that their support is a curved subset of the wire.

In order to fill the impedance matrix $[Z]$, an adaptive Gauss-Legendre quadrature rule is applied to compute the involved integrals.

After having solved the equation system, the currents I_n are known and other parameters of interest, such as input impedances, voltages, radiated power and directivity can be computed.

9.3 Excitation of the structure

If a discrete voltage source is placed at the i -th segment, the corresponding element in the voltage matrix is simply equal to the voltage of the generator. Thus,

$$[U] = \begin{bmatrix} 0 \\ \dots \\ U_i \\ \dots \\ 0 \end{bmatrix} \quad (14)$$

When an incident plane wave is used as the excitation, each wire segment is excited by the incoming field, which has the form:

$$\mathbf{E}_i(\mathbf{r}) = \mathbf{E}_0 e^{-j\mathbf{k}\cdot\mathbf{r}} \quad (15)$$

where \mathbf{k} is defined by the direction of propagation, so that $|\mathbf{k}| = k$ (wave number), and \mathbf{r} is the evaluation point, Fig. 9.3. The elements of the voltage matrix are then defined by:

$$U_m = \int_{S_m} \mathbf{E}_i(\mathbf{r}(s)) \cdot \mathbf{T}(s) ds \quad (16)$$

where the integration is performed over the m -th segment, and the vectors $\mathbf{r}(s)$ and $\mathbf{T}(s)$ are given by (5) and (6), respectively.

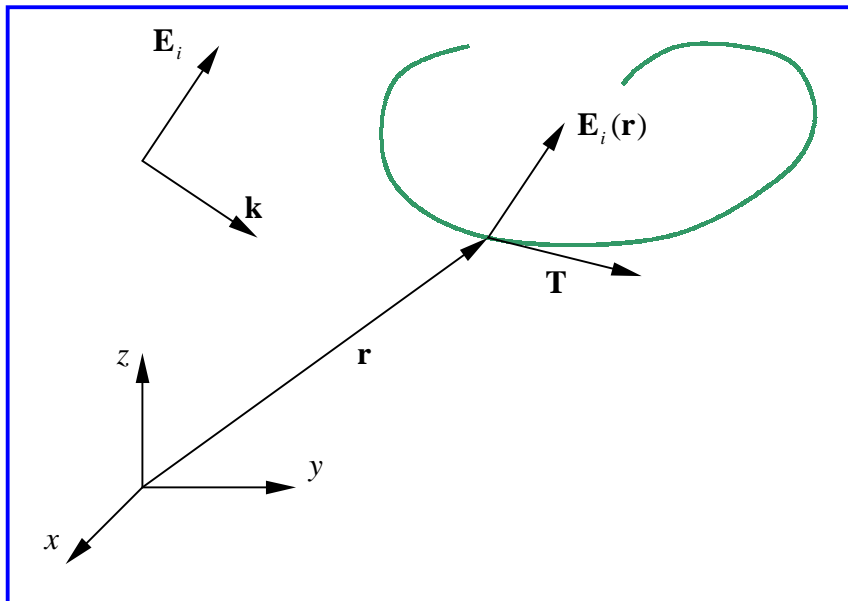


Fig. 9.3: Incident plane wave exciting a wire.

9.4 Curved segments vs. Straight segments

Several examples show the advantages of using curved segments with respect to the stability and convergence properties of the solutions. As a consequence of the improved convergence rate, reduced computation time and memory space can be obtained for accurate results.

As an illustration, the figures below show a comparison between **EMMCAP**, which uses curved segments, and a straight wire approximation to a normal mode helix antenna. The convergence properties of the input impedance and admittance versus the number of unknowns are investigated.

As can be seen from these results, by using curved segments significantly fewer unknowns are needed to predict the input impedance. However, the admittance convergence is questionable for the straight wire case, while it has a notorious convergent behavior for the curved case.

The improvement depends on the geometry and frequency, but generally, if N straight segments are needed to obtain a convergent value, then N/k curved segments are needed to obtain the same value, with $k = 2 \dots 10$. For a straight geometry the improvement factor is $k = 1$, as can be expected, because there are no curved segments in this case.

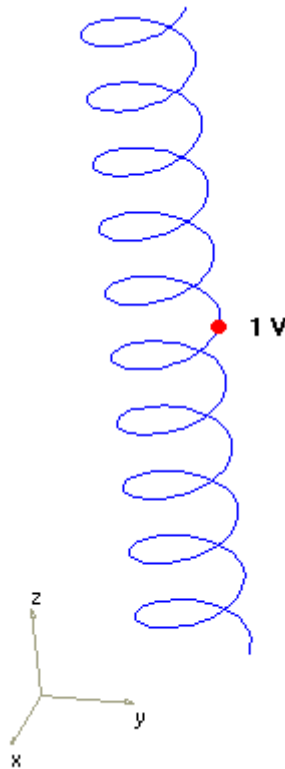


Fig. 9.4: Center-fed helical antenna (normal mode) in free space. Helix radius = 0.0273 wavelengths. Pitch = 0.0363 wavelengths. Number of turns = 10. Wire radius = 0.001 wavelengths.

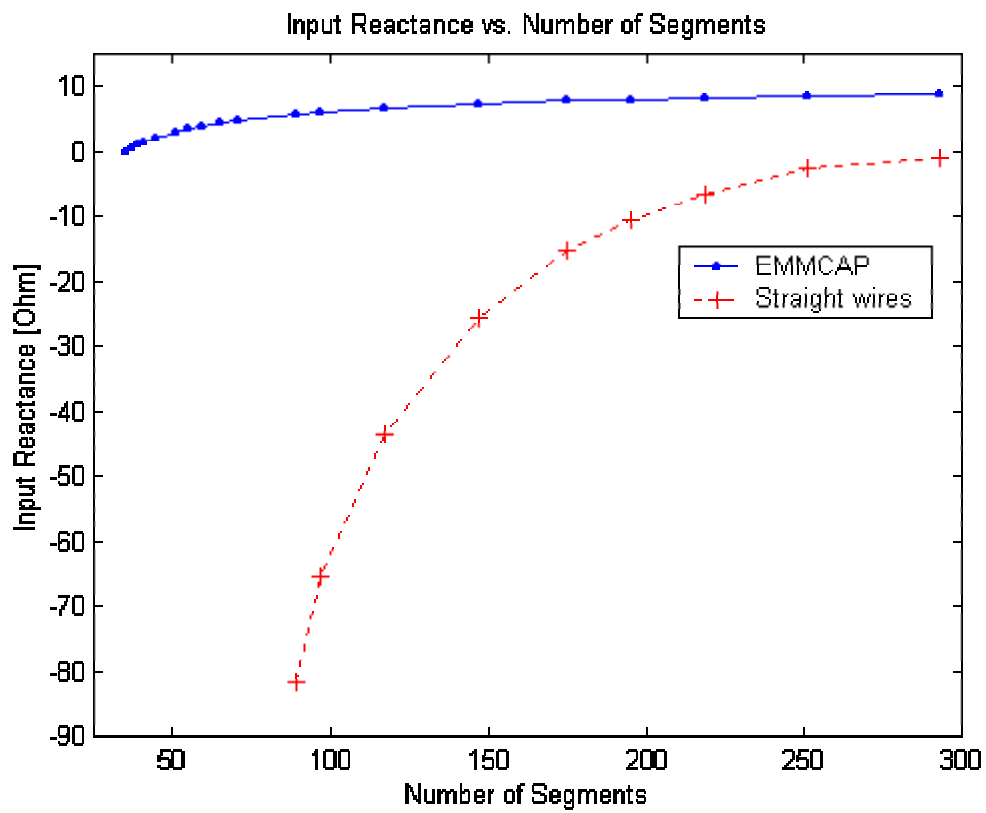
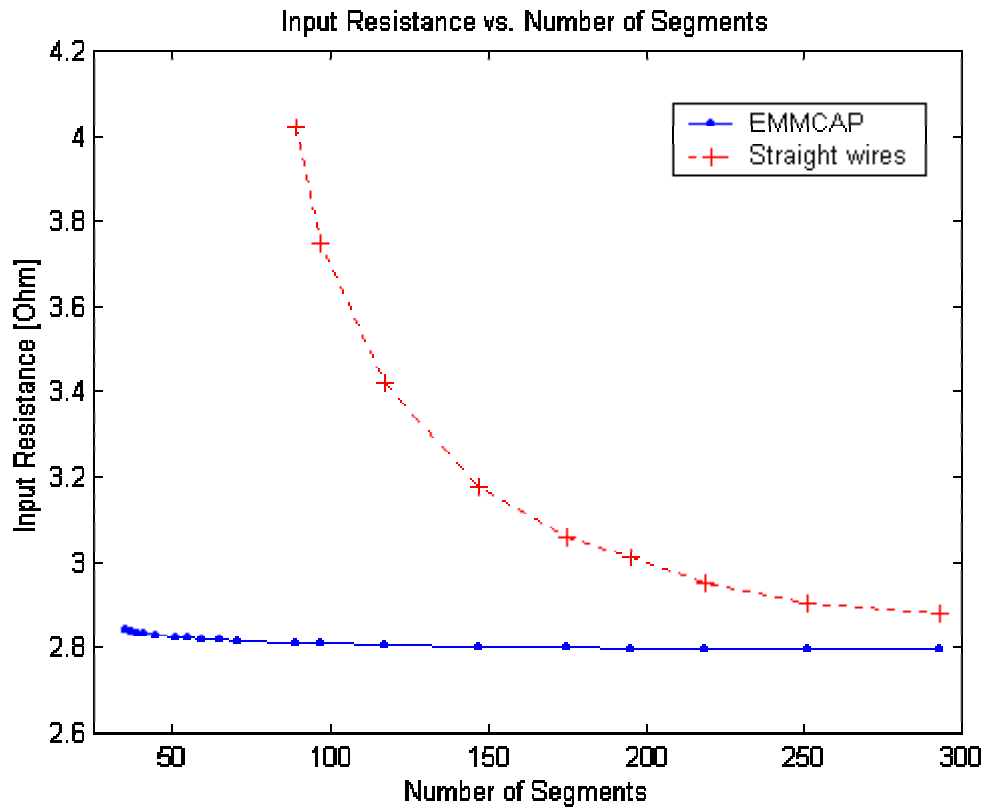


Fig. 9.5: Impedance convergence plot for the helix of Fig. 9.4.

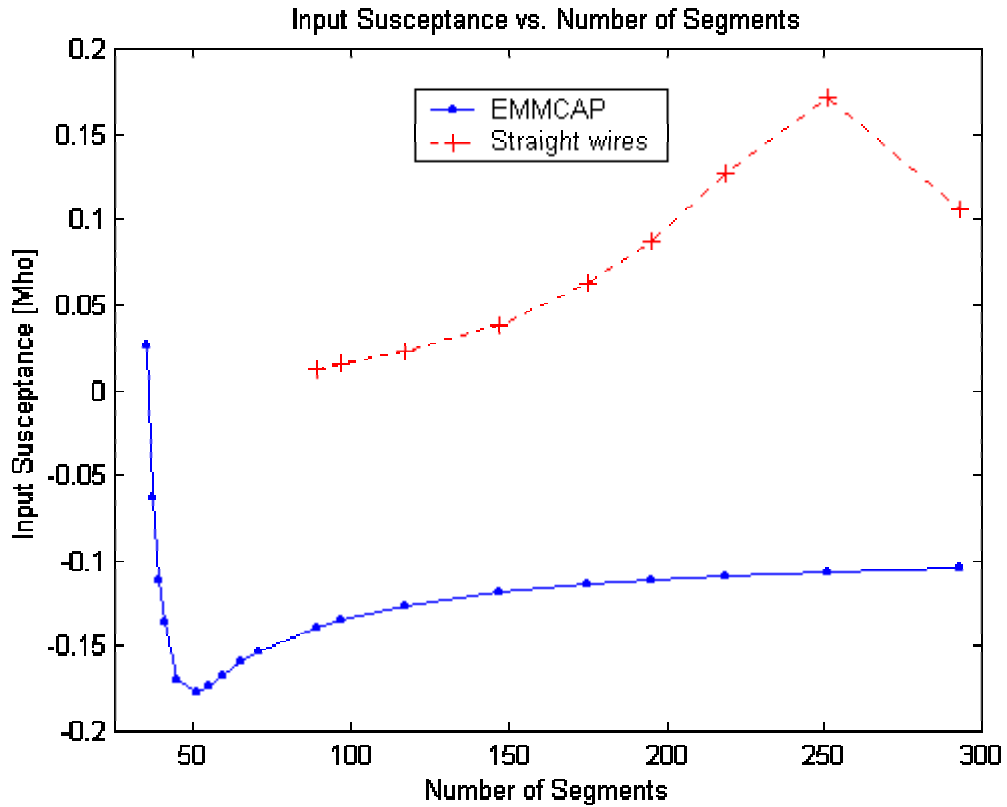
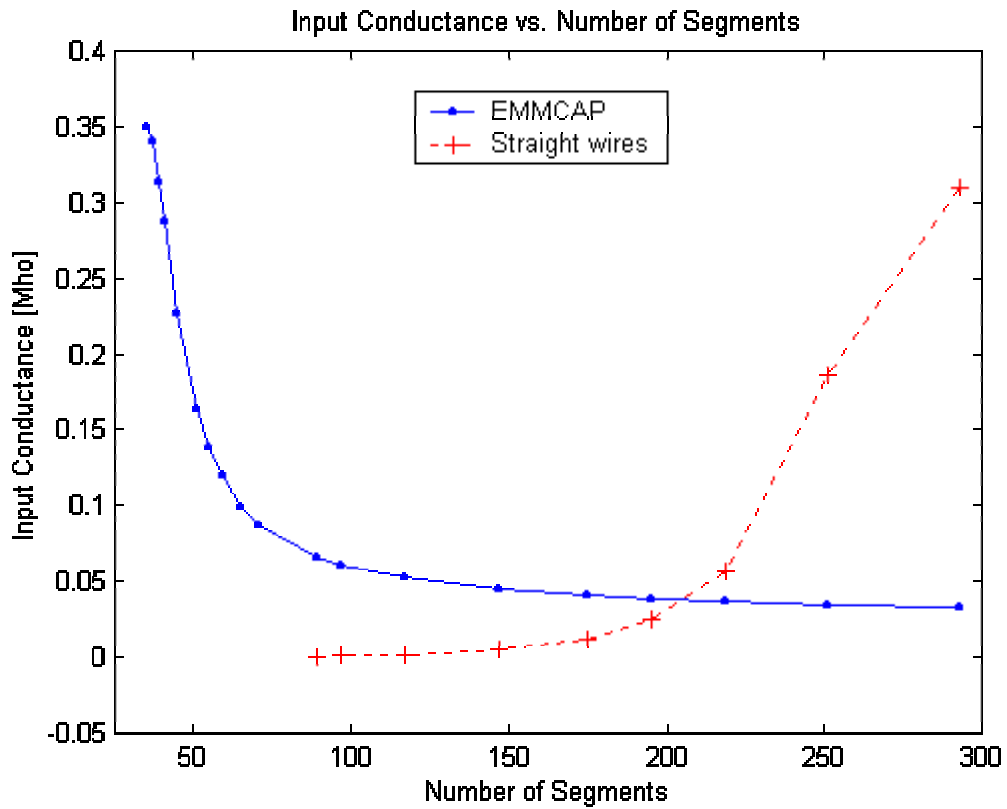


Fig. 9.6: Admittance convergence plot for the helix of Fig. 9.4.

References

- [1] Burke, G. J. and Poggio, A. J., "*Numerical Electromagnetics Code (NEC) - Method of Moments, Part I: Program Description - Theory*", Lawrence Livermore Laboratory, January 1981.
- [2] Davis, W. A., "*Numerical methods for wire structures*", draft. <http://www.vt.edu:10021/eng/ee/faculty/Wdavis/antenna/>, March 1995.
- [3] Champagne, N. J., Williams, J. T., and Wilton, D. R., "*The use of curved segments for numerically modeling thin wire antennas and scatters*", IEEE Trans. on Antennas and Prop., vol. 40, pp. 682-689, June 1992.
- [4] Song, J. M. and Chew, W. C., "*Moment method solutions using parametric geometry*", J. of Electromagnetic Waves and Appl., vol. 9, no. 1/2, pp. 71-83, January-February 1995.
- [5] Harrington, R. F., *Field Computation by Moment Methods*, MacMillan, New York, 1968.