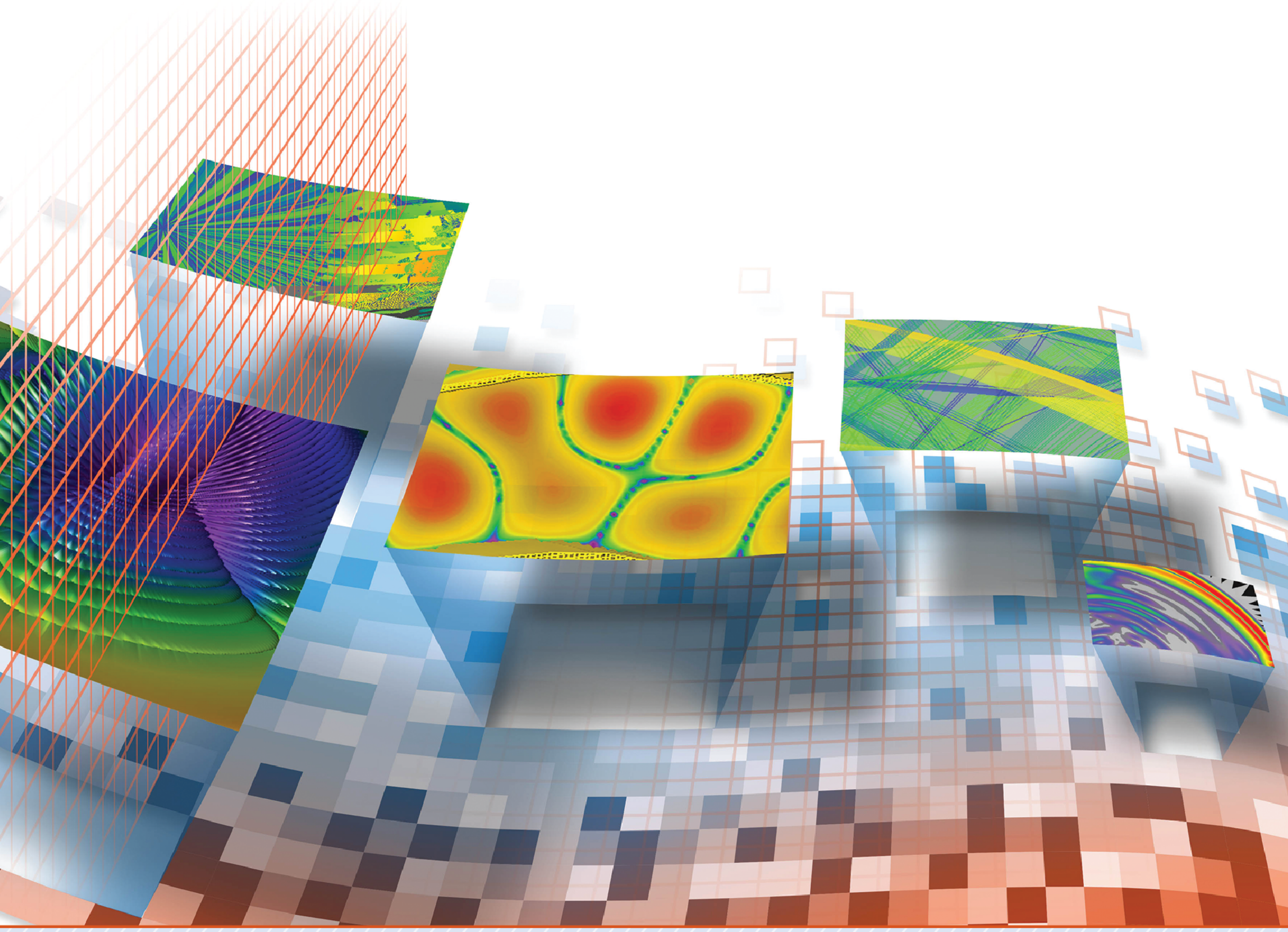
# XGTD

General Purpose, Ray-Based
Electromagnetic Analysis Software

**REFERENCE MANUAL**



REMCOM®
*Electromagnetic Simulation Solutions*

# XGtd® Reference Manual

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Remcom Inc.
315 S. Allen St., Suite 416
State College, PA 16801

+1.888.7.REMCOM
+1.814.861.1299
+1.814.861.1308 *fax*
+1.888.9.REMCOM *fax*
**www.remcom.com**

# Contents

# Chapter 1

# Introduction to XGtd®

*In this chapter, you will learn...*

- → the main purpose of and flow of operations within XGtd
- → common formats, keywords and symbols used in this manual

## 1.1 XGtd Summary

XGtd is a general purpose ray-based electromagnetic analysis tool. Its capabilities include modeling propagation in the vicinity of complex objects (aircraft, vehicles, anechoic chambers, etc.), performing antenna placement analysis, and determining the effects of objects on an antennas' far zone pattern. XGtd predicts how the locations of the transmitters and receivers interact with general geometry to calculate the signal strength and far zone antenna gain. Far zone radar cross section (RCS) can be calculated for plane waves incident on the geometry, and co- and cross-polarized components can be observed with respect to frequency or bistatic scattering angle. XGtd models the physical characteristics of objects and anechoic chambers, performs the electromagnetic calculations, and then evaluates the signal propagation characteristics.

XGtd provides useful editing tools for creating feature geometry. It is also possible to import geometry from a number of popular file formats, such as `DXF`, `SAT`, and `STL`.

Transmitter and receiver locations can be specified using XGtd's powerful site-defining tools, or imported from an external data file. Separate calculations for portions of the overall area may be specified by defining study areas.

The calculations are made by shooting rays from the transmitters and propagating them through the defined geometry. These rays interact with geometrical features and make their way to receiver locations. Ray interactions include *reflections* from feature faces, *diffractions* around feature edges, and *transmissions* through features faces. XGtd's ray-based solvers use the Uniform Theory of Diffraction (UTD) to evaluate a ray path's electric field. UTD provides accurate results when the scenario geometry is large compared to the wavelength of the propagating wave. For typical applications, the UTD-based models provide accurate predictions from approximately 100 MHz to approximately 100 GHz. The X3D propagation model includes atmospheric absorption, extending the validity of its wave propagation calculations up to millimeter wave frequencies.

At each receiver location, contributions from arriving ray paths are combined and evaluated to determine predicted quantities such as electric and magnetic field strength, received power, interference measures, path loss, delay spread, direction of arrival, impulse response, electric field vs. time, electric field vs. frequency, and power delay profile.

XGtd presents results in a number of ways. It provides visual representation of some results, such as transmitter coverage areas and power distributions, placing these visually within the modeled environment. XGtd is also capable of playing movies of time-domain E-field and H-field evolution. For other types of data, XGtd provides an advanced plotting system. Overlays of data allow quick comparison to imported measurements, or even previous XGtd calculations. All output files produced by XGtd are in a readable ASCII format.

## 1.2 Remcom Discussion Forum

Remcom's Discussion Forum allows you to engage with other EM Simulation professionals and Remcom's own experts. You may view discussions as a guest, or join the community to participate and post your own comments. Registration is fast and free!

The Discussion Forum is a great place to start when you need answers or want to get opinions from other Remcom software users; however, please note that it is not a substitute for Remcom Professional Support (RPS). To receive all the benefits of RPS, including free upgrades to the latest versions of Remcom's products, telephone support, and access to the support portal, you must have a current RPS contract.

To create an account in the forum:

1. Go to `http://www.remcom.biz/forum`
2. Click the "Register" tab in the upper right corner of your browser window.
3. After entering the required information, be sure to click the Agreement box underneath the terms of use.
4. Click the Complete Registration button.

## 1.3 How to Read This Manual

After installing XGtd, reading the overview (Chapter 2), and working through the tutorials in the XGtd User's Guide, new users of XGtd will find the organization of the software intuitive and will quickly be able to set up projects, run calculations, and view the propagation predictions.

In this manual, the reader will find the text formatted according to the following:

- (icon)XGtd Windows, such as Main Window, Project View, etc.
- (icon)Main Window Elements, such as Antennas, Transmitters, etc.
- (icon)*Types* of Main Window Elements, such as *Route* Transmitters, *Horn* Antennas, etc.

- *Menu Options*
- BUTTONS
- $\boxed{\text{KEYBOARD INSTRUCTIONS}}$
- `File Names`

A succession of menu selections will be separated by the → symbol. For example, *Project→Open→Feature→Object* would be the succession of menu choices to open a file containing object data.

The instruction to "click" will always mean to click with the left mouse button and release. A few operations require the left mouse button to be held down, and the instruction in these cases will be to "click and hold". When it is necessary to click with the right mouse button, the instruction will be to "right-click". This action in most cases will generate what is referred to as a "context menu" throughout the manual.

All values in this manual will be in the following units:

- angles in degrees
- lengths in meters
- E-field magnitude in V/m
- H-field magnitude in amps/m
- frequency in MHz
- power in dBm
- power density in mW/$m^2$
- path loss in dB
- time in seconds

We have also incorporated several key icons in the manual to help organize the material and make it as easy to read as possible.

→ At the beginning of each chapter, there is a summarized list of topics you will find within. This symbol marks each topic.

▶ Wherever there is a reference to another section with additional information on the topic being discussed, this symbol will lead you there.

✓ This symbol marks a "smart tip", which offers a helpful way to think about a topic or complete a task.

There are times when the user must be careful to remember something or especially cautious. This symbol will warn you to pay attention!

## 1.4 Special Directories

The following directories are specified in this manual using a placeholder name. This is due to the fact that these locations can be changed as a part of the installation process and can vary depending on the version of the operating system you are using.

`install_location\` This is the location that the installer will place XGtd. By default this will be c:\Program Files\Remcom\XGtd 3.1.2 .

`examples_location\` The example files are available as a separate zip file that can be extracted to any location.

# Chapter 2

# Overview

*In this chapter, you will learn...*

→ the main windows and menus available in XGtd

→ how to set up a project, run calculations, and view results

→ how to adjust viewing and calculation preferences

In order to begin using XGtd, it is important to understand the organization of the graphical user interface (GUI) and the elements that comprise an XGtd project. This chapter begins with a description of the primary XGtd windows. Following this is a description of the context menus within XGtd and instructions on accessing these menus. The chapter concludes with an overview of the menus and procedures used in setting up an XGtd project, running calculations and viewing results.

## 2.1 XGtd Windows

The primary XGtd windows are the MAIN WINDOW, the PROJECT HIERARCHY, the PROJECT VIEW, the CALCULATION LOG, and the MOVIE PLAYER.

### 2.1.1 Main Window

The MAIN WINDOW, shown in Figure 2.1, is titled “XGtd” when you first start the application. Once a project is loaded, the title changes to the name of the project. The Main Window is the parent window of the application.

Closing the MAIN WINDOW will close down the application. All other windows can be closed independently of one another.

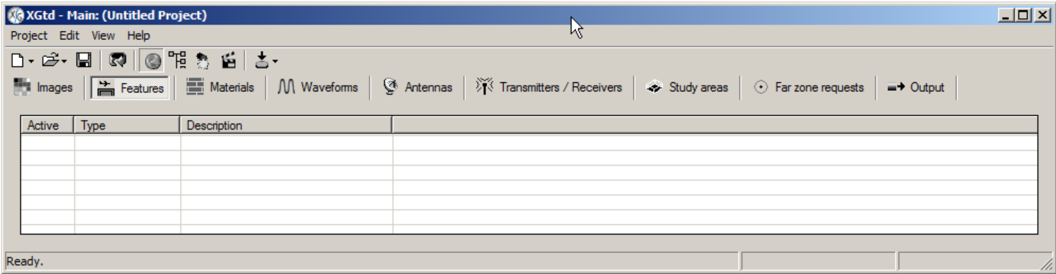


Figure 2.1: The Main Window

Once a project is loaded, the row of tabs below the toolbar allow the user to quickly view important project data. Much of this data is displayed in tabulated form. Other tabs use a hierarchal organization scheme. Right-clicking on any entry on a table opens a context menu. The complete editing options and properties for the selected entry are accessible from this menu.

Depending on the size of the MAIN WINDOW, some tabs may not be visible. When this is the case, you will notice two arrows ( ) to the right or left. These arrows can be used to scroll to the right or left along the row of tabs. It is usually possible to resize the window so that all the tabs are visible. All of XGtd's primary windows can be resized and the new sizes will be saved and used at restart.

Each tab controls an important element of an XGtd project, as described in the following sections.

### IMAGES

This tab is a list of all the `*.jpeg` and `*.tiff` images included in the project.

- See Section 2.7 for more information on images.

### FEATURES

A FEATURE comprises all of the geometrical *Chamber* or *Object* data. Each feature is subdivided into structure-groups, structures, substructures and faces. Features also contain data on the material properties of each face. The set of material properties are referred to collectively as "material types", and the properties and editing options for these are best accessed from the PROJECT HIERARCHY.

- See Chapter 3 for more information on features.

### MATERIALS

The electromagnetic interactions of each face are determined by the properties of the MATERIALS assigned to the face. The display properties, such as the color and thickness, are also part of the material definition. The *Material filter* is used to filter the display of materials in the project's material table and the material database table. The filter is not case sensitive. Exact expressions can be entered in quotation marks, and exclusion terms preceded by a minus sign (-) to further refine the filtering. For example, the filter text "dielectric" will show only dielectric materials, while the addition of the term "-concrete" will eliminate those dielectric materials which include concrete in their description.

▶ See Chapter 5 for more information on materials.

## WAVEFORMS

WAVEFORMS describe the signal radiated from transmitter ANTENNAS and act as a kind of bandpass filter at the RECEIVER. XGtd contains several built-in waveform definitions, the shape of which can be modified by providing carrier frequency and signal duration. All active and inactive waveforms associated with the XGtd project are listed under this tab. Waveforms are assigned to both TRANSMITTERS and RECEIVERS.

✓ The *Waveform filter* field follows the same format as the filter in the MATERIALS tab.

▶ See Chapter 6 for more information on waveforms.

## ANTENNAS

To perform propagation calculations using XGtd, the model requires both TRANSMITTERS and RECEIVERS, each with an associated WAVEFORM and ANTENNA. When an antenna is added to a project and its parameters are set using the ANTENNA PROPERTIES Window, it can be used in multiple instances by associating it with any number of transmitters and/or receivers. The location and position of the antenna will be set by the location and position of the associated transmitter or receiver for each new instance of the antenna. Any number of antennas can be added to the project to simulate real-world scenarios or to test the effects different antennas have on propagation performance.

✓ The *Antenna filter* field follows the same format as the filter in the MATERIALS tab.

The antennas used in a simulation can be generated from the following:

- Built-in models for various common antennas including *Dipoles*, *Monopoles*, *Helical*, pyramidal *Horn*, *Rectangular Aperture*, *Rectangular Patch*, and *Parabolic Reflector*
- Synthesized patterns defined by several beam parameters
- Imported patterns from several antenna pattern data standards, including *NSMA* and *Planet*

▶ See Chapter 7 for more information on antennas.

## TRANSMITTERS / RECEIVERS

TRANSMITTER RECEIVER and TRANSCEIVER locations and properties are defined in XGtd by means of transmitter, receiver or transceiver sets, which contain one or more location point, an ANTENNA type and orientation, WAVEFORM and other parameters, depending on what type of set it is.

▶ See Chapter 8 for more information on transmitters.

## STUDY AREAS

This tab lists all STUDY AREAS in the project. Study areas serve several purposes.

- They are used to select a region within the project that limits the space in which the calculation engine will find ray-paths. Only geometry within the study areas boundary will interact with the ray-casting, so the primary purpose of manually editing the study area boundary is to significantly decrease the runtime of the calculation for scenes with high face counts. Results will only be generated for transmitter and receiver points that lie within the region.
- As an organizational tool, they make it possible to keep predictions made with different parameters separate from each other. The user can create as many study areas as desired.

✓ Use *Duplicate* in the study area context menu to quickly create modified versions of a model.

▶ See Chapter 9 for more information on study areas.

**OUTPUT**

With this tab the user can access a hierarchical tree view of all currently available OUTPUT, including graphs. The output data is organized by STUDY AREA.

▶ See Chapter 11 for more information on output.

### 2.1.2 Project View

The PROJECT VIEW displays all the currently loaded data. After the calculations are complete, it is also possible to display most of XGtd's propagation predictions, as shown in Figure 2.2.

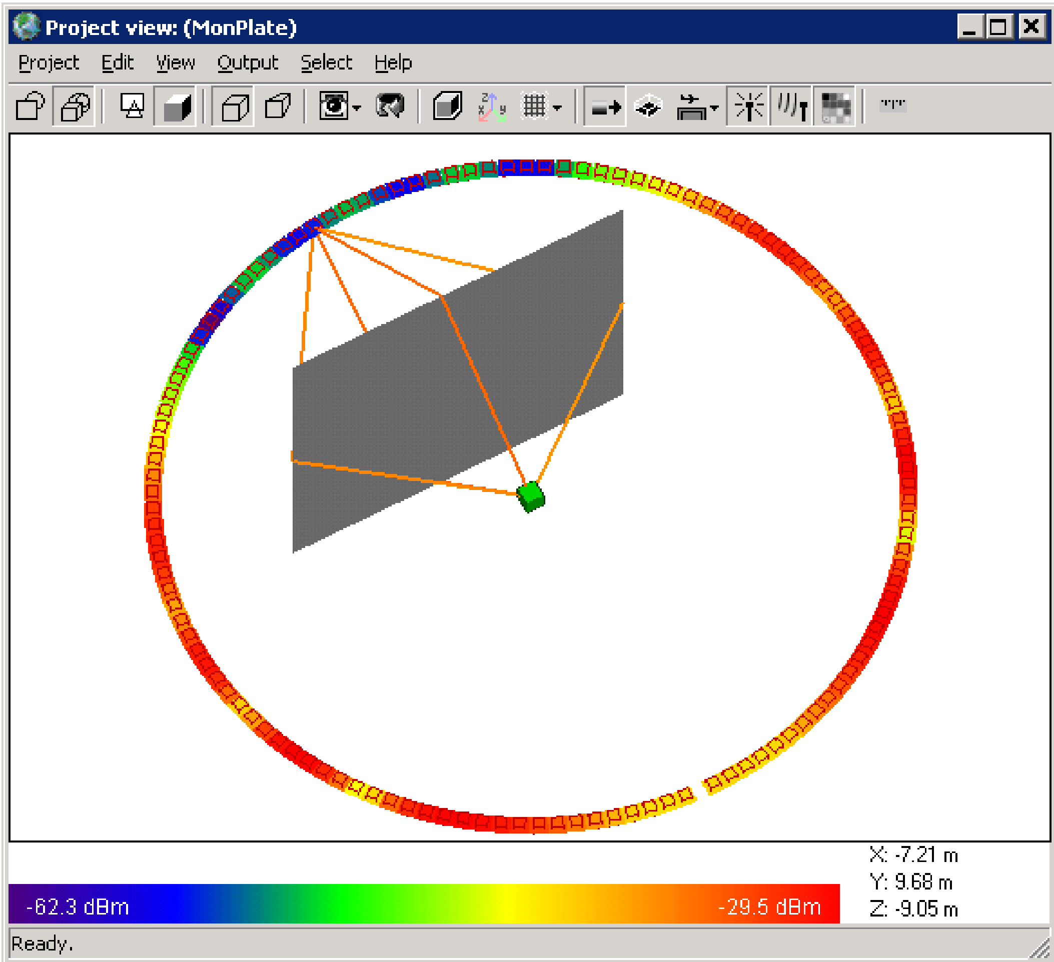


Figure 2.2: The Project View

▸ See Section 12.1 for more information on viewing OUTPUT in the Project View.

### The Menu Bar

The following menus can be found on PROJECT VIEW menu bar:

- *Project* - The options listed here are identical to those found in the MAIN WINDOW's Project menu. In addition to standard Windows menu items, the following options are available:
  - *Explore Project Directory* - Opens a separate explorer window, allowing the user to navigate through the project directory.
  - *Statistics* - Opens a window with statistics about the current project.
  - *Output properties* - Opens a window displaying output properties of the current project.

    - ▶ A detailed description of the Output Properties Window can be found in Section 11.4.

  - *Properties* - Opens a window displaying properties of the current project.

- *Edit* - Selected objects in the PROJECT VIEW can be removed from the project. The PREFERENCES Window is also accessible under this menu.

  - ▶ See Section 2.6 for more on the PREFERENCES Window.

- *View* - Many of view controls are toggle switches, with a check mark indicating an active status. Several of these options can also be accessed from the toolbar of the PROJECT VIEW.

  - *Import* - Reads in settings for a view of the project from a file.
  - *Save* - Saves the current view to the project.
  - *Save as TIFF* - Exports the PROJECT VIEW to a `*.tiff` file.
  - *Save as JPEG* - Exports the PROJECT VIEW to a `*.jpeg` file.
  - *Orthographic / Perspective*, *2D / 3D*, *Wireframe / Solid-body* - See the **Viewing Modes** section below.
  - *Hi-lites* - See the **Toggle Buttons** section below.
  - *Face normals* - Toggles the display of vectors normal to the faces which compose the FEATURES. The green arrow is the outward pointing normal and the red arrow is the inward pointing normal.
  - *Descriptions* - Toggles the display of the short descriptions for all visible TRANSMITTER and RECEIVER sets in the project.
  - *Global Origin*, *Grid* - See the **Toggle Buttons** section below.
  - *Legend* - Displays a list of the materials used by FEATURES in the project and the current grid spacing on the right hand side of the PROJECT VIEW. Users can access the properties for both by clicking on the square of color next to each entry.
  - *Reset*/*Refresh* - See the **Reset**/**Refresh** section below.
  - *Study areas, Anechoic Chambers, Objects, Receivers, Transceivers, Transmitters, and Images* - Toggles the display of each of these objects.

- *Output*

  - *View* - Toggles the display of OUTPUT data in the drawing area.
  - *Clear all output (no render)* - Eliminates the display of OUTPUT.
  - *Flush output (unload)* - Clears OUTPUT data currently loaded in memory.
  - *Reload output* - Replaces currently loaded OUTPUT data with data in the data files.

- *Select* - In order to select an object, it is first necessary to open the *Select* menu and specify its type. Click on the object to select it, and right-click in the PROJECT VIEW to access its context menu. To select multiple objects, press and hold CTRL and click on each object. To remove an object from the group of selected items, press and hold SHIFT and click on the object. To deselect all currently selected objects, click on *Select*→*Clear*. This also clears the selection type.

The *Select* menu contains the following options:

– *Clear* - Clears all current selections and also clears the current selection type.

– *Center on Selection* - Toggles the automatic centering of an item in the project view when it is selected.

– *Tx/Rx Set* - Allows the selection of an entire TRANSMITTER RECEIVER or TRANSCEIVER set.

– *Tx/Rx Point* - Allows the selection of an individual TRANSMITTER RECEIVER or TRANSCEIVER point.

– *Tx/Rx Point Pair* - Allows the selection of a pair of TRANSMITTER RECEIVER or TRANSCEIVER points. This is used primarily when viewing propagation paths between a transmitter and receiver or properties of the path. When selecting a new pair, it is only necessary to click on what is changing. For example, to change the receiver while keeping the transmitter, click only on the new receiver point. It can also be used to align boresites of two antennas.

– *Feature, Structure-group, Structure, Sub-structure, and Face* - Sets these respective types.

✓ It may be difficult to select an object in WIREFRAME mode. Try switching to SOLID BODY mode and try again.

✓ It may be difficult to select *Objects*, TRANSMITTERS or RECEIVERS which are on top of an object. If this happens, try turning off the display of the *object* (*View*→*Objects*) and selecting the object again. It may also be necessary to turn off the *Chamber* (*View*→ *Anechoic Chambers*) when selecting a transmitter or receiver which is adjacent to it.

✓ *Center on Selection* also applies when selecting items in the MAIN WINDOW and PROJECT HIERARCHY. If you lose track of the last item that was selected you can recenter it using *Center in* PROJECT VIEW from its context menu.

### Viewing Modes

Several viewing modes are available:

- WIREFRAME, in 2D or 3D
- SOLID BODY, in 2D or 3D
- ORTHOGRAPHIC, in 3D
- PERSPECTIVE, in 3D

The user has full control over zooming, rotating and panning in all viewing modes. When WIREFRAMEis active selected items will still appear in SOLID BODY. This allows the users to see more easily identify and view the selected item while still being able to visualize its surroundings.

### Reset/Refresh

RESET changes the perspective of the PROJECT VIEW to the option selected. The default perspective is to look straight down on the project, filling the entire window, with the $X$-axis pointing to the right and the $Y$-axis pointing north. Refresh forces a redraw of the Project View.

If *Current Selection* is selected from the menu the Project View will snap to the center of the bounding box of the selected item while maintaining the current rotation and zoom level.

### Toggle Buttons

The toggle buttons control the following:

- Highlights - Toggles a wireframe around each face. This is only available in the Solid Body viewing mode. Normally the edge color is based on the material of the face. If a Feature has been configured to show smooth edges, then the currently set smooth edge color will be used for edges that meet the criteria.
  - See Section 3.2.6 for more information about smooth edges.
- Global Origin - Toggles the visibility of the projects' global origin.
- Grid - Accesses display settings of a reference grid in the $XY$ plane. Every tenth grid line is highlighted to aid in visualization, and the global $X$- and $Y$-axes are displayed as dashed lines. From the Grid Properties Window, seen in Figure 2.3, it is possible to toggle the grid display, change the spacing and set the grid elevation. Setting the *Elevation* to **Automatic** will draw the grid at the minimum elevation of the project.

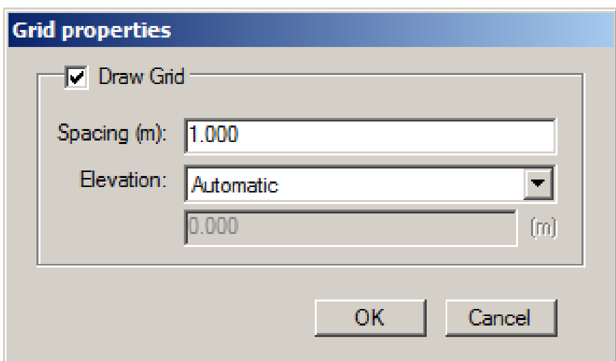


Figure 2.3: The Grid Properties Window

- Drawing Output - Toggles the display of Output data in the drawing area.
- Study Area - Toggles the display of the Study Area boundary.
- Features - Toggles the display of all Features.
- Transmitters - Toggles the display of the Transmitters.
- Receivers - Toggles the display of the Receivers.
- Images - Toggles the display of the Images overlaid on the project geometry.

### The Ruler

The RULER feature is used for measuring distances. Once the ruler is activated, clicking the mouse will place reference points in the PROJECT VIEW describing a route. Each segment of the route will have its distance displayed in the window. The status bar at the bottom of the window will provide more details about the route including the total distance of all segments and the bearing of the segment from the last point and the current mouse position. To clear the ruler, click the icon to clear the current route of points and start over, or right-click to deactivate it until it is needed again.

## 2.1.3 Project Hierarchy

XGtd's PROJECT HIERARCHY provides a convenient means to navigate within the input and output data of a project. If the Project Hierarchy is not visible, it can be toggled by clicking on *View→Project Hierarchy* from the menu bar of the MAIN WINDOW.

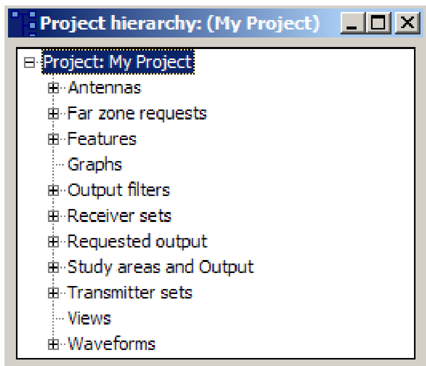


Figure 2.4: The Project Hierarchy Window

Each level in the hierarchy can be expanded to view the underlying levels, as shown in Figure 2.4. Absence of the expand sign indicates that the category is empty. The properties and editing options for most items are available in their context menus. The PROJECT HIERARCHY is especially useful for viewing and plotting OUTPUT.

- *Antennas* - Lists all ANTENNAS in the project.
- *Features* - Includes *Chambers*, and *Objects*. It expands to list the features' MATERIALS and structure groups. The structure groups can contain multiple structures, which can contain multiple sub-structures, etc. Typically all object faces are in the same substructure.
- *Images* - Lists all of the IMAGES in the project.
- *Graphs* - Lists all of the graphs in the project.
- *Receiver sets* - Lists all of the RECEIVER sets in the project.
- *Study Areas and Output* - Lists all of the STUDY AREAS in the project. Each study area can be expanded to display the available OUTPUT data.
- *Transmitter sets* - Lists all of the TRANSMITTER sets in the project.

- *Views* - Contains the views saved from the PROJECT VIEW. Selecting a view under this tab will return the orientation of the Project View to the saved settings. It is possible to modify, rename or delete a view from the context menu.
    - For more information on saving views in the PROJECT VIEW, see the entry under the *View* menu of Section 2.1.2.
- *Waveforms* - Lists all of the WAVEFORMS in the project.

### 2.1.4 Calculation Log

The CALCULATION LOG, as seen in Figure 2.5, is available by selecting *View→Calculation log* in the MAIN WINDOW. This window records all information generated while performing simulations, including the time and date the calculation starts and finishes. The information displayed in the Calculation Log can be cleared or saved by right-clicking in the window and selecting *Clear calculation log* or *Save log to text file* from the context menu.

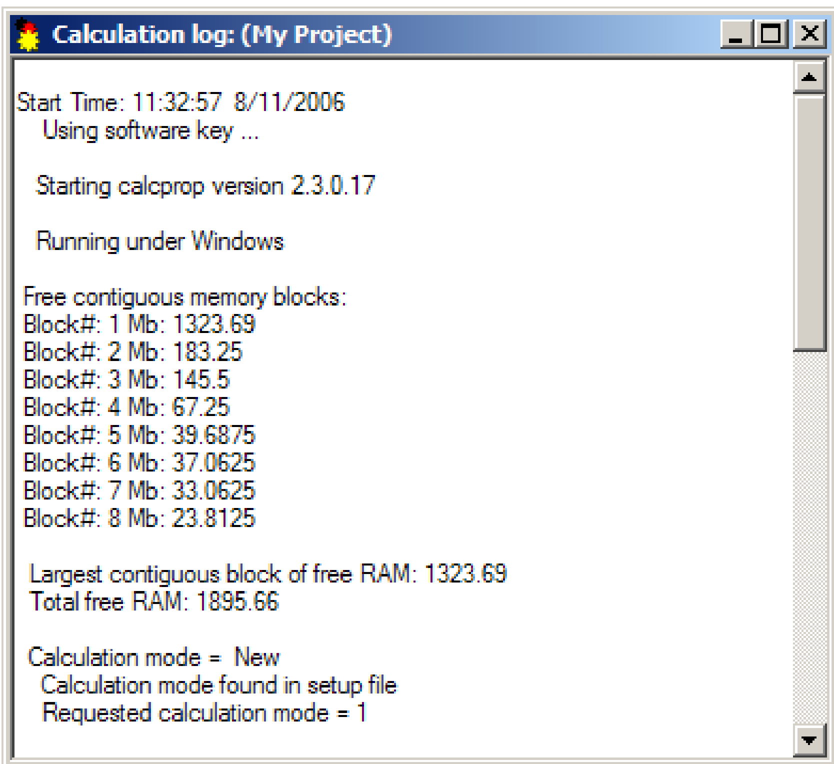


Figure 2.5: The Calculation Log Window

### 2.1.5 Movie Player

The MOVIE PLAYER provides a complete interface for selecting OUTPUT, choosing visualization options, and controlling playback of animated E-fields, H-fields and propagation path segments. The Movie Player is accessible by selecting *View*→*Movie Player*. While the Movie Player is open, all other windows are disabled except for the PROJECT VIEW, which permits changes to the viewing perspective (2D, 3D, WIREFRAME, SOLID BODY, etc.) while the movie plays.

- See Section 12.4 for more on the MOVIE PLAYER.

## 2.2 Context menus

Context menus are an important part of the XGtd GUI and contain entries specific to the selected entity. Right-clicking on an entry in one of the MAIN WINDOW tables or on an entry in the PROJECT HIERARCHY will open a context menu for that entry. Context menus can also be opened by selecting and right-clicking on an object in the PROJECT VIEW. Some of the options on the context menus are also available from the static menu bars.

- See Section 2.1.2 for more on how to select an item in the PROJECT VIEW.
- Some context menu options may be grayed out if multiple objects have been selected.

## 2.3 Setting Up a Project

### 2.3.1 Creating a New Project

MAIN WINDOW→*Project*→*New*→*Project*

Enter a short description and notes (optional) for the new project and press OK. The option to create a new project is also available from the context menu.

### 2.3.2 Opening an Existing Project

MAIN WINDOW→*Project*→*Open*→*Project*

Use this option to locate and load a previously created project `*.xgtd` file and open it. The five most recently opened projects can be more easily accessed through the menu under MAIN WINDOW→ *Project*→*Recent projects*.

When opening project files that were created previous to 2.7 you may need to reestablish links from the `*.xgtd` file to other supporting files within the project directory such as feature, transmitter and receiver files. If the current version does not support information in any of the files within the project, a warning message will appear detailing what information is not recognized. This will happen either because old information in the file is no longer valid, or you are opening a project file that was created with a newer version of XGtd that has newly added features with new values associated with them. Some elements are given defaults if there is a problem reading their type. These are:

**Antenna** - If it is referred to by a transceiver set the default ANTENNA configured in the application preferences will be used.

**Study Area Model** - Defaults to Full 3D.

**Waveform** - If it is referred to by a transceiver set the default WAVEFORM configured in the application preferences will be used.

### 2.3.3 Loading a Chamber File

MAIN WINDOW→*Project*→*Open*→*Feature*→*Anechoic chamber*

Once a project has been created, it is possible to load *Chamber* features from a data file. After navigating to the path above, locate the `*.cbr` file and open it.

### 2.3.4 Loading an Object File

MAIN WINDOW→*Project*→*Open*→*Feature*→*Object*

Once a project has been created, it is possible to load *Object* features from a data file. After navigating to the path above, locate the `*.object` file and open it. Object features may also be imported into XGtd from other formats, such as `*.dxf` files.

### 2.3.5 Creating a New Material

MAIN WINDOW→*Project*→*New*→*Material*

Select the type of MATERIAL to create, and define its parameters in the MATERIAL PROPERTIES Window.

### 2.3.6 Creating a New Waveform

MAIN WINDOW→*Project*→*New*→*Waveform*

Select the type of WAVEFORM and click OK. Define its parameters in the WAVEFORM PROPERTIES Window.

### 2.3.7 Creating a New Antenna

MAIN WINDOW→*Project*→*New*→*Antenna*

In the CREATE NEW ANTENNA Window, the ANTENNA type can be chosen from a list of XGtd's predefined antenna and supported file formats. Clicking OK will open the ANTENNA PROPERTIES Window where you can enter additional antenna characteristics.

### 2.3.8 Creating New Transmitter Sets

MAIN WINDOW→*Project*→*New*→*Transmitter set*

When creating a new TRANSMITTER set, the PROJECT VIEW will come to the foreground. The locations of the new set are defined by clicking the mouse on the drawing area. A right-click is used to exit this phase of the procedure. The TRANSMITTER/RECEIVER PROPERTIES Window will open to complete the definition of the new set.

One method of creating new TRANSMITTER locations is to create a new set of control points along a *Route*. The segments defined by the distance between each of these points represent the route along which equally spaced transmitter points will be placed. The spacing between points is specified using the properties window, which appears when you right-click after creating the control points. Points can also be placed within the bounds of such geometries as an *Arc*, an *XY Grid*, and a *Cylinder*.

If there are no ANTENNAS and/or WAVEFORMS in the project, a default will be added to the project upon creation of the first transmitter or receiver set. Their propertes are accessible from the sets' properties window by clicking the elipsis button next to the description.

### 2.3.9 Creating New Receiver Sets

MAIN WINDOW→*Project*→*New*→*Receiver sets*

See instructions for creating new transmitter sets above.

### 2.3.10 Creating a Far zone Output Request

MAIN WINDOW→*Project*→*New*→*Far zone request*→*Gain or RCS*

Far zone *Gain* and Radar Cross Section (*RCS*) OUTPUT can be generated by specifying one or more far zone requests of the desired type.

### 2.3.11 Importing an Object from a CAD File

MAIN WINDOW→*Project*→*Import*→*DXF* <or> *STL* <or> *Solid Model*

FEATURES may be imported from CAD files in `*.dxf` and `*.stl` formats as well as ACIS's `*.sat` format.

### 2.3.12 Importing Transmitter Sets from another Project

MAIN WINDOW→*Project*→*Import*→*Transmitter sets*

All TRANSMITTER set data in a project is saved to a file *ProjectName*`.tx`. Once a project is created or loaded, you can import transmitter sets from other projects into the new project.

### 2.3.13 Importing Receiver Sets from another Project

MAIN WINDOW→*Project*→*Import*→*Receiver sets*

All RECEIVER set data in a project is saved to a file *ProjectName*`.rx`. Once a project is created or loaded, you can import receiver sets from other projects into the new project.

### 2.3.14 Creating New Study Areas

MAIN WINDOW→*Project*→*New*→*Study area*

XGtd STUDY AREAS define the propagation model and its input parameters to be used during simulation, the geometric area of the simulation, and the requested output to be generated during the simulation.

XGtd STUDY AREAS make it possible to specify subsections of FEATURE data to be used in a calculation. FEATURES, RECEIVERS and TRANSMITTERS outside of the study area are not included in the computations. This allows XGtd to load a large set of features but restrict the calculations to a smaller subset, saving considerable calculation time.

The user has the option to automatically *Fit to features*, including the Tx/Rx locations, or to *Specify location and size* of the STUDY AREA manually. The latter option allows the user to click on points defining the perimeter of the area in the horizontal plane. Right-clicking will connect the last point to the first. The only restriction on the boundary is that sides are not allowed to cross. Finally, the user specifies the lower and upper height of the study area boundary.

Users can further edit the study area boundary, as well as the type of propagation model and the associated parameters, in the STUDY AREA PROPERTIES Window.

- See Section 9.2 for an explanation of the Study Area Properties Window.

### 2.3.15 Changing Transmitter and Receiver Set Properties

Select the set using the MAIN WINDOW, PROJECT VIEW or PROJECT HIERARCHY and then right-click and select *Properties*.

### 2.3.16 Changing Material Types

To change the properties of an existing MATERIAL, first expand the PROJECT HIERARCHY down to the entry for that material. The levels to expand are *Features*→*Chamber*→*Materials*. Right-click on the material type to be changed and select *Properties* from the context menu.

To change the MATERIAL assigned to a particular structure, first select the structure in the PROJECT VIEW or the PROJECT HIERARCHY, and then right-click and select *Change material*. Alternatively, one material can be substituted for another in a FEATURE through the REPLACE command. To do so, select a material which is currently in use, right-click, and choose *Replace*. In the window that appears, select a replacement material that is already in the project, or create a new material. All faces in the feature which were assigned the selected material will be changed to the new material.

✓ The *Replace* command is also available for ANTENNAS and WAVEFORMS, and allows their assignment to TRANSMITTER and RECEIVER sets to be changed quickly.

## 2.4 Running Calculations

After project parameters are completely defined, it is time to generate results. The *Run* menu is accessible from the MAIN WINDOW by clicking the RUN button, as seen in Figure 2.6, or navigating to *Project*→*Run*. Choose *New* from this menu to begin a new calculation, which will produce the results that are selected in each active STUDY AREA's *Requested Output* checklist.

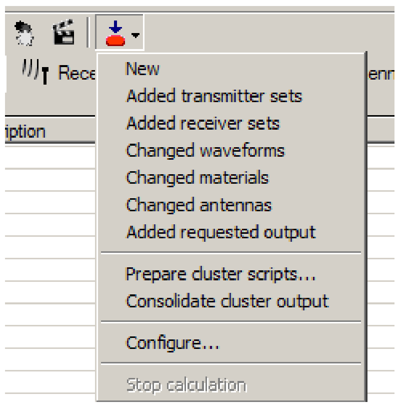


Figure 2.6: The Run Menu

The other RUN menu choices are used to generate a new set of predictions when using the FULL 3D model. These models have the ability to reuse ray paths that were calculated previously, thus saving computation time. For example, the *Changed materials* mode should be selected when different material properties are assigned to the face of a FEATURE. This mode recalculates the REQUESTED OUTPUT using the existing path database. The ability of XGtd to recalculate the propagation predictions using previously calculated ray paths is controlled by the following calculation mode options:

- *New* - Create an initial database of paths
- *Added transmitter sets* - Run after adding transmitter sets or making existing sets active
- *Added receiver sets* - Run after adding receiver sets or making existing sets active
- *Changed waveforms* - Run after changing center frequency or bandwidth of waveforms
- *Changed materials* - Run after changing a features' material properties
- *Changed antennas* - Run after changing any antenna-related parameters
- *Added requested output* - Run after adding new types of output

There is often a substantial savings in run time when recalculating results for additional TRANSMITTER sets. The project geometry and the RECEIVER locations must remain the same to make use of this capability. To recalculate the paths in this instance, use *Added transmitter sets* mode. All the REQUESTED OUTPUT is then calculated automatically after the new paths are found.

RECEIVER and TRANSMITTER sets can be changed from inactive to active and the new rays calculated and added to the database of calculated ray paths. If the status of the Tx/Rx point set is later set back to inactive, the ray paths for that site will remain in the database. Additional receiver and transmitter sets can be added to the project at any time; however, it is not possible to delete sets selectively from the database. Deleting a set requires deleting the entire existing path database and making a new XGtd calculation. If the number of points within each set or the spacing between the points is changed, a new XGtd calculation is required. Only the height, antenna parameters, and ray-tracing related parameters can be changed once a set has been added to the project and a calculation has been made.

The antenna type, antenna beam direction, and transmitted power also can be changed and propagation characteristics recalculated without repeating any ray tracing. This is done using the RUN option *Changed antennas*.

Once a calculation is started, you can exit XGtd without affecting the calculation process. It is also possible to stop the process by choosing *Stop calculation* in the RUN menu. This option can leave incomplete and inaccurate files in the study area folder. If *Stop calculation* is chosen, the next run must be new to ensure the validity of the generated output.

- It is also possible to run a calculation engine from the DOS command line. The options required by the calculation engine to do this are described in Section 17.5.

## 2.5 Viewing Output

### 2.5.1 Selecting Output Data

Once the calculation finishes, all *Requested Output* is available for analysis. Output can be selected under OUTPUT in the MAIN WINDOW or by using the PROJECT HIERARCHY. The output is presented in a tree view, which can be expanded to show the different types of output generated by all completed calculations. The highest levels in the Output Tree are the STUDY AREAS. Each study area which is not empty can be expanded to show the different types of output.

XGtd's output is generated in two main output types: "point-to-multipoint" output and "point-to-point". For "point-to-multipoint" data, "point" refers to a single TRANSMITTER point and "multipoint" refers to all the points on a RECEIVER set. For "point-to-point" data, "point" refers to a single TRANSMITTER point and single RECEIVER point. When output of a particular type exists, sub-items appear below it. The output is organized according to transmitter set, point number, and receiver set. For example, there might be an entry under *Received Power* such as "(short description for transmitter set 3), point #1→(short description for receiver set 2)" for an output file that contains the values of that output type involving the first point in transmitter set 3 and all points in receiver set 2.

### 2.5.2 Creating Plots

To plot output, locate the entry in the output tree for the type of output of interest and select *Plot* from the context menu, as seen in Figure 2.7. This will open the CHOOSE PLOT Window. This window is used to specify properties of the plot specific to the output desired. In the case of a receiver set, for example, this window gives the user the option to plot the output as a function of distance or receiver number. If other graphs have been created, the user will be given the option of creating a new graph or adding the plot to an existing graph.

- See Section 12.2 for more on plotting output.

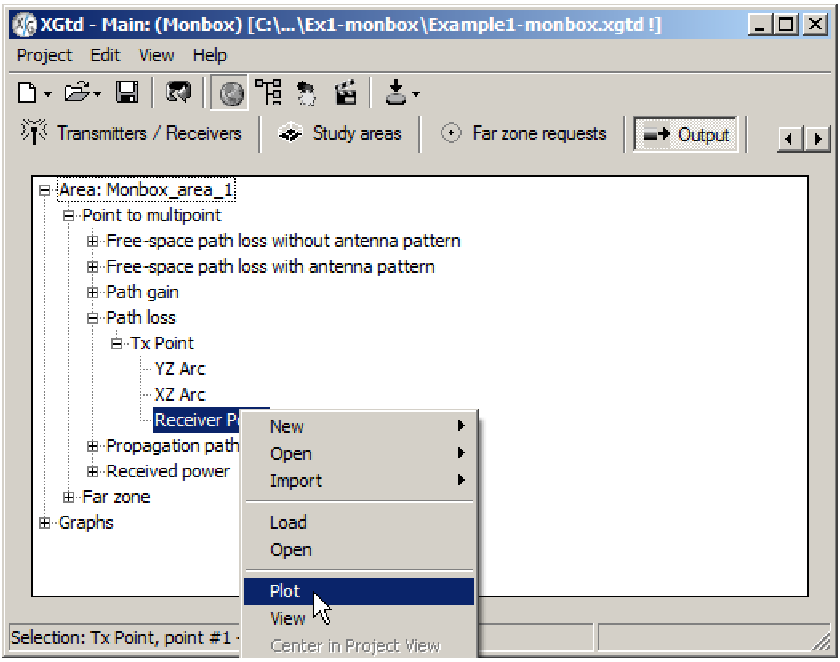


Figure 2.7: The context menu used to plot an output file

### 2.5.3 Displaying Output in Project View

To add a color-coded display of OUTPUT data to the PROJECT VIEW, select *View* from the context menu. A color-coded representation of the power will appear. The scale bar in the lower-left corner of the PROJECT VIEW shows the numerical values of the colors. To change the scale on the color bar:

1. Right-click anywhere on color bar.
2. Select *Scale limits*→*Manual* scaling.
3. Set *range* and click OK.

If more than one type of output is displayed, the color bar mode can be changed by right-clicking on the color bar. Select *Scale mode* and then choose the output type.

- See Section 12.1 for more information on viewing OUTPUT in the Project View.

### 2.5.4 Viewing Propagation Paths

The strongest propagation paths between a TRANSMITTER and RECEIVER can be displayed in the PROJECT VIEW. First, choose *Load* from the context menu for the particular receiver set of interest. This is done in the Output Tree under the Propagation paths entry, which has one sub-item for each output file that represents a particular Tx/Rx set combination. Once the data is loaded, expand the tree to view the individual receiver points in the set. To display the propagation paths to one of these points, right-click on the point, and choose *View* from the context menu.

To clear OUTPUT from the view, toggle the view action off by right-clicking on the viewed item. You will see a check mark next to *View* that can be turned off. You can clear all the viewed output by clicking *Output→Clear all output* on the PROJECT VIEW menu bar.

- See Section 12.1 for more information on viewing propagation paths.

## 2.6 Application Preferences

The overall appearance of XGtd can be customized in several ways. To customize these aspects, select *Edit→Preferences* in the MAIN WINDOW, which will bring up the window shown in Figure 2.8.

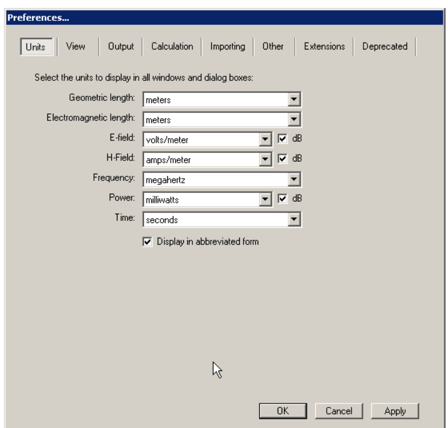


Figure 2.8: The Preferences Window

### 2.6.1 Units

Under this tab, the user can change the units of measure for all data displayed in XGtd. By checking the *Display in abbreviated form* option, units will be shown as an abbreviation (e.g. “m” instead of “meters”). All aspects of the application that involve the display of quantitative information will immediately update to reflect any changes made, including graphs that are currently open.

✓ The *Electromagnetic length* preference controls the units used to describe ANTENNA dimensions and MATERIAL thicknesses, and is separate from geometric lengths.

### 2.6.2 View

This group of settings, seen in Figure 2.9, controls certain aspects of the viewing windows within the application. There are several settings that can be adjusted:

- *Background Color* - This option will change the background color of all viewing windows. Any text in the viewing windows will be shown in a color that provides the best contrast to the newly selected color.
- *Grid Color* - This option will change the color of the grid lines in all editor windows.
- *Smooth Edge Color* - This option will change the color of edges in a feature that are seen as smooth edges by the calculation engine.
  - See Section 3.2.6 for more information about smooth edges.
- *Text Color* - This option controls the color of text within all of the viewing windows. It also controls the text of the Tx/Rx set descriptions that appear in the PROJECT VIEW.
- *Display bounding boxes during rotation* - When selected, the PROJECT VIEW will render the geometry while the user is performing any movement commands. Instead, a box will be rendered for every structure to indicate its maximum boundary and position. This option should be selected for large and/or complicated geometries to improve rendering performance.

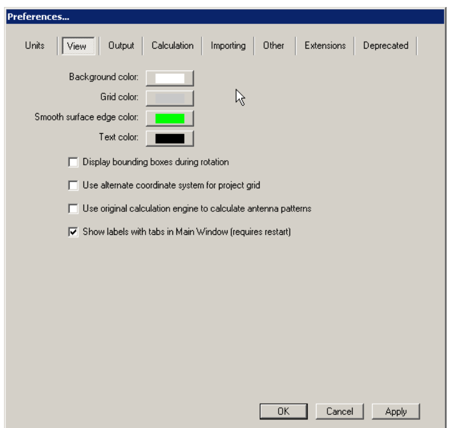


Figure 2.9: The View tab of the Preferences Window

### 2.6.3 Output

These settings set the DEFAULT OUTPUT REQUESTS for a project and control how output files are presented to the user in the Output Tree or under a STUDY AREA in the PROJECT HIERARCHY. Double clicking the DEFAULT OUTPUT REQUESTS button opens the REQUESTED OUTPUT CATEGORIES list. Before starting a project, select the desired outputs on this list. All STUDY AREAS in the project will default to this set of requested output. To modify the requests for specific study areas, see Section 11.5.

All of the possible sorting criterion are presented in the table, as shown in Figure 2.10. In addition, each level of the hierarchy can have its items sorted in *Ascending* or *Descending* order based on their short description (*Alphabetical*) or the order of the objects as they appear in their respective tabs in the MAIN WINDOW (*Project order*).

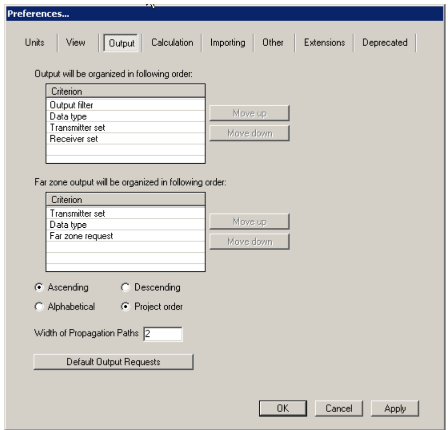


Figure 2.10: The Output tab of the Preferences Window

To change the sorting order, select the criterion in the table and click on the MOVE UP or MOVE DOWN buttons to move them within the table.

- *Width of Propagation Paths* - Controls the width of propagation paths when they are rendered in the PROJECT VIEW.

### 2.6.4 Calculation

XGtd has the ability to make use of multi-core processors and can run multiple instances of the FULL 3D model in parallel for projects that contain multiple TRANSMITTER points or RECEIVER sets. When a new run is initiated by selecting RUN→*New* from the menu, the user interface will initiate multiple calculations based on the settings listed in Calculation tab, as seen in Figure 2.11.

- *Multi-thread mode* - This controls if the calculation is distributed by TRANSMITTER points or RECEIVER sets. For majority of projects with multiple TRANSMITTER points, using the TRANSMITTER option will result in the greatest decrease in calculation time. The RECEIVER set option will only result in faster run times when the time to evaluate the output at the RECEIVER locations greatly exceeds the ray tracing portion of the calculation.
- *Maximum concurrent jobs* - This controls how many processes can run at the same time. This number should not be set above the amount of processors that are on the PC running the simulation, as there is no advantage to be gained beyond this point.
- *Priority* - This sets the priority of the processes. It allows the user to prevent calculations from interfering with other processes that have more immediate priority or allows the calculation to use more resources to complete faster.

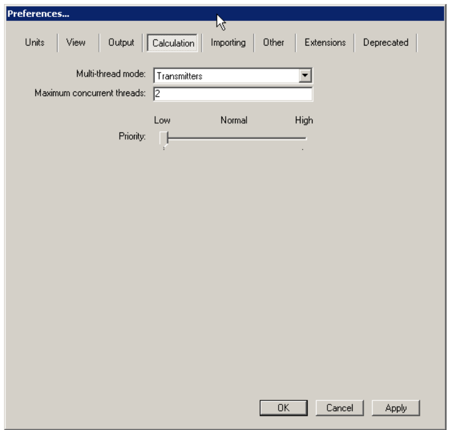


Figure 2.11: The Calculation tab of the Preferences Window

### 2.6.5 Other

This tab, seen in Figure 2.12, contains the following preferences:

- *Default transmitter/receiver height* - New transmitter or receiver points will be initially set to this height.
- *Arrange Main Window tables side-by-side* - Some of the tabs in the MAIN WINDOW contain more than one table, such as the database tables for antennas, materials and waveforms. By setting these tables to be side-by-side as opposed above/below each other, the user can show more entries (with less detail).
- *Reactivate hidden messages* - Various message boxes appear throughout the application and contain helpful information about the particular action being performed. Some of these messages can be hidden once the user becomes familiar with the application in order to allow work to be performed without interruption. This button will reactivate all of these messages so that they will appear the next time the action they are related to is performed.
- *Default antenna and waveform* - If an antenna or waveform is required to complete an action and none currently exist in the project, these preconfigured options are automatically added and used for the current operation. When this happens, the user is informed by a pop-up message. A default antenna is specified for both surface mounted and regular transmitter/receiver sets separately.

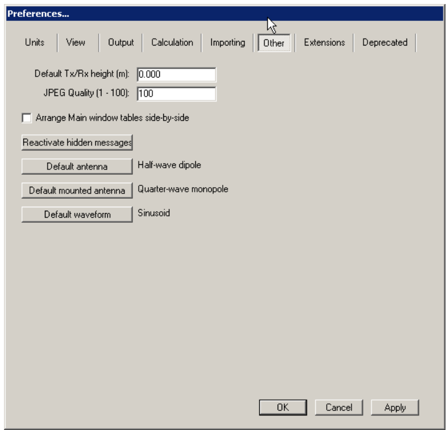


Figure 2.12: The Other tab of the Preferences Window

## 2.7 Images

Overlay of the imported image files in the PROJECT VIEW can be performed by selecting *Project*→ *Open*→*Image*. The position of the image and the distance per pixel of the image is controlled in the IMAGE PROPERTIES Window. The default settings will result in the image fit to the FEATURES as well as the TRANSMITTER and RECEIVER sets in the project. Cropping the image is also possible by checking the *Crop image* option when the image is loaded. The IMAGES tab in the MAIN WINDOW lists all images that have been added to the project.

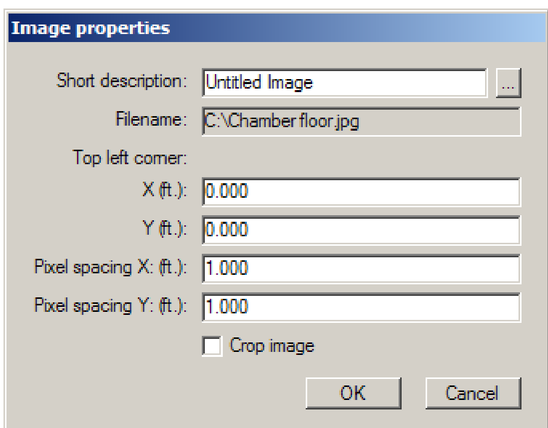


Figure 2.13: Adding an image to the project

## 2.8 Calculation Engine

The calculation engine for XGtd is called `calcgtd`. It is located beneath the bin directory of the XGtd installation path on Linux, or in `install_location`\\calc* by default in Windows. The calculation engine may be run from the command line.

- See Section 17.5 for more on calculation engine command line options.

# Chapter 3

# Features

*In this chapter, you will learn...*

- → how features are structured at the most basic level
- → the differences between objects and chambers
- → how to open a feature from COLLADA or KMZ files
- → the properties and operations of features

There are two main Feature types used in XGtd to define problem geometry: chambers (`*.cbr`) and objects (`*.object`). *Chambers* provide a way to represent anechoic chambers within XGtd, while *Objects* provide a more general framework for representing everything from airplanes to simple thin plates. This chapter describes each features' composition, properties, operations and file structure.

## 3.1 Hierarchical Organization of Feature Data

Features are essentially composed of planar polygons with three or more vertices, also known as "faces." The coordinates of the vertices are specified with respect to the same coordinate axes. The vertices on each face are defined in counter-clockwise order, with the outward normal given by the right-hand rule.

The Full 3D, propagation model makes a distinction between "one-sided" and "double-sided" faces. When faces are "one-sided," rays will only interact with the face when incident on the side with the outward normal, and they will not "see" the face from the "back" side. This means that in order to model a knife edge or a free-standing wall using these models, it is necessary to either place two facets back-to-back or specify that the facet is "double-sided." Each face is also assigned a Material. X3D lets rays hit either side of a face, ignoring the single-sided versus double-sided property of a face.

The geometric data is grouped in a hierarchy. Its levels, from lowest to highest, are described below.

- **Face** - An individual planar surface described by a set of coplanar points that form its perimeter.

- **SubStructure** - A collection of faces; each must share an edge with at least one other face.
- **Structure** - A collection of sub-structures; each must overlap with at least one other. If there is only one sub-structure in the structure, then no overlap with another sub-structure is necessary.
- **Structure-Group** - A collection of structures. Typically, the DXF importer will load each DXF layer into a separate structure-group.
- **Feature** - A collection of structure-groups, which together form a complex model.

Each level can contain multiple items of the level below it. For example, a sub-structure can have more than one face, a structure more than one sub-structure, etc. The main purpose of the intermediate levels is to make the selection of collections of faces more manageable. Figure 3.1 illustrates the hierarchal organization of geometrical data comprising each FEATURE.

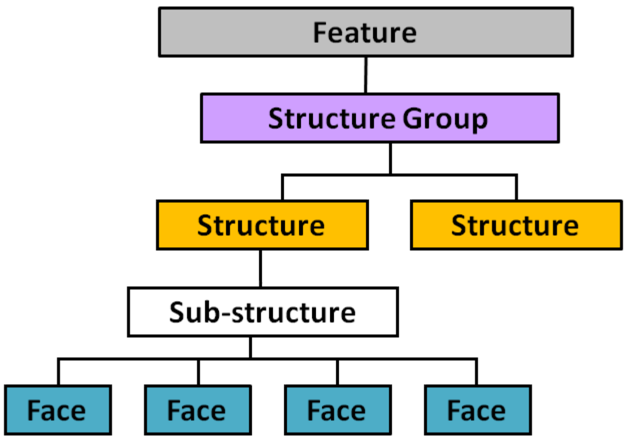


Figure 3.1: Typical organizational hierarchy of feature geometry

## 3.2 Objects

Excluding *Chambers*, all geometry in XGtd is represented using *Object* features. Object complexity can range from thin plates and simple cubes to aircraft models composed of thousands of faces.

### 3.2.1 Modeling Geometry in XGtd

Although XGtd is capable of loading complicated objects from `CAD` files, the geometry in these files is not always in an optimal format for analysis in XGtd. Ideally, objects such as aircraft and vehicles should be composed of a closed set of single-sided faces. Thin plates can also be modeled in XGtd, provided the faces are defined as double-sided. Each face in an object should intersect other faces along edges defined by points common to the adjoining faces. Below is a list of guidelines users should follow when creating and modifying geometry for analysis in XGtd.

### 3.2.2 Faces

☑ Faces are defined by three or more coplanar vertices, but should be composed of the minimum number of vertices needed to define the perimeter of the face. Adjacent collinear vertices should be avoided. The face on the left of Figure 3.2 provides an example of a poorly defined face with several collinear vertices. Ideally, this face should only be defined by four vertices, as shown on the right.

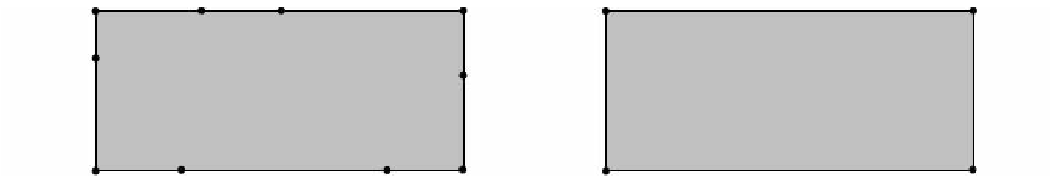

Figure 3.2: A face which has unnecessary vertices that should be removed

☑ Faces should not be self-intersecting. Improper ordering of the vertices can create self-intersecting faces, as shown in the left of Figure 3.3. It is important to monitor the order of the vertices to prevent self-intersecting faces in order to correctly orient the face normal.

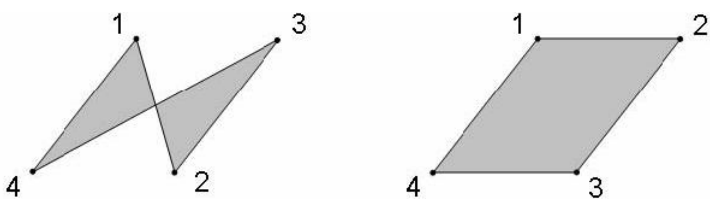


Figure 3.3: An example of a self-intersecting faces is shown on the left. The normal for the face on the left is pointing into the page.

☑ Coplanar faces should be combined in order to minimize the number of faces that compose an object and reduce the calculation time. Figure 3.4 shows a coplanar face made up of four faces on the left, and the optimal representation of the face on the right.

Figure 3.4: Combining coplanar faces

☑ Faces should not contain duplicate vertices.

☑ No overlapping faces

**Edges between faces**

☑ Intersections between faces should be identified by an edge common to all adjoining faces.

☑ All vertices along a shared edge should be present in the definition of the intersecting faces.

While violating these guidelines does not necessarily invalidate calculation results, proper geometry definition ensures all diffracting edges are found and ray paths are properly constructed. The following examples depict two common problems encountered when importing object geometry from CAD files.

Figure 3.5 depicts the intersection of a horizontal thin plate (blue) and a vertical thin plate (gray). The configuration on the left does not properly define the intersecting edge of the plate. The edge is not a common edge to both faces, and the vertices along the edge are not common to the intersecting faces. To properly define the intersecting edge, the gray plate needs to be broken up into several faces, as shown on the right. In this configuration, the edge is defined by a set of vertices common to all adjoining faces.

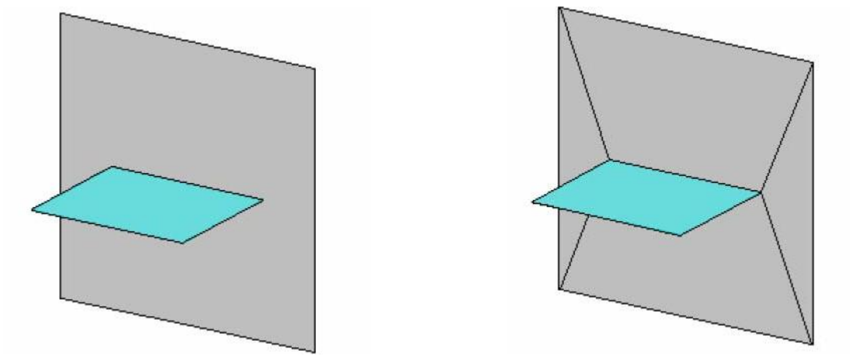

Figure 3.5: Example of intersecting faces

In Figure 3.6, the geometry on the left is constructed from stacked boxes and contains 12 faces. The light blue face represents an overlapping face with the top face of the lower box. The geometry on the right correctly indicates how this geometry should be defined. Note that it contains nine faces (the minimum number) and does not contain any faces that overlap.

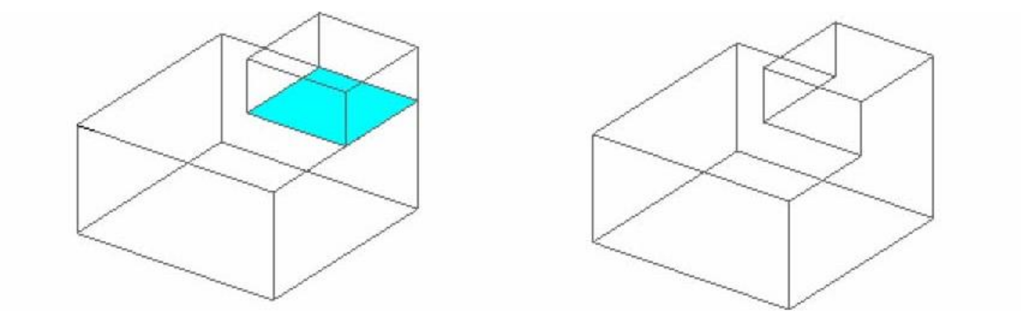

Figure 3.6: Example of overlapping faces

### 3.2.3 Object Editor

Basic *Objects* can be created in the OBJECT EDITOR by defining their cross-section in the horizontal plane, and then extruding the outline in the $Z$-direction. The top and bottom faces of the object are created as horizontal polygons, while the side faces are vertical rectangular faces.

The MATERIAL used for new components can be configured by the user. By default it is set to metal. Clicking on the button for each MATERIAL allows the user to either view the current material properties, or to replace the material with:

- A new material of a different type.
- A material in the material database.
- A material that is in another FEATURE within the project. If this option is used, then the feature currently being edited will make a copy of that material for its own use.

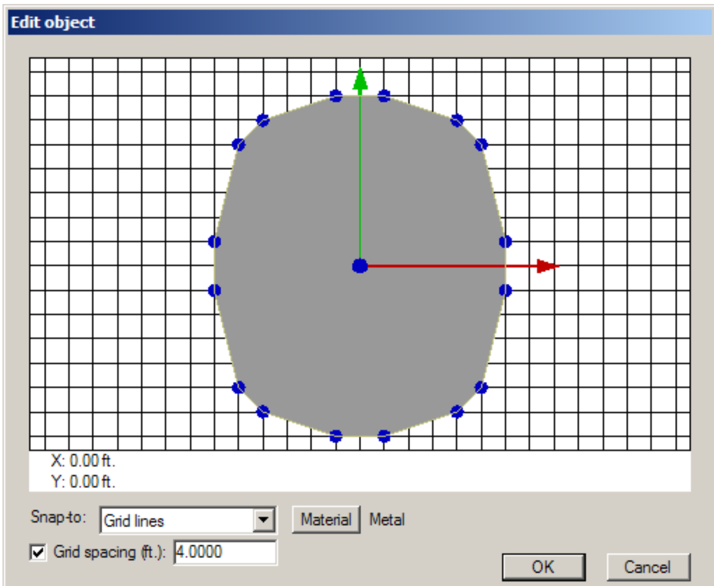


Figure 3.7: Creating an object in the Object Editor

To create a new *Object*:

1. Select *Project*→*New*→*Feature*→*Object*.
2. The *Grid spacing* and *Snap-to* modes can be adjusted as desired. The view in the CREATE CHAMBER Window can be adjusted using the zoom and pan controls.
3. Assign MATERIALS to the object using the MATERIAL button.
4. Right-click in the drawing area and select *New component*.
5. Click in the drawing area to define the vertex locations and right-click after placing the last point.
6. Enter a *Base height* and *Top height* to locate the bottom and top faces of the object. Click OK.
7. Click OK in the OBJECT EDITOR Window.
8. In the FEATURE PROPERTIES Window, enter a *Short description* to identify the object.
9. Check *Show origin when active* to display the local origin of the object in the PROJECT VIEW.
10. Click OK to finish the creation of the *Object*.

To create a **cylinder with a regular polygonal (triangle, square, pentagon, etc.) cross-section**:

1. Select *Project→New→Feature→Object*.
2. Right-click in the drawing area and select *Create regular polygon*.
3. Enter the number of sides on the polygon.
4. Define the polygon's radius or the length of each side. Click OK.
5. Enter a *Base height* and a *Top height* to set the heights of the lower and upper end caps of the extruded cylinder, or set the base height equal to the top height to create a thin plate. Click OK.
6. Click OK in the OBJECT EDITOR Window.
7. In the FEATURE PROPERTIES Window, enter a *Short description* to identify the object.
8. Check *Show origin when active* to display the local origin of the object in the PROJECT VIEW.
9. Click OK to finish the creation of the *Object*.

To create a **vertical thin plate**:

1. Select *Project→New→Feature→Object*.
2. Right-click in the drawing area and select *New component*.
3. Click in the drawing area to define the vertex locations. Right-click after placing the second point.
4. Enter a *Base height* and a *Top height* to locate lower and upper edges of the plate. Click OK.
5. Click OK in the OBJECT EDITOR Window.
6. In the FEATURE PROPERTIES Window, enter a *Short description* to identify the object.
7. Check *Show origin when active* to display the local origin of the object in the PROJECT VIEW.
8. Click OK to finish the creation of the *Object*.

To create a **horizontal thin plate**, define the vertices in the drawing area. Enter the same *Base height* and a *Top height* when prompted, and a horizontal thin plate will be created at the specified height.

#### 3.2.3.1 Editing Control Points

The control point of an object can be moved within the object while in the OBJECT EDITOR. From the editor context menu, enter the *Control point* sub-menu and select one of the following:

- *Enter new local coordinates* - Brings up the ADJUST CONTROL POINT Window. Enter the values to move the control point and click OK. The control point will then move within the object by the specified amount.
- *Move within object* - Performs the same operation as above, but allows the user to place the control point using the mouse.

▶ See Section 3.9 for more on control points.

### 3.2.4 Simplify Feature

The excessive detail sometimes included in DXF and SAT files can considerably increase computational time, and in some cases even produces less accurate results. XGtd contains an automated *Simplify Feature* operation capable of simplifying and cleaning up imported object files, and formatting them correctly for the propagation model.

To simplify a feature, in the MAIN WINDOW, right-click on an object and select *Pre-proecessing→ Simplify Feature*. A percent reduction factor can be entered in the upper left-hand corner of the window. To apply the simplification, click on UPDATE VIEW.

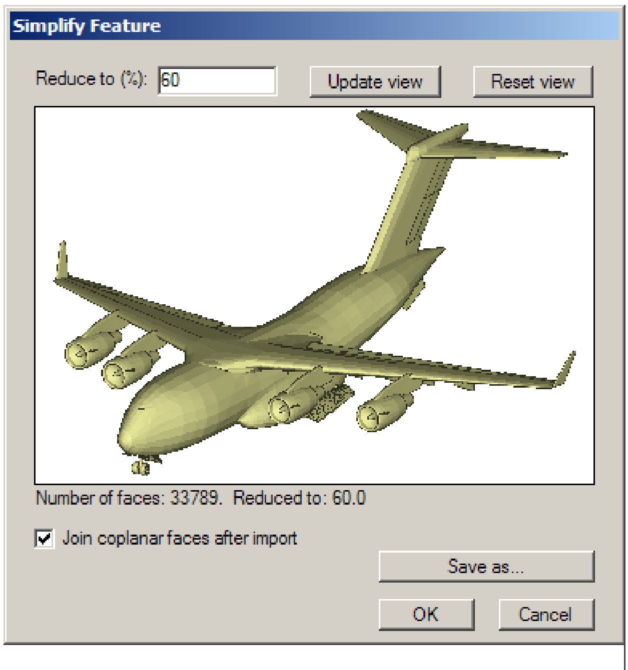


Figure 3.8: Simplifying the object

Finding the correct reduction can be a trial-and-error process. As a greater reduction is applied, detail in the *Object* begins to disappear. The optimal level or reduction occurs when the number of faces in the object is minimized, but the object retains all important details. Tail fins and wings are usually the first details to be removed when simplifying plane models.

It is important to use the *Join coplanar faces* option to increase accuracy and reduce runtime. This option iterates through the faces in the given geometry and joins all coplanar faces that have shared edges. This option can be done without simplification and is recommended after CAD import. Note that the join coplanar option may not function correctly on geometry that would make an invalid face. Such an example of this is pictured in Figure 3.9. This geometry cannot have coplanar faces joined because valid faces in XGtd cannot contain holes.

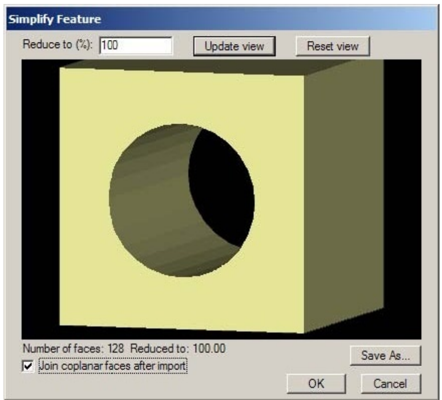


Figure 3.9: An example of geometry with a hole in the middle of an invalid face

### 3.2.5 Geometry Validation

If XGtd cannot properly calculate the normal of a face, it will be ignored. It is good practice to inspect invalid faces before the calculation by selecting *Pre-processing→Validate faces* from the context menu of a FEATURE. It is also possible to select, delete or edit a face from this window.

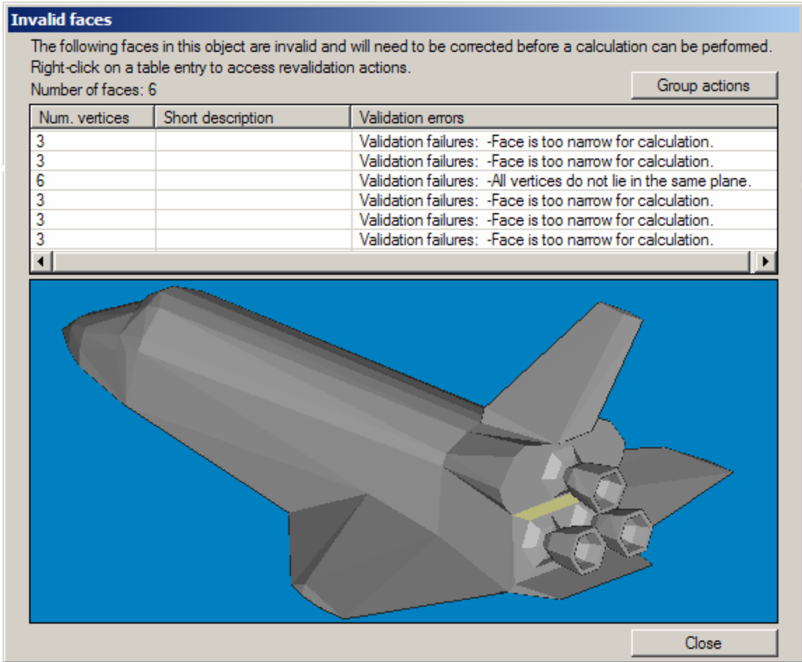


Figure 3.10: Rectifying invalid faces

### 3.2.6 Smooth Surface Edges

Although geometry in XGtd is represented as planar faces, XGtd has the ability to model radar cross section scattering and creeping wave diffraction for curved surfaces. When the angle between adjacent faces falls within the range specifed by the curved surface angle settings in the advanced STUDY AREA properties window, those faces are modeled as forming a smooth curved surface in the calculations. XGtd offers visual feedback in the PROJECT VIEW that will display face edges that meet the curved surface angle criteria in a user specified color to distinguish them edges the calculation will treat as wedges. This is done by associating the feature with a specific STUDY AREA in its properties window, as seen in Figure 3.13.

- See Section 2.6.2 for more on defining viewing preferences.

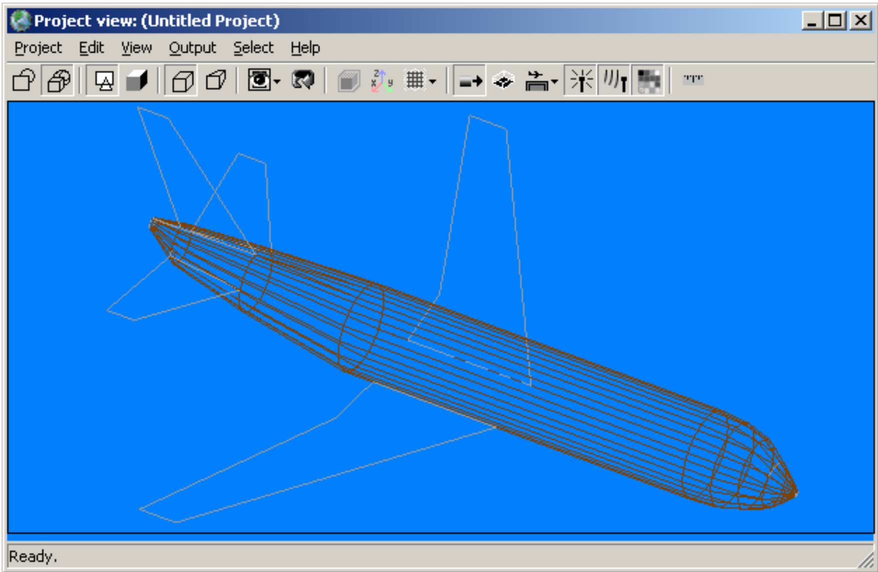


Figure 3.11: Displaying smooth edges in red

## 3.3 Chambers

Custom anechoic chamber layouts can be modeled in XGtd using the *Anechoic Chamber* feature type. Chambers allow users to define wall locations, wall heights, and the corresponding material properties. By default, chambers created within XGtd are composed of a set of single-sided inner and outer faces for easy viewing in the PROJECT VIEW. A chamber is created by defining the outline in the horizontal plane and then entering a *Base height* and *Top height* of the walls. The side walls of the chambers are all created as vertical rectangular faces. The floor and ceiling are defined as horizontal polygons.

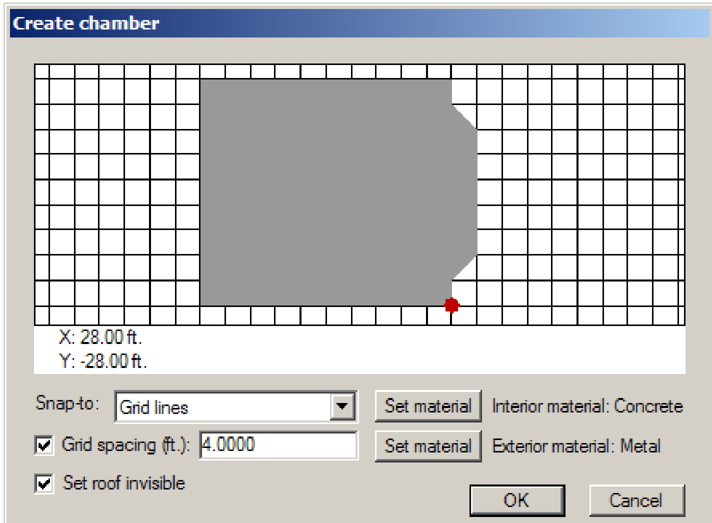


Figure 3.12: Creating a Chamber Feature

### 3.3.1 Chamber creation tool

*Anechoic Chamber* layouts can be created within XGtd using the chamber creation tool. The following steps illustrate the creation of a new chamber.

1. Select *Project→New→Feature→Anechoic chamber* to open the Create Chamber Window.
2. The *Grid spacing* and *Snap-to:* fields can be adjusted as desired. The view in the Create Chamber Window can be adjusted using the zoom and pan controls.
3. Assign Materials to the interior and exterior walls using the Set material buttons located at the bottom of the window.
4. Right-click in the drawing area and select *Create chamber*.
5. Click in the drawing area to define the vertex locations and right-click after placing the last point.
6. Enter a *Base height* and *Top height* to locate the floor and ceiling of the chamber and click OK.
7. Click OK in the Create Chamber Window.
8. In the Feature Properties Window, enter a *Short description* to identify the chamber.
9. Check *Show origin when active* to display the chamber's local origin in the Project View.
10. Click OK to finish the creation of the *Chamber*.

## 3.4 Opening COLLADA Files

Features can be opened from COLLADA files which can also be embedded in KMZ files.

To open a COLLADA (*.dae) or KMZ (*.kmz) file in an existing project, select *Project→Open→ Feature* and select the type of Feature to be opened. XGtd will prompt you for the file's location and attempt to open it.

✓ Only the first COLLADA asset is imported from a KMZ file. If you need to open multiple assets in this manner, each one will need to be contained in a separate *.kmz file and opened as a separate Feature.

A KMZ file exists for every **.object* and **.cbr* file. The file will contain the following files when uncompressed:

1. `doc.kml`
2. models/<kmz_filename>.dae - The COLLADA asset.
3. models/<kmz_filename>.shadow - A version of the asset that contains information about the materials used by the Feature that is required by the calculation models

## 3.5 Feature Properties

The FEATURE PROPERTIES Window, seen in Figure 3.13, displays the hierarchy of structure types and faces represented by the tag structure of the file. To access this window, right-click on the feature under the FEATURES tab in the MAIN WINDOW, and select *Properties*.

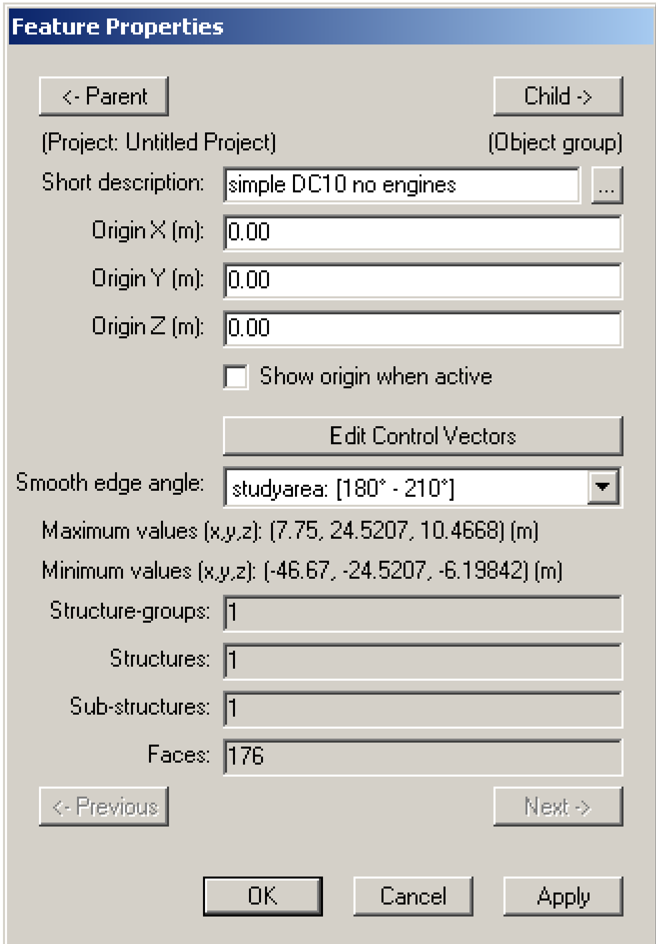


Figure 3.13: Properties window for a feature

Information used to generate the project statistics, as well as the short description and notes, are available from this window. The lower half of the window displays information about the region that the feature occupies and the number of sub-level structures. By using the buttons PARENT and CHILD, it is possible to browse the FEATURE HIERARCHY and PROJECT PROPERTIES which contain the feature. The PREVIOUS and NEXT buttons allow you to cycle through the features in the project, and when you are at a lower level you can cycle among the elements at that level as well. For example, clicking the CHILD button in this case shows the properties for the first structure group, and clicking on the NEXT button would begin cycling through the other structure groups within the feature.

The FEATURE PROPERTIES window for a terrain contains a *Do sparse rendering* check box that allows the user to choose to render the terrain at a lower resolution. This only modifies the on-screen rendering of the terrain to improve performance and does not affect the level of detail that will be used for calculations. A manual value for the resolution can be entered in the *Sparse rendering distance* field. When importing or opening a terrain with a high face count, XGtd will open a dialogue box warning of potential performance issues and suggest to use sparse rendering with an automatically generated resolution value. Note that the *Color by height* function is disabled while using sparse rendering.

## 3.6 Editing Vertex Coordinates

The FACE PROPERTIES Window allows exact specification of vertex coordinates to precisely position and size a face. To access this window, select a face, right-click and select *Properties*. To edit the coordinates, click on the VIEW VERTICES button and edit the values in the VIEW/EDIT VERTICES Window, as seen in Figure 3.14. Double-clicking any entry will enable editing.

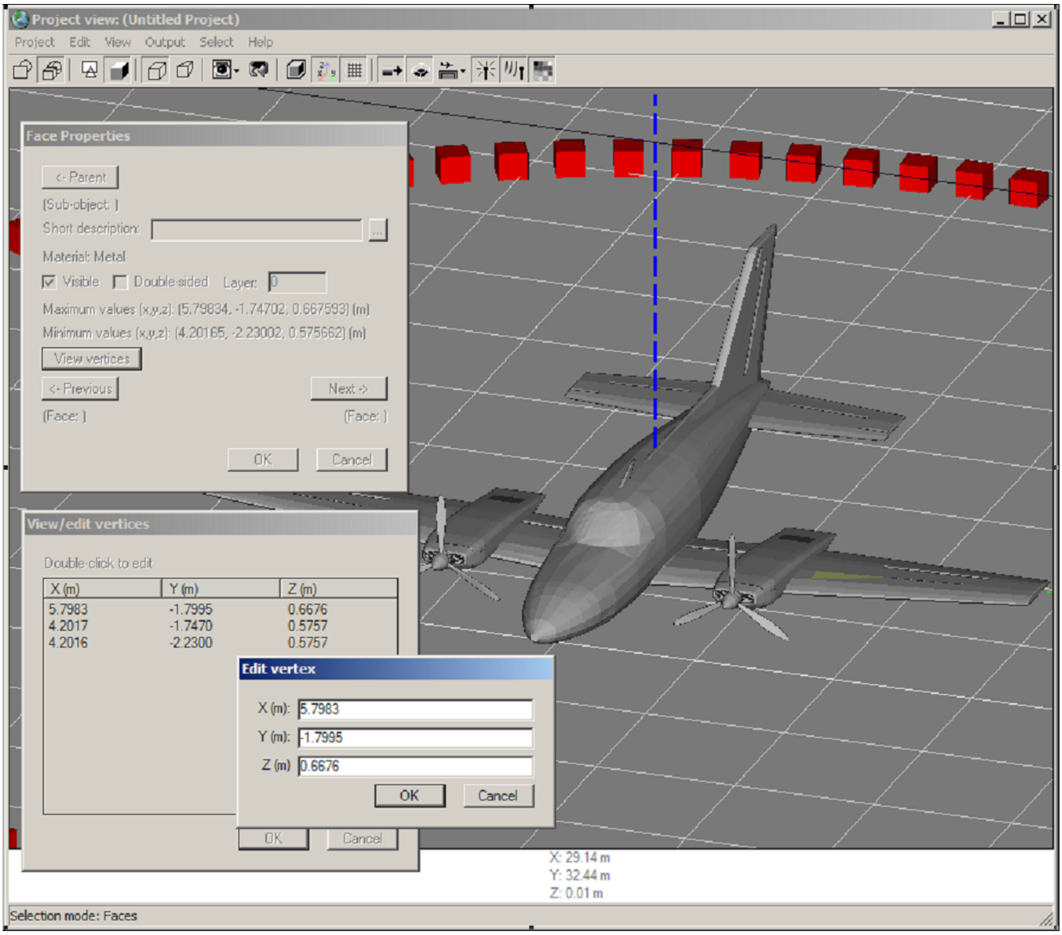


Figure 3.14: Modifying a face by manually editing its vertices

## 3.7 Feature Operations

A number of operations are available to position and modify the properties and appearance of each FEATURE. To perform an operation, select a feature by navigating to *Select*→*Feature* from the

PROJECT VIEW. Click on the desired feature, or select multiple features by holding the CTRL key while clicking on each one.

✓ If finer control is needed for any of the operations, then groups of faces can be selected at any of the intermediate levels of the feature hierarchy.

▶ See Sections 2.1.2 and 2.1.3 for more information on selecting items in the PROJECT VIEW or the PROJECT HIERARCHY.

The features context menu includes the following operations.

- *Remove empty levels* - Cleans up the features organization to only sections that have faces.
- *Remove unused materials* - Removes any materials from the feature that are no longer associated with any of its faces.
- *Visibility* - Sets the selected items as visible or invisible (transparent). In either case, the items will still be considered in the calculations.
- *Sided* - Specifies whether a face is single- or double-sided.
- *Change height* - Provides two alternatives for changing the heights of all the selected structures. The first is to assign the same height to all selected structures. The second is to multiply the current height by a scaling factor.
- *Change material* - Changes the material assigned to all selected items.

  ▶ See Chapter 5 for more information about assigning material properties.
- *Center in* PROJECT VIEW - This will move location viewing position of the PROJECT VIEW so that it is centered on the FEATURE. The PROJECT VIEW will maintain the current rotation and scaling and will rotate about the center of the FEATURE.
- *Translate in* PROJECT VIEW - Uses the PROJECT VIEW to do a visual translation in the x-y plane. When this is activated the part of the FEATURE that will act as the anchor point for the operation must be selected. The FEATURE can then be moved around in the PROJECT VIEW until the desired location is achieved. Clicking at this point will translate the FEATURE to that position. In figure 3.15 a point on the shuttle was selected as the anchor point and then used to translate it to the position indicated by its outline at the new location.
- *Translate* - Moves any item by selecting *Translate→Relative to local origin*. This will bring up a window in which the Cartesian components of the translation vector can be specified. The other option in the translation menu is *Local origin within object*. Selecting this option allows the local origin of the object to be moved in the global reference frame.
- *Scale by* - Increases or decreases the size of the selected item's along each principal axis by the specified factors. Separate factors can be entered for each Cartesian axis. When the scaling is complete, the selected items will be positioned so that the position of the object's control point is unchanged in the global frame.
- *Rotate* - Brings up a dialog for selecting the axis and rotation angle (in degrees). A positive angle gives a counter-clockwise rotation, and a negative angle a clockwise rotation. The axis of rotation is defined by selecting two points (point, point), a point and vector (point, vector), the object's control vectors, or the principle axes of the global reference frame ($X$, $Y$, or $Z$).

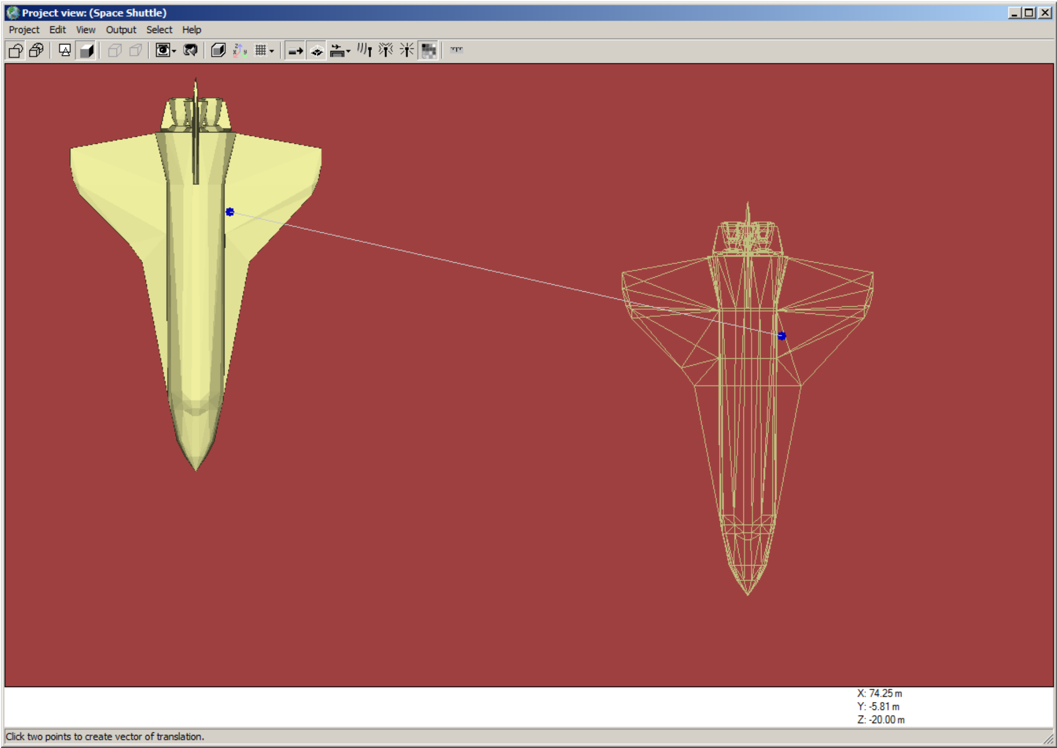


Figure 3.15: Visually translating an object in the Project View.

- *Pre-processing* - Displays all of the operations that can be performed on the feature to make it easier to interact with the calculation or to make it run more efficiently.
  - *Add indices to description* - Adds a number to the beginning of each item's short description indicating its position within the next higher grouping level.
  - *Join coplanar faces* - Joins all faces that share a common edge and lie in the same plane.
  - *Validate faces* - Displays the faces in the feature that prevent it from creating a proper normal. The failure conditions for a face check are:
    1. The vertices do not describe an area.
    2. Two or more sides intersect.
    3. A side is described by two or more colinear points.
    4. All vertices do not lie in the same plane.
    5. The face has less than three vertices.
    6. The face desribes an acceptably large area, but is too narrow.

    Such faces are ignored by the calculation and should be edited to correct the problem or deleted before running a calculation.

✓ Generally, deleting the faces that fail validation for the last two conditions will not affect the results.

– *Simplify Feature* - Provides a method for removing excessive details from objects that can result in slow calculation times and that do not affect the results. For example, an imported model of a vehicle may include details of the tire treads, but at a low enough frequency this appears as a flat surface and should be removed.

– *Triangulate Feature* - Splits all of the faces in the feature into triangles. If a feature has faces with more than three vertices, the simplification process will not work correctly. This is provided as a separate operation as it can be computationally expensive for large features and should be avoided when possible.

## 3.8 Face Operations

Similar to the operations available for modifying FEATURES, there exists a set of operations to edit the position, appearance, and properties of faces. While most of the operations for a selected level of a feature (i.e. structure group, structure, or substructure) work on the faces contained within that level, the additional operations listed below are specific to faces and are not available at any other level in the feature Hierarchy. The operations will be applied to selected faces only.

▶ See Section 2.1.2 for a description of how to select objects.

- *Add absorber* - Places radar-absorbing materials within the *Chamber*. Only available when the face of a chamber floor is selected.
- *Cover with (Transmitter or Receiver Points)* - Applies a uniform grid of transmitters or receivers to the surface of a face.
- *Place Points (Transmitters or Receivers)* - Opens the selected face in an editor window where transmitter or receiver points can be placed at specific locations.

  ▶ See Chapter 8 for more information about the Points-on-Face Tx/Rx set.
- *Sided (Single or Double)* - Determines if the face will be visible only from the front (single) or both sides (double).
- *Change material* - Changes the material that composes the face.
- *Reverse normals* - Reverses the direction of the face normal, effectively flipping the face in its current position.
- *Center in* PROJECT VIEW - This will move location viewing position of the PROJECT VIEW so that it is centered on the face. The PROJECT VIEW will maintain the current rotation and scaling and will rotate about the center of the face.
- *Translate, Scale by, and Rotate* - Performs normal geometric operations.

## 3.9 Control Vectors and the Control Point

*Objects* have a special set indicators associated with them called control vectors. This is a set of basis vectors centered on the control point (or origin) of the object that describes its current orientation within the projects global coordinate system. They can also be thought of as the objects' local Cartesian axes with the colors of the control vectors corresponding to the colors of the origin when it is drawn on the screen; the $X$-axis is red, $Y$-axis is green and $Z$-axis is blue. The main purpose of these vectors is to more easily discern the position of the object with respect to other items within the scene.

### 3.9.1 Control Vector Properties

The Control Vector Properties Window enables the user to edit the properties of control vectors. To access it, select *Control vector properties* from the context menu of the selected option, or click the Edit Control Vectors button in the object's properties window. The properties include:

- *Orientation* - Shows the current directions of all three control vectors.
  - *Reset* - Resets the control vectors to the default orientation, which is the global basis.
  - *Align* - Used to change the orientation of the control vectors within the object itself. The angles used for the control vectors determine how the object is referenced within the scene.
  - ▶ See Section 3.9.3 for a description of the Align Window.
- *Viewing options*
  - *Display* - Indicates if the control vectors will display in the Project View for that object.
  - *Draw as dashed line* - Draws the vectors as a set of dashed lines, making it easier to distinguish the control vectors from the origin if they are both drawn at the same time.
  - *Thickness* - Sets the thickness of the lines when they are drawn on the screen. The default is 3 pixels and may need to be enlarged to make them more apparent on large objects.
  - *Length* - Allows for adjustment to the length of each vector (the default is 10 meters). This allows the control vectors to act like laser pointers to see if the object is pointing at the exact spot that is desired.

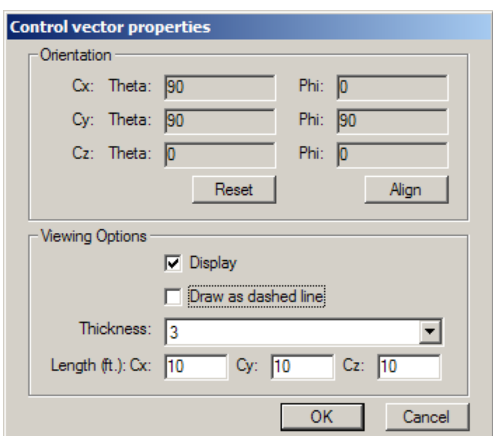


Figure 3.16: Control Vector Properties Window

### 3.9.2 Conversion Between Reference Frames

The control vectors' orientation values are displayed using spherical coordinates while the project uses the Cartesian system to orient objects in the MAIN WINDOW. The difference between the two systems is that in the Cartesian system the positive $X$-axis is 0° for both theta and phi angles and the positive $Z$-axis is 0° for the roll angle ($\psi$). In spherical coordinates the positive $Z$-axis is 0° for theta and the positive $X$-axis is 0° for the phi and psi angles. This means that the difference between the two systems in their un-rotated state is that the $X$- and $Z$-axes are swapped. This difference is shown graphically in Figure 3.17.

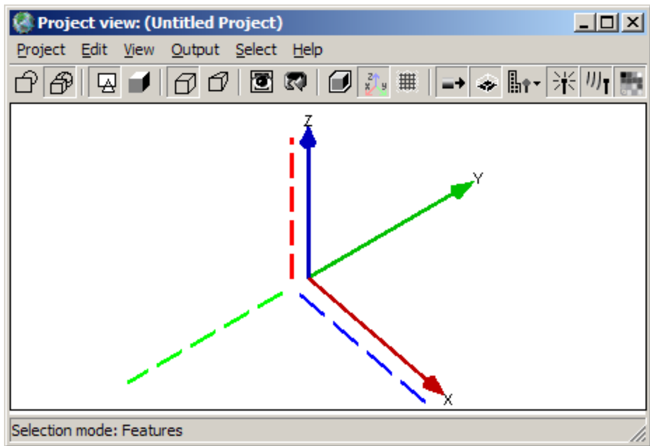


Figure 3.17: Difference between coordinate systems without rotations

An un-rotated object in the projects' Cartesian system would have a rotation of 90° theta, 0° phi and a psi angle of 180° in spherical coordinates. By default, an objects' control vectors are given these values so that the object begins in the projects' reference frame. The following section describes how to correctly specify the rotational values of an object immediately following the import process.

### 3.9.3 Object Alignment

When an *Object* is first imported into a project, it may already appear to have a non-zero rotation with respect to the projects' global coordinate system. In this case, the initial rotation of the object will need to be specified by aligning the control vectors to the object, as seen in Figure 3.18. To perform this alignment, click on the ALIGN button in the *Orientation* box of the CONTROL VECTOR PROPERTIES Window and specify the current spherical rotational values of the object.

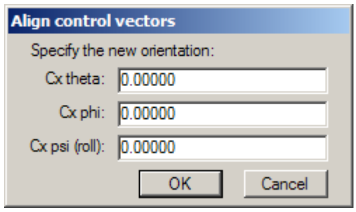


Figure 3.18: Alignment window for control vectors

Another approach is to rotate the imported object until it is “un-rotated” with respect to the projects’ coordinate system, and then click on the RESET button in the *Orientation* box of the CONTROL VECTOR PROPERTIES Window. This will apply the spherical rotation values of an un-rotated object in the projects’ coordinate system to the object. This is an easier approach if the object is the only FEATURE in the project, because the axes of the control vectors lie in the same direction as the project axes and the object will swivel about its local $Z$-axis, making it easier to manipulate the object with the mouse on the screen. This is due to the fact that no matter what rotation is applied to an object, the PROJECT VIEW always rotates about the $Z$-axis of the projects’ coordinate system. Therefore it is desirable to align the $Z$-axes of both the object and the project to achieve this behavior.

Once the vectors are aligned to the *Object*, they will be rotated with the object in order to maintain their orientation with respect to it.

### 3.9.4 Translation

The set of control vectors are drawn centered on the control point of the *Object*. In some cases, it may be desirable to move this point with respect to the object. The available options for accomplishing this, as listed below, are accessible through the *Translate* option on the object’s context menu.

- *Relative to Control point* - Moves the object with respect to the control point while it remains stationary. Using this option will move the object with respect to the other features in the project.
- *Control point within Object* - Moves the center of the control point within the object without moving the object with respect to the other features in the project. This will change the origins location when it is viewed in the objects’ properties window.

✓ To move both the object and the control point as a unit, adjust the control point’s location in the properties window for the object.

### 3.9.5 Rotation

When an *Object* is rotated, its control vectors rotate with it and their values update to reflect the new directions. To perform a rotation of an object, select *Rotate* from the context menu. This will bring up the 3D ROTATE Window shown in Figure 3.19. Rotations are performed for the object so that it rotates about one of the control vectors, or any vector positioned at an indicated point.

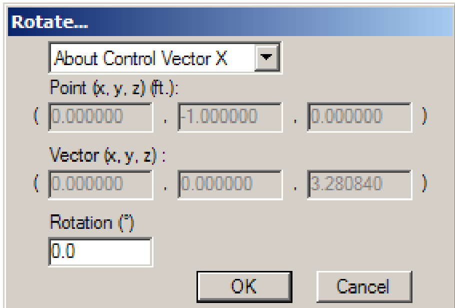


Figure 3.19: Rotation Input Window

### 3.9.6 Graphical Editing

The control point of an *Object* can also be positioned in the object editor. The context menu for these options is shown in Figure 3.20.

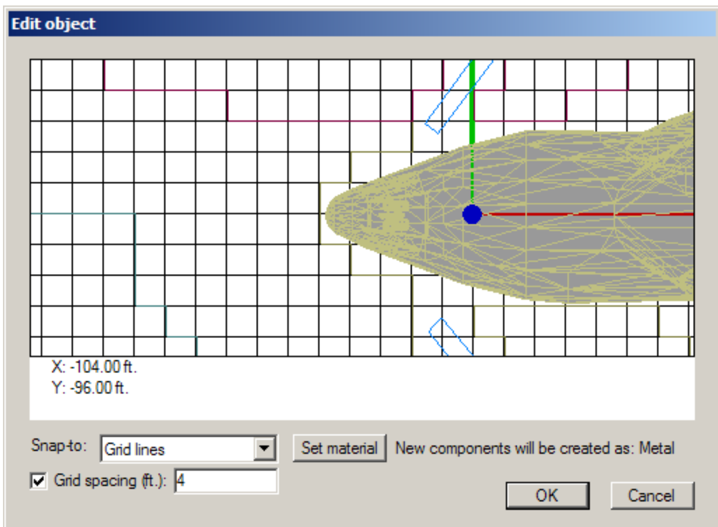


Figure 3.20: Using the Object Editor to place the control point

- *Enter new local coordinates* - Moves the control point from its current position by the distances specified.
- *Move within object* - Positions the control point precisely when the user clicks on the desired location.

When moving the control point location with the mouse, you can turn on the same snapping mode options as when editing the current geometry of the object. This makes it much simpler to position the control point. For example, you could position the control point on the nose tip of a plane by choosing “Vertices” as the *Snap-to* option, and move it 20 meters from the tip into the fuselage by correctly counting the gridlines.

### 3.9.7 Control Vectors Tutorial

In order to show how to properly use the control vector feature, we will use a sample file named `747.stl`, which is included on the CD in the `examples_location\stl` folder.

The left side of Figure 3.21 shows an imported `*.stl` model of a 747. From the position of the origins axes, which are pointing along the projects basis vectors, you can see that the plane is pointing along the positive $Y$-axis. This means that before any settings are changed, the nose of the plane is considered to be pointing to the left.

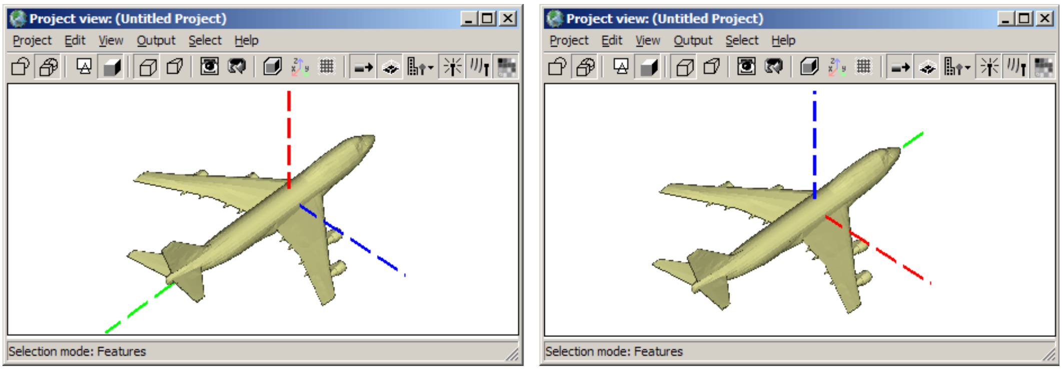


Figure 3.21: Reorienting an imported 747 STL model

Now the current orientation of the object needs to be changed to reflect the orientation it had based on the information on the import file. In spherical coordinates, the plane has a rotation of 90° for theta and phi, and a psi angle of 180° with respect to the projects' coordinate system. Applying these values in the CONTROL VECTOR PROPERTIES Window, the orientation is corrected. Now the front of the plane is pointing along the projects' positive $Z$-axis, and the top is also correctly pointing along the projects' positive $Y$-axis, as seen to the right of Figure 3.21.

# Chapter 4

# Objects

*In this chapter, you will learn...*

→ how to create and edit an *Object* in XGtd

→ how to import an *Object* from DXF

*Objects* represent generic geometric data, usually in the form of objects such as automobiles or aircraft. They can be created from scratch using the XGtd Object Editor, but are normally used to represent CAD data imported from various formats.

XGtd creates each new Object as a separate FEATURE and saves it to a KMZ (`*.kmz`) file. This file contains a version of the feature in COLLADA format as well as a file that contains information about the materials used by the *Object* that is required by the calculation models.

## 4.1 Object Editor

XGtd's Object Editor is used to layout components or edit an existing *Object*.

The current material to use when creating components can be changed during the editing process and is applied to new components as they are created. The default material type is a PEC called *Metal* as shown in Figure 4.1. Clicking the button for the material allows the user to either view the current material properties, or to replace the material with:

- A new material of a different type
- A material in the material database
- A material that is in another feature within the project. If this option is used, then the feature currently being edited will make a copy of that material for its own use.

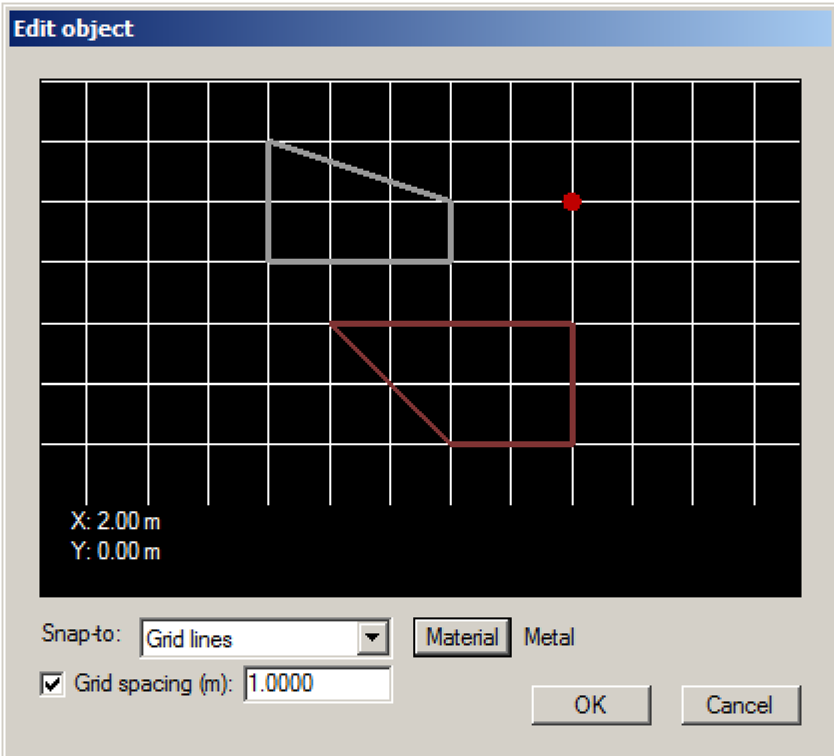


Figure 4.1: The Edit object Window

### Creating a New Object

To create a new *Object*:

1. Click on *Project*→*New*→*Feature*→*Object*
2. Select *New component* from the editor's context menu.
3. Zoom or pan the view whenever necessary. The EDIT OBJECT Window may also be resized or maximized if needed.
4. Define the footprint by clicking on the vertex locations, then right-click after the last point.

   ✓ There is no need to close the footprint by clicking on the starting vertex.
5. Enter the *Height*, as seen in Figure 4.2.

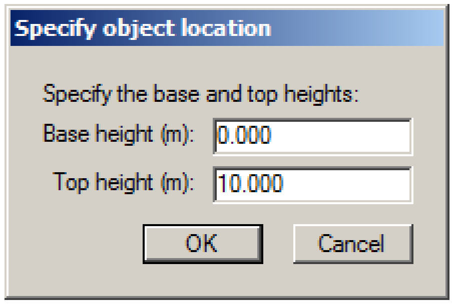


Figure 4.2: Creating a new component in the Object Editor

6. Repeat Steps 2-5 to add another component.
7. Click OK to close the EDIT OBJECT Window.

## 4.2 Importing DXF Files

DXF files can be created in many different ways. Unfortunately, not all of these are compatible with XGtd. The XGtd DXF converter can only convert the following DXF objects:

- Polylines
- Polyface meshes
- 3D faces

Object components should be created using AutoCAD "grip points" to specify points used for face edges. This will force the spatial positions of the face points to be identical. This practice is especially important when the point is an endpoint of an edge that is common to two faces. If the face edges are not exactly coincident, the DXF converter cannot identify the faces as touching.

Drafting symbols (e.g. graduated scales, lettering, and other symbols) should be removed prior to import.

To import a DXF file into an existing project, select *Project→Import→DXF*. Open the desired DXF file and a new IMPORT DXF DATA Window will appear, as seen in Figure 4.3.

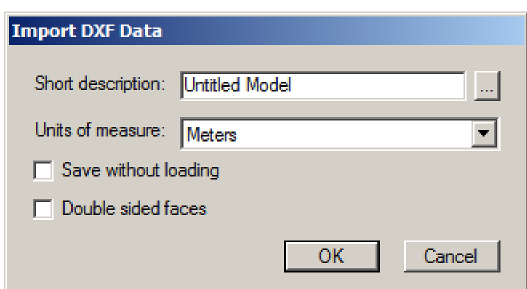


Figure 4.3: Import DXF Data Window

The fields in this window are described below.

- *Short description* - Identifies the imported object.
- *Units of measure* - Set the distance units that the values in the file are given in.
- *Save without loading* - When checked, the `DXF` file is converted into a `*.object` file but is not loaded into the project. When unchecked, the *Object* is added to the project, but the `*.object` file is not saved. Save the file by selecting *Project→Save*.
- *Double Sided Faces* (available for object import). When checked, the faces of the imported feature are created as double-sided. When unchecked, the faces are created as one-sided.

When everything is set up correctly, click OK and the `DXF` file will be converted.

# Chapter 5

# Materials

*In this chapter, you will learn...*

→ the types of materials available in XGtd, and their properties

→ equations used to define material properties

→ how to plot reflection and transmission coefficients

→ material file formats

In XGtd, all FEATURES are ultimately composed of MATERIALS. The properties of a material are collectively referred to in this manual as "material types". The material properties include both the electromagnetic properties of the face as well as the display properties. The reflection and transmission coefficients are determined directly from the material properties, but the diffraction coefficients are determined indirectly through their dependence on the reflection and transmission coefficients. For some material types, the thickness is used to determine the reflection and transmission coefficients, but for others it only affects how the facet is displayed. Color and shininess, on the other hand, only affect how the facet is displayed for all material types. XGtd provides tools which allow the user to easily assign a MATERIAL to individual faces as well as groups of faces. Materials may also be saved to the material database for use in other projects.

- See Chapter 3 for more on the properties of FEATURES, including the options for changing the MATERIAL assigned to a face.

The reader should be aware that in some ways the term "materials" may be misleading, since it usually describes the reflection and transmission coefficients rather than the intrinsic properties of the material itself. Because no single term seems to describe the various ways in which the electromagnetic characteristics are determined, we have decided to use the generic term "materials" rather than a more specific term which may be more accurate in some contexts, but less so in others.

## 5.1 Creating a Material

A MATERIAL is created by selecting *Project→New→Material* and choosing from the list of material types. To access the materials in a project, click on the MATERIALS tab in the MAIN WINDOW.

## 5.2 Material Properties

Materials used in an XGtd project are listed under the MATERIALS tab in the MAIN WINDOW, as shown in Figure 5.1. Clicking on the bar near the bottom of the window reveals a list of materials in the material database, displayed in a similar format.

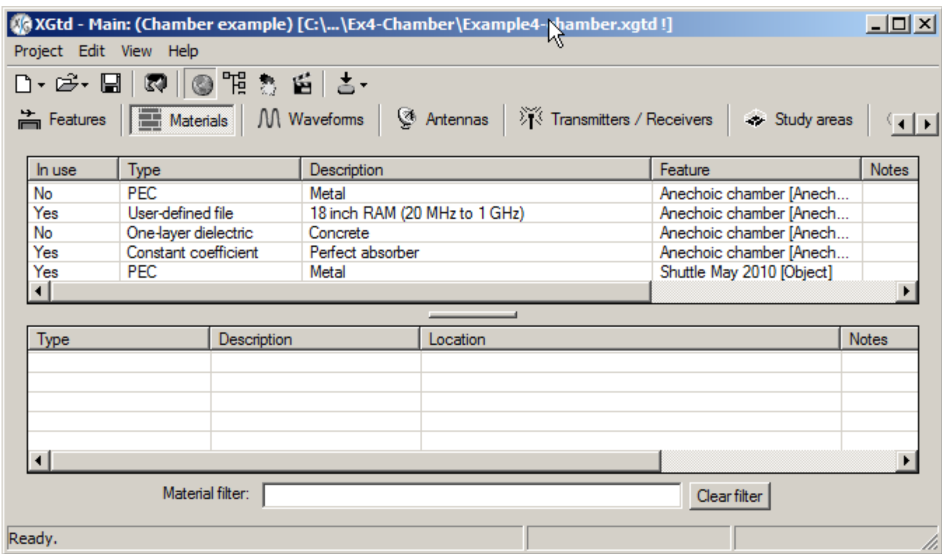


Figure 5.1: The list of materials under the Materials tab

The fourth column shows the FEATURE to which the MATERIAL belongs. It is important to understand that materials are saved separately for each feature. Therefore, the user may create a material called "Metal" for more than one feature, but each of these "Metals" may have different properties than the others. The material properties for each feature are saved to the same file which contains the geometrical data of the feature. In order to add the same material to a number of features, first add the material to the material database, and then add it to each feature from the database.

▶ The material database is discussed in Section 5.4.

The context menu for each MATERIAL includes the following options:

- *Copy to personal database* places a copy of the selected material into the material database for use in other XGtd projects.
- *Duplicate* creates a copy of the selected material.
- *Delete* removes the selected material from the feature which contains it.

- *Replace* assigns a different material to all faces in the feature which are made of the selected material.
- *Plot* displays a 2D plot of material reflection or transmission coefficients versus incident angle or frequency.
- *Properties* accesses the properties of the selected material.

The properties window for each material type contains all parameters which define the material. Some values appear in each window, such as thickness and roughness; however, most values are unique to a material type. Below is a list of common fields present in the material properties window.

- *Roughness* - The standard deviation of the surface height relative to the mean height, in meters.
- *Thickness* - The thickness of the material, in meters. Several material types use the thickness to determine the reflection and transmission coefficients, but for other material types the thickness is only used for display purposes. For example, a thickness must be entered for a *Dielectric Half-Space*, even though the reflection and transmission coefficients do not depend on the thickness. It is best in this case to enter a reasonable value, which can be zero, so the wall is displayed in an appropriate manner. Material types with more than one layer have a thickness for each layer, and in these cases the total thickness is used in the display.
- *Permittivity* - The permittivity of the material, specified relative to free space permittivity ($\epsilon_0$ = 8.854x$10^{-12}$). Several material types allow the user to enter one or more permittivity values.
  - More information about different representations of the dielectric parameters and conversions between them can be found in Section 5.5.
- *Conductivity* - The conductivity of a material is entered in units of S/m. Several material types allow the user to enter one or more conductivity values.
  - More information about different representations of dielectric parameters and conversions between them can be found in Section 5.5.
- *Reflection Coefficient (parallel), etc.* - When using a *Constant Coefficient* Material, values are entered for the reflection and transmission coefficients for the electric field (polarized, parallel, and perpendicular to the plane of incidence).
- *Reflection/Transmission Coefficient Filename* - The names of the files containing the reflection and transmission coefficients for a *User-Defined* Material.

## 5.3 Material Types

The following material types are available in XGtd.

1. *Dielectric Half-Space*

   The reflection coefficients for Dielectric Half-Space are that of a semi-infinite dielectric block. The transmission coefficients are always zero for this material type. The angle- and frequency-dependent reflection coefficients are calculated from the Fresnel plane wave reflection coefficients. The parameters needed are permittivity, conductivity, roughness, and thickness (used only for display purposes).

- See Section 5.8 for information on Fresnel Coefficients.

2. *Layered Dielectric*

   This material is defined by plane wave reflection and transmission coefficients for multiple finite thickness dielectric layers. The parameters needed for each dielectric layer are permittivity, conductivity, roughness, and thickness. The field is always assumed to be incident on the first dielectric layer.

3. *PEC Backed Layer*

   This material is defined by plane wave reflection and transmission coefficients for a single finite thickness dielectric layer backed by a perfectly conducting layer. The field is always assumed to be incident on the dielectric layer, not the PEC layer. The transmission coefficient is zero. The parameters required for this material are the permittivity, conductivity, roughness, thickness of the dielectric, and thickness of the PEC layer, with the latter only used for display purposes.

4. *Constant Coefficient*

   This material is defined independent of angle and frequency. Separate coefficients are assigned for each polarization. The coefficients are given as the ratio of the reflected or transmitted field to same component of the incident field, that is:

   $$R_\perp = \pm \left| \frac{E_\perp^r}{E_\perp^i} \right| \tag{5.1}$$

   The coefficients must be real numbers, and as such cannot include phase except for an overall negative sign.

5. *Perfect Electrical Conductor (PEC)*

   Faces assigned with this material act as perfect electrical conductors, from which all energy is reflected. The transmission coefficient is zero, and the parameters are roughness and thickness.

6. *Free Space*

   Faces assigned this type are rendered as transparent. The reflection coefficient is zero and the transmission coefficient is one for both polarizations.

7. *User-Defined*

   XGtd can read user-defined material files with reflection and transmission coefficients. The coefficients can vary in angle of incidence, orientation of the incident plane (optional), and frequency (optional). When a project is run at a frequency not listed in the user-defined material file, reflection and transmission coefficients are interpolated using the magnitude in dB and phase of coefficients at the adjacent frequency records. If the project frequency is above or below the frequency records contained in the user-defined material file, then the nearest frequency record is used. A complete description of the user-defined material file is available in Appendix E.

## 5.4 Material Database

The material database includes a small number of common generic material types. When one of these materials is assigned to one or more faces within a FEATURE, the material properties are written to the feature file and become part of that particular feature. No link to the entry in the database is retained. Once a material in the database is applied to a feature, modifications to the properties of the material are only applied to that particular feature, and the original properties of the material in the database are left unchanged.

▶ The procedures for adding new materials to the database and modifying existing ones can be found in Chapter 14.

A brief description of the materials in the database follows. The symbols $\epsilon$ and $\sigma$ are used to designate the relative permittivity and the conductivity, respectively.

### Exterior Building Materials

- **Concrete Wall**: *type* = *Layered Dielectric*
  - Layer 1: $\epsilon = 7$, $\sigma = 0.015$ S/m, $thickness = 0.3$ m
- **Brick Wall**: *type* = *Layered Dielectric*
  - Layer 1: $\epsilon = 4.44$, $\sigma = 0.001$ S/m, $thickness = 0.125$ m
- **Wood**: *type* = *Layered Dielectric*
  - Layer 1: $\epsilon = 5$, $\sigma = 0$ S/m, $thickness = 0.03$ m
- **Plate Glass**: *type* = *Layered Dielectric*
  - Layer 1: $\epsilon = 2.4$, $\sigma = 0$ S/m, $thickness = 0.003$ m

### Interior Building Materials

- **Layered drywall**: *type* = *Layered Dielectric*
  - Layers 1 and 3: Drywall $\epsilon = 2.8$, $\sigma = 0.001$ S/m, $thickness = 0.013$ m
  - Layer 2: Air $\epsilon = 1$, $\sigma = 0$ S/m, $thickness = 0.089$ m

### Miscellaneous Materials

- **Free Space**: *type* = *Free Space*
  - $R_\perp = 0$, $R_{||} = 0$, $T_\perp = 1$, $T_{||} = 1$
- **Perfect Absorber**: *type* = *Constant Coefficient*
  - $R_\perp = 0$, $R_{||} = 0$, $T_\perp = 0$, $T_{||} = 0$

## 5.5 Dielectric Parameters

There are various ways of representing the constitutive parameters of a lossy dielectric medium. XGtd commonly uses the real part of the materials' permittivity and conductivity. At present, all MATERIALS in XGtd are nonmagnetic, and the permeability for all materials is that of free space ($\mu_0 = 4\pi\, x\, 10^{-7}$ H/m).

Some of the commonly encountered parameters used for lossy dielectric materials, along with formulas for converting between them, are discussed below. In all formulas, the permittivity is designated by $\epsilon$, and the real and imaginary parts by $\epsilon'$ and $\epsilon''$, respectively. The real part of the relative permittivity is sometimes referred to as the dielectric constant, although this term is also used for the complex quantity. In many formulas it is the relative permittivity which is one of the parameters, and the absolute permittivity is obtained by multiplying the relative value by the permittivity of free space ($\epsilon_0 = 8.854x10^{-12}$ F/m). To avoid any confusion, an "r" subscript will be placed on all relative values, and an absolute value should be assumed otherwise.

- The notation used here generally follows that described in [1, Ch. 2]. More information on dielectric constitutive parameters is also found in this reference.

It is important to note that many of the formulas given below are only accurate for a single frequency, so if calculations are made at significantly different frequencies, it may be necessary to recompute the dielectric parameters.

### Permittivity and Conductivity

The complex permittivity can be written as:

$$\epsilon = \epsilon' - j\frac{\sigma_e}{\omega} \tag{5.2}$$

where $\epsilon'$ is the real part of the permittivity and $\sigma_e$ is the effective conductivity of the material.

### Complex Permittivity

The permittivity can also be expressed as:

$$\epsilon = \epsilon' - j\epsilon'' \tag{5.3}$$

where the static conductivity is assumed to be zero ($\sigma_s = 0$).

The effective conductivity is given by:

$$\sigma_e = \epsilon''\omega \tag{5.4}$$

where $\omega$ is the angular frequency in radians/s.

## Complex Permittivity and Static Conductivity

When both the imaginary part of the permittivity and the static conductivity, $\sigma_s$ , are given, the complex permittivity can be expressed as:

$$\epsilon = \epsilon' - j\epsilon'' - j\frac{\sigma_s}{\omega} \tag{5.5}$$

where an additional term involving the static conductivity is also present in this representation.

The effective conductivity is then given by:

$$\sigma_e = \epsilon''\omega + \sigma_s \tag{5.6}$$

where $\omega$ is the angular frequency in radians/s and $\sigma_s$ is the static conductivity.

The effective conductivity can also be expressed as:

$$\sigma_e = \sigma_s + \sigma_a \tag{5.7}$$

where

$$\sigma_a = \epsilon''\omega \tag{5.8}$$

and is sometimes called the alternating field conductivity.

The effective complex permittivity can also be written as:

$$\epsilon = \epsilon' - j\epsilon''_e \tag{5.9}$$

where the imaginary part of the effective permittivity is given by:

$$\epsilon''_e = \epsilon'' + \frac{\sigma_s}{\omega} \tag{5.10}$$

## Electric Loss Tangent

Instead of specifying an imaginary part of the permittivity and/or a conductivity, the loss can be expressed as a tangent of the phase angle between the real and imaginary part of the effective permittivity:

$$tan(\delta_e) = \frac{\sigma_e}{\omega\epsilon'} = \frac{\sigma_s}{\omega\epsilon'} + \frac{\epsilon''}{\epsilon'} \tag{5.11}$$

The effective conductivity is given by:

$$\sigma_e = \omega\epsilon' tan(\delta_e) \tag{5.12}$$

## Susceptibility

In terms of the susceptibility, the complex permittivity (omitting the conductivity) is:

$$\epsilon_r = (1 + \chi') - j\chi'' \tag{5.13}$$

where

$$\epsilon_r' = 1 + \chi' \tag{5.14}$$

$$\epsilon_r'' = \chi'' \tag{5.15}$$

The effective conductivity can be found from:

$$\sigma_e = \chi''\epsilon_0\omega + \sigma_s \tag{5.16}$$

## Index of Refraction

Instead of the permittivity one may occasionally find values for the index of refraction of a material, usually given as a complex number, $n = n' - jn''$. The index of refraction is related to the permittivity by $n = \sqrt{\epsilon_r}$. It is straightforward to show that the loss tangent angle is given by:

$$\delta = 2tan^{-1}\left(\frac{n''}{n'}\right) \tag{5.17}$$

and the real part of the permittivity is found from:

$$\epsilon_r' = \sqrt{\frac{n'}{sec(\delta)cos\left(\frac{\delta}{2}\right)}} = \sqrt{\frac{n''}{sec(\delta)sin\left(\frac{\delta}{2}\right)}} \tag{5.18}$$

and the effective value for the imaginary part of the permittivity is given by:

$$\epsilon_r'' = \epsilon_r' tan(\delta) \tag{5.19}$$

and the effective conductivity by:

$$\sigma_e = \epsilon''\epsilon_0\omega \tag{5.20}$$

## Propagation Constant

The propagation vector of a wave propagating in a dielectric medium is given by:

$$k \;=\; nk_0 \;=\; \sqrt{\epsilon_r k_0} \;=\; k' \;-\; jk'' \tag{5.21}$$

where

$$k_0 \;=\; \frac{2\pi}{\lambda_0} \;=\; \omega/c \tag{5.22}$$

and $\lambda_0$ is the wavelength in free space.

Equations 5.18 and 5.19 can be applied to the propagation vector by replacing $n'$ by $\frac{k'}{k_0}$ and $n''$ by $\frac{k''}{k_0}$.

In some cases, it is useful to write the propagation constant in the form:

$$k \;=\; k_0(1 \;+\; \kappa' \;-\; j\kappa'') \tag{5.23}$$

Solving for the permittivity gives:

$$\epsilon_r' \;=\; (1 \;+\; \kappa')^2 \;-\; \kappa''^2 \tag{5.24}$$

$$\epsilon_r'' \;=\; 2\kappa''(1 \;+\; \kappa') \tag{5.25}$$

When the real part of the permittivity and the attenuation are known, the imaginary part of the permittivity is given by:

$$\epsilon_r'' \;=\; 2\kappa''\sqrt{\epsilon_r' \;+\; \kappa''^2} \tag{5.26}$$

When $\kappa'$,$\kappa''$ $<<$ $1$, the equations for the relative permittivity reduce to:

$$\epsilon_r' \;\approx\; 1 \;+\; 2\kappa' \tag{5.27}$$

$$\epsilon_r'' \;\approx\; 2\kappa'' \tag{5.28}$$

## Skin Depth

The skin depth is the distance into a material at which the amplitude of the electric field has decayed to $e^{-1} \;=\; 0.37$ of its value at the surface of the dielectric for a plane wave normally incident on the surface. The skin depth is easily shown to be equal to $\frac{1}{k''}$ where $k''$ is the imaginary part of the propagation constant. In general, $k''$ is given by:

$$k'' \;=\; k_0\sqrt{\epsilon_r'^2 \;+\; \left(\frac{\sigma_e}{\omega\epsilon_0}\right)^2} sin\left(\frac{\delta_e}{2}\right) \tag{5.29}$$

For a good dielectric $\left(\left(\frac{\sigma}{\omega\epsilon'}\right)^2 << 1\right)$ the skin depth is equal to:

$$\frac{1}{k''} \approx \frac{2}{\sigma}\sqrt{\frac{\epsilon'}{\mu_0}} \tag{5.30}$$

and for a good conductor $\left(\left(\frac{\sigma}{\omega\epsilon'}\right)^2 >> 1\right)$ the skin depth is equal to:

$$\frac{1}{k''} \approx \sqrt{\frac{2}{\omega\mu_0\sigma}} \tag{5.31}$$

## 5.6 Plotting Reflection and Transmission Coefficients

There are two methods for accessing the PLOT COEFFICIENTS Window, as seen in Figure 5.2. The first is to right-click on a material in the MATERIALS list, and the other is by clicking on the PLOT button on a MATERIAL PROPERTIES Window.

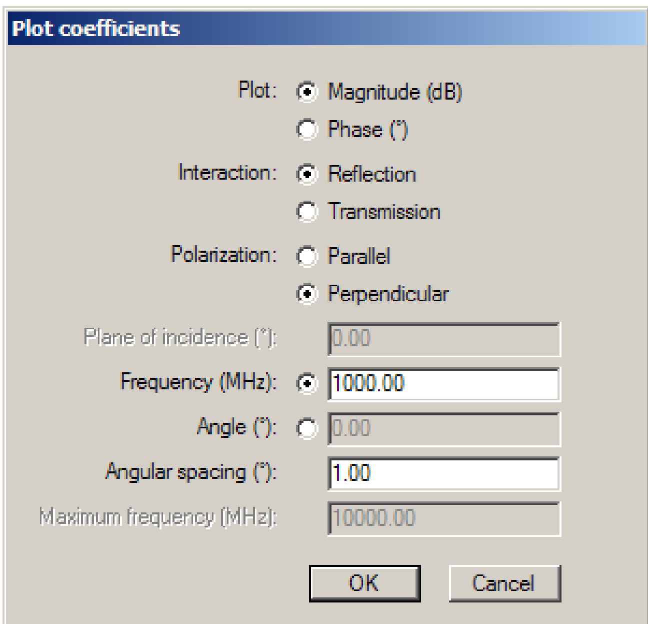


Figure 5.2: Plotting the coefficients of a material

The following options are available when plotting coefficients:

- *Plot* specifies whether the magnitude or the phase is plotted
- *Interaction* specifies whether reflection or transmission coefficient is plotted
- *Polarization* specifies the component

- *Plane of incidence* is active only for *User-Defined* data files
- *Frequency* shows plot vs. angle of incidence at the specified frequency
- *Angle* shows plot vs frequency at the specified angle of incidence
- *Angular/Frequency Spacing* increments in angle or frequency depending on plot type
- *Maximum frequency* is only active for plots as a function of frequency

Once the graph is displayed, it can be modified using the Graph and Plot Properties Windows.

▶ For more on adjusting graph properties, see Chapter 12.

## 5.7 Ray-Fixed Coordinate System

Most materials can have different values for the field components parallel and perpendicular to the plane of incidence. It is especially important to understand this coordinate system if *User-Defined* coefficient files are being created. XGtd uses one of two commonly used ray-fixed systems, which differ in the sign of the field component parallel to the plane of incidence.

▶ The ray-fixed system used by XGtd is defined in Section 10.1, under Electric Field Evaluation.

▶ This system corresponds to the one used in most UTD literature, but it differs from the system used in many electrical engineering textbooks on electromagnetics, such as [1, Ch. 5].

Using the incorrect coordinate system can lead to a 180°phase error in the parallel component.

## 5.8 Fresnel Coefficients

The first four material types are based on the Fresnel plane wave transmission and reflection coefficients for a semi-infinite lossy dielectric half space of relative permittivity $\epsilon_r$. Assuming that the incident field is propagating in free space, the Fresnel coefficients are given by the following formulas:

$$R_\perp = \frac{cos(\theta_i) - \sqrt{\epsilon_r} cos(\theta_t)}{cos(\theta_i) + \sqrt{\epsilon_r} cos(\theta_t)} \quad (5.32)$$

$$R_\parallel = \frac{\sqrt{\epsilon_r} cos(\theta_i) - cos(\theta_t)}{\sqrt{\epsilon_r} cos(\theta_i) + cos(\theta_t)} \quad (5.33)$$

$$T_\perp = \frac{2cos(\theta_i)}{cos(\theta_i) + \sqrt{\epsilon_r} cos(\theta_t)} \quad (5.34)$$

$$T_\parallel = \frac{2cos(\theta_i)}{\sqrt{\epsilon_r} cos(\theta_i) + cos(\theta_t)} \quad (5.35)$$

where $\theta_i$ is the angle of incidence measured from the face normal, and $\theta_t$ is the angle given by Snell's law of refraction:

$$sin(\theta_i) = \sqrt{\epsilon_r} sin(\theta_t) \quad (5.36)$$

## 5.9 Roughness Correction

To account for the decrease in the reflected energy in the specular direction, the reflection coefficient for a rough surface is determined using [2]:

$$R = R_0 exp\left[ -8\left(\frac{\pi(\triangle h)cos\theta_i}{\lambda_0}\right)^2\right] \quad (5.37)$$

where

$R_0$ is the smooth surface coefficient

$\theta_i$ is the angle of incidence

$\triangle h$ is the standard deviation in the surface height about the mean height, and corresponds to the roughness parameter that is entered in the GUI for roughness

$\lambda_0$ is the wavelength

The same roughness correction is used for both sides of a double-sided face. The transmission coefficients are unaffected by the surface roughness.

## 5.10 Data Sources for Materials

Reliable measured values for the permittivity and conductivity of common materials over the VHF and UHF bands are just now becoming available. However, some values that are frequently quoted in the literature may have obtained more validity than they deserve simply by repetition. It is also important to be aware that there is, at present, no good model for the frequency dependence of any building material (concrete, brick, glass, wood, etc.), so it is impossible to confidently extrapolate from values measured at one frequency to a significantly higher or lower frequency.

- Some sources for material permittivity and conductivity include [1], [3], [4], [5], [6], [7], [8], [9, Ch. 3], [10], and [11].

While it would be preferable if accurate angle-dependent coefficients could be assigned to every surface, this is unfortunately rarely possible. However, fairly accurate predictions can often still be obtained without precise information of the material properties of each object. The permittivity is sometimes considered to be the sole adjustable parameter through which a ray-based model can be “tuned” to give the best agreement with measurements. If the *Dielectric Half-Space* Material type is used, the conductivity will not usually be important, but if the dielectric layer coefficients are used with a realistic thickness, it will be important to enter a reasonably accurate value for the conductivity. For simulations of propagation in an environment where transmissions are important, an accurate conductivity should always be specified.

- Formulas for the reflection and transmission coefficients for a finite thickness dielectric layer containing a regular mesh of reinforcing bar are presented in [3]. These coefficients can be imported into XGtd by using the *User-Defined* Material.

# Chapter 6

# Waveforms

*In this chapter, you will learn...*

→ how to define a waveform

→ each waveform type and its properties

The WAVEFORMS in XGtd allow the user to enter parameters which describe the time and frequency dependence of the signal radiated from the transmitting ANTENNA. The waveform also acts as a kind of bandpass filter at the RECEIVER.

With the exception of the *Gaussian Derivative* and *User-Defined* Waveforms, all waveforms are modulated to a carrier frequency. Parameters such as pulse width and excess bandwidth factor control the time-domain envelope of the waveform. Once a waveform is defined, it may be assigned to any antenna, transmitter set or receiver set. Waveforms may also be saved to the waveform database for use in other projects.

## 6.1 Creating a Waveform

A WAVEFORM can be created by selecting *Project→New→Waveform* and choosing from the list of waveform types presented. To access the waveforms, click on the WAVEFORMS tab in the MAIN WINDOW, as seen in Figure 6.1.

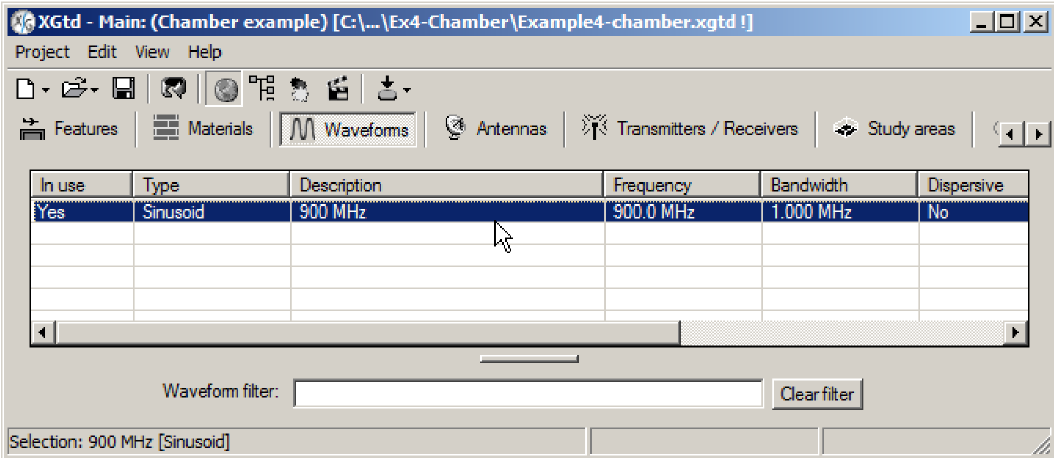


Figure 6.1: The Waveform Table in the Main Window

Right-click on a waveform in this tab to access a context menu with the following options:

- *Copy to personal database* - Places a copy of the selected waveform into the waveform database for use in other XGtd projects.
  - ▶ See Chapter 14 for more information on the waveform database.
- *Duplicate* - Creates a copy of the selected waveform in the current project.
- *Delete* - Removes the selected waveform from the project.
- *Replace* - Assigns a different waveform to all transmitter sets, receiver sets, and antennas in the project which reference the selected waveform.
- *Export time domain envelope* - Writes time-domain samples of the waveform to a file.
- *Plot*
  - *Time domain* - Plots the time domain envelope of the selected waveform.
  - *Frequency* - Plots the selected waveform in the frequency domain.
- *Properties* - Accesses the properties of the selected waveform.

## 6.2 Waveform Types

Many commonly used pulse shapes are available including:

- *Blackman* envelope
- *Chirp*
- *Gaussian*
- *Gaussian Derivative*

- *Hamming* envelope
- *Hanning* envelope
- *Raised Cosine*
- *Root Raised Cosine*
- *Sinusoid*
- *Tukey* envelope

Alternatively, a *User-Defined* Waveform file may be specified which contains time- or frequency-domain samples.

▶ A description of this file format is given in the Section 6.2.10.

Plots of the waveform versus time and versus frequency, as seen in Figure 6.2, are available by clicking on the drawer button on the right-hand side of the properties window. The APPLY button causes the plots to redraw in the properties window and display any changes to the waveform.

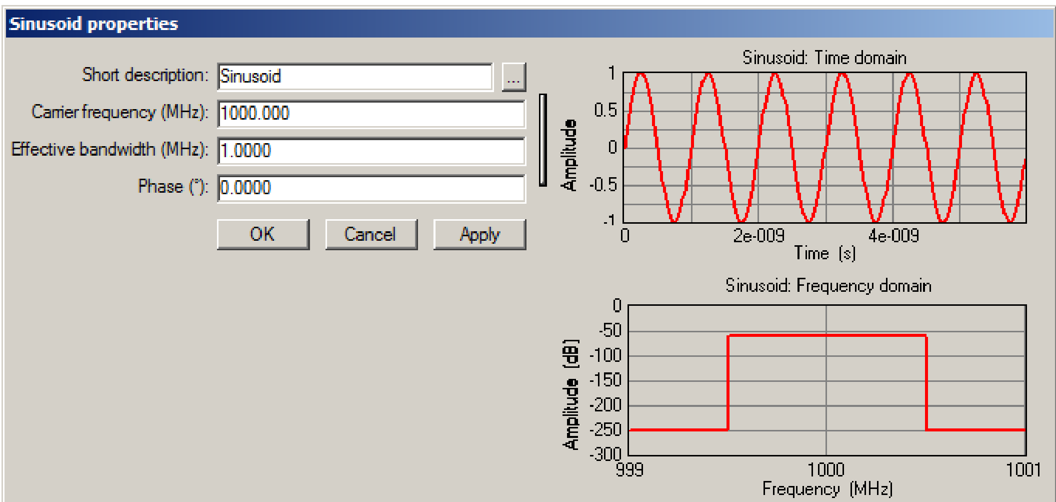


Figure 6.2: The Waveform Properties Window for a Sinusoid Waveform

The *Carrier frequency* may be specified for all waveforms except *Gaussian Derivative* and *Chirp* pulse, which are not modulated, and the *User-Defined* Waveform. The *Pulse width* specifies the time duration of all waveforms except the *Sinusoid* and *User-Defined* Waveforms.

✓ The bandwidth of a waveform, which is determined by the pulse width, must not exceed twice the carrier frequency.

The *Phase* field specifies the phase shift of all waveforms except *Gaussian Derivative*, *Chirp*, and *User-Defined*. The *Dispersive* checkbox controls how certain output types are generated when calculations are performed. Additionally, some WAVEFORM PROPERTIES Windows contain entries for parameters specific to that waveform type.

▶ See Chapter 11 for more information regarding generating output types.

### 6.2.1 Blackman

The BLACKMAN WAVEFORM PROPERTIES Window is shown in Figure 6.3.

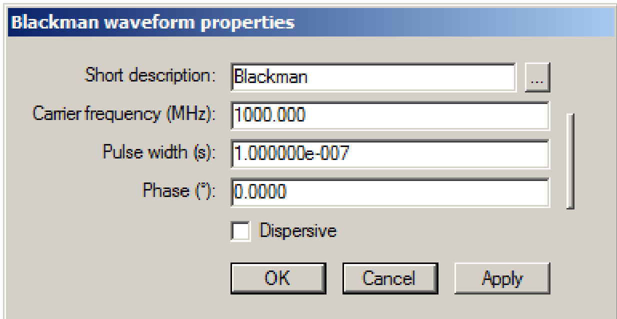


Figure 6.3: The Blackman Waveform Properties Window

The *Blackman* envelope is defined by:

$$0.42 - \frac{1}{2}cos\left(\frac{2\pi t}{\tau}\right) + 0.08cos\left(\frac{4\pi t}{\tau}\right) \tag{6.1}$$

where $\tau$ is the pulse width and $0 \leq t \leq \tau$. [12]

### 6.2.2 Chirp

The CHIRP WAVEFORM PROPERTIES Window is shown in Figure 6.4.

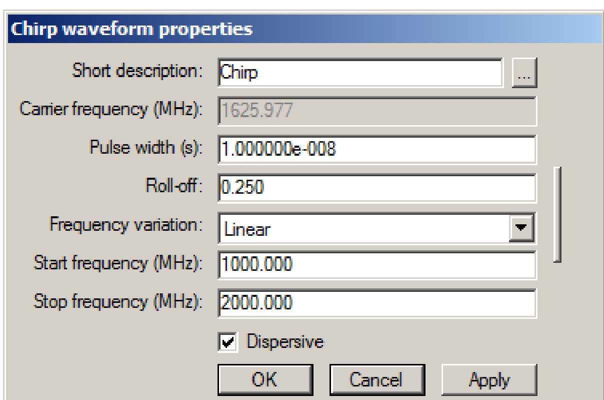


Figure 6.4: The Chirp Waveform Properties Window

The linear *Chirp* pulse is defined by:

$$P_{RC}(t)sin\left(2\pi f_0 + \frac{2\pi(f_1 - f_0)}{2T}t\right)t \tag{6.2}$$

for $0 \leq t \leq T$.

The exponential *Chirp* pulse is defined by:

$$P_{RC}(t) sin\left(2\pi\left(\frac{T}{ln(f_1 - f_0)}\left(f_0\left(\frac{f_1}{f_0}\right)^{\frac{t}{T}} - f_0\right)\right)\right) \quad (6.3)$$

for $0 \leq t \leq T$, where $T$ is the pulse width, $f_0$ is the start frequency, $f_1$ is the stop frequency, and $P_{RC}(t)$ is defined by:

$$P_{RC}(t) = \begin{cases} \frac{1}{2}\left[1 + cos\left(\frac{(1+\beta)\pi}{\beta T}\left(t - \frac{\beta T}{1+\beta}\right)\right)\right] & \text{for } 0 \leq t \leq \frac{\beta T}{1+\beta} \\ 1 & \text{for } \frac{\beta T}{1+\beta} \leq t \leq \frac{T}{1+\beta} \\ \frac{1}{2}\left[1 + cos\left(\frac{(1+\beta)\pi}{\beta T}\left(t - \frac{T}{1+\beta}\right)\right)\right] & \text{for } \frac{T}{1+\beta} \leq t \leq T \\ 0 & \text{otherwise} \end{cases} \quad (6.4)$$

where $0 \leq \beta \leq 1$ is the roll-off factor.

Up-chirp waveform is obtained when $f_0 < f_1$, while down-chirp waveform is obtained when $f_0 > f_1$. The Chirp pulse has no specific carrier frequency. Consequently, the Chirp pulse always generates output using the dispersive option. The Chirp pulse properties window displays the frequency with maximum amplitude in the *Carrier frequency* field.

### 6.2.3 Gaussian

The GAUSSIAN WAVEFORM PROPERTIES Window is shown in Figure 6.5.

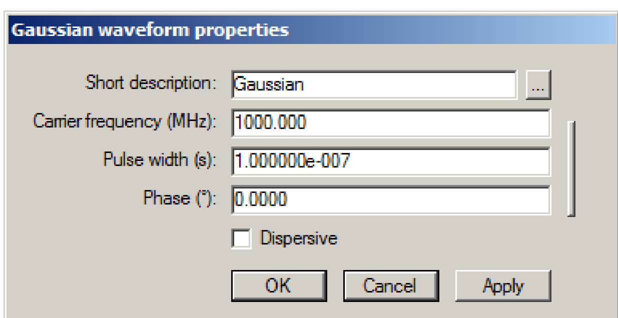


Figure 6.5: The Gaussian Waveform Properties Window

The *Gaussian* pulse is defined by:

$$exp[-\alpha(t-\tau)^2] \tag{6.5}$$

for $0 \leq t \leq 2\tau$, where $\tau$ is the pulse width and $\alpha = \frac{16}{\tau^2}$. [13]

The pulse will exist from $t = 0$ until $t = 2\tau$; it is approximated as zero outside this range, with a peak value at $t = \tau$. The value at truncation ($t = 0$ and $t = 2\tau$) is determined by $\alpha$, and the Gaussian pulse at truncation will have a value $exp(-\alpha\tau^2)$ down from the maximum value. With $\alpha = \frac{16}{\tau^2}$, the value at truncation will be $e^{-16}$, approximately 140 dB down from peak.

### 6.2.4 Gaussian Derivative

The GAUSSIAN DERIVATIVE WAVEFORM PROPERTIES Window is shown in Figure 6.6.

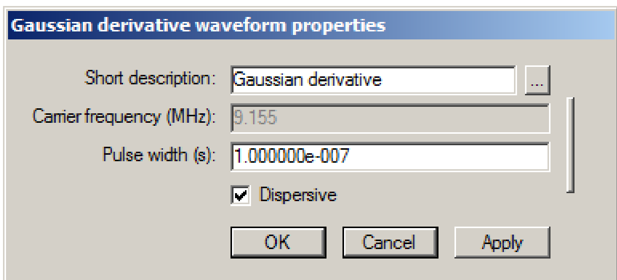


Figure 6.6: The Gaussian Derivative Waveform Properties Window

The *Gaussian Derivative* pulse is defined by:

$$-2\sqrt{\frac{e}{2\alpha}}\alpha(t-\tau)exp[-\alpha(t-\tau)^2] \tag{6.6}$$

for $0 \leq t \leq 2\tau$, where $\tau$ is the pulse width and $\alpha = \frac{16}{\tau^2}$.

The pulse will exist from $t = 0$ until $t = 2\tau$; it is approximated as zero outside this range. As a broadband pulse, the *Gaussian Derivative* Waveform has no specific carrier frequency. Consequently, the Gaussian Derivative always generates output using the dispersive option. The GAUSSIAN DERIVATIVE PROPERTIES Window displays the frequency with maximum amplitude in the *Carrier frequency* field.

### 6.2.5 Hamming

The HAMMING WAVEFORM PROPERTIES Window is shown in Figure 6.7.

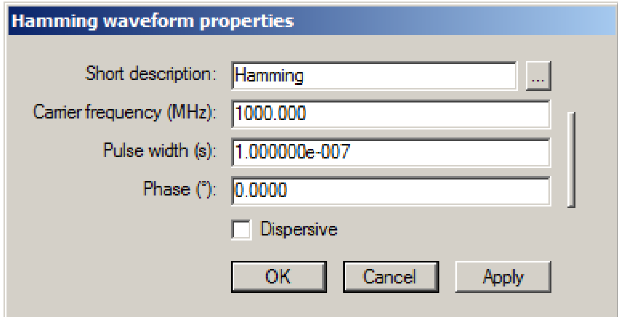


Figure 6.7: The Hamming Waveform Properties Window

The *Hamming* envelope is defined by:

$$0.54 - 0.46cos\left(\frac{2\pi t}{\tau}\right) \tag{6.7}$$

where $\tau$ is the pulse width and $0 \leq t \leq \tau$. [12]

### 6.2.6 Hanning

The HANNING WAVEFORM PROPERTIES Window is shown in Figure 6.8.

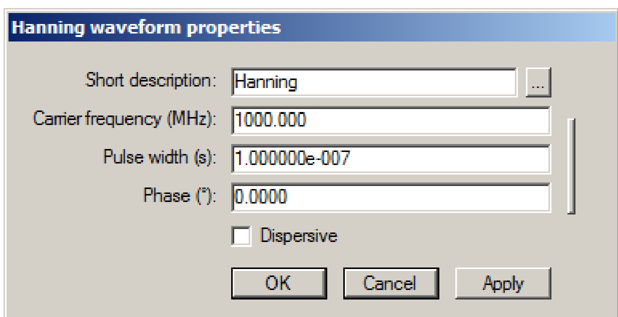


Figure 6.8: The Hanning Waveform Properties Window

The *Hanning* envelope is defined by:

$$0.5 - 0.5cos\left(\frac{2\pi t}{\tau}\right) \tag{6.8}$$

where $\tau$ is the pulse width and $0 \leq t \leq \tau$. [12]

### 6.2.7 Raised Cosine and Root Raised Cosine Pulses

The RAISED COSINE PROPERTIES Window is shown in Figure 6.9. The *Root Raised Cosine* properties window is nearly identical.

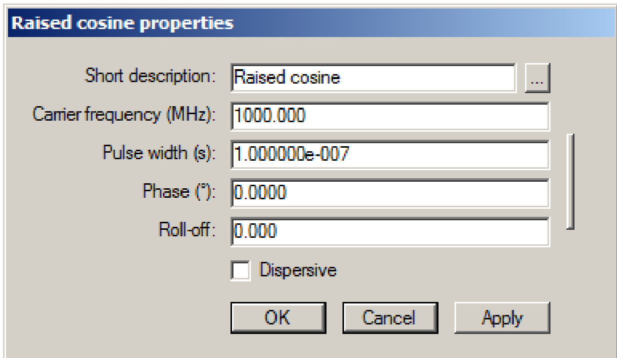


Figure 6.9: The Raised Cosine Properties Window

The *Raised Cosine* pulse [14] is defined by:

$$sinc\left(\frac{\pi t}{\tau}\right)\frac{cos\left(\frac{\pi\beta t}{\tau}\right)}{\frac{1-4\beta^2t^2}{\tau^2}} \tag{6.9}$$

and the *Root Raised Cosine* [15] by:

$$\frac{4\beta cos\left[\frac{(1+\beta)\pi t}{\tau}\right]+sin\left[\frac{(1-\beta)\pi t}{\tau}\right]\left(\frac{4\beta t}{\tau}\right)^{-1}}{\pi\sqrt{\tau}\left[\frac{1-16\beta^2t^2}{\tau^2}\right]} \tag{6.10}$$

where $\tau$ is the pulse width and $0 \leq \beta \leq 1$ is the excess bandwidth roll-off factor. In order to ensure a causal system, the Raised Cosine pulse is typically delayed by $3\tau$ and truncated at $6\tau$.

### 6.2.8 Sinusoid

Although the *Sinusoid* Waveform continues infinitely in the time-domain, it is modeled by a flat power spectral density over its effective bandwidth $B << f_c$. Thus, the transmitted power of the *Sinusoid* is uniform over $B$ Hz, centered at $f_c$. Receiver sets use waveform information as a front-end bandpass filter, with uniform response over the band $B$ Hz wide, centered at $f_c$. The purpose of specifying the effective bandwidth $B$ is to allow calculation of the carrier-to-interferer ratio when transmitted waveforms overlap. An initial phase offset, $\theta_0$ in degrees, is also permitted.

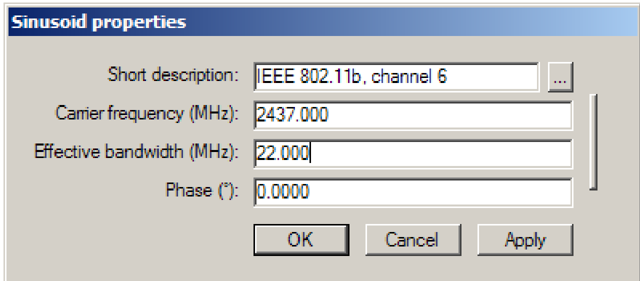


Figure 6.10: Sinusoid Waveform Properties Window

Mathematically, the *Sinusoid* is defined by

$$s(t) = sin(2\pi f_c t + \theta_0) \tag{6.11}$$

And

$$S(f) = \begin{cases} \frac{1}{B} & \text{for } f_c - \frac{B}{2} < f < f_c + \frac{B}{2} \\ 0 & \text{otherwise} \end{cases} \tag{6.12}$$

Lastly, because the *Sinusoid* is not time-limited, it cannot generate output using the dispersive option.

### 6.2.9 Tukey

The TUKEY WAVEFORM PROPERTIES Window is shown in Figure 6.11.

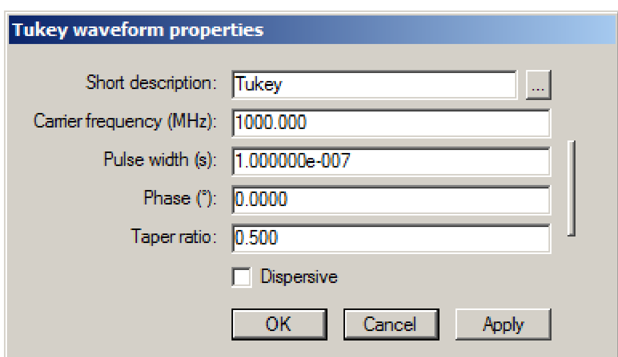


Figure 6.11: The Tukey Waveform Properties Window

The *Tukey* envelope is defined by:

$$
\begin{cases}
1 & \text{for } \left|t - \frac{\tau}{2}\right| \leq \alpha\frac{\tau}{2} \\[2ex]
\frac{1}{2}\left[1 + cos\left(\frac{\pi\left(t - \frac{(1+\alpha)\tau}{2}\right)}{\frac{(1-\alpha)\tau}{2}}\right)\right] & \text{for } \alpha\frac{\tau}{2} \leq \left|t - \frac{\tau}{2}\right| \leq \frac{\tau}{2} \\[2ex]
0 & \text{otherwise}
\end{cases}
\tag{6.13}
$$

where $\tau$ is the pulse width and $0 \leq \alpha \leq 1$ is the constant-to-taper ratio. When $\alpha = 0$, the envelope of the Tukey is that of a cosine, while $\alpha = 1$ is a flat square pulse. All other values of $\alpha$ provide a “tapered” sinusoidal shape which ramps up, remains flat, and ramps down to 0 again. [16]

### 6.2.10 User-Defined Waveform

The User-Defined Waveform Properties Window displays the specified filename and the frequency at which the maximum amplitude occurs. No additional modulation is performed on the waveform, and thus the carrier frequency cannot be specified through the user interface. The display of the waveform in both the time- and frequency-domains is provided as a reference by taking the FFT or IFFT, as necessary. All output generated using a *User-Defined* Waveform is performed dispersively.

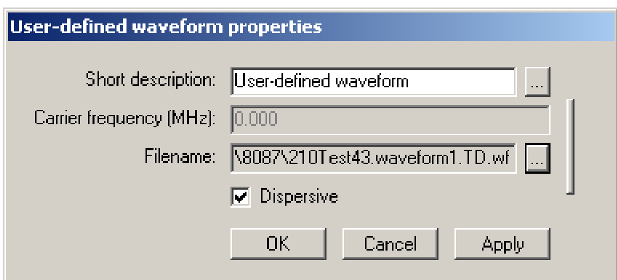


Figure 6.12: User-Defined Waveform Properties Window

When creating a *User-Defined* waveform, keep in mind the following guidelines:

- ✓ Time domain waveforms should start at 0 amplitude at (t=0) and should end at zero amplitude.
- ✓ It may be necessary to ramp up or down the amplitude at the start and end times to avoid high frequency components in the FFT.
- ✓ The minimum sampling rate for time domain waveforms should be the period/10.

# Chapter 7

# Antennas

*In this chapter, you will learn...*

→ how to create and define an antenna

→ the types of antennas and patterns available in XGtd

→ how to plot an antenna pattern

Propagation calculations in XGtd require both TRANSMITTERS and RECEIVERS, each with an associated ANTENNA and WAVEFORM. When an antenna is added to a project and its parameters are set using the ANTENNA PROPERTIES Window, it can be used in multiple instances by associating it with any number of transmitters and/or receivers. Each time the antenna is assigned to a transmitter or receiver set, it becomes a new "copy" of the antenna. The location, orientation, and polarization of the antenna are set by the location of the associated transmitter or receiver and the rotation angles about $X$-, $Y$-, and $Z$-axes for each association of the antenna with a transmitter or receiver. The coordinate system used for these rotations is shown in Figure 7.1. These rotations are specified in the TRANSMITTER/RECEIVER PROPERTIES Window.

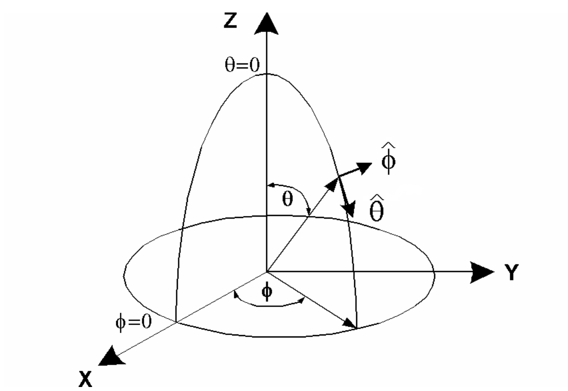


Figure 7.1: The XGtd spherical coordinate system

Any number of different types of antennas can be added to the project to simulate real-world scenarios or to test the effects that different antennas have on propagation performance. Antennas may also be saved to the antenna database for use in other projects.

## 7.1 Creating an Antenna

To add a new ANTENNA to an existing project, select *Project→New→Antenna* and choose from the list of antenna types presented, as seen in Figure 7.2. If you have added an antenna to the database, it will also be available from the database window by selecting *Add to Project* from the context menu.

▶ See Chapter 14 for more information on the antenna database.

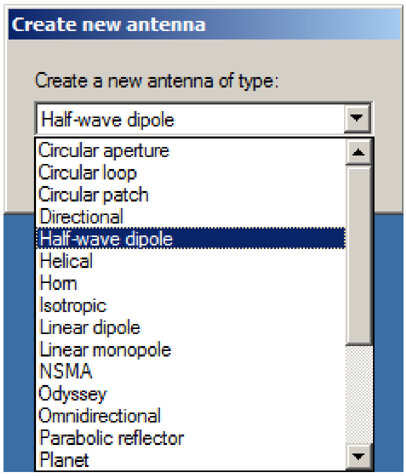


Figure 7.2: Adding a new antenna to the project

After selecting an antenna, the ANTENNA PROPERTIES Window will appear. The properties windows includes parameters specific to that antenna type. To access the antennas after they are created, click on the ANTENNAS tab in the MAIN WINDOW.

## 7.2 Antenna Properties

All of the ANTENNAS used in a XGtd calculation include a set of common parameters used to define the antenna and some immediate system parameters. They are:

- Gain (maximum gain)
- Waveform
- Transmission line loss

The the ANTENNA PARAMETERS Window, seen in Figure 7.3, allows the user to enter the antenna characteristics. The WAVEFORM associated with the antenna can be selected from a pull-down menu of the waveforms already defined in the project or by clicking the "..." button and defining a new waveform. In the TRANSMITTER/RECEIVER PROPERTIES Window, the antenna waveform selection can be overridden or the antenna's waveform may be selected.

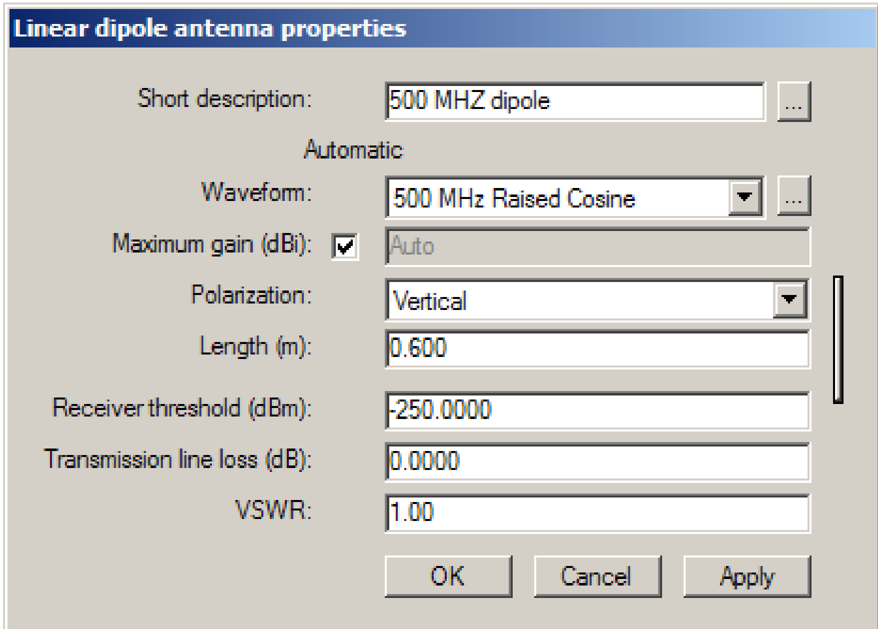


Figure 7.3: Properties for the Linear Dipole Antenna

The remaining shared antenna parameters are summarized below.

- *Maximum gain* - Sets the maximum gain of the ANTENNA to the value listed in the field. It is possible to enter nonphysical gain values for an antenna, so the user is responsible for realistic manual entries. User-defined antennas have additional options for setting the maximum gain that are detailed in section 7.5.1.1.

- *Receiver threshold* - Determines which individual ray paths to ignore when evaluating the power at a RECEIVER point. Ray paths are ignored when their power falls beneath this value.

- *Transmission line loss* - Simulates line losses, return losses, feed losses, or other system losses between the TRANSMITTER or RECEIVER and its ANTENNA. The number entered here is taken as a loss (in dB) and has the effect of reducing signal strength between antenna and Tx/Rx, whether it is entered as a negative or positive number.

- *VSWR* - Defines the Voltage Standing Wave Ratio (VSWR) that must be greater than or equal to 1, with 1 representing a perfect impedance match between the ANTENNA and transmission line resulting in no addition loss. VSWR values greater than 1 will result in an additional mismatch loss during the calculation of received power:

$$Mismatch\ loss(dB) = 10log_{10}\left[1 - \left(\frac{VSWR-1}{VSWR+1}\right)^2\right] \quad (7.1)$$

### 7.2.1 Maximum Gain

The *Maximum gain* in the ANTENNA PROPERTIES Window allows the automatically calculated gain of an antenna pattern to be overriden with a user specified value. In general, FULL3D, will set the maximum antenna component, $\theta$ or $\phi$, to the *maximum gain*. Details of the calculations are presented below.

With the distance dependence suppressed, the far zone electric field of the antenna can be expressed as:

$$E(\theta,\phi) = f_\theta(\theta,\phi)\hat{e}_\theta + f_\phi(\theta,\phi)\hat{e}_\phi \tag{7.2}$$

where $E(\theta,\phi)$ has been normalized such that the larger of either $|f_\theta(\theta,\phi)|$ or $|f_\phi(\theta,\phi)|$ has a maximum value of 1. The maximum gain (and directivity) is then defined to be:

$$G_{max} = \frac{4\pi}{\left[\int \; |f_\theta(\theta,\phi)|^2 + |f_\phi(\theta,\phi)|^2 \; d\Omega\right]} \tag{7.3}$$

and the maximum gain in dBi is $G_{max}[dBi] \;=\; 10log_{10}(G_{max})$.

If the *Automatic* box next to this field is unchecked and a value is entered, $G_{max}[dBi]$ will be set to the user specified value.

Once the maximum gain is set, either by the above calculation or to the value entered by the user, the components of the gain pattern in dBi are calculated from:

$$G_\theta(\theta,\phi) = 10log_{10}\left[G_{max}\,|f_\theta(\theta,\phi)|^2\right] = 10log_{10}\left[\;|f_\theta(\theta,\phi)|^2\right] \;+\; G_{max}[dBi] \tag{7.4}$$

$$G_\phi(\theta,\phi) = 10log_{10}\left[G_{max}\,|f_\phi(\theta,\phi)|^2\right] = 10log_{10}\left[\;|f_\phi(\theta,\phi)|^2\;\right] \;+\; G_{max}[dBi] \tag{7.5}$$

#### Maximum Gain for X3D

For X3D, the pattern is normalized such that the maximum magnitude of the complex vector $E(\theta,\phi)$ in equation 7.2 in the direction of the maximum total gain is 1. The direction where $|E| = 1$ is the direction of the *maximum gain*. The *maximum gain* is also calculated from equation 7.3. Once the maximum gain is set, either by the above calculation or to the value entered by the user, the components of the gain pattern in dBi are calculated from equations 7.4 and 7.5.

### 7.2.2 Antenna Arrays

ANTENNA arrays can be created from any antenna. XGtd uses the amplitude, phase, and relative location of each element to create a combined antenna pattern that users can assign to a single TRANSMITTER, RECEIVER, or TRANSCEIVER. Antenna arrays do not treat each antenna element as independent. Instead, the combined effect of the array is represented as a single antenna pattern. Antenna arrays can be specified by clicking on EDIT ARRAY in the ANTENNA PROPERTIES window. This will bring up the window shown in Figure 7.4. In this window, begin specifying points by selecting *New array point* from the table's context menu. After selecting an element, the user can edit it by double-clicking on the point. Users can also delete points by choosing *Delete* from the context menu.

### Array point properties

Users can specify the following properties of an array point:

- *Amplitude and Phase* - The amplitude represents a scaling factor that is applied to the gain of the elements antenna pattern. The phase represents a relative phase offset between the elements in the array.
- $X$, $Y$ *and* $Z$ *position* - This is an offset from the origin of the antenna indicating where the point is located within the array.

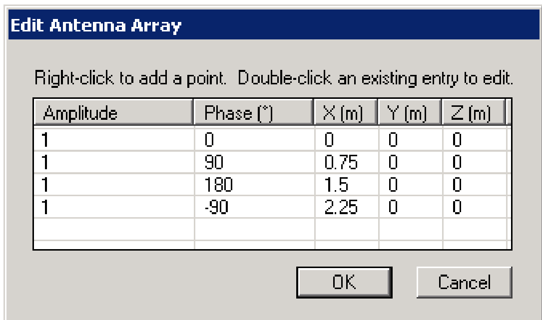


Figure 7.4: The Edit Antenna Array Window, used to create the antenna array in Figure 7.5

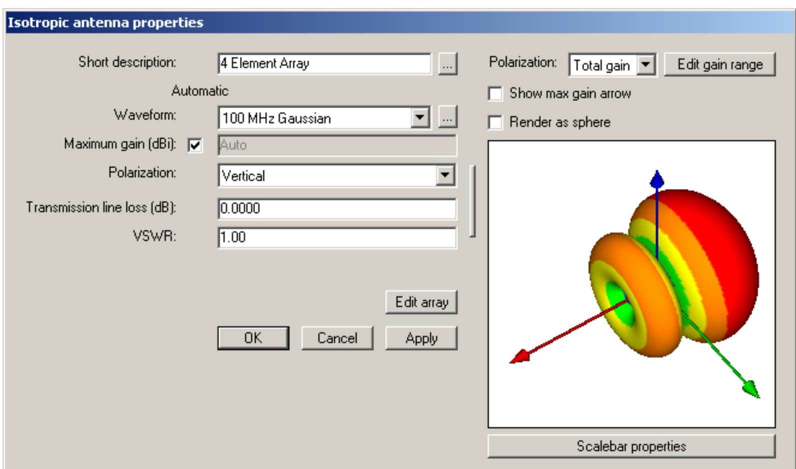


Figure 7.5: The radiation pattern for an array of four isotropic elements

## 7.3 Antenna Types

XGtd has several choices for the ANTENNAS used in a simulation. The antenna patterns can be generated from:

- **Built-in models**
  - *Short Dipole*
  - *Short Monopole*
  - *Linear Dipole*
  - *Half-Wave Dipole*
  - *Linear Monopole*
  - *Quarter-Wave Monopole*
  - *Axial Mode Helix*
  - *Circular and Square Loops*
  - *Circular and Rectangular Apertures*
  - *Circular and Rectangular Patch*
  - *Horn* - pyramidal, E-plane sectoral, H-plane sectoral
  - *Parabolic Reflector*
  - *Directional*
  - *Omnidirectional*
  - *Isotropic*
- **User-Defined and Imported Patterns**
  - *NSMA*
  - *Planet*
  - *Odyssey*
  - *XFdtd*

▶ Sections 7.4 and 7.5 describe each antenna type in XGtd.

## 7.4 Built-in Antennas

There are several built-in choices for the ANTENNAS used in a simulation. For each, the antenna dialog requests only a few parameters from the user, and the patterns are generated automatically for both propagation calculations and plotting.

The models used for these pattern calculations are approximate. In each case, a reference is included for further information on how the pattern was calculated.

Each of the built-in ANTENNAS in XGtd is in one of two groups: **Freestanding** or **Ground-plane mounted**. The following sections describe the antennas in each classification.

### 7.4.1 Freestanding Antennas

The freestanding ANTENNAS include:

- *Dipoles*
- Pyramidal *Horn*
- *Parabolic Reflector*
- *Circular Loop*
- *Square Loop*
- *Axial Mode Helix*
- *Directional*
- *Omnidirectional*
- *Isotropic*

For *Dipoles*, if vertical polarization is selected, the wire is along the $Z$-axis with the omnidirectional E-plane pattern in the $XY$ plane. If horizontal polarization is chosen, the wire is along the $Y$-axis and the omnidirectional E-plane pattern is in the $ZX$ plane. The other types of freestanding antennas, *Horns* and *Parabolic Reflectors*, have a default orientation such that the main beam is $X$-directed.

▶ The polarizations for these antennas are described in the next several sections.

*Circular Loop* and *Square Loop* Antennas are considered freestanding, but do not allow polarization to be defined as an antenna parameter. By default, these antennas lie in the $XY$ plane. The orientation used in the simulation is achieved by rotating the associated TRANSMITTER or RECEIVER.

The remaining freestanding antenna is an *Axial Mode Helix*. The axis of the helix is along the $X$-axis by default and produces a circularly-polarized main beam along the $X$-axis.

#### 7.4.1.1 Short Dipole

This antenna is also called the *Infinitesimal Dipole* and is ideal in the mathematical sense. Its length is much less than one wavelength. It generates a field proportional to sin($\theta$). If the antenna *Polarization* is set to "Vertical," its orientation is along the $Z$-axis and the main beam is omnidirectional in the $XY$ plane. Selecting "Horizontal" polarization will rotate the antenna about the $X$-axis by 90° so that it will lie along the $Y$-axis and the main beam is omnidirectional in the $ZX$ plane.

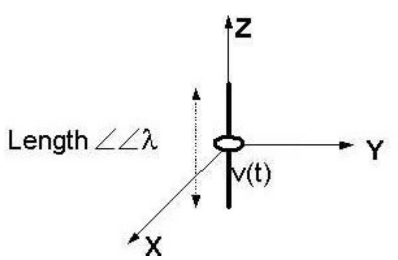


Figure 7.6: Vertically-polarized Short Dipole Antenna

#### 7.4.1.2 Linear Dipole

For the *Linear Dipole*, the user sets the antenna *Length* and *Polarization* in the ANTENNA PROPERTIES Window, seen in Figure 7.7. The wire is considered thin with respect to a wavelength. The excitation is considered to be a truncated sinusoidal current distribution.

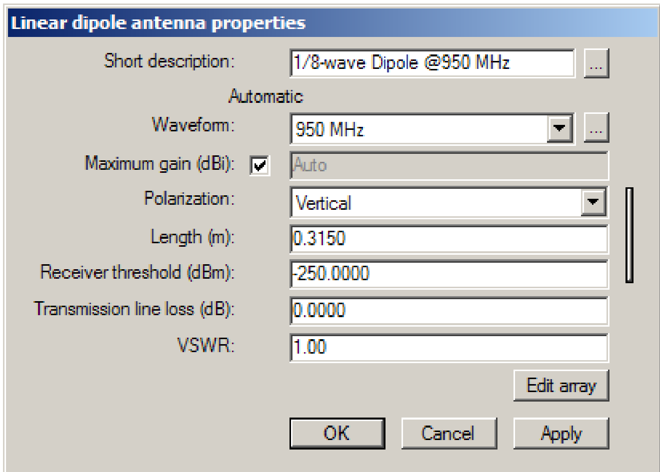


Figure 7.7: Properties window for a Linear Dipole Antenna

If the antenna *Polarization* is set to “Vertical”, its orientation is along the $Z$-axis and the main beam is omnidirectional in the $XY$ plane. Selecting “Horizontal” polarization will rotate the antenna about the $X$-axis by 90° so the antenna will lie along the $Y$-axis and the main beam is omnidirectional in the $ZX$ plane.

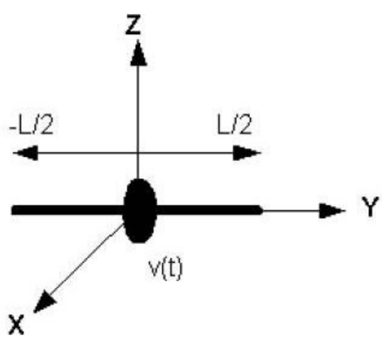


Figure 7.8: Horizontal Linear Dipole Antenna

#### 7.4.1.3 Half-Wave Dipole

The length of the *Half-Wave Dipole*, seen in Figure 7.9, is automatically adjusted to be one-half wavelength at the waveform frequency. The wire is considered thin with respect to a wavelength. The polarization is set in the ANTENNA PROPERTIES Window. If the antenna *Polarization* is set to “Vertical,” its orientation is along the $Z$-axis and the main beam is omnidirectional in the $XY$ plane. Selecting "Horizontal" polarization will rotate the antenna about the $X$-axis by 90° so the antenna will lie along the $Y$-axis and the main beam is omni-directional in the $XZ$ plane.

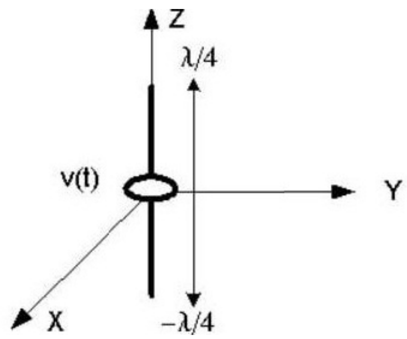


Figure 7.9: Vertical Half-Wave Dipole Antenna

#### 7.4.1.4 Horn

The *Horn* is a freestanding antenna, as shown in Figure 7.10. It is assumed to be made of perfect electrical conductor (PEC). The input parameters, entered through the ANTENNA PROPERTIES Window, are the *Aperture dimensions*, *Feed dimensions*, and the distance from the feed aperture to the horn aperture (*Feed-aperture length*). With these parameters, users can define a pyramidal horn, E-plane sectoral horn, or H-plane sectoral horn based on flare angles of the horn and the polarization. [17, p. 682]

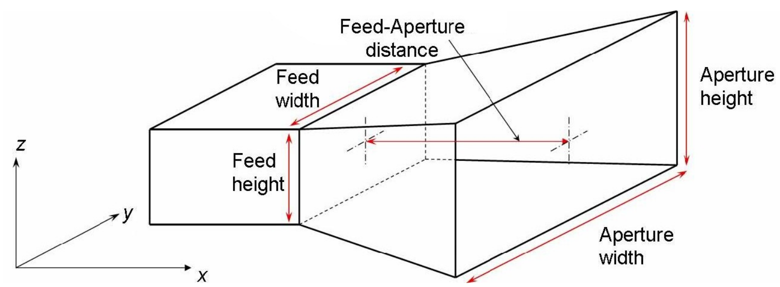


Figure 7.10: Description of a Horn Antenna

The default orientation of the *Horn* aligns the main beam with $X$ direction. The antenna can be oriented in the project by entering the appropriate rotations in the TRANSMITTER/RECEIVER PROPERTIES Window. Pyramidal *Horns* are created when the horn has nonzero flare angles in both the E and H-planes. E-plane and H-plane sectoral horns are created when the *Horn* flares in only one plane. For E-plane sectoral horns, the flare angle of the horn is parallel to the E-Plane or polarization. H-plane sectoral horns are created when the horn flare is perpendicular to the E-plane. If the antenna *Polarization* is set to "Vertical," the horn E-plane lies in the $XZ$ plane for the default orientation. "Horizontal" polarization aligns the E-plane with the $XY$ plane. Diagrams of an E-plane and H-plane sectoral horn, assuming the E-plane is in the $XZ$ plane, are shown in Figure 7.11.

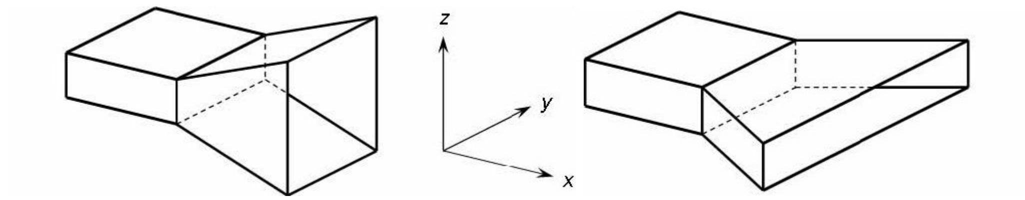


Figure 7.11: Sectoral Horns aligned to the E-plane (left) and the H-plane (right

Figure 7.12 shows a HORN ANTENNA PROPERTIES Window defining a Pyramidal *Horn*. The resulting 2D cut plane pattern produced using the *Plot pattern* function is shown in Figure 7.13.

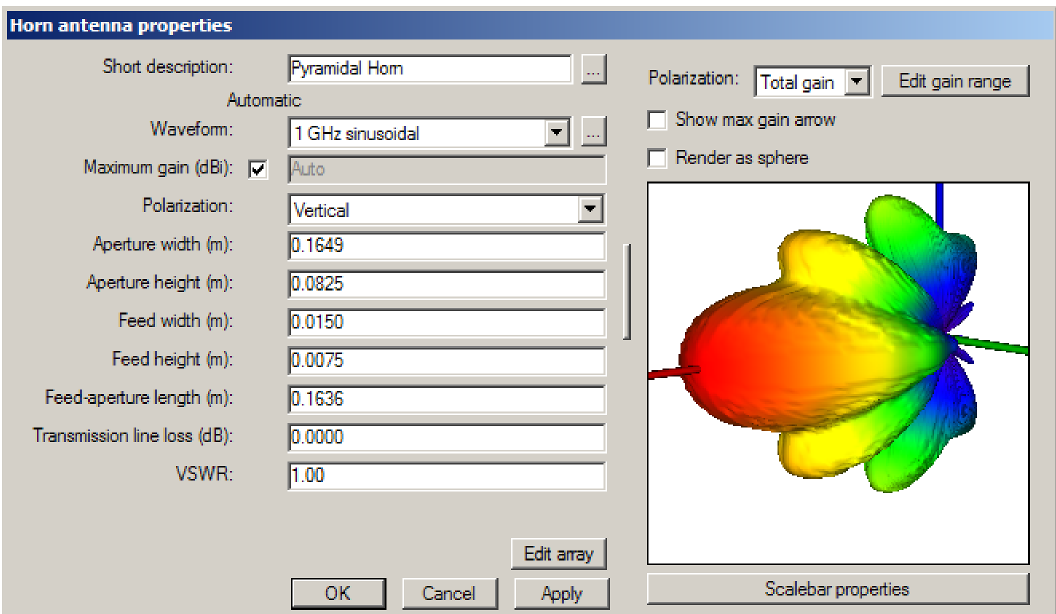


Figure 7.12: Properties for a Horn Antenna configured as a Pyramidal

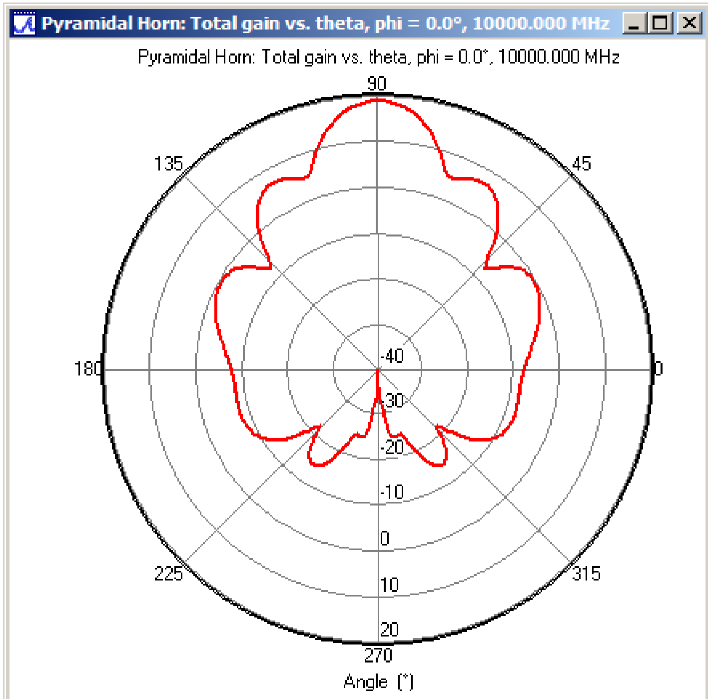


Figure 7.13: Plot of the Horn Antenna pattern

#### 7.4.1.5 Circular Loop

This antenna is a single continuous loop of wire that is thin compared to a wavelength. A uniform, in-phase current is assumed on the loop. The loop radius is set in the ANTENNA PROPERTIES Window. For the default antenna polarization, "Vertical," as seen in Figure 7.14, the loop lies in the $XY$ plane with the normal to the loop being the $Z$-axis. This produces an omnidirectional field pattern in the $XY$ plane. To operate the antenna in the "Horizontal" polarization, the associated transmitter is rotated to the desired direction in the TRANSMITTER PROPERTIES Window.

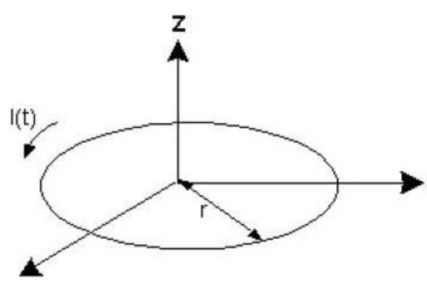


Figure 7.14: Circular Loop Antenna

#### 7.4.1.6 Square Loop

This antenna is a single continuous square loop of wire that is thin compared to a wavelength, as seen in Figure 7.15. A uniform, in-phase current is assumed on the loop. The dimension of the loop is $\frac{\lambda}{4}$ or the perimeter is $1\lambda$ at the frequency of the associated waveform. The loop lies in the $XY$ plane and produces an omnidirectional pattern in the $YZ$ plane.

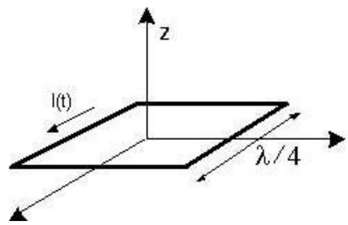


Figure 7.15: One wavelength-long Square Loop Antenna

#### 7.4.1.7 Axial Mode Helix

The *Axial Mode Helix* is a single continuous monofilar circular helix of wire that is thin compared to a wavelength. The antenna is assumed to be mounted on a finite ground plane [18]. The input parameters, entered through the ANTENNA PROPERTIES Window, are the helix *Radius*, *Length* and *Pitch (turns/meter)*. The antenna *Polarization* is “Circular.” Both “Left-hand” and “Right-hand” polarizations are available. The default orientation is in the $X$-direction. The orientation is associated with the transmitter’s and is adjusted through the TRANSMITTER PROPERTIES Window.

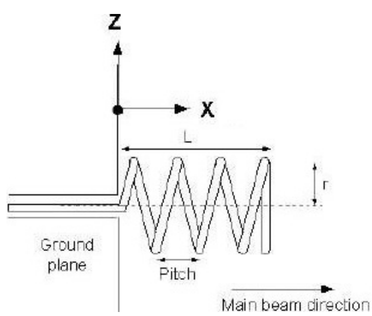


Figure 7.16: Default orientation of the Axial Mode Helix

#### 7.4.1.8 Parabolic Reflector

The *Parabolic Reflector* is a *Circular Aperture* with a particular field distribution and a finite amount of central blockage to simulate the antenna feed. The parabola can have one of three commonly used *Aperture distributions*: “Uniform,” “Parabolic,” or “Parabolic squared.” The main parameters, entered through the ANTENNA PROPERTIES Window, are the parabola *Radius*, the feed or central *Blockage radius*, the *Aperture distribution*, and the antenna *Polarization*. The default antenna orientation points the main beam in the $Z$-direction with linear polarization ($X$-directed). The desired orientation is set by rotating the associated transmitter(s) or receiver(s).

If the antenna *Polarization* is set to “Vertical” (default), the antenna E-plane lies in the $XZ$ plane. Setting the polarization to “Horizontal” will rotate the antenna about the $X$ axis by 90° to produce an E-plane pattern in the $XY$ plane. [19]

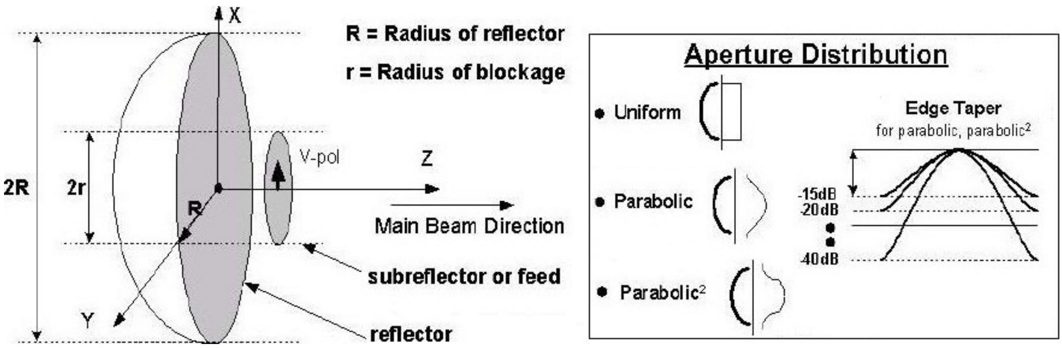


Figure 7.17: Description of a Parabolic Reflector Antenna

Shown below are the Parabolic Reflector Antenna Properties Window and the resulting antenna field pattern.

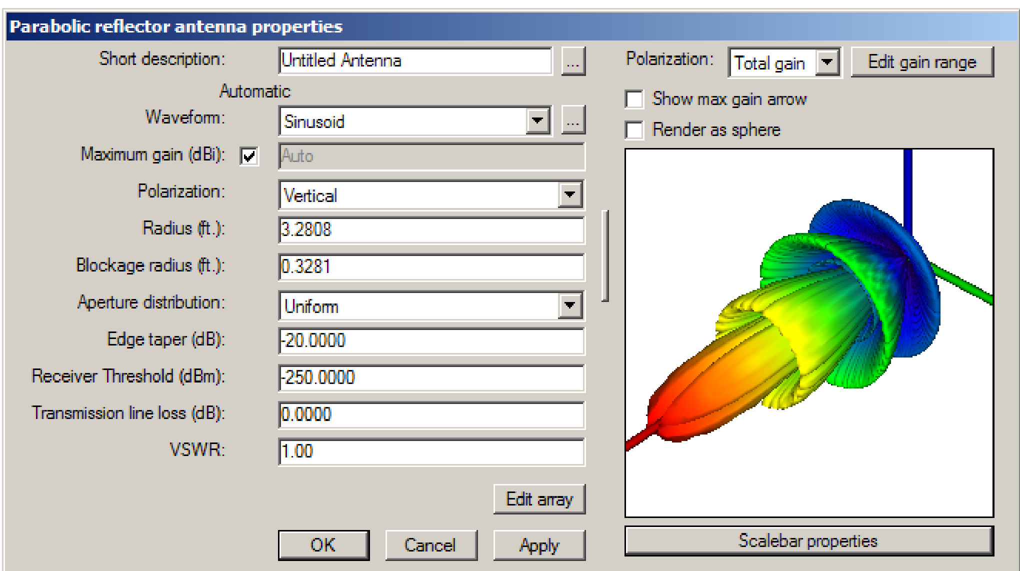


Figure 7.18: Properties of a Parabolic Reflector Antenna and the resulting gain pattern

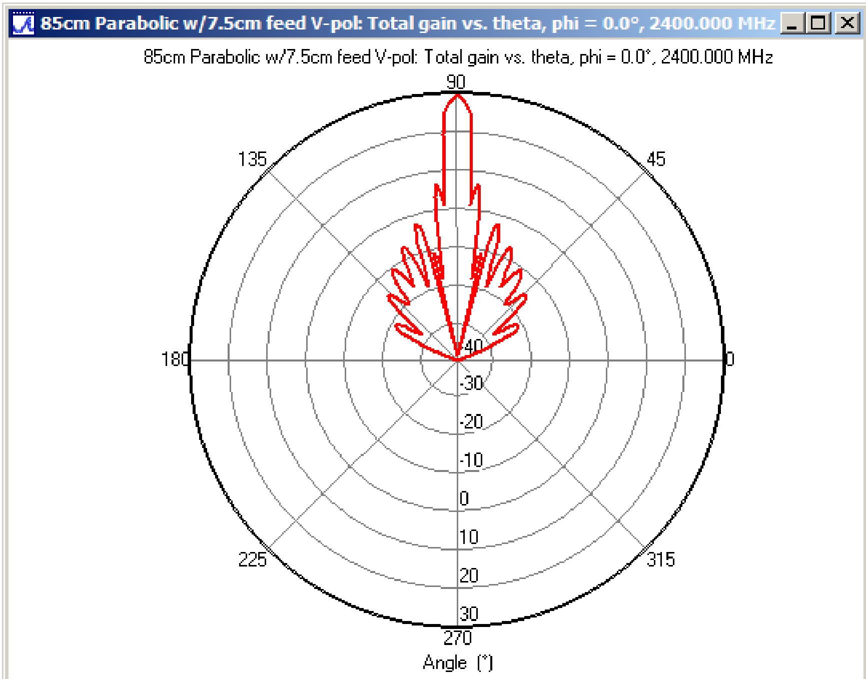


Figure 7.19: Plot of the Parabolic Reflector Antenna pattern

#### 7.4.1.9 Directional

The geometrically defined *Directional* antenna beam is one of the idealized antenna patterns in XGtd. It is not associated with any particular type of physical antenna, rather it is completely defined by the beamwidth parameters. The *Directional* antenna provides a simple means of defining the main beam of a high gain antenna while disregarding the sidelobes. It produces a beam pattern aimed along the $X$-axis.

This antenna pattern is specified by:

- *E-plane half-power beamwidth*
- *E-plane first null beamwidth*
- *H-plane half-power beamwidth*
- *H-plane first null beamwidth*

For “Circular” polarization, the beamwidth parameters are:

- *Vertical-plane half-power beamwidth*
- *Vertical-plane first null beamwidth*
- *Horizontal-plane half-power beamwidth*
- *Horizontal-plane first null beamwidth*

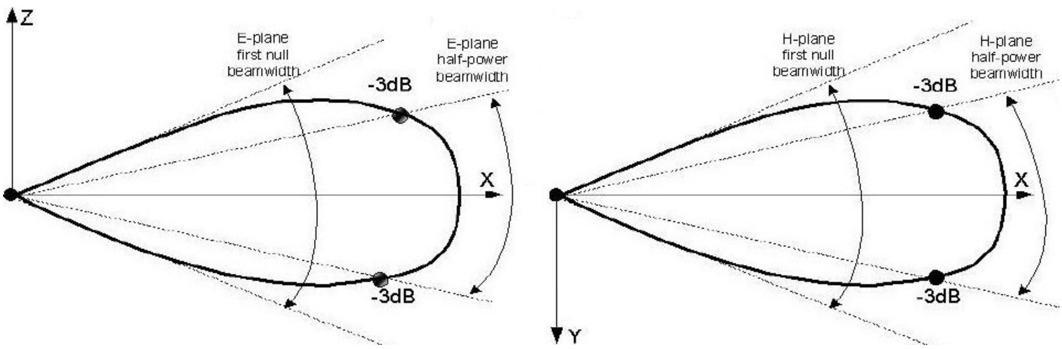


Figure 7.20: The E-plane pattern (left) and H-plane pattern (right) of a generic Directional Antenna

Figure 7.21 shows the DIRECTIONAL ANTENNA PROPERTIES Window.

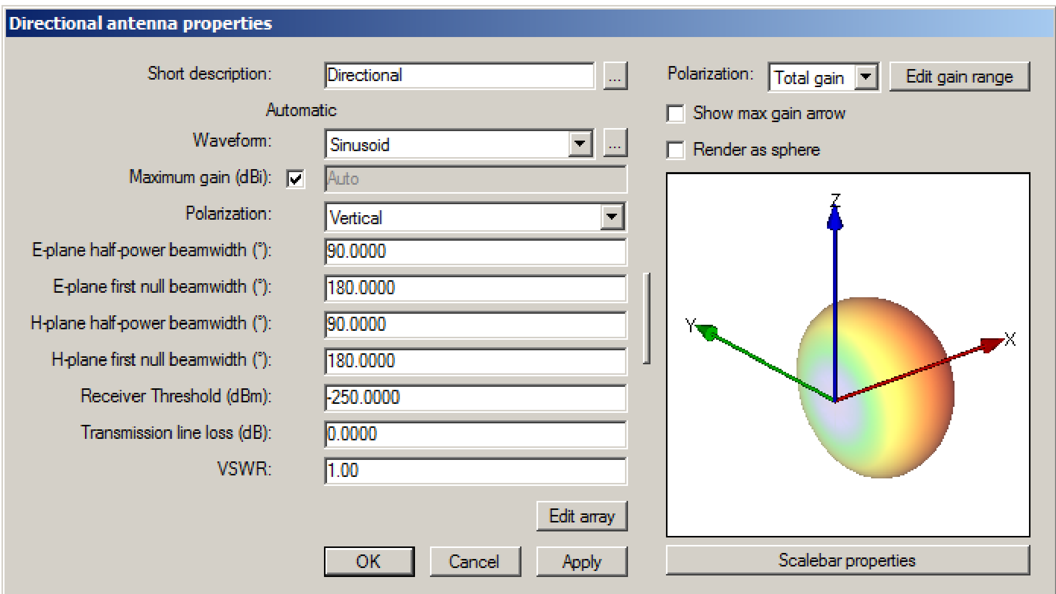


Figure 7.21: Properties of a Directional Antenna

#### 7.4.1.10 Omnidirectional

The geometrically defined *Omnidirectional* antenna pattern is one of the idealized antenna patterns in XGtd. It is not associated with any particular type of physical antenna, rather it is completely defined by the beamwidth parameters. The *Omnidirectional* antenna produces an omni pattern in the azimuthal $XY$ plane with a null on the $Z$-axis.

For “Vertical” polarization, this antenna pattern is specified by:

- *E-plane half-power beamwidth*

- *E-plane first null beamwidth*

For "Horizontal" polarization, the antenna pattern is specified by:

- *H-plane half-power beamwidth*
- *H-plane first null beamwidth*

For "Circular" polarization, the beamwidth parameters are:

- *Vertical-plane half-power beamwidth*
- *Vertical-plane first null beamwidth*

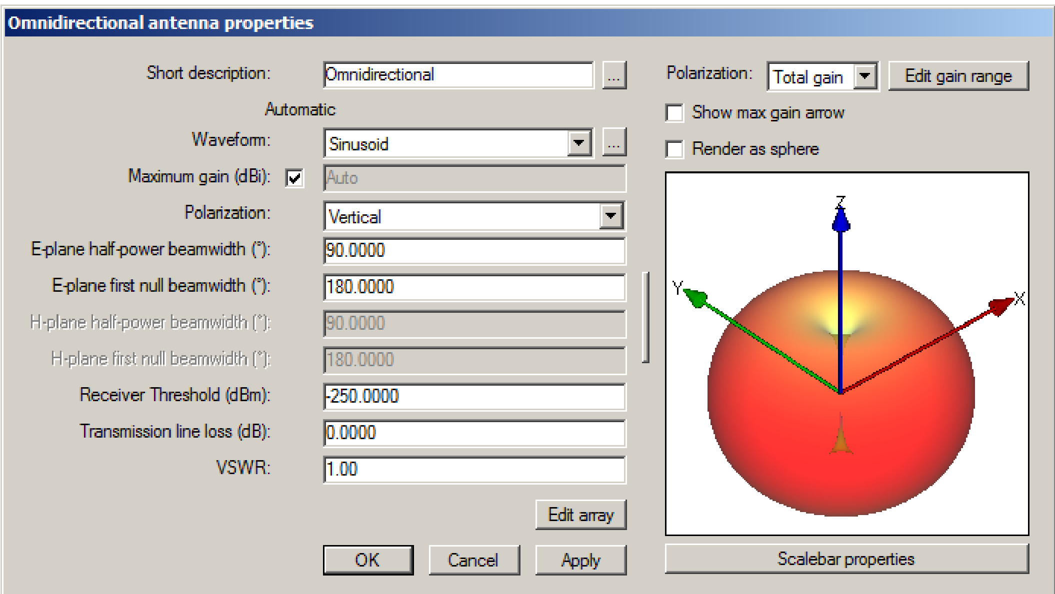


Figure 7.22: Properties of an Omnidirectional Antenna

#### 7.4.1.11 Isotropic

The *Isotropic* pattern is one of the idealized antenna patterns in XGtdnot associated with any particular type of physical antenna. It provides a uniform field strength in one linear polarization or circular polarization. The default polarization is vertical, but a different polarization can be set in the ANTENNA PROPERTIES Window. When using this type of antenna, it is important to keep in mind that away from the horizontal plane, the vertically polarized Isotropic is more accurately described as being theta-polarized, and the horizontal Isotropic is more accurately regarded as phi-polarized.

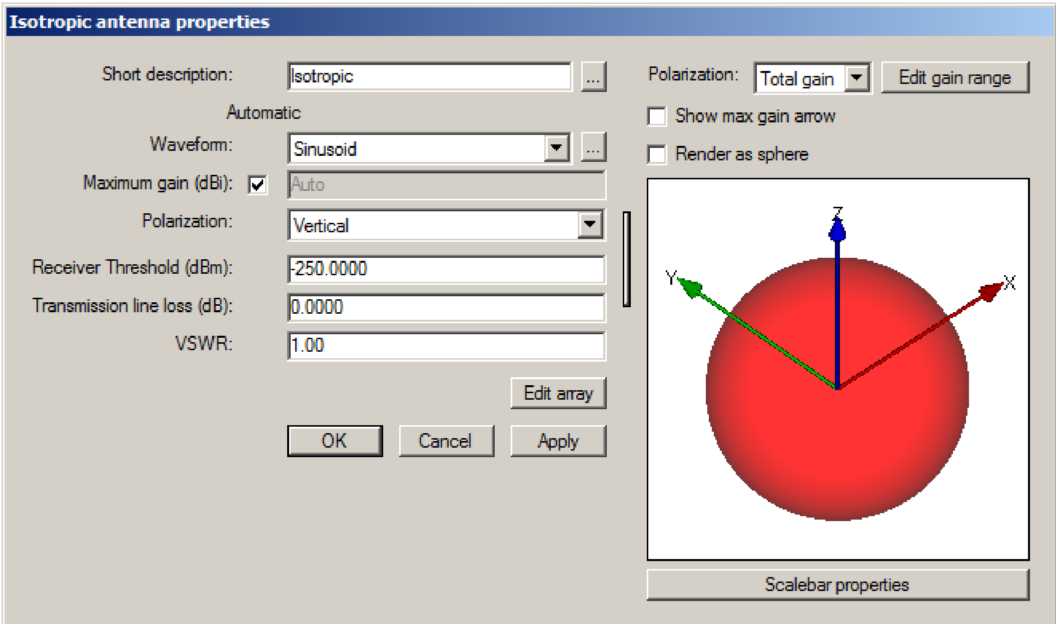


Figure 7.23: Properties of an Isotropic Antenna

#### 7.4.1.12 Orientation and Rotation of Freestanding Antennas

It should be noted that these specifications are for the antenna parameter definitions. The actual antenna orientation and polarization for a XGtd calculation is also determined by rotating the associated TRANSMITTER or RECEIVER control vectors. The rotations for freestanding antennas are always done in the $X$-$Y$-$Z$ order for simplicity. For *Omnidirectional* patterns and patterns “boresighted” along the $X$-axis, this is no restriction at all. The final orientation of the antenna after these rotations are applied can be viewed in the PROJECT VIEW by making the transmitter or receiver’s control vectors visible.

Figure 7.24 shows the properties window of a TRANSMITTER that is using an ANTENNA. The rotation parameters that control the orientation of the antenna are associated with the Tx/Rx set that is using it, rather than with the antenna.

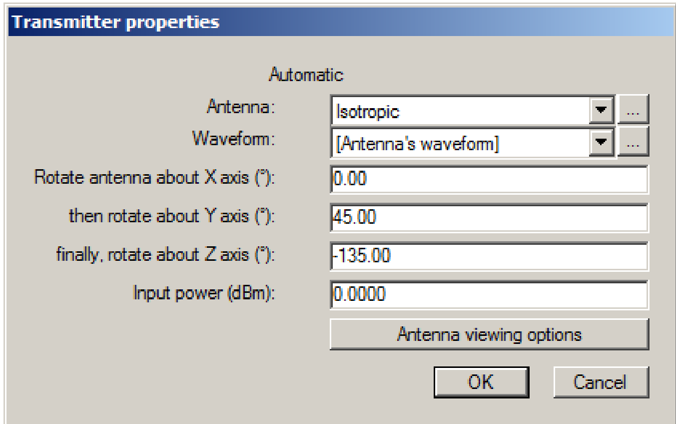


Figure 7.24: The properties window of a transmitter using an antenna

## 7.4.2 Ground-Plane Mounted Antennas

*Aperture*, *Monopole*, and *Patch* Antennas, which are mounted on a ground plane or other planar surface, are oriented such that the antenna normal points in the $+Z$ direction by default. Thus for *Aperture* or *Patch* Antennas the pattern is plotted with the main beam in the $+Z$ direction. For *Monopoles* the pattern is plotted with the wire in the $+Z$ direction. *User-Defined* Antennas can also be treated as being mounted on a ground plane.

### 7.4.2.1 Short Monopole

This antenna is similar to the *Short Dipole*. The length is much less than one wavelength. It generates a field pattern proportional to sin($\theta$) in the upper half-space only. The lower boundary of the space where the *Short Monopole* radiates is defined by the surface the antenna is mounted on. The orientation is parallel to the normal of that surface.

### 7.4.2.2 Linear Monopole

This antenna is similar to the *Linear Dipole*. The *Length* of the *Linear Monopole* is defined in the ANTENNA PROPERTIES Window. This antenna generates a field pattern proportional to sin($\theta$) in the upper half-space only. The lower boundary of the space where the *Linear Monopole* radiates is defined by the surface the antenna is mounted on. The orientation is parallel to the normal of that surface.

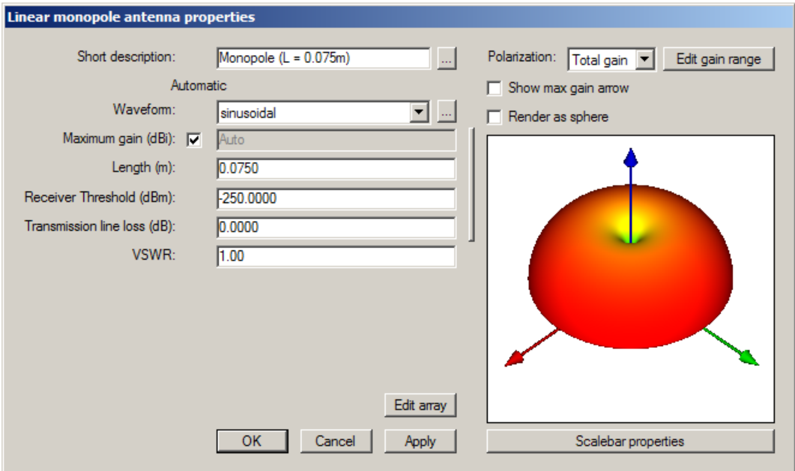


Figure 7.25: Linear Monopole Antenna with antenna pattern display active

#### 7.4.2.3 Quarter-Wave Monopole

The *Quarter-Wave Monopole* is identical to the *Linear Monopole*, with the exception that the length of the monopole is always set to be one quarter of the wavelength of the assigned waveform.

#### 7.4.2.4 Rectangular Aperture

The *Rectangular Aperture* is a rectangular opening in a PEC sheet. The pattern is calculated as if the PEC sheet were infinite in extent. The actual surface used to support the antenna will, of course, be finite. The opening can support one of two possible electric field distributions: "Uniform" or "TE10." The input parameters, entered through the ANTENNA PROPERTIES Window, are the aperture dimensions (*Side A* and *Side B*) and the *E-field distribution*. The default antenna orientation is such that the main beam is in the $Z$-direction. The desired orientation is achieved by placing the antenna's associated TRANSMITTER or RECEIVER on a surface. The antenna aperture will lie in the plane of that surface. The main beam will be parallel to the mounting surface normal.

The antenna's polarization is linear ($Y$-directed, E-plane is the $YZ$ plane) by default. The polarization can be adjusted by setting the rotation about the antenna's $Z$ axis (the normal to the transmitter or receiver's mounting surface) in the TRANSMITTER/RECEIVER PROPERTIES Window. Once the antenna and associated transmitter or receiver is placed on a surface, the antenna's $Z$ axis lies parallel to the mounting surface's normal. Rotations applied in the TRANSMITTER/RECEIVER PROPERTIES Window about the $Z$ axis are about this mounting surface normal. [17, p.584]

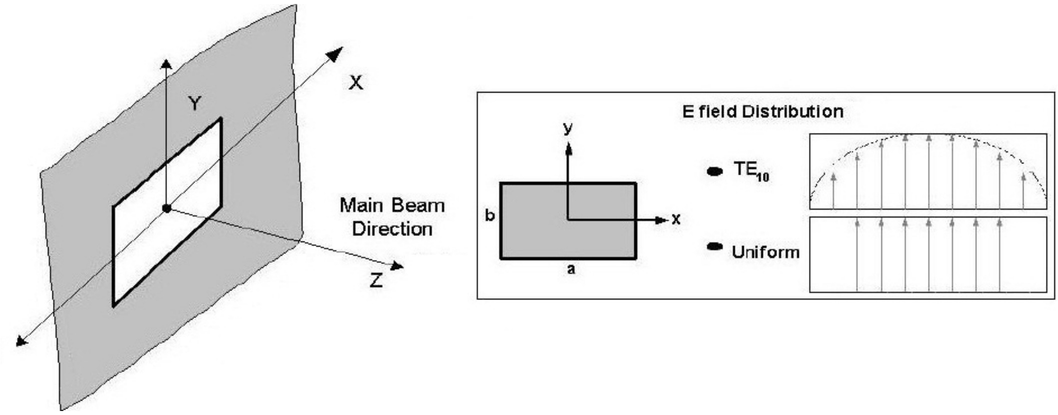


Figure 7.26: Description of the Rectangular Aperture Antenna

#### 7.4.2.5 Circular Aperture

The *Circular Aperture* is a circular opening in an infinite PEC sheet. The opening can support one of two possible electric field distributions: “Uniform” or “TE11.” The input parameters, entered through the ANTENNA PROPERTIES Window, are the aperture *Radius* and the *E-field distribution*. The default antenna orientation is such that the main beam is in the $Z$-direction. The desired orientation is achieved by placing the antenna’s associated transmitter or receiver on a surface. The antenna aperture will lie in the plane of the surface. The main beam will be parallel to the mounting surface normal. The antenna polarization is linear ($Y$-directed) by default. The polarization can be adjusted by setting the rotation about the antenna’s $Z$-axis (the normal to the surface) in the TRANSMITTER/RECEIVER PROPERTIES Window. Once the antenna and associated Tx/Rx are placed on a surface, the antenna’s $Z$-axis lies parallel to the mounting surface’s normal. Rotations applied in the TRANSMITTER/RECEIVER PROPERTIES Window about the $Z$-axis are about this mounting surface normal. [17, p. 603]

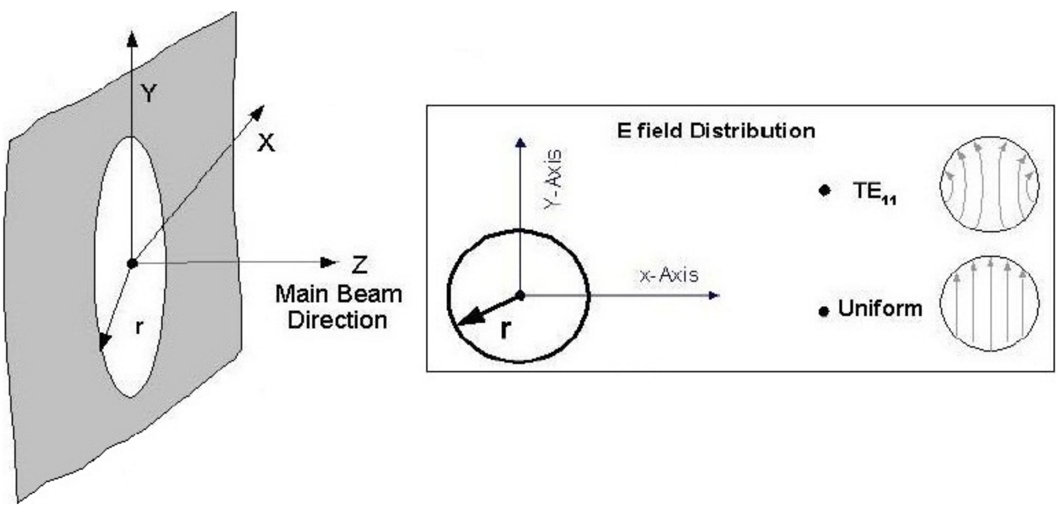


Figure 7.27: Description of the Circular Aperture Antenna

#### 7.4.2.6 Circular Patch

The *Circular Patch* is a circular printed patch of PEC lying on a dielectric slab of a given relative dielectric constant. The horizontal extent of the dielectric substrate is that of the patch surface. The patch excitation and feed point are not modeled and it is assumed the patch is excited near the dominant $TM_{11}$ mode.

The input parameters, entered through the ANTENNA PROPERTIES Window, are the patch *Radius*, the relative *Dielectric constant* of the substrate and the substrate height. The default antenna orientation is such that the main beam is in the $Z$-direction. The desired orientation is achieved by assigning the antenna to a transmitter or receiver on a surface with the desired orientation. The antenna polarization is linear. [17, p. 752]

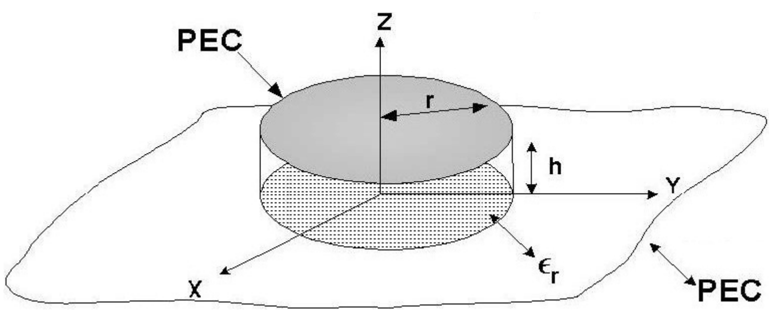


Figure 7.28: Description of the Circular Patch Antenna

#### 7.4.2.7 Rectangular Patch

The *Rectangular Patch* is a rectangular printed patch of PEC lying on a dielectric slab of a given relative dielectric constant. The horizontal extent of the dielectric substrate is that of the patch surface. The patch excitation and feed point are not included in the model.

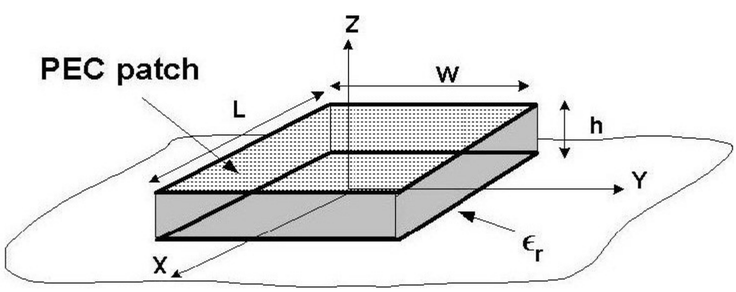


Figure 7.29: Description of the Rectangular Patch Antenna

The input parameters, entered through the ANTENNA PROPERTIES Window, are the patch *Length*, the patch *Width*, and the relative *Dielectric constant* and *Height* of the substrate. The default antenna orientation is such that the main beam is in the $Z$-direction. The desired orientation is achieved by assigning the antenna to a transmitter or receiver on a surface with the desired orientation. The antenna polarization is linear. The E-plane for this antenna is parallel to the longer of the patch dimensions *Length* and *Width*. For example, if *Length* ($X$-dimension) $>$ *Width* ($Y$-dimension), the dominant mode is the $TM^z_{010}$ mode. This will orient the E-plane in the $XY$ plane and is the default orientation. Setting *Length* $<$ *Width* produces the $TM^z_{001}$ mode and the E-plane will be the $YZ$ plane.

The polarization can be adjusted by setting the rotation about the antenna's $Z$-axis (the normal to the transmitter or receiver's mounting surface) in the TRANSMITTER/RECEIVER PROPERTIES Window. Once the antenna and associated transmitter or receiver are placed on a surface, the antenna's $Z$-axis lies parallel to the mounting surfaces normal. Rotations applied in the TRANSMITTER/RECEIVER PROPERTIES Window about the $Z$-axis are about this mounting surface normal. [17, p. 727]

#### 7.4.2.8 Orientation and Rotation of Ground-Plane Mounted Antennas

One way to orient these ANTENNAS for the calculation is to position the *Aperture*, *Monopole*, or *Patch* on a facet. Once the antenna and associated TRANSMITTER or RECEIVER is placed on a surface, the antenna's $Z$-axis lies parallel to the mounting surface's normal. Rotations applied in the TRANSMITTER/RECEIVER PROPERTIES Window about the $Z$-axis are about this mounting surface normal. For the *Monopole*, this rotation has no effect since the pattern is symmetric in the $XY$ plane.

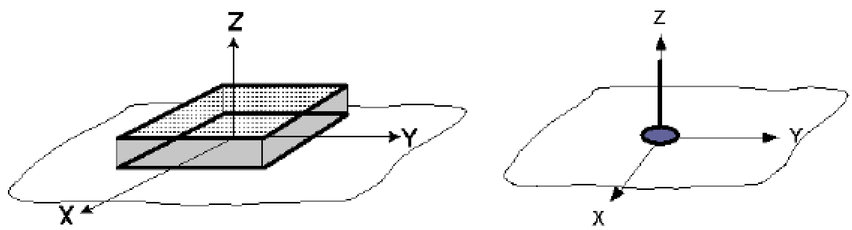


Figure 7.30: A Rectangular Patch in default orientation (left), and a Monopole in default orientation (right)

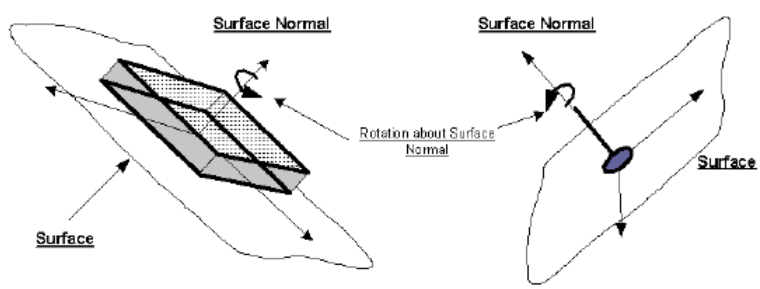


Figure 7.31: A Rectangular Patch after placement on a surface (left), and a Monopole mounted on a surface (right)

This approach to specifying and locating antennas allows great flexibility. Each antenna type is defined independently of how it will be oriented in the calculation. Thus the same *Monopole* may be mounted on several different model surfaces with different orientations, or the same *Horn* may be directed in one way for transmit and in a different direction for receive.

## 7.5 User-Defined and Imported Antenna Patterns

XGtd also has the capability to import *User-Defined* Antenna patterns. These antennas are considered to be freestanding. XGtd has its own pattern data file format or can import data in several commonly used formats. If the pattern data is only available on the E-plane and H-plane, a full three-dimensional pattern will be generated through interpolation [20] [21] [22].

The pattern data used for import can be obtained from manufacturer websites, or generated from a full-wave electromagnetic simulator such as NEC or XFdtd®.

### 7.5.1 XGtd Format

The XGtd *User-Defined* Antenna format (*.uan) starts with a parameter section as shown below.

```
begin_<parameters>
     format free
     phi_min 0
     phi_max 360
     phi_inc 4
     theta_min 0
     theta_max 180
     theta_inc 3
     complex <or> real
     mag_phase <or> real_imag (only required when complex is specified)
     pattern gain <or> power <or> field
     magnitude dB <or> linear
     maximum_gain 0 (optional parameter, measured in dBi)
     phase degrees <or> radians
     direction degrees <or> radians
     polarization theta_phi <or> phi_theta <or> theta <or> phi
end_<parameters>
```

✓ If additional parameters are included in the file beyond what is described above, XGtd will ignore them. This is particularly the case when the *.uan file is created using an external program, such as XFdtd®.

Following the parameters section, the first four lines of data might be:

```
90.000 0.000 -10.0 -25.0 90.0 172.50
90.000 4.000 -11.5 -24.0 92.0 174.50
90.000 8.000 -12.0 -24.0 94.0 176.50
90.000 12.00 -13.5 -20.0 97.0 178.50
```

where the data format is theta, phi, gain (theta component), gain (phi component), phase (theta component), phase (phi component).

The min, max and inc values for theta and phi must be integers.

If phase is not given, the keyword `complex` should either be omitted from the parameter section, or replaced by `real` (which is the default). Further, the mag_phase **or** real_imag keywords, which specify the format of the complex values, are not required in the header. The data in the file would be:

```
90.000 0.000 -10.0 -25.0
90.000 4.000 -11.5 -24.0
90.000 8.000 -12.0 -24.0
90.000 12.00 -13.5 -20.0
```

✓ If the data only specifies a horizontal cut at theta = 90 and a vertical cut at phi = 0/180, then XGtd will automatically interpolate the pattern to produce a full 3D-gain pattern. When doing this, ensure that the theta min and max are specified at 90°.

The XGtd antenna type also allows full 3D far zone radiation patterns calculated by XGtd and XFdtd to be imported into other XGtd projects and used as antenna patterns.

#### 7.5.1.1 Maximum Gain Settings for User-Defined Antennas

Additional options are available for setting the maximum gain of user-defined antenna patterns in the antenna's properties window:

- *From UAN File* - The value of this field is taken from the `Maximum_gain` keyword in the `*.uan` header. If `maximum_gain` is omitted, the maximum total gain of the pattern data is used. Users cannot edit the value in this field.
- *From integration* - Determines the gain by first normalizing the user-defined antenna pattern data and using equation 7.3. Users cannot edit the value in this field.
- *User-specified* - Sets the maximum gain of the ANTENNA to the value listed in the field. It is possible to enter nonphysical gain values for an antenna, so the user is responsible for realistic manual entries.

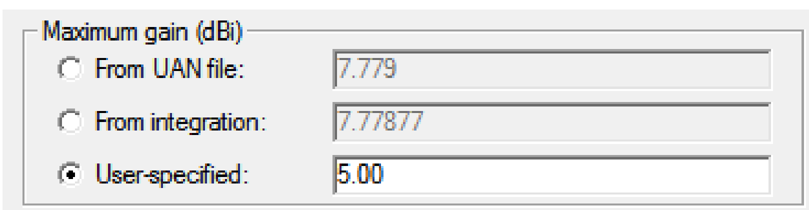


Figure 7.32: Maximum gain settings for user-defined antenna patterns

### 7.5.2 NSMA

The National Spectrum Managers Association (NSMA, www.nsma.org) file specification is a commonly used format. The XGtd GUI lists *NSMA* among its antenna types and allows for direct use of files that conform to the NSMA format recommendation WG16.99.050. The format is described in the file `wg16.99.050.pdf`, which can be found in the `install_location\Documentation\` directory.

Upon selecting the *NSMA* Antenna and specifying a `NSMA` file, the NSMA ANTENNA PROPERTIES Window, seen in Figure 7.33, allows the user to select from any pattern frequency contained in the `NSMA` file that represents a full 3D antenna pattern. The GUI automatically detects which polarizations are defined and to what geometry the pattern cuts conform. The gain of the antenna is also determined.

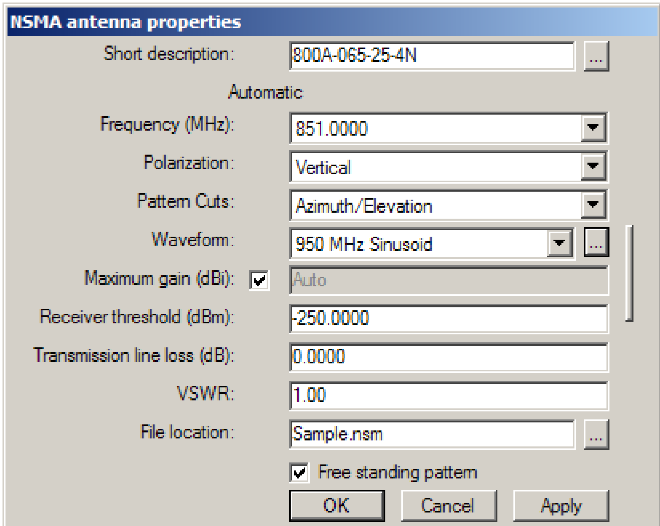


Figure 7.33: Properties for an imported NSMA Antenna

Additional information read from the `NSMA` file is stored in the notes section of the antenna, as shown in Figure 7.34.

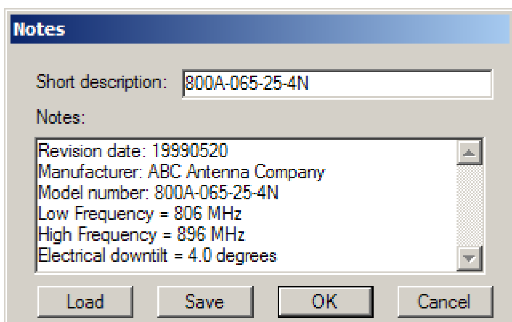


Figure 7.34: Additional notes for the NSMA imported antenna

### 7.5.3 Odyssey

Aethos *Odyssey* Antenna files contain horizontal and vertical cut-planes which are interpolated to form a full 3D pattern. Supported keywords include:

- `NAME`
- `FREQUENCY`

- BEAM_WIDTH
- DIAMETER
- GAIN
- GAIN_UNIT
- TILT
- ANTENNA_TYPE
- COMMENTS
- POLARIZATION

Possible values for select keywords are shown below. The gain unit may either be on the same line as the gain value or may be listed on a separate line using the keyword GAIN_UNIT. Information found using these keywords is saved in the antenna's *Notes*.

Each cut-plane consists of 360 data points, for angles 1 to 360 degrees. Zero degrees corresponds to north in the horizontal plane and the horizon in the vertical plane. The data columns for angle and gain may be separated by either tabs or spaces. Cut-plane values are given in dBm relative the maximum gain (0 dBm), and must not include the minus sign.

```
NAME BCD-8706-0-25
FREQUENCY 900
BEAM_WIDTH 360
GAIN 8.14 dBi [dBd]
GAIN_UNIT dBi [dBd]
TILT ELECTRICAL
POLARIZATION VERTICAL [HORIZONTAL]
HORIZONTAL 360
1 0.050
2 0.090
.
.
359 0.090
360 0.050
VERTICAL 360
1 0.090
2 0.170
.
.
359 0.090
360 0.000
```

### 7.5.4 Planet

An MSI *Planet* Antenna file consists of ASCII pattern data for the vertical and horizontal cut-planes. Valid parameters at the beginning of the file are shown below. This information is read and saved in the antenna's *Notes*. antenna gain is given in dBd by default; if the gain is specified in dBi it must be so labeled after the gain value, separated by a space.

Each cut-plane consists of 360 data points, for angles 0 to 359 degrees. Zero degrees corresponds to north in the horizontal plane and the horizon in the vertical plane. Data columns may be separated by either tabs or spaces. Cut-plane values are given in dBm relative the maximum gain (0 dBm), and must not include the minus sign.

By convention, the antenna name is listed first.

```
NAME Andrew Corp
MAKE PCS19HA-11015-2
FREQUENCY 1920
H_WIDTH 115.97
V_WIDTH 4.77
FRONT_TO_BACK 25.32
GAIN 14.50 dBi
TILT Electrical
HORIZONTAL 360
0 0.000
1 0.261
.
.
358 0.261
359 0.261
VERTICAL 360
0 1.401
1 0.300
.
.
359 3.098
360 0.000
```

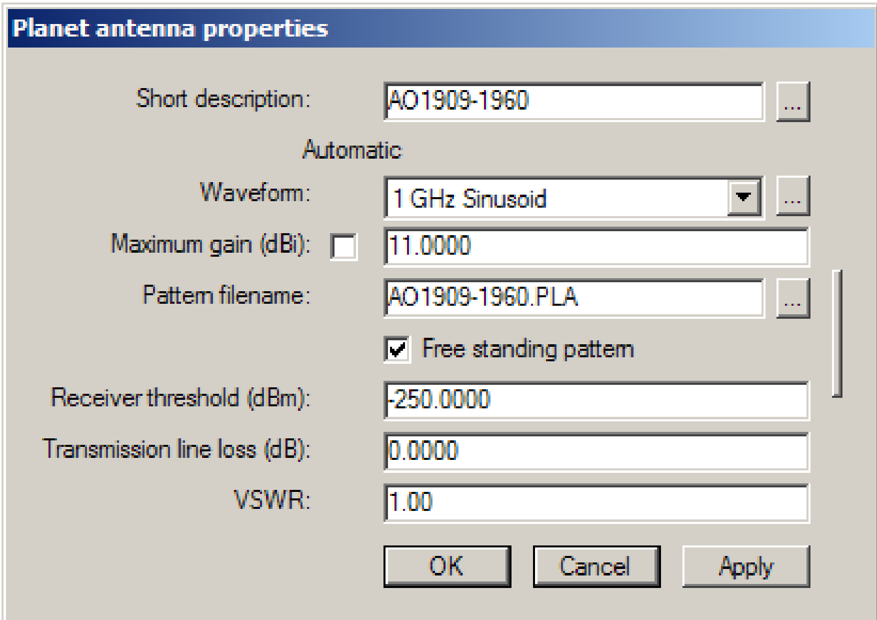


Figure 7.35: Properties of an imported Planet Antenna

### 7.5.5 Orientation of User-Defined and Imported Antenna Patterns

Just as with the built-in antenna types, the *User-Defined* Antenna patterns may be rotated to aim the antenna in the desired direction. As stated earlier, the *User-Defined* Antenna is considered freestanding. The actual antenna orientation and polarization for a XGtd calculation is also determined by rotating the associated transmitter or receiver control vectors. The rotations for freestanding antennas are always done in $X$-$Y$-$Z$ order for simplicity. The final orientation of the antenna after these rotations are applied can be viewed in the PROJECT VIEW by making the transmitter or receiver's control vectors visible. If the user has the choice, it is best to generate the *User-Defined* pattern such that the direction of maximum gain is along the $X$ axis. This allows total freedom to aim the main beam in any desired direction and to set the polarization.

## 7.6 Antenna Pattern Plotting

### 7.6.1 Cut-plane Pattern Plotting

The XGtd GUI can verify antenna characteristics by plotting antenna patterns. In order to plot the pattern of an antenna, the user right-clicks on the antenna and selects *Plot pattern*, as seen in Figure 7.36.

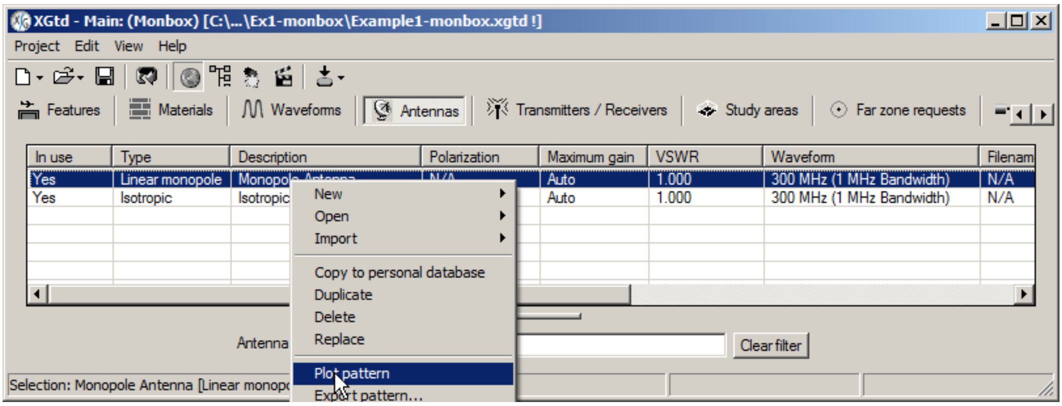


Figure 7.36: The Antenna tab of the Main Window

After right-clicking on the antenna, the user can select the cut-plane using the window shown below. Options include:

- *Plot* - Plots either the magnitude or phase for a particular pattern.
- *Polarization* - Gives the option of selecting one of “Total gain,” “Theta,” “Phi,” “LHCP” or “RHCP” polarizations.
- *Mode* - Extracts one of two types of cut planes at a particular angle; those with “Constant Phi” or “Constant Theta.”
- *Plot Frequency* - Defines the antenna pattern plot frequency as the default frequency, which is that of the waveform associated with the antenna, or a user-defined frequency.
- *Magnitude format* - Gives the option of selecting between plotting actual gain values and a normalized plot.

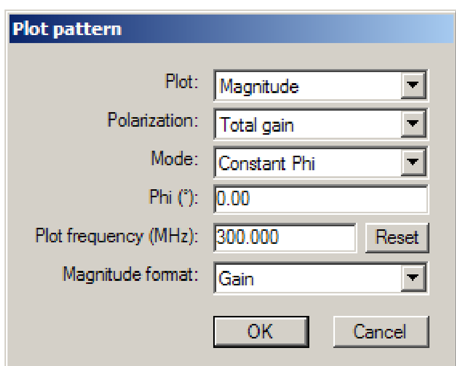


Figure 7.37: Setting the parameters for an antenna pattern plot

✓ You can elect to save the antenna pattern plot to a graph using the same method as regular output file plots. These graphs are maintained under *Graphs* in OUTPUT.

- When plotting an antenna, it is shown in the default orientation. The actual direction used in the simulation will depend on the orientation of the associated transmitter or receiver.
- The project must be saved before plotting the antenna pattern.

### 7.6.2 3D Pattern Display

XGtd also has the capability of showing the full 3D pattern of an ANTENNAin the ANTENNA PROPERTIES Window. The standard XGtd controls for zooming, rotating and panning operate as they do in the PROJECT VIEW. To show the 3D pattern in the ANTENNA PROPERTIES Window, left-click on the vertical button on the right hand side of the window.

Once the antenna pattern appears, there are options to change the manner in which it is displayed. These options only change the display of the pattern and do not have any effect on calculations. The *Component* option changes the component displayed to total gain, theta or phi components or either “LHCP” or “RHCP” polarizations. The *Gain range* sets the value below the maximum gain that will be considered zero or the center of the pattern when it is displayed. This setting changes both the shape of the surface and the colors of the pattern. Red always represents the maximum gain and violet the minimum. By lowering the gain range it becomes easier to see the directionality of the antenna. The pattern can also be shown as a sphere and an arrow in the direction of maximum gain can be activated. The colors that the antenna uses can be changed by clicking on the SCALEBAR PROPERTIES button and the scale bar in the PROJECT VIEW shows the range used to display the last antenna that was selected for displaying in this manner. The red, green and blue axes correspond to $X$, $Y$ and $Z$ respectively, and show the default orientation in the global coordinate system of the antenna pattern.

# Chapter 8

# Transmitters and Receivers

*In this chapter, you will learn...*

→ the types and properties of transmitters, receivers, and transceivers

→ how to edit, aim and align them

→ how to change the way they display in XGtd

In XGtd, a TRANSMITTER (Tx) point is the location of a source of input radiation, a RECEIVER (Rx) acts as a field point that collects radiation, and a TRANSCEIVER acts as both a transmitter and receiver. Transmitter and receiver points are grouped into sets where all the points in a given set share the same properties, such as:

- Coordinate system
- Relative elevation
- Antenna
- Waveform
- Antenna rotations
- Input power (transmitters only)

▶ Additionally, distant transmitters can be modeled using *Plane Wave* transmitter sets, which are discussed separately in Section 8.1.12.

Sets, as seen in Figure 8.1, provide a way to create a large amount of points quickly. They are arranged in patterns that provide the type of feedback that would be most useful during the analysis process. Once a calculation is complete, the output is arranged based on how these sets are layed out. Line plots are generated which follow the arrangement of the points in a set.

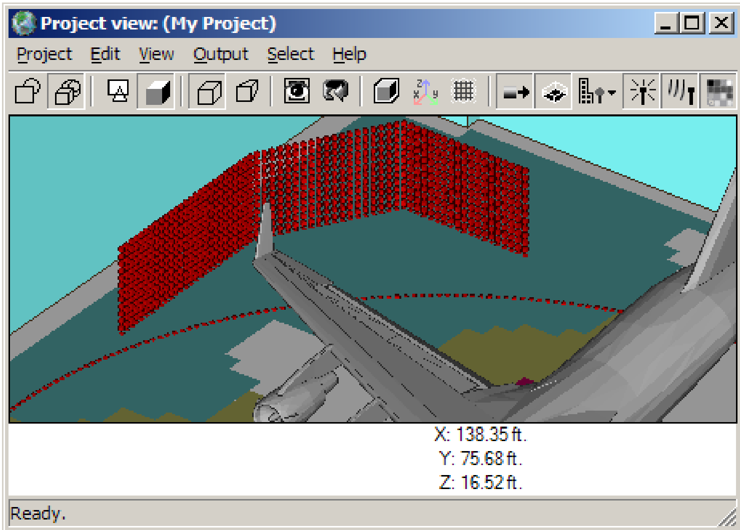


Figure 8.1: A project showing different types of transmitter and receiver sets

The remainder of this chapter describes the types of Tx/Rx layouts that are possible, Tx/Rx properties, advanced operations for aiming antennas in Tx/Rx set, and setting bounding boxes around sets.

All examples and references in this chapter relate to receivers, but the user should be aware that transmitters and transceivers function almost identically.

# 8.1 Types of Transmitters and Receivers

## 8.1.1 Points

The simplest set of transmitter and receiver locations can be defined using *Points*, where each point can be located independently. To create a receiver set of Points, select *Project*→*New*→*Receiver Set*→*Points*. The PROJECT VIEW will change to 2D WIREFRAME mode, allowing the user to click on as many points as desired. Figure 8.2 shows a point, represented by a small square, which has been placed in an *Anechoic Chamber*. To complete the set, right-click and verify the values in the properties window.

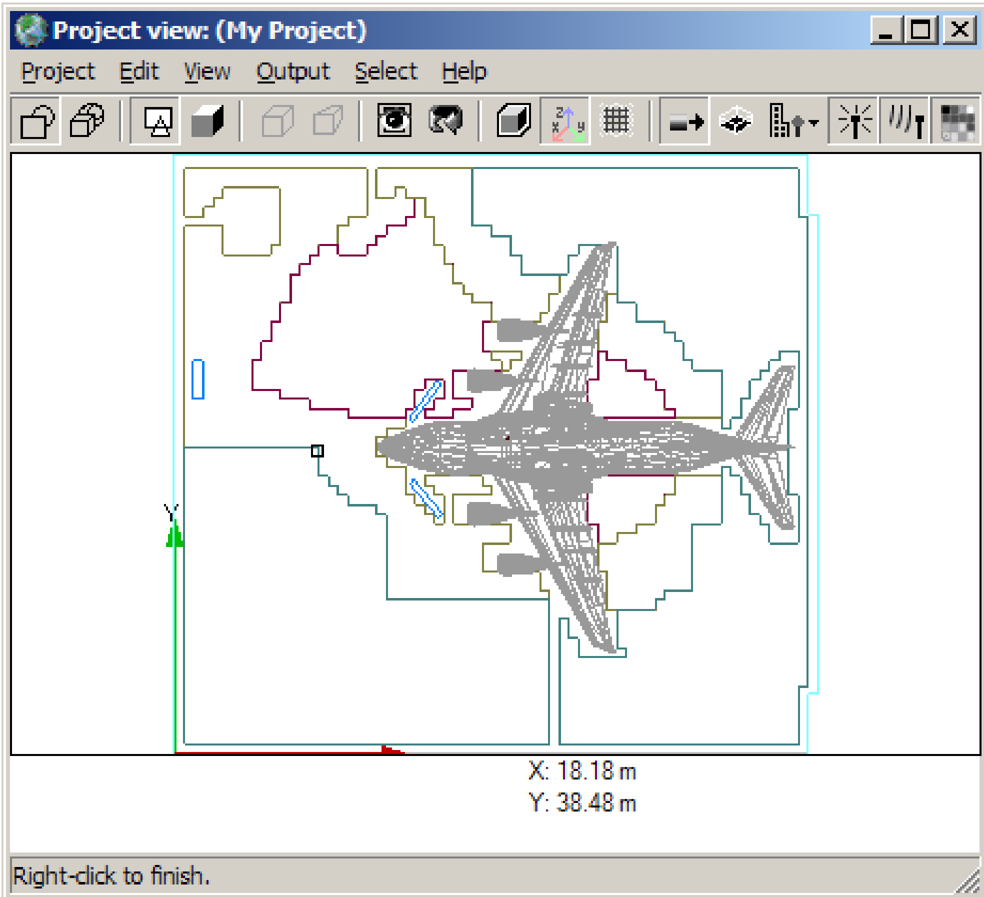


Figure 8.2: Creating a Tx/Rx Point set

### 8.1.2 Routes

*Routes* are composed of evenly spaced points along a connected series of line segments. To create a RECEIVER Route, select *Project→New→Receiver Set→Route*. Each point that is clicked in the PROJECT VIEW defines the beginning or end of a line segment to be included in the route. The route is completed when the user right-clicks.

The heights of the receiver points along the length of the route are defined by the heights of the points which were clicked when the set was created. While the default height of the control points is two meters, these heights may be changed by clicking on the EDIT CONTROL POINTS button in the TX/RX LAYOUT PROPERTIES Window at the completion of the set creation. The height of receivers between control points is determined by a linear interpolation of the heights of the closest control points.

Figure 8.3 shows the PROJECT VIEW in the middle of the creation of a *Route*. The values shown between the control points indicate the length of the line segments. In the TX/RX LAYOUT PROPERTIES window that is accessible from TX/RX PROPERTIES window after completing the route, the number of points along a particular route can be adjusted by changing the value in the *Spacing* field.

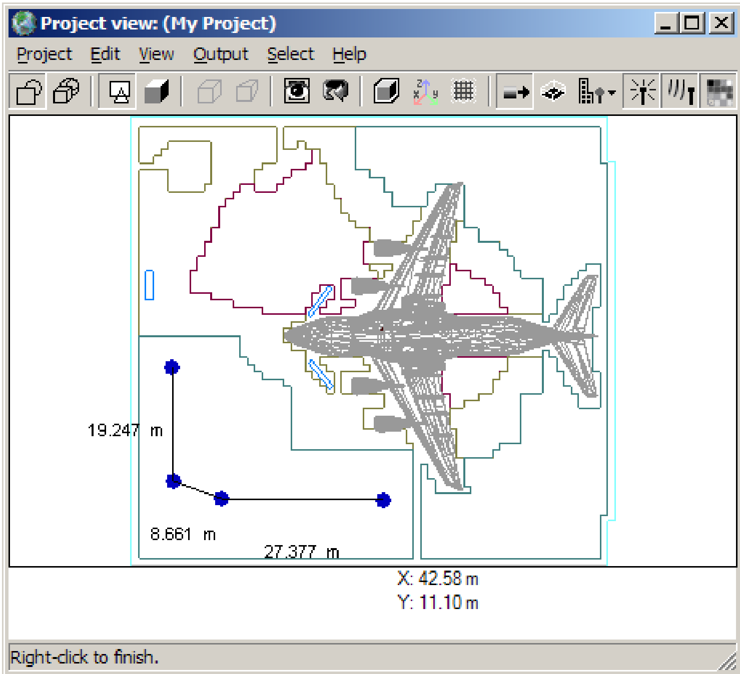


Figure 8.3: The control points in blue define a route of Tx/Rx points

### 8.1.3 Trajectories

*Trajectory* sets are a special type of route that can be used to model moving TRANSMITTER or RECEIVER points. For example, a Trajectory can be used to define the path an aircraft or ground-based vehicle takes through the project geometry and the velocity at which it is moving. Trajectories differ from other sets in two important ways:

- Antenna orientation is not uniform throughout the set, but rather differs from point to point based on the location of the next point, radius of curvature, and velocity.
- Received power, path loss and path gain OUTPUT for Trajectory sets can be plotted versus time.

*Trajectory* sets, like other sets, are created by specifying control points that define its location in the project. A spline is fit to the control points and then individual transmitter or receiver points are located along the spline according to the spacing provided by the user in the set's property window. Figure 8.4 shows the editor window with a series of control points (in blue).

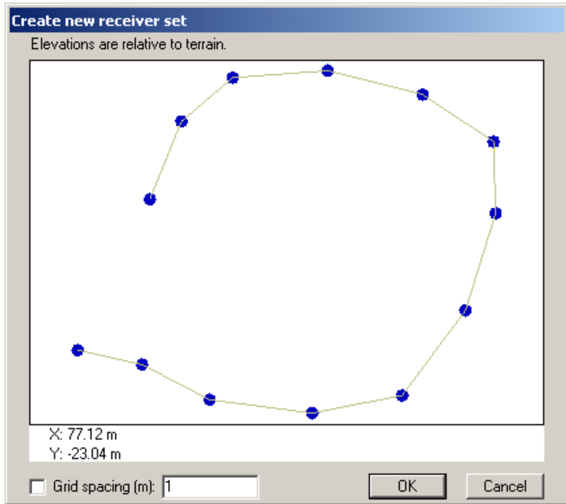


Figure 8.4: Editing window for placing Trajectory control points

After the control points are placed, the user can enter the desired spacing and assign a velocity to the Trajectory set in the advanced set properties window. The velocity for a Trajectory set is assumed to be constant along the entire Trajectory and must be greater than zero. Also in the advanced properties window, a start time for the Trajectory can be assigned. The start time acts as an offset for plotting results versus time.

When placing the control points for this type of set, the final arrangement of points is very sensitive to the curvature between the control points. If the roll angles for the created points have any discontinuities, this can be corrected by making small adjustments to the control points that make curves more gradual.

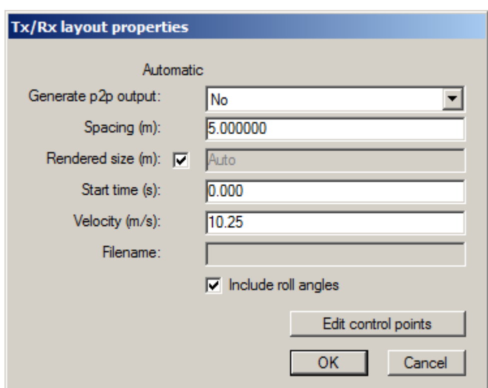


Figure 8.5: Tx/Rx layout properties window for a trajectory set

After definition of the set is complete, the interface calculates the point locations along the spline and displays the set in the PROJECT VIEW, as seen in Figure 8.6.

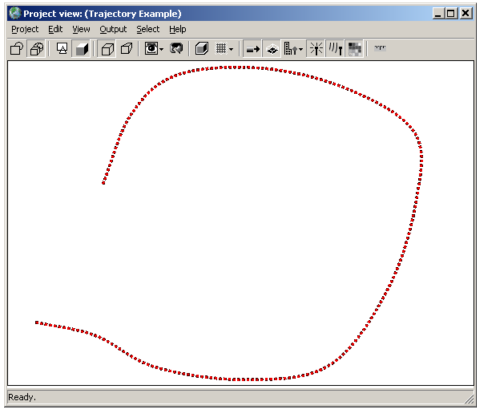


Figure 8.6: Trajectory set defined by the control point shown in Figure 8.4

Figure 8.7 shows the orientation of one of the receiver points along the Trajectory route. Antenna patterns are oriented by first aligning their $X$-axis to the next point in the Trajectory set. Roll angle calculations are then applied about this direction.

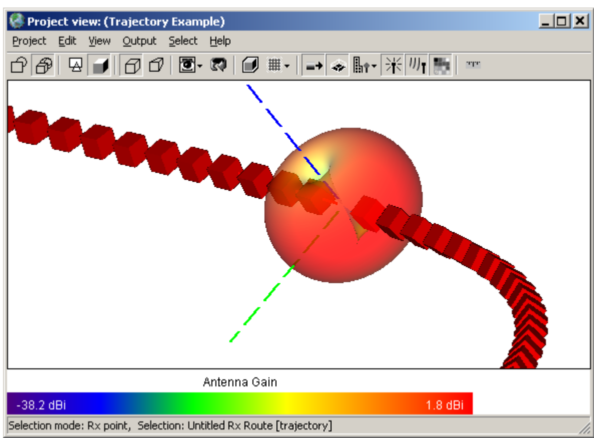


Figure 8.7: Orientation of antenna pattern along a Receiver Trajectory

The roll angles are calculated from a force balance between the aircraft's lift and centrifugal force:

$$R = \frac{V^2}{g tan\phi} \tag{8.1}$$

where

$V$ is the velocity

$g$ is the acceleration due to gravity

$\phi$ is the roll angle

The calculation of $\phi$ is only valid for aircraft making banking turns at a constant velocity and constant elevation. This calculation should be disabled for all other cases. More complicated Trajectory orientations can be specified with the user -defined Trajectory set.

Projects may only contain transmitter *Trajectory* sets or receiver *Trajectory* sets, but not both. Transmitter Trajectories in particular can result in long run times and a large number of output files. Users should consider if they can make use of the principle of reciprocity and replace the Transmitter Trajectory with a Receiver Trajectory in order to reduce the number of transmitter points in the project.

#### 8.1.3.1 User-Defined Trajectories

*Trajectory* sets can also be imported from a `*.traj` file by selecting *Project→Import→User-defined Transmitter / Receiver Set*. The *Files of type* setting in the bottom of the window should be changed to **Tx/Rx trajectory files (*.traj)**. Defining Trajectories using this file provides more control over the time, location, and orientation of the ANTENNA at each point in a Trajectory set. A constant time increment is required, but the actual locations of the points can vary, allowing users to create trajectories with a varying velocity. Further, complete control over the antenna orientation at each point is accessible, allowing users to specify more complicated trajectories than what is possible with the built-in Trajectory set. Each user-defined Trajectory file requires a header describing the data contain in the file. The components of the header are described below.

```
format rx <or> tx
minimum_time [float]
maximum_time [float]
time_increment [float]
time_units seconds
angle_units degrees
cartesian
longitude [double]
latitude [double]
sealevel <or> terrain
spline
has_rotations
[time] [x] [y] [z] [roll] [pitch] [yaw]
```

where:

*format* - Must be `tx` for a transmitter set and `rx` for a receiver set.

*minimum_time* - Mimum time listed in the file

*maximum_time* - Maximum time listed in the file

*time_increment* - Time spacing used in the file, must be constant

*time_units* - Must be seconds

*angle_units* - Must be degrees

*cartesian* - Cartesian indicates that point locations are metric offsets from the sets origin; otherwise they are assumed to be geographic coordinates.

`longitude` - Geographic longitude of the set's origin

`latitude` - Geographic latitude of the set's origin

`sealevel` or `terrain` - Indicates if height values are given relative to terrain or sea-level.

`spline` - If this is set the points are interpreted as a set of waypoints from which the rest of the points positions and roll/pitch/yaw are calculated.

`spacing` - If *spacing* is set this controls the spacing between the calculated points.

`[time]` - The temporal locations of each point. This field should only be present if *spline* is not specified. The header must be present in the file or the points will not be read.

### 8.1.4 XY Grid

The *XY Grid* allows a large area to be easily covered with evenly spaced points. To create an XY Grid, select *Project→New→Receiver Set→XY Grid*. Click and hold the left mouse button down while moving the mouse in the PROJECT VIEW to outline the area to be filled with points. Release the left mouse button when the area has been drawn. Figure 8.8 shows an XY Grid drawn in the Project View.

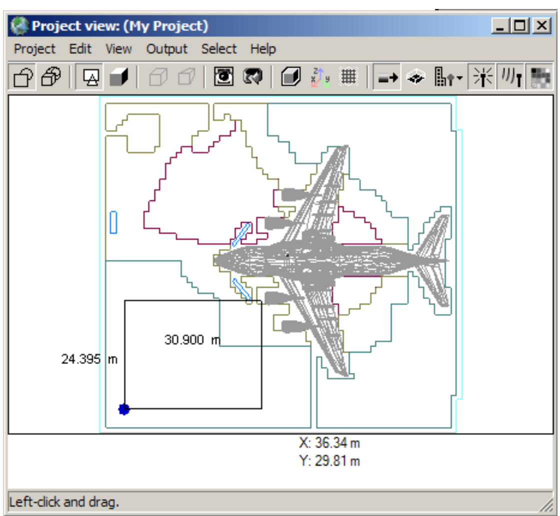


Figure 8.8: Defining the outline of an XY Grid of Tx/Rx points

In the properties window that appears, specify the *Spacing in meters between points*. The TX/RX LAYOUT PROPERTIES Window contains the lengths of the *XY Grid*. *Length (X)* refers to the grid dimension along the projects' $X$-axis, and *Length (Y)* refers to the grid length along the $Y$-axis.

### 8.1.5 Arc

A horizontal arc of receiving points may be placed using type *Arc*, which requires the user to specify the center position and radius, in meters, of a circle. To create a receiver set of type *Arc*, select *Project→New→Receiver Set→Arc*. In the PROJECT VIEW, click and hold the left mouse button to define the center point, then move the mouse to the desired radius and release the left mouse button. The radial distance is shown in meters as the mouse is moved. Figure 8.9 shows an Arc defined in the Project View.

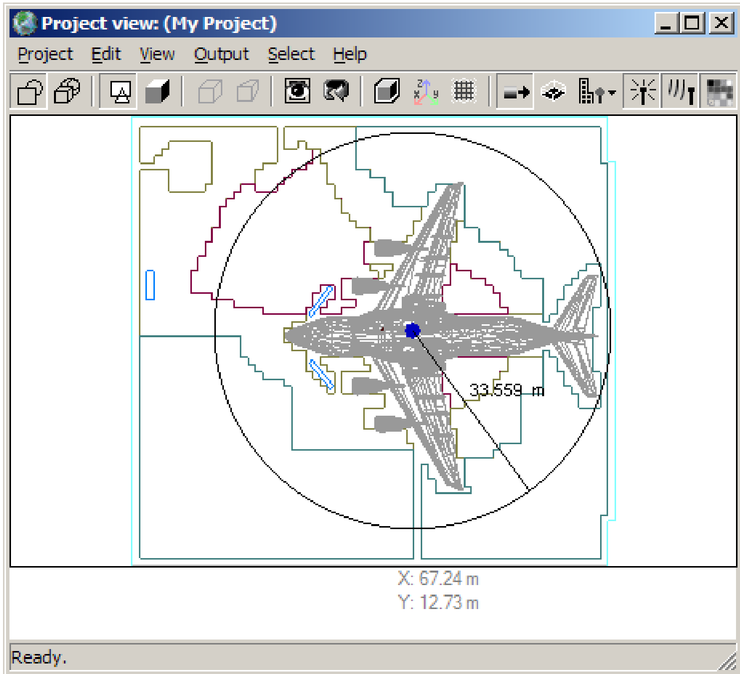


Figure 8.9: Defining the outline of an Arc of Tx/Rx points

By default the *Arc* is a complete circle, however the user may input start and stop angles, in degrees, through which receivers are placed on the circle. In addition, the user may choose to order the points in a clockwise or counter-clockwise direction. The height of the center point determines the height of all RECEIVERS in the Arc. The start angle, stop angle, direction and radius parameters are located in the LAYOUT PROPERTIES Window.

### 8.1.6 Vertical Arc

Similar to a receiver set of type *Arc*, a *Vertical Arc* allows points to be placed around an arc which extends above and below the $XY$ plane. To create a Vertical Arc, select *Project*→*New*→*Receiver Set*→ *Vertical arc*. In the PROJECT VIEW, click and hold the left mouse button to define the center of the Vertical Arc and move the mouse to the desired radial distance. Note that the orientation of the Vertical Arc is shown as a double-sided line segment and is controlled by the mouse placement. Release the left mouse button to complete the creation of the Vertical Arc, as seen in Figure 8.10.

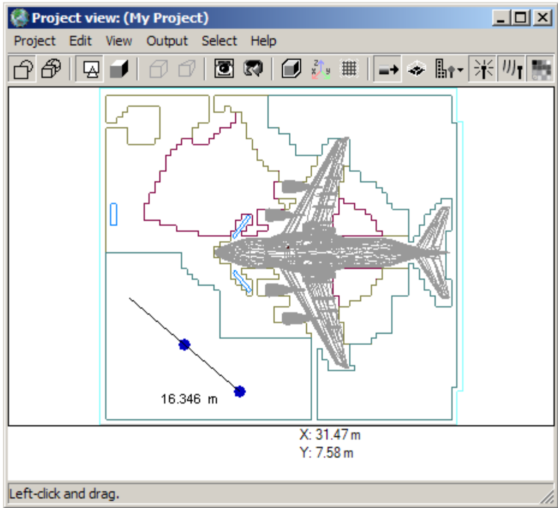


Figure 8.10: Describing the outline of a Vertical Arc of Tx/Rx points

In the properties window, the angle of the *Vertical Arc* out of the $XZ$ plane is shown in the *Rotation* field. The user may alter the value displayed to rotate the arc to a specific angle, if desired.

✓ The 0-degree reference point for the VERTICAL ARC lies directly above the arc's center.

### 8.1.7 Cylinder

A vertical *Cylinder* of receiver points can be created by selecting *Project→New→Receiver Set→Cylinder* and following the same procedure for that of an *Arc*. When the left mouse button is released to complete creation of the Cylinder, the SPECIFY HEIGHTS Window appears, which allows the user to define the base and top heights of the central axis of the Cylinder.

### 8.1.8 Sphere

You can create a three-dimensional *Sphere* of receiver points by selecting *Project→New→Receiver Set→Cylinder*, clicking a center point, and dragging the mouse to the desired radius. When the left mouse button is released to complete the Sphere, the RECEIVER PROPERTIES Window appears. Additional parameters for creating partial Spheres are located in the TX/RX LAYOUT PROPERTIES Window.

### 8.1.9 Polygon

A *Polygon* set is defined by a closed planar region consisting of three or more points. To create a Polygon set, select *Project→New→Receiver Set→Polygon*. The PROJECT VIEW will change to 2D WIREFRAME mode, and each point selected here defines a vertex on the Polygon. The Polygon is completed when the user right-clicks.

After the editing is complete, the Polygon can be rotated out of the $XY$-plane. However, once a set has been rotated out of the $XY$-plane it can no longer be modified using the graphical editor. The coordinates of the vertices can be edited manually by selecting *Edit control points* in the properties window, seen in Figure 8.11. You can also add and delete vertices and change the order of the points in this window.

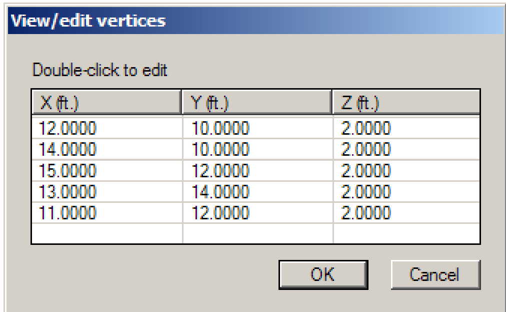


Figure 8.11: The vertices of a Tx/Rx set

A *Polygon* set can also be created to fit any face within the geometry. Begin by selecting a face graphically or in the PROJECT HIERARCHY and right-click. In the context menu that appears, select *Cover with→Receiver points*. The TX/RX PROPERTIES Window then appears to complete the creation of the set.

The TX/RX LAYOUT PROPERTIES Window contains the *Offset* parameter, which may be used to adjust the placement of the points slightly above or below the selected face. Positive offset values move the points the specified distance in the direction of the face's normal vector; negative values move the points opposite to the normal vector.

✓ This parameter is especially useful, and necessary, when the selected face is set double-sided and its material thickness is large. In this case, the offset is used to ensure that the points are visible and not contained within the thick face. A warning message will appear if an adjustment is necessary for this reason.

### Surface-Mounted Polygon Sets

It is possible to create polygon-shaped TRANSMITTER or RECEIVER sets to fit any face within the geometry. Begin by selecting a face graphically or in the PROJECT HIERARCHY, choose the *Cover with* option from the context menu, and specify the set as transmitter or receiver. This will create a polygon set that is properly aligned with the face.

- If you move the face within the scene the set will not move with it.

▶ If you want to create points on a face that move with the face, see Section 8.1.11.

## 8.1.10 Vertical Surface

A *Vertical Surface* is a *Route* that has been extruded in the $Z$-direction to form a curtain of points in space. To create a Vertical Surface set, click *Project→New→Receiver Set→Vertical Surface*. Draw the

2D contour of the Vertical Surface as instructed for a *Route*. When completed, the user is prompted to enter base and top heights to completely define the *Vertical Surface*.

The LAYOUT PROPERTIES Window contains two parameters that control the *Vertical Surface*. The space between points of adjacent rows is determined by *Vertical spacing*. The height that the Vertical Surface extends above its base is determined by *Height*.

### 8.1.11 Points On Face

TRANSMITTER and RECEIVER points may also be placed individually on a face. First select a face, and right-click. In the context menu that appears select *Place points→Receivers*. In the editor that appears, click within the outlined face to define receiver locations. Right-click when all desired points have been placed. By right-clicking in the editor, the user may add points or change the height above or below the face of all the points. If the mouse cursor is on top of an existing point when right-clicked, additional options will appear in the context menu which allow the position of that point to be changed by selecting *Edit position*. The point can also be deleted.

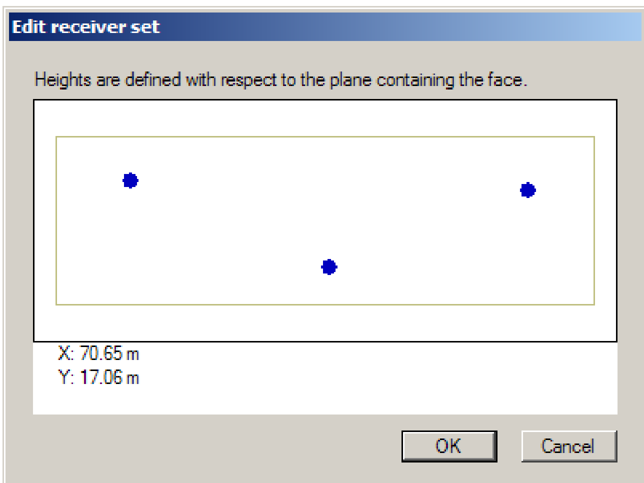


Figure 8.12: Placing Receiver points on a face

When a "Points On Face" set is created, a relation is made between the Tx/Rx set and the face it is mounted on. The sets can not exist without their referenced face. This relation allows the Tx/Rx points to move with the face. In addition, because there is a relationship between the face and the set, if the face is deleted then the points on face sets will also be deleted. Also, when a FEATURE that possesses "Points On Face" sets is made inactive, the sets will also be made inactive. When the feature is set back to active, a prompt will query whether to make the sets active once again.

### 8.1.12 Plane Waves

For TRANSMITTERS only, one or more incident plane waves can be modeled in XGtd by defining *Plane Wave* transmitter sets. To add a Plane Wave to the current project, select *Project→New→Transmitter Set→Plane wave*.

The PLANE WAVE PROPERTIES Window, seen in Figure 8.13, permits each plane wave to be specified by the following parameters:

- *Waveform* - The spectral characteristics of the Plane Wave
- *Polarization* - Theta, phi, left-hand circular, or right-hand circular
- *Power density/ Received power / RMS E-field* - The amplitude of the Plane Wave may be defined by specifying one of the above quantities. If received power is chosen, a power density will be determined by assuming the presence of an *Isotropic* Antenna whose effective aperture is determined by $\frac{\lambda^2}{4\pi}$, where $\lambda$ is the wavelength at the carrier frequency of the selected waveform.
- *Incident direction* - Defines the direction from which the Plane Wave originated.
- *Vary Incident Angle* - Defines the Plane Wave to represent a group of plane waves positioned along an arc in a theta or phi plane. If this option is selected, then only the constant angle can be specified in the *Incident direction* group.
- *Constant Theta/Phi* - Indicates the plane that the arc of varying incident angles lies on. The desired angle can then be specified in the *Incident direction* group.
- *Start/Stop/Increment* - Indicate the location of the arc within the plane of the constant angle.

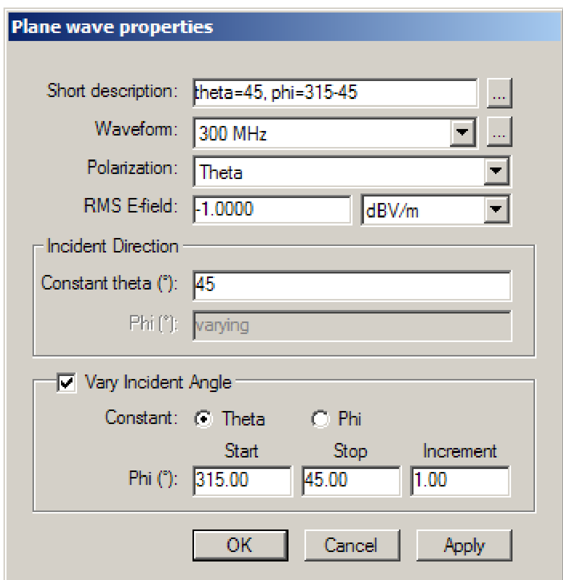


Figure 8.13: Properties of a Plane Wave

The size and position of the *Plane Wave* in the PROJECT VIEW is determined automatically based on its specified incident direction and the size and position of any active FEATURES and RECEIVER sets, so that it illuminates the entire project. The Plane Wave is rendered transparent so that it does not obscure elements of the project, and the green normal arrow indicates the Plane Wave's direction of propagation.

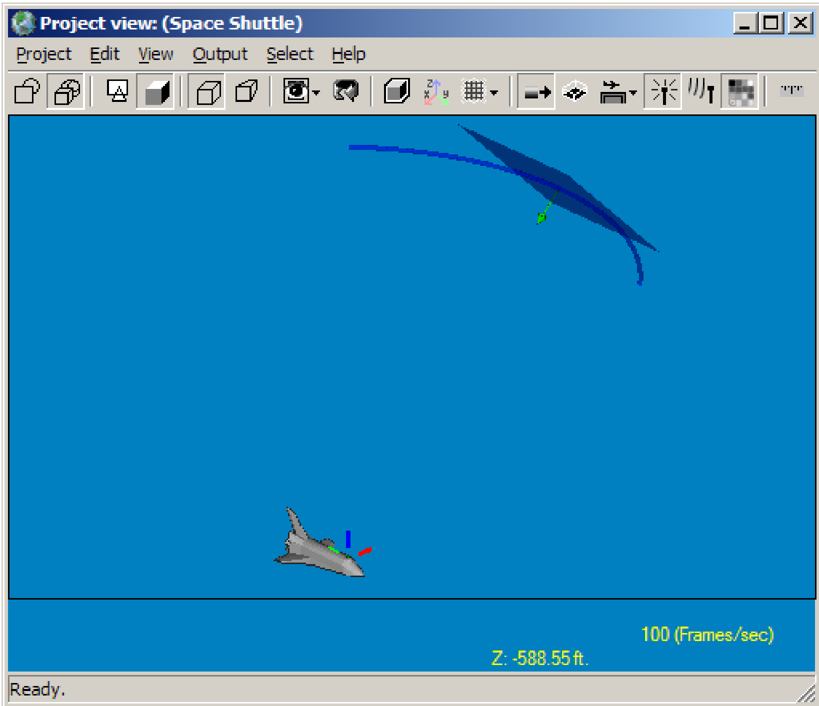


Figure 8.14: The shuttle example with a varying incident angle plane wave source. The range of incident angles are represented by the arc that is attached to the Plane Wave.

The primary application of *Plane Waves* in XGtd is in calculating Radar Cross Section (*RCS*), which is accomplished by creating one or more Far Zone *RCS* output requests. Each *RCS* output request results in the calculation of *RCS* data versus frequency or scattering angle for a single Plane Wave.

▶ More information regarding RCS output requests can be found in Chapter 11.

Most other types of Requested Output can be generated for *Plane Wave* transmitters. Only path loss and path gain will not be generated by Plane Waves since the plane wave source is assumed to be infinitely far away. This assumption also complicates the calculation of time of arrival; thus, time of arrival is defined to be the propagation time from the position of the rendered Plane Wave to the Receiver. The distance of the Plane Wave away from the project is chosen arbitrarily, and therefore the time of arrival is also somewhat arbitrary. Interaction with requested output generated for a Plane Wave is otherwise identical to output generated by sets of Transmitter points, and consists of displaying in the Project View, creating plots, and using the Movie Player.

The use of *Plane Waves* is limited to Study Areas, which use Shooting and Bouncing Ray (SBR) as the ray tracing method. The use of the Eigenray ray tracing method is only permitted if no active Plane Waves are present in the project.

▶ See Section 10.1 for more on the SBR and eigenray methods.

### 8.1.13 User-Defined Files

TRANSMITTER , RECEIVER and TRANSCEIVER sets can be specified in a text file and added to a project by selecting *Project→Import→User-Defined Receiver / Transmitter) Set*. In the dialog that appears, select the text file, which should have the extension `*.pts`. The ADVANCED TX/RX PROPERTIES Window appears to complete the creation of the set. Here the user may specify the local origin of the set.

An example of a `*.pts` file is shown below:

```
format tx
set_type route
system cartesian
description MyCustomRoute
1 100 100 0
2 110 110 0
3 120 120 0
```

The first three lines are required in order to provide information about the type of set. The description line is optional.

- `format` - Must be "tx" for a transmitter set, "rx" for a receiver set, or "txrx" for a transceiver set.
- `set_type` - Indicates what type of set to create. The currently supported options are `route`, `vertical surface`, `polygon` and `points`.
- `system` - This indicates the coordinate system that the points are listed in. "Cartesian" indicates they are metric offsets from the sets origin, and "geographic" indicates they are absolute earth coordinates that must be converted into the final Cartesian offsets.
- `description` - Provides a short description for the set.

Each line thereafter specifies, in order:

- `Point_number X_coordinate Y_coordinate Z_coordinate`

The points may be placed in any arrangement, and are not required to be equally spaced. Point number should be an integer.

## 8.2 Transmitter/Receiver Properties Window

The TRANSMITTER/RECEIVER PROPERTIES Window, seen in Figure 8.15, allows the user to define and modify the characteristics of a TRANSMITTER , RECEIVER or TRANSCEIVER set. The window appears after the creation of a new Tx/Rx set, or it can be accessed by right-clicking on the set in the MAIN WINDOW and selecting *Properties*.

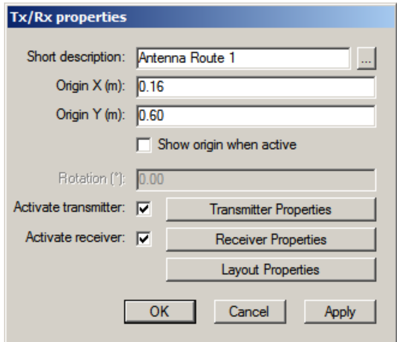


Figure 8.15: The properties window for a receiver set

The following are descriptions of the parameters found in the properties window:

- *Short description* - Defines the name which will refer to this Tx/Rx set throughout the GUI.
- *Origin $X$, Origin $Y$* - Defines the Cartesian coordinates of the Tx/Rx set's local origin.

  XGtd automatically rounds the values in the *Origin* boxes to two significant digits. For a more precise definition, try adjusting the units in APPLICATION PREFERENCES.
- *Show origin when active* - Displays the Tx/Rx set's local origin in the PROJECT VIEW.
- *Rotation* - Rotates the Tx/Rx set location in the project about the $Z$-axis. It does not affect the orientation of the antenna patterns in that set.
- *Active transmitter* - When checked, the set will act as a transmitter in the calculation.
- *Active receiver* - When checked, the set will act as a receiver set in the calculation.

## 8.3 Transmitter Properties

By clicking on the TRANSMITTER PROPERTIES button in the Tx/Rx properties window, you can access transmitter specific properties of the set, as seen in Figure 8.16. Some of these settings are specific to the type of set that is currently being viewed.

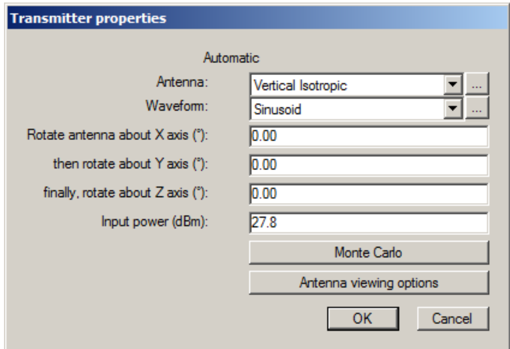


Figure 8.16: The transmitter properties window

The following are descriptions of the parameters found in the TRANSMITTER PROPERTIES Window:

- *Antenna* - Specifies the ANTENNA used by each point in the Tx/Rx set.
- *Waveform* - Specifies the WAVEFORM used by each point in the Tx/Rx set. The default choice is *[Antenna's waveform]*, which is the waveform that was assigned to the antenna in the ANTENNA PROPERTIES Window. If the user wishes to override the waveform that was assigned to the antenna, any waveform in the project may be selected.
- *Rotate antenna about $X$ axis, then $Y$ axis, and finally $Z$ axis* - Applies these angles, in degrees, to the antenna pattern in the order indicated and adjusts the direction of the electrical boresight of the antenna pattern. The angles must be specified in the range 0 to 360. The default values are 0 degrees for all axes.
  - See Section 8.6 for more information about this feature.
- *Input power* - Defines the total input power at each TRANSMITTER point. The default value is 0.0 dBm.
  - See Section 11.2 for more on input power and how it relates to radiated power.
- *Antenna viewing options* - Access to the antenna viewing options decribed in 8.6.

## 8.4 Receiver Properties

By clicking on the RECEIVER PROPERTIES button in the Tx/Rx properties window, you can access receiver specific properties of the set, as seen in Figure 8.17.

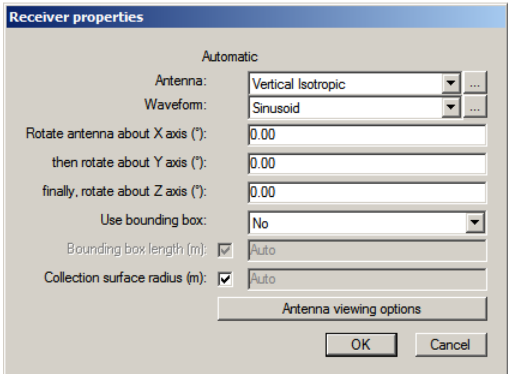


Figure 8.17: The receiver properties window

The following are descriptions of the parameters found in the RECEIVER PROPERTIES Window:

- *Antenna* - Specifies the ANTENNA used by each point in the RECEIVER set.
- *Waveform* - Specifies the WAVEFORM used by each point in the RECEIVERset. The default choice is *[Antenna's waveform]*, which is the waveform that was assigned to the antenna in the ANTENNA PROPERTIES Window. If the user wishes to override the waveform that was assigned to the antenna, any waveform in the project may be selected.
- *Rotate antenna about $X$ axis, then $Y$ axis, and finally $Z$ axis* - Applies these angles, in degrees, to the antenna pattern in the order indicated and adjusts the direction of the electrical boresight of the antenna pattern. The angles must be specified in the range 0 to 360. The default values are 0 degrees for all axes.
  - ▶ See Section 8.6 for more information about this feature.
- *Use bounding box*, *Bounding box length* - Defines properties for the calculation related to intersections between propagation paths and Rx sets.
  - ▶ These options are more fully described in Section 8.10.
- *Collection surface radius* - Sets the size of the collection surface constructed around receiver locations. Manually setting this value needs to be done in conjunction with the ray spacing to ensure accurate results. See section 10.1 for more details.

## 8.5 Tx/Rx Layout Properties

By clicking on the LAYOUT PROPERTIES button in the Tx/Rx properties window, you can access transmitter specific properties of the set, as seen in Figure 8.18. Some of these settings are specific to the type of set that is currently selected.

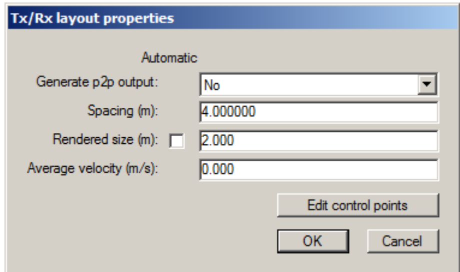


Figure 8.18: The Tx/Rx Layout properties window for a route set.

The following are descriptions of the parameters found in the LAYOUT PROPERTIES Window:

- *Spacing* - Defines the spacing in meters between adjacent points along a *Route*, for Tx/Rx sets which require it. This also applies in the plane of the *XY Grid* or *Polygon*, or around the *Arc* or *Cylinder*. The spacing for circular sets can also be specified as a constant angle, which results in the distance between points varying with the sets' radius.
- *Rendered size* - Controls the size of the boxes that are rendered at each point in the set.
- *Average velocity (Route, Arc and Trajectory sets only)* - Describes the speed at which an object would be moving along the path of the set.
- *Area lengths (XY Grid only)* - Defines dimensions of the grid in the $X$- and $Y$-direction with respect to the global coordinate system.
- *Direction (Arc, Vertical Arc and Cylinder sets only)*: including *Arc radius*, *Arc start angle*, and *Arc stop angle* - Control which direction points move around the perimeter of the set, and the segment of a circle with the given radius that the points lie within. For an *Arc*, the angle starts at the positive $X$-axis moves counter-clockwise in the $XY$ plane from that point. For a *Vertical Arc*, the angle starts at the positive $Z$-axis and moves counter-clockwise in the $YZ$ plane from that point.
- *Offset (Polygon set only)* - Indicates how far the actual Tx/Rx points are placed above or below the *Polygon* defined by the control points.
- *Vertical spacing (Vertical Surface only)* - Since a *Vertical Surface* is considered to be a stack of *Route* sets, this option controls how far apart each route is from the other in the vertical direction.
- *Height (Vertical Surface and Cylinder sets only)* - Indicates the height from the bottom row of points in the set to the top row.
- *Draw mast* - If set to "Yes", then a vertical line is drawn from each point in the set to the $XY$ plane at $Z$=0.
- *Start time (Trajectory sets only)* - Defines the time offset used when plotting output versus time.
- *Include roll angles (Trajectory sets only)* - Applies a roll angle to the points in the *Trajectory*.
  - ▸ See Section 8.1.3 for more details on the roll angle.

## 8.6 Viewing Transmitter/Receiver Control Vectors and Antenna Patterns

Every TRANSMITTER and RECEIVER set has a set of associated vectors, called "Control Vectors", which can be rendered in the PROJECT VIEW. These vectors indicate how the antenna used by the set is oriented within the project. When a Tx/Rx set is first created, by default the red vector points along the $X$-axis, green along the $Y$-axis and blue along the $Z$-axis. In most cases, the $X$-axis vector corresponds to the electrical boresight of the antenna and the $Z$-axis to the polarization of the boresight.

✓ An exception to this general rule is when the antenna is not vertically polarized by design. For example, if the antenna is an imported pattern, then the boresight and polarization lie in the default directions of a new antenna, as indicated above.

▶ To see if an antenna is not vertically polarized by default, see Chapter 7 to make this determination for the type of antenna you will be using.

By using the rotation fields in the TRANSMITTER/RECEIVER PROPERTIES Window, the control vectors can be correctly oriented within the project. To do this, first rotate the polarization indicator around the electrical boresight by entering a value in the *Rotate antenna about $X$ axis* field to give the signal the desired polarity. Next, indicate the direction of the electrical boresight by putting the theta angle in the *Rotate about $Y$ axis* field and the phi angle in the *Rotate about $Z$ axis* field. These rotations are always applied in the order listed when the control vectors are rendered in the PROJECT VIEW.

The ANTENNA VIEWING PROPERTIES Window, as seen in Figure 8.19, is accessible by clicking on the ANTENNA VIEWING OPTIONS button in the properties window of the Tx/Rx set. This window allows the user to customize the appearance of the control vectors for each set individually.

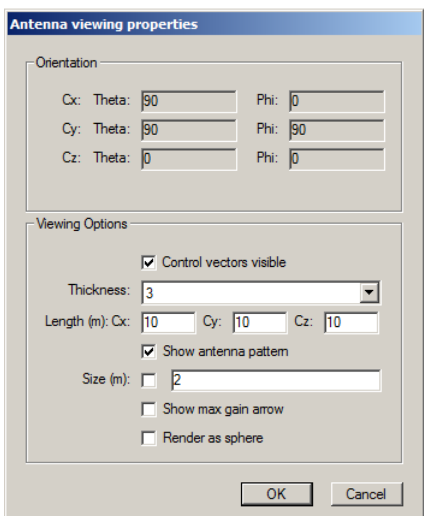


Figure 8.19: Properties of a Tx/Rx sets' antenna boresight

The following are descriptions of the parameters found in the viewing properties window:

- *Orientation* - Displays the current direction of all three indicators based on the rotation values that were given in the TRANSMITTER/RECEIVER PROPERTIES Window. These values are read-only and can only be changed by changing the rotation values.

- *Viewing Options* - Modifies how the boresight indicators are drawn on the screen.
  - *Control vectors visible* - Toggles the display of the boresight in the PROJECT VIEW.
  - *Thickness* - Alters the thickness of the lines drawn in the PROJECT VIEW.
  - *Length* - Lengthens the boresight indicators to help the user determine if they are pointed at specific points in the project. Each indicator can be adjusted independently.
  - *Pattern visible* - Renders the antenna pattern of the Tx/Rx sets' antenna at the currently selected point in the set. If no point is selected, then the first/only point will be used for this purpose. The Tx/Rx set will generate a pattern for the antenna at its waveform frequency.

    If the waveform that the Tx/Rx sets' antenna is using is changed or replaced, then the pattern will automatically be regenerated.
  - *Size* - Defines the size of the antenna pattern when it is rendered. When the pattern is first created for display, it is set to have a maximum size of 1 meter. This value is the largest distance from the Tx/Rx point to the point on the pattern with the maximum gain.

    When the antenna pattern is first rendered, there will be a slight delay as the pattern is calculated and created for display.

Figure 8.20 shows the use of the boresight with the antenna pattern activated. A TRANSMITTER point (left side) has been aligned with a RECEIVER (right side) on the wing of the aircraft. The transmitter uses a *Parabolic Reflector* and the receiver is using an *Isotropic* Antenna. The pattern is colored so that red represents the higher values and blue the lower. The electrical boresight of the transmitter point is visible and is aligned with the receiver's *Isotropic* Antenna.

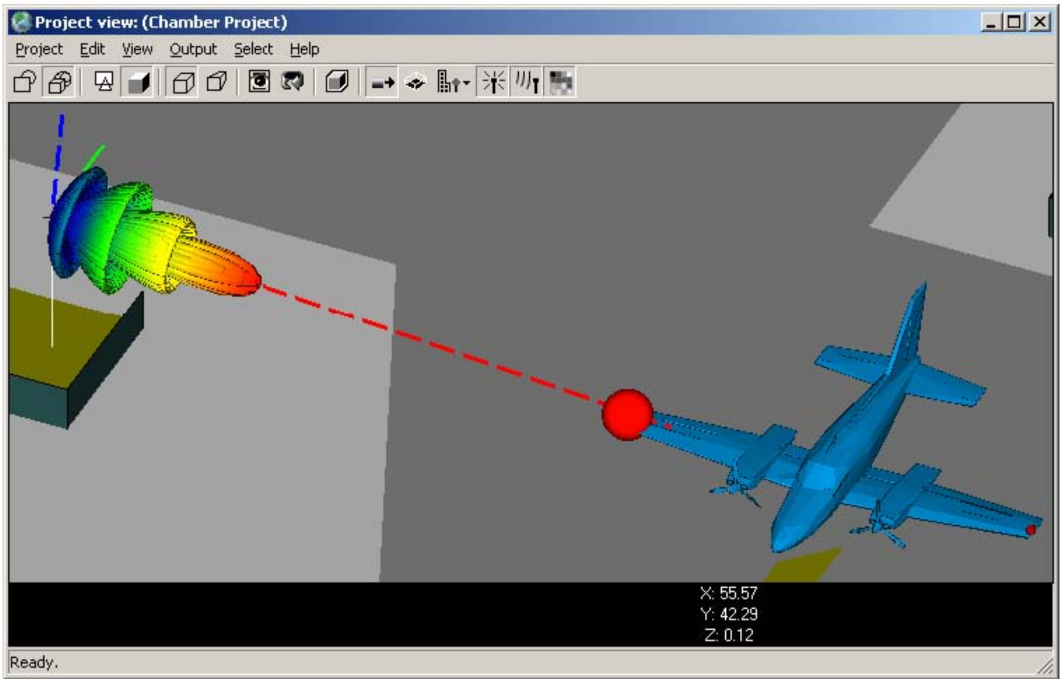


Figure 8.20: The main beam of the transmitting antenna has been aimed directly at the receiving antenna on the end of the wing.

When a set is first created, the antenna pattern appears at the first point in the set. For Tx/Rx sets that contain multiple points, the antenna pattern for the set will be displayed at the last selected point in the set.

## 8.7 Aiming Transmitting and Receiving Antennas

The AIM AT LOCATION and ALIGN BORESIGHTS features provide an alternate method of setting the rotation of the ANTENNAS associated with a TRANSMITTER or RECEIVER set .

To aim a transmitter (or receiver) point at a Cartesian point in space, choose *Select→Transmitter point* in the PROJECT VIEW, click on the desired point and select *Aim at location* from the right-click context menu. This will bring up the AIM AT LOCATION Window, as seen in Figure 8.21.

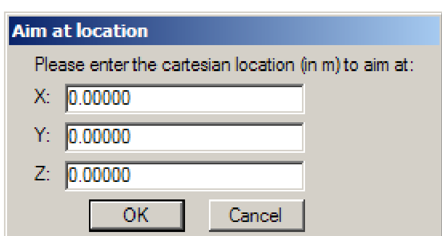


Figure 8.21: Aiming the boresight of the transmitting or receiving antenna to a point

The ALIGN BORESIGHTS feature allows the user to select a transmitter and receiver pair, and then point them at one another. To do so, choose *Select→Transmitter ->Receiver pair* in the PROJECT VIEW, click on the transmitter and receiver points and select *Align boresights* from the right-click context menu.

The $Y$-axis and $Z$-axis rotations of the transmitter and/or receiver set will be modified in the process, while the rotation about the $X$-axis will not change. Because the rotations are specified on a per-set (rather than per-point) basis, all points within the set will use the same rotation and most likely will not point to the same location. The aiming function assumes that the boresight of the antenna is directed along the positive $X$-axis.

## 8.8 Editing Transmitter and Receiver Sets

Once a TRANSMITTER or RECEIVER set has been created, several new options are available in the context menu. To access this menu, select it in either the PROJECT HIERARCHY or MAIN WINDOW and right-click. The options are as follows:

- *Edit* - Allows for graphical editing of the sets control points as described below.
- *Translate/Rotate/Scale* - All of the control points of a set can be translated, rotated and scaled in the same way that FEATURES are. All of these operations work with respect to the sets' local origin. Operations that are available for each set are as show in Table 8.1.
- *Center in* PROJECT VIEW - This will move location viewing position of the PROJECT VIEW so that it is centered on the TRANSCEIVER. The PROJECT VIEW will maintain the current rotation and scaling and will rotate about the center of the TRANSCEIVER.

Table 8.1: Control Point Set Operations

| Set Type | Rotate | Scale | Translate |
|---|---|---|---|
| Arc | | | ✓ |
| Cylinder | | | ✓ |
| XY Grid | ✓ (soft) | | ✓ |
| Points | ✓ | ✓ | ✓ |
| Polygon | ✓ | ✓ | ✓ |
| Route | ✓ | ✓ | ✓ |
| Sphere | | | ✓ |
| Trajectory | | | ✓ |
| Vertical Arc | ✓ (soft) | | ✓ |
| Vertical Surface | ✓ | | ✓ |

Sets marked with the word "soft" in this table refer to the *Rotation* field in the properties window which rotates the set in the $XY$-plane. This is used to create a grid that is not axis-aligned to the project's $X$- and $Y$-axes, and to specify the angle of a *Vertical Arc* as it appears from above in the $XY$-plane. User-defined sets can only be modified by editing the `*.pts` file.

- *Duplicate* - Creates an identical set and appends a number to the Short description to differentiate the two sets.

- *Duplicate as* - Creates an identical set of the opposite type; i.e. a transmitter set is duplicated as a receiver set and vice versa.
- *Delete* - Removes the selected set from the project.
- *Save* - Commits all changes to every transmitter or receiver set, depending on which type was selected.
- *Save As* - Allows the selected set to be written to a `*.tx` or `*.rx` file that is not related to the project.
- *Properties* - Opens the properties window for the selected set. This window may also be accessed by double-clicking on the set in the MAIN WINDOW.

In edit mode, the control points of a set are displayed in the editor as blue dots, which may be moved or altered by right-clicking on them. The menu that is displayed varies for different types of sets. Common functions include:

- Continuing a *Route* or *Vertical surface*
- Adding points to a set
- Changing the height or location of one or all of the control points
- Deleting the point that was clicked

The shape of a *Route* or *Vertical surface* may be changed by adding control points; simply click on the line defining the *Route* to add a point.

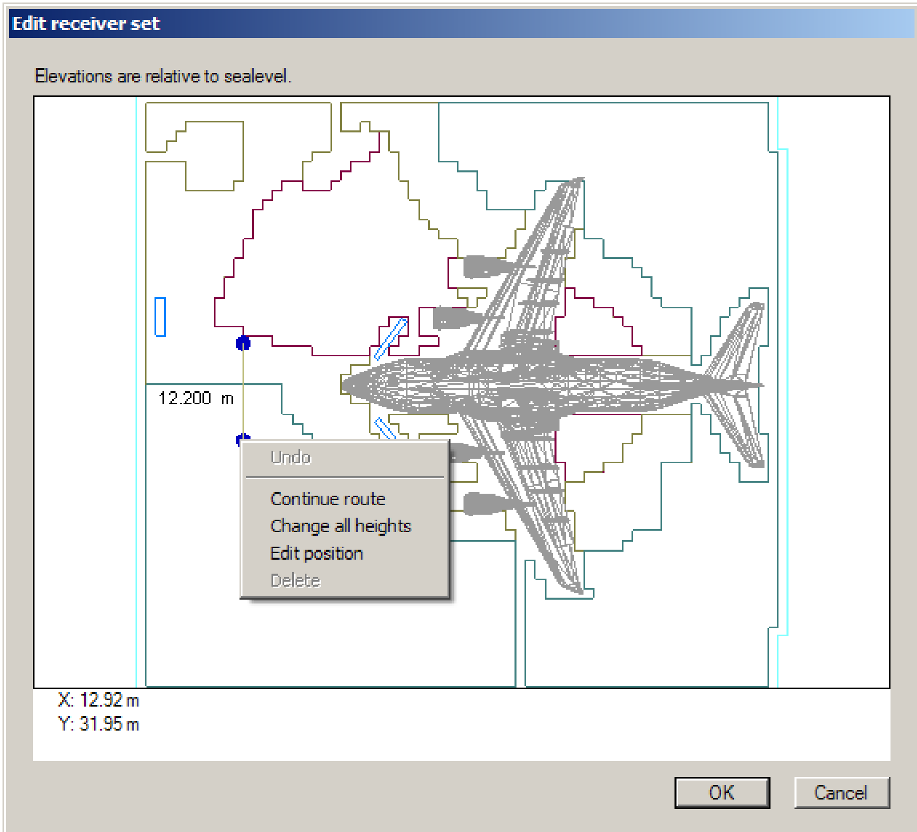


Figure 8.22: The options for editing an existing Route are shown. If the Route were to have more than two points, then the Delete option would also be available.

*Arcs*, *Vertical Arcs* and *Cylinders* can be edited by clicking on and moving the point which defines either the center or outer radius of the set. To move the circle, click and move the center; to increase or decrease the radius, click and move the radial point. The displayed radial distance will update when changed, as seen in Figure 8.23.

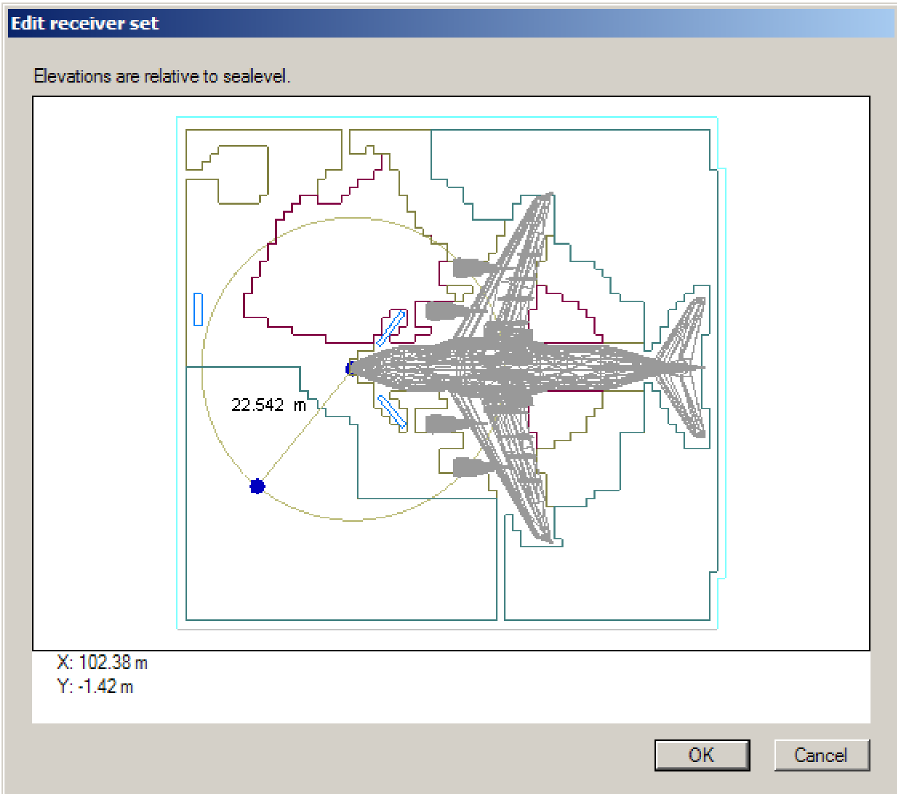


Figure 8.23: Editing the radial point of a Sphere set

The EDIT CONTROL POINTS button in the properties window allows the user to view and edit the control points, which are used to define the TRANSMITTER or RECEIVER set, without entering the graphical editor. The number of control points and their significance is dependent upon the set type. Brief descriptions of how control points are used for each type of set is described below:

- *Route* - Defined by at least two control points, each control point along a Route represents the beginning and/or end of a line segment. The first point is always (0,0), which corresponds to the local origin of the set.
- *XY Grid* - A single control point (0,0,$Z$) marks the lower left-hand corner of the grid, with $Z$ determining the constant $Z$-coordinate for all points in the grid. The lower left-hand corner before applying the rotation is also the local origin of the set.
- *Arc* - A single control point (0,0 $Z$) marks the center of the Arc, with $Z$ determining the constant $Z$-coordinate for all points in the Arc. The center is also the local origin of the set.
- *Vertical Arc* - A single control point (0,0,$Z$) marks the center of the Vertical Arc, which is also the local origin of the set. The angle of the set as viewed from above is indicated by the set's rotation value.
- *Cylinder* - Two control points define the endpoints of the central axis of the Cylinder. The $X$- and $Y$-coordinates must be equal and the $Z$ values determine the top and bottom of the Cylinder.

- *Polygon* - The control points are identical to the coordinates entered when the Polygon was first defined. If the Polygon was created by selecting *Cover with→Receiver points* from a FACES context menu, then the control points are the same as the vertices of the face being covered. Graphical editing is only available for Polygon sets that lie in the $XY$-plane. The set can be rotated out of the $XY$-plane after the editing is complete.
- *Vertical Surface* - Identical to *Route*.
- *Sphere* - A single control point (0,0,$Z$) marks the center of the Sphere, with $Z$ determining the height of the center of the sphere. The locations of the points are determined by the spheres radius and the subset that is specified by the starting and ending phi/theta angles.
- *Trajectory* - Defined by at least three control points, each control point between the beginning and ending point of a Trajectory represents a transition point in the path that is defined by the set.
- *Points* - Each control point represents the offset of a point from the sets origin.
- "Points-on-face" - The control points define, in order, the points placed on the face when the set was created. The coordinates are defined as offsets in the $X$- and $Y$-directions from the first vertex of the face. The $Z$ component defines the distance of the point above or below the face, along the face's normal vector.

## 8.9 Display Options

The PROJECT VIEW displays TRANSMITTERS as green cubes, RECEIVERS as red cubes, and TRANSCEIVERS as blue cubes. The size of the cubes can be changed for a set, as seen in Figure 8.24, by selecting the set and choosing *Properties* from the context menu. In the properties window, select LAYOUT PROPERTIES and change the value labeled *Rendered size*.

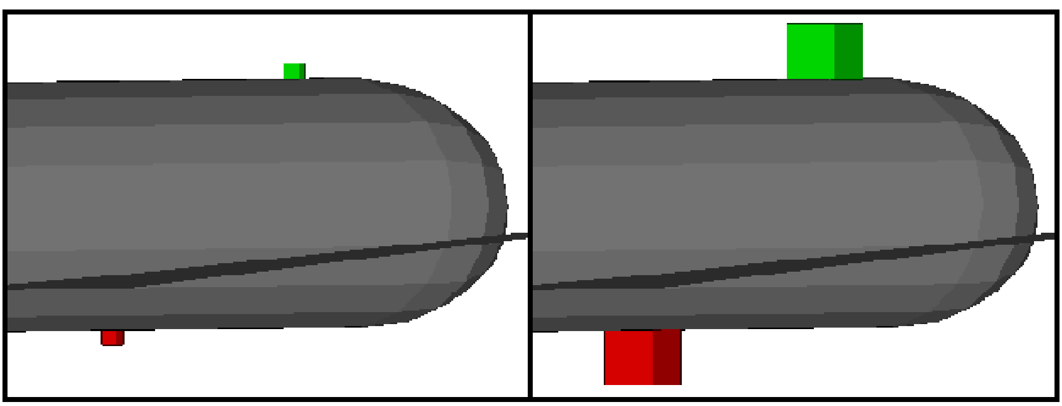

Figure 8.24: Adjusting the rendered size of a transmitter and receiver

Each transmitter set can also be made visible or invisible, as desired, to ease viewing other elements of the project. To change the visibility of a set, select it an click on *Visible* in the cotext menu to toggle its visibility in the PROJECT VIEW. To change the visibility of other aspects of the set, you can also select *Show origin*, *Show control vectors*, *Show antenna pattern* and *Show Description*. Each set can also be deactivated so that future calculations are not performed for the set. To toggle the set active or inactive, select *Active* in the context menu.

## 8.10 Receiver Bounding Boxes

The RECEIVER bounding box is used to reduce the computation time for the ray tracing. It does so by grouping receiver points within larger bounding boxes, considering the intersections of rays with the bounding boxes, and then checking for the intersection of each ray with the small collection surfaces surrounding each receiver point.

The bounding box should be used in most situations for all receiver set types except *Points* and "Points-on-Face". If there are a large number of points in the set ($> 25$), then it may be helpful to use bounding boxes.

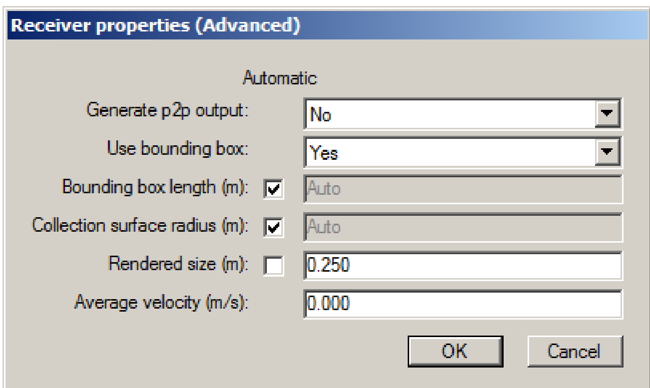


Figure 8.25: Properties for a receiver route

Receiver bounding boxes properties can be set in the RECEIVER PROPERTIES Window, as seen in Figure 8.25. To define a bounding box around a RECEIVER set, first set *Use bounding box* to "Yes". The size of the bounding box can be automatically set by the calculation engine, or it can be entered manually by un-checking the *Auto* box and entering a value in the *Bounding box length* field. The size of auto-determined bounding boxes are written to the "Receiver Sets" section of the `*.diag` file.

When manually setting the bounding box size, some care must be taken in selecting the length. Incorrectly sizing a bounding box can lead to increased run times.

Below are general rules of thumb for manually setting the bounding box length based on the type of Tx/Rx set:

- For *XY Grids*, *Vertical Surface*, *Polygon*, and *Cylinder* sets, define the bounding box size as 10 times the spacing between points.
- For *Routes*, *Arcs*, *Vertical Arcs*, *Trajectory*, and *Spheres*, set the box size to 20 times the spacing between points.
- For *Points*, set the box size so that encloses about 25 points.

# Chapter 9

# Study Areas

*In this chapter, you will learn...*

→ how to create and define a study area

→ how to set up the study area to meet the requirements of your XGtd project

A STUDY AREA defines three important aspects that determine what information will be used during a simulation: the region of the project in which to perform a simulation, the propagation model to be used in calculating the power transferred from active TRANSMITTERS to active RECEIVERS within the study area, and the set of outputs to generate during the simulation. Multiple study areas can be defined in a project, each with a unique short description, independent propagation models, and parameters. Through this mechanism, results from various calculation techniques can be compared. TRANSMITTERS RECEIVERS and *Objects* falling outside the study area boundary are not considered.

## 9.1 Creating a Study Area

To create a STUDY AREA, right click in the PROJECT VIEW and choose *New→Study area*. The window shown in Figure 9.1 will appear.

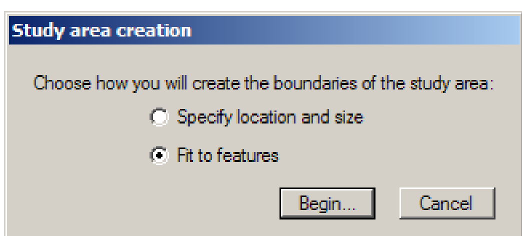


Figure 9.1: Creating a new study area

Specify the method the application should use to create the STUDY AREA boundaries. The first option, *Specify location and size*, allows the user to draw the boundary perimeter manually and specify the bottom and top heights. To do so, use the mouse to select vertices along the desired boundary in the PROJECT VIEW. These points are connected by straight lines, and any number of points can be selected, allowing the user to define irregularly-shaped study areas. After clicking on the last point of the boundary, right-click to connect the last point to the first. The base and top height of the study area are specified in the window seen in Figure 9.2.

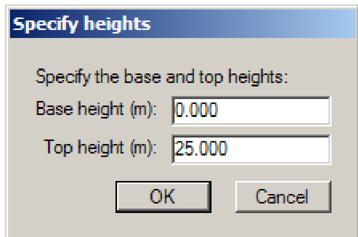


Figure 9.2: Finishing the creation of a new study area

The second option, *Fit to Features*, automatically fits the study area boundary around all FEATURES, TRANSMITTERS, and RECEIVERS in the project. The size expands and contracts as items are added, deleted, or repositioned.

## 9.2 Study Area Properties

After clicking OK in the SPECIFY HEIGHTS Window, the STUDY AREA PROPERTIES Window will appear. Figure 9.3 shows the default study area properties window. Once created, this window can also be accessed by right-clicking on the study area entry in either the table under the STUDY AREA tab on the MAIN WINDOW or in the PROJECT HIERARCHY.

Note that the contents and layout of the STUDY AREA PROPERTIES window will change to reflect relevant parameters associated with the selected *propagation model*. After selecting the desired *Propagation model*, enter a *Short description*; this will be used to name the output folder where files generated during the simulation are written. Only valid filename and directory characters may be used for a short description. If one is not entered, folders will be named after the selected model. For example x3d, full3d, full3d(2) etc.

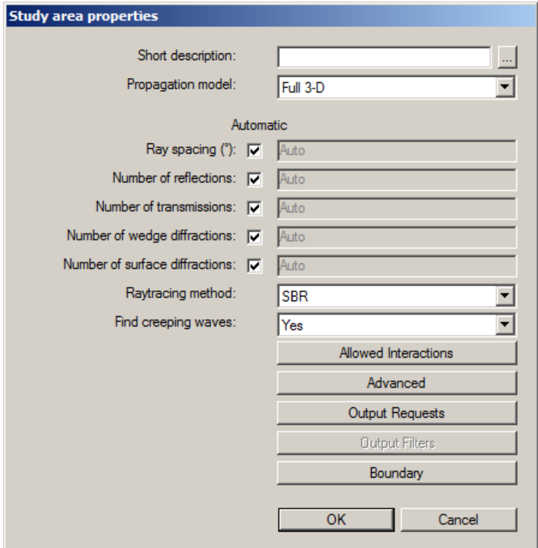


Figure 9.3: Study area properties window

The FULL 3D model allows the user to set the ray spacing and the maximum number of reflections, transmissions, and diffractions. This model uses the Shooting and Bouncing Ray (SBR) method as its default ray tracing algorithm. The X3D model provides RCS calculations that use methods based on Physical Optics (PO), the Method of Equivalent Currents(MEC), and UTD. The model uses ray-tracing that combines image theory and SBR, and it also provides GPU acceleration and parallel-processing capabilities. The FREE SPACE propagation model calculates output based on the line of sight ray from the transmitter to the receivers without including any effects of Features in the project.

Table 9.1 lists the inputs available for each propagation model.

Table 9.1: Summary of Study Area inputs by Propagation Model

| Model | Model Input Parameters | Output Requests | Output Filters | Boundary |
|---|---|---|---|---|
| X3D (RCS ONLY) | Ray interactions<br>Calculation Method<br>Advanced<br>CPU Threads<br>Use GPU<br>Partitioning and Queuing<br>Atmosphere | No | No | ✓ |
| FULL3D | Ray spacing<br>Ray interactions<br>Raytracing Method<br>Find creeping waves<br>Allowed Interactions<br>Advanced | ✓ | ✓ | ✓ |
| FREESPACE | No | No | No | No |

The *Automatic* checkboxes next to the parameter entries are used to request that the calculation engine use default values for a parameter when the calculations are made. Each parameter can be set independently by turning off the automatic option and entering a number or selecting the desired option.

✓ The novice user is encouraged to make use of these options when initially performing calculations. After acquiring more experience with XGtd, the user may find that setting some of the properties manually may improve results.

The remaining parameters in the STUDY AREA PROPERTIES Window are described below.

## Model Input Parameters

The different propagation models included in XGtd support different input parameters. The FREESPACE does not require any model inputs.

- For ray-tracing models these include:
  - *Ray spacing*: used during the ray tracing portion of the calculations. The proper setting for this parameter depends on several factors, including the size of the project, the size of the facets in the project and the distance of facets from the transmitter. Note: for the X3D model, ray-spacing is placed on the advanced parameters tab and includes new options, as discussed later in this section.

    ✓ As a rule of thumb, for a 500 m x 500 m area, set the ray spacing to 0.2° or smaller.

    ✓ The angular spacing should be decreased in inverse proportion to the size of the chamber area.
  - *Number of reflections*: this indicates the maximum number of reflections which a path can undergo. When diffractions are present, additional logic determines when reflections can occur before, after and between diffractions. FULL 3D has additional settings in the advanced parameters tab to control reflections for diffracted paths. For the X3D model, this is the number of allowed reflections *to or from* the target. The total round-trip reflections will therefore be up to *twice this number*.

    ✓ In our experience, four reflections are usually sufficient when multiple separate objects or structures are present, and two are usually sufficient for individual objects (e.g. vehicles), although areas with highly reflective objects or fine geometric features may require more. For the X3D model, these numbers should be halved (1 reflection for single objects and 2 for multiple objects), due to the doubling that will occur for the round-trip paths, as described above.
  - *Number of transmissions*: indicates the maximum number of transmissions which a non-diffracted path can undergo (other settings in the advanced parameters tab control transmissions for diffracted paths). Transmissions through dielectric bodies are used to find propagation paths to points inside an object.

    The user should be aware that the run time will increase as the number of reflections and transmissions increase, and, in some cases, it may increase dramatically.

    For the FULL 3D model, the combined number of reflections and transmissions is limited to 30. If they exceed this value, they are reduced proportionately so that they sum to 30. The X3D model does not currently support transmissions.

  - *Number of diffractions*: indicates the maximum number of diffractions which a path can undergo. For the X3D model, it should be clearly noted that this is the maximum number of diffractions that are incurred traveling to *or* from the target. The total round-trip diffractions will therefore be up to *twice this number*.

    ✓ In our experience, one diffraction is usually sufficient. This is particularly true for the X3D model due to the doubling effect described above.

    ✓ The maximum number of diffractions in the FULL 3D model is 4. For the X3D model, it is 3.

    Additional diffractions can dramatically increase run time, even more so than additional reflections and transmissions.

- For model-specific input parameters, please refer below to Section 9.3 or to the appropriate section of Chapter 10.

## Output Requests

The FULL 3D model has an *Output Requests* button, which allows the user to select which output files will be generated during simulation. The FREESPACE model only generates a very limited number of outputs, and does not have this button. It will generate all of its outputs for every simulation.

## Output Filters

TheFULL 3D propagation model supports OUTPUT FILTERS. OUTPUT FILTERS allow paths with certain interactions to be filtered out when generating output. It is possible to change an output filter and quickly recalculate the results using the *Add requested output* calculation mode.

## Boundary

The BOUNDARY button provides two ways for the user to redefine the region contained within a manual STUDY AREA either by editing the control points or by graphically moving the vertices of the STUDY AREA within the PROJECT VIEW.

### Edit Control Points

The vertices of the STUDY AREA can be edited using the EDIT CONTROL POINTS button. Clicking on the button causes the VIEW/EDIT VERTICES Window to appear, as seen in Figure 9.4. Point coordinates are given in meters relative to the global origin. Vertices' locations can be modified by double-clicking on the entry for a vertex and entering new $X$-, $Y$-, and $Z$-coordinates. The $Z$-values are heights described relative to the terrain or sea level, as determined by the *Elevations relative to* drop-down menu in the STUDY AREA PROPERTIES Window. Selecting a vertex and then right-clicking allows users to add a *New vertex*, *Delete vertex*, or move a vertex up or down in the list.

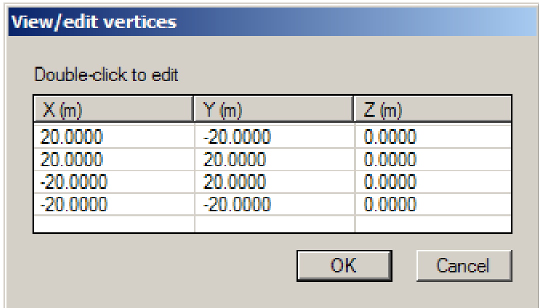


Figure 9.4: The vertices describing the outline of a study area

### Edit Boundary

The EDIT BOUNDARY button allows the user to graphically reposition the vertices of the STUDY AREA. Clicking on the button causes the EDIT STUDY AREA BOUNDARY Window to appear, as seen in Figure 9.5. Each of the blue points represents a vertex. To change the position of the vertex, click and drag the point to its new location. Also from this window, the *Auto-boundary* checkbox can be clicked to switch to the automatic boundary mode described above. If this checkbox is selected and a vertex is moved, the study area reverts back to the manual mode.

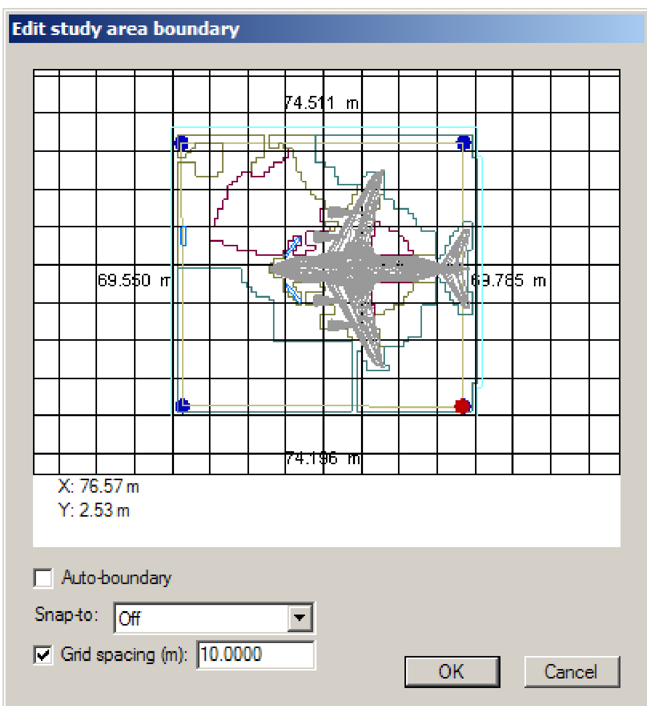


Figure 9.5: Editing the boundary of a study area

When the user clicks OK and the *Auto-boundary* checkbox is unchecked, the SPECIFY HEIGHTS Window will appear, allowing the specification of the bottom and top heights of the study area.

## 9.3 Model-Specific Study Area Inputs

▶ For more information on propagation models and their parameters, see Chapter 10.

### 9.3.1 Full 3D Study Area Inputs

✓ The ADVANCED STUDY AREA PROPERTIES Window allows the user to further adjust these values for diffracted rays when necessary.

#### Raytracing Method

Choose between Shooting and Bouncing Ray (SBR) and Eigenray (ER).

The ER method can only be used for RCS calculations if there is an active *Plane Wave* within the project and if the *Number of diffractions* is set to 1. If the project contains near-zone RECEIVER sets, the SBR method should be selected.

For the ER method, the sum of the number of interactions (reflections, transmissions, and diffractions) must be no greater than 3.

▶ Ray tracing methods are explained in Section 10.1.

#### Find Creeping Wave

- *Find creeping waves* - This option controls whether or not the calculation should attempt to find propagation paths which propagate over the surface of smooth bodies.
  - ▶ Creeping waves for the respective models are explained in Section 10.1 and Section **??**.

#### Allowed Interactions

This option applies to the FULL 3D model. It allows each kind of interaction to be turned off for each FEATURE type. For example, it is possible to turn off reflections from a *Chamber* or transmissions through an *Object* using this feature. By default, all interactions are enabled when a new STUDY AREA is created. In Figure 9.6, the allowed interaction types are checked, and the disallowed types are unchecked.

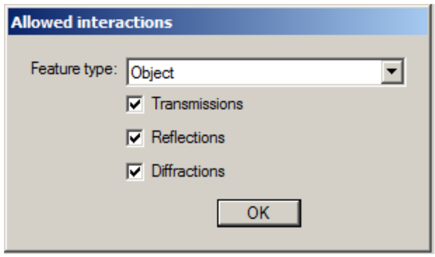


Figure 9.6: Setting types of interactions that are allowed in the study area

This capability is similar in some respects to the OUTPUT FILTERS. However, when an interaction in a STUDY AREA is disallowed, the specified ray paths are never found; but the unwanted interactions in output filters are filtered out when the output is generated. It is possible to change an output filter and quickly recalculate the results using the *Add requested output* calculation mode, whereas if the allowed interaction settings in a study area are changed it is necessary to run a new calculation.

**Advanced Model Parameters**

The ADVANCED button provides additional options for customizing the calculation model. Figure 9.7 shows the ADVANCED MODEL PARAMETERS window for Full 3D. For FULL 3D, the user can specify several ray tracing parameters to set the maximum number of reflections and transmissions for ray paths which undergo diffractions. The maximum number of reflections and transmissions can be specified independently; before the first diffraction, between diffractions, and after the last diffraction. The user can also select the RCS method (PO or PO/MEC) used to calculate monostatic or bistatic RCS returns.

✓ We suggest that the maximum number of interactions (reflections and transmissions) that can occur before the first diffraction be the same as the number after the last diffraction, and that the number between diffractions be 0, 1 or 2.

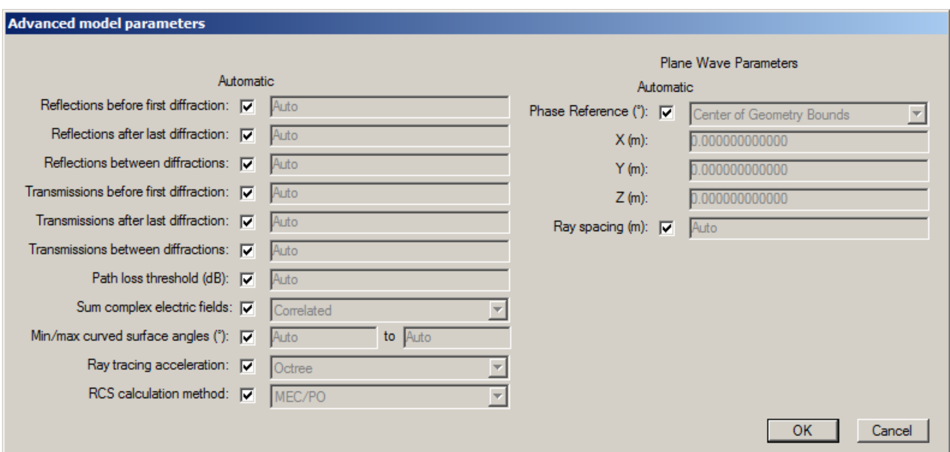


Figure 9.7: Advanced model parameters for the Full3D model

- *Plane Wave Ray Spacing*

The spatial separation of rays shot from *Plane Wave* transmitters can be set manually, or using the automatic option, an optimal value set at calculation time.

- *Number of Reflections*

  The first three fields on the window above allow the maximum number of reflections before, after and between diffractions to be set manually. If the *Automatic* box is checked, the maximum number before and after diffractions will be half the maximum number for non-diffracted paths set in the STUDY AREA PROPERTIES Window, with fractions rounded up to the next whole number. For example, if the maximum number of reflections is set to 5, the maximum number before and after a diffraction will be 3. The maximum number between diffractions will be set to 0, 1 or 2 if the *Automatic* box is checked, depending on the maximum number of reflections.

- *Number of Transmissions*

  Propagation paths with transmissions through walls are usually only found in the FULL 3D model, the only exception being when the material type is set to *Free Space*. The maximum numbers of transmissions are set in the basically the same way as the numbers of reflections. If the *Automatic* box is checked, the maximum number before and after diffractions will be one half the maximum number for non-diffracted paths set in the STUDY AREA PROPERTIES Window, and with fractions rounded up to the next whole number. For example, if the maximum number of transmissions is set to 3, the maximum number before and after a diffraction will be 2. The maximum number between diffractions will be set to 0, 1 or 2 if the *Automatic* box is checked, depending on the maximum number of transmissions.

- *Path Loss Threshold*

  This parameter provides a means to omit ray paths with very small power levels from the latter stages of the computations, which can help to reduce the computation time. For models which use a path loss threshold, the default setting is 70 dB. The calculation engine will ignore all paths for which the path loss exceeds the free space loss by the amount specified. For example, with the 70 dB default value, all paths which are 70 dB below the $\frac{1}{r^2}$ free space path loss are ignored. This threshold is applied to the electric field assuming an *Isotropic* source, so any antenna pattern effects at either the TRANSMITTER or RECEIVER are not taken into account.

  In general, the *Automatic* box should be left checked since it will be set to a very large value. However, if the user is concerned that extremely weak paths may be missed, this value can be adjusted. In the VHF and UHF bands an excess path loss above 60 dB would be rare, so setting this value too much higher will usually have no effect. The drawback to setting it too high is that this can lead to significantly longer run times as computations are performed on a large number of very weak paths which make no contribution to the final results.

  ✓ For each calculation, the geometrical path data is retained, and this threshold can be reduced and new predictions generated without repeating the ray tracing procedures.

  In some situations, the user may wish to set the threshold even lower as a way of screening out all weak paths. An alternative means of doing this is to use the *Minimum received power* setting in the ANTENNA PROPERTIES Window. In the latter case all antenna pattern effects as well as the input power to the transmitter will be considered.

- *Sum Complex Electric Fields*

This setting controls whether the phase of the electric field of each ray path is retained when combining the fields to predict the received power and path loss. The differences among the options have to do with whether ray paths are combined by adding complex-valued electric fields or by summing powers.

- *None* - The received power is found by adding the power of each path. The phase difference between rays is ignored.
- *All* - All fields are first summed with phase and then XGtd finds the total power from the magnitude of the total field.
- *Correlated* - The ray paths which follow nearly the same path through the environment (the correlated paths) are combined with phase, and then the powers of all the correlated groups are added.

▶ For a more thorough explanation on computing received power, see Section 11.1.

- *Min/Max Curved Surface Angles*

  The propagation of creeping waves over a body requires a smooth surface; however, in XGtd *Objects* are represented as faceted geometries. Therefore, edges formed by two adjacent faces for which the exterior angle between the faces is between some minimum and maximum angles are considered to form a curved surface. XGtd will treat the adjacent facets as a smooth surface when the exterior angle between the facets is between the minimum and maximum angles considered to form a curved surface. The default values for these minimum and maximum angles are 180°and 198°, respectively. These angles can be set in the ADVANCED MODEL PARAMETERS Window, which is accessible by clicking on the ADVANCED button in the STUDY AREA PROPERTIES Window. The edges of any FEATURES that meet this criteria can be displayed in the PROJECT VIEW.

  ▶ See Section 3.2.6 for more information about smooth edges.

- *RCS Calculation Method*

  Choose whether to use a method based solely on physical optics (PO), or to also include diffraction effects using the method of equivalent currents (MEC).

- *Plane Wave Parameters*

  Set the phase reference point for plane waves.

### 9.3.2 X3D Specific Study Area Inputs

#### Advanced

The ADVANCED button provides additional options for customizing the calculation model. Figure 9.8 shows the ADVANCED X3D PARAMETERS window.

When using X3D, the user can modify parameters that control how rays are shot, and set the phase reference for plane waves. The former defaults to a method that targets every facet in the geometry, to support high-resolution models. The user can also enter Cartesian coordinates for the plane wave phase reference point.

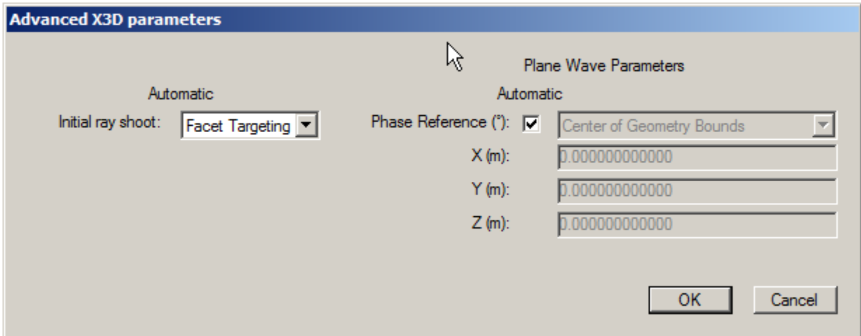


Figure 9.8: Advanced X3D parameters

- *Initial Ray Shoot*

  Controls the method used for initial ray shooting in the X3D model, with the default set to Facet Targeting. With this setting, rays are shot at each facet, ensuring complete illumination of high-resolution facet models. When set to uniform sweep, a point transmitter shoots rays in an angular sweep using the ray spacing parameter on the study area parameters form, and plane waves use the uniform linear ray spacing on this form.

- *Plane Wave Parameters*

  Set the phase reference point for plane waves.

**Atmosphere**

- *Temperature*, relative *Humidity*, and *Pressure* - Used by the X3D model to calculate atmospheric absorption. Details of the algorithm are provided in Section 10.2.
- *Calculation method* - Choose whether to use a method based solely on physical optics (PO), or to also include diffraction effects using the method of equivalent currents (MEC).

**Partitioning and Queuing**

By selecting PARTITIONING AND QUEUING the user can choose whether to partition jobs for parallel-processing. An image of the PARTITIONING AND QUEUING PROPERTIES window in one configuration of parameters is shown in Figure 9.9. The job may be partitioned into separate processes, subdivided according to the *Partitioning type* parameter *by receiver set*, or *by transmitter point*. The user must choose the *Queue type*. *Local* queuing will spawn multiple processes on the users workstation. *External* queuing will create a batch job for execution on a cluster. When a job is partitioned *by transmitter point*, the user must additionally specify the *Number of Partitions* to create, which will result in the grouping of transmitter points into the number of specified partitions. Each partition will use the number of threads specified in the STUDY AREA PROPERTIES window, displayed for convenience on this form as well. The *Constraints* field is used for diagnosing problems by the engineering team and should generally be left blank by users.

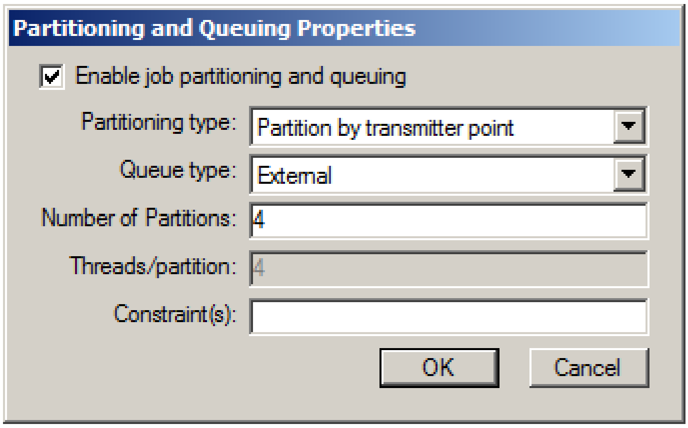


Figure 9.9: Partitioning and Queueing Properties for a Sample Configuration

## 9.4 Study Area Operations

A set of operations are available to modify the Study Area through its context menu. Multiple study areas can be selected and modified by holding the control key while clicking on their entries in the Project Hierarchy.

- *Duplicate* - Creates a duplicate of the study area, including the model type and all related parameters.
- *Delete* - Removes the study area from the project.
- *Edit Boundary* - Opens the boundary editor so that the vertices of its footprint can be edited manually.
- *Center in* Project View - This will move location viewing position of the Project View so that it is centered on the Study Area. The Project View will maintain the current rotation and scaling and will rotate about the center of the Study Area.

# Chapter 10

# Propagation Models

*In this chapter, you will learn...*

→ the characteristics, limits and electric field evaluation of each XGtd propagation model

XGtd provides three models for propagation and scattering calculations: Full 3D, X3D (GPU-accelerated full 3-D ray-tracer), and Free Space. The Full 3D and X3D models combine ray-tracing algorithms with Geometric Optics (GO) and the Uniform Theory of Diffraction (UTD) , and for far-zone radar cross-section calculations, Physical Optics (PO) and the Method of Equivalent Currents (MEC). Ray-tracing methods are used to find the propagation paths between each transmitter and receiver point. The physics methods (GO, UTD, PO and MEC) are then used to evaluate the complex electric fields associated with each ray path.

- Chapter 11 describes how the propagation predictions for quantities, such as received power, path loss, and radar cross section (RCS), are computed from the electric fields and propagation paths.

Each section of this chapter starts with an overview describing how the model works, followed by a short summary of the model's capabilities and limitations. Then the under-lying algorithms used for that model are described, and the section concludes with a discussion of how the electric fields are calculated. The angles used in discussions of the electric field components or antenna gain are specified in terms of the spherical components at the Transmitter or Receiver point using a spherical coordinate system, shown in Figure 10.1.

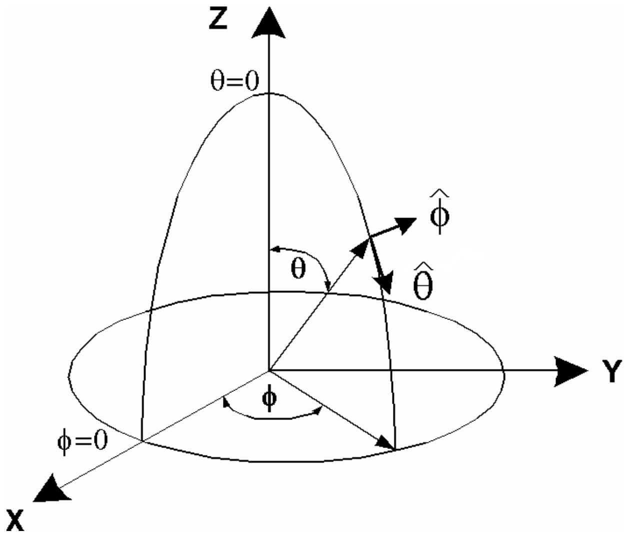


Figure 10.1: The XGtd spherical coordinate system

## 10.1 Full 3D Model

### Overview

The FULL 3D model is the primary ray-tracing algorithm of XGtd. The FULL 3D model propagates rays through the project's urban geometry and includes the effects of reflections, transmissions, and diffractions on the electric field.

The combined number of reflections and transmissions cannot exceed 30. If the combined number of reflections and transmissions is greater than 30, each value is reduced proportionately so that they sum to 30. When transmissions are included in a project, all facets should typically be doubled-sided.

- Refer to Chapter 3 for more information on the differences between doubled-sided and single-sided facets and the options for changing this attribute.

### Summary

The following list summarizes the capabilities of the FULL 3D model:

- Maximum reflections: 30 (SBR,assuming no transmissions), 3 (Eigenray, assuming no diffractions)
- Maximum transmissions: 30 (SBR,assuming no reflections), 30 (Eigenray)
- Maximum wedge diffractions: 4 (SBR), 3 (Eigenray, assuming no reflections)
- Maximum surface diffraction: 30 (SBR method only)
- Objects: all
- Chambers: all

- Range: depends on application
- Antenna types: all
- Ray tracing: SBR or Eigenray
- Minimum frequency: 100 MHz
- Maximum frequency: depends on application

## Ray Tracing

Three ray tracing methods are available with the FULL 3D model: the Shooting and Bouncing Ray (SBR) method, the Eigenray method, and an accelerated ray tracing for radar cross section calculations.

### Shooting and Bouncing Ray (SBR) Method

The SBR method is first employed to trace ray paths through the geometry without regard for the location of specific field points, using the procedure described in [23] and [24]. Rays are first traced from the source points with the rays reflecting specularly from the facets. The rays that hit facets are reflected specularly and continue to be traced up to the maximum number of reflections, or when the rays hit the STUDY AREA boundary.

Before describing how the SBR paths are used to find the geometrical propagation paths from the transmitter to the receiver points, the procedure for identifying diffracting edges will be described. In the Geometrical Theory of Diffraction (GTD), wedge diffractions occur at the points where the field becomes discontinuous. The first order diffracting edges are found by searching for adjacent rays which follow different paths through the geometry, since such occurrences identify discontinuities in the Geometrical Optics (GO) fields. A diffracting edge can then be located between these rays.

Figures 10.2 and 10.3 show examples of how the rays shot from the transmitter are used to identify diffracting edges. For example, the two adjacent SBR rays in Figure 10.2 both reflect from facet 3, but only one reflects from a facet 55. This means that a diffracting edge lies between these two rays, and it is then quite simple to locate a diffraction point on edge 55-56 and to construct the path followed by the incident field.

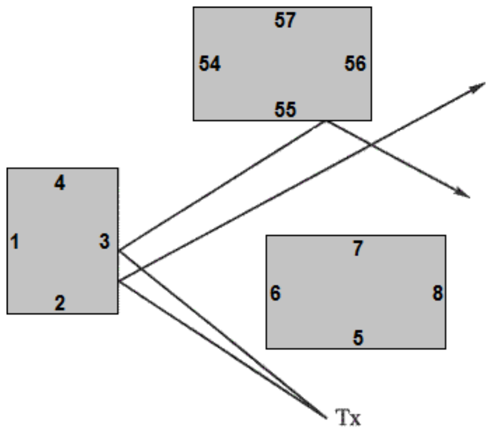


Figure 10.2: Rays which identify edge 55-56 as a diffracting edge

A different diffraction situation is shown in Figure 10.3, where the edge 10-11 would be identified as a diffracting edge for the incident field, which first reflects from facet 13.

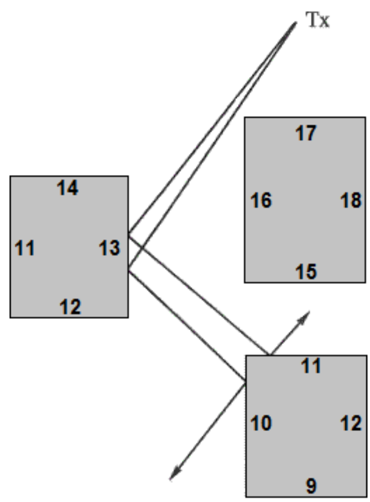


Figure 10.3: Rays which identify edge 10-11 as a diffracting edge

The two situations differ in that the latter example has two reflection shadow boundaries, whereas the former example has an incident shadow boundary and a reflection shadow boundary. Either situation can give rise to a strong diffracted field.

Once the rays have been shot and bounced from all the active TRANSMITTERS, rays are then shot and traced from all the diffracting edges. This procedure is then repeated if higher order diffractions are to be included.

Once the SBR paths have been traced from a transmitter or edge, the next step is to construct the specific geometrical paths to each field point from the transmitter or diffracting edge. Because SBR launches rays at discrete angles, it is unlikely that any ray will pass exactly through a field point. To compensate for the spacing between rays, a collection sphere is constructed around the field point. Rays that pass through this surface are used to construct the specific GO and GTD ray paths to the field point.

The SBR method can construct ray paths with up to 30 total reflections and transmissions. The ray paths can also undergo diffractions. There are two types of diffractions: WEDGE and SURFACE. As described above, WEDGE diffractions occur at the point where the field becomes discontinuous. SURFACE diffractions are diffractions from edges on the same facet as the proceeding diffraction, and the maximum allowed is 30.

Although the method allows for up to 30 reflections and transmissions on a ray path, the computation time can become large when both reflections and transmission are requested. The computation time is roughly proportional to:

$$\frac{(N_R + N_T + 1)!}{N_R! N_T!} \tag{10.1}$$

where $N_R$ is the number of reflections and $N_T$ the number of transmissions. If no diffractions are requested, the computation time will roughly be proportional to the number of facets in the geometry, with double-sided facets counting as two facets. When a single wedge diffraction is requested, the computation time is roughly proportional to the number of facets squared. Requesting additional surface diffractions does not greatly affect the run time due to the limitation to coplanar edges.

#### Eigenray Method

The other ray tracing method is the called the Eigenray method. This approach involves an explicit construction of the ray paths between each TRANSMITTER and RECEIVER which satisfy Fermat's Principle of least time, except that there is no refraction at transmissions. The Eigenray method is limited to ray paths with up to three reflections and diffractions. Like the SBR method, it finds up to 30 transmissions per ray path. However, this method has the following path-finding restrictions:

- No more than a combined total of 3 reflections and diffractions per ray path are found (Tx-D-D-R-Rx or Tx-R-R-R-Rx).
- Paths which diffract, reflect, and then diffract (Tx-D-R-D-Rx) are not constructed.
- Paths with 3 diffractions (Tx-D-D-D-Rx) must diffract off of parallel edges (typically all vertical or all horizontal edges).

The computation time with the Eigenray method is roughly proportional to $(N_F)^{\chi}$, where $N_F$ is the number of facets, and $\chi$ is the maximum number of reflection plus diffraction interactions on any path, with the maximum being three.

✓ Because the computation time does not increase significantly with the number of transmissions, the Eigenray method will often be a good choice for applications requiring a large number of transmissions, as long as the restrictions on the number of reflections and diffractions is acceptable.

### Accelerated Ray Tracing for Radar Cross Section Calculations

XGtd will use an accelerated ray tracing method for RCS calculations when the *Number of wedge diffractions* and the *Number of surface diffractions* is set to “1”. The *Number of Reflections* and *Number of*

*Transmissions* should be left on the *Auto* setting or should be manually set to 0. Additionally, the project cannot contain any near-zone RECEIVER sets.

## Electric Field Evaluation

The first step in evaluating the electric field is to find the electric field in the far zone of the transmitting antenna. At present, XGtd does not consider any near zone fields. In free space the electric field in the direction $(\theta, \phi)$ in the far field of the transmitting antenna at a distance $r$ can be written as:

$$E(r, \theta, \phi) = (A_\theta(\theta, \phi)\hat{e}_\theta \; + \; A_\phi(\theta, \phi)\hat{e}_\phi) \; \frac{e^{-j\beta r}}{r} \tag{10.2}$$

where

$$A_\theta(\theta, \phi) = \sqrt{\frac{P_T \eta_0}{2\pi}} g_\theta(\theta, \phi) \tag{10.3}$$

$$A_\phi(\theta, \phi) = \sqrt{\frac{P_T \eta_0}{2\pi}} g_\phi(\theta, \phi) \tag{10.4}$$

$$g_\theta(\theta, \phi) = \sqrt{\mid G_\theta(\theta, \phi) \mid} e^{j\psi_\theta} \tag{10.5}$$

$$g_\phi(\theta, \phi) = \sqrt{\mid G_\phi(\theta, \phi) \mid} e^{j\psi_\phi} \tag{10.6}$$

$$\beta = \frac{\omega}{c} \tag{10.7}$$

where

$G_\theta(\theta, \phi)$ is the $\theta$ component of the gain of the transmitting antenna

$\psi_\theta$ is the relative phase of the $\theta$ component of the far zone electric field

$P_T$ is the time-averaged power radiated by the transmitter

$r$ is the distance from the transmitter to the field point

In a fully three-dimensional calculation, the equations for the electric field amplitudes are somewhat complicated. This is primarily because the polarization of the incident electric field at each reflection is neither entirely parallel or perpendicular to the plane of incidence but is some combination of the two, and therefore must be broken down into these components by using a ray-fixed coordinate system at each reflection. The reflected field is then calculated from the dyadic reflection coefficient, where the components of the reflected electric field parallel and perpendicular to the reflection plane are given by:

$$\begin{pmatrix} E_\parallel^r \\ E_\perp^r \end{pmatrix} = \begin{pmatrix} R_\parallel & 0 \\ 0 & R_\perp \end{pmatrix} \begin{pmatrix} E_\parallel^i \\ E_\perp^i \end{pmatrix} \tag{10.8}$$

where

$$E_\perp^i = \hat{e}_\perp \cdot E^i$$
$$E_\parallel^i = \hat{e}_\parallel \cdot E^i$$
$$\hat{e}_\perp = \frac{k \times \hat{n}}{|\, k \times \hat{n}\,|}$$
$$\hat{e}_\parallel = \frac{k \times \hat{e}_\perp}{|k \times \hat{e}_\perp|}$$
$$\hat{e}'_\parallel = \frac{k' \times \hat{e}_\perp}{|k' \times \hat{e}_\perp|}$$

The reflected field in the original reference frame is $E^r = \hat{e}'_\parallel \cdot E_\parallel^r + \hat{e}_\perp \cdot E_\perp^r$.

The vector **k** is in direction of propagation of the incident field, **k'** is in the direction of propagation of the reflected field, and **n** is the unit vector normal to the reflecting face.

Equation 10.8 gives the amplitude for a ray which undergoes a single reflection. For rays undergoing multiple reflections, the amplitude no longer simply depends on a product of the reflection coefficients, but must be evaluated by transforming to the new ray-fixed frame at each reflection.

The diffraction coefficients used for the FULL 3D model are similar to those given in [25]. These coefficients include the angle-dependent reflection coefficients for the particular FEATURE face and thus keep the fields continuous at the reflection boundaries. These diffraction coefficients are for fields polarized either parallel or perpendicular to the diffracting edge. In two dimensions this always holds since the fields are always incident normal to the edge, whereas in three dimensions the fields may be obliquely incident and the field can be polarized in any direction relative to the edge. In order for the fields to remain continuous at the reflection boundaries, it is necessary to generalize the coefficients in Luebbers [25] using the results in Burnside [26] to allow for arbitrary incident direction and polarization.

First, the incident and diffracted fields are expressed in terms of an edge-fixed coordinate system [26]. The unit vector **l** is parallel to the diffracting edge, **k** is the propagation vector for the diffracted field, and **k'** is the propagation vector for the incident field. The following unit vectors are then defined by:

$$\hat{\phi}' = \frac{-\hat{l} \times \hat{k}'}{\left|\hat{l} \times \hat{k}'\right|} \tag{10.9}$$

$$\hat{\beta}' = \hat{\phi}' \times \hat{k}' \tag{10.10}$$

The components of the incident field in this edge-fixed coordinate system are $E_{\phi'}^i = E^i \cdot \hat{\phi}'$ and $E_{\beta'}^i = E^i \cdot \hat{\beta}'$. The components of the diffracted field at the receiver location (omitting any reflections following the diffraction) in this coordinate system are given by:

$$\begin{pmatrix} E_\beta^d \\ E_\phi^d \end{pmatrix} = \begin{pmatrix} D_{ss} & D_{sh} \\ D_{hs} & D_{hh} \end{pmatrix} \begin{pmatrix} E_{\beta'}^d \\ E_{\phi'}^d \end{pmatrix} \sqrt{\frac{r_{TD} \cdot r_{DR}}{r_{TD} + r_{DR}}} \frac{e^{-j\beta\, r_{DR}}}{r_{DR}} \tag{10.11}$$

The diffracted field is then given by:

$$E^d = E_\beta^d\, \hat{\beta} + E_\phi^d \hat{\phi} \tag{10.12}$$

The dyadic equation allows for the fields to be arbitrarily polarized and for any angle-dependent reflection coefficient to be used. The elements of the diffraction dyadic are given by:

$$\begin{aligned} D_{ss} = \;& D^{+}(\phi - \phi') \;+\; D^{-}(\phi - \phi') - \\ & \left[R_{\parallel}^{0} cos^2\alpha_1 - R_{\perp}^{0} sin^2\alpha_1\right] D^{-}(\phi + \phi') - \left[R_{\parallel}^{n} cos^2\alpha_2 - R_{\perp}^{n} sin^2\alpha_2\right] D^{+}(\phi + \phi') \end{aligned} \tag{10.13}$$

$$\begin{aligned} D_{hh} = \;& D^{+}(\phi - \phi') \;+\; D^{-}(\phi - \phi') + \\ & \left[R_{\parallel}^{0} sin^2\alpha_1 - R_{\perp}^{0} cos^2\alpha_1\right] D^{-}(\phi + \phi') + \left[R_{\parallel}^{n} sin^2\alpha_2 - R_{\perp}^{n} cos^2\alpha_2\right] D^{+}(\phi + \phi') \end{aligned} \tag{10.14}$$

$$D_{sh} = -\left[R_{\parallel}^{0} \;+\; R_{\perp}^{0}\right] cos\alpha_1 sin\alpha_1 D^{-}(\phi+\phi') \;-\; \left[R_{\parallel}^{n} + R_{\perp}^{n}\right] cos\alpha_2 sin\alpha_2 D^{+}(\phi+\phi') \tag{10.15}$$

$$D_{hs} = \left[R_{\parallel}^{0} + R_{\perp}^{0}\right] cos\alpha_1 sin\alpha_1 D^{-}(\phi + \phi') + \left[R_{\parallel}^{n} + R_{\perp}^{n}\right] cos\alpha_2 sin\alpha_2 D^{+}(\phi + \phi') \tag{10.16}$$

The $0$ and $n$ superscripts are used to designate the two sides of the wedge as shown in Luebbers [25] and in Holm [27] as well as other papers on the UTD; $\phi$ and $\phi'$ are the observation and incidence angles as measured in Balanis [1] and Luebbers [25].

The angles $\alpha_1$ and $\alpha_2$ are determined from $sin\ \alpha_1 \;=\; \hat{e}_{\parallel}^{0} \;\cdot\; \hat{\phi}'$ and $sin\ \alpha_2 \;=\; \hat{e}_{\parallel}^{n} \;\cdot\; \hat{\phi}'$, where the unit vectors $\hat{e}_{\parallel}^{0}$ and $\hat{e}_{\parallel}^{n}$ are the ray-fixed vectors parallel to the plane of incidence.

The functions $D^{\pm}(\phi \;\pm\; \phi')$ are given by:

$$D^{\pm}(\phi \pm \phi') = \frac{-e^{-j\pi/4}}{2n\sqrt{2\pi k}} cot\left(\frac{\pi \pm (\phi \pm \phi')}{2n}\right) \cdot F(kLa^{\pm}(\phi \pm \phi')) \tag{10.17}$$

where $F(kLa^{\pm}(\phi \;\pm\; \phi'))$ is the Fresnel integral, defined in several references ([1],[28],[25]).

When the field is incident normal to the edge $(\alpha_1 \;=\; \alpha_2 \;=\; 90°)$, the off-diagonal elements vanish $(\,D_{sh} \;=\; D_{hs} \;=\; 0\,)$ and the diagonal elements $D_{hh}$ and $D_{ss}$ reduce to the diffraction coefficients in Luebbers [25]. For perfect conductor $\left(\,R_{\parallel} \;=\; 1,\ R_{\perp} \;=\; -1\,\right)$, again $D_{sh} \;=\; D_{hs} \;=\; 0$, and the diagonal elements reduce to the coefficients in [1] and [28].

After each reflection or diffraction is applied, the electric field is transformed back into Cartesian components. The final step is to determine the spherical components of the electric field at the receiver point from the Cartesian components using:

$$\begin{pmatrix} E_r \\ E_\theta \\ E_\phi \end{pmatrix} = \begin{pmatrix} sin(\theta_A)cos(\phi_A) & sin(\theta_A)sin(\phi_A) & cos(\theta_A) \\ cos(\theta_A)cos(\phi_A) & cos(\theta_A)sin(\phi_A) & -sin(\theta_A) \\ -sin(\phi_A) & cos(\phi_A) & 0 \end{pmatrix} \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix} \tag{10.18}$$

where $(\theta_A, \phi_A)$ is the direction from which the ray arrives at the receiver. For TEM fields, the radial component $E_r$ calculated from the above equation should be always be zero.

## Creeping Wave

In many problems it is often necessary to consider the diffraction of electromagnetic waves by curved surfaces. Within the framework of Uniform Theory of Diffraction (UTD) and Shooting and Bouncing Rays (SBR), diffractions from curved surfaces are modeled by creeping waves. Let us consider what happens when a series of rays hits a curved surface such as a cylinder. This case is illustrated in Figure 10.4. When a ray is incident on the curved surface, it will be reflected and transmitted in the usual manner according to geometric optics. However, just like scattering from wedges or corners, there are shadow regions where no direct rays or reflected rays can reach. Electromagnetic fields in this region are due purely to rays diffracted from the curved surface.

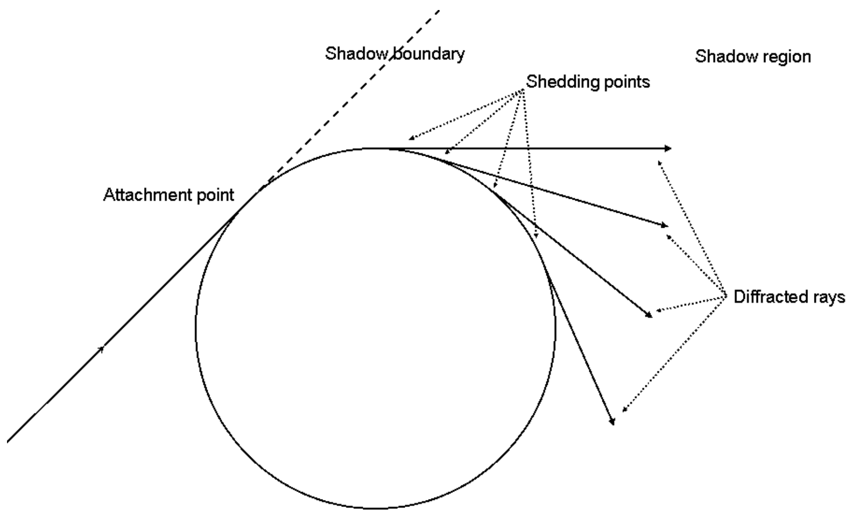


Figure 10.4: Illustration showing diffraction over a cylinder

When a ray incident on the curved surface at grazing, so that the direction of propagation of the ray is tangent to the curved surface at the incident point, surface rays are launched. These surface rays, or “creeping waves”, propagate along geodesic paths on the convex surface starting from the incident point. As these creeping waves propagate along the surface, they continuously shed rays, which then carry energy into the shadow region. We call the point at which the source ray incident on the curved surface at grazing the attachment point, since this is the point at which the “attaches” to the surface. The attachment point is also the point on the surface that separates the lit portion of the surface from the shadow portion of the surface. The points at which the rays leave the surface are known as the shedding points. The shedding points form a continuum along the geodesic path of the surface, since diffracted rays are being continuously launched into space as the creeping wave propagates along the surface. The directions of propagation of the diffracted rays are along the forward tangent to the curved surface at the shedding points.

Just like with diffraction from wedges and corners, the electric fields associated with the creeping waves and the diffracted rays are determined by calculating the diffraction coefficient for each ray ([29],[30],[31],[32]). The diffraction coefficients are dependent on the arc length of the creeping wave between the attachment point and the shedding point, the local radius of curvature along the creeping wave, the tangent and normal unit vectors at the attachment and shedding points, etc.

Currently, the creeping wave capability in XGtd has the following limitations:

1. XGtd only considers creeping waves on convex curved surfaces. Concave surfaces can give rise to multiple reflected rays and trapped rays, and thus complicate the problem considerably.
2. The surface is assumed to be composed of perfect conducting material. This is due to the fact that diffraction coefficients are readily available only for perfectly conducting surfaces. Also, inhomogeneous surfaces can complicate the geodesic path considerably.
3. As the creeping waves propagate on a 3D surface, the field polarization directions associated with the creeping wave can twist and turn, giving rise to a torsion factor in the diffraction coefficient. It is very difficult to calculate the torsion factor for creeping waves on general 3D surfaces. Therefore, currently the creeping wave is most accurate when considering diffraction from cylindrical objects, such as the fuselage of most aircraft.

### Creeping Waves on Faceted Surfaces

In XGtd, *Objects* are represented as faceted geometries, which cannot represent curved surfaces exactly. Therefore, to trace the path of creeping waves, we use the following procedure.

1. For each edge formed by two adjacent faces, the angle between the faces is calculated. By default, if the angle is greater than 180° and less than 198°, we mark the edge and the two joining faces as being part of a curved surface. The minimum and maximum angles can be changed in the Advanced Study Area Properties Window.
2. Ray tracing then occurs in the usual manner. For each ray that intercepts an edge associated with a curved surface at a tangent direction, we then trace the geodesic on the surface using the direction of the incident ray and the intercept point as the starting point of the geodesic. Since we assume that the curved surface is composed of perfect electric conductors, the geodesic can be found by simply projecting the incident ray onto the faces of the curved surface. We look for edges on the surface that intercept the geodesic, and store the position of the points of interception.
3. Interpolating between the points of interception generates smooth, continuous curves. These curves are then used to calculate the local tangent vectors, radius of curvature, etc.
4. Diffraction coefficients are calculated from the radius of curvature and local tangent vectors, and are used to evaluate the electric field of the creeping wave.

## Radar Cross Section Calculations

XGtd uses a hybrid model for calculating radar cross section quantities that differs from the field evaluation used for near zone outputs and far zone antenna gain outputs. The hybrid model leverages the advantages of the Method of Equivalent Currents (MEC) and Physical Optics (PO) to improve the accuracy of the RCS calculations in all scattering directions. Depending on the incidence angle of the plane wave and the scattering angle, the model chooses the best method for the calculation. An important part of the new field evaluation capabilities is the ability to classify the facets as belonging to one of three surface types:

Planar facets

Surfaces with 2 radii of curvature (spheres, ellipsoids, etc.)

Surfaces with 1 radius of curvature (cylinders, cones, etc.)

The identification of the surface type is required in order to determine which method (MEC, PO or a combination of these) to use when evaluating the electric field. Which method(s) to use also depends on the frequency and the directions of incidence and scattering. Typically, PO is used to calculate scattering contributions from curved surfaces and specular reflections from flat facets. MEC is used in the remaining cases.

## 10.2 X3D Ray Model

### Overview

The X3D ray model was developed to provide a highly accurate, full 3D propagation model capable of running on a graphics processing unit (GPU) and using multi-threading to take advantage of multi-core processors. This full 3D ray-tracing model also uses Remcom's depth-first and exact path algorithms to overcome some of the shortcomings of the traditional shooting and bouncing ray method. Key benefits of the X3D model are the speed-ups achieved by the GPU acceleration and multithreading, and the accuracy achieved through the exact path calculations.

### Summary

The following list summarizes the capabilities of the X3D model:

- GPU Acceleration and multithreading
- Highly-Optimized PO/MEC model for RCS calculations
- Maximum reflections: 30
- Maximum wedge diffractions: 3
- Objects: all
- Range: limited to RCS
- Ray tracing: SBR with Exact Path correction
- Minimum frequency: 100 MHz
- Maximum frequency: depends on application, but extends into the millimeter wave frequencies

### Ray Tracing

The X3D SBR algorithm is similar to the algorithm as described for the Full 3D model, with the following differences:

- Diffractions are not identified by looking for direction differences between adjacent rays from similar reflections. Instead, when a reflection occurs close enough to an edge, a discrete set of points along that edge are considered. The reflected path off the face, and the diffracted paths from the edge points are traced further.

- After finding the SBR paths, X3D implements an Exact Path Calculator (EPC) algorithm. As discussed in Section 10.1, ray paths intersect receiver targets within a tolerance defined by a sphere. EPC then adjusts the actual interaction points (reflections, diffractions and transmissions) so that the path hits the exact receiver center. EPC also validates that all of the diffraction and reflection angles are valid and that the corrected path does not get blocked by any intervening faces. Paths that fail this validation are discarded.
- X3D lets rays hit either side of a face, ignoring the single-sided versus double-sided property of a face.

▶ FULL 3D 's SBR ray tracing method is described in Section 10.1.

For far-zone plane waves, X3D also uses a new *Targeted Ray Shooting* Algorithm that seeds SBR ray-tracing with an initial set of rays that are specifically targeted at the geometry and receivers in the scene. This method ensures that all facets are hit with sufficient rays to ensure dense ray spacing when targets with large numbers of facets are present, and is a critical new capability for high-resolution facet models that are now frequently used for RCS calculations.

## Exact Path calculations

The shooting and bouncing method requires a collection radius to be constructed around receiver locations to compensate for the discrete ray shooting. Rays that intersect this sphere are considered to reach the receiver. Exact path corrects SBR ray paths so that they end at the exact receiver location. This correction reduces errors in calculated power and phase associated with SBR, but without the longer run times required by methods based on image theory.

## Electric Field Evaluation

Electric fields in X3D are evaluated in the same manner as FULL 3D.

▶ See description in Section 10.1.

## Atmospheric Absorption

Simulations made with the X3D Ray Model include frequency dependent absorption due to oxygen and water content of the atmosphere. Users can specify the temperature, relative humidity, and pressure within the X3D ATMOSPHERICPROPERTIES window, accessed through the ATMOSPHERE button in the X3D study area properties window. Path loss and received power calculations will be reduced based on the distance a ray travels, frequency, and specified atmospheric properties. Setting each field to zero will turn off the absorption loss.

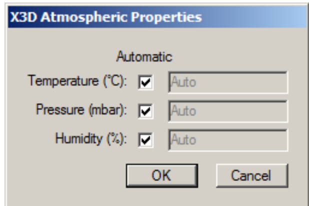


Figure 10.5: The X3D Atmospheric Properties Window

The atmospheric absorption model used in the software was adapted from a public domain model presented in [33]. The behavior of the specific attenuation of the model as a function of frequency conforms to ITU recommendation ITU-R P.676-9 [34]. Results from the atmospheric absorption model integrated into Wireless InSite are shown in Figure 10.6, below, while the loss described in the ITU recommendation is shown in Figure 10.7.

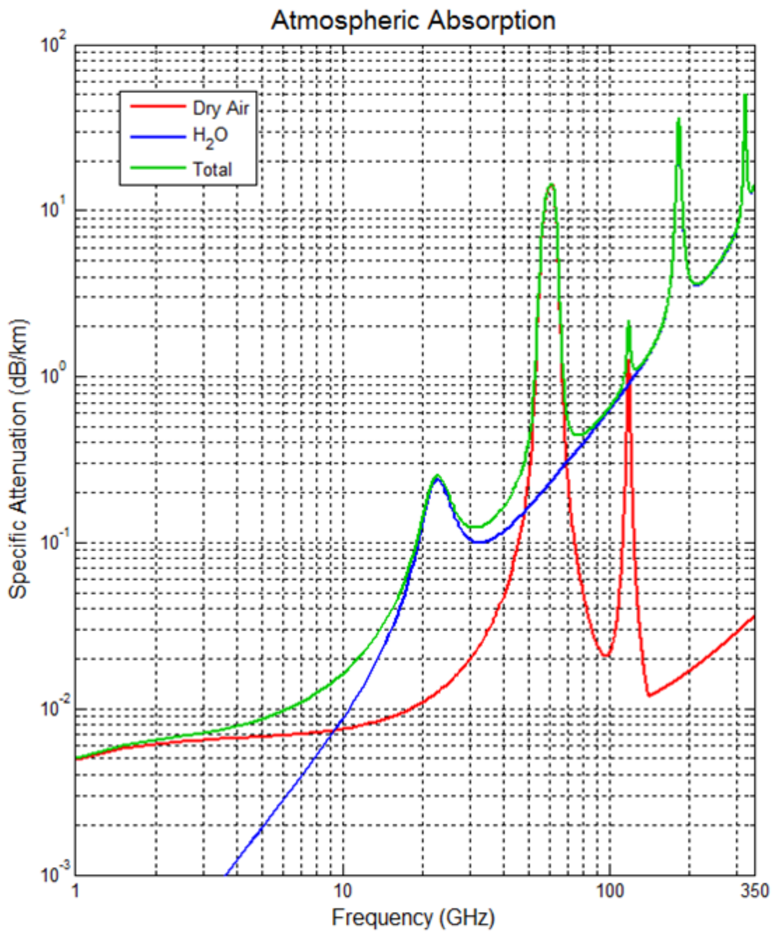


Figure 10.6: Specific Attenuation as predicted by Wireless InSite's X3D

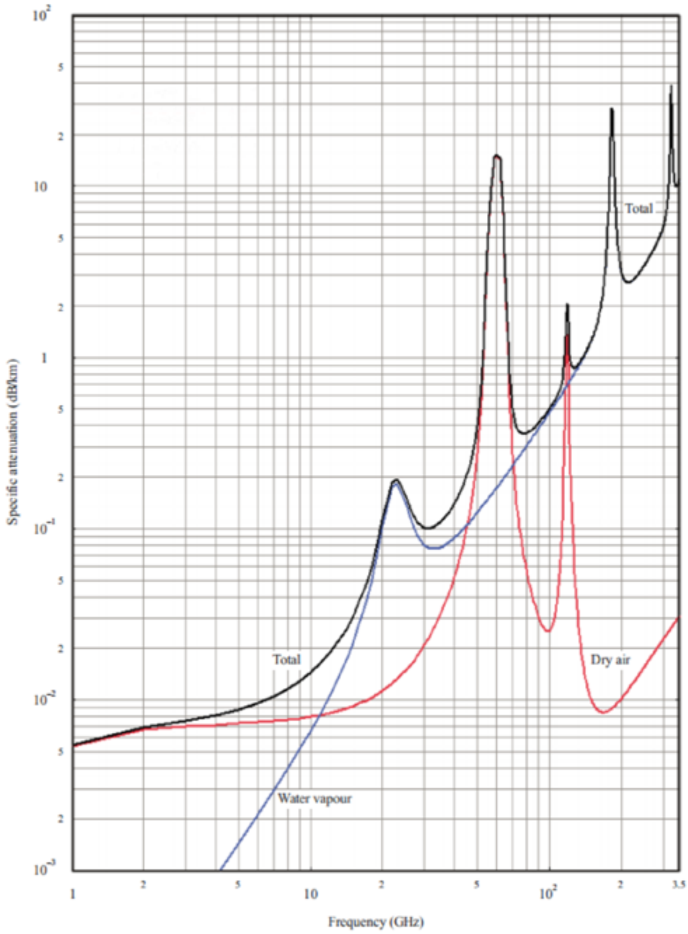


Figure 10.7: ITU-R P.676-9 Specific Attenuation due to Oxygen and Water Vapor

## Calculation of RCS using Physical Optics (PO)

RCS Calculations are performed using highly-optimized Physical Optics (PO) techniques, combined with edge effects calculated using the Method of Equivalent Currents (MEC). Physical Optics can be defined as a high-frequency approximation in which the incident fields at the surface of a target are determined by a ray-based method (in this case, the Uniform Theory of Diffraction UTD in X3D), the scattered fields at the surface are determined by assuming the incident field from each ray is locally a plane wave at each point on the surface, and the scattered field at an observation point is found by a surface integral on the target. If only the directly incident field is included, PO can be considered a first-order Born approximation because the scattered field from one part of the target is not included as part of the incident field at another part. However, the UTD method potentially adds scattered field contributions from one part of the target to another part, described later in this section.

The target object is a set of facets that define a closed surface, S. The receiver(s) are outside this surface. The ray-tracing step for the target is similar to standard UTD ray-tracing with the important extension that shadow paths are also established. These provide required incident field data needed by the PO method due to its implicit use of scattered fields, rather than the total fields calculated by UTD. Figure 10.8 shows example paths, including potential multipath with objects other than the target, and the aforementioned shadowed paths. Once paths have been found to each facet on the target, path combinations are constructed by pairing paths from the transmitter to the facet with paths from the facet to the receiver(s). If there are $N$ transmitter paths and $M$ receiver paths for a facet, $N \times M$ composite paths are created for that facet.

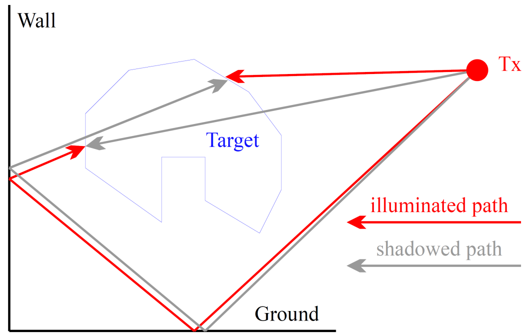


Figure 10.8: examples of illuminated and shadowed paths

Next, individual returns (received voltages) for each facet are calculated through the use of a generalized Green's function that uses incident fields calculated through UTD methods, and new algorithms based on Physical Optics. In general terms, the scattered surface currents, **J** (electric) and **M** (magnetic), are determined for each facet of the target. There may be multiple paths from each facet on the target to the receiving antenna. Each facet and path to the receiving antenna has its own generalized Green's function, $G_{facet,path}$, which can be written

$$G_{facet,path} = G\left(\vec{J}_{Scat}, \vec{M}_{Scat}\right) e^{-j\vec{k}_{Ant}\cdot\vec{r}} \tag{10.19}$$

where the exponential term gives the phase variation on the facet surface. The Green's function for each facet and path, integrated over the respective facets, gives a complex voltage contribution, $V_{facet,path}$, at the receiving antenna. The total time-averaged power in the receiving antenna, $P_{Rx}$, is obtained by summing all complex voltage contributions:

$$P_{Rx} = \frac{|\sum V_{facet,path}|^2}{2R_{Ant}} \tag{10.20}$$

where $R_{Ant}$ is the resistance of the load impedance, which is assumed to be matched with the antennas impedance.

The Radar Cross Section (RCS) must then be computed from the total received voltage. The definition of RCS is the following limit:

$$RCS \equiv \lim_{r\to\infty} 4\pi r^2 \frac{S_{obs}}{S_{inc}} \tag{10.21}$$

where $S_{inc}$ is the incident time-averaged power density at the target, $S_{obs}$ is the scattered time-averaged power density at the receiver, and r is the distance to the target. In the case of multiple paths to the target, these values must be replaced by equivalent values that are in some sense averaged over all paths.

The incident power density, $S_{inc}$, is usually the incident power density at the geometric center of the object. In the case of a transmitter close to the target or many paths, $S_{inc}$ can be considered to be the area-weighted average of the incident power for each incident ray at each facet:

$$S_{inc} = \frac{\displaystyle\sum_{Rays} A_{facet} \frac{|E_{inc}|^2}{2Z_0}}{\displaystyle\sum_{Rays} A_{facet}} \tag{10.22}$$

where $A_{facet}$ is the area of the facet that the incident ray hits and $Z_0$ is the impedance of free space or air, depending on the choice of temperature, pressure, and humidity in the study area.

$S_{obs}$ is the observed power density at the receiving antenna. For the co-polarized portion, the power in the antenna is related to the observed co-polarized power density by

$$\frac{|V|^2}{2R_{Ant}} = G_{Rx} S_{obs} \frac{\lambda^2}{4\pi} \quad \text{or} \quad S_{obs} = \frac{4\pi}{\lambda^2} \frac{|V|^2}{2R_{Ant} G_{Rx}} \tag{10.23}$$

where $\lambda$ is the wavelength and $G_{Rx}$ is the gain of the receiving antenna in the direction of the target. In the case of a receiver in the near zone of the target, $G_{Rx}$ is averaged over all paths, weighted by the power of each individual path.

## RCS Edge Effects using the Method of Equivalent Currents (MEC)

RCS edge effects are calculated using a method that is based on the concept of correcting the scattered fields in the vicinity of edges to account for the discontinuities arising from representation of the surface by flat triangular facets. This method is designed to work with PO as a correction without the use of blending functions. Although a slightly different derivation than that used with the Full 3D model, the name *Method of Equivalent Currents* (MEC) is still applied because the method finds equivalent electric and magnetic currents associated with each edge that will produce a better numerical approximation for RCS than surface PO alone.

The basis of the method is to find equivalent electric and magnetic edge currents, $I_{eq}$ and $K_{eq}$ respectively, which are included in the generalized Greens function surface integral as line integrals to supplement the PO surface integral. The edge currents can be thought of as surface currents that for the purpose of integration have been concentrated along an edge. The formulas for $I_{eq}$ and $K_{eq}$ are:

$$\vec{I}_{eq} = \frac{g(\alpha)}{k} \left\{ \begin{aligned} &\sin(\alpha)(\hat{n}_1 + \hat{n}_2) \times \vec{H}_{avg} + [1 - \cos(\alpha)](\hat{u}_1 - \hat{u}_2) \times \vec{H}_{avg} \\ &\qquad + \left[\frac{1 - \cos(\alpha)}{\alpha}\right](\hat{n}_1 - \hat{n}_2) \times \vec{H}_{12} + \left[\frac{\alpha - \sin(\alpha)}{\alpha}\right](\hat{u}_1 + \hat{u}_2) \times \vec{H}_{12} \end{aligned} \right\} \tag{10.24}$$

$$\vec{K}_{eq} = -\frac{g(\alpha)}{k}\left\{\begin{array}{r}\sin(\alpha)(\hat{n}_1+\hat{n}_2)\times\vec{E}_{avg}+[1-\cos(\alpha)](\hat{u}_1-\hat{u}_2)\times\vec{E}_{avg}\\ +\left[\frac{1-\cos(\alpha)}{\alpha}\right](\hat{n}_1-\hat{n}_2)\times\vec{E}_{12}+\left[\frac{\alpha-\sin(\alpha)}{\alpha}\right](\hat{u}_1+\hat{u}_2)\times\vec{E}_{12}\end{array}\right\} \tag{10.25}$$

where the subscripts 1 and 2 refer to two adjacent facets, $n$ is the unit normal vector, $t$ is the unit edge vector, $u = n \times t$, $E$ and $H$ are respectively the scattered electric and magnetic fields, subscript avg means average, subscript 12 means the quantity on facet 1 minus the quantity on facet 2, $k = \omega/s$ (s = speed of light in the propagation medium), $2\alpha$ is the angle by which $n_1$ differs from $n_2$, and $g(\alpha)$ is a dimensionless function derived empirically.

The integration of an edge contribution follows along the same lines as the surface integration discussed in the previous section, but with the surface of integration collapsed to a line segment. If we assume we are dealing with one path from the transmitting antenna and one path back to the receiving antenna, the incident wave vector on the path from the transmitter is $k_{inc}$ and the wave vector on the path to the receiving antenna with its sign reversed is $k_{ant}$. The scattered wave vectors on the respective adjoining surfaces are not the same, nor are they the same as $k_{inc}$, but their projections on the line, which is all that counts, are all the same. The phase integral on the edge is the following expression:

$$\int_{Edge} \mathrm{e}^{-j(\vec{k}_{inc}+\vec{k}_{ant})\cdot\hat{t}z}\mathrm{d}z \tag{10.26}$$

Figure 10.9 shows a comparison between physical optics, physical optics with the MEC edge effects included, and results from XFdtd® for a cube whose edges are four wavelengths in size. XFdtd® is a full-wave solver based on a direct solution of Maxwells equations using the Finite Difference Time Domain (FDTD) method, and is considered the benchmark for this comparison. As shown in the comparison, while the PO method is able to find the peaks in RCS returns, the addition of edge effects using MEC substantially improves the accuracy in the prediction of the nulls.

## 10.3 Free Space Model

### Overview

The FREE SPACE model assumes the electric field decreases as $1/r$ with distance in all directions. The predicted electric field includes the effect of the pattern of the transmitting ANTENNA. For receivers blocked by terrain, building or object FEATURES, this model returns a path loss of 250 dB.

### Summary

The following list summarizes the capabilities of the FREE SPACE model:

- Maximum reflections: N/A
- Maximum transmissions: N/A
- Maximum diffractions: N/A

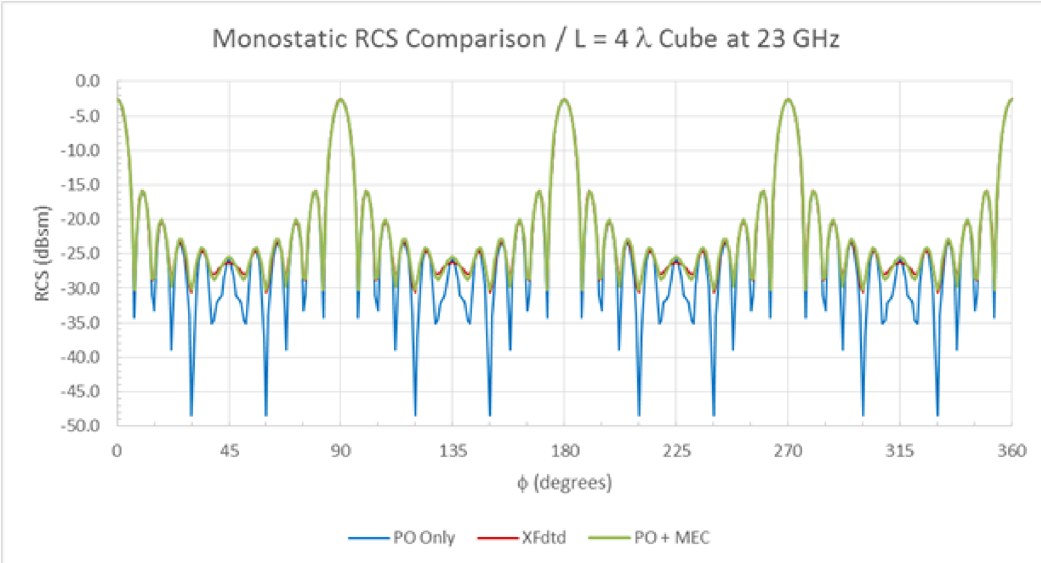


Figure 10.9: Comparison of PO, PO with MEC, and FDTD Full-Wave Solution

- Chambers: N/A
- Objects: N/A
- Range: unlimited
- Antenna types: all
- Ray tracing: single ray from Tx to Rx
- Minimum frequency: depends on application
- Maximum frequency: depends on application

## Ray Tracing

A single ray from the TRANSMITTER to the RECEIVER point is constructed. The ray path is used to determine the distance, time-of-arrival, direction-of-arrival and direction-of-departure. The directions are used to find the gains of the transmitting and receiving ANTENNAS.

## Electric Field Evaluation

The first step in evaluating the electric field is to find the electric field in the far zone of the transmitting antenna. At present, XGtd does not consider any near zone fields. In free space the electric field in the direction $(\theta, \phi)$ in the far field of the transmitting antenna at a distance $r$ can be written as:

$$E(r, \theta, \phi) = (A_\theta(\theta, \phi)\hat{e}_\theta \; + \; A_\phi(\theta, \phi)\hat{e}_\phi \;) \; \frac{e^{-j\beta \; r}}{r} \tag{10.27}$$

where

$$A_\theta(\theta, \phi) = \sqrt{\frac{P_T \eta_0}{2\pi}} g_\theta(\theta, \phi) \tag{10.28}$$

$$A_\phi(\theta, \phi) = \sqrt{\frac{P_T \eta_0}{2\pi}} g_\phi(\theta, \phi) \tag{10.29}$$

$$g_\theta(\theta, \phi) = \sqrt{\mid G_\theta(\theta, \phi) \mid} e^{j\psi_\theta} \tag{10.30}$$

$$g_\phi(\theta, \phi) = \sqrt{\mid G_\phi(\theta, \phi) \mid} e^{j\psi_\phi} \tag{10.31}$$

$$\beta = \frac{\omega}{c} \tag{10.32}$$

where

$G_\theta(\theta, \phi)$ is the $\theta$ component of the gain of the transmitting antenna

$\psi_\theta$ is the relative phase of the $\theta$ component of the far zone electric field

$P_T$ is the time-averaged power radiated by the transmitter

$r$ is the distance from the transmitter to the field point

# Chapter 11

# Output

*In this chapter, you will learn...*

- → the available output types in XGtd
- → how to define output properties
- → how to request specific output
- → about output file types and their units

With a few exceptions, all propagation predictions are generated by XGtd's calculation engine. The engine is a separate executable from the GUI. The engine writes all output to specific files, and when the user chooses to view or plot the results, the GUI loads the data. Whenever a Run is made, the output files for all active Transmitter and Receiver sets are updated, and all previously loaded Output is refreshed automatically when the run is completed.

▸ Refer to Chapter 12 for more information on how to display the predictions using XGtd's line plotting tools or graphically within the Project View.

This chapter describes the following features of the Output generated by the calculation engine:

- Output Types
- Settings That Affect Output
- Output Units
- Output Properties
- Requesting Output
- Output Files

## 11.1 Output Types

### Received Power

The way in which the power of each ray path is combined to determine the total received power depends on the setting of the “Sum complex electric fields” option in the ADVANCED STUDY AREA PROPERTIES Window.

- See Chapter 9 for more on the ADVANCED STUDY AREA PROPERTIES Window.
- Refer to Chapter 10 for more on how the electric field is calculated by the FULL 3D propagation model.

If the electric fields are summed without phase information, the time averaged received power in watts is given by:

$$P_R = \sum_{i=1}^{N_P} P_i \tag{11.1}$$

where

$N_P$ is the number of paths

$P_i$ is the time averaged power in watts of the $i^{th}$ path

$P_i$ is given by:

$$P_i = \frac{\lambda^2 \beta}{8\pi\eta_0} \; |E_{\theta,i} g_\theta(\theta_i, \phi_i) + E_{\phi,i} g_\phi(\theta_i, \phi_i)\;|^2 \tag{11.2}$$

where

$\lambda$ is the wavelength

$\eta_0$ is the impedance of free space (377 $\Omega$)

$E_{\theta,i}$ and $E_{\phi,i}$ are the theta and phi components of the electric field of the $i^{th}$ path at the receiver point

$\theta_i$ and $\phi_i$ give the direction of arrival

The direction of arrival is given by:

$$g_\theta(\theta, \phi) = \sqrt{|G_\theta(\theta, \phi)|} e^{j\psi_\theta} \tag{11.3}$$

where

$G_\theta$ is the theta component of the receiving antenna gain

$\psi_\theta$ is the relative phase of the $\theta$ component of the far zone electric field

The direction of arrival in terms of $g_\phi$ has an analagous definition.

The quantity $\beta$ is the overlap of the frequency spectrum of the transmitted waveform $S_T(f)$ and the spectrum of the frequency sensitivity of the receiver $S_R(f)$:

$$\beta = \frac{\displaystyle\int_{f_T-(B_T/2)}^{f_T+(B_T/2)} S_T(f) S_R(f)\, df}{\displaystyle\int_{f_T-(B_T/2)}^{f_T+(B_T/2)} S_T(f)\, df} \tag{11.4}$$

where $f_T$ and $B_T$ are, respectively, the center frequency and bandwidth of the transmitted waveform.

At present, a flat distribution is always assumed for narrowband waveforms, such that:

$$S(f) = \begin{cases} 1 & \text{for } f_0 - \dfrac{B}{2} < f < f_0 + \dfrac{B}{2} \\ 0 & \text{otherwise} \end{cases} \tag{11.5}$$

where $f_0$ is the center frequency and $B$ is the bandwidth.

When all fields are combined coherently (with phase) the total received power is:

$$P_R = \frac{\lambda^2 \beta}{8\pi\eta_0} \left| \sum_{i=1}^{N_p} \left[ E_{\theta,i} g_\theta(\theta_i, \phi_i) + E_{\phi,i} g_\phi(\theta_i, \phi_i) \right] \right|^2 \tag{11.6}$$

If the correlated option for combining paths is used, the time averaged power due to each group of correlated paths is found first using:

$$Q_j = \frac{\lambda^2 \beta}{8\pi\eta_0} \left| \sum_{i=1}^{M_j} \left[ E_{\theta,i} g_\theta(\theta_i, \phi_i) + E_{\phi,i} g_\phi(\theta_i, \phi_i) \right] \right|^2 \tag{11.7}$$

where $Q_j$ is the power due to the $j^{th}$ group of paths and $M_j$ is the number of paths in the group.

The total power is then found by summing the power of each group:

$$P_R = \sum_{i=1}^{N_c} Q_i \tag{11.8}$$

where $N_c$ is the number of groups.

Once the received power in watts is found, the power in dBm is determined from:

$$P_R(dBm) = 10log_{10}[P_R(W)] \; + \; 30dB \; - \; L_S(dB) \tag{11.9}$$

where $L_S$ is any additional loss in the system which can be specified through the cable loss and VSWR fields in the ANTENNA PROPERTIES Window. A value of -250 dBm is written to the output file if $P_R \leq 1 \times 10^{-25}\ mW$. The mismatch loss in decibels due to a $VSWR > 1$ is given by $10log_{10}(1 - \Gamma^2)$, where the reflection coefficient $\Gamma = \dfrac{VSWR - 1}{VSWR + 1}$.

## Received Power in Free Space with Antenna Patterns

Results for the received power due only to the free space $\left(\dfrac{1}{R^2}\right)$ loss are given with and without the effect of the antenna patterns. When the antenna patterns are included,

$$P_R = \frac{\lambda^2 P_T \beta}{(4\pi)^2 R^2} \left| g_{T,\theta}(\theta_D, \phi_D) g_{R,\theta}(\theta_A, \phi_A) + g_{T,\phi}(\theta_D, \phi_D) g_{R,\phi}(\theta_A, \phi_A) \right|^2 \tag{11.10}$$

where

$P_T$ is the time averaged radiated power

$g_T$ and $g_R$ are defined in the generic Equation 11.3

$\theta_D$ and $\phi_D$ give the direction in which the ray leaves the transmitter

$\theta_A$ and $\phi_A$ give the direction from which the ray arrives at the receiver

$R$ is the distance between the transmitter and receiver

Once the received power in watts is found, the power in dBm is determined from

$$P_R(dBm) = 10log_{10}[P_R(W)] + 30dB - L_S(dB) \tag{11.11}$$

## Received Power in Free Space without Antenna Patterns

The received power without considering the antenna patterns is equivalent to assuming polarization matched isotropic patterns, and is given by:

$$P_R = \frac{\lambda^2 \beta P_T}{(4\pi)^2 R^2} \tag{11.12}$$

## Received Power with Diffuse Scattering

DIFFUSE SCATTERING calculations produce a variant of received power output that contains specular power magnitude and phase, diffuse scattered power magnitude and phase, total power (coherent sum) magnitude and phase, diffuse scattered (power sum) magnitude, and total power (power sum) magnitude. For more information about each individual type of output contained in the received power with diffuse scattering file, go to section **??**.

### Path Loss

The most commonly used definition of path loss is:

$$L_{Path}(dB) = P_T(dBm) - P_R(dBm) + G_{T,Max}(dBi) + G_{R,Max}(dBi) - L_S(dB) \tag{11.13}$$

where

$G_{T,Max}$ and $G_{R,Max}$ are the maximum gains of the transmitting and receiving antennas, respectively

$L_S$ is the sum of all other losses in the system (in dB), including the bandwidth overlap factor

For *Directional* Antennas, the path loss depends on the orientation of the antenna. Keep this in mind when making use of the path loss as a term in a link budget.

### Path Gain

Path gain is equivalent to path loss, but is represented with the opposite sign.

$$G_{Path}(dB) = -L_{Path}(dB) \tag{11.14}$$

✓ The path gain is a less commonly encountered measure than path loss, but it sometimes used instead of the path loss when it provides a more convenient way to present results. In fact, the terms are sometimes used almost interchangeably, and one commonly encounters plots in literature labeled as path loss which are technically path gain. This generally does not present any confusion to the knowledgeable reader with a background in RF propagation, but may be confusing to readers without this background.

### Free Space Path Loss with Antenna Patterns

When the antenna patterns are included, the free path loss is calculated using above definition of the path loss (Equation (11.13)) and the free space received power (Equation (11.10)). Assuming polarization of the transmitter and receiver match, the path loss in free space reduces to:

$$L_{FS}(dB) = -10log_{10}\left(\frac{\lambda^2 G_T G_R}{(4\pi)^2 R^2}\right) + G_{T,Max}(dBi) + G_{R,Max}(dBi) \tag{11.15}$$

where

$G_T$ is the gain of the transmitting antenna in the direction of the receiver

$G_R$ is the gain of the receiving antenna in the direction of the transmitter

$R$ is the distance between the transmitter and receiver

### Free Space Path Loss Without Antenna Patterns

If the antenna patterns are ignored and isotropic patterns are assumed, the free space path loss reduces to:

$$L_{FS}(dB) = -10log_{10}\left(\frac{\lambda^2}{(4\pi)^2 R^2}\right) \tag{11.16}$$

The previous definition (Equation (11.15)) includes any loss due to a mismatch of the transmitting and receiving antenna polarizations, whereas the current one (Equation (11.16)) does not.

### Excess Path Loss with Antenna Patterns

The excess path loss is a measure of the loss above that due to free space loss,

$$L_X(dB) = L_{Path}(dB) - L_{FS}(dB) \tag{11.17}$$

where $L_{FS}(dB)$ is the free space loss with the antenna patterns.

### Excess Path Loss Without Antenna Patterns

The excess path loss is a measure of the loss above that due to free space loss,

$$L_X(dB) = L_{Path}(dB) - L_{FS}(dB) \tag{11.18}$$

where $L_{FS}(dB)$ is the free space loss *without* the antenna patterns.

### S-Parameters

The scattering parameter, or S-parameter $S_{ij}$ , is the ratio of output power at receiving port $i$ to input power at transmitting port $j$. This measure provides a useful way of characterizing the coupling between any two antennas in an XGtd project. The S-parameter output is calculated in the same manner as received power, however, it does not include effects from the input power of the transmitter. Like recieved power, S-parameters are only evaluated at the carrier frequency of a waveform.

S-parameters calculations include contributions from the following:

- Transmitter and receiver antenna gain and phase contributions
- Mismatch losses as characterized by the transmitter and receiver antenna's VSWR
- Losses due to a mismatch between a transmitter and receiver antenna's waveform
- Propagation losses between the transmitter and receiver

## Propagation Paths

Output of this type consists of the geometrical ray paths through the environment from the transmitter to the receiver, and the type of interactions each ray undergoes. The geometrical data for each path consists of the Cartesian coordinates of the endpoints of one or more connected line segments. With the exception of the last segment, which ends on the receiver, each line segment ends at a point where an interaction with the environment occurred. This interaction will typically be a reflection, transmission or diffraction. The interactions undergone by each path are stored in sequence form, such as Tx-R-R-D-T-Rx, which in this case indicates that a ray left the transmitter, reflected twice, diffracted from an edge, then underwent a transmission through a wall before finally arriving at the receiver. A list of the interaction designations is provided in Table **??**.

Table 11.1: Propagation Path Interactions

| Interaction Description | Full 3D |
|---|---|
| Transmitter | Tx |
| Receiver | Rx |
| Reflection | R |
| Transmission | T |
| Diffraction | D or d* |

*The Full 3D propagation model uses **D** to represent a diffraction from a vertical or near vertical edge and **d** to represent a diffraction from a horizontal or near horizontal edge.

- An example propagation paths output file can be found in Appendix H, along with a brief description of the format.

## Time of Arrival

The time of arrival for each propagation path is given by:

$$t_i = \frac{L_i}{c} \tag{11.19}$$

where

$L_i$ is the total geometrical path length

$c$ is the speed of light in free space (or in the defined air medium for the X3D model)

## Mean Time of Arrival

The mean time of arrival is given by:

$$\bar{t} = \frac{\sum_{i=1}^{N_P} P_i t_i}{P_R} \tag{11.20}$$

where $P_R$ and $P_i$ are defined by Equations 11.1 and 11.2, respectively.

### Delay Spread

The delay spread is a useful measure of a variety of multipath-related effects. It is a power-weighted rms of the time delays, calculated assuming a narrowband signal at the carrier frequency, using the following formula [35]:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N_P} (t_i - \bar{t})^2 P_i}{P_R}} \tag{11.21}$$

where $t_i$ and $\bar{t}$ are defined by Equations 11.19 and 11.20, respectively.

### Electric Field Magnitude

Magnitude of the total electric field at the receiver points is found by summing the complex valued electric field contributed by each ray path:

$$| E_{Tot}| = \left| \sum_{i=1}^{N_P} E_i \right| \tag{11.22}$$

where $E_i$ is the complex valued electric field due to the $i^{th}$ ray path. The field strength given here does not take into account the antenna pattern of the receiving antenna.

### Electric Field Phase

The phase of each Cartesian component of the total electric field, for example the phase of the $X$-component of the total field, is given by:

$$\phi_x = tan^{-1} \left( \frac{Im(E_{Tot,x})}{Re(E_{Tot,x})} \right) \tag{11.23}$$

with the phase set to $0$ if $E_x = 0$.

### Poynting Vector

The time-averaged Poynting vector magnitude and its components at a receiver point are given by the cross product of the electric field, $\mathbf{E}$, and the complex conjugate of the magnetic field, $\mathbf{H}^*$.

$$\mathbf{S}_{Av} = \frac{1}{2}(\mathbf{E} \times \mathbf{H}^*) \tag{11.24}$$

## Animated Fields

The magnitude of the Cartesian electric field components versus time are found by combining complex E-fields with time-of-arrival, direction-of-arrival and the shape of the radiated waveform.

- Results may be viewed using the MOVIE PLAYER, as described in Chapter 12.

## Complex Electric Field

The complex electric field output provides the spherical and Cartesian components of the electric field for individual ray paths between transmitter and receiver points. Because the Complex E-Field is provided for each ray path, the organization of the data differs from a common *.p2m file and this output type cannot be visualized from the graphical user interface. However, users can access this data from an ASCII file written to the study area directory.

Additional comments about the complex e-field output:

- The complex e-field values are the electric field values at the receiver point location and do not include any effects of the receiver antennas.
- Paths are organized by received power.
- The number of paths written to the file is controlled by the Maximum rendered output field in the Output Properties window. By default, 25 paths are written to the file.

The general format of the complex e-field output file consists of a header, the number of receiver points listed in the set, identification of an individual rx point and the complex e-field values of the paths reaching that point.

```
# Receiver Set:  rx short description
# Path TOA Mag($E_\phi$) Phase($E_\phi$) Mag($E_\theta$) Phase($E_\theta$) Mag($E_x$) Phase($E_x$) Mag($E_y$) Phase($E_y$) ...
    ...Mag($E_z$) Phase($E_z$)
<rx point 1> <number of paths to rx point 1>
<complex e-field data for path 1 to rx point 1>
<complex e-field data for path 2 to rx point 1>
...
<complex e-field data for last path to rx point 1>

<rx point 2> <number of paths to rx point 2>
<complex e-field data for path 1 to rx point 2>
<complex e-field data for path 2 to rx point 2>
...
<complex e-field data for last path to rx point 2>

⋮
<last rx point> <number of paths to last rx point>
<complex e-field data for path 1 to last rx point>
<complex e-field data for path 2 to last rx point>
...
<complex e-field data for last path to last rx point>
```

## Direction of Arrival

The angles $\theta_A$ and $\phi_A$, with reference to the spherical coordinate system, give the direction from which the propagation path arrives at receiver point.

- See Figure 7.1 for an image of the spherical coordinate system.

The direction in Cartesian coordinates is given by the unit vector:

$$\hat{\mathbf{a}} = sin(\theta_A)cos(\phi_A)\hat{\mathbf{x}} \; + \; sin(\theta_A)sin(\phi_A)\hat{\mathbf{y}} \; + \; cos(\theta_A)\hat{\mathbf{z}} \tag{11.25}$$

### Mean Direction of Arrival

The mean direction of arrival from which energy arrives at the receiver is in the direction:

$$\bar{\theta}_A = tan^{-1} \left( \frac{\sqrt{A_x^2 \; + \; A_y^2}}{A_z} \right) \tag{11.26}$$

$$\bar{\phi}_A = tan^{-1} \left( \frac{A_y}{A_x} \right) \tag{11.27}$$

where

$$A = \sum_{i=1}^{N_P} P_i \; \hat{\mathbf{a}}_i$$

$P_i$ is the power carried by $i^{th}$ ray path

$\hat{\mathbf{a}}_i$ is the unit vector in the direction from which the $i^{th}$ path arrives at the receiver point.

### Direction of Departure

The angles $\theta_0$ and $\phi_0$, with reference to the spherical coordinate system, give the direction in which the propagation path leaves the transmitter.

- See Figure 7.1 for an image of the spherical coordinate system.

The direction in Cartesian coordinates is given by the unit vector:

$$\hat{\mathbf{d}} = sin(\theta_D)cos(\phi_D)\hat{\mathbf{x}} + sin(\theta_D)sin(\phi_D)\hat{\mathbf{y}} + cos(\theta_D)\hat{\mathbf{z}} \tag{11.28}$$

### Mean Direction of Departure

The mean direction of departure from which energy leaves the transmitter is given by the angles:

$$\bar{\theta}_D = tan^{-1} \left( \frac{\sqrt{D_x^2 + D_y^2}}{D_z} \right) \tag{11.29}$$

$$\bar{\phi}_D = tan^{-1}\left(\frac{D_y}{D_x}\right) \quad (11.30)$$

where

$$D = \sum_{i=1}^{N_P} P_i\, \hat{\mathbf{d}}_i$$

$P_i$ is the power carried by the $i^{th}$ ray path

$\hat{\mathbf{d}}_i$ is the unit vector in the direction in which the $i^{th}$ path leaves the transmitter.

### Carrier-to-Interferer Ratio

The carrier-to-interferer ratio is the ratio of the received power from one transmitter (the carrier) to the sum of power received from all other transmitters (the interferers). The ratio is given by:

$$C/I(dB) = 10log_{10}(P_R(i)) - 10log_{10}\left(\sum_{j \neq i}^{N_T} P_R(j)\right) \quad (11.31)$$

where

$P_R(i)$ is the received power due to the $i^{th}$ transmitter

$N_T$ is the number of active transmitters

### Total Received Power

When the electric fields are combined without phase or using the correlated option, the total received power from all active transmitters is calculated using:

$$P_{Tot} = \sum_{i=1}^{N_T} P_R(i) \quad (11.32)$$

where

$P_R(i)$ is the received power due to the $i^{th}$ transmitter

$N_T$ is the number of active transmitters

- See the section on received power (at the beginning of Section 11.1) for more on using the correlated option.

When the fields are combined with phase, the total power is:

$$P_{Tot} = \frac{1}{Z_L}\left|\sum_{i=1}^{N_T} V_i\right|^2 \quad (11.33)$$

where

$V_i$ is the total complex voltage at the feed point of the receiving antenna due to the $i^{th}$ transmitter

$Z_L$ is the impedance of the transmission line attached to the receiving antenna

A value of -250 dBm is written to the output file if $P_{Tot} \leq 1 \times 10^{-25}\, mW$.

## Receiver's Strongest Transmitter

The output type identifies the transmitter which contributes the largest received power at each receiver point. The transmitter is identified by the set number and the number of the point within the set.

## Complex Impulse Response

The complex voltage at the feed point of the receiving antenna due to the $i^{th}$ propagation path is proportional to:

$$V_i = E_{\theta,i} g_\theta(\theta_i, \phi_i) + E_{\phi,i} g_\phi(\theta_i, \phi_i) \tag{11.34}$$

where $E$ and $g$ are defined under "Received Power" in Section 11.1. The complex impulse response is considered to be:

$$s_i = P_i e^{j\psi_i} \tag{11.35}$$

where

$P_i$ is the power carried by the $i^{th}$ ray path

$\psi_i = tan^{-1}\left(\frac{Im(V_i)}{Re(V_i)}\right)$ is the phase

## Power Delay Profile

This OUTPUT type is only available for the *Point* Receiver set. The evaluation of this output type depends on whether the waveform is non-dispersive or dispersive.

For **dispersive waveforms**, the voltage $V_0(f)$ on a hypothetical transmission line with a constant real impedance of $Z_L$ is first found from:

$$V_0(f) = \sqrt{Z_L P_0(f)} \tag{11.36}$$

where $P_0(f)$ is the total time averaged received power, calculated for a time averaged radiated power ($P_T$) of $1\, W$. .

The instantaneous voltage on the transmission line as a function of time is found from:

$$V(t) = F^{-1}[V(f)] \tag{11.37}$$

where

$V(f) = V_0(f)S(f)$

$S(f)$ is the radiated waveform scaled to give the correct total energy radiated from the transmitter

$F^{-1}$ designates the inverse Fourier transform

Finally, the instantaneous power is found using:

$$P(t) = \frac{V(t)^2}{Z_L} \tag{11.38}$$

For **non-dispersive waveforms**, the power delay profile is the envelope of the instantaneous received power as a function of time:

$$p(t) = \frac{\lambda^2 \beta}{8\pi\eta_0} \left| \sum_{i=1}^{N_P} e(t_i - t) V_i \right|^2 \tag{11.39}$$

where

$V_i$ is the complex voltage, defined by Equation 11.34

$e(t)$ is the envelope of the transmitted waveform

$t_i$ is the time-of-arrival

The bandwidth is assumed to be much less than the carrier frequency.

## Electric Field vs. Frequency

This OUTPUT type is only available for dispersive waveforms. It gives the Cartesian components of the complex electric field as a function of frequency.

- See Chapter 6 for more information on creating dispersive waveforms.

For all waveforms which are defined as a modulation of a carrier frequency, the electric field is calculated from:

$$\mathbf{E}(f) = \mathbf{E}_0(f)S(f) \tag{11.40}$$

where

$\mathbf{E}_0(f)$ is the complex electric field calculated at a frequency $f$, assuming a unit amplitude at a distance of a meter from the source

$S(f)$ is the inverse Fourier transform of the actual time domain electric field, $\mathbf{E}(t)$, radiated from the source in free space

$S(f)$ is evaluated at a distance of one meter from the source. The function $\mathbf{E}(t)$ is defined to give the correct radiated power as described in Section 11.2.

### Electric Field vs. Time

The evaluation of this output type depends on whether the waveform is non-dispersive or dispersive.

For **dispersive waveforms**, the electric field as a function of time is found from:

$$E(t) = F^{-1}[E(f)] \tag{11.41}$$

where $F^{-1}$ designates the inverse Fourier transform. The evaluation of $E(f)$ is described by Equation 11.40.

For **non-dispersive modulated waveforms**, the total electric field is calculated from:

$$E(t) = Re\left[\sum_{i=1}^{N_P} A_i m(t-t_i) e^{j\omega(t-t_i)}\right] \tag{11.42}$$

where

$m(\tau)$ is the normalized modulation

$N_P$ is the number of paths to the field point

$A_i$ is the complex electric amplitude of the $i^{th}$ path evaluated at the carrier frequency

$t_i$ is the time-of-arrival of the $i^{th}$ path

### Doppler Shift

Apparent change in frequency of the $i^{th}$ propagation path due to the motion of the transmitter and/or receiver is given by:

$$\triangle f_i = f_0\left[\frac{\mathbf{d}_i \cdot \mathbf{v}_T}{c} + \frac{\mathbf{a}_i \cdot \mathbf{v}_R}{c}\right] \tag{11.43}$$

where

$\mathbf{v}_R$ and $\mathbf{v}_T$ are the velocities of the receiver and transmitter

$\mathbf{a}_i$ and $\mathbf{d}_i$ are the directions of arrival and departure of the $i^{th}$ ray as defined above

$f_0$ is the carrier frequency

*Routes*, *Arcs* and *Vertical Arcs* are the only types of TRANSMITTER or RECEIVER sets that allow users to enter a velocity in the TX/RX LAYOUT PROPERTIES Window. For *Routes*, the direction of the velocity is along the Route segment in the order the points were defined. For *Arcs*, the direction is tangential to the Arc in the direction listed in the TX/RX LAYOUT PROPERTIES Window. Entering a negative velocity reverses the direction along the Route or Arc without redefining the transmitter or receiver set.

✓ Doppler shift data is generated when *Time of Arrival* output is requested.

## Antenna Gain

XGtd can be used to calculate the far field antenna pattern of one or more TRANSMITTERS placed on or near an object. The transmitting ANTENNAS are assumed to radiate as point sources, with the pattern of the source antenna assumed to be independent of distance. Although the pattern does not vary with distance, the field radiated by the source antenna is assumed to decay as $1/r$, where $r$ is the distance from the transmitter.

More than one transmitter can be active at a time, with the antenna gain patterns calculated for all active transmitters. If the transmitters are radiating at more than one frequency, which differ by more than 0.1 MHz, a pattern will be calculated for each frequency. However, if the transmitter frequencies differ by less than 0.1 MHz, the transmitters will be treated as if they are at the same frequency and the calculated antenna pattern will include effects from all transmitters operating at the same frequency. When a broadband waveform is assigned to an antenna, the center frequency or carrier frequency of the waveform is used depending on the type of waveform. For the *Sinusoidal* waveform, the phase is also taken into account.

The antenna gain is calculated by first calculating the complex electric field in the far field of the radiating antennas and any objects that are present. The distance $R$ to the far field is chosen to satisfy the standard criteria:

$$
\begin{gathered}
R > \frac{2D^2}{\lambda} \\
R >> D \\
R >> \lambda
\end{gathered}
\tag{11.44}
$$

where $D$ is the largest distance across the collection of transmitters and objects. The first condition is chosen to give a phase error of less than 22.5°. When a high frequency method such as UTD is used, often only the first condition is important since $D > \lambda$ and satisfying the first condition will usually guarantee that the second and third condition are also satisfied.

The antenna gain is calculated by first determining the electric field at points on a sphere of radius $R$. The center of the far field sphere is placed at the arithmetic mean of the Cartesian coordinates of all active TRANSMITTER points. An *Arc* receiver set is created for constant $\theta$ far zone requests and a *Vertical Arc* for all constant $\phi$ requests. These receiver sets are essentially the same as those created from the interface, except that antenna gain is the only output generated for these sets.

The far field electric is assumed to be of the form:

$$
\mathbf{E}(R,\theta,\phi) = (A_\theta(\theta,\phi)\hat{\mathbf{e}}_\theta + A_\phi(\theta,\phi)\hat{\mathbf{e}}_\phi)\,\frac{e^{-j\beta R}}{R}
\tag{11.45}
$$

in the spherical coordinate system shown in Figure 7.1.

Once the electric field, $\mathbf{E}(R,\theta,\phi)$, is calculated, the field patterns of the theta and phi components are determined from:

$$A_\theta(\theta,\phi) = \mathbf{E}(R,\theta,\phi)\cdot\hat{\mathbf{e}}_\theta R e^{j\beta R} \tag{11.46}$$

$$A_\phi(\theta,\phi) = \mathbf{E}(R,\theta,\phi)\cdot\hat{\mathbf{e}}_\phi R e^{j\beta R} \tag{11.47}$$

The $\theta$ and $\phi$ components of the antenna gain in a given direction is the ratio of power density in decibels relative to power density from an isotropic source radiating the same total power:

$$G_\theta(\theta,\phi) = 10log_{10}\left\{\frac{4\pi\left|A_\theta(\theta,\phi)\right|^2}{2\eta_0 P_{Tot}}\right\} \tag{11.48}$$

$$G_\phi(\theta,\phi) = 10log_{10}\left\{\frac{4\pi\left|A_\phi(\theta,\phi)\right|^2}{2\eta_0 P_{Tot}}\right\} \tag{11.49}$$

where $P_{Tot}$ is the sum of the time-averaged power radiated by all active transmitters at the given frequency. XGtd will output the gain on circles of either constant $\theta$ or $\phi$, as described in Section 11.5.

## Radar Cross Section

Several forms of Far Zone Radar Cross Section (*RCS*) data can be generated including backscatter versus frequency, bistatic scattering versus frequency and bistatic scattering versus constant $\theta$ or constant $\phi$ scattering angle.

We define the Radar Cross Section, $\sigma$, of a target to be ”the area intercepting that amount of power which, when scattered isotropically, produces at the receiver a density which is equal to that scattered by the actual target.” [1] Mathematically, we calculate RCS as:

$$\sigma_{\mu\nu} = \lim_{r\to\infty}\left[4\pi r^2\frac{\left|\mathbf{E}_s\cdot\hat{\mathbf{e}}_\mu\right|^2}{\left|\mathbf{E}_i\cdot\hat{\mathbf{e}}_\nu\right|^2}\right] \tag{11.50}$$

where

$r$ is the observation distance from the target

$\mathbf{E}_s$ is the scattered electric field vector

$\mathbf{E}_i$ is the field incident at the target vector

$\hat{\mathbf{e}}_\mu$ is the unit polarization vector of the scattered field

$\hat{\mathbf{e}}_\nu$ is the unit polarization vector of the incident field

the subscripts $\mu$ and $\nu$ can be either the linear polarization components $\theta$, $\phi$ or circular polarization components $rhcp$, $lhcp$

*RCS* output files contain magnitude and phase values for the co- and cross-polarized field components with respect to the polarization of the incident plane wave. For example, the cross polarized radar cross section for a $\phi$ polarized plane wave is given by

$$\sigma_{\theta\phi} = \lim_{r\to\infty}\left[4\pi r^2 \frac{|\mathbf{E}_s\cdot\hat{\mathbf{e}}_\theta|^2}{|\mathbf{E}_i\cdot\hat{\mathbf{e}}_\phi|^2}\right] \tag{11.51}$$

The *RCS* magnitude is provided in $dBsm$, which is the decibel measure relative to 1 square meter calculated by

$$\sigma_{\mu\nu}\,(dBsm) = 10log_{10}(\sigma_{\mu\nu}) \tag{11.52}$$

The absolute phase of one RCS value is not meaningful by itself, but becomes meaningful and useful when taking the phase differences between other RCS values.

## Scattering Amplitude Matrix

The incident scattered electric field components can be related to the incident electric field components through the scattering amplitude matrix. The following equation provides the scattering amplitude matrix for linear polarization

$$\begin{pmatrix} E^s_\theta \\ E^s_\phi \end{pmatrix} = \begin{pmatrix} f_{\theta\theta} & f_{\theta\phi} \\ f_{\phi\theta} & f_{\phi\phi} \end{pmatrix}\begin{pmatrix} E^i_\theta \\ E^i_\phi \end{pmatrix}\frac{e^{-jkr}}{r} \tag{11.53}$$

For circular polarization, $\theta$ and $\phi$ can be replaced with $rhcp$ and $lhcp$. The scattering amplitude matrix coefficients, $f_{\mu\nu}$, are provided for each ray path reaching the far zone. The scattering amplitude matrix coefficients are related to the radar cross section by

$$\sigma_{\mu\nu} = 4\pi\,|f_{\mu\nu}|^2 \tag{11.54}$$

where

the subscripts $\mu$ and $\nu$ can be either the linear polarization components $\theta$, $\phi$ or circular polarization components $rhcp$, $lhcp$

The phase of the scattering amplitude matrix is the global origin of the project.

## Diagnostic Data

When diagnostic data is selected as an OUTPUT type, several files containing geometry data, reflection/transmission coefficients, and antenna pattern data are written to a folder called “diag”, which is located in the same folder as the project file (`*.xgtd`). The name of the project is at the beginning of all file names. This data cannot be viewed or plotted by XGtd and is only provided for diagnostic and troubleshooting purposes.

- The file naming schemes are described in Section 11.6.

## 11.2 Settings That Affect Output

### Radiated Power

Radiated power is the power emitted by the transmitting ANTENNA. It is related to input power, or the power going into the transmitting antenna, by the following equation:

$$P_{rad} = P_{in} + L_{mismatch} + L_{cable} \tag{11.55}$$

where

$P_{rad}$ is the radiated power, in dBm

$P_{in}$ is the input power, in dBm

$L_{mismatch}$ is the mismatch loss between the input cable and the antenna (characterized by the VSWR value in the antenna properties window) in dB, always $\geq$ 0

$L_{cable}$ is the general loss of the antenna lines in dB, always $\geq$ 0

Input power is set as one of the TRANSMITTER properties. The way in which the specified value is used to determine the electric field depends on the type of WAVEFORM assigned to the transmitter. There are currently three kinds of waveforms in XGtd:

- *Sinusoid*
- Modulated sine waves
- Waveforms of a more general shape, including *Chirp*, *Gaussian Derivative* and *User-Defined* waveforms (either frequency or time domain)

For *Sinusoidal* waveforms, the radiated power is simply interpreted as the power averaged over one cycle of the sine wave. For modulated carrier waveforms, the radiated power is interpreted to be the peak time-averaged power, which is averaged over one period of the carrier wave. The electric field at a distance $R$ from an isotropic source is given by:

$$E(t) = \sqrt{\frac{\bar{P}\eta_0}{2\pi}}\frac{1}{R}m(t)sin(\omega t) \tag{11.56}$$

where

- $\bar{P}$ is the radiated power
- $m(t)$ is the modulation, defined to have a maximum value of 1
- $\eta_0$ is the impedance of free space
- $\omega$ is the angular frequency of the carrier in radians/second

For *Chirp*, *Gaussian Derivative* and *User-Defined* waveforms, the radiated power is interpreted to mean the time-averaged power over the entire duration of the pulse. Assuming $E(t)$ is the electric field in

$V/m$ at time $t$, at a distance $R$ from an isotropic source, the time averaged radiated power in Watts is then given by:

$$\bar{P} = \frac{4\pi R^2}{\eta_0 T_D} \int_0^{T_D} [E(t)]^2 \, dt \tag{11.57}$$

where $T_D$ is the duration of the pulse, such that $E(t) = 0$, for $t > T_D$.

Conversely, if $s(t)$ is a normalized time domain pulse, the electric field at a distance $R$ from an isotropic source is given by:

$$E(t) = A_0 s(t) \tag{11.58}$$

where

$$A_0 = \frac{\sqrt{\dfrac{\bar{P}\eta_0}{4\pi R^2}}}{\sqrt{\dfrac{1}{T_D} \displaystyle\int_0^{T_D} [s(t)]^2 \, dt}} \tag{11.59}$$

### Dispersive Waveforms

The calculation of a few OUTPUT types will depend on whether the transmitter waveform is dispersive or non-dispersive, but many other output types will not. By selecting the dispersive option, the calculation of electric field as a function of time will include the dispersion on the broadband waveform pulse as it propagates. The electric field is also calculated as a function of frequency for dispersive waveforms. The electric field vs. time and electric field vs. frequency output files are only created for *Points* and "Points-On-Face" RECEIVER sets.

Even when a WAVEFORM is designated as dispersive, many output types will still only be evaluated at a single frequency. The carrier frequency, or center frequency for a *Gaussian Derivative* and *User-Defined* waveform, will be used in these cases. Output types in this category include TOTAL ELECTRIC FIELD and COMPLEX ELECTRIC FIELD. The RECEIVED POWER, PATH LOSS/GAIN, and COMPLEX IMPULSE RESPONSE are also only evaluated at a single frequency, but in these cases the bandwidth is also taken into account through the frequency response of the receiver.

- See Section 11.1 for more on the calculation of the received power.

## 11.3 Output Units

The units listed below are the ones used for the numerical data in all output files. In some cases other units many be available when viewing output in the PROJECT VIEW or in line plots, but selecting one of these other options will not change the numerical data in the files.

- Received Power: dBm

- Time: seconds
- Frequency: Hz
- Length: meters
- Phase: degrees (-180 to 180)
- Direction: degrees (0 to 360)
- Electric Field: V/m
- Magnetic Field: A/m
- Poynting Vector: W/m$^2$
- Path Loss: dB
- Antenna Gain: dBi
- Radar Cross Section: dBsm, where sm stands for square meters
- Scattering Amplitude Matrix: meters
- S-Parameter: dB

## 11.4 Output Properties

The following properties can be set in the PROJECT OUTPUT PROPERTIES Window, seen in Figure 11.1, by selecting *Project→Output properties* from either the MAIN WINDOW or the PROJECT VIEW.

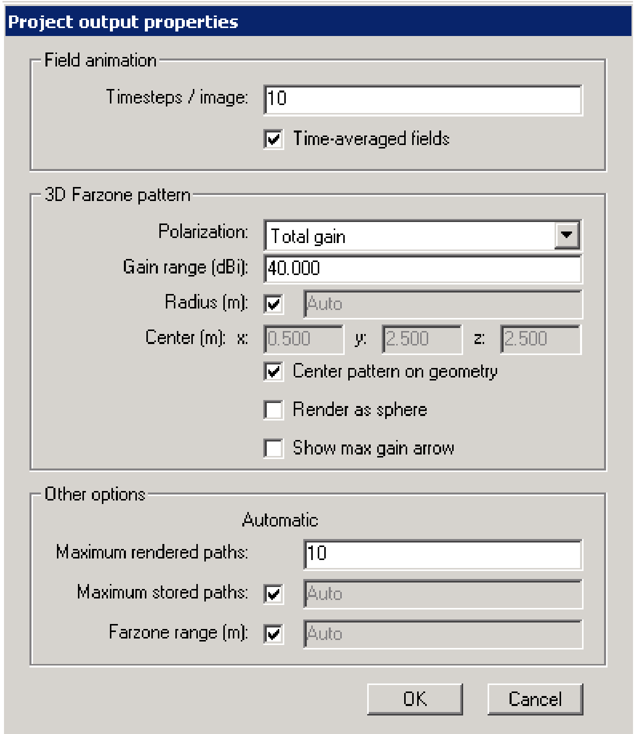


Figure 11.1: The output properties for the project

**Field animation**

*Timestep increment* - Determines how frequently timesteps are saved as a `jpeg` image for movie display purposes. The default value, 10, indicates that every 10th timestep calculated will be written to disk.

*Time-averaged fields* - Indicates that time-averaging is performed on the fields for movie display purposes.

**3D Far zone pattern**

Controls the appearance of the currently selected far zone pattern.

- The options in this section are discussed in more detail in Section 12.1.

*Polarization* - Controls which polarization of the pattern to display.

*Gain range* - Sets the minimum value of the patterns gain relative to its maximum gain. The smaller this number, the more directional the pattern appears.

*Radius* - Defines the distance of the patterns' maximum gain from its center.

*Global position* - Defines the position of the center of the far zone pattern within the project.

*Center pattern on geometry* - Calculates the global position of the pattern as the center of the geometry contained within the project.

*Render as sphere* - Causes the pattern to be displayed as a colored sphere.

*Render gain arrow* - Controls the visibility of an arrow pointing from the center of the pattern to the point of its maximum gain.

**Other options**

*Maximum rendered paths* - Allows the user to determine how large a subset of the *Maximum stored paths* are available for viewing between a transmitter and a receiver point. The strongest paths, up to this maximum, can be viewed from the user interface.

*Maximum stored paths* - Allows the user to set the maximum number of paths to be computed and stored between a transmitter and a receiver point. Many more paths may actually exist, however, only the strongest paths are stored up to this maximum.

*Farzone range* - Setting for the distance used when evaluating near zone outputs such as excess time of arrival, complex electric field, and electric field magnitude and phase in the far zone.

## 11.5 Requesting Output

In order to minimize calculation time and disk usage, only the REQUESTED OUTPUT is written to the output files. By default, only received power, path loss and propagation paths are selected. The default output requests for a project can be set by checking items on the REQUESTED OUTPUT CATEGORIES list, shown in Figure 11.2, which can be accessed through the DEFAULT OUTPUT REQUESTS button in the PREFERENCES window. Some propagation models allow specific output requests to be made per study area. This can be done via the REQUESTED OUTPUT button in the STUDY AREA PROPERTIES window. Models that generate a limited number of outputs do not have this button, and will generate all of their outputs for every simulation.

✓ Some models do not produce all outputs on the project-level default REQUESTED OUTPUT CATEGORIES list. The REQUESTED OUTPUT CATEGORIES listed in each study area show what outputs are supported by that model.

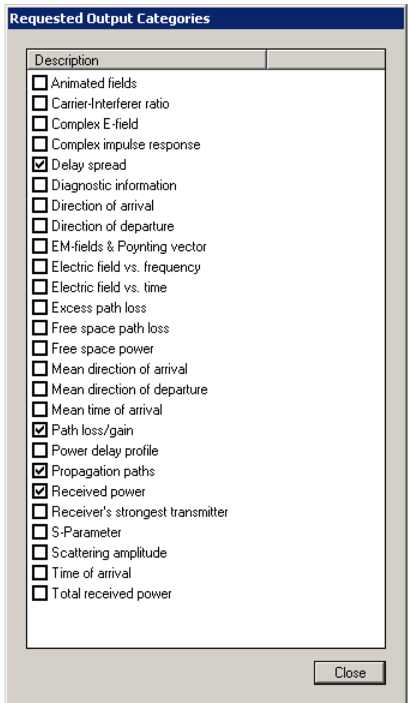


Figure 11.2: The requested output categories

### 11.5.1 Far Zone Requests

Two additional types of Far Zone output can be generated by XGtd: *Gain* and Radar Cross Section (*RCS*). In order to for this output to be generated, one or more Far Zone requests must be created by selecting *Project*→*New*→*Far zone request*→*Gain* or *Project*→*New*→*Far zone request*→*RCS*. All Far Zone requests which have been added to the project are listed in the lower portion of the REQUESTED OUTPUT tab. The lower half of the window can be viewed or hidden by clicking on the long rectangular button. The properties of each Far Zone request can be viewed by right-clicking on the request and selecting *Properties*. Far zone requests can also be set as inactive by right-clicking on the request and un-checking *Active*. Data generated for Far Zone requests are listed under the category “Far zone data” in each study area in the Output Tree.

#### 11.5.1.1 Far Zone Gain Requests

A Far Zone *Gain* request can be made by selecting *Project*→*New*→*Far zone request*→*Gain*. The FAR ZONE GAIN REQUEST PROPERTIES Window will appear, as seen in Figure 11.3. Far Zone *Gain* requests can be made for individual cut-planes or a full 3D pattern. Using XGtd’s spherical coordinate systems, far zone results for constant phi or theta cut planes can be identified.

After setting the type of request, the start and stop angles can be entered with an increment that indicates the angular separation between samples along the constant plane. The gain is calculated at each increment between the start and stop angles. When making a constant theta request, the phi angle constraints can be entered. Likewise, when constant phi is selected, the theta constraints can be entered. When selecting a "Full 3D pattern," both theta and phi constraints can be entered to limit the surface of the final pattern.

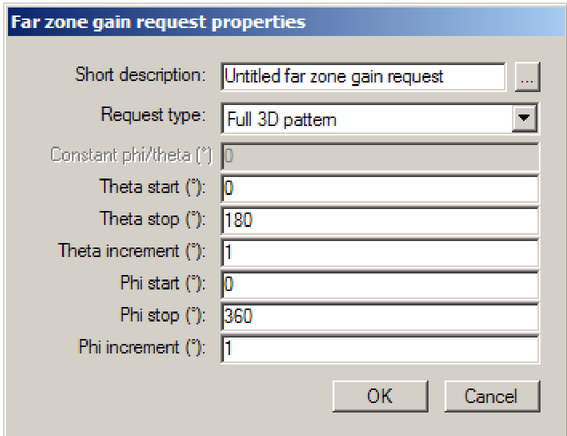


Figure 11.3: The properties of an antenna gain request

#### 11.5.1.2 Far Zone RCS Requests

Several forms of Far Zone *RCS* data can be generated, including backscatter versus frequency, bistatic scattering versus frequency and bistatic scattering versus constant theta or constant phi scattering angle. Calculation of RCS versus incidence angle can be performed by creating multiple Far Zone *RCS* requests and assigning to each a plane wave with a different incidence angle.

Each RCS request will produce data for a single incident plane wave, as selected in the Far Zone RCS Request Properties Window seen in Figure 11.4. In addition to the chosen scattering mode, the Waveform assigned to the selected plane wave will determine what RCS data is generated. If RCS versus frequency is desired, the plane wave's Waveform must not be *Sinusoidal* and its dispersive option must be engaged to allow the calculation to span the bandwidth of the waveform. If this criterion is not met, *RCS* will only be calculated at the waveform's carrier frequency. The Far Zone RCS Request Properties Window will alert you as to what type of waveform is being used and what data will result. Calculation of bistatic RCS versus frequency requires a single scattering angle to be entered, and RCS versus constant theta or constant phi scattering angle can be performed by specifying which angle remains constant and the start, stop and increment angles for the varying angle.

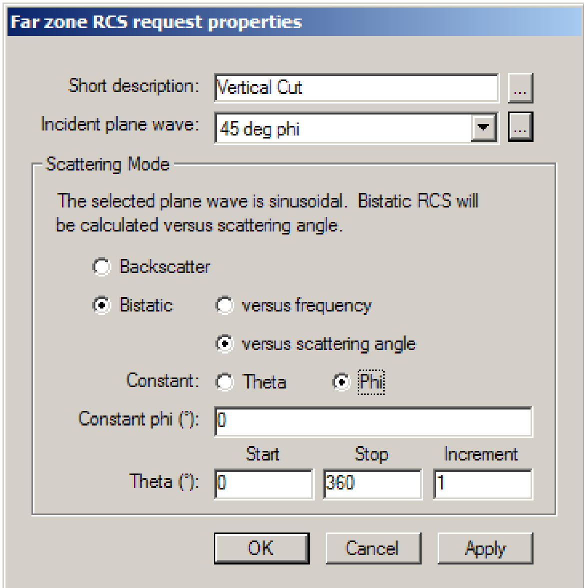


Figure 11.4: Properties for the bistatic RCS vs. scattering angle

## 11.6 Output Files

### Location of Output Files

When a calculation is made for a project for the first time, a folder is created for each active STUDY AREA and the OUTPUT is written to this folder. The folder names are derived from the first 50 characters of the short description given to the study areas. If the user does not enter a short description, the default description of “studyarea1” is used for the first area, “studyarea2” for the second, etc. antenna pattern output files are placed in a sub-folder within the study area folder, with the name of the sub-folder determined from the frequency in MHz.

### Output File Names

#### Point-To-Multipoint Files

These files follow the format `*.p2m` (short for point-to-multipoint). Most of the `*.p2m` files contain the predictions at all RECEIVER points on a set due to the energy radiated from a single TRANSMITTER point. The names of these files are of the form: `project.type.tx_y.rz.p2m`, where:

- `project` stands for the name of the project
- `type` is the keyword for the output type
- `x` is the number of the transmitter site within the set
- `y` is the number of the transmitter set

- `z` is the number of the receiver set

For example, the name of the file containing the received power for all points on “Receiver set 2” due to the “transmitter at point 3 of set 4” would be `project.power.t003_04.r002.p2m`.

The output type keywords along with a brief description of the output are listed below:

- `c2i` - Carrier to interferer ratio
- `cef` - Complex electric field for strongest paths
- `cir` - Complex impulse response
- `doa` - Direction of arrival for strongest paths
- `dod` - Direction of departure for strongest paths
- `doppler` - Change in frequency due to motion of transmitter and receiver
- `e?mag` - Magnitude of E-field components, where ? = $X$, $Y$ or $Z$
- `e?phs` - Phase of E-field components, where ? = $X$, $Y$ or $Z$
- `erms` - Time averaged E-field magnitude
- `fspl` - Path loss in free space in dB
- `fspl0` - Free space path loss with *Isotropic* Antennas
- `fspower` - Received power in free space in dBm
- `fspower0` - Received power in free space with *Isotropic* Antennas
- `h?mag` - Magnitude of H-field components, where ? = $X$, $Y$ or $Z$
- `h?phs` - Phase of H-field components, where ? = $X$, $Y$ or $Z$
- `hrms` - Time averaged H-field magnitude
- `mdoa` - Mean direction of arrival at receiver
- `mdod` - Mean direction of departure from the transmitter
- `mtoa` - Mean time of arrival in seconds
- `mxtoa` - Mean delay
- `paths` - Geometrical propagation paths
- `pg` - Path gain in dB
- `pl` - Path loss in dB
- `power` - Received power in dBm
- `s?` - Cartesian components of the Poynting vector, where ? = $X$, $Y$ or $Z$
- `savg` - Time averaged (RMS) magnitude of the Poynting vector
- `srms` - Time averaged propagation field magnitude
- `samp` - Scattering amplitude

- `sparameter` - S-Parameter
- `spread` - Delay spread in seconds
- `toa` - Time of arrival of strongest paths in seconds
- `xpl` - Excess path loss in dB
- `xpl0` - Excess path loss using *Isotropic* Antennas for free space loss

A few of the `*.p2m` output types depends on all the active transmitters, and hence specific transmitter set and point numbers are not included in file name. The file name for data of this type is of the form `project.type.rz.p2m`, where `z` is the number of the receiver set.

The currently available types are:

- `psum` - Sum of received power from all active transmitters
- `st2r` - Receiver's strongest transmitter

▶ See Appendix H for more on `*.p2m` files.

### Point-To-Point Files

These files end in the extension `*.p2p` (short for point-to-point) and can be produced for *Point* Receiver sets. All of the `*.p2p` files contain the predictions at a single RECEIVER point due to the energy radiated from a single TRANSMITTER point. The names of these files are of the form: `project.type.tx_y.rw_z.p2p`, where:

- `type` is the keyword for the output type
- `y` is the number of the transmitter set
- `x` is the number of the transmitter point within the set
- `z` is the number of the Receiver set
- `w` is the number of the receiver point within the set

For example, the name of the file containing the time domain electric field for "Receiver point 5 on Receiver set 2" due to the "transmitter at point 3 of set 4" would be `project.tdef.t003_04.r005_02.p2p`.

The currently available `*.p2p` output types are:

- `fdef` - Cartesian components of electric field vs. frequency
- `fztdef` - Spherical components of far zone electric field vs. time
- `fzfdef` - Spherical components of far zone electric field vs. frequency
- `pdp` - Power delay profile (received power vs. time)
- `tdef` - Cartesian components of electric field vs. time

### Far zone Antenna Gain Files

Far zone gain data files are located in a subfolder in the STUDY AREA folder named for the frequency at which they were calculated (rounded to the nearest tenth of a MHz). The names of the antenna gain files indicate whether the output is for a single cut plane or whether the file contains a 3D pattern.

The format of a file name is one of the following:

- Full 3D Pattern - `project.pvtv.tb0.te180.ti100.pb0.pe360.pi100.fz`
- Constant Phi Cut - `project.pvt90.pb0.pe360.pi100.fz`
- Constant Theta Cut - `project.tvp90.tb0.te360.pi100.fz`

where each component in the file name is as follows:

- `pvtv` - indicates both phi and theta angles vary (full 3D pattern)
- `pvt#` - indicates that phi varies and the theta angle is constant (theta cut-plane).
- `tvp#` - indicates that theta varies and the phi angle is constant (phi cut-plane)
- `tb#` - the theta start angle in degrees
- `te#` - the theta stop angle in degrees
- `ti#` - the theta increment angle in hundredths of degrees
- `pb#` - the phi start angle in degrees
- `pe#` - the phi stop angle in degrees
- `pi#` - the phi increment angle in hundredths of degrees

Notice that the difference between the two types of cut-plane requests is which angle in spherical coordinates varies and which is held constant. The increment angles are in hundredths of degrees, and all other angles are given as an integer number of degrees.

The far zone cut-plane files contain five columns of data consisting of the angle, phi-polarized gain in dBi, theta-polarized gain in dBi, phase of the phi component, and phase of the theta component. The full 3D patterns use the same format as a `*.uan` file.

▶ See Chapter 7.5.1 for more on `*.uan` files.

### Far Zone RCS Files

Far Zone *RCS* data files are located in the STUDY AREA folder and begin with `project.rcs??.tx`, where `??` is a two-character code which indicates the scattering mode chosen in the FAR ZONE RCS REQUEST PROPERTIES Window. The first character, either “m” or “b”, indicates monostatic (backscatter) or bistatic, respectively. The second character, “f”, “s” or “i”, indicates the file contains RCS versus frequency, scattering angle or incidence angle, respectively. Next, “x” is the set number of the plane wave for which the *RCS* data was calculated. Additional information after the plane wave number is dependent on the chosen scattering mode. The file names for bistatic RCS vs. scattering angle are similar to the file names for antenna gain on a constant theta or phi cut-plane (for example: `project.rcsbs.t02.pb0.pe360.pi100.fz`). The *RCS* output file names all end with `*.fz`.

Some of the Point to Multi-point output types are also available. These files have a `*.fz` extension; short for "far zone". Most of the `*.fz` files contain the predictions at all far zone points, that are created based on the request parameters, from the energy radiated from a single TRANSMITTER point. The names of these files are of the form: `project.type.tx_y.rz.p2m`, where:

- `project` stands for the name of the project
- `type` is the keyword for the output type
- `x` is the index of the plane wave angle within its variable incident angles
- `y` is the number of the plane wave
- `z` is the number of the output request

For example, the name of the file containing the scattering amplitude for all the far zone points in "Output Request 2" from "angle 3 of plane wave 4" would be `project.samp.t3_4.r2.fz`.

- `cef` - Complex electric field for strongest paths
- `e?mag` - Magnitude of E-field components, where ? = $X$, $Y$ or $Z$
- `e?phs` - Phase of E-field components, where ? = $X$, $Y$ or $Z$
- `erms` - Time averaged E-field magnitude
- `h?mag` - Magnitude of H-field components, where ? = $X$, $Y$ or $Z$
- `h?phs` - Phase of H-field components, where ? = $X$, $Y$ or $Z$
- `hrms` - Time averaged H-field magnitude
- `s?` - Cartesian components of the Poynting vector, where ? = $X$, $Y$ or $Z$
- `samp` - Scattering Amplitude
- `savg` - Time averaged (RMS) magnitude of the Poynting vector
- `xtoa` - (Excess time-of-arrival) delay of strongest paths in seconds

#### Diagnostic Data

Diagnostic data files are ASCII files written in a variety of formats. Many of the files have headers describing the format and the file names are generally descriptive of the contents. For example, the file `project.ant05.tht135.dat` contains the antenna pattern vs. phi at a constant theta of 135° for antenna number 5. Other files include:

- Reflection coefficients (`project.refl.xx.dat`)
- Transmission coefficients (`project.trans.xx.dat`)
- FEATURE geometry data (`project.object.dat`)

### Export S-Parameter Output to a Touchstone File

S-Parameter results can be exported to the ASCII-based v1.1 Touchstone file format. The export operation collects S-parameter results from all active transmitter, receiver, and transceiver locations, providing a convenient way to construct the S-paramter matrix.

To export S-parameter output to a Touchstone file:

1. Run a calculation with S-parameter output requested
2. In the MAIN WINDOW, click on the STUDY AREA tab
3. Right-click on the studyarea and select *Create Touchstone File*

A Touchstone file will be written to the selected studyarea directory. The file name is constructed from the XGtd project name and the number of active transmitter, receiver, and transceivers in the project:

`project.sNp`

where $N$ is the number of active transmitters, receivers, and transceivers.

# Chapter 12

# Data Visualization

*In this chapter, you will learn...*

→ how to choose the correct output to view in XGtd

→ how to display the data in 2D, 3D and/or animated format

XGtd has a wide range of built-in data visualization capabilities. Input data such as ANTENNA patterns and MATERIAL electrical parameters can be plotted to verify model assumptions and check performance. OUTPUT data can be plotted for any of the 2D data types that XGtd produces. For data types which are not appropriate for 2D plotting, powerful 3D graphics can be used to display data in various formats. The plots created can be edited to produce high quality graphs for both presentation and archive. What follows is an overview of OUTPUT viewing, viewing ray paths, line graphs and associated features, and several examples of how to create various plots.

✓ In general throughout the manual, “graph” refers to the figure that includes the title, axes, legends, and data, and “plot” refers to a particular data set being plotted on the graph. Using this terminology, one graph may contain several different plots.

## 12.1 Viewing Output

### Selecting Data

Once a calculation has finished, all of the data selected in the REQUESTED OUTPUT CATEGORIES list will be available for viewing. The data is accessible by clicking the OUTPUT tab in the MAIN WINDOW, which will display a window similar to the one seen in Figure 12.1.

For each STUDY AREA in the project, there will be an entry with the name of the study area. The data is generally organized in a hierarchical format by study area, then dataset type (point-to-point, point-to-multipoint, filtered), followed by output item, then the individual data items. Almost all operations involving data display and visualization will start by drilling down into the dataset through this hierarchy.

Some outputs are nested under one entry in the output tree. For example, *received power* and *received power with diffuse scattering* output files contain several types of output. Right click on the output tree entry to access output options.

✓ The output available under the OUTPUT tab is also available in the PROJECT HIERARCHY under “Study areas and Output”.

✓ The way that the output is organized can be modified in the application preferences. See section 2.6.3 for more information.

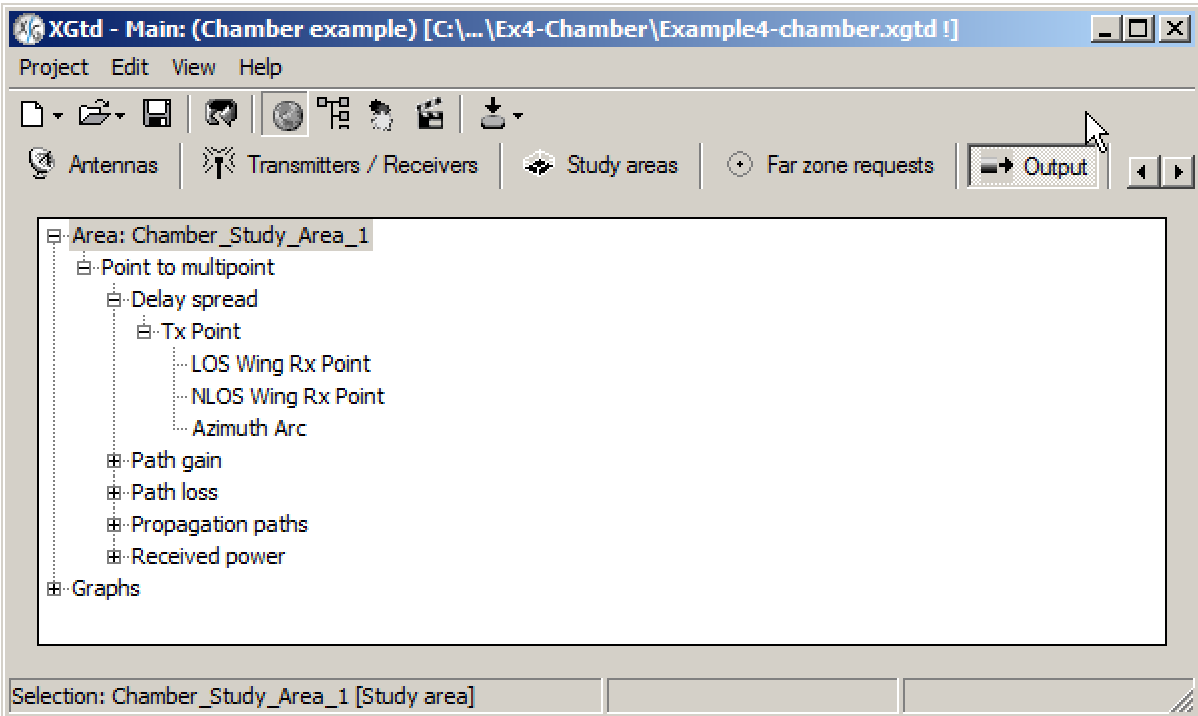


Figure 12.1: Display of output available in a projects’ study area

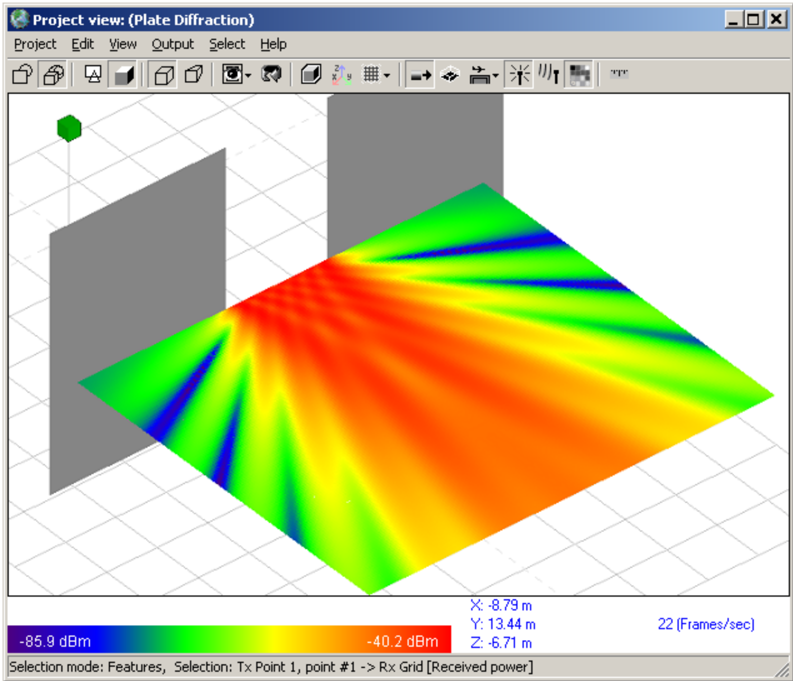


Figure 12.2: Viewing power of the diffraction pattern through a wide slit

## Viewing Output in the Project View

To demonstrate viewing OUTPUT in the PROJECT VIEW, we will use a simple example involving a diffraction around a thin plate. The example project consists of a TRANSMITTER and *XY Grid*. The project and its received power output is shown in Figure 12.2.

To view the output data in the PROJECT VIEW select *View* from the context menu of a file entry under the OUTPUT tab. This will load the data into the PROJECT VIEW and display it. A scale bar for that data type will appear in the lower left corner indicating the values of each color.

The scale bar automatically adjusts to fit the range of loaded values. If multiple files are loaded then the range will adjust to encompase the minimum and maximum of each one. This automated adjustment can be overridden with exact values by selecting *Range options→Manual scaling* from the scale bar's context menu. If the mouse pointer is placed at a point on the color bar text will appear showing the numerical value corresponding to that color and the current data type being viewed.

Specific points can be examined by selecting *Select→Output* in the menu bar of the PROJECT VIEW. While in this selection mode selecting any data point will create an indicator on the scale bar showing where it falls in the color spectrum and its exact value.

✓ When the selection mode in the PROJECT VIEW is *Select→Tx/Rx Point* selecting a receiver point with visible underlying output will not select the output item. This means that its value will not appear on the scale bar as described above. The selection mode must be *Select→Output* to do this.

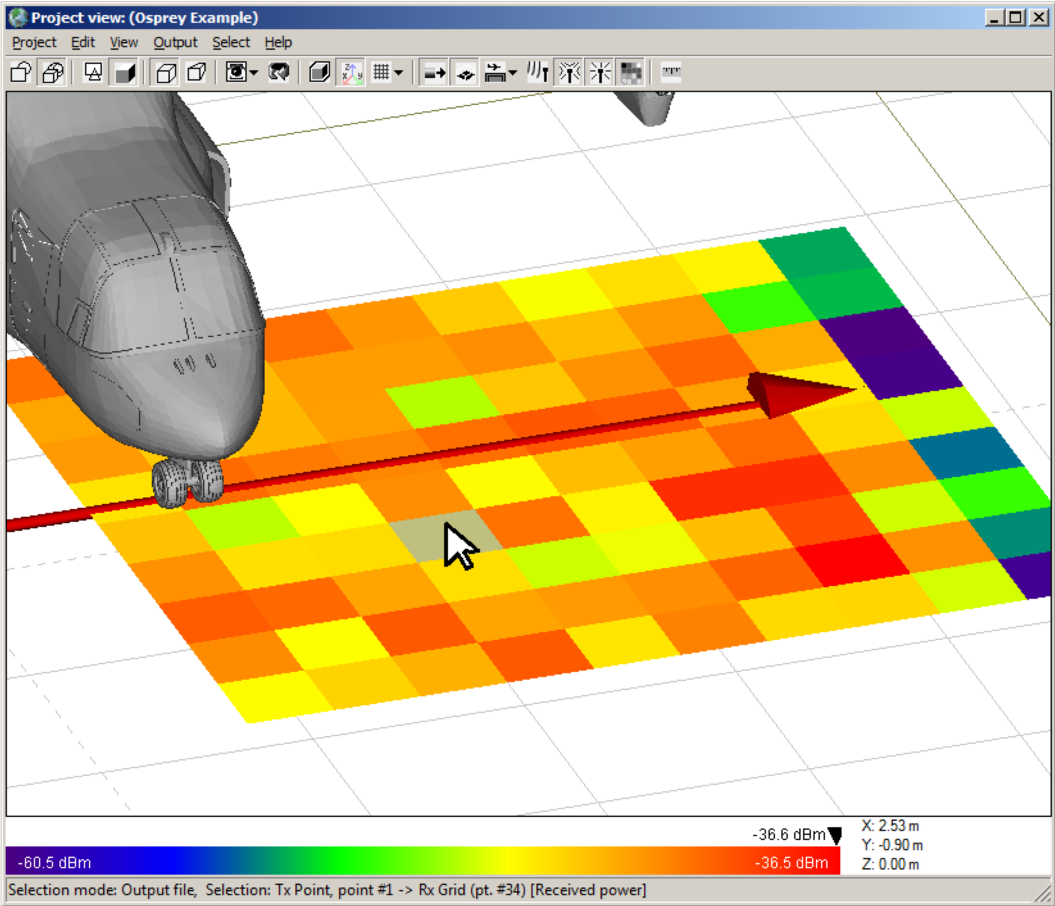


Figure 12.3: Selecting an output item and viewing its value on the scale bar.

The values of individual propagation paths can also be viewed, but they must be selected under the OUTPUT tab as shown in Figure 12.4. This will activate the path in the PROJECT VIEW and show the value for that path on the scale bar.

More details on viewing propagation paths can be found in section 12.1.

✓ The propagation paths use the same scale bar as the received power OUTPUT and uses the range as set for that OUTPUT type. This means that paths with small contributions to the overall received power may not appear on the scale bar as it could fall below the minimum for the consolidated values of received power for the currently loaded data sets.

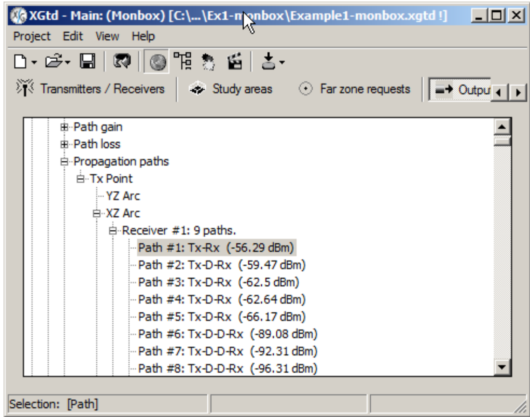


Figure 12.4: Selecting a path in the output tab.

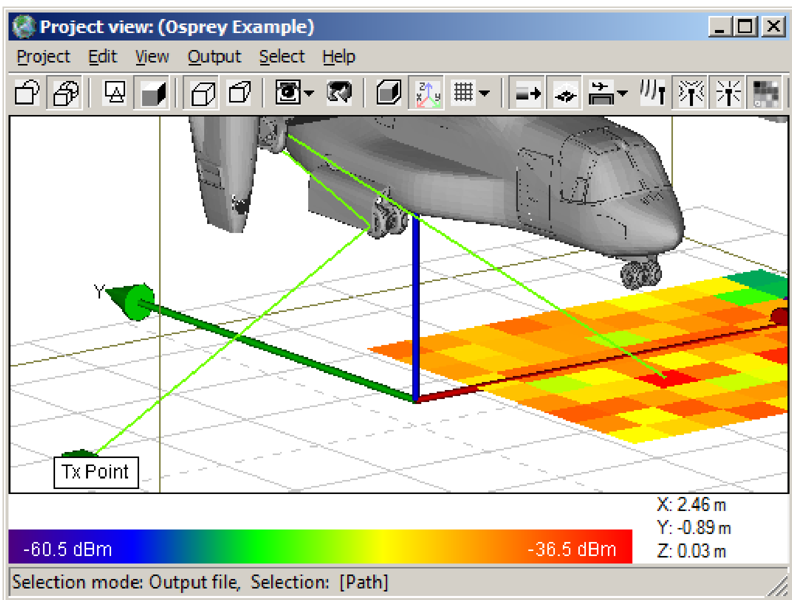


Figure 12.5: A selected path in the Project View with its value displayed in on the scale bar.

## Scale Bar Properties

Figure 12.6 shows the Scale Properties for Received Power Window. This window is accessed by right clicking on the scale bar and selecting *Properties*. This window allows you to customize all of the various aspects of the scale bar for each output type.

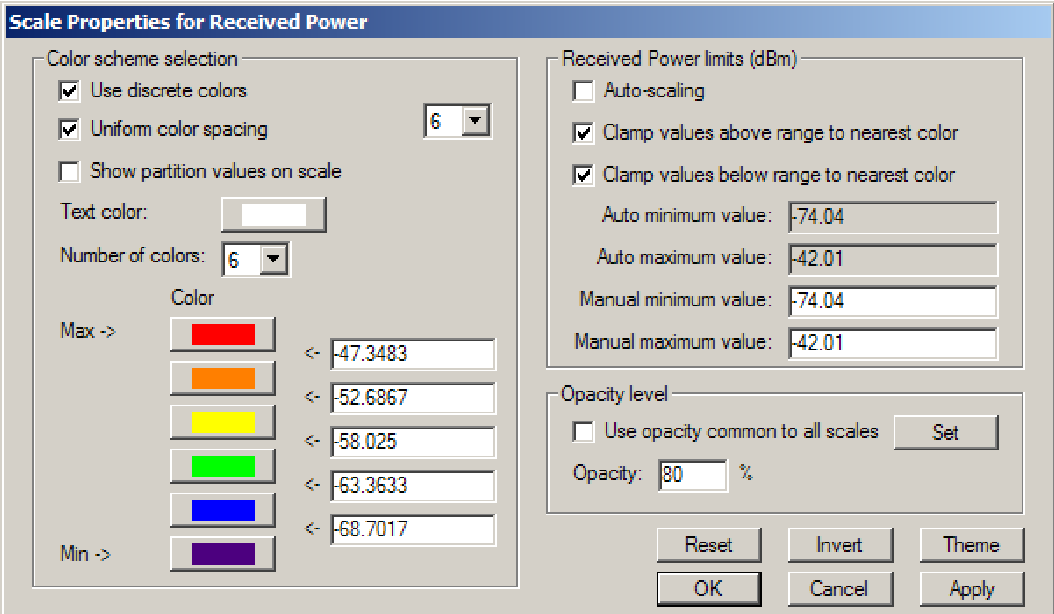


Figure 12.6: The properties of the received power scale bar

The properties set from this window are:

- **Color scheme selection**

  This section allows the user to set up the scale bar to display output in discrete colors as opposed to a continuous color spectrum. The sections within this area are as follows:

  – *Use discrete colors* - Enables or disables the use of discrete colors for displaying output.

  – *Uniform color spacing* - Calculates the range for each color based on the current min/max and cover an equal range of values. If this is deselected, then the points where the output data transitions from one color to the next can be adjusted from the defaults by putting a value in the appropriate partition point box.

  – *Show partition values on scale* - Displays the discrete color values on the scale bar in the *Text color* shown.

  – *Number of colors* - Allows the user to select the number of colors to use for discrete color output display. There can be from two to twelve colors used for discrete output.

  – *Color / partition points* - Determines the number of color buttons and partition points that appear. The color of a color button can be changed by clicking on it.

- **Received Power Limits**

  If the *Auto-scaling* box is checked, then the scale bar will automatically adjust the minimum and maximum as data is loaded to be inclusive of all of the sample points. The current values for the given scale bar are shown. If *Auto-scaling* is deselected, the minimum and maximum can be set manually. If the minimum is increased or the maximum is decreased, then any points that lie outside the range can either be displayed using the closest color in the range, or will be transparent when the *Clamp values above (or below) to nearest value* box is unchecked.

- **Opacity level**

  This determines the transparency of the rendered output. This is useful in situations where the underlying image still needs to be visible. This is also used to highlight a transmitter against a background of receiver grids when viewing the strongest transmitter output. The user can set the opacity for all of the scale bars by clicking on the SET button, or deselecting the *Use opacity common to all scales* checkbox and entering the desired percentage in the *Opacity* text box.

- RESET

  This option will put the scale bar in its default state. The default options are:

  – Color scheme set to Continuous.

  – Discrete color scheme reset to use uniform spacing. This overrides any applied theme.

  – Mins/maxes set to auto.

  – Clamping reactivated.

- INVERT

  Reverses the order of the colors.

- THEME

  Enables the user to select a color theme. There are a number of theme files in the installation directory in a folder named 'colormaps'.

- APPLY

  Applies all scale bar changes to the project without having to close the properties window. Note that the INVERT, THEME, and RESET actions are applied immediately.

Several of these options are available directly on the context menu for the scale bar. They are:

- *Output type* for selecting which scale bar to use based on what data needs to be viewed.
- *Range options* for selecting either auto or manual scales.
- *Scale options* for putting the scale bar into either continuous or discrete display mode.
- *Set common opacity level* for setting the globally used opacity level.
- *Select color theme* to apply a color theme to the current scale bar.
- *Save current settings* to save the settings for all scale bars in the current project into a scale bar configuration file (`*.sb`)
- *Load current settings* to load the `*.sb` file into the project and overwrite the current scale bar settings for any scale bar listed in the file.

The settings for all of the scale bars that have been modified from the default configuration are saved automatically into the project settings file, but the settings can also be saved individually to a separate scale bar settings file. This is useful for applying the same scale bar settings across multiple projects. The scale bar context menu contains the option to save the current settings.

### Viewing Propagation Paths

For many types of simulations it is useful to display the ray paths produced by the calculation. Viewing the individual paths is a powerful tool for gaining knowledge of the physics of the particular situation and also as a diagnostic tool for checking both model assumptions and the accuracy of the results.

By default, XGtd saves the set of paths (up to the maximum number chosen for the project) calculated for every Tx/Rx combination. To access the paths, click the OUTPUT tab in the MAIN WINDOW of your project. In this tab one or more STUDY AREAS will be listed. If the calculation completes successfully, it is possible to expand each study area and drill down to view the ray paths.

✓ The maximum number of paths which are viewable in the PROJECT VIEW can be set by clicking *Project→Output properties* in the MAIN WINDOW and entering the desired *Maximum Rendered Paths* value. The last field contains “Maximum paths”. The default for this setting is 25, which is often sufficient, but may need to be increased under special circumstances.

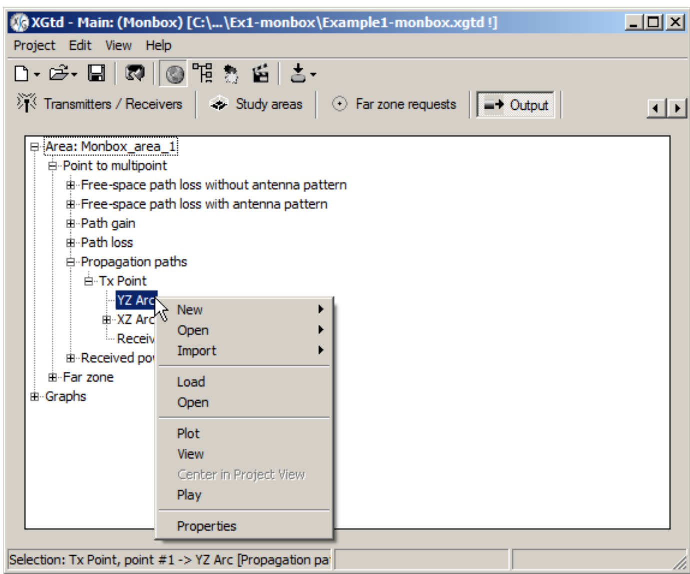


Figure 12.7: The context menu for a propagation path output file

Select the *Propagation Paths* branch of the Output Tree and right-click the desired data set, as seen in Figure 12.7. Clicking on *Load* will load all of the path data for the particular chosen path and make it available for viewing or plotting. Once loaded, the expand sign will appear next to the data set. Clicking it will expand the data set to show the individual receiver points. Expanding a point will show each ray path from the transmitter point to the receiver point, as seen in Figure 12.8.

✓ Clicking *Load* is not required if the user wants to directly view the ray paths. Selecting *View* will automatically load all of the paths for the receiver set selected and display them. This could potentially display thousands of rays for large receiver sets, so it is good practice to select *Load* and then *View* to select the ray paths.

✓ The output available under the OUTPUT tab is also available in the PROJECT HIERARCHY under *Study Areas and Output*.

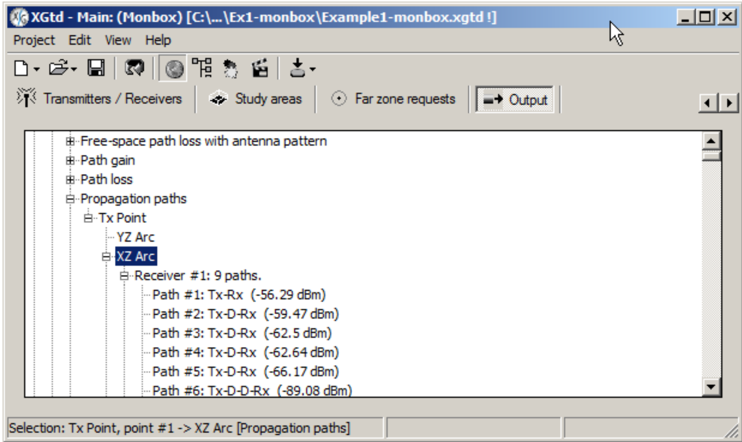


Figure 12.8: Viewing the receiver points and associated paths in the Output tab

At each of these levels you can view the paths by selecting *View* from the context menu at that point. Figures 12.9 and 12.10 show how to view a single ray path.

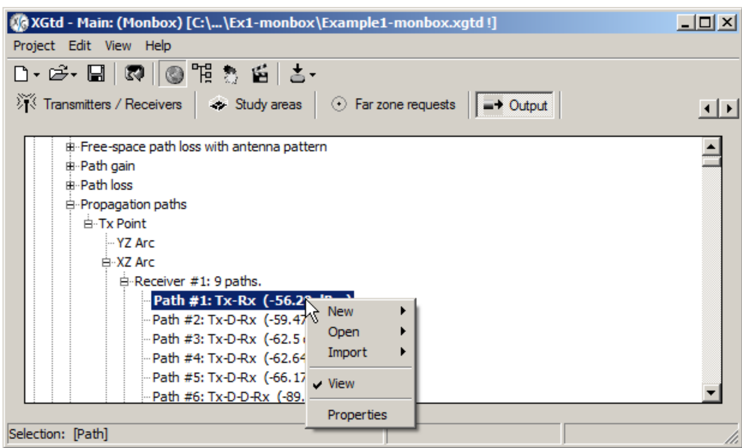


Figure 12.9: Viewing a specific path

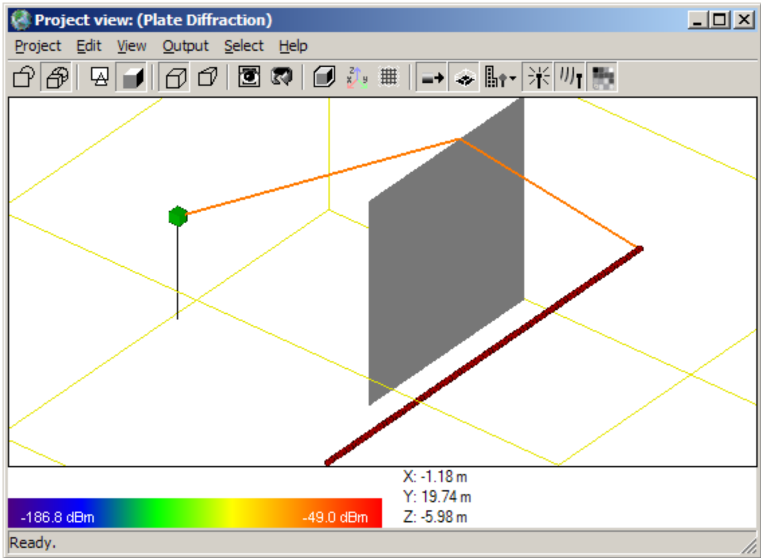


Figure 12.10: The specific path between the transmitter and first point of the receiver Route

The context menu of a specific receiver point in the list provides an option to *View All Paths* that will display the paths from the transmitter point in the PROJECT VIEW, as seen in Figure 12.11.

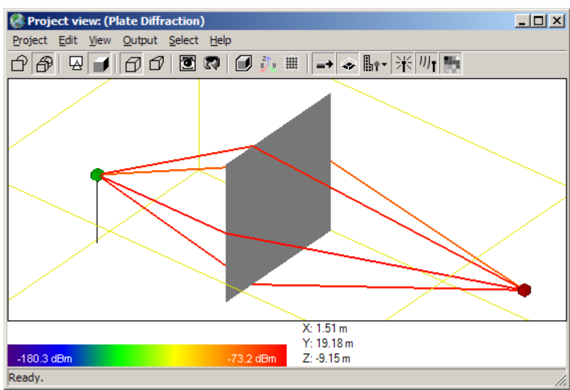


Figure 12.11: Viewing the propagation paths to the receiver point

If the user wants to view a certain subset of the paths for a given RECEIVER, clicking *View Some Paths* brings up the VIEW PATHS Window for choosing the way the paths are selected for display, as seen in Figure 12.12. Using this method, the user can choose a specific set of rays with maximum or minimum power or time-of-arrival (TOA).

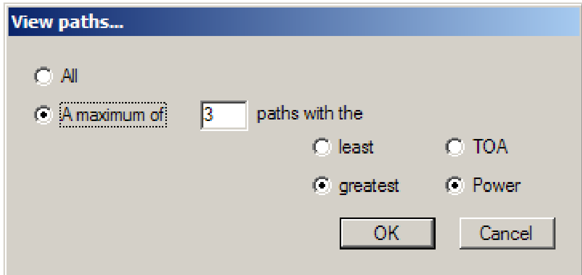


Figure 12.12: Filtering the paths to display

It is also possible to view single paths by selecting one or more of the paths listed under the desired receiver, as seen in Figure 12.13. The single ray chosen is displayed in Figure 12.14.

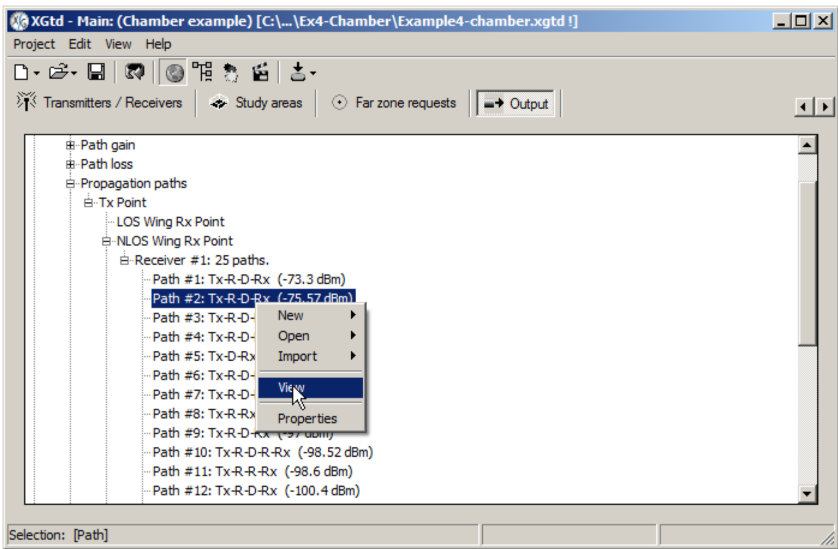


Figure 12.13: Selecting a single ray path to a receiver point

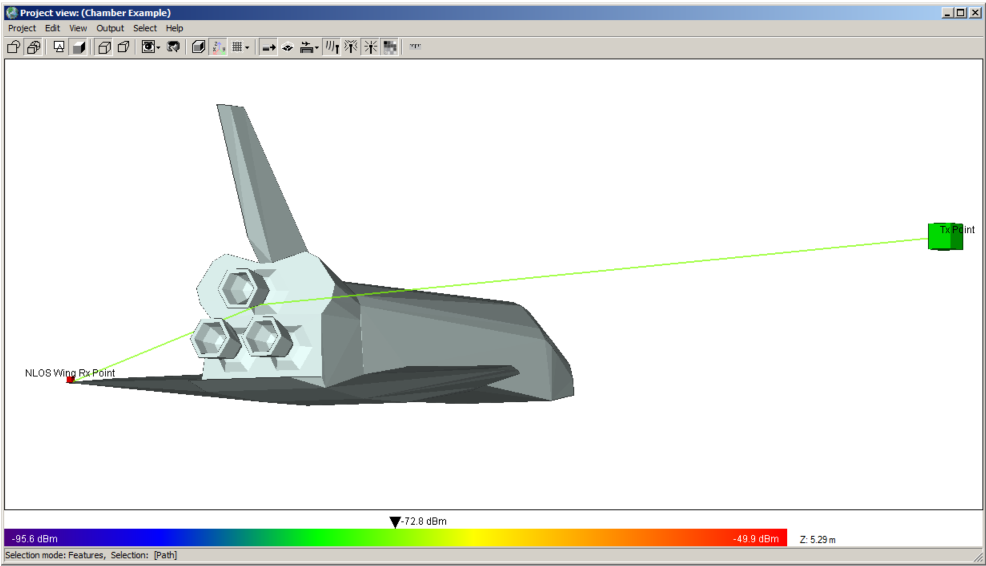


Figure 12.14: Display of single ray path to receiver point in project view

## Viewing Antenna Gain Patterns

Once a calculation is run for a project with a full 3D far zone gain request, the associated output file will appear under the OUTPUT tab of the MAIN WINDOW, as shown in Figure 12.15. The antenna gain pattern can be displayed in the PROJECT VIEW like other forms of output, but since it is not associated to an individual Tx/Rx set, it can be moved within the view.

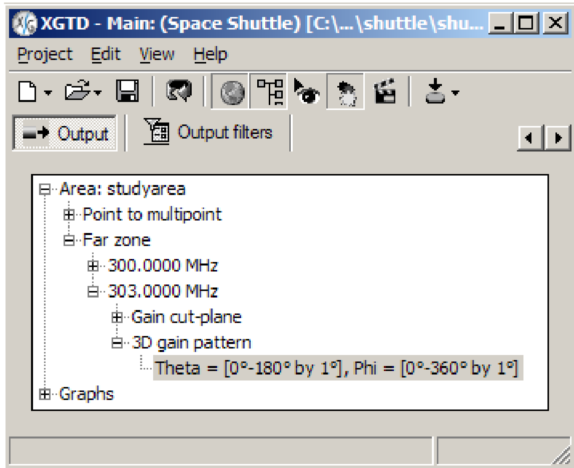


Figure 12.15: A 3D gain pattern as it appears in the Output Tree

The manner in which this type of output is displayed in the PROJECT VIEW is controlled through the **3D Far zone pattern** section of the PROJECT OUTPUT PROPERTIES, as shown in Figure 12.16. The properties window can be accessed by right-clicking on the entry in the Output Tree, or by selecting *Project→Output properties* in the MAIN WINDOW.

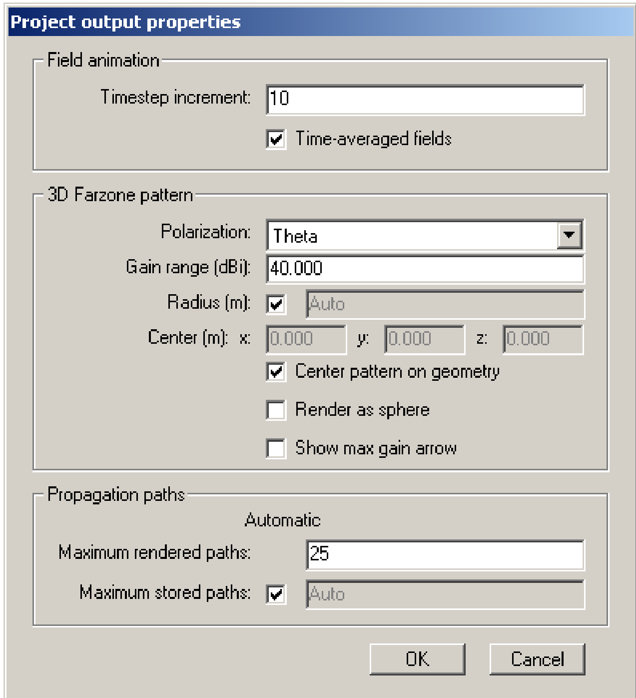


Figure 12.16: The Project Output Properties Window

The display options for 3D antenna gain patterns are listed below:

- *Polarization* - Controls which polarization component is displayed.
- *Gain range (dB)* - Sets the range of the pattern below the maximum gain which is displayed. Any point on the pattern with a gain (in dBi) below $GMax - GainRange$ will be drawn at a radius of 0 from the center.
- *Radius* - Defines the maximum distance of the displayed pattern from its center.
- *Global position* - Defines the position of the center of the displayed pattern surface within the project.
- *Center pattern on geometry* - Places the center of the pattern surface at the center of the geometrical FEATURES in the project.
- *Render as sphere* - Displays the pattern as a colored sphere, as seen in Figure 12.18.
- *Render gain arrow* - Controls the display of an arrow pointing in the direction of the maximum total gain.

Figure 12.17 shows the antenna radiation pattern rendered in the PROJECT VIEW using both shape and color to show variation in direction. This pattern was calculated for a linear phased array of four monopoles mounted on a flat metal plate. The calculated pattern is actually in the far zone, but is sized here to fit within the perimeter of the metal plate. The part of the pattern below the plate is not visible in this figure.

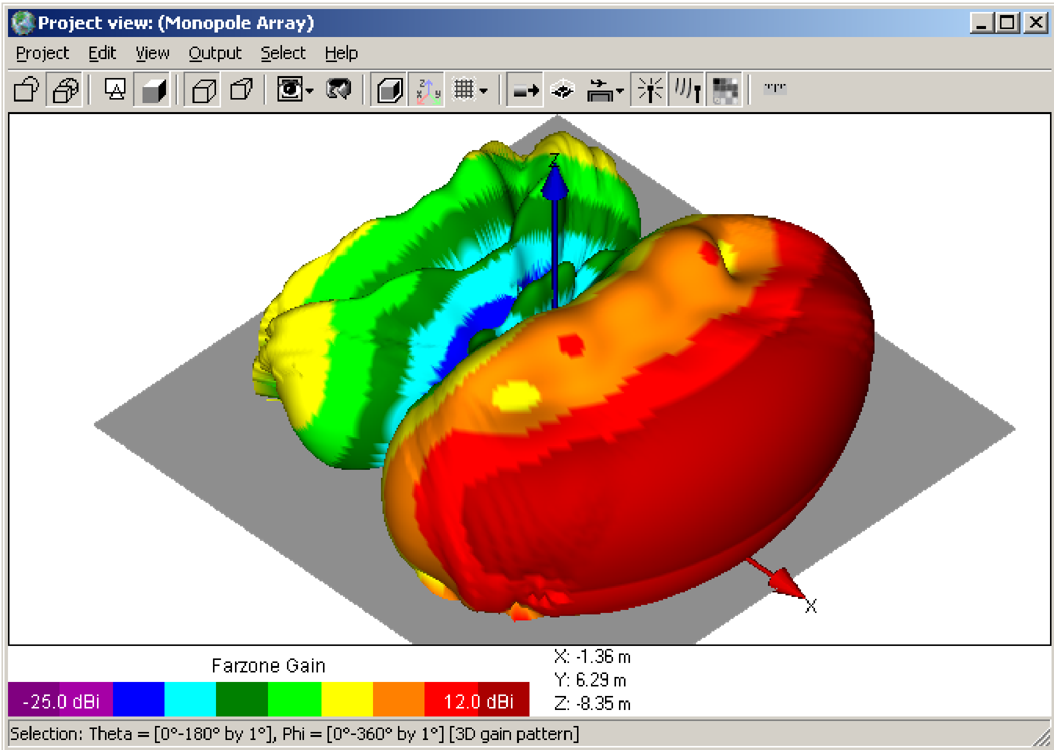


Figure 12.17: antenna radiation pattern for a linear phased array of four monopoles mounted on a flat metal plate

Figure 12.18 shows an alternative way of viewing the antenna pattern. In this representation, the color is just applied to the surface of sphere and there is no shaping of the surface as in the previous figure. The pattern on the lower half of the sphere is not visible in this figure.

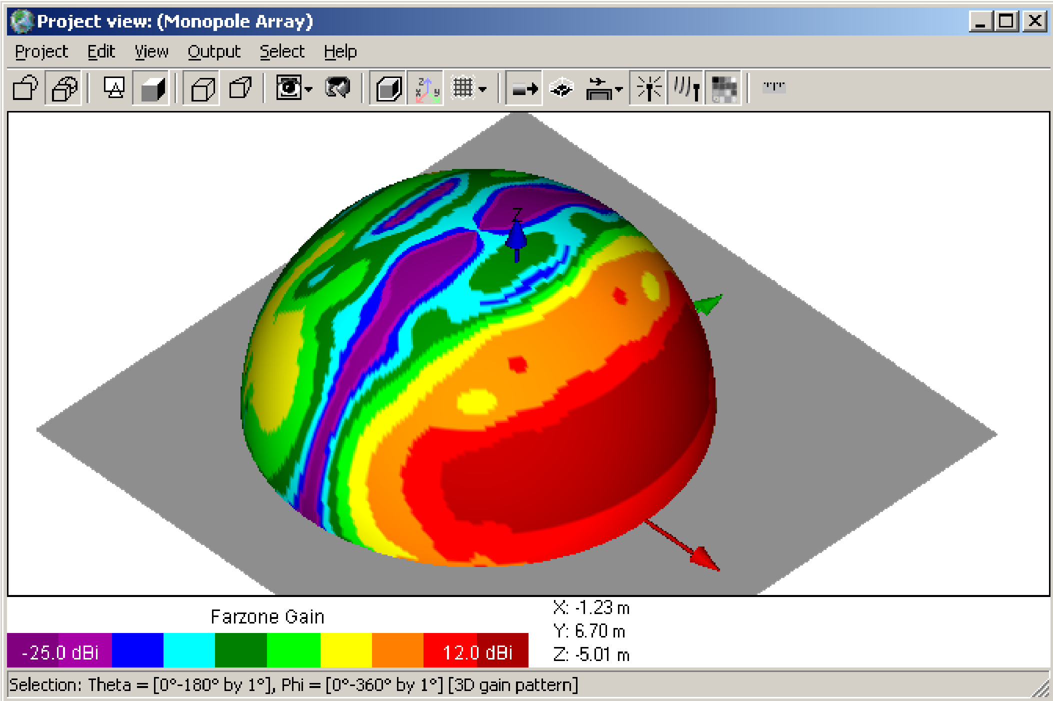


Figure 12.18: Antenna radiation pattern with no surface shaping

## 12.2 Line Plotting

XGtd has two types of 2D graphs: Rectangular and Polar. Users can plot input data, such as ANTENNA patterns and MATERIAL electrical parameters, to verify model assumptions and check validity.

In the following section, references to "graphs" mean the entire 2D graph, including the individual traces, the grid, the axes, and any titles and labels. The individual traces representing different data sets are referred to as "plots".

Most of the types of OUTPUT data can be plotted on a 2D graph. For certain types of data it may make more sense to use one type of graph or another. XGtd gives the user great control over how the data is displayed.

✓ Graphs are stored as part of the project and are available in the OUTPUT tab or PROJECT HIERARCHY output branch. Once a graph is created, all of the modifications and formatting to the graph are stored. If the data in the graph is re-calculated, the graph will update the associated plots (traces) automatically.

### Input Data

The primary types of input data for 2D plotting are ANTENNA patterns and MATERIAL electrical parameters.

### Input and Output Antenna Radiation Patterns

To verify the antenna pattern which will be used in the ray tracing calculation for each TRANSMITTER, RECEIVER, or Tx/Rx set, the user may plot the antenna pattern for any antenna in the project. The full 3D far zone patterns work in the same way as the antennas when it comes to plotting individual cut-planes from it.

- This procedure of plotting antenna patterns is described in detail in Chapter 7.

### Material Parameters

The *Objects* or *Chamber* walls which form a XGtd project each have an associated MATERIAL definition. These materials have reflection and transmission coefficients which are used in the ray tracing and dictate how the ray will interact with a given FEATURES' surface. The reflection and transmission coefficients can be functions of frequency as well as angle of incidence.

- Chapter 5 describes plotting reflection and transmission coefficients of materials.

## Output Data

In general, graphing begins the same way for any data type. The OUTPUT tab in the MAIN WINDOW contains the data available for plotting. Expanding the study area which contains the data of interest will show the list of available point-to-multipoint, point-to-point, or filtered data sets. By expanding the data set of interest, the available output will be listed. Choosing *Plot* from the context menu will open the CHOOSE PLOT Window, as seen in Figure 12.19. Here the user will be able to choose the ordinate and abscissa of the graph.

✓ If *Plot* is not an available option after right-clicking on a dataset, this indicates that the particular dataset is not applicable to 2D plotting.

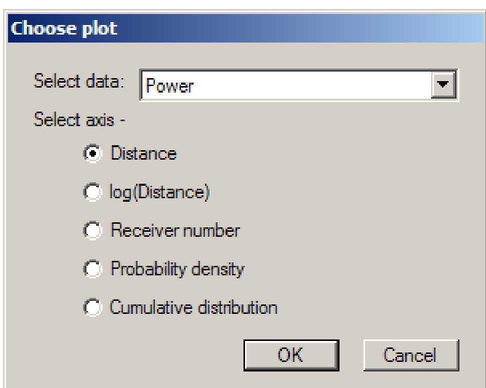


Figure 12.19: Determining the axis of the plot for received power. In this case the distance along the receiver Route is chosen.

From the example project (Section 12.1), the plot of the received power along the receiver *Route* is shown in Figure 12.20.

✓ For *Routes*, *Trajectory*, *Arcs*, *Vertical Arcs*, *Points*, and “Points-On-Face” Receiver sets, the distance given in the output file is the distance along the receiver set measured from the first point in the receiver set to the point of the sample. For *XY Grids*, *Cylinders*, *Spheres*, *Vertical Surfaces*, and *Polygon* sets, the distance associated with each receiver is the distance from the transmitter.

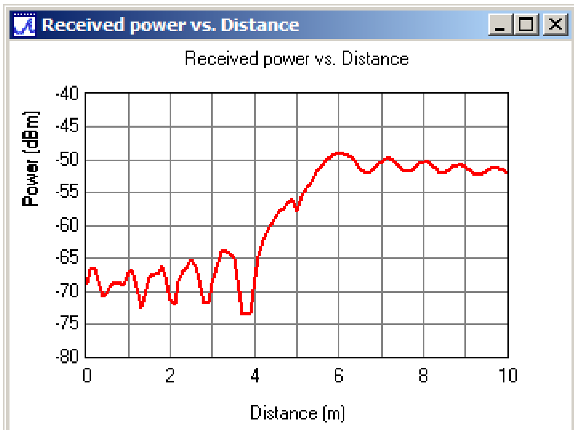


Figure 12.20: A plot of received power as a function of distance along the receiver route

## Graph Properties

After a graph is created, there are several options for controlling its display. These options are accessible under the OUTPUT tab in the context menu of a graph, as shown in Figure 12.21. It is also possible to edit the graph through the PROPERTIES Window, shown in Figure 12.22.

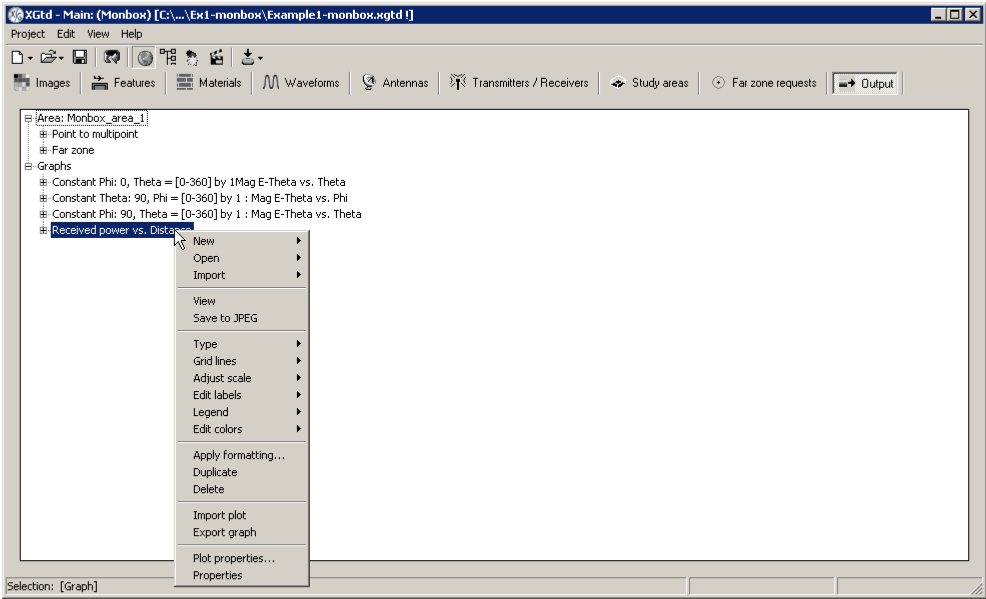


Figure 12.21: Selecting Graph Properties

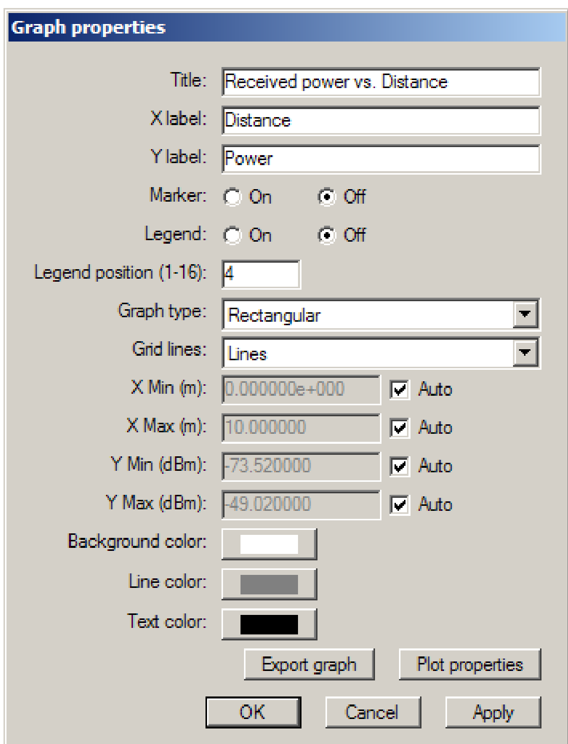


Figure 12.22: The Graph Properties Window

The items available in the context menu are:

- *New, Open and Import* - Project control items as described in Chapter 2.
- *View* - Toggles the view of the graph.
- *Save to JPEG* - Saves a graph to a `*.jpeg` image file. To save `*.jpeg` files for multiple graphs, the same procedure is followed and the `*.jpeg` images are numbered sequentially based on the filename entered, e.g. `Image1.jpg`, `Image2.jpg`, etc.
- *Type* - Determines the type of graph (Rectangular or Polar).
- *Grid Lines* - Determines whether to show lines, ticks, or nothing for the graph gridlines.
- *Adjust Scale* - Toggles auto scaling for each axis and determines manual scaling.
- *Edit Labels* - Defines the axis labels and graph title.
- *Legend* - Toggles the viewing of the legend and sets its position. The position is entered as an integer from 1-16. Position 1 is the upper left corner, position 4 the upper right, and the pattern continues to position 16 in the lower right corner.
- *Marker* (available in GRAPH PROPERTIES Window) - Toggles the display of the marker. The marker can be controlled to follow a trace or choose the nearest trace, or follow mouse clicks. The marker readout is in the lower left of the graph when this option is turned on.
- *Edit Colors* - Defines the background, grid, and label colors.
- *Apply formatting* - Allows the user to copy properties from another graph to apply to the selected graph.
- *Duplicate* - Makes a copy of the graph and adds it to the tree.
- *Delete* - Deletes the open graph.
- *Import Plot* - Launches a file browser to import a `*.plt` file
- *Export Graph* - Launches a SAVE AS dialog box for saving the entire graph (all traces, edits and formats changes) to a user-specified name `*.grf`. Saving a graph requires saving all of the plots on the graph. Each plot will require a unique `*.plt` file.
- *Plot Properties* - Starts a dialog for choosing the line type and color for each plot.
- *Properties* - Summarizes all of the controls described above in one window (Figure 12.22). It allows the user to APPLY the effects of their changes for immediate review.

## 12.3 Plotting Far Zone Data

### Constant Theta or Phi Cut-Planes

Requested Far Zone Antenna *Gain* and *RCS* results are available in the MAIN WINDOW or the PROJECT HIERARCHY after the completion of the calculation. To view Far Zone results, click on the OUTPUT tab in the Main Window. Far Zone results are grouped separately from point-to-multipoint results under the study area entry. Under Far Zone data, *Gain* and *RCS* results are listed by type. To plot a Far Zone result, right-click on the listing of the Far Zone pattern of interest and select *Plot*, as seen in Figure 12.23.

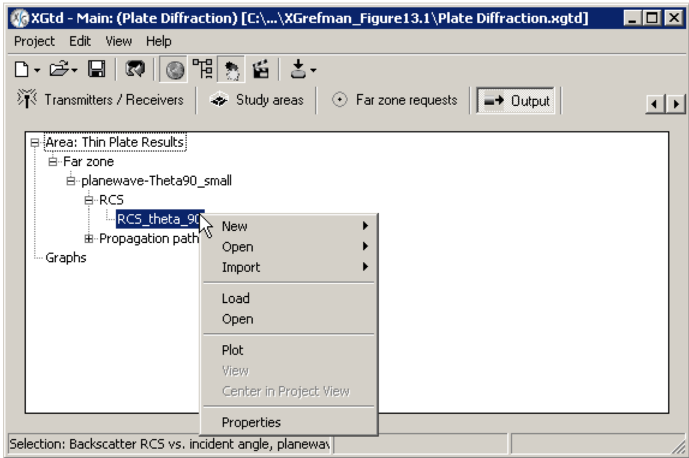


Figure 12.23: The context menu for the Far Zone Gain output

Select the type of data to be plotted from the *Select data* drop-down menu. For each Far Zone request, the magnitude and phase of the electric field components are available. Far Zone *Gain* data is always plotted versus angle, as shown in Figure 12.24, while *RCS* results may vary with frequency or scattering angle depending on the *RCS* request settings.

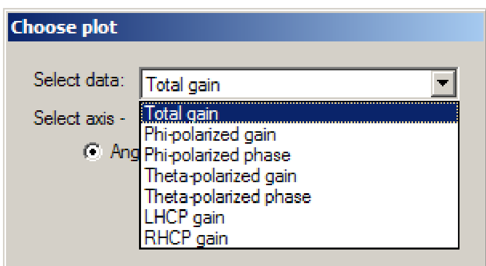


Figure 12.24: Possible data options for a Far Zone Antenna Gain plot

After selecting the data to plot and clicking OK, the plot of the Far Zone pattern can be added to a new or existing graph. Multiple plots of Far Zone patterns can be overlaid in the same graph for easy comparison using the *To an existing graph* option.

The Far Zone pattern of an transmitter 5 meters away from a thin plate is given in Figure 12.25. The plot represents the theta-polarized gain in the $XY$ plane. The effects of the plate on the Far Zone gain of the transmitter are clearly visible in the graph.

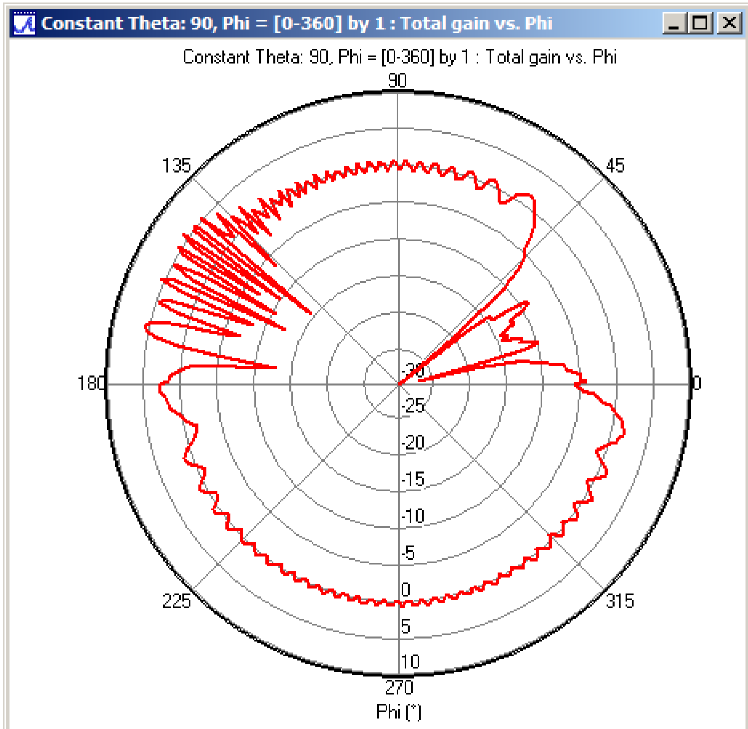


Figure 12.25: The Far Zone cut-plane gain pattern for an isotropic transmitter

### Full 3D Patterns

Full 3D patterns can have plots of cut-planes extracted in the same manner as antenna patterns.

- For more information on this topic, see Section 7.6.2.

## 12.4 Animated Field and Ray Path Movies

In order to better visualize propagation in the time domain, the XGtd MOVIE PLAYER is capable of displaying and saving movies which depict changing electric fields versus time, magnetic fields versus time, and the movement of propagation paths within the simulation space. The Movie Player Window contains playback controls, viewing options, and an OUTPUT selection interface.

- Prior to using the MOVIE PLAYER, predictions must be performed with the REQUESTED OUTPUT CATEGORIES type “Animated fields” activated.

- See Chapter 11 for more on adjusting the settings of the MOVIE PLAYER under OUTPUT PROPERTIES.

The MOVIE PLAYER, as seen in Figure 12.26, is accessible through the MAIN WINDOW by selecting *View-Movie player* or by clicking on the icon in the toolbar. A single E-field, H-field, or propagation path file may also be viewed quickly in the OUTPUT tab in the Main Window or in the PROJECT HIERARCHY.

To play a particular output file, select *Play* from the file's context menu. The Movie Player will open and the selected output will immediately begin playback.

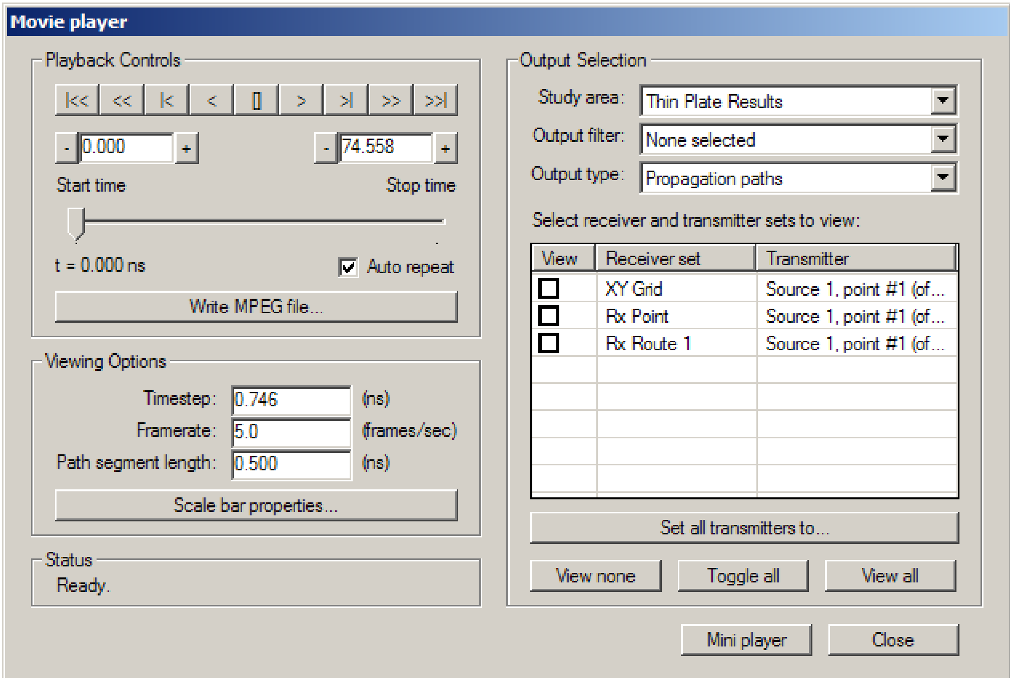


Figure 12.26: The Movie Player control panel

- **Playback Controls**

  The functionality of the Playback Controls resembles a video cassette recorder. The buttons are, from left to right:

  |<< Jump to the beginning

  << Rewind at 2x speed

  |< Move backward one frame

  < Play backward

  [] Stop playback

  > Play forward

  >| Move forward one frame

  >> Fast-forward at 2x speed

  >>| Jump to the end

  The *Start time* and *Stop time* limit the segment of the movie to play. The default values are determined automatically from the selected output files. The *slider* shows the point in the movie which is currently displayed, and moves when the control buttons are pressed, while the movie plays or when dragged by the mouse. Check the *Auto repeat* box to play the movie in a loop. The sequence is rewound to the *Start time* and played again when the *Stop time* is reached.

Click the WRITE MPEG FILE button to write the movie to an `*.MPEG` file. In the SAVE AS dialog box which appears, enter the desired directory and filename in which to save the movie. The movie will then play once, during which it is captured to the disk. You can halt the movie export by clicking on STOP MOVIE CAPTURE; the portion of the movie already captured will be saved. While the movie is being saved, user interaction with the PROJECT VIEW is disabled.

- **Viewing Options**

  The *Timestep* is determined automatically from the selected output files. Reducing this value will not allow E-fields to be viewed with greater resolution in the time domain, as the calculated fields were only saved at the default timestep. Increasing the timestep will cause the movie to skip over some of the saved timesteps, increasing the apparent speed of the playback. When viewing propagation path segments, however, the timestep can be adjusted freely, since path data was calculated in the frequency domain, and may be viewed at any given value of time.

  The *Framerate* controls how rapidly the frames of the movie are displayed. The rate of display is limited by the complexity of the scene being displayed and the speed of your computer hardware. Therefore, you may observe movie playback slower than the desired framerate, or observe the speed of playback changing during the movie as the complexity of the scene changes. This behavior is expected.

  While viewing propagation paths, the physical length of the path segments, in terms of speed of light propagation time, may be controlled by *Path segment length*. This field is disabled during playback of E-field and H-field output.

  The scale bar in the PROJECT VIEW will appear during playback to provide reference for the colors displayed. The scale bar settings may be changed by clicking the SCALE BAR PROPERTIES button before or during playback. The scale bar shown corresponds to the *Output type* selected in the MOVIE PLAYER.

- **Status**

  The status of the MOVIE PLAYER is displayed here during playback and capture of movies.

- **Output Selection**

  The user must select the desired output here before the movie can play. To select output, follow these steps:

  1. Select from the *Study areas* and *Output filters* in the project for which to view output. To view unfiltered output, select “None selected”. The *Output filter* selection is disabled when the chosen *Study area* is not based on a UTD propagation model.
  2. Choose what *Output type* will be displayed:
     (a) E-field or H-field $X$-, $Y$-, or $Z$-axis directed fields
     (b) E-field or H-field magnitude
     (c) Propagation path segments

3. Finally, select one or more of the project's receiver sets to view by checking the box next to the receiver set name. Each RECEIVER set can render output for a TRANSMITTER set and point.

To assign a different transmitter set and point to a receiver set, choose *Select transmitter* from the receiver set context menu. The SET ALL TRANSMITTERS TO button may be used to quickly assign a single transmitter set and point to all the receiver sets in the table. The VIEW NONE, TOGGLE ALL, and VIEW ALL buttons below the table may be used to quickly change which receiver sets to view.

- MINI PLAYER

  This button switches the MOVIE PLAYER Window to a smaller format which makes more of the screen visible for viewing output. To return to the original window layout, click the button again when it says NORMAL PLAYER.

- CLOSE

  This button closes the MOVIE PLAYER and stops the movie playback, if in progress. The *Start time*, *Stop time*, *Timestep*, *Framerate*, *Path segment length*, and *Auto repeat* settings are retained the next time the window is opened. Output selection settings are not retained, since study areas, receiver sets, and transmitter sets may have changed since last opening the window.

# Chapter 13

# Output Filters

*In this chapter, you will learn...*

→ how to set up and use output filters

→ how to filter interactions that occur with a feature

OUTPUT FILTERS allow the user to isolate ray paths with specific interactions when using the FULL 3D model. A filter defines the subset of generated output paths. This allows a user to identify which objects are the major contributors to the power received by a set of RECEIVERS.

## 13.1 Creating an Output Filter

From the MAIN WINDOW, output filters are created by selecting *Project→New→Output filter*. The OUTPUT FILTER PROPERTIES Window will open, prompting the user for a short description of the filter. After exiting the properties window, a new filter entry will appear in the PROJECT GEOMETRY INTERACTION FILTERS window accessible through the OUTPUT FILTERS button in the FULL 3D STUDY AREA PROPERTIES window. Associated with a filter are a number of settings which can be accessed through the context menu, as seen in Figure 13.1.

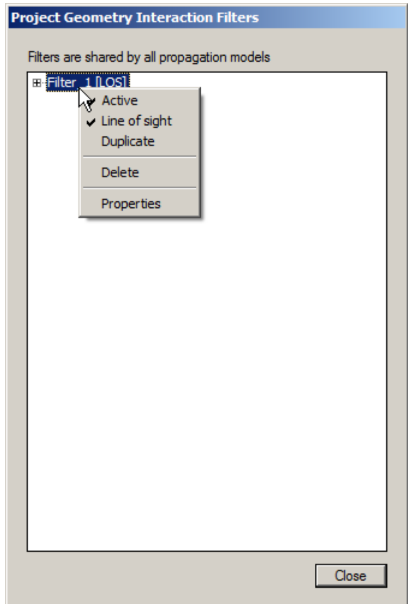


Figure 13.1: The Project Geometry Interaction Filters window with the context menu shown for a filter

The *Line of sight* option can be toggled from this menu. When turned off, output associated with the filter will not contain any line-of-sight (LOS) rays, which are those that travel from the TRANSMITTER to the RECEIVER without encountering any obstructions. This setting is not tied to any particular FEATURE since LOS rays do not interact with anything.

*Active* is also available as a menu option. When turned off, the filter is essentially non-existent for the next calculation run. No new output is generated for inactive filters.

## 13.2 Output Filter Properties

The *Properties* option opens the OUTPUT FILTER PROPERTIES Window, seen in Figure 13.2. This window allows the user to enter a specific description for the filter entry. The description must be unique and is used to reference the filter in the Output Tree.

In each of the study area output folders, subfolders are created corresponding to each filter. For this reason, filter names must be valid directory names and cannot contain special characters.

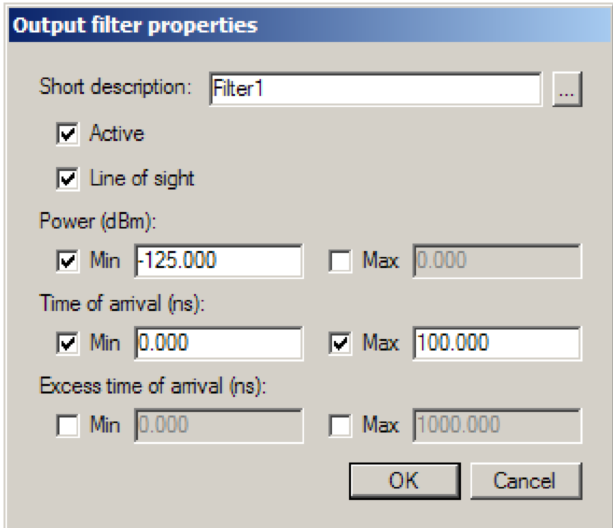


Figure 13.2: Properties of an output filter

From the OUTPUT FILTER PROPERTIES Window, the user can enter filter settings for *Power*, *Time of arrival*, and *Excess time of arrival*. The *Power* and *Time of arrival* settings are applied to the ray paths and do not have any association with geometry in the project. In reference to Figure 13.2, rays whose power is less than -125 dBm and which did not arrive between 0 ns and 100 ns will be excluded from the filtered results. The properties window also contains check boxes to change the *Active* status of the output filter and to exclude *Line of sight* rays.

## 13.3 Filter Settings

In order to filter interactions that occur with a FEATURE, it is necessary to accurately set the filter properties for each one. Expanding the filter entry will reveal each feature in the project as sub-items. Right-click on a feature and choose the *Properties* menu option to bring up the FILTER ENTRY PROPERTIES Window, as seen in Figure 13.3.

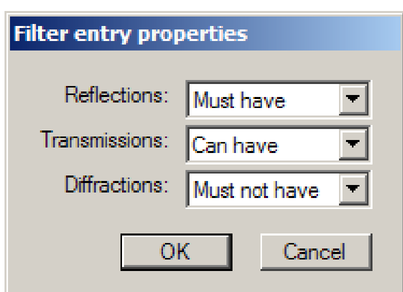


Figure 13.3: Properties of an entry in an output filter

From this window, the user can specify the types of possible interactions with the FEATURE: *Reflections*, *Transmissions*, and *Diffractions*. Each feature contains filtering options: “Must have”, “Can have”, and “Must not have”. The filter behavior is defined through these options.

Filters can also contain settings with the structure group level in the hierarchy. In order to set the filter settings associated with a structure group:

1. Select the structure group.
2. From the context menu, choose the specific filter from within the *Filters* submenu. A tree item below the feature containing the selected structure group will appear.

When a filter setting for a structure group conflicts with the setting for the FEATURE to which it belongs, the setting for the feature will be changed to “Can have”. For example, if the reflection setting for a particular structure group within a feature is set to “Must have”, but the setting for reflections from the feature is set to “Must not have”, the setting for the feature will be changed to “Can have” so that the settings do not conflict.

When filters are defined, the content of the Output Tree in the PROJECT HIERARCHY is slightly different. Beneath the point-to-multipoint tree item appears the filtered and unfiltered output sets. The Unfiltered tree contains all OUTPUT as it would be had there been no filters defined.

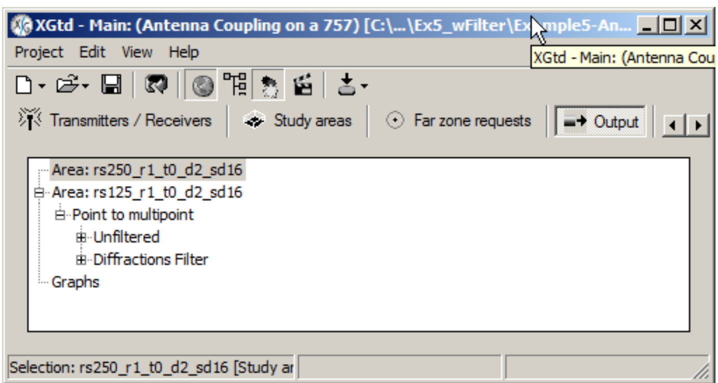


Figure 13.4: Display of unfiltered and filtered output in a study area

Along with the “Unfiltered” tree item, there are corresponding filtered output branches, each identifiable by the short descriptions associated with the filters. Output in each of these branches is a subset of the unfiltered output. The exact rules defined by the filter have been applied, and the resulting output is organized and made available here. Output from the unfiltered and filtered branches can be viewed and plotted together or separately.

Once an initial new RUN is completed, the *Added requested output* run option can be used to generate output for new filters or to make modifications to existing filters.

# Chapter 14

# Databases

*In this chapter, you will learn...*

→ how to set up a database

→ how to filter the components of a database

In order to allow the user to define and reuse components in many projects, XGtd contains ANTENNA, MATERIAL, and WAVEFORM databases. These databases are accessible to all projects in XGtd and save the user the trouble of entering the same information repeatedly.

## 14.1 Using Databases

Databases appear as a table in the ANTENNAS, MATERIALS, and WAVEFORMS tabs. If the database table is hidden in any tab, click on the long rectangular button at the bottom of the window to show the database. Each tab's database can be shown or hidden independently of the others.

The installation of XGtd places default objects in some of the databases. In order to add objects to the database, select an ANTENNA, MATERIAL, or WAVEFORM and right-click. Choose *Copy to personal database* to add a copy of the object to the object's database. If the object references an external file (MATERIAL reflection and transmission coefficients, imported ANTENNA pattern, or *User-Defined* waveform), it will be copied to the database automatically.

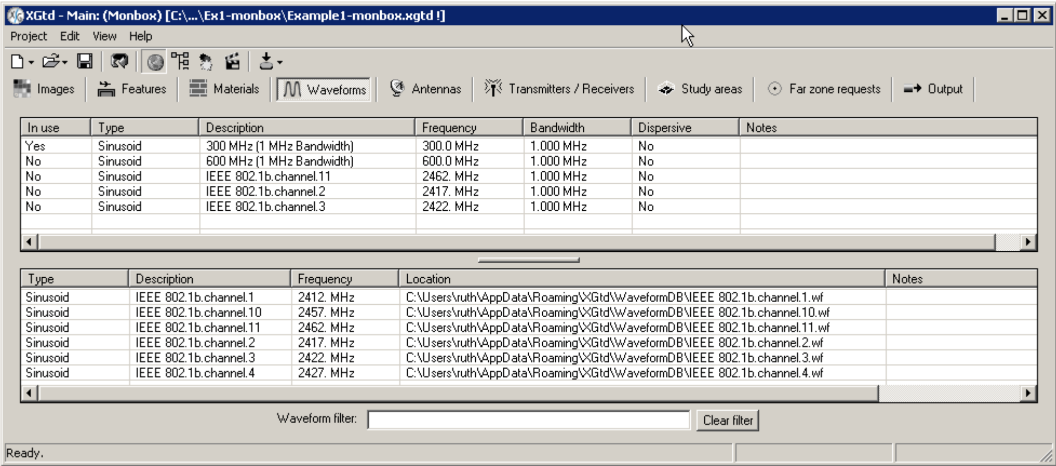


Figure 14.1: The waveforms database and context menu

The wording of right-click context menu, seen in Figure 14.1, may differ depending on the database, but each has similar function:

- *Add to project* - Places a copy of the selected database object in the current project. The MATERIAL database option *Add to feature* prompts the user to select a FEATURE within the project to which the selected material will be added. External files are copied to the project directory when this command is selected.
- *Remove from database* - Deletes the selected object from the database and deletes the file associated with the object. The user will be prompted before deleting any external files which the object references.
- *Antenna/Material/Waveform properties* - Displays the properties window for the selected object. Any object within a database is considered read-only within XGtd, and can not be modified until it is added to a project.

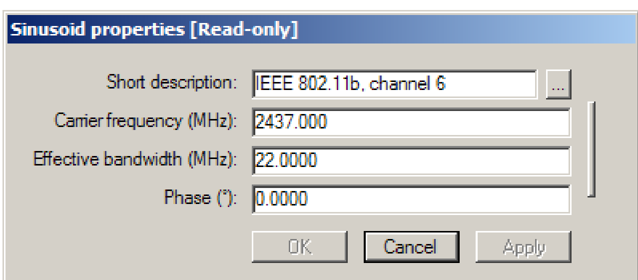


Figure 14.2: A waveform properties window for a read-only database object cannot be modified.

- *Database properties* - Displays the properties window for the database in which the object is contained. Each database contains a separate list of directories which are scanned when XGtd is loaded. Any object files present in these directories will be accessible through XGtd. In addition, the DATABASE PROPERTIES Window includes an *Active* option for each directory so that the database can be easily reduced or expanded depending on the work being performed. The default location defines the location where new entries are stored.

- *Add* - Allows the selection and addition of a new directory to the database.
- *Edit* - Allows the selected directory to be modified without removing and re-adding a new directory to the database.
- *Remove* - Eliminates the selected directory as a location to search for database objects. The directory is not deleted, and the contents of the directory are not modified.
- *Set as default* - Marks the selected directory as the path in which objects added to the database will be stored. Each database maintains its own default directory.

A database must have at least one path defined, and a default directory set. The Database Properties Window, seen in Figure 14.3, will not close if all directories have been removed or if a default directory has not been set.

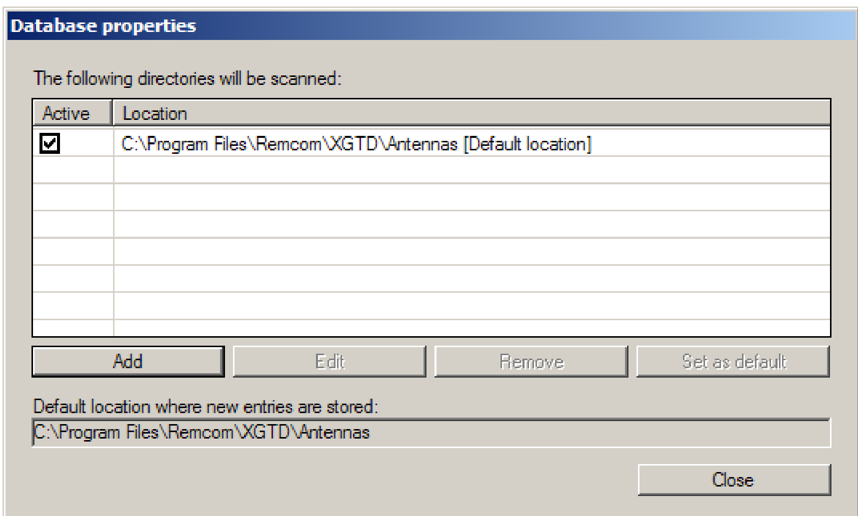


Figure 14.3: The Database Properties Window displaying the directories that will be scanned

## 14.2 Filtering Databases

In addition to deactivating directories in the databases, it is also possible to reduce the number of items which appear in the database by using the *Filter* field in the Antennas, Materials, and Waveforms tabs in the Main Window. For example, under the Antenna tab, entering text in the field labeled *Antenna filter* will cause the project's antenna table and the antenna database table to show only those items which match one or more terms in the filter text.

✓ The filtering is not case sensitive. Exact expressions can be entered in quotation marks, and exclusion terms preceded by a minus sign (-) to further refine the filtering. For example, the filter text "horn" will show only horn antennas, while the addition of the term "-1920MHz" will eliminate those horns which include 1920MHz in their description. Filtering MATERIALS and WAVEFORMS is performed similarly.

# Chapter 15

# Importing CAD Models

*In this chapter, you will learn...*

→ how to import models from various external file formats

XGtd has the ability to import files in the following formats:

- ACIS solid model files in Standard ACIS Text (`*.SAT`) format.
- AutoCAD's Data eXchange (`*.DXF`) format.

A simplification procedure is also available for imported objects.

▶ See Section 3.2.4 for more on simplifying imported objects.

## 15.1 Importing Objects From Solid Models

The Solid Model CAD Import Module allows users to import `*.SAT` files created in commonly used CAD packages into XGtd. To import a CAD model into XGtd, select *Project→Import→Solid Model*. An OPEN Window will appear where the type of solid model and the solid model file itself can be specified. Once it is selected, the file is read and the results displayed in the SOLID IMPORT Window, as seen in Figure 15.1.

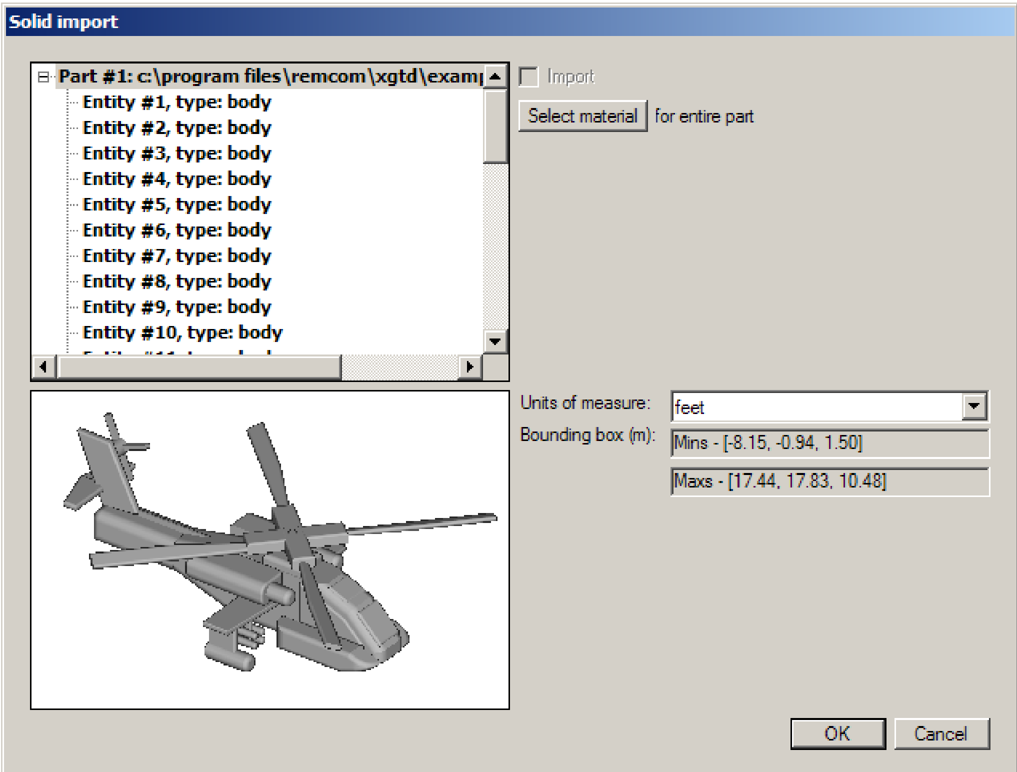


Figure 15.1: The Solid Import Window

The display box in the upper left of this window lists the entities that make up the solid model in a hierarchical structure. Users have the option of selecting which entities are imported in XGtd. Initially, all entities are flagged to be imported, but any unwanted entity can be unselected by highlighting it in the list and removing the check mark from the box in front of *Import*.

Likewise, the materials of the individual entities can be modified by highlighting the entity and clicking on the SELECT MATERIAL button. The entire model can be set to a single material by highlighting the part and choosing a material.

The model pre-viewer in the lower left of the SOLID IMPORT Window displays the contents of the solid model. The image can be rotated, translated, or zoomed by using the same controls that manipulate XGtd's PROJECT VIEW.

The *Units of measure* option determines how the values in the file are interpreted, and should be set at the time of import to match the units used in creating the model. XGtd's default units are meters, so proper conversion of the units is needed to ensure models import with the correct dimensions. For this example, the solid model dimensions are given in feet; selecting the wrong unit would incorrectly convert the data in the file to meters, resulting in a FEATURE that is too large or too small.

After the import options are set, the solid model can be imported into XGtd by clicking on OK. The model will appear in the PROJECT VIEW, as seen in Figure 15.2.

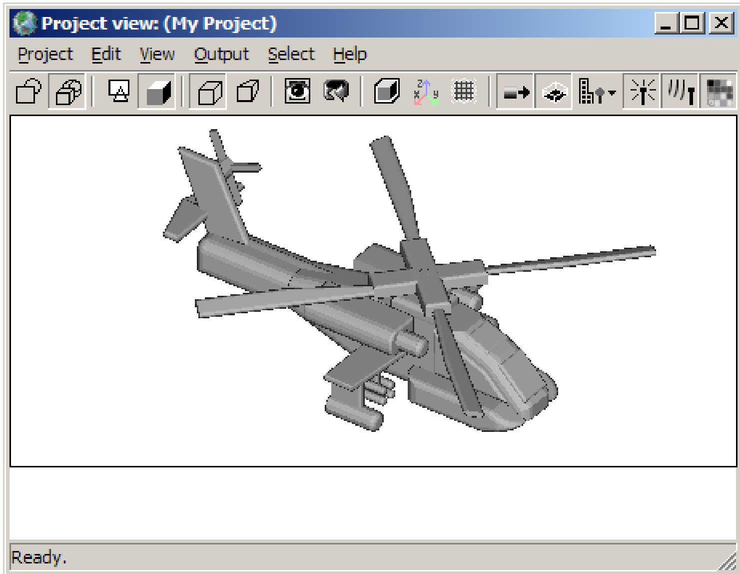


Figure 15.2: A CAD model import

## 15.2 Importing Objects From DXF Files

XGtd is able to read `*.DXF` files and convert the data to the `*.object` file format. Once the `*.DXF` file is read, it is easy to assign MATERIALS to the object. Unfortunately, not all of these are compatible with XGtd. The XGtd DXF converter can only convert the following `DXF` objects:

- Polylines
- Polyface meshes
- 3D faces

Additionally, for a proper data file to be generated, objects should be created using the AutoCAD “grip points” to specify points used for face edges. This will force the spatial positions of the face points to be identical. This is especially important when the point is an endpoint of an edge that is common to two faces. If the face edges are not exactly coincident, the `*.DXF` converter cannot identify the faces as touching.

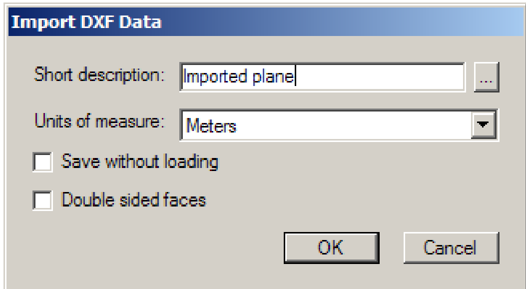


Figure 15.3: Importing the plane from a .DXF file

To import a `*.DXF` file into a project, select *Project→Import→DXF*. The IMPORT OBJECT Window will appear. Choose *Object* and click OK. Choose the `*.DXF` file to be imported and click on OPEN. The IMPORT DXF DATA Window will appear, as seen in Figure 15.3. A *Short description* can be entered for the imported objects. The *Units of measure* that the object are in can be specified. The object can also be saved without bringing it into the active project by checking the box next to *Save without loading*. By default, objects are imported with single-sided faces. If desired, the object can be composed of double-sided faces by checking the box next to *Double sided faces*.

# Chapter 16

# Chamber Management

*In this chapter, you will learn...*

→ how to place and define carts within an anechoic chamber

→ the purposes for creating an absorber layout plan

→ how to create an absorber layout plan and place it on the chamber floor

XGtd provides a set of tools to facilitate the creation and maintenance of a project involving the use of an *Anechoic Chamber*. These tools include the ability to:

- Place radar absorbing material (RAM) on the chamber floor.
- Indicate the placement of TRANSMITTER and RECEIVER carts.
- Create a `*.jpeg` file that can be printed for distribution to operations staff when configuring the chamber.
- Create a text file of information in a format that can be imported into a database or spreadsheet application.

## 16.1 Mounting Transmitter and Receiver Sets On Carts

Any TRANSMITTER or RECEIVER point set with a single point can be associated with a cart. This is done by selecting the point set and choosing *Show cart information* from its context menu, or selecting this option in its properties window. Once this is done, its cart information will appear in the *Project* legend, and a line with the angle and distance from the point to its reference can be activated through the *Cart properties* option in the set's context menu.

## 16.2 Cart Properties

The Cart Properties Window is shown in Figure 16.1.

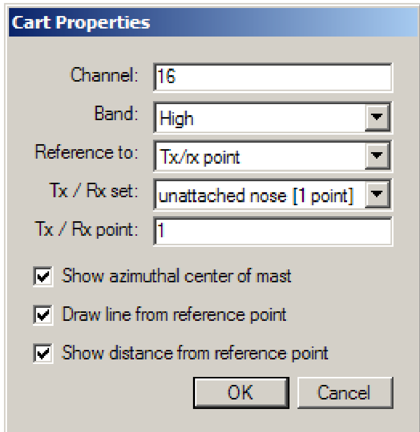


Figure 16.1: Properties of a point sets cart

The Cart properties include the following:

- *Channel* - Defines the channel that the cart mounted set operates on.
- *Band* - Indicates what type of band the set operates on. This also controls the color of the set, as defined in Plan View Controller Window.
    - See Section 16.4 for more on the Plan View Controller Window.
- *Reference to* - Indicates if the cart is referenced to the “Project Origin” or another “Tx/Rx point” in the project. If set to “Tx/Rx point” (the default), it is important to correctly select the *Tx/Rx set* and *Tx/Rx point* fields below the referenced set and point.
- *Show azimuthal center of mast* - Draws the angle between this cart and the referenced point next to the point set in the Project View.
- *Draw line from reference point* - Draws a line between this cart and the referenced point.
- *Show distance from reference point* - When activated, shows the distance between the cart and the reference point next to the line that is drawn between them.

## 16.3 Placing Absorber Within A Chamber

In order to place a region of electromagnetic absorbing material on the floor of the chamber, select the floor face and choose *Add absorber* from its context menu. This will bring up the Absorber Layout Editor. The grid in the editor can be used to create regions of the absorber by setting the grid spacing to the size of smallest block of absorber that will be placed within the chamber. Figure 16.2 shows a finished absorber layout on a chamber floor.

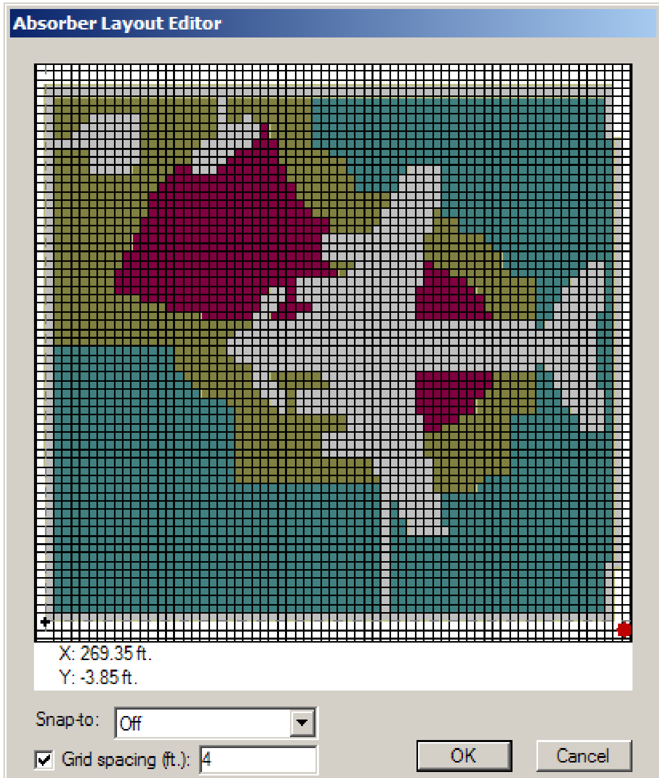


Figure 16.2: The absorber layout editor is used to create floor sections covered by different types of RAM.

The user must adhere to the following guidelines when creating absorbers:

1. The floor face is set to layer 0, while all absorber layers on top of the floor should have a layer number between 1 and 15. This is set in the FACE PROPERTIES Window, shown in Figure 16.4.
2. The layer number of any face should be at least one more than the face below it.
3. Coplanar faces must not cover more than one face, and may need to be broken up to meet this requirement. Figure 16.3 shows an example of overlapping faces (A), and the corrected face split into three faces (B).

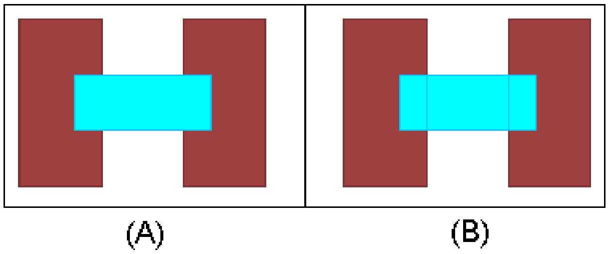


Figure 16.3: Example of Bad Faces (A) and Good Faces (B)

To add an absorber face:

1. From the context menu, select *New Face*.
2. Define the outline of the absorber region by clicking on vertex locations.
   - See Chapter 3 for information about correctly forming faces and geometry.
3. Right-click to close the region.
4. Enter a *Face layer* number greater than the chamber floor and a *Short description*.
5. Click on the SELECT MATERIAL button to select the RAM that the absorber is composed of.

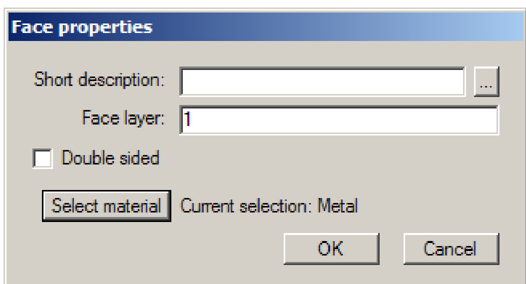


Figure 16.4: Setting the layer of an absorber face

## 16.4 Creating Absorber Layout Plans

Once the RAM layout and all transmitter and receiver cart-mounted point sets have been created and placed within the project, the results can be saved to a `*.jpeg` file for use in chamber management. This is done in the PLAN VIEW CONTROLLER Window, which is used to change the appearance of the PROJECT VIEW and legend for the `*.jpeg` export. This window is accessible through *Project→ Generate plan view* or by selecting *Generate plan view* directly from the context menu of the Project legend. The PLAN VIEW CONTROLLER is shown in Figure 16.5.

Once the PROJECT VIEW and PROJECT LEGEND Windows are configured, the SAVE VIEW button will save the current appearance of them to a single `*.jpeg` file. As changes are made in the PLAN VIEW CONTROLLER Window, the effects they have can be seen by clicking the PREVIEW button. A list of all items in the chamber in database- or spreadsheet-importable format can be created by clicking on the WRITE LIST button. Clicking CLOSE will exit the window without saving any changes since the last preview.

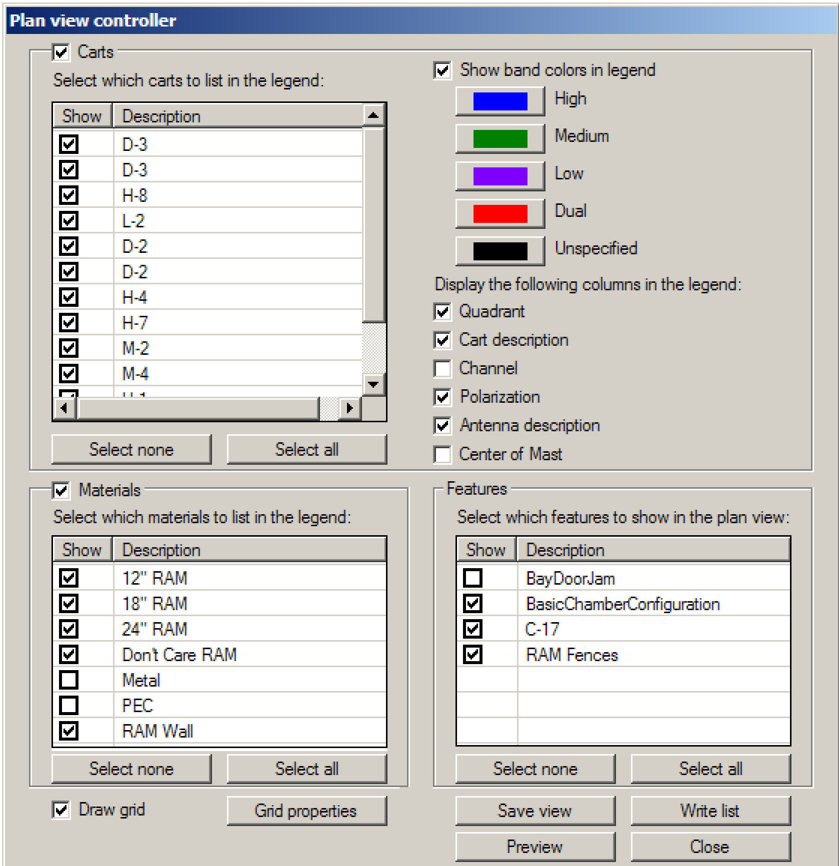


Figure 16.5: The Plan View Controller Window

If the detailed notes about an object are required, they can be exported to a text file by clicking SAVE from the NOTES Window, seen in Figure 16.6. This window appears when you click on the "..." button next to an item's *Short description*. The LOAD button will load notes from a text file.

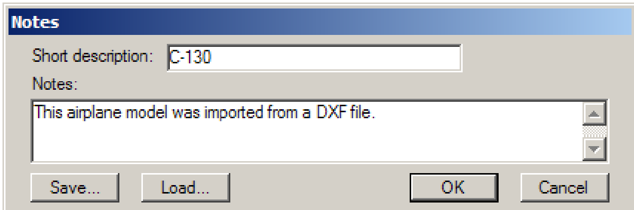


Figure 16.6: The Notes Window

## Antenna Carts

This section of the Antenna Carts Window controls which carts are displayed in the cart table of the Project Legend Window. All carts in the project will appear in the table and can be removed or added to the Project legend by checking their corresponding checkbox in the *Show* column.

The colors of cart-mounted Tx/Rx sets in the Project View are controlled by the appropriate color buttons. Unmounted Tx/Rx sets will appear with the default colors of green or red, respectively. The *Show band colors in legend* option controls whether a color table is drawn in the Project legend.

The cart table in the Project legend has columns of information as described below. The table can be hidden by deselecting the checkbox next to the heading title *Carts*.

- *Quadrant* - The quadrant of the project that the set lies in. Figure 16.7 gives a visual representation of how the quadrants are arranged.
- *Cart description* - The short description of the point set that is mounted on the cart.
- *Channel* - The channel that the point set uses.
- *Polarization* - The polarization of the set's antenna.
- *antenna description* - The short description of the set's antenna.
- *Center of Mast* - The angle between the point set and its point of reference using the positive $X$-axis as the reference.

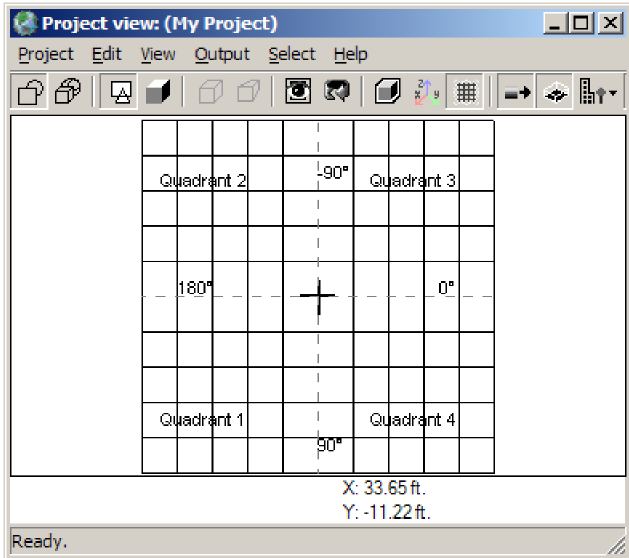


Figure 16.7: Display of the quadrants and their associated boundary angles

## Materials

This section is used to control which Materials appear in the *Material* table of the Project legend. All materials in the project will appear in the table and they can be removed or added to the Project Legend by checking their corresponding checkbox in the *Show* column of the table. The table can be hidden by deselecting the checkbox next to the heading title *Materials*. Materials that are in the project but currently unused will not appear in the table, with duplicates only appearing once.

## Features

This section is used to control which Features appear in the Project View. All features in the Project View will appear in the table and they can be removed or added to the Project legend by checking their corresponding checkbox in the *Show* column of the table.

## Grid settings

The grid can be configured specifically for how it should appear in the Project View when it is written to the `*.jpeg` file. It can be activated directly be checking the *Draw grid* checkbox, or all of its properties can be modified by clicking on the Grid settings button.

## 16.5 Chamber Example

The following figures show the different purposes for which an image of the chamber layout in the project view might be created. Figure 16.8 shows an image created for the purpose of placing the RAM within the chamber. For this, it is helpful to have the grid activated so the operations staff can easily count the number of absorber pieces along each edge of a region. The legend only shows the information relevant to the placement, which shows how each type of RAM is represented in color. The carts were included with this image so the workers could make allowance for their eventual inclusion in the chamber.

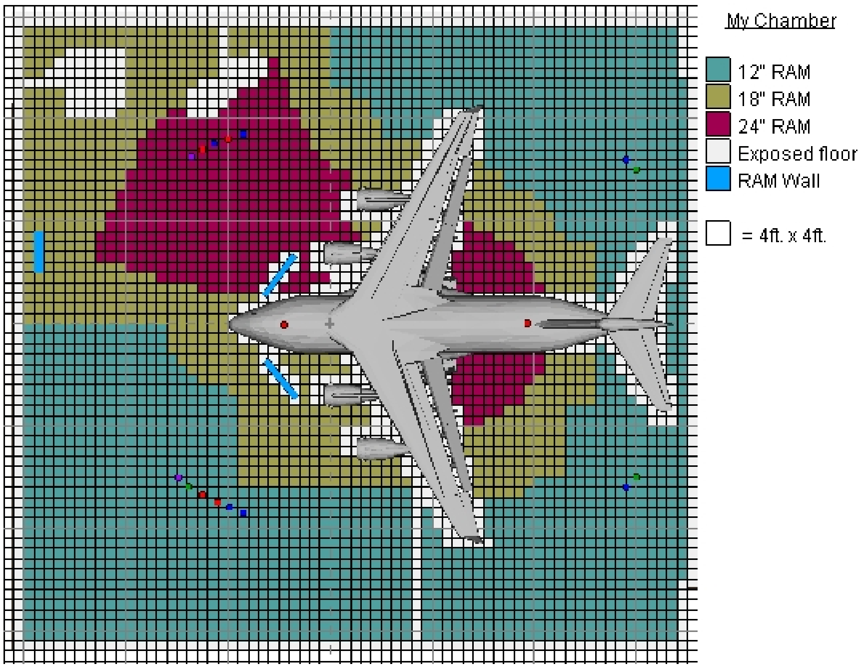


Figure 16.8: Image of RAM layout

Figure 16.9 shows an image created for the purpose of placing and configuring the carts. The grid is disabled so that it does not conflict with the text. All of the carts have their reference angles shown and radial lines drawn with exact distances for easy verification. The table in the legend shows all of the parameters for correctly configuring the cart for the project.

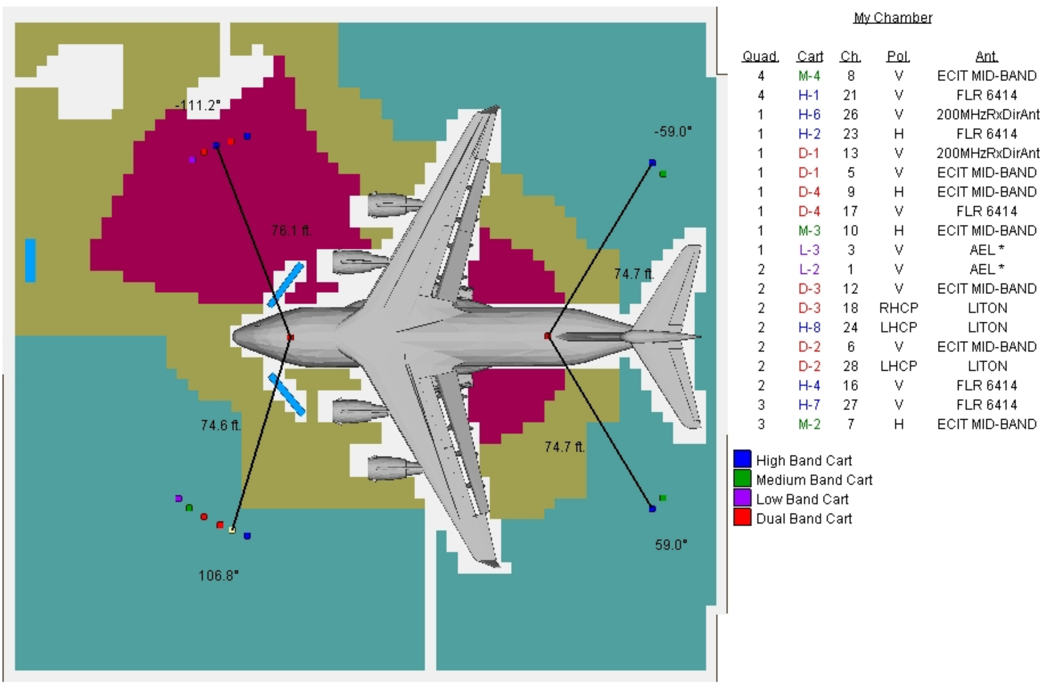


Figure 16.9: Image created for positioning carts

# Chapter 17

# Batch Management

*In this chapter, you will learn...*

→ how to run calculations faster with batch scripts

→ batch script keywords and constants

→ how to generate cluster scripts to manage batch scripts

→ how to use the command prompt to run the calculation engine

XGtd has the ability to generate batch scripts which can be submitted on a parallel computer, such as a cluster. Each script instructs the calculation engine to perform the simulation for a single Transmitter point, or alternatively to perform the analysis for a single large Receiver set. By submitting these scripts to a load balancing batch manager in a clustered environment running under Linux or Unix, the calculation engine can run on multiple transmitters at the same time and can complete the calculation more quickly.

## 17.1 Batch Calculation Steps

To run a calculation on a cluster, proceed through the following steps.

1. Create a script template, using the example in Section 17.3.
2. Use the Cluster Script Generator Window to generate the scripts that will be used to submit the calculation on the cluster separated by Transmitter point or Receiver set.
   - See Section 17.4 for more on the Cluster Script Generator Window.
   - See Section 17.5 for more on sending commands to the calculation engine.
3. Copy the project directory to the location on the cluster running the calculation.

   Remember that if you are specifying directories in the script that they must match the directories that exist on the cluster.

4. If a master submission script was created in the script, execute it to submit all of the batch jobs. Otherwise, each script will have to be manually submitted.
   - Section 17.3 contains an example of a master submission script.
5. Once all of the batch jobs have completed, copy the contents of the study area directory back to the computer running the XGtd GUI.
6. Some output files depend on the results from all TRANSMITTER points to the active RECEIVER sets in the project. For example, the total power cannot be calculated without knowing the power that a given receiver set receives from each transmitter point in the project. Therefore, these types of output will need to be consolidated from the results of all the files involving a given receiver set if the project was split up by transmitter point. To perform this action, select RUN→*Consolidate cluster output*.

## 17.2 Generating Batch Scripts

In order to submit batch jobs to the clusters batch management system, there must be a script for each calculation. Generating these scripts by hand would be a tedious task that would need to be repeated each time the variables controlling the calculation or the batch jobs environment changed. To simplify the creation and maintenance of the script files, XGtd provides the ability to automatically generate them for the user with a template that works as described in this section. The general format of a template is to:

1. Generate the commands for a driver script
2. Loop through all of the transmitter points or receiver sets in the project
3. Create the script files that will run each subcalculation

The template includes keywords that the script generator can extract to allow a user to provide values that they may want to change on a regular basis.

### 17.2.1 Keywords

The scripting engine provides a lot of flexibility through the use of keywords, which are special words recognized by the scripting module and interpreted to perform a custom action. Keywords can appear on any part of a line, nested or in sequence. If there is still text on the line once all keywords within it are processed, it will be written out to the currently opened file (if the script has already opened one). Keywords will be interpreted and added to the text that is written to the currently open file, depending on what action the keyword is intended to perform.

✓ To add blank lines in the final script files, include a line with one space. Blank lines without spaces will be ignored.

To allow the use of keywords for other purposes and prevent situations where the environment uses identical keywords, all keywords recognized by the scripting engine must be enclosed between angle brackets ("$<$" and "$>$"). Each keyword that is currently recognized is listed in the following subsections.

### Keyword "ask"

This keyword allows the user to specify required input to configure the script for the specific project that it will be used on. This also allows the scripts to be quickly modified without having to locate the information directly. All questions that are asked will appear in the CLUSTER SCRIPT GENERATOR Window.

- See Section 17.4 for more on the CLUSTER SCRIPT GENERATOR Window.

**Format**

```
<ask question_number type "question|default answer" variable_name>
```

**Parameters**

`question_number` - This indicates the index of the question with respect to other questions as they appear in the symbol table.

`type` - In order for the script generator to perform proper error checking, a type must be associated with the question. The types and the error checking they perform are:

`file` - Used for filenames. Filenames should not contain spaces or special characters that the operating system does not allow in filenames. If backslashes are used as directory separators when specifying a filename, they will be converted to forward slashes as they are recognized by both Windows and UNIX.

`int` - Used for integral values.

`real` - Used for floating point values.

`str` - Used for string substitutions.

`question|default answer` - The question will be the text that appears in the *Question* column in the CLUSTER SCRIPT GENERATOR Window. If the writer wants to specify a default answer that should satisfy most cases, it can be specified by following the question with a "`|`" character and then the default answer. This section must be included inside of double quotations.

`variable_name` - This is the variable name assigned to the "default answer". When enclosed in angle brackets, it makes the answer accessible from the CLUSTER SCRIPT GENERATOR Window.

### Keyword "for_each" / "end"

This keyword indicates the beginning of a loop that will go over all of the active TRANSMITTER or RECEIVER sets. This depends on the mode specified through the selection made under the *Create script for each* option in the CLUSTER SCRIPT GENERATOR Window.

**Format**

```
<for_each>
    ...statements that produce output for each Tx/Rx point...
<end>
```

#### Keyword “open”

This keyword will open an output stream that all of the following text will be written to. This stream remains the active stream until another open command is issued.

**Format**

```
<open filename>
```

**Parameters**

filename - This is the name of the file to open relative to the project directory. Once variable name substitutions are performed, the path will be re-verified.

The use of ../ and ./ to escape the project directory structure is not allowed.

#### Keyword “rem”

This keyword allows the user to comment out text that would otherwise be written out to the currently opened file.

**Format**

```
<rem comment>
```

**Parameters**

comment - The text of the remark.

### 17.2.2 Constants

Constants are variables that are always defined and are not modifiable by the client. They are:

<current_pt> - The current point being processed in a for_each loop. This is included separately from the point_option so that the current_pt can be used for creating filenames, allowing more flexibility.

<rank_option> - The switch option to add to the calculation engine command line that includes the current value of the loop counter in a for_each loop.

<point_option> - The switch option to add to the calculation engine command line that includes the current value of current_point.

<project_name> - The name of the project *.xgtd file, with all spaces converted to underscores.

### 17.2.3 Answer Books

Files can be created that have the answers to some or all questions in a given script template. The format of this file will be a set of lines with two columns. The first will indicate the question being answered in the script using the defined variable name, while the second column will contain the answer. Answer books are saved as simple text files by clicking the SAVE ANSWER BOOK button in the CLUSTER SCRIPT

GENERATOR Window. Once an answer book is saved, it can be reloaded by selecting LOAD ANSWER BOOK.

## 17.3 Example Script Template

The following section demonstrates how a script template can be used to gather information and create all of the required scripts for submitting a multiple-node job using the Portable Batch Scheduler (PBS). While the script template is commented through the use of the `rem` keyword, a line-by-line description is provided to clarify the purpose of the script template following the example.

- A copy of this script template is included with the installation and is located at `install_location\data\Batch Management\script.txt`.

```
1    <ask 1 str "Script sub-directory prefix|script" prefix>

     <rem create the driver file>
2    <open <prefix>/<ask 2 file "Driver filename|sub.pbs" driver> >

3    #!/bin/csh
     <rem create directories for each point to run in labeled:>
     <rem project_dir/script_1_1/>
     <rem project_dir/script_1_2/>
     <rem project_dir/script_2_1/>
     <rem project_dir/script_2_2/>
     .
     .
     <rem project_dir/script_2_n/>
     <rem ...>

4    <for_each>
     mkdir <prefix>_<current_pt>
     cd <prefix>_<current_pt>
     rm -rf *
     qsub ../<project_name>_<current_pt>.pbs
     cd ..
     <end>

5    <rem create the individual scripts for each transmitter point>
     <for_each active_tx>
     <rem this filename matches the qsub command above>

6    <open <prefix>/<project_name>_<current_pt>.pbs>

7    #!/bin/csh

     cd $PBS_O_WORKDIR
```

```
    #PBS -j eo
    #PBS -m be
    #PBS -l walltime=12:00:00
    #PBS -l nodes=<ask 3 int "Number of nodes to use|1" nodes>:ppn=<ask 4 int
    "Number of processes per node|1" processes>:production

8   <ask 5 file "Working directory|/cluster/user/project" workdir>

    setenv LD_LIBRARY_PATH '<ask 6 file "Location of dlls required for the
    calculation engine to run|<workdir>/lib" dll_location>'

    <ask 6 str "Memory to use|1.5G" memory>

    setenv CALDGTDOPTS
    '--project=<workdir>/<project_name>/<project_name>.xgtd
    < point_option > < rank_option > --memory=<memory>'

    setenv CALDGTD '<workdir>calcgtd'
9   <ask 7 str "MPI run command|mpiexec" MpiCommand>
    <ask 8 str "MPI command line options|-kill" MpiOptions>
    setenv MPIEXEC_OPTS '<MpiOptions>'
    <MpiCommand> $MPIEXEC_OPTS $CALDGTD $CALDGTDOPTS

10  <end>
```

**Description of activities in the example**:

1 A subdirectory for keeping the scripts located in the project directory can be specified here.

2 The name of a driver file that submits all of the individual scripts to the batch manager is gathered from the user and then opened.

3 These lines are written to the driver file as is, minus the remarks.

4 This loop will create lines in the driver file for submitting the scripts for each Tx/Rx point to run the calculation on. The working directory for each script is created. If it already existed, then it is cleaned out before submitting the job to the batch manager.

5 This is the beginning of the loop that will create the scripts for each Tx/Rx point that is submitted by the driver to the batch management system.

6 The script for the current point is opened for writing.

7 Information for configuring the batch manager that is being used is gathered from the user. In this case, the batch manager is a PBS system.

8 The client has decided to define environment variables for creating the strings to use for executing the calculation engine. The LD_LIBRARY_PATH variable MUST be adjusted to

include the path to the .dll files that are required to run the calculation engine. Note the use of the loop constants `point_option` and `rank_option` to correctly identify what part of the project each process will work on.

9 In this example, the client uses MPI for running jobs on their cluster and gathers additional information before running the calculation engine with it.

10 The loop started at step 5 is closed.

## 17.4 Cluster Script Generator Window

Once a template is created, it can be used to create the scripts for running the calculation through a batch manager. The CLUSTER SCRIPT GENERATOR Window, seen in Figure 17.1, will read the template file and present the options used to control how the scripts will be generated. This is accessible by selecting RUN→*Prepare cluster scripts*.

✓ In Figure 17.1, the template from Section 17.3 has been loaded and is displaying the questions and default answers that were specified in it.

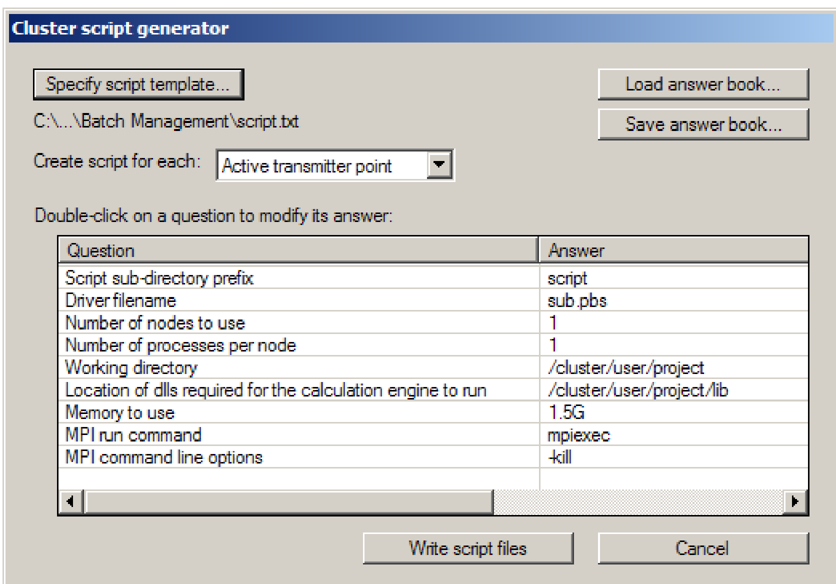


Figure 17.1: The Cluster Script Generator Window

The following describes the options in this window.

- SPECIFY SCRIPT TEMPLATE - Loads the template file that was created using keywords.
  - ▶ See Section 17.2.1 for a list of the keywords available.
- LOAD ANSWER BOOK - Loads an answer book file.

- ▶ See Section 17.2.3 for more on answer book files.

- SAVE ANSWER BOOK - Saves the current set of answers to the questions in the currently loaded template to a file for future use.

- *Create script for each* - Controls whether the scripts will be created for running the calculation for each active transmitter point or for each active receiver set.

- **Question/Answer Table** - Displays all of the questions that were specified in the template through the use of the `ask` keyword. If they need to be changed, an *Edit symbol* option is available through the context menu for a given line.

## 17.5 Calculation Engine Command Line Options

It is possible to run the calculation engine using the command prompt.

When using `calcgtd` the command line parameters are:

- `--calc-mode=<mode>`

  `<mode>` must be one of the following: New, AddTransmitters, AddReceivers, ChangeHeights, ChangeFrequency, ChangeAntennas, ChangeMaterials, AddOutput, or ConsolidateClusterRun.

- `--clean-run`

  All previously generated data files will be deleted and recreated.

- `--delete-temp`

  All temporary files will be deleted at the end of the run.

- `--help`

  Print help text showing valid command line options

- `--memory=<memoryspec>`

  A memory specification is a number followed by K, M, or G for Kilobytes, Megabytes, or Gigabytes. The number optionally may have a decimal point. If the `--memory` command line option is not given under Windows, an algorithm tries to determine a “polite” maximum amount of memory to use. Under Linux, `calcgtd` will attempt to use 800 Megabytes unless the `---memory` command line option is specified. Some example valid memory specifications are:

  `--memory=450000K`

  `--memory=450M`

  `--memory=1.75G`

- `--project=[<path>]/<file>.xgtd`

  The project command line option is the only required option. A full path to the `*.xgtd` file may be given or a relative path may be given. No path is required if the `*.xgtd` file is in the current working directory.

- `--rank=<num>`

Transmitters may be split into individual runs for running on a Linux cluster. The rank parameter is used to assign a unique numeric ID, normally an integer starting at zero or one, to each process. XGtd provides tools for generating appropriate cluster scripts.

Use of the `-rank` parameter requires a separate CalcPropNode license.

- `--rx-set=<set-num>[-set-num];<rx-set>`

  Receiver sets may be split with one or more receiver sets running on a Linux cluster node. Example valid entries are:

  `--rx-set=1`

  Receiver set 1.

  `--rx-set=3;5;9-11`

  Receiver sets 3, 5, 9, 10, and 11.

  Use of the `-rx-set` parameter requires a separate CalcPropNode license.

- `--tx-set=<set-num>:<point-num>[-<point-num>][,<point-num>[-<point-num>]]...;<tx-set>`

  Transmitters may be split across Linux cluster nodes. An example valid entry is:

  `--tx-set=1;2:5-7;15-17`

  Transmitter set 1 (every point), transmitter set 2 points 5, 6, and 7, and all points in transmitter sets 15, 16, and 17.

  ✓ Transmitter sets can be split by points within sets, while receiver sets must remain whole.

  Use of the `-tx-set` parameter requires a separate CalcPropNode license.

When using `xgbatch`, point to the project `.xml` file located in your project directory. The name will be in the format: `ProjectName.StudyAreaName.xml`. Specify the directory where output should be written. (When using the GUI, this directory is created as a subfolder of the project file location.)

An example command is as follows:

```
‘‘C:\Program Files\Remcom\XGtd 3.1.2 \bin\calc\xgbatch.exe’’—f
x3d_test01\x3d_test01.StudyareaName.xml —out StudyareaName
```

# Appendices

# Appendix A

# Appendix Notation

*In this appendix, you will learn...*

→ how to read the notation in the following appendices

All XGtd input files are `ASCII` text files. In addition to the explanation given in the following appendices, users can also set up the problem using the XGtd GUI and open the input file in a text editor to better understand how settings in the user interface translate to text in the input files.

A common format is applied throughout the appendices to describe XGtd file formats.

- `Regular teletype text` represents keywords that are required to be in the file.
- The <`or`> operand separates mutually exclusive keywords, such as "`active` <`or`> `inactive`".
- Keywords are commonly followed by a character string, integer, or other value. In these cases, the keyword is listed in teletype, and in the place of the argument is a description of the value that should follow is written in *`italicized teletype text`* and enclosed by brackets, i.e.:

    StudyAreaNumber [*integer ID number of study area*]

- Regular gray text represents a note about the current line.

# Appendix B

# Project File Format

*In this appendix, you will learn...*

- how the `*.xgtd` project file is formatted

## B.1 Project File Format

The XGtd project file (`*.xgtd`) is the primary file used by the GUI and the FULL 3D model. It contains basic information about the project and complete paths to other files needed by the project. Specifically, the project file contains:

- The location of the global origin
- STUDY AREA description (propagation model, number of reflections, diffractions, transmissions, location of the study area)
- A list of the FEATURE files used in the project
- Locations of the TRANSMITTER and RECEIVER files used in the project
- ANTENNA information (type, polarization, associated waveform, etc.)
- WAVEFORM information (type, frequency, etc.)
- OUTPUT FILTER definitions
- A list of the REQUESTED OUTPUT (received power, pathloss, delay spread, Far Zone *Gain*, *RCS*, etc.)
- A list of graphs referencing OUTPUT files
- Color bar display information

- Appendix A describes the notation for these file formats.

## B.2 Building a Project File

Project files should be built up from each the following sections in the order the sections appear above. The code has been tabbed for readability.

### B.2.1 Project File Header

```
begin_<project> [short description of project, 72 char max]
```

### B.2.2 Global Origin Definition

```
begin_<globals>
     offset_mode manual
     longitude 0
     latitude 0
end_<globals>
```

### B.2.3 Study Area Definition

```
FirstAvailableStudyAreaNumber [integer ID used for next studyarea]
begin_<studyarea> [short description of study area, 72 char max]
     StudyAreaNumber [integer ID number of study area]
     active <or> inactive
     autoboundary 0 (manual) <or> 1 (auto)
     begin_<model>
          [propagation model type]
          [propagation model parameters]
          full3d <or> freespace
          raytracingmode sbr <or> eigenray
          creepingwaves Yes <or> No (only available with SBR ray tracing)
          max_reflections [integer]
          max_transmissions [integer]
          max_surface_diffractions [integer] (only available with SBR ray tracing)
          max_wedge_diffractions [integer]
     end_<model>
     begin_<boundary>
          begin_<reference>
               cartesian <or> longlat
               longitude 0.0
               latitude 0.0
               visible no <or> yes
               sealevel <or> terrain
          end_<reference>
          zmin 0.100000 (bottom of the studyarea)
          zmax 4.900000 (height of the studyarea)
```

```
            nVertices 4
            0.000000 0.350000 0.000000
            12.765600 0.350000 0.000000
            12.765600 9.150000 0.000000
            0.000000 9.150000 0.000000
        end_<boundary>
    end_<studyarea>
```

### B.2.4 Project Features

XGtd project files reference the feature file. All FEATURE definitions must be included in this file.

- Refer to Appendix C for the feature file format.

```
begin_<feature>
     feature [integer ID number]
     object <or> chamber
     active <or> inactive
     filename [full path to the feature file]
end_<feature>
```

### B.2.5 Transmitter and Receiver Files

XGtd project files reference a single transmitter and receiver file. All transmitter and receiver definitions must be included in this file.

- Refer to Appendix D for the transmitter/receiver file format.

```
begin_<transmitter>
     filename [full path to the transmitter file (<project_name>.tx)]
     FirstAvailableTxNumber [integer ID used for the next Tx set]
end_<transmitter>

begin_<receiver>
     filename [full path to the receiver file (<project_name>.rx)]
     FirstAvailableRxNumber [integer ID used for the next Rx set]
end_<receiver>
```

### B.2.6 Waveforms and Antennas

All WAVEFORMS and ANTENNAS used in a project must be defined in the `*.xgtd` file.

- Antenna and waveform files are described in Appendix F and Appendix G, respectively.

### B.2.7 Output Filter Definition (optional)

```
FirstAvailableFilterNumber [integer ID used for next filter]
```

```
begin_<filter> [short description of output filter, 72 char max]
     FilterNumber [integer ID number of the filter]
     active <or> inactive
     los 1 <or> 0
     PowerMin [minimum ray path power in dBm]
     PowerMax [maximum ray path power in dBm]
     TOAMin [minimum time of arrival in seconds]
     TOAMax [maximum time of arrival in seconds]
     XTOAMin [minimum excess time of arrival in seconds]
     XTOAMax [maximum excess time of arrival in seconds]
     begin_<filter_entry>
          feature [integer ID for the feature]
          reflections can <or> must <or> must_not
          transmissions can <or> must <or> must_not
          diffractions can <or> must <or> must_not
     end_<filter_entry>
end_<filter>
```

### B.2.8 Output requests

```
begin_<requests>
     cartesian
     sealevel
     local
     CalculationMode New
     CEF yes <or> no
     DelaySpread yes <or> no
     DirectionOfArrival yes <or> no
     DirectionOfDeparture yes <or> no
     ElectricFieldVsFrequency yes <or> no
     ElectricFieldVsTime yes <or> no
     FieldAnimation yes <or> no
     MeanDirectionOfArrival yes <or> no
     MeanDirectionOfDeparture yes <or> no
     Paths yes <or> no
     MeanTimeOfArrival yes <or> no
     EField yes <or> no
     FSPathloss yes <or> no
     FSPower yes <or> no
     Power yes <or> no
     Pathloss yes <or> no
     XPathloss yes <or> no
     InputData yes <or> no
     TimeOfArrival yes <or> no
     TotalReceivedPower yes <or> no
     C2I yes <or> no
     ComplexImpulseResponse yes <or> no
```

```
PowerDelayProfile yes <or> no
StrongestTx yes <or> no
PoyntingVector yes <or> no
MaxRenderedPaths 25
FieldAnimationIncrement 10
FieldAnimationTimeAveraged yes <or> no
farzone_polarization TotalGain
farzone_gain_range [Gain range in dB for displaying far zone gain output]
farzone_auto_radius yes <or> no
farzone_radius [size in meters that far zone gain patterns are rendered]
farzone_x [x coordinate in meters of rendered far zone gain patterns]
farzone_y [y coordinate in meters of rendered far zone gain patterns]
farzone_z [z coordinate in meters of rendered far zone gain patterns]
farzone_auto_positioned yes <or> no
farzone_display_as pattern <or> sphere
farzone_show_gain_arrow yes <or> no
```

### B.2.9 Far zone gain output requests

```
FirstAvailableOutputRequestNumber [integer ID used for next request]
begin_<gain> [short description of far zone gain request, 72 char max]
     OutputRequestNumber [integer ID of output request]
     active <or> inactive
     vary theta <or> phi <or> both
     theta_start [start angle in degrees]
     theta_stop [stop angle in degrees]
     theta_inc [theta angle increment in degrees]
     phi_start [start angle in degrees]
     phi_stop [stop angle in degrees]
     phi_inc [phi angle increment in degrees]
end_<gain>
```

### B.2.10 RCS output requests

```
begin_<RCS>[short description of far zone gain request, 72 char max]
     OutputRequestNumber [integer ID of output request]
     active <or> inactive
     PlaneWave [integer ID of planewave transmitter set]
     Backscatter <or> Bistatic
     Versus frequency <or> scatterAngle <or> incidentAngle
     [angle definitions]
end_<RCS>
```

### B.2.11 Angle Options

Depending on the type of *RCS* request and the *Plane Wave* transmitter set, different angle options are needed to complete the request. The following five examples show the keywords and how they are used for each request type.

#### B.2.11.1 Backscatter from a single plane wave set

```
begin_<RCS>Backscatter
     OutputRequestNumber 0
     active
     PlaneWave 1
     Backscatter
     Versus frequency
end_<RCS>
```

**Bistatic scattering from a single plane wave set**

```
begin_<RCS>Bistatic vs frequency
     OutputRequestNumber 1
     active
     PlaneWave 1
     Bistatic
     Versus frequency
     theta 45.000
     phi 90.000
end_<RCS>
```

**Bistatic scattering to a constant cut plane from a single plane wave set**

```
begin_<RCS>Bistatic vs Scattering Angle
     OutputRequestNumber 2
     active
     PlaneWave 1
     Bistatic
     Versus scatterAngle
     vary phi
     theta 90.000
     phi_start 0.000
     phi_stop 360.000
     phi_inc 1.000
end_<RCS>
```

**Backscatter from a variable incidence plane wave**

```
begin_<RCS>Backscatter vs Incident Angle
     OutputRequestNumber 3
     active
     PlaneWave 2
     Backscatter
     Versus incidentAngle
end_<RCS>
```

**Bistatic scattering to a single far zone point from a variable incidence plane wave**

```
        begin_<RCS>Bistatic vs Incident Angle
             OutputRequestNumber 4
             active
             PlaneWave 2
             Bistatic
             Versus incidentAngle
             theta 30.000
             phi 180.000
        end_<RCS>

  end_<requests>
```

### B.2.12 Scale Bar

Scale bar definitions are only used by the user interface for displaying OUTPUT. Their definition does not affect and calculation engine output. An example scale bar for displaying ray paths is provided below.

```
begin_<Scales>
     begin_<NPaths>
          AutoScaling 1
          AutoUpdating 1
          Discrete 0
          UseGlobalOpacity 1
          ManualValuesSet 0
          ClampedHigh 1
          ClampedLow 1
          Alpha 1.000e+000
          ManualMin 0.000e+000
          ManualMax 1.000e+000
          Colors 6
          0.300 0.000 0.500
          0.000 0.000 1.000
          0.000 1.000 0.000
          1.000 1.000 0.000
          1.000 0.500 0.000
```

```
            1.000 0.000 0.000
            PartitionValues
            0
       end_<NPaths>
  end_<Scales>

end_<project>
```

# Appendix C

# Feature File Format

*In this appendix, you will learn...*

▶ how to format a feature file

## C.1 Feature File Format

Project geometry is stored in feature files (*.object or *.cbr). Specifically, each feature file contains:

- a <begin> delimiter, indicating the geometry is an *Object* or a *Chamber*, followed by an optional short description of less than 50 characters
- notes (optional), with each line preceded by the keyword description
- the location of the feature origin
- a list of MATERIALS and their parameters that are referenced in the object
- a list of faces which define the geometry, each composed of a list of vertices and an assigned a material.
    - ✓ The outward normal for a face is determined by the order of the vertices and the right hand rule. Related faces can be organized into sub-structures, structures, and structure groups.
- the control vector for object geometry.

▶ Appendix A describes the notation for the following file formats.

## C.2 Building a Feature File

The basic hierarchical organization of any feature file is given below with a general description of the data contained in each section. The notes are only shown for the feature, but descriptions can be given for any section in the file. The code has been tabbed for readability.

The example is for an *.object file, but the only difference between the format of *.object and *.cbr files is that the tag <object> in the first and last line would be replaced by <chamber>.

## Feature File Header

```
begin_<object> short description
     description [notes] (optional)
     smoothrender yes <or> no
```

where:

- SmoothRender - Indicates that the feature should be rendered in the PROJECT VIEW using smooth shading.

## Feature Location

```
begin_<reference>
     cartesian <or> longlat
     longitude 0.0000000000
     latitude 0.000000000
     visible no <or> yes
     terrain <or> sealevel
end_<reference>
```

where:

- cartesian - Coordinate system used for the control points. When Cartesian is used, the control points of the set are interpreted as Cartesian offsets from the longitude/latitude origin of the set.
- longlat - Control points as listed in longitude and latitude and elevation.
- longitude - Longitude of the set's origin.
- latitude - Latitude of the set's origin.
- visible no <or> yes - Controls the display of the set's origin in the user interface.
- terrain <or> sealevel - Reference for the $Z$-coordinates of the control points. If a terrain does not exist in the project and the terrain keyword is used, the heights are relative to $Z$=0.

## Feature Material

```
begin_<Material>
     .
     .
end_<Material>
```

One or more materials may be defined in a feature file.

▶ See Appendix E for a description of the material definition format.

## Feature Structure Groups

```
begin_<structure_group> [short description]
     begin_<structure> [short description]
          begin_<sub_structure> [short description]
               begin_<face> [short description]
                    double_sided (optional)
                    Material 1
                    nVertices 4
                    [x1],[y1],[z1]
                    [x2],[y2],[z2]
                    [x3],[y3],[z3]
                    [x4],[y4],[z4]
               end_<face>
               .
               .
          end_<sub_structure>
          .
          .
     end_<structure>
     .
     .
end_<structure_group>
```

where:

- `structure_group` - A group of structures (i.e., a city block).
- `structure` - A structure (i.e., a building).
- `sub_structure` - A section of a structure (i.e., the entryway to a building).
- `face` - The faces that define the sub-structure (i.e., the roof of an entryway).
- `Material` - A reference to the material, by number, that makes up the face.
- `nVertices` - The vertices that define each face.
- `double_sided` - Specifies that the face is double-sided. If omitted, the face is single-sided (by default).

Each structure-group can contain multiple structures, each structure multiple sub-structures, and each sub-structure multiple faces.

▶ See Section 3.1 for a description of feature hierarcy.

### Object Control Vectors

The control vector segment is only included in object (`*.obj`) files.

```
begin_<ControlVectors>
     CVsVisible yes <or> no
     Stippled yes <or> no
     CVsThickness 3
     CVxLength 10.0000000000
     CVyLength 10.0000000000
     CVzLength 10.0000000000
     CVsXaxis 1.0000000000 0.0000000000 0.0000000000
     CVsZaxis 0.0000000000 0.0000000000 1.0000000000
end_<ControlVectors>

end_<object>
```

where:

- `CVsVisible` - defines the visibility of the control vector.
- `Stippled` -
- `CVsThickness` - defines the display thickness of the control vector.
- `CVxLength, CVyLength, CVzLength` - the respective $X$, $Y$, and $Z$ control vector lengths, in meters.
- `CVsXaxis, CVsZaxis` -

## C.3 Feature File Examples

### Object File

```
begin_<object> simple block
   SmoothRender No
   begin_<reference>
      cartesian
      longitude 0.00000000
      latitude 0.00000000
      visible yes
      terrain
   end_<reference>
   begin_<Material> Free Space
      Material 0
      Freespace
      thickness 0.000
      begin_<Color>
```

```
        ambient 0.500000 0.500000 0.500000 1.000000
        diffuse 0.500000 0.500000 0.500000 1.000000
        specular 0.500000 0.500000 0.500000 1.000000
        emission 0.000000 0.000000 0.000000 0.000000
        shininess 50.000000
      end_<Color>
    end_<Material>
    begin_<structure_group>
      begin_<structure>
        begin_<sub_structure>
          begin_<face> 1
            Material 0
            nVertices 4
              -40.0000000000 -30.0000000000 10.0000000000
              -110.0000000000 -30.0000000000 10.0000000000
              -110.0000000000 -30.0000000000 0.0000000000
              -40.0000000000 -30.0000000000 0.0000000000
          end_<face>
          begin_<face> 2
            Material 0
            nVertices 4
              -40.0000000000 10.0000000000 10.0000000000
              -40.0000000000 -30.0000000000 10.0000000000
              -40.0000000000 -30.0000000000 0.0000000000
              -40.0000000000 10.0000000000 0.0000000000
          end_<face>
          begin_<face> 3
            Material 0
            nVertices 4
              -110.0000000000 10.0000000000 10.0000000000
              -40.0000000000 10.0000000000 10.0000000000
              -40.0000000000 10.0000000000 0.0000000000
              -110.0000000000 10.0000000000 0.0000000000
          end_<face>
          begin_<face> 4
            Material 0
            nVertices 4
              -110.0000000000 -30.0000000000 10.0000000000
              -110.0000000000 10.0000000000 10.0000000000
              -110.0000000000 10.0000000000 0.0000000000
              -110.0000000000 -30.0000000000 0.0000000000
          end_<face>
          begin_<face> 5
            Material 0
            nVertices 4
              -40.0000000000 -30.0000000000 10.0000000000
              -40.0000000000 10.0000000000 10.0000000000
              -110.0000000000 10.0000000000 10.0000000000
```

```
              -110.0000000000 -30.0000000000 10.0000000000
          end_<face>
          begin_<face> 6
             Material 0
             nVertices 4
                -110.0000000000 -30.0000000000 0.0000000000
                -110.0000000000 10.0000000000 0.0000000000
                -40.0000000000 10.0000000000 0.0000000000
                -40.0000000000 -30.0000000000 0.0000000000
          end_<face>
       end_<sub_structure>
    end_<structure>
   end_<structure_group>
   begin_<ControlVectors>
      CVsVisible no
      Stippled no
      CVsThickness 3
      CVxLength 10.0000000000
      CVyLength 10.0000000000
      CVzLength 10.0000000000
      CVsXaxis 1.0000000000 0.0000000000 0.0000000000
      CVsZaxis 0.0000000000 0.0000000000 1.0000000000
   end_<ControlVectors>
end_<object>
```

### Chamber File

```
begin_<chamber> simple anechoic chamber
   SmoothRender No
   begin_<reference>
      cartesian
      longitude 0.00000000
      latitude 0.00000000
      visible no
      sealevel
   end_<reference>
   begin_<Material> Metal
      Material 0
      PEC
      thickness 0.000e+000
      begin_<Color>
         ambient 0.6 0.6 0.6 1
         diffuse 0.6 0.6 0.6 1
         specular 0.6 0.6 0.6 1
         emission 0 0 0 0
         shininess 75
      end_<Color>
```

```
   roughness 0.000e+000
end_<Material>
begin_<structure_group>
   begin_<structure>
      begin_<sub_structure>
         begin_<face> Ceiling
             invisible
             Material 0
             nVertices 3
                -10.0000000000 0.0000000000 5.0000000000
                10.0000000000 30.0000000000 5.0000000000
                -30.0000000000 30.0000000000 5.0000000000
         end_<face>
      end_<sub_structure>
   end_<structure>
end_<structure_group>
begin_<structure_group>
   begin_<structure>
      begin_<sub_structure>
         begin_<face> Floor
             Material 0
             nVertices 3
                -30.0000000000 30.0000000000 0.0000000000
                10.0000000000 30.0000000000 0.0000000000
                -10.0000000000 0.0000000000 0.0000000000
         end_<face>
      end_<sub_structure>
   end_<structure>
end_<structure_group>
begin_<structure_group>
   begin_<structure>
      begin_<sub_structure>
         begin_<face>
             Material 0
             nVertices 4
                -10.0000000000 0.0000000000 5.0000000000
                -30.0000000000 30.0000000000 5.0000000000
                -30.0000000000 30.0000000000 0.0000000000
                -10.0000000000 0.0000000000 0.0000000000
         end_<face>
      end_<sub_structure>
   end_<structure>
end_<structure_group>
begin_<structure_group>
   begin_<structure>
      begin_<sub_structure>
         begin_<face>
             Material 0
```

```
            nVertices 4
               10.0000000000 30.0000000000 5.0000000000
               -10.0000000000 0.0000000000 5.0000000000
               -10.0000000000 0.0000000000 0.0000000000
               10.0000000000 30.0000000000 0.0000000000
         end_<face>
      end_<sub_structure>
   end_<structure>
end_<structure_group>
begin_<structure_group>
   begin_<structure>
      begin_<sub_structure>
         begin_<face>
            Material 0
            nVertices 4
               -30.0000000000 30.0000000000 5.0000000000
               10.0000000000 30.0000000000 5.0000000000
               10.0000000000 30.0000000000 0.0000000000
               -30.0000000000 30.0000000000 0.0000000000
         end_<face>
      end_<sub_structure>
   end_<structure>
end_<structure_group>
begin_<structure_group>
   begin_<structure>
      begin_<sub_structure>
         begin_<face>
            Material 0
            nVertices 3
               -30.0000000000 30.0000000000 5.0000000000
               10.0000000000 30.0000000000 5.0000000000
               -10.0000000000 0.0000000000 5.0000000000
         end_<face>
      end_<sub_structure>
   end_<structure>
end_<structure_group>
begin_<structure_group>
   begin_<structure>
      begin_<sub_structure>
         begin_<face>
            Material 0
            nVertices 3
               -10.0000000000 0.0000000000 0.0000000000
               10.0000000000 30.0000000000 0.0000000000
               -30.0000000000 30.0000000000 0.0000000000
         end_<face>
      end_<sub_structure>
   end_<structure>
```

```
    end_<structure_group>
    begin_<structure_group>
       begin_<structure>
          begin_<sub_structure>
             begin_<face>
                 Material 0
                 nVertices 4
                    -10.0000000000 0.0000000000 0.0000000000
                    -30.0000000000 30.0000000000 0.0000000000
                    -30.0000000000 30.0000000000 5.0000000000
                    -10.0000000000 0.0000000000 5.0000000000
             end_<face>
          end_<sub_structure>
       end_<structure>
    end_<structure_group>
    begin_<structure_group>
       begin_<structure>
          begin_<sub_structure>
             begin_<face>
                 Material 0
                 nVertices 4
                    10.0000000000 30.0000000000 0.0000000000
                    -10.0000000000 0.0000000000 0.0000000000
                    -10.0000000000 0.0000000000 5.0000000000
                    10.0000000000 30.0000000000 5.0000000000
             end_<face>
          end_<sub_structure>
       end_<structure>
    end_<structure_group>
    begin_<structure_group>
       begin_<structure>
          begin_<sub_structure>
             begin_<face>
                 Material 0
                 nVertices 4
                    -30.0000000000 30.0000000000 0.0000000000
                    10.0000000000 30.0000000000 0.0000000000
                    10.0000000000 30.0000000000 5.0000000000
                    -30.0000000000 30.0000000000 5.0000000000
             end_<face>
          end_<sub_structure>
       end_<structure>
    end_<structure_group>
 end_<chamber>
```

# Appendix D

# Transmitter and Receiver File Format

*In this appendix, you will learn...*

- how to format a transmitter and receiver file

## D.1 Transmitter and Receiver File Format

The information for all Transmitters or Receivers used in the project is stored in a transmitter or receiver file, respectively. Each file shares the same directory and name of the project file followed by `*.tx` or `*.rx` extension. For example, if a project is named `TxRxFormats.xgtd`, the transmitter set will be named `TxRxFormats.tx` and the receiver set will be named `TxRxFormats.rx`.

Transmitter and Receiver sets generally share the same file format. Each file contains:

- Transmitter (Receiver) name
- Set type (*Point*, *Route*, *XY Grid*, etc.)
- Control point locations for defining the set
- Rotations
- Display information
- A reference to the antenna and waveform assigned to the transmitter

- Appendix A describes the notation for the following file formats.

## D.2 Building a Transmitter or Receiver File

Within the `*.tx` or `*.rx` file, freestanding transmitter and receiver sets have the following general format given below. The code has been tabbed for readability.

## Tx/Rx File Header

```
begin_<[set type]>[short description of the Tx/Rx set, 72 characters max]
     TxSet <or> RxSet [integer ID number for the set]
     active <or> inactive
```

where:

- `set type` - defines the type of Tx/Rx set. XGtd allows the following sets for both Tx and Rx sets:
  - `points`
  - `route`
  - `grid`
  - `arc`
  - `VerticalArc`
  - `cylinder`
  - `sphere`
  - `trajectory`
  - `polygon`
  - `VerticalSurface`
  - `PointsOnFace`
  - `userdefined`
  - `planewave (only available for a transmitter set)`
  - ▶ The full definition of each set type is available in Chapter 8.
  - ▶ Examples of each type of set are provided in Section D.3.
- `TxSet [integer ID number for the set]` - The ID number is used when naming the output files.
- `active <or> inactive` - The status of the Tx/Rx sets. Inactive sets are ignored during the calculation.

## Tx/Rx Display Properties

These properties are described by a set of keywords which define how the user interface displays the Tx/Rx set.

- `vertical_line yes <or> no` - Display of a vertical line from the point to height reference.
- `cube_size` - Size of points in meters
- `CVxLength` - $X$ control vector length in meters

- `CVyLength` - $Y$ control vector length in meters
- `CVzLength` - $Z$ control vector length in meters
- `AntennaPatternScale` - Display size of the antenna pattern in meters
- `CVsVisible yes <or> no` - Display of the control vectors
- `CVsThickness` - Thickness of the control vectors

## Tx/Rx Location

```
begin_<location>
     begin_<reference>
          cartesian <or> longlat
          longitude 0.0000000000
          latitude 0.000000000
          visible no <or> yes
          terrain <or> sealevel
     end_<reference>
     [set properties]
     nVertices [integer number of control points]
     [list of control points]
end_<location>
```

where:

- `cartesian` - Coordinate system used for the control points. When Cartesian is used, the control points of the set are interpreted as Cartesian offsets from the longitude/latitude origin of the set.
- `longlat` - Control points as listed in longitude and latitude and elevation.
- `longitude 0.0` - Longitude of the set's origin.
- `latitude 0.0` - Latitude of the set's origin.
- `visible no <or> yes` - Controls the display of the set's origin in the user interface.
- `terrain <or> sealevel` - Reference for the $Z$-coordinates of the control points. If a terrain does not exist in the project and the terrain keyword is used, the heights are relative to $Z$=0.
- *`[set properties]`* - Set properties vary by the type of set used. These are additional properties that define how the points are arranged in the set.
  - ▶ See Section D.3 for set examples with applicable keywords.
- `nVertices [`*`integer number of control points`*`]` - Lists the number of control points that follow.
- `[list of control points]` - Along with the set properties, the control point locations complete the description of the set. The values the control points define vary by set type.
  - For *Points*, each control point is the location of an individual point.

- For *Routes*, the control points define the end points of each segment.
- For *XY Grids*, the control points define opposite corners of a rectangular region.
- For *Arcs* and *Vertical Arcs*, the control point defines the center of the arc.
- For *Polygons*, the control points describe the location of the vertices.
- For *Sphere*, the control point is the center of the sphere.
- For *Trajectory*, the control points define the endpoints of the path and all points inbetween.
- For *Cylinder*, the control points represent the centers of the bottom and top discs of the cylinder.
- For *Vertical Surface*, the control points represent the bottom line segment of the vertical surface.

### Tx/Rx Antenna

```
begin_<antenna>
     antenna [antenna ID number used by the set]
     waveform [waveform ID number used by the set]
     rotation_x [rotation about x-axis in degrees]
     rotation_y [rotation about y-axis in degrees]
     rotation_z [rotation about z-axis in degrees]
     power [transmitter's input power in dBm]
end_<antenna>
```

```
end_<[set type]>
```

where:

- `antenna [antenna ID number used by the set]` - Defines the antenna used by the set.
- `waveform [waveform ID number used by the set]` - Defines the waveform used by the set. If this value is -1, the set will use the waveform assigned to the antenna.
- `rotation_x, rotation_y, rotation_z [rotation in degrees]` - Specifies the orientation of the antenna pattern for the particular set in the project. All points in a set will use these rotations. Rotations are applied first about the $X$-axis, then the $Y$-axis, and finally the $Z$-axis. If points in a set need to be oriented in different directions, the set should be divided.
- `power [transmitter's input power in dBm]` - For the transmitter only, specifies the input power of the transmitter set. This keyword is ignored for receiver sets.

## D.3 Transmitter Examples

Below are examples for TRANSMITTER sets, for each type of set. Receiver sets are nearly identical; the word “TxSet” before the integer ID number is replaced by “RxSet”. The code has been tabbed for readability.

### Tx Point

```
begin_<points> Tx Point
     TxSet 1
     active
     vertical_line yes
     cube_size 0.25000
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AntennaPatternScale 1.00000
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude -0.0001502742
               latitude 0.0000136580
               visible no
               terrain
          end_<reference>
          nVertices 1
          0.00000 0.00000 2.00000
     end_<location>
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
end_<points>
```

### Tx Route

```
begin_<route> Tx Route
     TxSet 2
     active
     vertical_line no
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AntennaPatternScale 1.00000
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude -0.0001417045
               latitude 0.0000139258
               visible no
               terrain
          end_<reference>
          spacing 0.50000
          nVertices 4
          0.00000 0.00000 2.00000
          2.71274 0.02981 2.00000
          4.91870 -1.16260 2.00000
          4.88889 0.98374 2.00000
     end_<location>
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
     begin_<sbr>
          bounding_box
     end_<sbr>
end_<route>
```

### Tx XY Grid

```
begin_<grid> TxGrid
     TxSet 3
     active
     vertical_line no
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AntennaPatternScale 1.00000
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude -0.0000886794
               latitude 0.0000040171
               visible no
               terrain
          end_<reference>
          side1 7.12466
          side2 3.36856
          spacing 0.50000
          nVertices 1
          0.00000 0.00000 2.00000
     end_<location>
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
     begin_<sbr>
          bounding_box
     end_<sbr>
end_<grid>
```

### Tx Arc

```
begin_<arc> Tx Arc
     TxSet 4
     active
     vertical_line no
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AntennaPatternScale 1.00000
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude -0.0001320636
               latitude 0.0000390993
               visible no
               terrain
          end_<reference>
          radius 2.66785
          phistart 0.00000
          phistop 360.00000
          spacing 0.50000
          counterclockwise
          nVertices 1
          0.00000 0.00000 2.00000
     end_<location>
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
     begin_<sbr>
          bounding_box
     end_<sbr>
end_<arc>
```

### Tx Vertical Arc

```
begin_<VerticalArc> Tx Vertical arc
     TxSet 5
     active
     vertical_line no
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AntennaPatternScale 1.00000
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude -0.0000980525
               latitude 0.0000570421
               visible no
               terrain
          end_<reference>
          radius 2.25599
          phistart 0.00000
          phistop 360.00000
          spacing 0.50000
          counterclockwise
          nVertices 1
          0.00000 0.00000 2.00000
     end_<location>
     rotation 88.36000
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
     begin_<sbr>
          bounding_box
     end_<sbr>
end_<VerticalArc>
```

### Tx Cylinder

```
begin_<cylinder> Tx Cylinder
     TxSet 6
     active
     vertical_line no
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AntennaPatternScale 1.00000
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude 0.0
               latitude 0.0
               visible no
               terrain
          end_<reference>
          radius 1.58023
          phistart 0.00000
          phistop 360.00000
          spacing 0.50000
          counterclockwise
          nVertices 2
          0.00000 0.00000 1.00000
          0.00000 0.00000 4.00000
     end_<location>
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
     begin_<sbr>
          bounding_box
     end_<sbr>
end_<cylinder>
```

### Tx Polygon

```
begin_<polygon>Untitled Tx Polygon
     TxSet 7
     active
     vertical_line no
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AntennaPatternScale 1.00000
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude 0.0000000000
               latitude 0.0000000000
               visible no
               sealevel
          end_<reference>
          spacing 0.50000
          offset 0.00000
          begin_<face>
               nVertices 5
               0.00000 0.00000 2.00000
               2.00000 0.00000 2.00000
               2.00000 3.00000 2.00000
               1.00000 4.00000 2.00000
               0.50000 5.00000 2.00000
          end_<face>
     end_<location>
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
     begin_<sbr>
          bounding_box
     end_<sbr>
end_<polygon>
```

## Tx Vertical Surface

```
begin_<VerticalSurface> Tx Vertical surface
     TxSet 8
     active
     vertical_line no
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AntennaPatternScale 1.00000
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude -0.0001257230
               latitude 0.0000856971
               visible no
               terrain
          end_<reference>
          HorizontalSpacing 0.50000
          VerticalSpacing 0.50000
          Height 4.00000
          nVertices 2
          0.00000 0.00000 0.00000
          4.94851 0.00000 0.00000
     end_<location>
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
     begin_<sbr>
          bounding_box
     end_<sbr>
end_<VerticalSurface>
```

### Tx Points On Face

```
begin_<PointsOnFace> Tx Points on Face
    TxSet 9
    active
    WasActive Yes
    vertical_line no
    cube_size 0.53385
    CVxLength 10.00000
    CVyLength 10.00000
    CVzLength 10.00000
    AntennaPatternScale 1.00000
    CVsVisible no
    CVsThickness 3
    begin_<location>
        begin_<reference>
            cartesian
            longitude 0.0000000000
            latitude 0.0000000000
            visible no
            terrain
        end_<reference>
        nVertices 1
        9.82264 1.42472 0.00000
        begin_<face>
            double_sided
            Material 0
            nVertices 4
            -18.00000 11.00000 0.00000
            1.00000 11.00000 0.00000
            1.00000 11.00000 3.00000
            -18.00000 11.00000 3.00000
        end_<face>
    end_<location>
    begin_<antenna>
        antenna 0
        waveform -1
        rotation_x 0.00000
        rotation_y 0.00000
        rotation_z 0.00000
        power 0.00000
    end_<antenna>
end_<PointsOnFace>
```

## Tx Polygon (On Face)

```
begin_<polygon> Tx Polygon (On Face)
    TxSet 10
    active
    vertical_line no
    CVxLength 10.00000
    CVyLength 10.00000
    CVzLength 10.00000
    AntennaPatternScale 1.00000
    CVsVisible no
    CVsThickness 3
    begin_<location>
        begin_<reference>
            cartesian
            longitude 0.0000000000
            latitude 0.0000000000
            visible no
            sealevel
        end_<reference>
        spacing 2.00000
        offset 0.00000
        begin_<face>
            double_sided
            nVertices 4
            -18.00000 0.00000 0.00000
            -18.00000 11.00000 0.00000
            -18.00000 11.00000 3.00000
            -18.00000 0.00000 3.00000
        end_<face>
    end_<location>
    begin_<antenna>
        antenna 0
        waveform -1
        rotation_x 0.00000
        rotation_y 0.00000
        rotation_z 0.00000
        power 0.00000
    end_<antenna>
    begin_<sbr>
        bounding_box
    end_<sbr>
end_<polygon>
```

✓ This set is created by selecting *Cover with* in the face's context menu.

### Tx Sphere Set

```
begin_<sphere> > Tx Sphere Set
     TxSet 11
     active
     vertical_line no
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AutoPatternScale
     ShowDescription yes
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude -0.0002972014
               latitude -0.0003480607
               visible no
               terrain
          end_<reference>
          radius 121.30000
          phistart 0.00000
          phistop 360.00000
          thetastart 0.00000
          thetastop 180.00000
          spacing 0.50000
          counterclockwise
          nVertices 1
          0.00000 0.00000 2.00000
     end_<location>
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
     begin_<sbr>
          bounding_box
     end_<sbr>
     pattern_show_arrow no
     pattern_show_as_sphere no
     generate_p2p no
end_<sphere>
```

### Tx Set From File

```
begin_<userdefined> Tx Set from File
     TxSet 12
     active
     vertical_line yes
     cube_size 0.25000
     CVxLength 10.00000
     CVyLength 10.00000
     CVzLength 10.00000
     AntennaPatternScale 1.00000
     CVsVisible no
     CVsThickness 3
     begin_<location>
          begin_<reference>
               cartesian
               longitude 0.0000000000
               latitude 0.0000000000
               visible no
               terrain
          end_<reference>
          filename D:\XGtd_Projects\PointFile.pts
     end_<location>
     begin_<antenna>
          antenna 0
          waveform -1
          rotation_x 0.00000
          rotation_y 0.00000
          rotation_z 0.00000
          power 0.00000
     end_<antenna>
end_<userdefined>
```

## Tx Trajectory Set From File

The following is an example of a user-defined *Trajectory* file that can be imported into Rosslyn streets example.

```
begin_<parameters>
     format rx
     minimum_time 0.0
     maximum_time 10.0
     time_increment 0.50
     time_units seconds
     angle_units degrees
     cartesian
     longitude -77.0738143921
     latitude 38.8944740295
     terrain
     from_trajectory
end_<parameters>
[time] [x] [y] [z] [roll] [pitch] [yaw]
0.00 0.0000 0.0000 2.0000 81.07298882 0.0000 0.0000
0.50 0.7759 4.9394 2.0000 81.07300795 0.0000 0.0000
1.00 1.5518 9.8789 2.0000 81.07301847 0.0000 0.0000
1.50 2.3276 14.8183 2.0000 81.07300004 0.0000 0.0000
2.00 3.1035 19.7577 2.0000 81.07285447 0.0000 0.0000
2.50 3.8794 24.6972 2.0000 81.07299357 0.0000 0.0000
3.00 4.6553 29.6366 2.0000 81.07305338 0.0000 0.0000
3.50 5.4312 34.5761 2.0000 81.07298225 0.0000 0.0000
4.00 6.2071 39.5155 2.0000 81.07298225 0.0000 0.0000
4.50 6.9829 44.4549 2.0000 81.07305338 0.0000 0.0000
5.00 7.7588 49.3944 2.0000 81.07281245 0.0000 0.0000
5.50 8.5347 54.3338 2.0000 81.07298225 0.0000 0.0000
6.00 9.3106 59.2732 2.0000 81.07305824 0.0000 0.0000
6.50 10.0865 64.2127 2.0000 81.07298871 0.0000 0.0000
7.00 10.8623 69.1521 2.0000 81.07297093 0.0000 0.0000
7.50 11.6382 74.0915 2.0000 81.07291108 0.0000 0.0000
8.00 12.4141 79.0310 2.0000 81.07298871 0.0000 0.0000
8.50 13.1900 83.9704 2.0000 81.07297093 0.0000 0.0000
9.00 13.9659 88.9098 2.0000 81.07302428 0.0000 0.0000
9.50 14.7418 93.8493 2.0000 81.07297093 0.0000 0.0000
10.00 15.5176 98.7887 2.0000 81.07298871 0.0000 0.0000
```

### Tx Plane Wave

Plane Waves can only be modeled for transmitter sets.

```
begin_<PlaneWave> Plane Wave
     TxSet 13
     active
     begin_<location>
          begin_<reference>
               cartesian
               longitude 0.0001325697
               latitude 0.0001325697
               elevation 8.7272539139
               visible no
               sealevel
          end_<reference>
          theta 45.00000
          phi 45.00000
          generate_p2p yes
          begin_<PlaneWaveBoundary>
               nVertices 4
               13.06494 13.89828 10.53077
               16.44883 12.77032 8.93559
               16.44883 15.61550 6.92374
               13.06494 16.74346 8.51892
          end_<PlaneWaveBoundary>
     end_<location>
     begin_<antenna>
          polarization theta
          waveform 0
          power 1.00000
          preferredUnit powerDensity
     end_<antenna>
end_<PlaneWave>
```

# Appendix E

# Material Definition Format

*In this appendix, you will learn...*

- how to format a material file

This appendix provides several examples of singular MATERIAL definitions. Material are stored as part of a feature within a (*.object) or `*.cbr` file. There is no limit on the number of materials that can be defined within a file, and it is permissible for the FEATURE to include MATERIALS that are not currently assigned to any face.

✓ When used in a feature file, the material definitions must precede geometrical data.

- Appendix A describes the notation for the following file formats.

## E.1 Material Definition Format

The general format for a MATERIAL is:

```
begin_<Material> [short description]
     description [notes] (optional)
     material [ID number]
     [material type]
     thickness [thickness in m]
     [material display information]
     [material parameters]
end_<Material>
```

where:

- *[short description]* - Text entered by the user to describe the material. Description must be less than 72 characters.

- *[ID number]* - An integer number associated with the material. The value associates a material with a feature.
- *[material type]* - Keyword identifying the type of material.
- *[material display information]* - the keywords used here, including `ambient`, `diffuse`, `specular`, `emission`, and `shininess`, control the color and appearance of the faces in the GUI.
  - ✓ Some of these parameters can be changed once the feature file is loaded into the interface, but others, such as the “shininess”, can only be changed by editing the file.
  - ✓ It is safe to omit these lines from the file if it is created from another software package. In this case, default values will be assigned to the material when the file is loaded into the XGtd GUI and will be included in the properties when the FEATURE is saved from the GUI.
- *[material parameters]* - Keywords and values specific to the type of material.

## E.2 Material Definition Examples

The code has been tabbed for readability.

### Dielectric Half-Space

```
begin_<Material> short description
    description notes (optional)
    Material 1
    DielectricHalfspace
    Thickness 0.30
    begin_<Color>
        ambient 0.500000 0.500000 0.500000 1.000000
        diffuse 0.500000 0.500000 0.500000 1.000000
        specular 0.500000 0.500000 0.500000 1.000000
        emission 0.000000 0.000000 0.000000 0.000000
        shininess 50.000000
    end_<Color>
    begin_<DielectricLayer>
        conductivity 0.0150
        permittivity 15.0000
        roughness 0.000
        thickness 0.300
    end_<DielectricLayer>
end_<Material>
```

### Layered Dielectric

```
begin_<Material> short description
     description notes (optional)
     Material 1
     LayeredDielectric
     begin_<Color>
          ambient 0.500000 0.500000 0.500000 1.000000
          diffuse 0.500000 0.500000 0.500000 1.000000
          specular 0.500000 0.500000 0.500000 1.000000
          emission 0.000000 0.000000 0.000000 0.000000
          shininess 50.000000
     end_<Color>
     nLayers 2
     begin_<DielectricLayer> description
          conductivity 0.0010
          permittivity 2.8000
          roughness 0.000
          thickness 0.013
     end_<DielectricLayer>
     begin_<DielectricLayer> description
          conductivity 0.0010
          permittivity 4.4400
          roughness 0.000
          thickness 0.125
     end_<DielectricLayer>
end_<Material>
```

### PEC Backed Layer

```
begin_<Material> short description
     description notes (optional)
     Material 1
     PECBackedLayer
     thickness 0.300
     begin_<Color>
          ambient 0.500000 0.500000 0.500000 1.000000
          diffuse 0.500000 0.500000 0.500000 1.000000
          specular 0.500000 0.500000 0.500000 1.000000
          emission 0.000000 0.000000 0.000000 0.000000
          shininess 50.000000
     end_<Color>
     begin_<DielectricLayer>
          conductivity 0.0150
          permittivity 15.0000
          roughness 0.000
```

```
        thickness 0.300
    end_<DielectricLayer>
end_<Material>
```

## Constant Coefficient

```
begin_<Material> short description
    description notes (optional)
    Material 1
    ConstantCoefficient
    thickness 0.300
    begin_<Color>
        ambient 0.500000 0.500000 0.500000 1.000000
        diffuse 0.500000 0.500000 0.500000 1.000000
        specular 0.500000 0.500000 0.500000 1.000000
        emission 0.000000 0.000000 0.000000 0.000000
        shininess 50.000000
    end_<Color>
    reflection_pl 1.000000
    reflection_pr 1.000000
    transmission_pl 0.000000
    transmission_pr 0.000000
    roughness 0.000
end_<Material>
```

## Perfect Electrical Conductor

```
begin_<Material> short description
    description notes (optional)
    Material 1
    PEC
    thickness 0.000
    begin_<Color>
        ambient 0.500000 0.500000 0.500000 1.000000
        diffuse 0.500000 0.500000 0.500000 1.000000
        specular 0.500000 0.500000 0.500000 1.000000
        emission 0.000000 0.000000 0.000000 0.000000
        shininess 50.000000
    end_<Color>
    roughness 0.000
end_<Material>
```

## Free Space

```
begin_<Material> short description
     description notes (optional)
     Material 1
     Freespace
     thickness 0.300
     begin_<Color>
          ambient 0.000000 0.000000 0.000000 1.000000
          diffuse 0.000000 0.000000 0.000000 1.000000
          specular 0.000000 0.000000 0.000000 1.000000
          emission 0.000000 0.000000 0.000000 0.000000
          shininess 50.000000
     end_<Color>
end_<Material>
```

## User-Defined

```
begin_<Material> short description
     description notes (optional)
     Material 1
     UserDefined
     thickness 0.000
     begin_<Color>
          ambient 0.500000 0.500000 0.500000 1.000000
          diffuse 0.500000 0.500000 0.500000 1.000000
          specular 0.500000 0.500000 0.500000 1.000000
          emission 0.000000 0.000000 0.000000 0.000000
          shininess 50.000000
     end_<Color>
     reflection_filename path to file with reflection coefficients
     transmission_filename path to file with transmission coefficients
end_<Material>
```

### Reflection/Transmission Coefficient File

The reflection and transmission coefficients of a user-defined material must be stored in separate files. Each file contains parameters describing how the data is represented and formatted. Figure E.1 shows a visual description of the reflection and transmission coefficients.

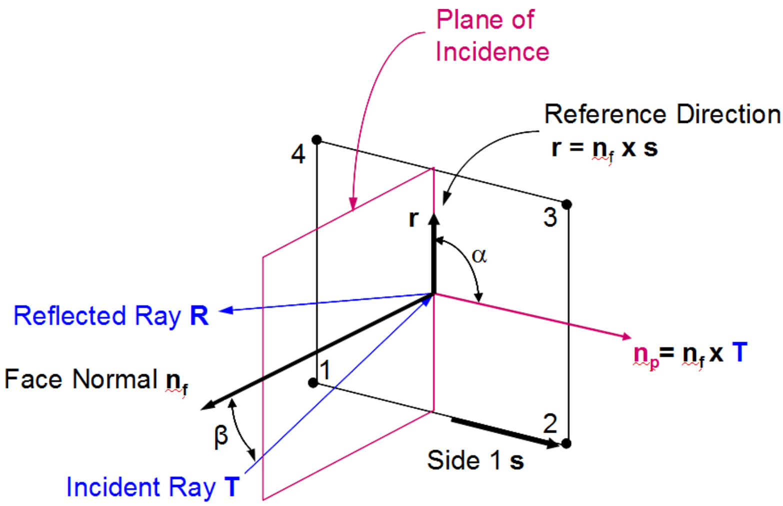


Figure E.1: A description of user-defined material coefficients

Concerning the above figure, note the following:

- The Plane of Incidence is determined by the face normal $\mathbf{n}_f$ and the incident ray $\mathbf{T}$.
- The Incident Angle, $\beta$, is the angle between the incoming ray and the face normal.
- $\alpha$ is the angle between the reference direction and the normal of the Plane of Incidence:

$$\alpha = arccos(\mathbf{r} \cdot \mathbf{n}_p) \tag{E.1}$$

- The reference direction, $\mathbf{r}$, is the cross product of the face normal and the unit vector from Vertex 1 to Vertex 2.

The reflection/transmission coefficient file is formatted in the following manner:

```
begin_<parameters>
     reflection <or> transmission
     frequency_min 900e6
     frequency_max 900e6
     frequency_inc 1.e6
     alpha_min 0
     alpha_max 90
     alpha_inc 45
     beta_min 0
     beta_max 90
     beta_inc 10
     magandphase <or> realandimag
     magnitude dB <or> linear
     phase degrees <or> radians
     side 1
end_<parameters>
begin_<frequency> 1900 MHz
```

```
    begin_<plane> 0 Degrees
          0 -5.0 135.0 -5.0 135.0
          .
          .
          90 0.0 180.0 0.0 0.00
    end_<plane>
    begin_<plane> 90 Degrees
          0 -9.0 135.0 -9.0 135.0
          .
          .
          90 0.0 180.0 0.0 0.00
    end_<plane>
end_<frequency>
```

A brief description of the possible keywords follows:

`alpha_min` - minimum incident plane direction

`alpha_max` - maximum incident plane direction

`alpha_inc` - increment between incident planes

`beta_min` - minimum incident angle

`beta_max` - maximum incident angle

`beta_inc` - increment between incident angles

`frequency_min` - minimum frequency in Hz

`frequency_max` - maximum frequency in Hz

`frequency_inc` - frequency increment in Hz

`magandphase` - magnitude and phase of coefficient

`realandimag` - real and imaginary parts of coefficient

`magnitude` - units for magnitude

`phase` - units for phase

`side` - side on the face relative to which the incident plane angle is measured

`reflection` - data represents reflection coefficients

`transmission` - data represents transmission coefficients

`begin_<frequency>` and `end_<frequency>` - data for each frequency is placed between these delimeters. They must be present even if the file only contains data for a single frequency.

`begin_<plane>` and `end_<plane>` - data for each incident plane is placed between these delimeters. They must be present even if only a single incident plane is present. The format of the data for each incident plane is:

```
incidence angle
```

`magnitude of coefficient` (perpendicular to incident plane)

`phase` (perpendicular)

`magnitude` (parallel)

`phase` (parallel)

✓ The limits on the incidence plane angle (alpha) and the incidence angle (beta) are $0^\circ$ to $90^\circ$, with $0^\circ$ referenced to the face normal.

In the above example, the "`side 1`" entry specifies that the incident plane is measured with respect to the first side on the face. Unfortunately, at present there is no simple way of using the GUI to determine the ordering of the sides on a particular face. However, this may not be a serious drawback, since all vertical faces created using XGtd's chamber creation tool and object editor have a horizontal edge as the first side on the face, and second side is always a vertical edge.

- ✓ The VIEW VERTICES button on the FACE PROPERTIES Window allows the user to determine the direction of the edges on any face.

# Appendix F

# Waveform Definition Format

*In this appendix, you will learn...*

- how to format a waveform file

WAVEFORM definitions are located in the project file (*.xgtd). All waveforms except *Sinusoids* require a time domain waveform file. XGtd's user interface automatically generates this file when the calculation engine is called from within the interface. For users who are creating their own project files without aid from the interface, it may be easier to use the *User-Defined* Waveform type with an associated time domain or frequency domain waveform file.

The code has been tabbed for readability.

- Appendix A describes the notation for the following file formats.

## F.1 Built-in Waveform File Format

The general format for a built-in WAVEFORM is:

```
begin_<Waveform> [short description]
     [waveform type]
     waveform [ID number]
     [waveform properties]
     TDFilename [path to time domain waveform file (*.wf)]
end_<Waveform>
```

where:

- *[short description]* - Text entered by the user to describe the waveform. Description must be less than 72 characters.
- *[waveform type]* - Keyword identifying the type of waveform. A list of the keywords for built-in waveforms is provided in Table F.1.

- *[ID number]* - An integer number associated with the waveform. The value associates a waveform with antennas, transmitters and receivers.
- *[waveform properties]* - Keywords and values specific to the type of waveform that define the waveforms shape and properties. A description of the keywords is provided below:
  - `CarrierFrequency` [*frequency in Hz*] - Center frequency of the waveform
  - `Bandwidth` [*frequency in Hz*]
  - `PulseWidth` [*time in seconds*] - Time duration of the waveform
  - `Phase` [*degrees*] - Initial phase shift for *Sinusoid* waveforms
  - `Rolloff` [*real value between 0.0 and 1.0*] - Excess bandwidth roll-off factor
  - `TaperRatio` [*real value between 0.0 and 1.0*] - Constant-to-taper ratio used by the *Tukey* Waveform
  - `Dispersive` - When present, the calculation of electric field as a function of time for certain output types will include dispersion on the broadband pulse.

Table F.1: Built-in Waveform Keywords and Associated Properties

| Waveform Type | CarrierFrequency | Bandwidth | PulseWidth | Phase | Rolloff | TaperRatio | Dispersive |
|---|---|---|---|---|---|---|---|
| Blackman | ✓ | | ✓ | | | | Optional |
| Chirp | ✓* | | ✓ | ✓ | ✓ | | Always |
| Gaussian | ✓ | | ✓ | | | | Optional |
| GaussianDerivative | | ✓ | | | | | Always |
| Hamming | ✓ | | ✓ | | | | Optional |
| Hanning | ✓ | | ✓ | | | | Optional |
| RaisedCosine | ✓ | | ✓ | | ✓ | | Optional |
| RootRaisedCosine | ✓ | | ✓ | | ✓ | | Optional |
| Sinusoid | ✓ | ✓ | | ✓ | | | N/A |
| Tukey | ✓ | | ✓ | | | ✓ | Optional |

* Chirp Waveforms require both a *Start frequency* and *Stop frequency*, in Hz. They also require a *Frequency Variation* (Linear or Exponential), which describes how the frequency of the Chirp waveform varies between the start and stop frequencies.

## F.2 Waveform Examples

Examples of three representative waveforms are given below.

### Sinusoid

```
begin_<Waveform> Sinusoid
    Sinusoid
    waveform 0
```

```
    CarrierFrequency 1000000000.000
    phase 0.000
    bandwidth 1000000.000
end_<Waveform>
```

### Blackman

```
begin_<Waveform> Blackman
    Blackman
    waveform 1
    CarrierFrequency 1000000000.000
    PulseWidth 1.000000e-007
    Phase 0.00000
end_<Waveform>
```

### Dispersive Blackman

```
begin_<Waveform> Dispersive Blackman
    Blackman
    waveform 2
    CarrierFrequency 1000000000.000
    PulseWidth 1.000000e-007
    Phase 0.000
    Dispersive
end_<Waveform>
```

### Chirp

```
begin_<Waveform> Chirp
    Chirp
    waveform 3
    CarrierFrequency 1625977050.781
    PulseWidth 1.00e-008
    Dispersive
    TDFilename C:\LocalFiles\XGtd\Chirp\Chirp.waveform0.TD.wf
    Phase 0.000
    Rolloff 0.250
    FrequencyVariation Linear
    StartFrequency 1000.000
    StopFrequency 2000.000
end_<Waveform>
```

## F.3 User-Defined Waveforms

In addition to the built-in waveforms, XGtd allows *User-Defined* waveforms. They can be defined in either the time domain (TDFilename) or frequency domain (FDFilename).

*User-Defined* Waveforms are specified in the <project_name>.xgtd file using the following format:

```
begin_<Waveform> [short description]
     UserDefinedWaveform
     waveform [ID number]
     FDFilename <or> TDFilename
     [full path to the waveform file (*.wf)]
end_<Waveform>
```

The user may specify time- or frequency-domain samples of a waveform by referencing an external file beginning with the following parameters:

```
begin_<parameters>
     TimeDomain <or> FrequencyDomain
     MinValue 0
     MaxValue 6e-007
     Increment 2.08333e-011
     RealImag <or> MagPhase
     Phase degrees <or> radians
end_<parameters>
```

The first keyword in the parameters section must be either TimeDomain or FrequencyDomain, which indicates that waveform data to follow are samples in time or frequency. The MinValue, MaxValue, and Increment keywords specify the time or frequency range over which the samples were taken and the constant increment between each sample.

The last two possible keywords are only relevant to files which contain frequency-domain samples. RealImag specifies that the last two columns of data represent the real and imaginary components, respectively, of the waveform in the frequency domain. Alternatively, MagPhase specifies that the last two columns of data represent the magnitude and the phase, respectively, of the waveform in the frequency domain. If magnitude and phase are present, the last keyword Phase degrees or Phase radians must be used to specify whether the unit of the phase values is degrees or radians.

After the parameters section, time- or frequency-domain samples must be listed which cover the entire range, MinValue to MaxValue, specified at the top of the file.

If the samples are in the **time-domain**, two columns are required which contain the time and corresponding amplitude of the waveform.

- ✓ Time domain waveforms should start at 0 amplitude at (t=0) and should end at zero amplitude.
- ✓ It may be necessary to ramp up or down the amplitude at the start and end times to avoid high frequency components in the FFT.
- ✓ The minimum sampling rate for time domain waveforms should be the period/10.

```
0.000000e+000 0.000000e+000
```

```
2.500000e-008 9.510565e-001
5.000000e-008 8.090170e-001
.
.
4.500000e-007 8.090171e-001
4.750000e-007 9.510565e-001
5.000000e-007 0.000000e+000
```

If the samples are in the **frequency-domain**, three columns are required which contain the frequency and corresponding real and imaginary, or magnitude and phase of the waveform, e.g.:

```
0.0000000E+00 -0.4422828E-02 0.0000000E+00
0.1725166E+07 0.2102985E+01 0.1144734E+03
0.3450332E+07 0.8423647E+01 0.2288267E+03
.
.
0.3795365E+08 0.9898643E+03 0.2309188E+04
0.3967881E+08 0.1078863E+04 0.2394124E+04
0.4140398E+08 0.1171272E+04 0.2476455E+04
```

# Appendix G

# Antenna Definition Format

*In this appendix, you will learn...*

- how to format the antenna section of an XGtd project file

ANTENNA definitions are located in the project file `*.xgtd`.

The code has been tabbed for readability.

## G.1 Antenna File Format

The general format for an antenna definition is:

```
begin_<antenna> [short description of the Tx/Rx set, 72 characters max]
      antenna [integer ID number for the antenna]
      type [antenna type]
      waveform [integer ID number of the assigned waveform]
      cable_loss [transmission line loss in dB]
      min_snr [receiver threshold in dBm]
      [antenna properties]
end_<antenna>
```

where:

- `antenna` [*integer ID number for the set*] - The ID number used to refer to this antenna. Antenna ID numbers are used to assign antennas to transmitter and receiver sets in the `*.tx` and `*.rx` files.
- `type` [*antenna type*] - The keyword that follows defines the type of antenna. XGtd uses the following keywords for antenna type:
  - `CircularAperture`
  - `CircularLoop`
  - `CircularPatch`

  - `directional`
  - `HalfWaveDipole`
  - `Helical`
  - `Horn`
  - `userdefined`
  - `isotropic`
  - `linear_dipole`
  - `linear_monopole`
  - `omnidirectional`
  - `ParabolicReflector`
  - `QuarterWaveMonopole`
  - `RectangularAperture`
  - `RectangularPatch`
  - `short_dipole`
  - `short_monopole`
  - `SquareLoop`

- `waveform [`*`integer ID number of the assigned waveform`*`]` - A reference to the waveform assigned to the antenna.
- `cable_loss [`*`transmission line loss in dB`*`]` - Value is used to simulate line losses, feed losses, or other system losses. The value can either be positive or negative.
- `min_snr [`*`receiver threshold in dBm`*`]` - Individual ray paths whose power falls below this value are ignored when evaluating the power at a receiver point.
- *`[antenna properties]`* - Antenna properties vary by the type of antenna used. The properties are generally used in formulas to generate a full 3D antenna pattern. Examples of keywords that appear in this section include `polarization`, `height`, `radius`, etc. Some antennas, such as the *Quarter-Wave Monopole* and the *Square Loop*, do not require any additional properties.

  ▶ See Section G.2 for applicable keywords for each type of set.

## G.2 Antenna File Examples

Below are examples of ANTENNA definitions for the built-in antennas supported by XGtd.

▶ Appendix A describes the notation for the following file formats.

### Circular Aperture

```
begin_<antenna> Circular Aperture
     antenna 0
     type CircularAperture
     waveform 0
     cable_loss 0
     min_snr -250
     radius 1
     EFieldDistribution uniform <or> TE11
end_<antenna>
```

### Circular Loop

```
begin_<antenna> Circular Loop
     antenna 1
     type CircularLoop
     waveform 0
     cable_loss 0
     min_snr -250
     radius 1
end_<antenna>
```

### Circular Patch

```
begin_<antenna> Circular Patch
     antenna 2
     type CircularPatch
     waveform 0
     cable_loss 0
     min_snr -250
     epsilon 1
     radius 1
     height 1
end_<antenna>
```

### Directional

```
begin_<antenna> Directional
     antenna 3
     type directional
     waveform 0
     polarization vertical <or> horizontal
     cable_loss 0
```

```
     min_snr -250
     eplane_hpbw 90
     hplane_hpbw 90
     eplane_fnbw 180
     hplane_fnbw 180
end_<antenna>
```

### Half-wave Dipole

```
begin_<antenna> Half-wave Dipole
     antenna 4
     type HalfWaveDipole
     waveform 0
     polarization vertical <or> horizontal
     cable_loss 0
     min_snr -250
end_<antenna>
```

### Helical

```
begin_<antenna> Helical
     antenna 5
     type Helical
     waveform 0
     polarization RightCircular <or> LeftCircular
     cable_loss 0
     min_snr -250
     radius 1
     length 1
     pitch 1
end_<antenna>
```

### Horn

```
begin_<antenna> Horn
     antenna 6
     type Horn
     waveform 0
     polarization vertical <or> horizontal
     cable_loss 0
     min_snr -250
     HornApertureWidth 1.6489
     HornApertureHeight 0.8244
     FeedApertureWidth 0.1499
```

```
      FeedApertureHeight 0.0749
      Length 1.499
end_<antenna>
```

### Isotropic

```
begin_<antenna> Isotropic
      antenna 7
      type isotropic
      waveform 0
      polarization vertical <or> horizontal
      cable_loss 0
      min_snr -250
end_<antenna>
```

### Linear Dipole

```
begin_<antenna> Linear Dipole
      antenna 8
      type linear_dipole
      waveform 0
      polarization vertical <or> horizontal
      cable_loss 0
      min_snr -250
      length 1
end_<antenna>
```

### Linear Monopole

```
begin_<antenna> Linear Monopole
      antenna 9
      type linear_monopole
      waveform 0
      cable_loss 0
      min_snr -250
      length 1
end_<antenna>
```

### Omnidirectional Antenna

```
begin_<antenna> Omnidirectional
      antenna 10
      type omnidirectional
      waveform 0
```

```
    polarization vertical <or> horizontal <or> RightCircular <or> LeftCircular
    cable_loss 0
    min_snr -250
    eplane_hpbw 90
    eplane_fnbw 180
end_<antenna>
```

### Parabolic Reflector Antenna

```
begin_<antenna> Parabolic Reflector
    antenna 11
    type ParabolicReflector
    waveform 0
    polarization vertical <or> horizontal
    cable_loss 0
    min_snr -250
    radius 1
    blockageradius 0.1
    EFieldDistribution Uniform <or> Parabolic <or> ParabolicSquared
    EdgeTaper -20
end_<antenna>
```

### Quarter-Wave Monopole Antenna

```
begin_<antenna> Quarter-wave Monopole
    antenna 12
    type QuarterWaveMonopole
    waveform 0
    cable_loss 0
    min_snr -250
end_<antenna>
```

### Rectangular Aperture Antenna

```
begin_<antenna> Rectangular Aperture
    antenna 13
    type RectangularAperture
    waveform 0
    cable_loss 0
    min_snr -250
    sideA 1
    sideB 1
    EFieldDistribution uniform <or> TE10
end_<antenna>
```

### Rectangular Patch Antenna

```
begin_<antenna> Rectangular Patch
     antenna 14
     type RectangularPatch
     waveform 0
     cable_loss 0
     min_snr -250
     epsilon 1
     length 1
     width 1
     height 1
end_<antenna>
```

### Short Dipole Antenna

```
begin_<antenna> Short Dipole
     antenna 15
     type short_dipole
     waveform 0
     polarization vertical <or> horizontal
     cable_loss 0
     min_snr -250
end_<antenna>
```

### Short Monopole Antenna

```
begin_<antenna> Short Monopole
     antenna 16
     type short_monopole
     waveform 0
     cable_loss 0
     min_snr -250
end_<antenna>
```

### Square Loop Antenna

```
begin_<antenna> Square Loop
     antenna 17
     type SquareLoop
     waveform 0
     cable_loss 0
     min_snr -250
end_<antenna>
```

## User-Defined Antenna

```
begin_<antenna> User Defined Antenna
     antenna 18
     type userdefined
     waveform 0
     cable_loss 0
     min_snr -250
     gain 7.782
     filename D:\XGtd\UserDefinedAntenna.uan
end_<antenna>
```

- See Section 7.5 for a description of the `*.uan` file format.

# Appendix H

# Propagation Paths Output File Format

*In this appendix, you will learn...*

→ the format of a propagation paths output file

The endpoint locations that make up the ray path segments between a TRANSMITTER and RECEIVER are accessible in the `*.paths...p2m` output file. These files can be viewed with a text editor. A separate file is created for each active transmitter point and receiver set in the project. The filename includes the transmitter and receiver set ID numbers of the rays that are contained within the file, such as:

```
ThinPlate.paths.t001_01.r001.p2m
(<Project name>.paths.t<tx number>_<tx set number>.r<rx set
number>.p2m)
```

The number of rays saved for each Tx/Rx pair can be set by selecting *Project→Output Properties* and entering the desired value next to *Maximum number of paths*. The default value is 25, and the maximum number that can be saved depends on the value of *Maximum stored paths*.

- *Maximum stored paths* sets the number of ray paths used in XGtd's calculation of output between a Tx/Rx pair. The default setting is 250 paths.
- *Maximum rendered paths* sets the number of rays that are saved to a file, not the number used in the calculation of output.
- Appendix A describes the notation for the following file formats.

## H.1 Organization of the Propagation Paths Output File

### Propagation Paths File Header

The propagation paths output file begins with a description of the receiver set.

#Receiver Set: <*Short description of Rx set*>
<*Total number of receivers in set*>

### Propagation Paths Receiver Header

Following the header is a summary of transmission between the transmitter and the first receiver point in the receiver Set.

<*Rx ID number*> <*Number of saved paths between Tx/Rx pair*>
<*Total received power (dBm)*> <*Mean time of arrival (sec)*> <*Delay spread (sec)*>

This header is repeated at the beginning of the list of interactions for each subsequent receiver in the set.

### Propagation Paths Data

Following the receiver header is a list of the individual ray paths between the transmitter and receiver points. The rays are listed in order of strength starting with the strongest ray. The number of rays listed depends of the value of *Maximum number of paths*. XGtd will save this quantity of rays, provided they exist, for the given the number of reflections, transmissions, and diffractions defined in the project's STUDY AREA. $\theta_a$, $\phi_a$, $\theta_d$ and $\phi_d$ are the angles of arrival and departure. The total received power between transmitter and receiver points includes phase information, and therefore cannot be generated by simply summing the received power of the individual rays listed.

<*RayID*> <*#interactions*> <*Ray'srcvdpower(dBm)*> <*Timeofarrival*> <$\theta_a$> <$\phi_a$> <$\theta_d$> <$\phi_d$>
<*List of interactions* (Tx:Transmitter, R:Reflection, T:Transmission, D:Diffraction, Rx:Receiver)>
<*Tx X coordinate (m)*> <*Tx Y coordinate (m)*> <*Tx Z coordinate (m)*>
<*interaction X coordinate*> <*interaction Y coordinate*> <*interaction Z coordinate*>
.
.
<*Rx X coordinate*> <*Rx Y coordinate*> <*Rx Z coordinate*>

The file organization continues until the rays for all the receiver points in the given receiver set are listed.

## H.2 Example paths.p2m File

An example of the `*.paths...p2m` for a simple example containing a single transmitter point and an receiver set containing two receiver points is given below. The *Maximum number of paths* was set to 4.

```
#Receiver Set:  Rx points
2
1 4
-46.89 0.12070E-06 0.31116E-07
1 1 -63.7590 0.95380E-07 90.0000 59.3935 90.0000
120.6065
```

```
Tx-R-Rx
-0.3939858E-06 -0.9692657E-06 1.500
-0.1817652E+01 0.2916138E+01 1.500
-0.1456212E+02 -0.1847147E+02 1.500
2 2 -63.8990 0.95904E-07 84.0122 59.3935 84.0122
120.6065
Tx-R-R-Rx
-0.3939858E-06 -0.9692657E-06 1.500
-0.1817654E+01 0.2916138E+01 1.874
-0.7281058E+01 -0.6163047E+01 2.843
-0.1456212E+02 -0.1847147E+02 1.500
3 2 -63.8990 0.95904E-07 95.9878 59.3935 95.9878
120.6065
Tx-R-R-Rx
-0.3939858E-06 -0.9692657E-06 1.500
-0.1817654E+01 0.2916138E+01 1.126
-0.7281058E+01 -0.6163047E+01 0.157
-0.1456212E+02 -0.1847147E+02 1.500
4 3 -64.3611 0.97456E-07 101.8477 59.3935 78.1523
120.6065
Tx-R-R-R-Rx
-0.3939858E-06 -0.9692657E-06 1.500
-0.1817652E+01 0.2916138E+01 2.249
-0.3640530E+01 -0.8833901E-02 2.843
-0.1092159E+02 -0.1231726E+02 0.157
-0.1456212E+02 -0.1847147E+02 1.500
2 4
-49.33 0.12175E-06 0.25628E-07
1 1 -64.8169 0.10706E-06 90.0000 8.3745 90.0000
351.6255
Tx-R-Rx
-0.3939858E-06 -0.9692657E-06 1.500
0.4956527E+01 -0.7527094E+00 1.500
-0.2153662E+02 -0.4675870E+01 1.500
2 2 -64.9173 0.10753E-06 95.3384 8.3745 95.3384
351.6255
Tx-R-R-Rx
-0.3939858E-06 -0.9692657E-06 1.500
0.4956527E+01 -0.7527094E+00 1.017
-0.5655232E+01 -0.2337935E+01 0.157
-0.2153662E+02 -0.4675870E+01 1.500
3 2 -64.9173 0.10753E-06 84.6616 8.3745 84.6616
351.6255
Tx-R-R-Rx
-0.3939858E-06 -0.9692657E-06 1.500
0.4956527E+01 -0.7527094E+00 1.983
-0.5655232E+01 -0.2337935E+01 2.843
-0.2153662E+02 -0.4675870E+01 1.500
```

```
4 3 -65.2561 0.10892E-06 100.5857 8.3745 79.4143
351.6255
Tx-R-R-R-Rx
-0.3939858E-06 -0.9692657E-06 1.500
0.4956527E+01 -0.7527094E+00 2.466
0.2285461E+01 -0.1168969E+01 2.843
-0.1359593E+02 -0.3506904E+01 0.157
-0.2153662E+02 -0.4675870E
```

# Appendix I

# Troubleshooting

*In this appendix, you will learn...*

→ how to correct known issues in XGtd

## I.1 Rendering Graphics

Some video cards may exhibit problems when rendering graphics. Updating video card drivers or allowing Windows to handle the OpenGL rendering may fix these issues. Some Matrox, Intel and SiS video cards have been known to exhibit problems.

First try to obtain an updated driver from the video card manufacturer. Most manufacturers provide direct downloads from their website. If this does not resolve the issue, it is possible to force Windows to handle OpenGL calls. Doing this will significantly affect program performance; however, it will allow XGtd to function correctly.

To force Windows to handle OpenGL calls, adjust your local Display Properties by navigating to Advanced Settings and setting the *Hardware Acceleration* to "None". If after restarting XGtd OpenGL errors continue to appear, contact Remcom Professional Support. If this fixes the problem it may be possible to move the slider to a higher level of hardware acceleration to improve rendering speed and avoid rendering issues.

# Appendix J

# SBIR Rights Notice

# Glossary

**Anechoic Chamber**

An enclosed 3-D space composed of single-sided inner and outer faces 38

**Antenna**

An object associated with a transmitter or receiver which propagates a specific wave pattern 77

**Calculation Log**

The window which records all information generated while performing simulations 14

**Chamber**

See Anechoic Chamber 38

**Context Menu**

The right-click menu of an item 15

**Control Point**

The origin of the Control Vectors 45

**Control Vectors**

A set of basis vectors centered on the control point of an object, which describes its current orientation within the projects global coordinate system 45

**Creeping Waves**

Waves that propagate along a curved surface 155

**Database**

A table of antenna, material or waveform components that are accessible to all projects 227

**Double-Sided Face**

A FULL 3D, VERTICAL PLANE, and URBAN CANYON specific setting for a face, allowing rays to interact with both sides of the face, independent of the face normal 29

**Eigenray Method**

A method used to trace ray paths between transmitters and receivers which satisfies Fermat's Principle of least time, except that there is no refraction at transmissions 151

**Faces**

The components that make up a feature, composed of planar polygons with three or more vertices 29

**Feature**

A geometric object with material properties that comprises all chamber or object data loaded from a file 29

**Free Space Propagation Model**

A model which simulates propagation assuming no interactions with features and an electric field which decreases as $1/r$ with distance in all directions 164

**Full 3D Propagation Model**

A model which uses the SBR method and allows the user to set the ray spacing and the maximum number of reflections, transmissions, and diffractions 148

**GUI (Graphical User Interface)**

The XGtd display screen 5

**Images**

A tab in the Main Window which lists all image files included in the project 6

**Main Window**

The parent window of XGtd, which contains the main tabs that control the elements of the project 5

**Material**

A set of display and electromagnetic properties applied to a feature, in part or whole 55

**Movie Player**

The window used to play back available simulation results 14

**One-Sided Face**

A FULL 3D, VERTICAL PLANE, and URBAN CANYON specific setting for a face, allowing rays to interact only when incident on the side with the outward normal 29

**Output Filters**

Filters applied to XGtd output to isolate ray paths with specific interactions and identify objects contributing to received power 223

**Output Tree**

The tree displayed in the Output tab of the Main Window 20

**Output**

Propagation predictions generated by the calculation engine 167

**Project Hierarchy**

The window used to navigate through the input and output data of a project 13

**Project View**

The window which displays the data which is currently loaded into the project 8

**RAM**

Radar Absorbing Material; a material commonly used in anechoic chambers 235

**Radar Cross Section (RCS)**

The area intercepting that amount of power which, when scattered isotropically, produces at the receiver a density which is equal to that scattered by the actual target 182

**Receiver**

A point that collects radiation 107

**Scale Bar**

A color-coded representation of output values displayed in the Project View 199

**Shedding Points**

In a creeping wave propagation model, the points at which electromagnetic rays leave a curved surface 155

**Shooting and Bouncing Ray (SBR) Method**

A method used to trace ray paths through the geometry without regard for the location of specific field points 149

**Soft Rotation**

A way to rotate Tx/Rx sets in the XY plane without them being X- or Y-axis aligned 129

**Study Area**

A user-defined region of the project in which to perform a simulation 135

**Surface Diffraction**

A ray deflection from an edge on the same facet as the proceeding ray deflection 151

**Transmitter**

The location of a source of input radiation 107

**Tx/Rx**

Transmitter/Receiver 2

**Uniform Theory of Diffraction (UTD)**

A high-frequency method for solving electromagnetic scattering problems 147

**Waveform**

A signal radiated from a transmitting antenna which is time and/or frequency dependent 67

**Wedge Diffraction**

A ray deflection that occurs at the point where the field becomes discontinuous 151

**X3D Ray Propagation Model**

A model which uses the SBR method and allows the user to set the ray spacing and the maximum number of reflections, transmissions, and diffractions 157

**XGtd**

A general purpose ray-based electromagnetic analysis tool 1

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315 S. Allen St., Suite 416
State College, PA 16801 USA

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