B

EM.Terrano

Tutorial Lessons

EMAG Technologies Inc.
775 Technology Dr. St. 300, Ann Arbor, MI 48108
Phone: (734) 996-3624 Fax: (734) 996-3623

11

EM.Terrano Tutorial Lesson 11

Performing Link Margin Analysis Over the Spherical Earth

Table of Contents

11.1 What You Will Learn

In this tutorial lesson, you will learn how to set up an aerial communication link above the earth and perform link margin analysis using the long-haul channel analyzer.

EM.Terrano Manual:

http://www.emagtech.com/wiki/index.php/EM.Terrano

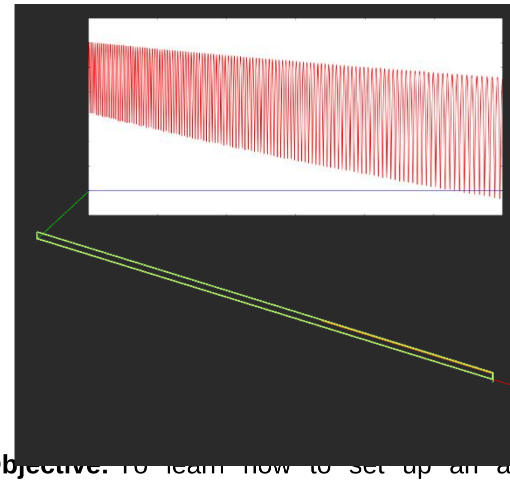
EM.Terrano Tutorial Gateway:

http://www.emagtech.com/wiki/index.php/EM.Cube#EM.Terrano_Documentation

Download projects related to this tutorial lesson:

http://www.emagtech.com/downloads/ProjectRepo/EMTerrano_Lesson11.zip

Tutorial Project: Performing Link Margin Analysis Over the Spherical Earth



Objective: To learn how to set up an aerial communication link and perform link margin analysis using long-haul channel analyzer.

Concepts/Features:

- Aerial Link
- Long-Haul Channel Analyzer
- Communication Link Solver
- Spherical Earth
- Link Margin vs. Range Plots
- Maximum Range

Minimum Version Required: All versions

11.2 Getting Started

Using the new project wizard, start a new "generic" project in the EM.Terrano module with the following parameters:

Starting Parameters	
Name	EMTerrano_Lesson11
Length Units	Meters
Frequency Units	GHz
Center Frequency	1GHz
Bandwidth	0.1GHz

11.3 A Note About Long-Haul Channel Analyzer

In Tutorial Lesson 9, you learned how to use the SBR channel analyzer to characterize the propagation channel independent of the transmitter and receiver properties. The shooting-bouncing-rays (SBR) method, as its name implies, shoots a large number of rays in all directions from each transmitter and traces these rays in the scene as they bounce off the ground and buildings, or are diffracted off building edges or penetrate the building walls. The rays that reach the receivers are recorded as the solution. The SBR channel analyzer assumes conceptual, non-physical, isotropic radiators at the transmitter and receiver locations and generates two data files with reserved names "sbr_channel_matrix.DAT" and "sbr_ray_path.DAT". These files contain all the information about the rays that arrive at each individual receiver in the computational domain. Once the channel is characterized and its transfer function is determined, you can use the communication link solver (based on EMAG's near-real-time Polarimatrix solver technology) to simulate the propagation scene with actual antennas and actual transmitter and receiver waveforms.

The SBR method assumes a flat ground at the bottom of the computational domain. The SBR simulations are accurate for computational domain sizes up to a few square kilometers. This covers most urban areas. At larger distances, the spherical shape of the earth must be taken into account. The earth has a nominal radius of 6,370 km. In a typical aerial link involving communicating aircraft, the range can easily exceed tens of kilometers. In this case, the ground distances must be measured along the surface of the spherical earth. The altitude of the aircraft at a certain location on the earth is measured along the normal to the surface of the earth passing through its center. Figure 1 shows a propagation scene with two aerial nodes with different altitudes above the spherical earth, where a_e denotes the radius of the earth and d denotes the ground distance.

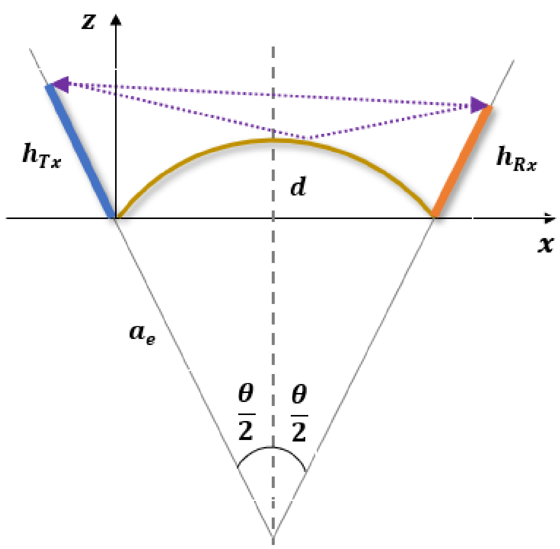


Figure 1. *A propagation scene with two aerial nodes of different altitudes above the spherical earth.*

The long-haul channel analyzer is intended for characterizing the propagation channel at long ranges in the presence of a spherical earth. It performs a 2D analysis in the vertical plane that passes through each transmitter-receiver pair and finds the direct line-of-sight (LOS) and ground-reflected rays originating from the transmitter and reaching the receiver. In the case of a perfect spherical earth with no obstructions such as irregular terrain or hills or mountains, there will be only one ground-reflected ray arriving at the receiver as seen from Figure 1. Similar to SBR channel analyzer, the long-haul channel analyzer generates two data files with reserved names "sbr_channel_matrix.DAT" and "sbr_ray_path.DAT" that contain all the information about the received rays. After running a long-haul channel analysis, you can use the communication link solver to simulate the propagation scene with actual antennas and actual transmitter and receiver waveforms. In a nutshell, both SBR and long-haul channel analyzer do the same thing, i.e., they characterize the channel transfer function, but they do it in different ways involving different approximations.

11.4 Defining the Transmitter & Receivers

In Tutorial Lesson 1, you learned how to first create point radiator sets to represent antennas and then create point transmitter and receiver sets associated with those radiators.

In this tutorial lesson, create a vertically (Z) polarized dipole transmitter (TX1) associated with the point radiator “TXB” and a grid of 3,000 vertically (Z) polarized receivers (RX1) associated with the point radiator “RXB”. Your transmitter will be located at Point_1(5000m, 0, 100m)

Object	Geometry	Block Group	Physical Structure	Location Coordinates
Point_1	Point	TXB	Point Radiators	(0, 0, 100m)

You should zoom to fit your structure into the screen using the keyboard shortcut **Ctrl+E** or by clicking the **Zoom Extents**  button of the **View Toolbar** (Figure 2). To create the grid of receivers, draw a point at the location (5000m, 0, 100m).

Object	Geometry	Block Group	Physical Structure	Location Coordinates
Point _2	Point	RXB	Point Radiators	(5000m, 0, 100m)

and build an array of points as indicated in the tables below (Figure 3):

Array Object	Parent Object	Element Count X	Element Count Y	Element Count Z	X Spacing	Y Spacing	Z Spacing
Point_2_Array_2	RXB	3000	1	1	1m	0	0

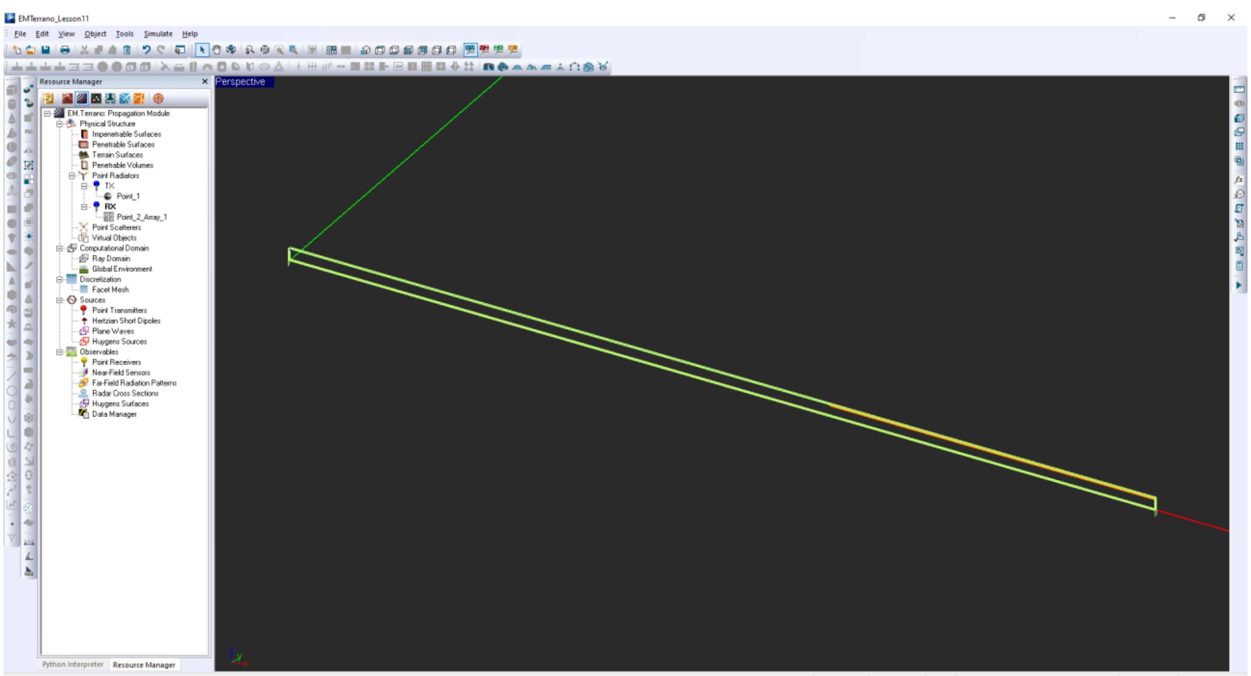


Figure 2. *The free-space propagation scene with two points 5000m apart.*

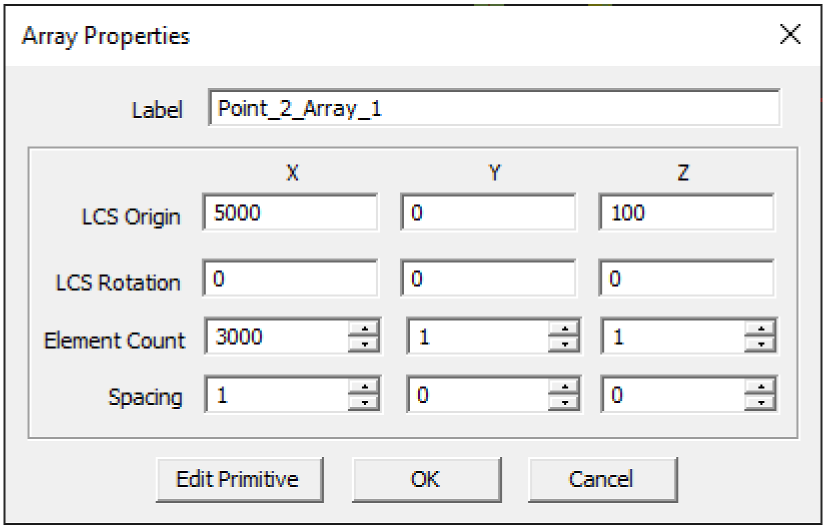


Figure 3. *The Array Properties dialog.*

Figure 4 shows the free-space propagation scene with the transmitter and receiver sets.

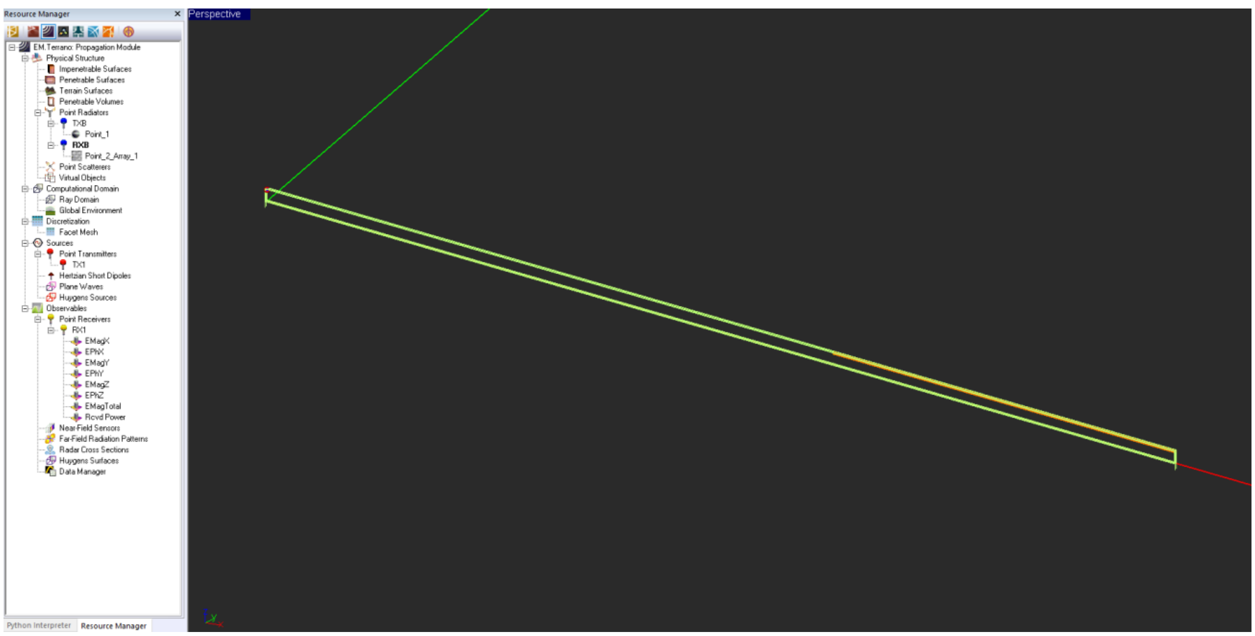


Figure 4. *The free-space propagation scene with the transmitter and receiver sets.*

Just for inspection, open the Transmitter Set property dialog. As shown in Figure 5, the default power of the transmitter is 1 Watt. Next, open the Receiver Set property dialog. As shown in Figure 6, the **Transmission or Receiver Filter Bandwidth** is set to 1 GHz. This is the same as the nominal bandwidth of the project, which is set at the beginning when starting a new project. Both the center frequency and bandwidth of the project can be set or modified from the Frequency Settings dialog or by double-clicking on the frequency value in the Status Bar to open this dialog. You can also see from Figure 5 that the default **Modulation Type** has been set to "None (Baseband Transmission)" and the default value of **Min Required SNR** is set to 10dB. For now, keep all the default settings and close the dialog.

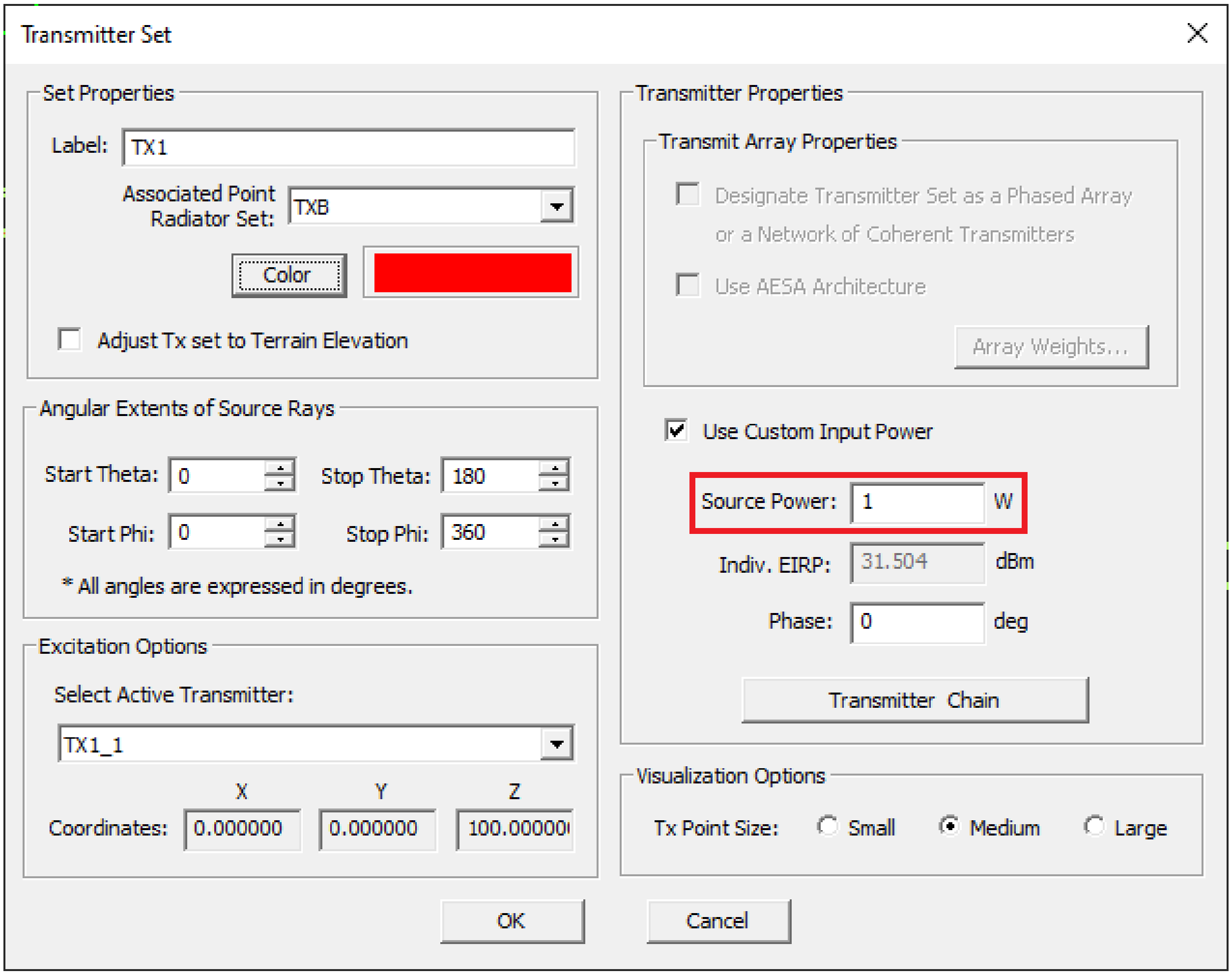


Figure 5. *The Transmitter Set property dialog.*

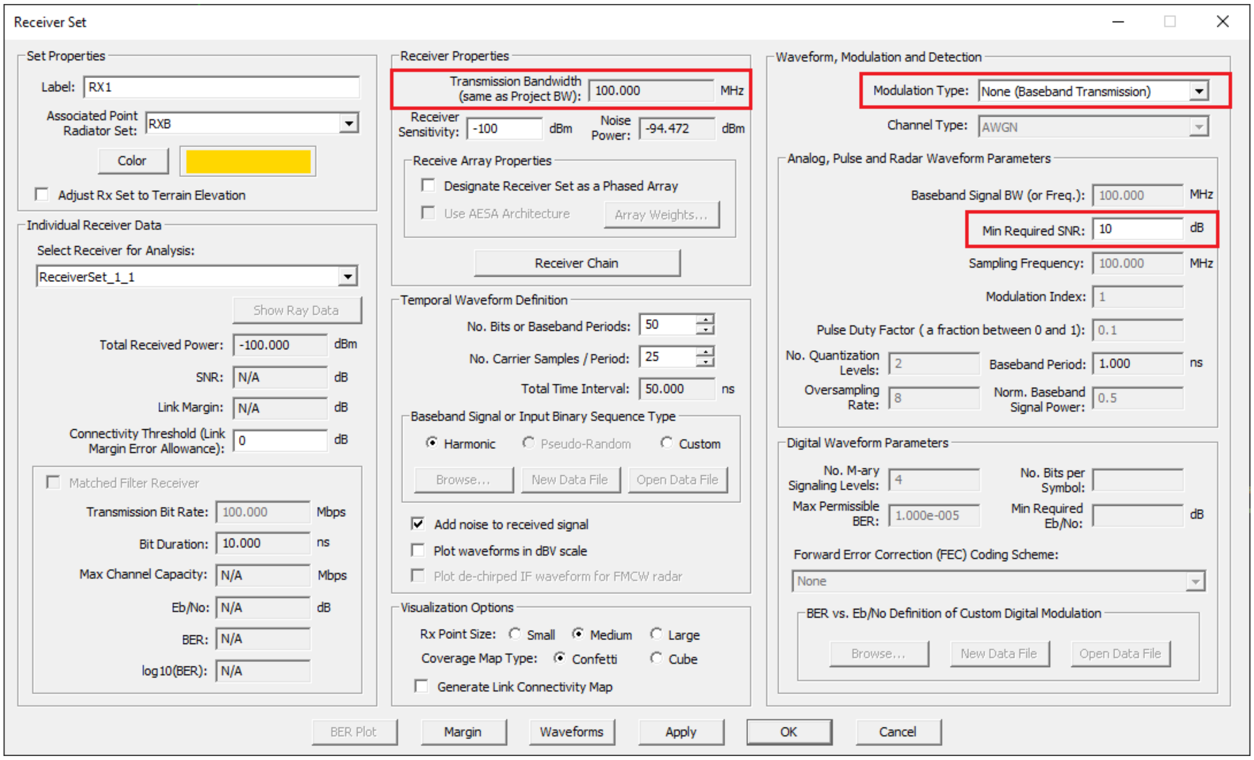


***Figure 6**. The Receiver Set property dialog.*

11.5 Running the Long-Haul Channel Analyzer

In this tutorial lesson, we will treat the propagation scenario of Figure 4 as a long-range link. In that case, EM.Terrano's simulation engine will consider a spherical earth model of the global ground in conjunction with a standard atmosphere model to perform the ray tracing simulation. The simulation in this case consists of two steps:

1. Running the "Long-Haul Channel Analyzer" to generate the transfer function of the channel.
2. Running the "Communication Link Solver" to generate the link data.

Open the Run Simulation dialog and select the simulation of the "Single-Frequency Analysis" option for the **Simulation Mode** and choose "Long-Haul Channel Analyzer" from the drop-down list labeled **Select Simulation or Solver Type** (Figure 7). Click the **Run** button of the dialog to start the simulation. Once the simulation is finished a message opens up saying this type of simulation doesn't have any visualization data just as a reminder.

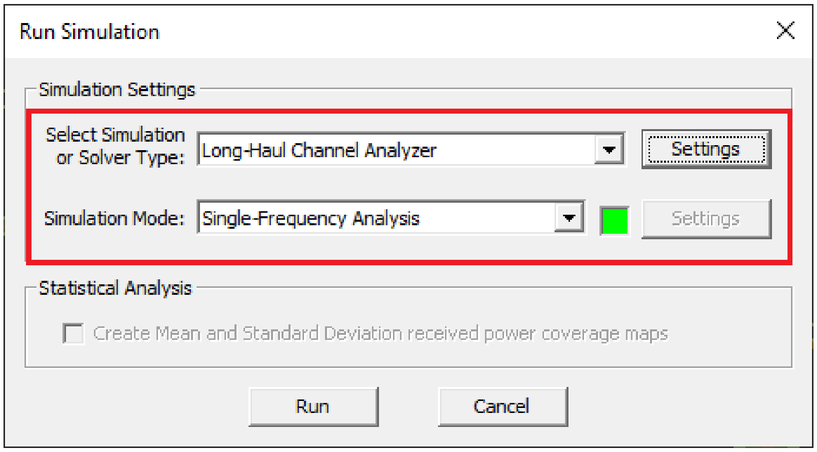
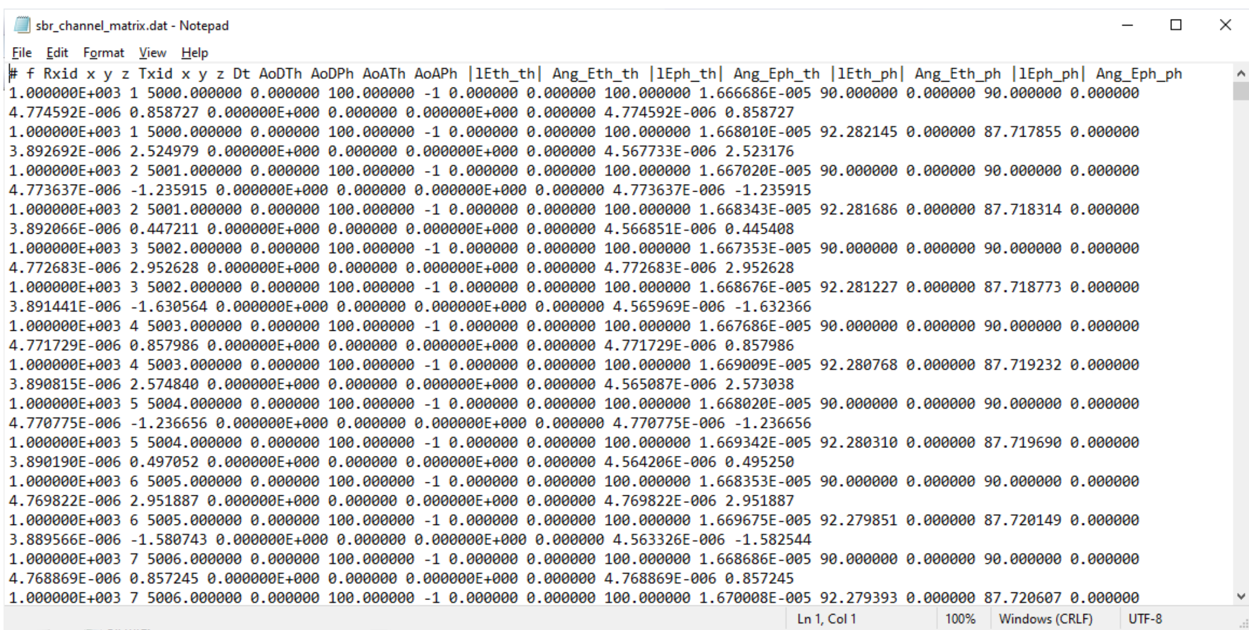


Figure 7. *EM.Terrano's Run Simulation dialog showing the Long-haul Channel Analyzer selected as the simulation/solver type.*

At the end of the Long-Haul channel analysis simulation, two data files called "sbr_channel_matrix.dat" and "sbr_ray_path.dat" (see Figures 8 and 9) are generated. The former file contains the delay, angles of arrival and departure and complex-valued elements of the channel matrix for all the individual rays that leave each transmitter and arrive at each receiver. The latter file contains the geometric aspects of each ray such as hit point coordinates.



sbr_channel_matrix.dat - Notepad

File Edit Format View Help

```
# f Rxid x y z Txid x y z Dt AoDTh AoDPh AoATh AoAPh |lEth_th| Ang_Eth_th |lEph_th| Ang_Eph_th |lEth_ph| Ang_Eth_ph |lEph_ph| Ang_Eph_ph
1.000000E+003 1 5000.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.666686E-005 90.000000 0.000000 90.000000 0.000000
4.774592E-006 0.858727 0.000000E+000 0.000000 0.000000E+000 0.000000 4.774592E-006 0.858727
1.000000E+003 1 5000.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.668010E-005 92.282145 0.000000 87.717855 0.000000
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1.000000E+003 2 5001.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.667020E-005 90.000000 0.000000 90.000000 0.000000
4.773637E-006 -1.235915 0.000000E+000 0.000000 0.000000E+000 0.000000 4.773637E-006 -1.235915
1.000000E+003 2 5001.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.668343E-005 92.281686 0.000000 87.718314 0.000000
3.892066E-006 0.447211 0.000000E+000 0.000000 0.000000E+000 0.000000 4.566851E-006 0.445408
1.000000E+003 3 5002.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.667353E-005 90.000000 0.000000 90.000000 0.000000
4.772683E-006 2.952628 0.000000E+000 0.000000 0.000000E+000 0.000000 4.772683E-006 2.952628
1.000000E+003 3 5002.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.668676E-005 92.281227 0.000000 87.718773 0.000000
3.891441E-006 -1.630564 0.000000E+000 0.000000 0.000000E+000 0.000000 4.565969E-006 -1.632366
1.000000E+003 4 5003.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.667686E-005 90.000000 0.000000 90.000000 0.000000
4.771729E-006 0.857986 0.000000E+000 0.000000 0.000000E+000 0.000000 4.771729E-006 0.857986
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1.000000E+003 5 5004.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.668020E-005 90.000000 0.000000 90.000000 0.000000
4.770775E-006 -1.236656 0.000000E+000 0.000000 0.000000E+000 0.000000 4.770775E-006 -1.236656
1.000000E+003 5 5004.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.669342E-005 92.280310 0.000000 87.719690 0.000000
3.890190E-006 0.497052 0.000000E+000 0.000000 0.000000E+000 0.000000 4.564206E-006 0.495250
1.000000E+003 6 5005.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.668353E-005 90.000000 0.000000 90.000000 0.000000
4.769822E-006 2.951887 0.000000E+000 0.000000 0.000000E+000 0.000000 4.769822E-006 2.951887
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1.000000E+003 7 5006.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.668686E-005 90.000000 0.000000 90.000000 0.000000
4.768869E-006 0.857245 0.000000E+000 0.000000 0.000000E+000 0.000000 4.768869E-006 0.857245
1.000000E+003 7 5006.000000 0.000000 100.000000 -1 0.000000 0.000000 100.000000 1.670008E-005 92.279393 0.000000 87.720607 0.000000
```

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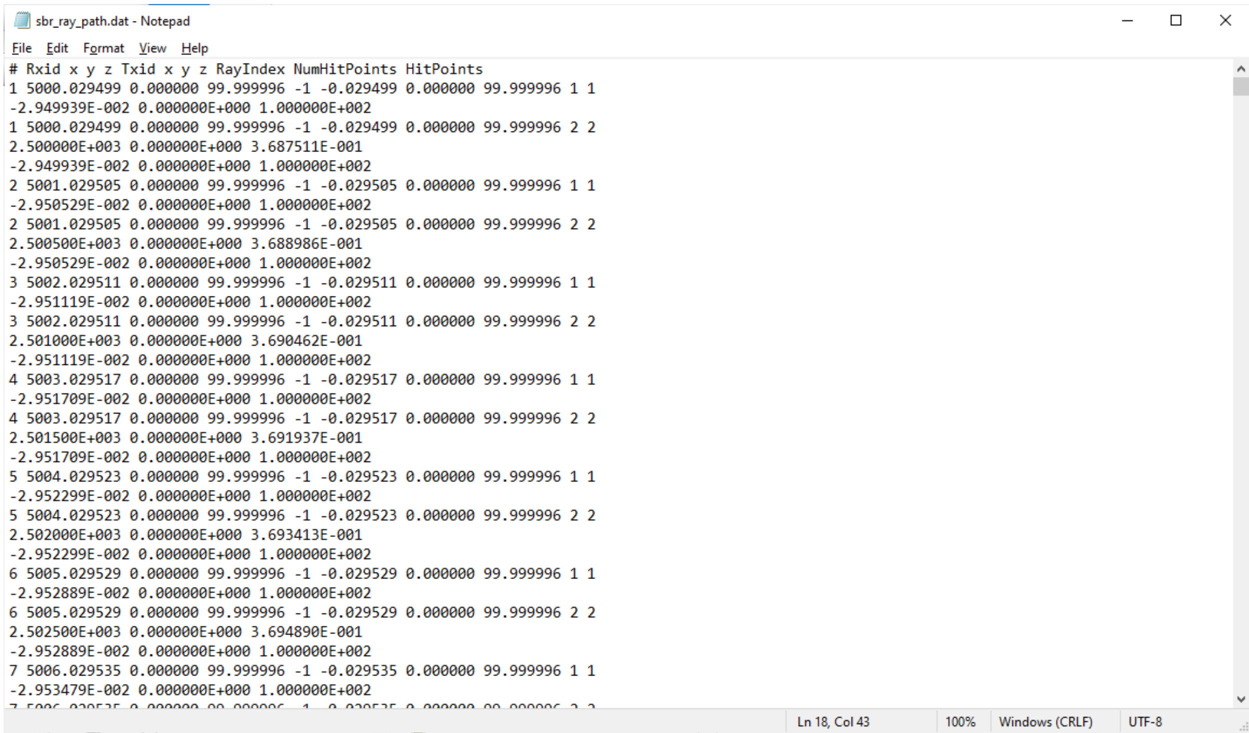
Figure 8. *The contents of sbr_channel_matrix.DAT data file.*




```
# Rxid x y z Txid x y z RayIndex NumHitPoints HitPoints
1 5000.029499 0.000000 99.999996 -1 -0.029499 0.000000 99.999996 1 1
-2.949939E-002 0.000000E+000 1.000000E+002
1 5000.029499 0.000000 99.999996 -1 -0.029499 0.000000 99.999996 2 2
2.500000E+003 0.000000E+000 3.687511E-001
-2.949939E-002 0.000000E+000 1.000000E+002
2 5001.029505 0.000000 99.999996 -1 -0.029505 0.000000 99.999996 1 1
-2.950529E-002 0.000000E+000 1.000000E+002
2 5001.029505 0.000000 99.999996 -1 -0.029505 0.000000 99.999996 2 2
2.500500E+003 0.000000E+000 3.688986E-001
-2.950529E-002 0.000000E+000 1.000000E+002
3 5002.029511 0.000000 99.999996 -1 -0.029511 0.000000 99.999996 1 1
-2.951119E-002 0.000000E+000 1.000000E+002
3 5002.029511 0.000000 99.999996 -1 -0.029511 0.000000 99.999996 2 2
2.501000E+003 0.000000E+000 3.690462E-001
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4 5003.029517 0.000000 99.999996 -1 -0.029517 0.000000 99.999996 2 2
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5 5004.029523 0.000000 99.999996 -1 -0.029523 0.000000 99.999996 1 1
-2.952299E-002 0.000000E+000 1.000000E+002
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2.502500E+003 0.000000E+000 3.694890E-001
-2.952889E-002 0.000000E+000 1.000000E+002
7 5006.029535 0.000000 99.999996 -1 -0.029535 0.000000 99.999996 1 1
-2.953479E-002 0.000000E+000 1.000000E+002
```

Figure 9. *The contents of sbr_ray_path.DAT data file.*

Next, open again the Run Simulation dialog and select "Communication Link Solver" from the **Select Simulation or Solver Type Mode** drop-down list and choose "Transmitter Sweep" for the **Simulation Mode** (Figure 10). Click the **Run** button to proceed.

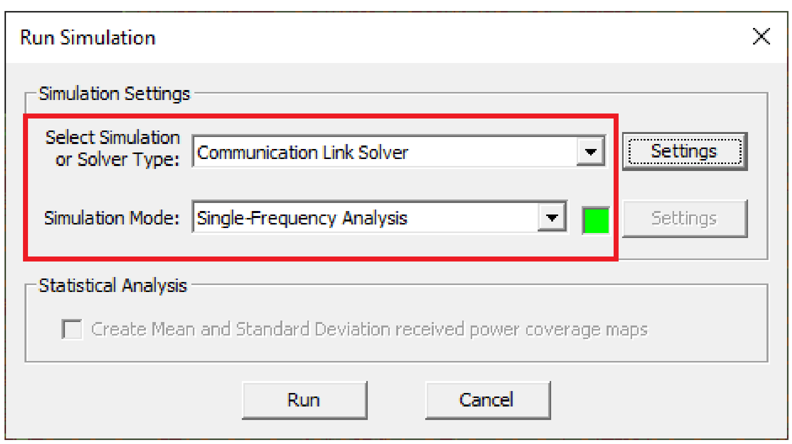


Figure 10. *Selecting Communication Link Solver in EM.Terrano's Run Simulation Dialog.*

11.6 Examining the Simulation Results

Unlike urban propagation scenes that produce colorful received power coverage maps under the **Point Receivers** item of the navigation tree, the resulting coverage map of this particular project is not very useful. Instead, we are more interested in the link margin graph. Open the property dialog of the Receiver Set as shown in Figure 11. In the section titled **Individual Receiver Data**, you see that the first receiver labeled "RX_1" has been selected; its **Total Received Power** is shown to be -71.481dBm and the computed **SNR** is 22.991dB.

The computed **Link Margin** is 12.991dB. The margin is computed with respect to the specified minimum required SNR, which was set to the default value of 10dB. You can select another receiver from the drop-down list and view the corresponding total received power, SNR and link margin value. Since the value of **Connectivity Threshold (Link Margin Error Allowance)** is set to 0dB, a link margin value above 0dB means that the communication link is closed, and the transmitter and the selected receiver are connected. The box labeled **Link ON** has a green color showing connectivity.

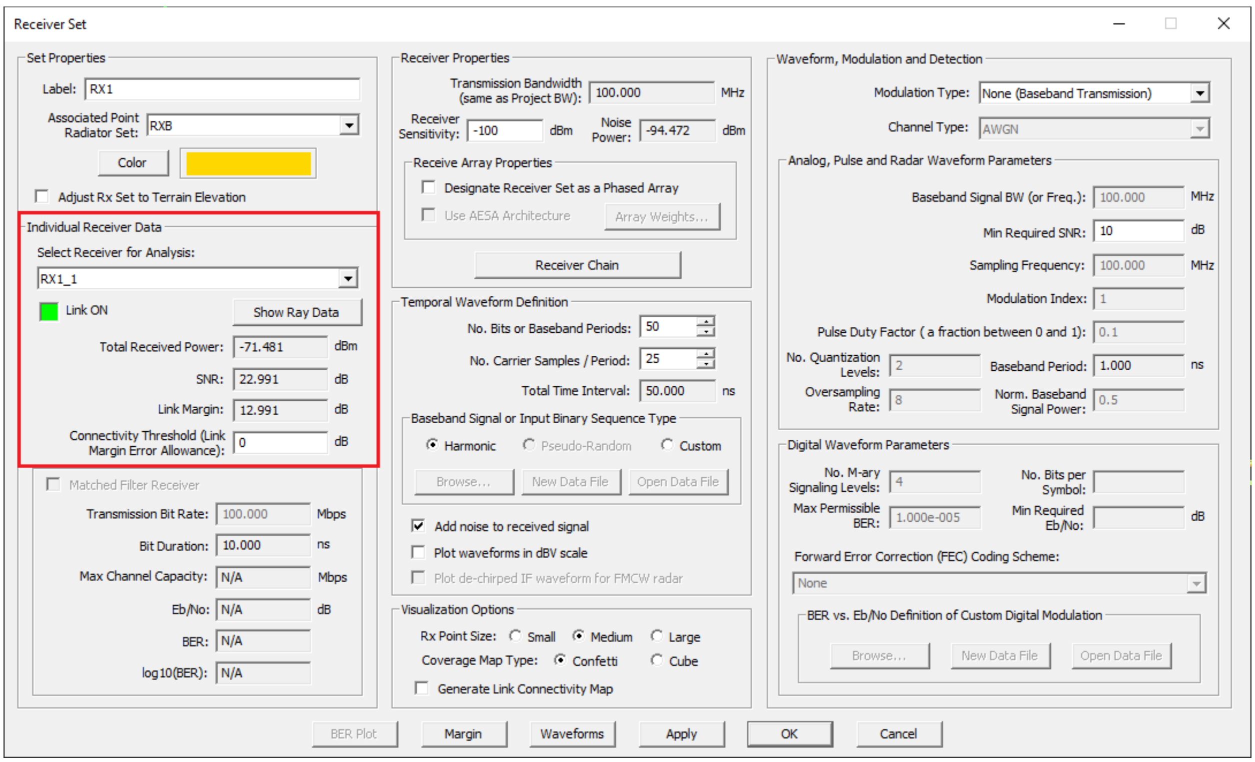


Figure 11. *The Receiver Set property dialog after running a communication link simulation.*

Click the **Margin** button at the bottom of the Receiver Set dialog and wait for the margin data to be calculated. The link margin plot opens up in a separate window as shown in Figure 12. This is a regular EM.Cube PyPlot window similar to the graphs you plot from EM.Cube's Data Manager. The generated link margin data are saved to a data file called "COMM_Link_Margin_Range.DAT", which can be accessed and opened from the Data Manager. As with other EM.Cube graphs, you must first close any open PyPloy window before plotting another graph or performing another computation. Besides "COMM_Link_Power_Range.DAT", two more data files called "COMM_Link_SNR_Range.DAT" and "COMM_Link_Margin_range.DAT" are also generated that contain the receiver power and SNR data vs. range.

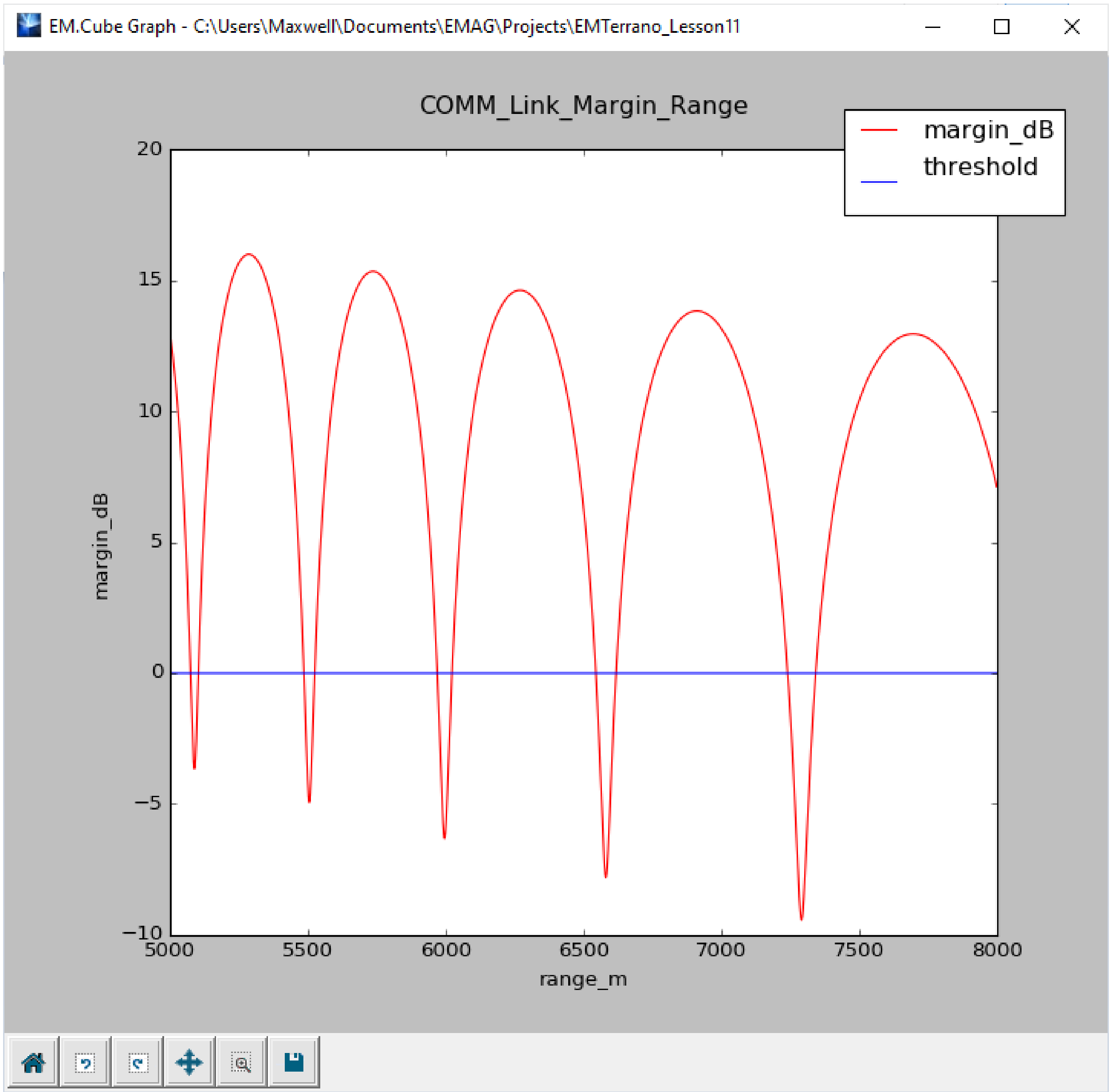


Figure 12. *A plot of the computed link margin vs. range at an altitude of 100m.*

11.7 Interpreting the Simulation Results

The range is defined as the distance between the transmitter and receiver nodes. The link margin is defined as the different between the computed signal-to-noise ratio (SNR) of each individual receiver and the **Minimum Required SNR** specified by the user, which has a default value of 10dB:

Link Margin = SNR - SNR_{min}

Oftentimes, a communication link designer may allow additional margin to account for various other factors not included in the simulation model. This is termed **Connectivity Threshold (Link Margin Error Allowance)** in the receiver set property dialog and has a default value of zero. The criterion for link connectivity is then defined as follows:

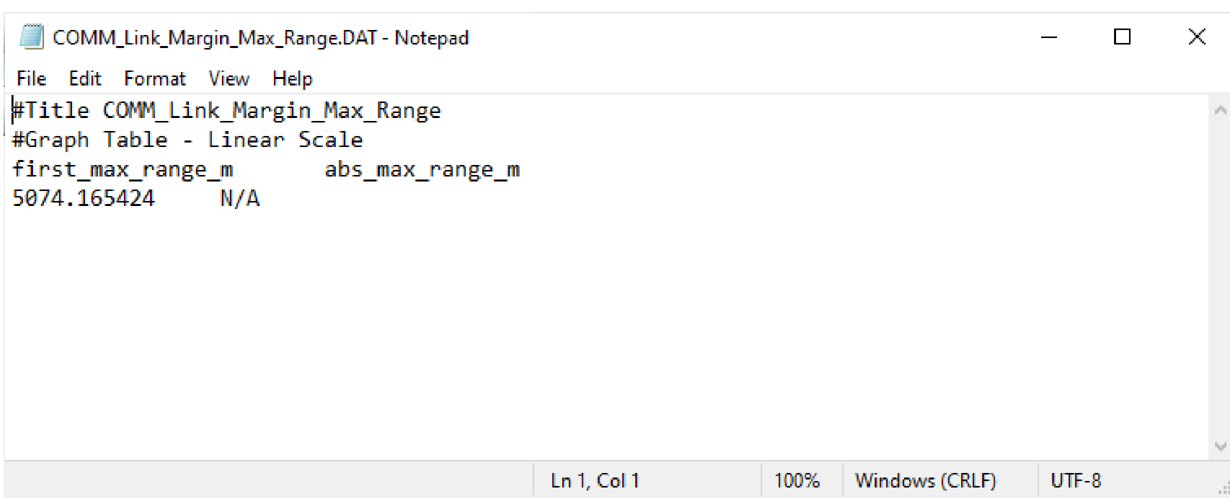
Link Margin - Connectivity Threshold ≥ 0

or

SNR – (SNR_{min} + Link Margin Error Allowance) ≥ 0

The 3,000 receiver points placed along a straight line form the transmitter represent the range of a moving receiver node with the spacing of 1m. In other words, you determine the received power by the mobile node as it moves away from the transmitter at increments of 1m. Figure 12 shows a successive pattern of constructive and destructive interferences. This is due to the coherent addition of the direct (LOS) and ground-reflected rays arriving at each receiver.

The blue horizontal line in Figure 12 shows the specified value of the **Connectivity Threshold (Link Margin Error Allowance)**. Whenever the red margin curve is above the blue line, the communication link is connected, and when it goes under, the link is disconnected. For this specific range of 5km to 8km, the first maximum range occurs at 5,074.2m, which is the first intercept of the link curve with the threshold line. At longer ranges, you get to a point after which the red link curve stays below the blue threshold line for good. That point is called the absolute maximum range as the link stays perpetually disconnected any further away. The values of the first maximum range and absolute maximum range are calculated and saved in a file called "COMM_Link_Margin_Max_Range.DAT" (Figure 13). In this case, the absolute maximum range cannot be determined, therefore, its value is indicated as "N/A".


COMM_Link_Margin_Max_Range.DAT - Notepad
File Edit Format View Help

```
#Title COMM_Link_Margin_Max_Range
#Graph Table - Linear Scale
first_max_range_m       abs_max_range_m
5074.165424     N/A
```

Ln 1, Col 1 | 100% | Windows (CRLF) | UTF-8

Figure 13. *The contents of COMM_Link_Margin_Max_Range.DAT file.*

11.8 Raising the Altitude of Aerial Nodes

As the next step, let us raise the altitude of the transmitter and receiver nodes to 500m and see how the link margin curve and the state of link connectivity are affected. To change the location of transmitters and receivers, you need to change the coordinates of their associated point radiators. Open the property dialog of the point object called "Point_1" and change its Z coordinate to 500. Then open the property dialog of the point array called "Point_2_Array_1" and change the Z coordinate to 500 (see Figure 14). Note that in the array property dialog, the reported coordinates represent those of the anchor element. Figure 15 shows the free-space propagation scene with the transmitter and receiver sets at an altitude of 500m.

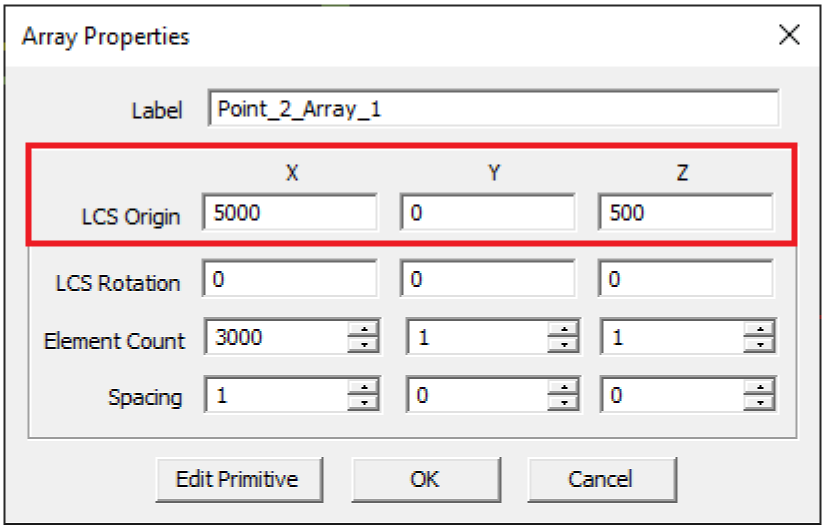


Figure 14. *Raising the altitude of the of the receiver nodes to 500m.*

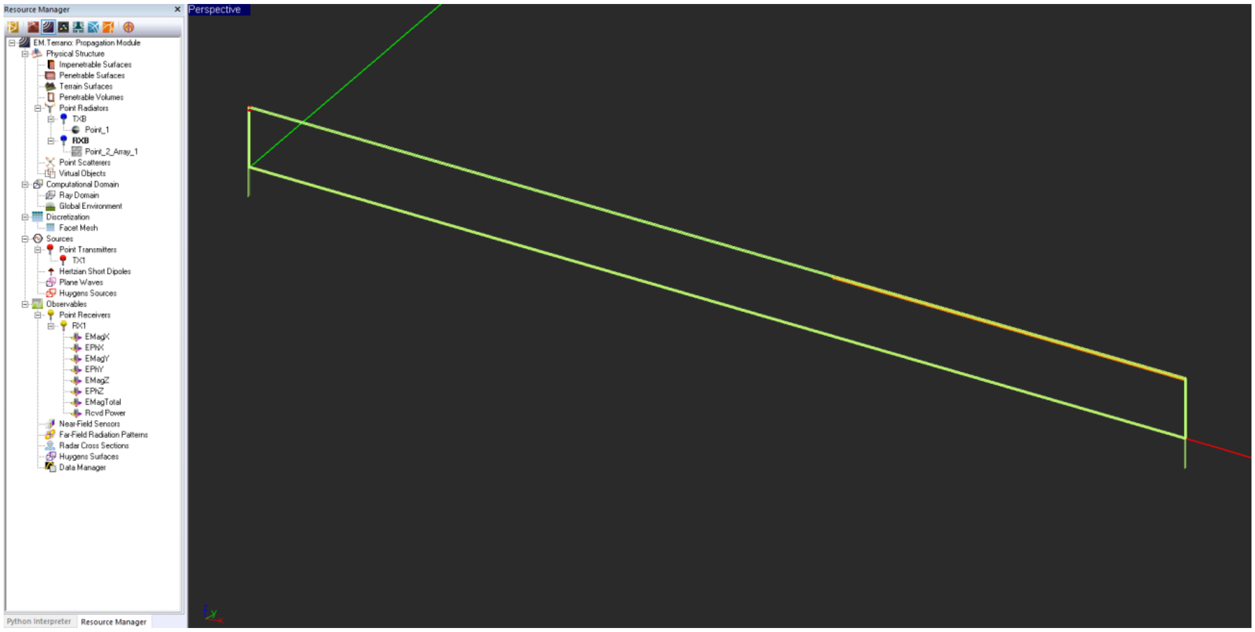


Figure 15. *The free-space propagation scene with the transmitter and receiver sets at an altitude of 500m.*

Let us next allow for 2 dB of possible errors in our propagation or system models, etc. In other words, let us bump up the connectivity threshold by 2 dB above the zero line. Open the receiver set dialog and set the value of **Connectivity Threshold** (**Link Margin Error Allowance)** equal to 6 (see Figure 16).

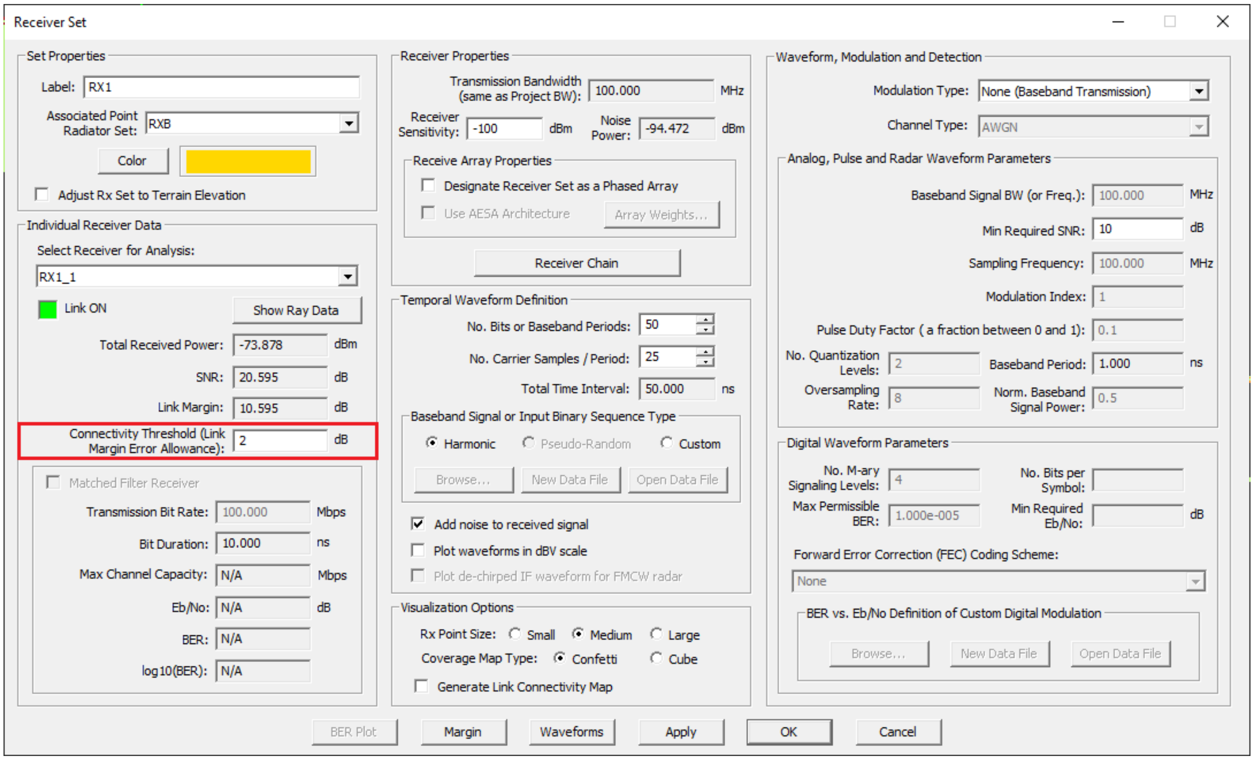


Figure 16. *Changing the value of Connectivity Threshold (Link Margin Error Allowance) in the Receiver Set dialog.*

Since the physical properties of the radiators have changed, you need to run the long-haul analyzer all over again. Next, run the communication link solver. Open the property dialog of the receiver set and click the **Margin** button to plot the link vs. range graph. The results are shown in Figure 17. It looks like this is a compressed and much denser version of the plot of Figure 12. Another big difference is that most of the red margin curve stays above the blue threshold line, meaning the link is connected most of the time.

Open the file called “COMM_Link_Margin_Max_Range.DAT”. You will see that the value of the first maximum range has increased to 7,482.2m. This means that up to a range of 7.48km, the communication link stays steadily connected even though the SNR value of the receiver fluctuates wildly.

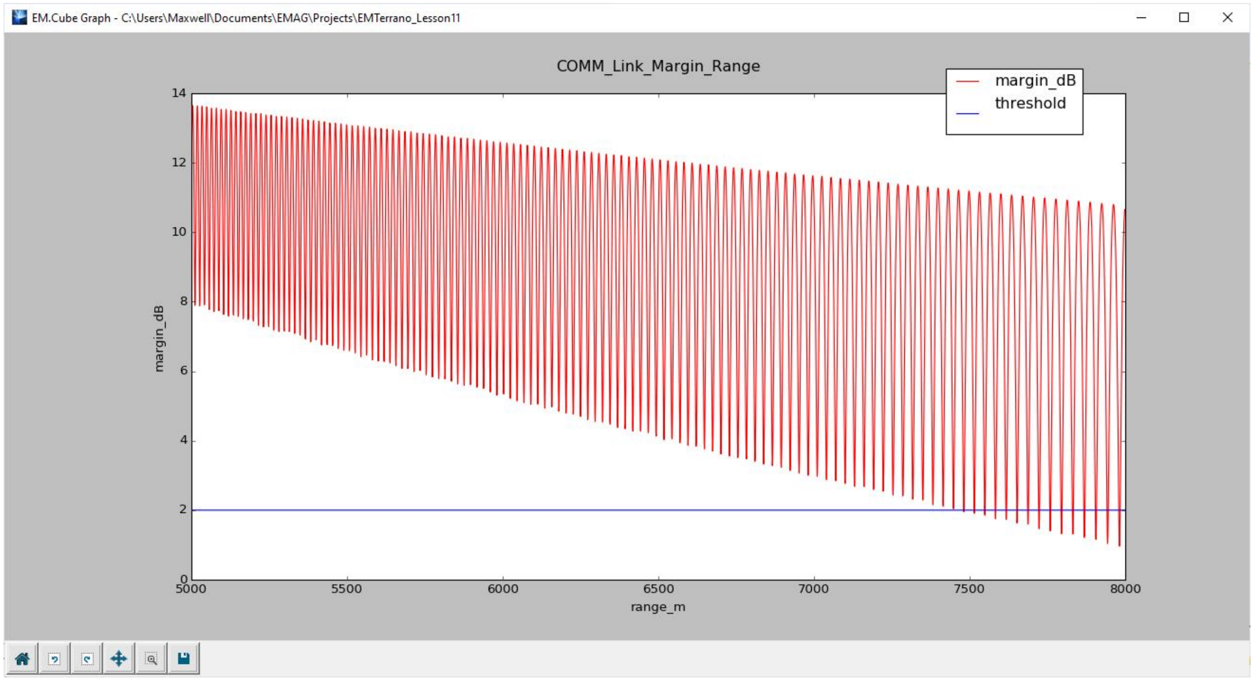


Figure 16. *A plot of the computed link margin vs. range at an altitude of 500m.*