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Introduction

The Sensor Planning Tool is used to explore RF signal propagation and predict signal detection coverage, depending on proposed sensor placements and anticipated detection methodologies.

The signal power of RF signals decays with distance away from the emitter at different rates depending on the environment or channel model as well as the carrier frequency. This tool may be used to determine how many sensors should be deployed to detect, and or locate, a particular type of emitter in a given region.

The SPOT tool can also be used to understand the coverage differences between coherent detection, as is used in Time Difference of Arrival (TDOA) and Keysight’s proprietary power based location methods, and non-coherent detection, as is used in Radio Direction Finding DF and standard received signal strength (RSS) location algorithms.

The Sensor Planning and Optimization Tool (SPOT) can be run independently of other Keysight RF sensor Software programs.

In a typical experiment, the basic steps needed to simulate coverage in a specific environment include:

1. Entering and calibrating the system map.
2. Choosing the terrain model and other parameters describing the RF propagation environment.
3. Entering proposed sensor details: Location, antenna gain, height, cabling and noise floor. The latter are useful when comparing distributed network sensors (e.g. N6841A) to those from high gain DF systems (e.g. N7100).
4. Entering the transmitter characteristics for the signals of interest.
5. Simulating and viewing plots of interest: spatial coverage of signal detection, geometric dilution of precision (GDOP), TDOA or RSS contours. For DF or standard signal power detection, coverage can be simulated using a set number of sensors and observing the signal above the noise floor. For TDOA or Keysight Proprietary power algorithms, coverage can be simulated as a function of the number of correlation pairs.
Install and Start SPOT

Installation

SPOT is installed along with SMS on a computer in the course of a normal Keysight RF Receiver software installation. After SMS is installed no further installation steps need to be taken.

Start SPOT

To launch SPOT, use the following steps:

1. Click: Start > All Programs > Keysight RF Sensor > Planning Tool
2. See that SPOT displays the splash screen. (Be patient, this may take a few minutes the first time the tool is started).
3. See that SPOT displays the Dashboard window, which should look like the figure below.

Navigation

Navigating the SPOT interface is done using three main controls. The menu bar at the top of the window is used for standard SPOT functions such as loading and saving projects, getting help, etc.
The ribbon is located just below the menu bar and is used to organize commands into logical groups. Upon startup, the Map ribbon is displayed by default. To change to another panel simply click on the panel label at the top (e.g. “Terrain”). The ribbon panels are ordered from left to right to progress through the basic procedures for obtaining coverage results (described in more detail below).

The layer panel is located to the left of the map display area and is used to control how elements on the map are displayed.
Set up a Simulation

This section describes the basic steps needed to simulate coverage in a specific environment, including entering and calibrating a map, choosing terrain models, and adding sensors.

Entering Map Data

The first step is to import a map which covers the area of interest. Maps are not included with SPOT, but can be obtained from a number of online sources. SPOT supports the import of a wide variety of image file formats including (BMP, JPEG, PNG, GIF, TIFF, etc.). SPOT also supports the import of pre-calibrated images in the "geotiff" format, and image files which have calibration information stored in an accompanying "world file."

Note that SPOT does not impose any limitations on the size of the map image, but larger images will require more memory and longer processing time. The size of images that SPOT can handle will depend on the PC configuration.

To enter a map, first make sure that the 'Map' ribbon is selected in the ribbon bar (this is the default when SPOT is first launched). Select either the “New Map” button in the upper left corner or select File → Open Image. A Windows file explorer will open allowing selection of an image. The image will be displayed in SPOT's main window.

If the file is in the "geotiff" format or has a supporting world file, then SPOT will attempt to automatically import the calibration information from the file. If it is not able to convert the calibration data or if the file is not in either of those formats, then SPOT will ask for calibration of the image as a map. Calibration is the process of assigning physical coordinates to the pixel locations on the image. If a calibration of the map is not wanted now, it is possible to continue exploring the features of SPOT by choosing the default calibration of one meter per pixel (each pixel is assumed to be one pixel wide and high). Otherwise, additional information will be requested to calibrate the map.

Map Calibration Wizard

When calibrating the map, SPOT will display the map calibration wizard. There are a number of ways to calibrate the map, but they all begin by placing a reference point at a known location on the map. Automatically place a reference point at one of the map’s corners, or, manually place a point at any location by clicking with the mouse. Once the method is selected, click “Next”.
If a pre-defined corner is selected, a reference point will appear at that corner. If manual placement is selected, a crosshairs symbol will appear when the mouse is over the map. Move the mouse to the location selected and click. After the point is placed, an input box will appear which is used to enter an absolute location in Latitude and Longitude, or in another local coordinate system. If the location is entered using Latitude and Longitude, it is possible to enter the location using most standard formats, a few examples are displayed in the box. If a local coordinate system is used, select the proper units (meters, km, miles, feet etc.) from the pull-down menu, since this will set the map’s default units, and the units to be used to define any additional reference points.

SPOT will now prompt for how to proceed with the calibration.

Select from the following methods:

1. Enter up to two additional reference points and assign them a location.
2. Enter a second reference point and specify the distance between it and the first reference point.

To use Calibration Methods 1 and 2, select the ‘Enter another reference point’ button.

3. Scale the map directly by specifying the size of a pixel in physical coordinates.

To use Calibration Method 3 select the ‘Scale the map directly’ button. Press ‘Next’ when the selection is made.
As mentioned, if Calibration Methods 1 or 2 are selected, there is the option of placing a reference point at a pre-defined corner, or of placing the point manually with the mouse.

Note that if a pre-defined corner is selected for the first reference point, the only option for selecting the opposite point is along the diagonal, to ensure an accurate calibration.

If entering the point manually is selected, the crosshairs will appear on the map. Click to place a second reference point.

Note: if a total of two reference points are entered, the second point should be on a diagonal from the first (as opposed to on a horizontal or vertical line), so that the change in x and y is substantial enough to provide an accurate calibration. After the point is placed, the following dialog will be displayed:

**Calibration Method 1**

To use Method 1, select the ‘Enter Coordinates’ button. The ‘Enter Distance’ button is for Method 2.

Enter the coordinates of the new reference point as for the first point. Note it is required to use the same units as for the first point.

Now, choose to enter a third reference point (recommended if the first two points are not on a diagonal), or finish.
If a third reference point is used, the calibration will be done using a least squares fit to the points that were entered, so the calibration may not match the reference points entered exactly.

Calibration Method 2
To use Method 2, select the ‘Enter Distance’ button. After entering the second reference point the calibration wizard will prompt to enter the distance. Enter either the line-of-sight distance between the two points, or, the x- and y-distances separately. Click ‘Next’ to finish the calibration.

Calibration Method 3
To scale the map directly, input the map scale, which is defined as the size of a pixel in physical coordinates. Enter the scale and click ‘Next’ to finish.

Once the calibration completes successfully, the wizard will display a final window. If the calibration was not successful, or if it is cancelled, the calibration will be completed using the default setting of one meter per pixel.
Map Navigation

After completing the calibration process, the map image will be displayed in SPOT’s main display area. The name of the file is displayed on the top-right corner of the map. Markers will indicate the location of the reference points on the map; reference locations are denoted using a square on top of a crosshairs. It is possible to customize the size and appearance of the reference point markers using the “Map” layer selections available on the left of the map. Selecting or deselecting any of the check boxes makes the component appear or disappear. The size and color of the reference makers can also be customized. It is possible to select to skew the map display using the calibration. If the image scale is identical in the x- and y- directions then no change will be visible, otherwise the map will stretch so that distances on the map in the x- and y-directions are equal.

Use the zoom toolbar directly above the map to zoom in or out of the display. If the mouse has a scroll-wheel, use it to zoom in or out when a zoom button has been selected. Click ‘Full Map’ to return the map display to its original size.
Map Ribbon

The Map ribbon at the top summarizes the calibration information. To get a new map at any time click on the ‘New Map’ button, which will re-initialize the map entry and calibration process. Select the ‘Properties’ button to see a display of the map’s image properties, such as height and width. The ‘Reference Location’ sub-panel displays the input reference locations. Use the list box to select a reference location and its coordinates will be updated in the ribbon panel. The image scale is also displayed.

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<th>Terrain</th>
<th>Sensors</th>
<th>Transmitter</th>
<th>Simulation</th>
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<tbody>
<tr>
<td>New Map</td>
<td>Lock Calibration</td>
<td>x 131.3</td>
<td>154.3 pixels</td>
<td>x 1.249</td>
</tr>
<tr>
<td>Properties</td>
<td>Ref Point 1</td>
<td>y 10°30′30″</td>
<td>-10°30′30″</td>
<td>y 1.405</td>
</tr>
<tr>
<td></td>
<td>y deg</td>
<td>626.2</td>
<td>492.9</td>
<td>m per pixel</td>
</tr>
<tr>
<td></td>
<td>Reference Locations</td>
<td>Image Scale</td>
<td>Distance Tool</td>
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The calibration can be adjusted by un-locking the calibration using the ‘Lock Calibration’ check box. Note: This operation cannot be performed if sensors have been added (as described below) since the sensor locations will become invalid by re-calibrating. It is necessary to re-lock the calibration before any new sensors can be added. After un-locking the calibration the location of the reference points can be adjusted by entering new coordinates in the location boxes of the panel.

The Distance Tool is used to measure physical distances on the map. To measure a distance, first click the ‘Measure’ button on the panel. A crosshair will appear when the mouse is over the map. Click and release the left mouse button to select the first end point, then click and release the left mouse button to select the second endpoint. A line will be created on the map and the distance will appear in the Distance Tool sub-panel. Change the distance units using the pull-down menu. Drag the line by clicking in the center and holding the mouse button down to drag it to a new location. Change the endpoints by clicking on the end of the line and moving them to a new location. Delete the line by either clicking ‘Delete’ in the panel, or by right-clicking on the line and selecting ‘Delete’. Right-clicking also provides the option of changing the line color if needed.

At the bottom of the map is a coordinate display which shows the cursor coordinates. Use the pull-down menu to select the location units (the default units are those entered during calibration). Note: if the map was calibrated using Latitude and Longitude then all units are available for display, otherwise, lat-lon type coordinates cannot be displayed.

Entering Terrain Data

To continue setting up the simulation select the “Terrain” tab at the top of the window, which opens the Terrain ribbon panel. In order to provide a useful simulation of the RF coverage, SPOT needs to know something about the signal propagation environment. Signals rarely propagate as they would in free-space, so a model is used to describe how signals propagate in the environment. Choose the model that best describes the situation using the pull-down menu. Note that these models are statistical in nature, do not expect them to take into account specific features of the environment or map, such as buildings or other large obstructions. Selecting the indoor propagation model allows entry of the number of walls and floors in the adjacent panel, which is defined as the average number of walls and floors an emitter traverses during propagation. It is also possible to select the wall type, which defines the amount of attenuation expected by a typical wall.
The models used in SPOT are standard propagation models used in the industry. They include:

- **Urban NLOS**: Urban Non-Line-of-Sight. Use this for urban areas with significant obstructions blocking line of sight between emitters and sensors. The maximum recommended emitter-sensor distance is 5 km for this model.

- **Suburban NLOS**: Suburban Non-Line-of-Sight. Use this for suburban areas with significant obstructions blocking line of sight between emitters and sensors. The maximum recommended emitter-sensor distance is 5 km.

- **Indoor-Outdoor**: Use the when sensors are indoors and the emitter is suspected to be outdoors or vice versa, such as at a large campus of buildings. The maximum recommended emitter-sensor distance is 1 km.

- **Urban/Suburban LOS**: Urban or Suburban Line-of-Sight. Use this for urban or suburban areas where there is generally good line of sight between emitters and sensors. The maximum recommended emitter-sensor distance is 5 km.

- **Rural NLOS**: Rural Non-Line-of-Sight. Use this for rural areas with significant obstructions blocking line of sight between emitters and sensors. The maximum recommended emitter-sensor distance is 10 km.

- **Rural LOS**: Rural Line-of-Sight. Use this for rural areas with good line of sight between emitters and sensors. The maximum recommended emitter-sensor distance is 10 km.

- **Indoor**: Use this model along with the parameters in the adjacent panel for indoor deployments. The maximum recommended emitter-sensor distance is 100 m.

- **Ideal (free space)**: Use this model for comparison to other models. It is not recommended for predicting coverage.

Note: Spot will compute a simulation even if the recommended distance ranges are exceeded, but will display a warning dialog if that happens. To prevent seeing these warnings, de-select the "Warn if exceeded" check box.

**Entering Proposed Sensor Locations**

To enter trial sensor locations:

1. Select the "Sensors" ribbon at the top of the window.
2. Click "Add" in the top right corner.

Use the mouse to move the cursor to the desired location to place the sensor and click. A marker will indicate the location of the sensor on the map. Sensor locations are denoted using a circle on top of a crosshairs. Change the appearance of any sensor marker on the map using the "Sensors" layer on the left side of the map.
Sensors Ribbon

After adding a sensor, the Sensors ribbon panel is updated with the location of the sensor and the default sensor information. A default sensor name is assigned to the sensor and it is added to the list-box in the ‘Sensor Array’ sub-panel. In order to edit a sensor’s information, first select the sensor for edit by clicking on it in the list box (adding a sensor will automatically select it for edit). Change the name of the sensor by typing a new name below the list-box. Use the panel to edit features of the sensor by changing its noise floor, location, antenna gain and height, and cable type and length. Change a sensor’s location by clicking on it with the cursor and dragging it to a new location. Note: this feature is disabled when a simulation image is displayed over the map (as described below). Note also that sensors are confined to stay on the map: it is not possible to drag a sensor off of the map, or to move its location off the map using the edit boxes. To delete a sensor first select it in the list-box and then click ‘Delete’.

Selecting Transmitter Properties

The last step is to specify properties for the signal of interest. Click on the ‘Transmitter’ label in the ribbon panel, which will open the ‘Transmitter’ ribbon panel. The primary signal attributes that impact signal propagation are signal power, bandwidth, carrier frequency, number of samples, duty cycle, and antenna height.

Higher frequency signals tend to decay more quickly, and wide-band signals have a lower power spectral density. Thus, a wide-band signal will appear closer to the noise floor of a sensor than a narrow band signal of the same power level. These factors, along with signal power, will tend to reduce the propagation distance of a given signal. Intermittent signals can be modeled by modifying the duty cycle (percentage of the time that the emitter is turned on), and the duration (the amount of time over which the emitter signal is received and measured). Raising the emitter antenna height will increase the signal propagation distance.

While it is not necessary for most of the simulations, it is possible to place a sample transmitter on the map by clicking the ‘Add’ button. A crosshair will appear that can be used to place the transmitter by clicking on the map, in the same way that sensors are added. The layers panel on the left also controls display preferences for the transmitter. The transmitter can then be used for displaying certain contour simulations, as shown in the next section.
Simulation

Simulated TDOA coverage map of each sensor detecting the signal by itself. Make sure to select “Show RF Coverage”. Signal detection of one sensor is shown below.

Simulated TDOA coverage using correlation with single sensor pairs. Once one of the sensors detects a signal the other sensors can correlate the signal detection to provide better coverage as shown below.
TDOA Hyperbola Contour lines spaced evenly 2000 meters apart, shows the calculations used to detect signals. An area with more lines indicates better detection.

TDOA Hyperbola Contour lines evenly spaced 5000 meters apart
Relative Signal Strength (RSS) Circle Contour lines evenly spaced 2000 meters apart

RSS Circle Contour lines evenly spaced 5000 meters apart
Time Difference of Arrival (TDOA) Hyperbola contour lines for transmitter with no random noise (0%).

TDOA Hyperbola contour lines for transmitter with 10% random noise.
Effect of the poor geometric dilution of precision (GDOP) using TDOA
The example below, where “Show GDOP” is selected, shows satellites that are at the horizon versus evenly dispersed overhead which provides poor coverage and results in poor geolocation accuracy. Better accuracy is achieved with satellites directly overhead.

Effect of the poor geometric dilution of precision (GDOP) using RSS (Relative Signal Strength) Layers. Better accuracy is achieved with satellites directly overhead.
The left side menus (layers) allow different types of displays. The selections allow you to customize what is displayed. Below is a display with default settings.

Selecting skew within the map section, will fill the screen, ignoring aspect ratio:
Removing Reference Points (Upper Left, Lower Right - Ref Icons and Ref Labels unchecked)

Removing Sensor icons and labels (Sensor Icons and Labels unchecked)
Notice the emitter location icon is red, with a size of "1".

Notice the emitter size is changed from 1 to 3, and color from red to white. Sensor, emitter and reference labels:

- Color choices are: black, white, blue, green and red.
- Size choices are: 0.25, 0.50, 1, 2, 3.
Changing RF coverage transparency slider shows more of the map and less of the RF coverage.

Changing RF Coverage transparency shows more of the RF coverage and less of the map.
Changing TDOA Contour line colors from the default black to white.
Contour line color choices are black, white, blue, green and red.

Changing RSS Contour line color from black to green: