

Professional Path Analysis Using a Spreadsheet

*Use any common spreadsheet application to
do your path-analysis number crunching.*

By James Lawrence Sr, WB5HVV

Modern spreadsheet programs have the power to compute and to present line-of-sight radio-path analyses. The accuracy of the predictions and the quality of the presentations can exceed that obtained with commercial software. By developing your own spreadsheet application, you can supplement or replace your current path-analysis application. Capable spreadsheet programs can be obtained for a modest price or even free of charge.¹

The formulas and methods required to build a path-analysis spreadsheet application are in the public domain and are readily discovered using the Internet or your public library. Virtually any modern spreadsheet program

has the horsepower to handle the straightforward math. The only thing remaining is “elbow grease” and ingenuity. This paper will explain the math and the graphics required to build your own application for frequencies ranging from VHF to G-band microwave. It is based on a working application with field-proven results. The resulting application is accurate, inexpensive, simple to use and easily transportable.

Cover Sheet

Having come from a telecom and control-systems engineering background, I prefer the “data sheet” format for presentation. This format lends itself nicely to the path analysis application. Also, I prefer a “3D” spreadsheet approach. That is, multiple “sheets” within a “book,” with each sheet having a specific purpose. Fig 1 shows the cover sheet of my multi-sheet example application. Notice the datasheet format.

The “cover sheet” provides for user input, and it presents the numeric and graphic results. At the top of the sheet, there is a typical data-sheet area for title, revision history and other documentation. Both ends of the path (the sites) are documented in parallel columns. Just below the user input, there is a section for the numeric results. At the bottom, there is the obligatory visual representation of the path complete with ground elevation, foliage and Fresnel clearances.

Only the cells for user input are left unprotected. All other cells are protected for the purpose of document integrity. Calculation formulas may be hidden if desired. This portion of the document can be left austere or embellished with “pull-down” choices for user input if desired.

The example presented in this paper calculates path loss from site “A” to site “B” only. If there are separate transmit and receive antennas at the sites,

¹Notes appear on page 44.

WIDGET LOGO HERE WIDGi-CORP COMMUNICATIONS DEPARTMENT RADIO HOP DATA SHEET			REV	BY	REVISION DESCRIPTION	FILE NAME	REV	
			A	DATE	EXAMPLE	S-Path.xls	A	
				J.R. Lawrence		HOP NAME	SITE A to SITE B	
				29-May-02		HOP TYPE	2.4 GHz Spread Spectrum	
						BY	CHKD	APRVD
						jrl		

GEN	01	SITE NAME		SITE ALPHA				SITE A		SITE BETA				SITE B	
	02	ADDRESS		#1 ALPHA DRIVE				#2 BETA COURT							
	03	CITY, STATE, ZIP		ALPHA HILLS, TEXAS 78957				BETA VALLEY, TEXAS 77478							
04	NORTH LATITUDE		NAD 27		32 DEG	26 MIN	52.0 SEC	32.448 DEG	32 DEG	20 MIN	23.0 SEC	32.340 DEG			
	WEST LONGITUDE				87 DEG	46 MIN	5.0 SEC	87.768 DEG	87 DEG	55 MIN	1.0 SEC	87.917 DEG			
TOWER	06	ELEVATION	TOWER HEIGHT	HEIGHT AGL	195 FT	360 FT	555 FT		310 FT	270 FT	580 FT				
	07	CALCULATED IN METERS			59.4 M	109.7 M	169.2 M		94.5 M	82.3 M	176.8 M				
	08	MANUFACTURER			ROHN				ALLIED						
	09	MODEL			TYPE 45				BETA						
	10	FCC/FAA TOWER NUMBER			87654321				12345678						
11	OTHER INFO			GUYED TOWER W/STROBE AND DIAL-UP ALARM				SELF SUPPORTING W/STROBE AND TOWER WATCHER							
ANTENNA	12	TYPE			SOLID DISH W/RADOME				GRID DISH						
	13	MANUFACTURER		MODEL											
	14	SIZE	BEAMWIDTH	GAIN	6 FT	1.8 M	4.8 DEG	30.8 dBd	8 FT	2.4 M	3.6 DEG	33.3 dBd			
	15	HEIGHT AGL	BEARING		350 FT	106.7 M	229.4 DEG	DEG A to B	260 FT	79.2 M	49.4 DEG	DEG B to A			
16	OTHER INFO		POLARIZATION					HORIZ							
FEED LINE	17	TYPE													
	18	MANUFACTURER													
	19	MODEL		SIZE											
	20	LENGTH 1	FREQ	ATTEN. / 100 FT	360 FT	2455.0 MHz	2.22 dB / 100 FT		270 FT	2455.0 MHz	2.22 dB / 100 FT				
	21	LENGTH 2	FREQ	ATTEN. / 100 FT	30 FT	2455.0 MHz	5.93 dB / 100 FT		30 FT	2455.0 MHz	5.93 dB / 100 FT				
22	OTHER INFO														
RADIO	23	MANUFACTURER													
	24	MODEL		SERIAL NO.											
	25	TRANSMITTER	FREQ	GAIN	2455.0 MHz	27.0 dBm			2455.0 MHz	27.0 dBm					
	26	RECEIVER	SENS		-94.0 dBm				-94.0 dBm						
27	OTHER INFO														
RESULTS	28	HOP DISTANCE	HOP FACTORS		11.46 MILES	18.44 KM	0.40	(0.125 DRY to 0.500 HUMID)		1.00	(4.0 SMOOTH to 0.25 MOUNTAINS)				
	29	SYSTEM GAINS: SITE A TO SITE B			27.0 dB XMIT	94.0 dB XCEIVE	30.8 dB "A" ANT	33.3 dB "B" ANT	185.2 TOTAL						
	30	SYSTEM LOSSES			131.1 dB PATH	9.8 dB COAX "A"	7.8 dB COAX B	2.8 dB OTHER	151.4 TOTAL						
	31	FADE MARGIN	AVAILABILITY	DOWNTIME	33.8 dB	99.99985%	49	SEC / YR or		0.8	MIN / YR or		0.014	HR / YR	

Path Profile

The graph displays the path profile for a radio hop between Site A and Site B. The vertical axis represents Elevation in feet, ranging from 0.00 to 600.00. The horizontal axis represents Data Points from 1 to 22. A dashed line indicates the Line of Sight (LOS) path, which is a straight line at approximately 550 feet. A blue line shows the Fresnel Clearance, which follows the LOS path with a slight curve. A red line represents the 60% Fresnel zone clearance, which is slightly above the blue line. An orange line shows the Adjusted Ground Elevation, which fluctuates between approximately 200 and 400 feet. A green line represents the Foliage Elevation, which follows the ground elevation but with some peaks, notably around data points 12 and 16.

Fig 1—The author's cover sheet for his path-analysis spreadsheet.

it may be desirable to calculate from site B to site A also. Creating another instance of the file and swapping the site A and B parameters can easily do this. One could also get crafty and enhance the application to calculate both cases. Also, path diversity is not covered but can be readily handled if required.

As previously stated, my approach is to place the logical calculation groupings on separate sheets. This breaks the problem down into easy-to-manage sections. Each separate calculation sheet pulls data from the cover sheet, completes the calculations as required and pushes the result back up to the cover sheet. Examples of discrete calculation sheets are "Bearing and Distance," "Path Loss" and "Availability."

Bearing and Distance

For the bearing-and-distance calculations, you will need the latitude and the longitude of each site as input. The required output is the bearing from site A to site B, the bearing from site B to site A, and the distance between the sites in various units including Earth surface arc.

The latitude and longitude are available from user input on the cover sheet. The calculation will require these values in decimal format. Here is a method for making the latitude/longitude conversion to decimal.

$$=Cover!R24+((Cover!V24)+(Cover!Z24/60))/60$$

In this example, the values for "Degrees," "Minutes" and "Seconds" reside on the cover sheet in cells R24, V24 and Z24 respectively. Error checking can be implemented to ensure that the user does not enter values outside the valid range, that is "61 seconds."

Now that we have the latitudes and longitudes from user input and we have made the conversion to decimal, let us look at the distance calculation. The distance between any two points on the surface of a sphere can be determined with the formula:

$$\cos D = \sin A \sin B + \cos A \cos B \cos L \quad (\text{Eq 1})$$

where

D = distance in degrees of arc

A = site A latitude in decimal degrees

B = site B latitude in decimal degrees

L = site A longitude minus site B longitude

Since A , B and L are known, the value for distance is easy to calculate. Although "degrees of arc" will be required to find the bearing, it is not very useful from the human perspective. To resolve this, here are some useful conversions:

$$111.23 \text{ km} = \text{degree of arc (for this planet only)}$$

$$0.621371 \text{ mi} = 1 \text{ km}$$

Now, let's consider the bearing calculation. The bearing from site A to site B can be obtained with the following formula:

$$\cos C = (\sin B - \sin A \cos D) / (\cos A \sin D) \quad (\text{Eq 2})$$

where

C = bearing from North

D = distance of arc between the sites, in degrees of arc (from the distance calculation above)

Again, this is a simple calculation, but there are caveats. First, the raw result only works half of the time. Second, know your spreadsheet's result format (degrees or radians) and make the necessary conversion when required. Knowing the sine of L allows you to resolve the "half the time" problem. Here is a way to work it all out:

$$=IF(E40 < 0, 360 - E46, E46)$$

confirms the raw bearing calculation from site A to site B. This means, "If the sine of L is less than zero, subtract the raw bearing from 360°, otherwise the answer is good.

In this calculation, cell E40 contains $\sin L$ and cell E46 contains the raw bearing in degrees,

$$=IF(E47 > 180, E47 - 180, E47 + 180)$$

derives the bearing from site B to site A. If the confirmed bearing is greater than 180°, subtract 180°, otherwise add 180°. Where cell E47 contains the confirmed bearing from site A to site B.

Please note that this calculation example works in north latitude and west longitude. It may require tweaking for the rest of the planet. This completes the bearing and distance calculations.

Path Loss

Next, we will tackle path loss. Path loss is loosely defined as the loss in signal associated with the line-of-sight or free-space distance between sites A and B. The formula for free-space path loss is readily available in textbooks and vendor catalogs.

$$L_{fs} = K + 20 \log f + 20 \log D \quad (\text{Eq 3})$$

where

L_{fs} = loss in decibels

K = pseudo constant (based on frequency)

f = frequency in gigahertz

D = distance in miles

We have already calculated the distance between the sites. The frequency of the hop is known from user input. The only thing remaining is the constant, K . In general, K is equal to 96.6 dB plus some small frequency-dependent amount or addend. This would be a good application for a "pull-down" pick-list. My path-analysis application was only used within a known range of frequencies, so I simply interpolated between the lowest and the highest "frequency addend." The results came out very close to those obtained with a commercial application.

Availability

Another required calculation sheet is that of availability. There are several mathematical models for availability. I chose Barnett's:²

$$Av = (1 - a \times b \times 10^{-5} \times f/4 \times d^3 \times 10^{-FM/10}) \times 100\% \quad (\text{Eq 4})$$

Where

Av = availability (uptime) expressed in percent

a = terrain roughness factor

b = climate factor

f = frequency in gigahertz

d = distance between sites in miles

FM = fade margin

This one is not tough, but it requires a bit more explanation. Terrain roughness and climate factors are subjective input from the user on the cover sheet. The terrain-roughness factor varies between 0.25 for mountains (rough) and 4.0 for Groom Lake (smooth). The climate factor varies between 0.125 for Groom Lake (dry) and 0.50 for Houston (humid). Again, frequency and distance are known values at this point. The last variable is fade margin. Fade margin is simply the sum of all gains minus the sum of all losses. This reminds me of one of the two "rules of engineering": "Some of it plus the rest of it equals all of it."³ Fade margin will be discussed in more detail later; but for the sake of this calculation, its value resides in a cell on the cover sheet.

Miscellaneous Gains and Losses

There needs to be a place for the user to apply miscellaneous gains, losses and "guesstimates." This will be the last calculation sheet. It is an exception to the "user input on cover sheet" rule. Examples of losses would be connectors, lighting arrestors and old coaxial cable. Gains could include power amplifiers or receive preamplifiers. Just add it all up and stick the total on this sheet.

Path Profile

The most complex portion of creating this path-analysis application is the graphic presentation of the path profile. As a minimum, the path profile should show the straight line of sight between the two antenna elevations, the 60% Fresnel zone and the ground elevations corrected for earth curvature. I choose to add the full Fresnel zone and average foliage height plus an option for "point addends" to represent buildings or towers that might protrude through foliage and possibly into the Fresnel zone.

Like most graphs, this profile is created from a table of values. Some of the values are borrowed from user input on the cover sheet, some are input by the user into the table and most are calculated. The last exception to "user input on the cover sheet" is elevation data taken from a topographic map. Yes, you need a "topo" map to do a proper path analysis.⁴ Even when you use the electronic topographic information from commercial programs, you should check it against actual maps. I have found that electronic three-second data are not suitable for a reliable line-of-sight analysis. Peaks in or near the path are often missed and I have found endpoint elevations to be off by over 100 feet. Fig 2 is an example of a table of values.

In Fig 2, the shaded areas are protected; user input is allowed in the "Ground Elevation" and the "Point Addend" columns. Here is an explanation of the table column by column:

Data Point: Data points A and B represent the elevations at the two sites. I chose to use a total of 20 data points between sites because that provides adequate resolution for most paths of 900 MHz and above.

Distance d1 (miles): This is simply the distance from each data point to site "A." These are equidistant segments of the

entire path length, (in this case, 11.46 miles divided by 21 or 0.5457 miles each). Here is the easy way. Data Point 1: " $= \frac{1}{21} \times D36$ " (where cell D36 contains the path length in miles). Data Point 2: " $= \frac{2}{21} \times D36$," and so on. This data column will be used in the earth-curvature calculation.

Ground Elevation: The ground elevations for points A and B come from user input on the cover sheet. Those for the other 20 points are read from a topo map. The user simply draws a line between the two Sites on the topo map (or maps), divides the line into 21 equal parts, and reads the highest elevation at, or near, each of the 20 resulting points.

Distance d2 (miles): This is the same data as distance d1 but from site B. This data column will also be used in the earth-curvature calculation.

LOS Path: The line-of-sight path column will draw a straight line between the antenna AGL (above ground level) elevations on the graph. The data for sites A and B are simply the corresponding ground elevation from that data column plus the antenna height (AGL) from the cover sheet. Each of the 20 data points builds on the previous point. For example, the Data Point 1 calculation would be " $=F12 + ((F33 - \$F\$12) / 21)$ " where cell F12 represents Data Point A, and cell F33 represents Data Point B. The next calculation for Data Point 2 would be " $=F13 + ((F33 - F13) / 21)$ " and so on.

Fresnel Clearance: Fresnel clearance elevation for each data point can be calculated with this series of calculations:

Data Point A: $=F12 - 72.1 \times \text{SQRT}((C12 \times (D36 - C12)) / (D35 \times D36))$

Data Point 1: $=F13 - 72.1 \times \text{SQRT}((C13 \times (D36 - C13)) / (D35 \times D36))$

Where cell D35 contains the frequency in gigahertz, and cell D36 contains the path length in miles.

I leave it to you to research and confirm this calculation

A	B	C	D	E	F	G	H	I	J	K	L
9	Path Information										
10	Data Point	Distance d1 (miles)	Ground Elevation	Distance d2 (miles)	LOS Path	Fresnel Clearance	60% Fresnel	Adjusted Ground Elev	Foliage Elevation	Earth Curvature	Point Addend
12	A (1)	0.00	195	11.46	545.00	545	545	195.00	195.00	0	
13	2	0.55	203	10.91	546.19	513	526	205.98	245.98	2.98	
14	3	1.09	191	10.37	547.38	502	520	196.66	236.66	5.66	
15	4	1.64	199	9.82	548.57	494	516	207.04	247.04	8.04	
16	5	2.18	202	9.28	549.76	489	513	212.12	252.12	10.12	
17	6	2.73	212	8.73	550.95	485	511	223.91	263.91	11.91	
18	7	3.27	192	8.18	552.14	482	510	205.40	245.40	13.40	
19	8	3.82	245	7.64	553.33	480	509	259.59	299.59	14.59	
20	9	4.36	250	7.09	554.52	479	509	265.48	305.48	15.48	
21	10	4.91	210	6.55	555.71	479	509	226.07	266.07	16.07	
22	11	5.46	251	6.00	556.90	479	510	267.37	307.37	16.37	
23	12	6.00	292	5.46	558.10	480	511	408.37	348.37	16.37	100
24	13	6.55	249	4.91	559.29	482	513	265.07	305.07	16.07	
25	14	7.09	251	4.36	560.48	485	515	266.48	306.48	15.48	
26	15	7.64	208	3.82	561.67	488	518	222.59	262.59	14.59	
27	16	8.18	273	3.27	562.86	492	521	286.40	326.40	13.40	
28	17	8.73	210	2.73	564.05	498	524	221.91	261.91	11.91	
29	18	9.28	229	2.18	565.24	504	529	239.12	279.12	10.12	
30	19	9.82	159	1.64	566.43	512	534	167.04	207.04	8.04	
31	20	10.37	245	1.09	567.62	522	540	250.66	290.66	5.66	
32	21	10.91	218	0.55	568.81	536	549	220.98	260.98	2.98	
33	B(22)	11.46	310	0.00	570.00	570	570	310.00	310.00	0	

Frequency	2.455	GHz
Path Length	11.46	miles
Curvature Height	$h = d1*d2 / 1.5k$	feet
k	1.33	4/3 (default)
Foliage Height	40	feet
Beam elevation	0.001900949	radians

Fig 2—The last worksheet of the project accepts user input that is not handled by the cover sheet. User input goes in the areas clear of shading.

method. It is readily verifiable. This data column draws the bottom of the Fresnel zone curve on the path-analysis graph.

60% Fresnel: This is simply the Fresnel data multiplied by 0.6. This data column draws the 60% Fresnel-zone curve on the graph.

Adjusted Ground Elev: This data column is simply the ground-elevation column plus the addend for Earth curvature plus any manual addends from the last column. This data column will draw the ground elevation line between each of the tower bases.

Foliage Elevation: This data column is the ground elevation plus the addend for Earth curvature plus a user-input constant for average foliage height. In this example, an average foliage height of 40 feet was used.

Earth Curvature: The formula for calculating earth curvature is $h = d1 \times d2 / 1.5 k$. The values for $d1$ and $d2$ for each data point have previously been calculated. " k " is typically $4/3$ or 1.333; " k " should be set as user input with a default to 1.333.

Point Addend: This data column is for user input. The example shows 100 feet added to data point 11. Notice how this is depicted in the graph; there is a protrusion through the average foliage at a point approximately 6 miles from site "A." This could represent a tower or a building. The example proves that it does not penetrate the Fresnel zone.

This completes the explanation of the data table. All that remains is to define the graph. The process would depend upon the graph application used, but it should be straightforward. Be sure to let the graph adjust the Y-axis automatically. Once this is set up properly, the user only need enter the 20 elevations taken from the topo map. (Note: Spreadsheet programs with integral graphing capabilities are more convenient, but external graphing applications can be used if needed.)

Numeric Results

The last thing that needs to be done is to present the numeric results on the cover sheet. I used the area just above the graph for this purpose. The fade margin and the availability are the "bottom line" so I show them in bold type. As previously mentioned, the fade margin is equal to the system gains less the system losses. This is a good place to calculate and summarize those gains and losses. It is also nice to present the path distance in miles and kilometers.

A spin-off of availability is predicted downtime. This comes in handy when trying to explain costs; for example, \$10,000 can buy you maybe 15 seconds a year. There are 31,557,600

seconds in a year.⁵ One minus the availability times this number of seconds gives you the predicted downtime.

Conclusion

In summary, this paper provides the basic information required so that readers can create a line-of-sight path analysis application from a spreadsheet. The features and the presentation of your application are left to you. I strongly feel that a spreadsheet program, configured properly, can rival a commercial path-analysis application. A spreadsheet application similar to the one described in this paper has been tested repeatedly against commercial applications for the same path, and it consistently yields comparable results. If anything, the custom spreadsheet application makes more accurate and conservative predictions.

Notes

¹Open Office, Gnumeric or KSpread for Linux.

²Barnett's model for outage or unavailability. "Engineering Considerations for Microwave Communications Systems," *AG Communication System*, 4th Edition, 1991, pp 68-69.

³The other rule is, "You can't push a rope."

⁴Topographic maps are available from several sources, overnight if necessary. Use the free Legend maps for each state to determine which topo or topos you will need for a path. I don't recommend using anything but the 7.5-minute series of maps. Other scales are too difficult to read. Topo map software is also available from several vendors and there are some topo maps available free of charge on the Internet.

⁵Do not forget leap years.

James received a Bachelors degree in Telecommunications from Texas A&M University, and is employed as a Principal Engineer in the Communications Department of a Fortune 100 corporation. He has been a licensed Amateur for almost 30 years. □□