RADIO PATH STUDIES 101

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The use of computer generated software to predict radio frequency (RF) path studies has been around for several years. Combined with the latest GPS and Google map data you can determine how well your network will work, RF path link reliability, link budgets, Fresnel zones, multi-path and if you may need to invest in different towers, use more repeaters or add additional technologies to try to cover the area you need communication. The following is a discussion of the real benefits of the software. Like anything else regarding computers and GPS coordinates, the best information will provide the best results and poor information will provide poor results. Here, we examine guidelines and some fairly simple explanations of how to get the correct information and put all of that into a form that will allow someone to run a path study to find out how well a communication network should work. Additionally, this paper highlights items you may want to consider when you receive the path study and how this will save time and limit the trial and error of designing your private radio network. First, some things to get started –

1) Invest in a high quality GPS device – don't scrimp here.
2) Make sure that you double check the GPS readings on the radio sites you want to verify.
3) Put all the information in an excel spread sheet and make sure the data format will work with the folks that are going to do the path study - 49.05083 and 99.05083 most do not want degrees, minutes and seconds.
4) Fill in the path study form (**Figure 1**) with as much information as possible; type and average vegetation in the area, alternate tower locations, do you have alternate repeater sites, do you have AC power at any of your locations, what type of radio and antennas are you planning on using, antenna height above ground, if you are using licensed frequencies your FCC license will be based on either the master location or the repeater site if you have a repeater (not both).
5) If towers need to be built they can be expensive above 50 feet and you will have additional permits, engineering, soil and ground testing, wind and ice loads to think about, grounding, concrete, rebar and the associated labor costs.
6) Plan for your future needs– any advanced planning will save you money and time in the future.

Path studies usually contain the following information after they are completed:

1) Maps (**Figure 2**) – these will provide topographic information on the terrain.
2) Link Reports (**Figure 5**) – these will provide equipment recommendations, diffraction calculations and fade loss information.
3) Link Profiles (**Figure 3**) – these will show the graphical representations of the terrain between two points of a link which include line of sight, curvature of earth factors and Fresnel zone.
4) KML files (Google Earth) (**Figure 4**) - this file launches into Google Earth and allows the customer to orient their network along various points of interest within the Google Earth Platform.

RADIO SIGNAL PATH LOSS

Radio signal path loss is a particularly important element in the design of any radio communications system or wireless system. The radio signal path loss will determine many elements of the radio communications system, in particular the transmitter power and the antennas, especially their gain, height and general location. The radio path loss will also affect other elements such as the required receiver sensitivity, the method of transmission used and several other factors.

As a result, it is necessary to understand the reasons for radio path loss, and to be able to determine the levels of the signal loss for a given radio path.

The signal path loss can often be determined mathematically and these calculations are often undertaken when preparing coverage or system design activities. These depend on a knowledge base of the signal propagation properties.

Accordingly, path loss calculations are used in many radio and wireless survey tools for determining signal strength at various locations. These wireless survey tools are being increasingly used to help determine radio signal strength estimates, before installing the equipment. For cellular operators, radio coverage surveys are important because the investment in a macro cell base station is high. Also, wireless survey tools provide a very valuable service for applications such as installing wireless Local Area Network (LAN) systems in large offices and other centers because they enable problems to be mitigated before installation, enabling significant cost reductions. Accordingly, there is an increasing importance being placed onto wireless survey tools and software.

Signal path loss basics

The signal path loss is essentially the reduction in power density of an electromagnetic wave or signal as it propagates through the environment in which it is traveling. There are many reasons for the radio path loss that may occur:

- ***Free space loss:*** The free space loss occurs as the signal travels through space without any other effects attenuating the signal and it will still diminish as it spreads out. This can be thought of as the radio communications signal spreading out as an ever increasing sphere. As the signal has to cover a wider area, conservation of energy tells us that the energy in any given area will reduce as the area covered becomes larger.

- ***Absorption losses:*** Absorption losses occur if the radio signal passes into a medium which is not totally transparent to radio signals. This can be likened to a light signal passing through transparent glass.

- ***Diffraction:*** Diffraction losses occur when an object appears in the path. The signal can diffract around the object, but losses occur. The loss is higher the more rounded the object. Radio signals tend to diffract better around sharp edges.

- ***Multipath:*** In a real terrestrial environment, signals will be reflected and they will reach the receiver via a number of different paths.

  These signals may add or subtract from each other depending upon the relative phases of the signals. If the receiver is moved, the scenario will change and the overall received signal will vary with position. Mobile receivers (e.g. cellular telecommunications phones) will be subject to this effect which is known as Rayleigh fading.

- ***Terrain:*** The terrain over which signals travel can significantly affect the signal. Obviously hills which obstruct the path will considerably attenuate the signal, often making reception impossible. Additionally, at low frequencies the composition of the earth will have a marked effect. For example, on the Long Wave band it is found that signals travel best over more conductive terrain, e.g. sea paths or over areas that are marshy or damp. Dry sandy terrain equates to higher levels of attenuation.

- ***Buildings and vegetation:*** For mobile applications, buildings and other obstructions including vegetation have a marked effect. Not only will buildings reflect radio signals, they will also absorb them. Cellular communications are often significantly impaired within buildings. Trees and foliage can attenuate radio signals, particularly when wet.

- ***Atmosphere:*** The atmosphere can affect radio signal paths. At lower frequencies, especially below 30 - 50MHz, the ionosphere has a significant effect; reflecting (or more correctly refracting) them back to Earth. At frequencies above 50 MHz, the troposphere has a major effect, refracting the signals back to earth as a result of changing refractive index. For UHF broadcast this can extend coverage to approximately a third beyond the horizon.

These reasons represent some of the major elements causing signal path loss for any radio system.

Predicting Path Loss

One of the key reasons for understanding the various elements affecting radio signal path loss is the ability to predict the loss for a given path, or to predict the coverage that may be achieved for a particular base station, broadcast station, etc.

Although prediction or assessment can be fairly accurate for the free space scenarios, for real life terrestrial applications it is not easy, as there are many factors to take into consideration and it is not always possible to gain accurate assessments of the resulting effects.

Despite this challenge, there are wireless survey tools and radio coverage prediction software programs that are available to predict radio path loss and estimate coverage. A variety of methods are used to undertake this.

Free space path loss varies in strength as an inverse square law, i.e. 1/(range)^2, or 20 dB per decade increase in range. This calculation is very simple to implement, but real life terrestrial calculations of signal path loss are far more involved.

Most path loss predictions are made using techniques outlined below:

- ***Statistical methods:*** Statistical methods of predicting signal path loss rely on measured and averaged losses for typical types of radio links. These figures are entered into the prediction model, which is able to calculate the figures based around the data. A variety of models can be used depending upon the application. This type of approach is normally used for planning cellular networks, estimating the coverage of Private Mobile Radio (PMR) links and for broadcast coverage planning.

- ***Deterministic approach:*** This approach to radio signal path loss and coverage prediction utilizes the basic physical laws as the basis for the calculations. These methods must take into consideration all the elements within a given area and although they tend to give more accurate results, they require additional data and computational power. In view of their complexity, they tend to be used for short range links where the amount of required data falls within acceptable limits.

These wireless survey tools and radio coverage software packages are growing in their capabilities. However, it is still necessary to have a good understanding of radio propagation so that the correct figures can be entered and the results interpreted satisfactorily.

Radio signal path loss can be caused by many factors. Only in the free space scenario is the calculation straightforward. In a terrestrial environment there are many factors that affect the actual RF path loss. When planning any radio or wireless system, it is necessary to have a broad understanding the elements that give rise to the path loss, and in this way design the system accordingly.

Free Space Path Loss Basics

The free space path loss (FSPL) is the loss in signal strength that occurs when an electromagnetic wave travels over a line-of-sight path in free space. In these circumstances there are no obstacles that might cause the signal to be reflected, refracted, or that might cause additional attenuation.

The free space path loss calculations only look at the loss of the path itself and do not contain any factors relating to the transmitter power, antenna gains or the receiver sensitivity levels.
These factors are normally addressed when calculating a link budget and these will also be used within radio and wireless survey tools and software.

To understand the reasons for the FSPL, it is possible to imagine a signal spreading out from a transmitter. It will move away from the source spreading out in the form of a sphere. As it does, the surface area of the sphere increases. As this will follow the law of the conservation of energy, as the surface area of the sphere increases, the intensity of the signal must decrease. As a result, the signal decreases in a way that is inversely proportional to the square of the distance from the source of the radio signal.

$$\text{Signal} = \frac{1}{\text{distance}^2}$$

Free space path loss formula

The free space path loss formula or free space path loss equation is quite simple to use. Not only is the path loss proportional to the square of the distance between the transmitter and receiver, but the signal level is also proportional to the square of the frequency in use for other reasons explained in a section below.

$$\mathbf{FSPL} = (4 \pi d / \lambda)^2$$

$$= (4 \pi d f / c)^2$$

Where:

FSPL is the Free space path loss
d is the distance of the receiver from the transmitter (meters)
λ is the signal wavelength (meters)
f is the signal frequency (Hertz)
c is the speed of light in a vacuum (meters per second)

The speed of light is 2.99792458 x 10^8 meters per second, although for most practical purposes, this is taken to be 3 x 10^8 meters per second.
The free space path loss formula is applicable to situations where only the electromagnetic wave is present, i.e. for far field situations. It does not hold true for near field situations.

Free Space Loss Formula Frequency Dependency

Although the free space loss equation given above seems to indicate that the loss is frequency dependent, the attenuation provided by the distance traveled in space is not dependent upon the frequency. This is constant.

The reason for the frequency dependence is that the equation contains two effects:

1. The first results from the dispersal of the energy as the sphere over which the energy is spread increases in area. This is described by the inverse square law.
2. The second effect results from the antenna aperture change. This affects the way in which any antenna can pick up signals and this term is frequency dependent.

As one constituent of the path loss equation is frequency dependent, this means that there is a frequency dependency within the complete equation.

Decibel version of free space path loss equation

Most RF comparisons and measurements are performed in decibels. This gives an easy and consistent method to compare the signal levels present at various points. Accordingly, it is very convenient to express the FSPL formula in terms of decibels. It is easy to take the basic free space path loss equation and manipulate into a form that can be expressed in a logarithmic format.

$$\mathbf{FSPL\ (dB) = 20 \log_{10}(d) + 20 \log_{10}(f) + 32.44}$$

Where:
d is the distance of the receiver from the transmitter (km)
f is the signal frequency (MHz)

Effect of antenna gain on path loss equation

The equation above does not include any component for antenna gains. It is assumed that the antenna gain is unity for both the transmitters. In reality, though, all antennas will have a certain amount of gain and this will impact the overall effect. Any antenna gain will reduce the "loss" when compared to a unity gain system. The figures for antenna gain are relative to an isotropic source, i.e. an antenna that radiates equally in all directions.

$$\mathbf{FSPL\ (dB) = 20\ log_{10}\ (d) + 20\ log_{10}\ (f) + 32.44 - Gtx - Grx}$$

Where:
Gtx is the gain of the transmitter antenna relative to an isotropic source (dBi)
Grx is the gain of the receiver antenna relative to an isotropic source (dBi)

The FSPL equation or formula given above is an essential tool that is required when making calculations for radio and wireless systems either manually or within applications such as wireless survey tools, etc. By using the free space path loss equation, it is possible to determine the signal strengths that may be expected in many scenarios. While the FSPL is not fully applicable where there are other interactions, e.g. reflection, refraction, etc. as are present in most real-life applications, the equation can nevertheless be used to give an indication of what may be expected. It is obviously fully applicable to satellite systems where the paths conform closely to the totally free space scenarios.

LINK BUDGET

When designing a complete, i.e. end-to-end radio communications system, it is necessary to calculate what is termed the link budget. The link budget enables factors such as the required antennas gain levels, radio transmitter power levels, and receiver sensitivity figures to be determined. As the name implies, it is an accounting of all the gains and losses in a transmission system. By assessing the link budget, it is possible to design the system so that it meets said requirements and performs correctly without being over designed, thereby incurring extra costs.

Link budgets are often used for satellite systems. In these situations it is crucial that the required signal levels are maintained to ensure that the received signal levels are sufficiently high above the noise level to ensure that signal to noise levels (or bit error rates) are within the required limits. However, larger antennas and high transmitter power levels that are required can add considerably to the cost. Therefore it is necessary to balance these to minimize the cost of the system while still maintaining performance.

In addition to satellite systems, link budgets are also used in many other radio communications systems. For example, link budget calculations are used for calculating the power levels required for cellular communications systems, and for investigating the base station coverage.

Link budget style calculations are also used within wireless survey tools. These wireless survey tools will not only look at the way radio signals propagate, but also the power levels, antennas and receiver sensitivity levels required to provide the required link quality.

What Does A Link Budget Include?

The link budget looks at the elements that will determine the signal strength arriving at the receiver. The link budget may include the following items:

- Transmitter power.

- Antenna gains (receiver and transmitter).
- Antenna feeder losses (receiver and transmitter).
- Path losses.
- Receiver sensitivity (although this is not part of the actual link budget, it is necessary to know this to enable any pass/fail criteria to be applied).

Where the losses may vary with time, e.g. fading, an allowance must be made within the link budget for this - often the worst case may be taken, or alternatively an acceptance of periods of increased bit error rate (for digital signals) or degraded signal to noise ratio for analog systems.

In essence, the link budget will take the form of the equation below:

Received power (dBm) = Transmitted power (dBm) + gains (db) - losses (dB)

The basic calculation to determine the link budget is quite straightforward. It is primarily a matter of accounting for all the different losses and gains between the transmitter and the receiver.

Link Budget Equation

In order to devise a link budget equation, it is necessary to investigate all the areas where gains and losses may occur between the transmitter and the receiver. Although guidelines and suggestions can be made regarding the possible areas for losses and gains, each link has to be analyzed on its own merits.

A typical link budget equation for a radio communications system may look like the following:

PRX = PTX + PTX + GTX + GRX - LTX - LFS - LP - LRX

Where:

PRX = received power (dBm)

PTX = transmitter output power (dBm)

GTX = transmitter antenna gain (dBi)

GRX = receiver antenna gain (dBi)

LTX = transmit feeder and associated losses (feeder, connectors, etc.) (dB)

LFS = free space loss or path loss (dB)

LP = miscellaneous signal propagation losses (these include fading margin, polarization mismatch, losses associated with medium through which signal is travelling, other losses...) (dB)

LRX = receiver feeder and associated losses (feeder, connectors, etc.) (d)B

NB for the sake of showing losses in the link budget equation is "minus" actual loss figures, e.g. LTX or LFS, etc. should be taken as the modulus of the loss.

ANTENNA GAIN AND LINK BUDGET

The basic link budget equation where no levels of antenna gain are included assumes that the power spreads out equally in all directions from the source. In other words, the antenna is an isotropic source, radiating equally in all directions.

This assumption is good for theoretical calculations, but in reality, all antennas radiate more in some directions than others. In addition, it is often necessary to use antennas with gain to enable interference from other directions to be reduced at the receiver and at the transmitter, in order to focus the available transmitter power in the required direction.

In view of this assumption, it is necessary to accommodate these gains into the link budget equation as they have been in the equation above because they will affect the signal levels - increasing them by levels of the antenna gain, assuming the gain is in the direction of the required link. When quoting gain levels for antennas it is necessary to ensure they are gains when compared to an isotropic source, i.e. the basic type of antenna assumed in the equation when no gain levels are incorporated. The gain figures relative to an isotropic source are quoted as dBi, i.e. dB relative to an isotropic source. Often gain levels given for an antenna may be the gain relative to a dipole where the figures may be quoted as dBd, i.e. dB relative to a dipole. However a dipole has gain relative to an isotropic source, so the dipole gain of 2.1 dBi needs to be accommodated if figures relative to a dipole are quoted for an antenna gain.

EFFECT OF MULTIPATH PROPAGATION

For true free space propagation such as that encountered by satellites, there will be no noticeable reflections and there will only be one major path. However for terrestrial systems, the signal may reach the receiver via a number of different paths as a result of reflections, etc. that will occur as a result of the objects around the path. Buildings, trees, objects around the office and home can all cause reflections that will result in the signal variations.

The multipath propagation will cause variations of the signal strength when compared to that calculated from the free space path loss. If the signals arrive in phase with the direct signal, then the reflected signals will tend to reinforce the direct signal. If they are out of phase, then they will tend to cancel the signal. If either the transmitter or receiver moves, then the signal strength will be seen to vary as the relative strengths and phases of the different signals change.

In order to allow for this in a link budget, a link margin is added into the equation to account for this variation.

Link budget calculations are an essential step in the design of a radio communications system. The link budget calculation enables the losses and gains to be seen, and devising a link budget enables the apportionment of losses, gains and power levels to be made if changes are necessary, to enable the radio communications system to meet its operational requirements. Only by performing a link budget analysis is this possible (**Figure 7**).

CONCLUSION

Radio path studies can take all the guess work out of your network design as long as you have collected the GPS data properly, filled out the path study forms correctly and the person doing the path study has the latest topographic maps and data. The bottom line is many companies will do this as a free service and the information is worth thousands of dollars. As an example, most software will allow mass update changes for customers to try different frequencies or antenna height. Regardless, this will save a great amount of time and money spent doing physical path studies.

Table 1 – Link Details

Site 1 Name	Site 1 Antenna model	Site 1 Antenna height	Site 1 TX line type	Site 1 TX line length	Site 1 Fade Margin (dB)	Site 1 ERP (dBm)	Site 2 Name
Southside Tank	EAN0906YA	15	LMR-400	25	40.06	33.7	Allendale Tank
Main Office (Central)	EAN0906WB	30	LMR-400	30	32.38	33.65	South Pump Station
Main Office (Central)	EAN0906WB	30	LMR-400	30	38.68	33.65	Northside Tank
Main Office (Central)	EAN0906WB	30	LMR-400	30	31.31	33.65	Northside Pump
Main Office (Central)	EAN0906WB	30	LMR-400	30	39.41	33.65	Southside Tank
Main Office (Central)	EAN0906WB	30	LMR-400	30	26.12	33.65	Jansen Tank

Table 2 – Link Details

Site 2 Antenna model	Site 2 Antenna height	Site 2 TX line type	Site 2 TX line length	Site 2 Fade Margin (dB)	Site 2 ERP (dBm)	Radio model	Path length
EAN0906YA	29	LMR-400	30	40.06	33.5	HT PLUS	1.2
EAN0906YA	30	LMR-400	30	32.38	33.5	HT PLUS	1.54
EAN0906YA	26	LMR-400	30	38.68	33.5	HT PLUS	1.5
EAN0906YA	30	LMR-400	30	31.31	33.5	HT PLUS	2.34
EAN0906YA	26	LMR-400	30	39.41	33.5	HT PLUS	1.38
EAN0906YA	37	LMR-600	40	26.12	33.7	HT PLUS	3.75

For information about path studies please call technical support at 303.444.3862. Form must be sent ELECTRONICALLY to pathstudy@freewave.com. FIELDS MARKED WITH * ARE REQUIRED FIELDS.

IMPORTANT: Use the format on the next page labeled "Coordinate Form" accessible through the tabs located at the bottom of the page.

DO NOT FAX OR SEND AS PDF***DO NOT FAX OR SEND AS PDF***DO NOT FAX OR SEND AS PDF

Company Information- (company name will be used to identify this study)

Company Name* ______ *RADIO MODEL* ______
Contact Person* ______ FW Sales Person* ______
Phone* ______ email* ______

End User Information

End User Company* ______ Phone* ______
End User Contact* ______ Mobile* ______

Network Information

Location ______
City* ______
State*(ie. AZ) ______
Number of Sites* ______

Required Master Location
Name* ______
Latitude* ______
Longitude* ______
Antenna Height Above Ground Level* ______

Pre-Existing Criteria (If Any)

Existing Towers that May be Used

Name ______ Latitude ______ Longitude ______
Height ______ ft. Above Ground Level
Name ______ Latitude ______ Longitude ______
Height ______ ft. Above Ground Level
Name ______ Latitude ______ Longitude ______
Height ______ ft. Above Ground Level
Name ______ Latitude ______ Longitude ______
Height ______ ft. Above Ground Level

Tree Factor: Please indicate the type of tree in the area and the height of the tree factor to be inserted in your study***

Tree Type ______ Please indicate here the most prolific type of tree and the average height of the tree in the area. This will be factored into the results of the study.
Tree Height ______

Other Information: Specify Instructions, Parameters, or Limitations for Us To Be Aware
Include additional information about height maximums, or the heights and coordinates of any obstructions in the area.

Failure to provide all information accurately could result in delays or inaccuracies to your path study.

Figure 1 – Sample Path Study Form

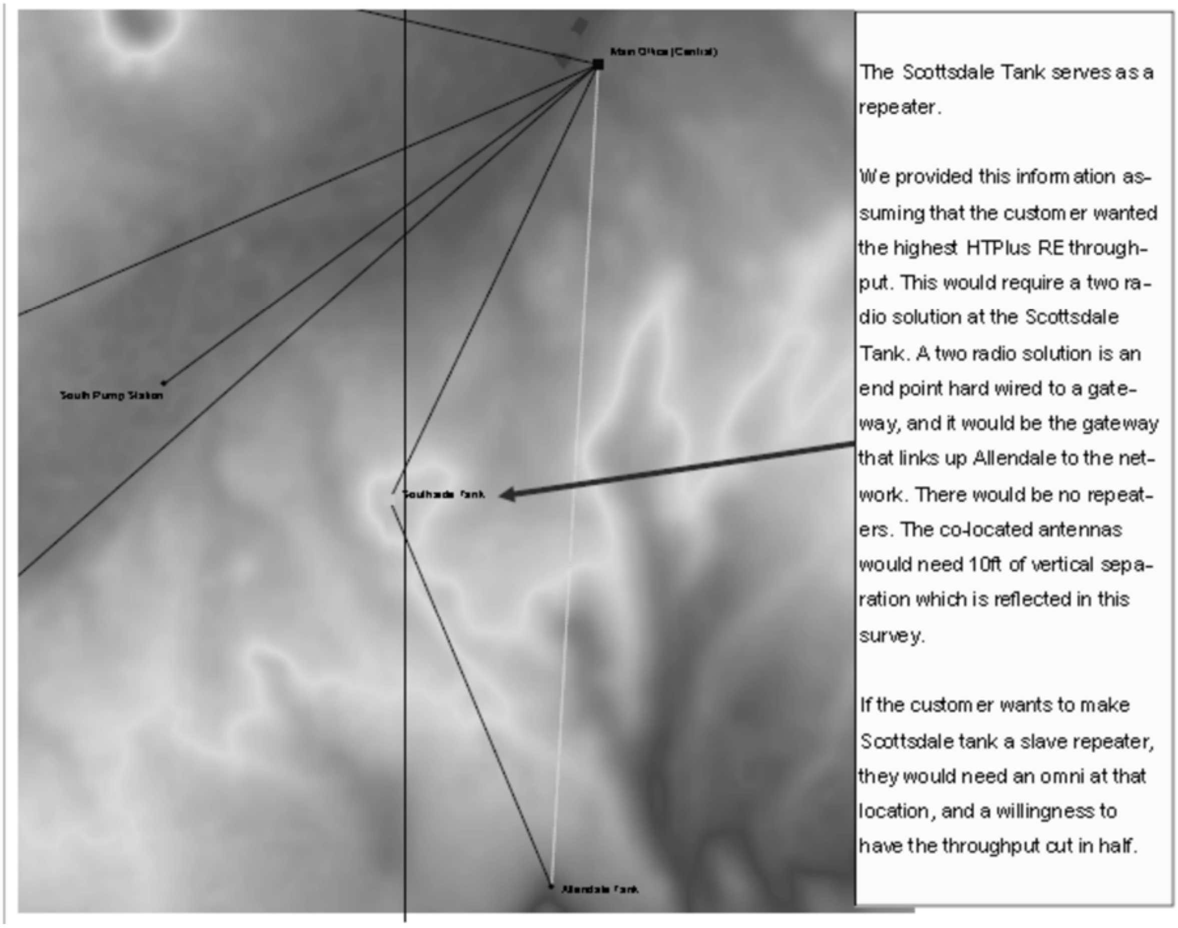


Figure 2 - Path Study Map showing the radio sites and type

Link Profiles

Each link generates a graphical profile of the terrain between each point in the link. This profile includes a summary of each location, pathlength, antenna direction, and the height requirement to achieve clear line of sight. The Red Line is the line of sight and the Blue Line is the Fresnel Zone. The Orange Outline is representative of the curvature of earth.

Figure 3 – Link Profiles

Figure 4 – Google Map picture of the path study area

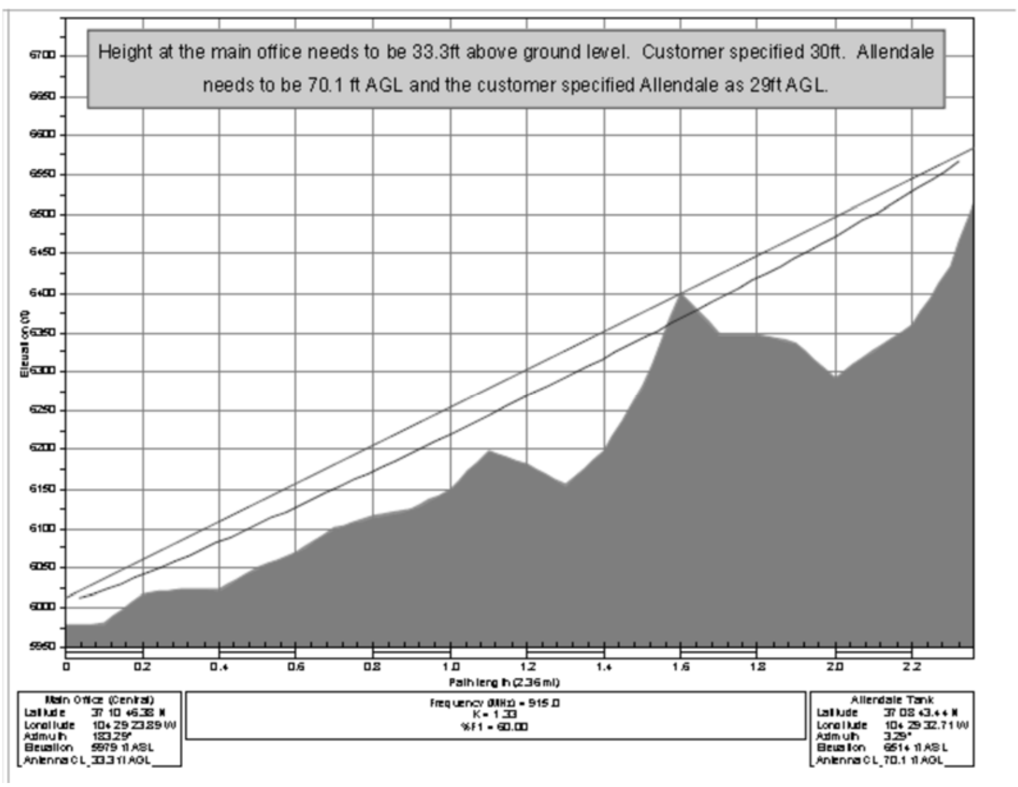
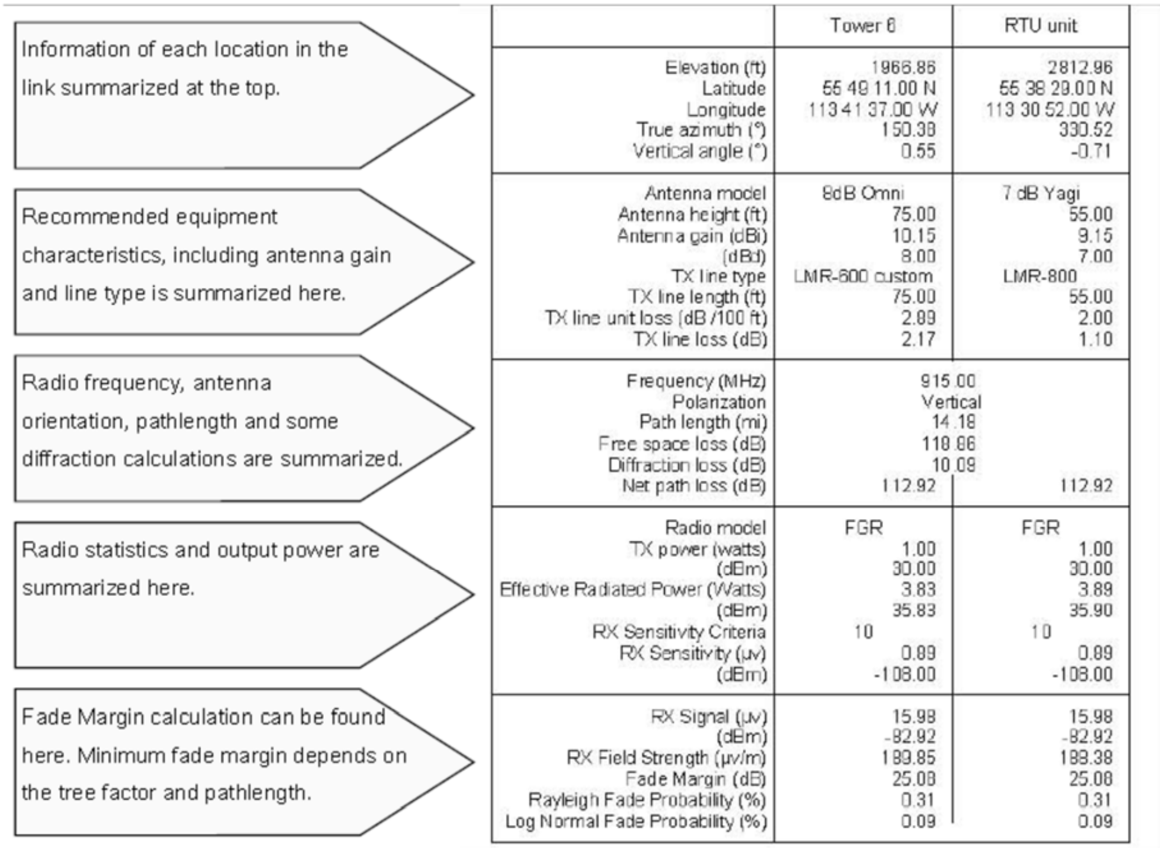


Figure 5 – Height Specifications



	Tower 6	RTU unit
Elevation (ft)	1966.86	2812.96
Latitude	55 49 11.00 N	55 38 29.00 N
Longitude	113 41 37.00 W	113 30 52.00 W
True azimuth (°)	150.38	330.52
Vertical angle (°)	0.55	-0.71
Antenna model	8dB Omni	7 dB Yagi
Antenna height (ft)	75.00	55.00
Antenna gain (dBi)	10.15	9.15
(dBd)	8.00	7.00
TX line type	LMR-600 custom	LMR-800
TX line length (ft)	75.00	55.00
TX line unit loss (dB /100 ft)	2.89	2.00
TX line loss (dB)	2.17	1.10
Frequency (MHz)	915.00	
Polarization	Vertical	
Path length (mi)	14.18	
Free space loss (dB)	118.86	
Diffraction loss (dB)	10.09	
Net path loss (dB)	112.92	112.92
Radio model	FGR	FGR
TX power (watts)	1.00	1.00
(dBm)	30.00	30.00
Effective Radiated Power (Watts)	3.83	3.89
(dBm)	35.83	35.90
RX Sensitivity Criteria	10	10
RX Sensitivity (µv)	0.89	0.89
(dBm)	-108.00	-108.00
RX Signal (µv)	15.98	15.98
(dBm)	-82.92	-82.92
RX Field Strength (µv/m)	189.85	188.38
Fade Margin (dB)	25.08	25.08
Rayleigh Fade Probability (%)	0.31	0.31
Log Normal Fade Probability (%)	0.09	0.09

Figure 6 – Point-to-Point link report explained

	Southside Tank	Allendale Tank
Elevation (ft)	6284.90	6514.19
Latitude	37 09 41.26 N	37 08 43.44 N
Longitude	104 30 02.77 W	104 29 32.71 W
True azimuth (°)	157.40	337.41
Vertical angle (°)	2.19	-2.21
Antenna model	EAN0906YA	EAN0906YA
Antenna height (ft)	15.00	29.00
Antenna gain (dBi)	8.00	8.00
(dBd)	5.85	5.85
TX line type	LMR-400	LMR-400
TX line length (ft)	25.00	30.00
TX line unit loss (dB/100ft)	4.00	4.00
TX line loss (dB)	1.00	1.20
Miscellaneous loss (dB)	0.55	0.55
Frequency (MHz)	915.00	
Polarization	Vertical	
Path length (mi)	1.20	
Free space loss (dB)	97.40	
Diffraction loss (dB)	0.84	
Net path loss (dB)	85.34	85.34
Radio model	HT PLUS	HT PLUS
TX power (watts)	0.87	0.87
(dBm)	29.40	29.40
Effective Radiated Power (Watts)	2.34	2.24
(dBm)	33.70	33.50
RX Sensitivity (uv)	3.54	3.54
(dBm)	-96.00	-96.00
RX Signal (uv)	356.66	356.66
(dBm)	-55.94	-55.94
RX Field Strength (uv/m)	5063.86	5171.57
Fade Margin (dB)	40.06	40.06
Rayleigh Fade Probability (%)	9.87E-03	9.87E-03
Log Normal Fade Probability (%)	1.23E-09	1.23E-09

Mon, Jun 08 2009
Southside Tank-Allendale Tank.pl4
Location - Woodland (sigma = 6 dB)

Figure 7 – Sample RF link report