TSM&O
Transportation Systems Management & Operations
Managing and Operating for an Efficient Transportation System

Wireless Traffic Signal Interconnect Design Report

SR 25/US 27 from CR 561 to N. of O'Brien Road

Prepared for:

FDOT District 5
719 South Woodland Boulevard
DeLand, Florida 32720

FDOT

Financial Project ID: 434407-1-52-01
Consultant Project No.: 10993

Prepared by:
Traffic Engineering Data Solutions, Inc.
Certificate of Authorization License Number: 27392
80 Spring Vista Drive
DeBary, Florida 32713

Professional Engineer:

Alexander Teal Mims, P.E.

P.E. Number 77095

DOCUMENT CONTROL PANEL		
File Name:	43440715201.docx	
File Location:	Z:\2016 Projects\10993\Wireless Analysis	
Version Number:	1.01	
	Name	**Date**
Created By:	Alexander T. Mims, P.E.	02/07/2017
Reviewed By:	Philip Boykin	02/20/2017
Modified By:	Alexander T. Mims, P.E.	02/20/2017
	Alexander T. Mims, P.E.	04/11/2017
Approved By:		

Table of Contents

List of Tables

List of Figures

1. Overview

Traffic Engineering Data Solutions, Inc. was tasked by FDOT District 5 with designing a series of microwave point-to-point Ethernet communication links for interconnection of three traffic signals along SR 25/US 27 in Lake County, at the following intersections: US 27 at CR 561, US 27 at Citrus Grove Road, and US 27 at Southern Breeze Dr./Lake Minneola Shores. Fiber optic cable is present at the southernmost intersection, US 27 at Southern Breeze Dr./Lake Minneola Shores, which will serve as the tie in point for the proposed wireless network with Lake County's existing ATMS network. Figure 1 provides a project overview map of the wireless site locations and link paths.

1.1 Document Purpose & Scope

The purpose of this document is to describe the design approach and findings related to the proposed wireless network links described in the previous section. Frequency utilization, bandwidth estimation, transmitter and antenna parameters, link profiles, antenna mounting heights, and estimated received signal strength will be determined and documented within this report. The findings of this report will be used to guide development of ITS plans and supporting specifications.

1.2 Frequency Utilization and Bandwidth Requirements

Based on discussions with Lake County, the 5 GHz WiFi unlicensed frequency band was selected for use in completion of the microwave point-to-point links. No on-site spectral analysis was performed at the antenna locations, but due to the rural nature of the area, the 5 GHz band is expected to be relatively free of interference. The project specifications will require that the installer adjust the selected WiFi channel to one that provides optimum performance and largest signal to noise ratio.

The primary purpose of the interconnect is to support transmission of traffic signal operational data, which requires marginal bandwidth—less than 1 Mbit/s per signal. There is the high probability that CCTV cameras will be added along the corridor in the future to support Lake County's ATMS objectives; therefore, the system bandwidth requirement will be based upon this potential outcome. Table 1 provides an approximation of the bandwidth requirements for the most burdened link at the southern end of the wireless network—this value will be used as the minimum bandwidth requirement for all links.

Figure 1 – Project Overview

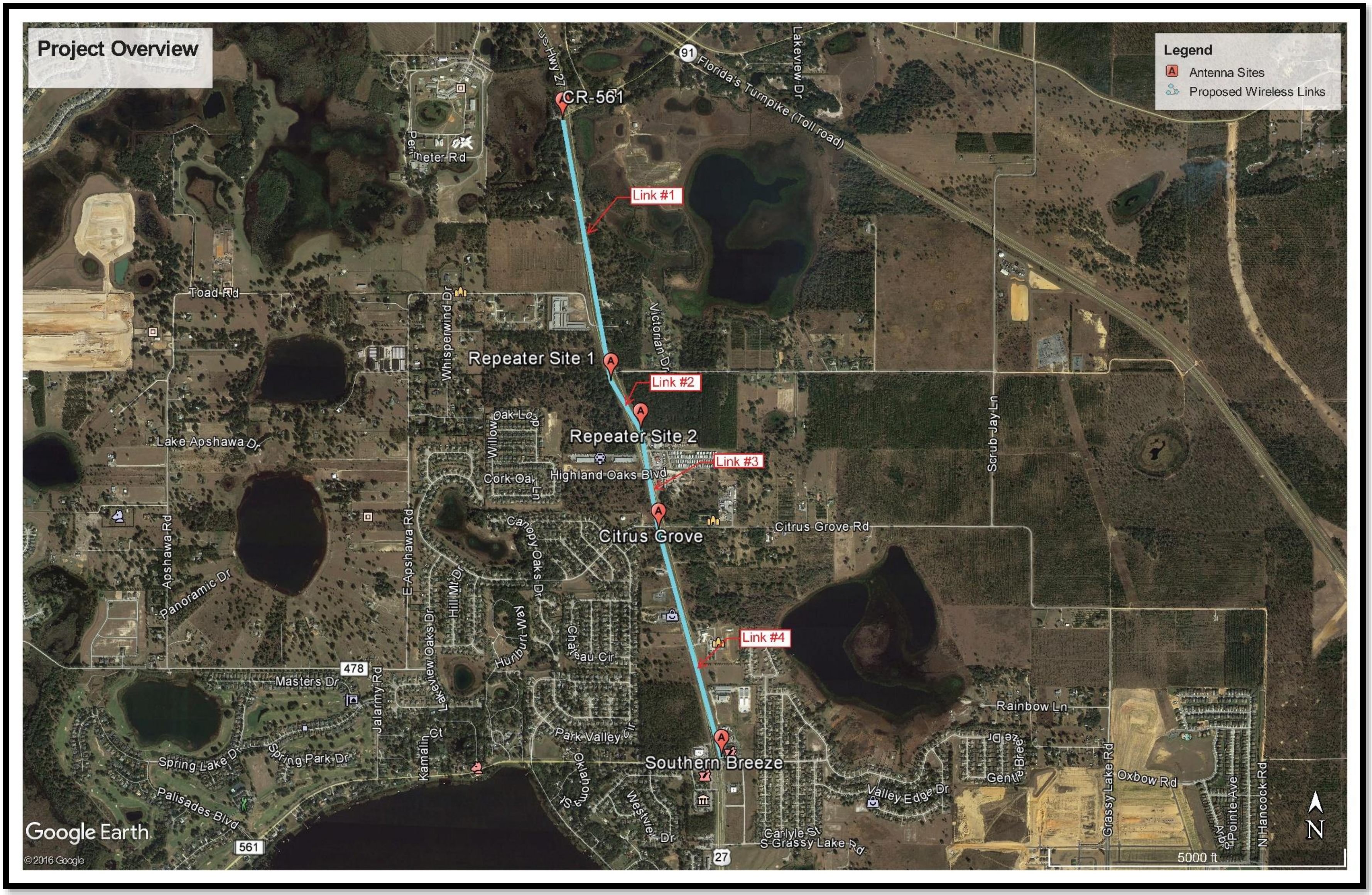


Table 1 – Bandwidth Requirements

Device	Number of Devices	Bandwidth Per Device (Mbit/s)	Sub-Total (Mbit/s)
Traffic Signal	3.0	1.0	3.0
CCTV Camera	3.0	7.0[1]	21.0
		Overhead Factor:	1.25
		Total:	**30.0**

1.3 Transmitter and Antenna Parameters

Lake County operates a number of wireless links for similar purposes in their jurisdictional area. Considering technician familiarity and to maintain consistent maintenance activities, a Wireless Ethernet Bridge consisting of a panel antenna and built in transmitter within a weatherproof housing was selected. These Bridges will be attached to existing reinforced concrete signal poles, where they exist, and proposed reinforced concrete poles at required repeater locations. An Ethernet switch will be placed in field cabinets, from which a CAT-6A outdoor rated cable will be run to each antenna. Since the transmitter and antenna are in the same housing for these bridges, no cable transmission loss will be incurred; however, a maximum limitation on cable distance must be adhered to for the Ethernet data transmission. Power for the Bridges will be provided by Power-Over-Ethernet (PoE), through the use of inline injectors. The wireless network will be a daisy-chain architecture; no redundant links will be provided. In order to prevent interference between antennas located on the same pole facing opposite directions, due to the backward directed EMF, RF shields will be installed when this condition is proposed.

For the purposes of baseline design parameters to use in specification development and path loss calculations, the Ubiquiti NSM5 Ethernet Bridge was selected: this device is stated as being capable of 84.50 Mbit/s bandwidth using 64QAM 5/6 modulation with a 20 MHz channel width, and 175.51 Mbit/s bandwidth using 64QAM 5/6 modulation with a 40 MHz channel width. It is important to note that proprietary items cannot be specified on FDOT projects without proper justification—such justification was deemed to not be warranted for this project. Equipment cut sheets for the aforementioned bridges are provided in Appendix C.

Antenna mounting heights were selected to provide first Fresnel zone clearance from the terrain and other path obstacles noted during field review—ensuring that such obstructions would not significantly interfere with link performance. Ground topographic data, used to approximate ground elevations at the antenna locations and along the link paths, was extracted from the 1 arc-second SRTM-1 Version 2.1 topographic data published by USGS. SPLAT! Version 1.3.1 computer software was used to model the first Fresnel zone and ground topography.

---

[1] CCTV camera bandwidth assumes H.264 encoding, high-quality video, and 1080p HD stream at 30 FPS.

1.4 Link Summary

Table 2 provides an overview of the proposed links. Detailed path profiles and path loss calculations are provided in Appendix A and Appendix B respectively. Note that the System Operating Margin values provided are conservative, in that they include a 6 dB margin for miscellaneous losses, are based on high bandwidth performance link parameters exceeding the system requirements and not simply functionality of the link, use rain attenuation based on a 100-yr 1-hr storm, and include a multi-path fade margin selected to provide greater than 99.9995% link availability.

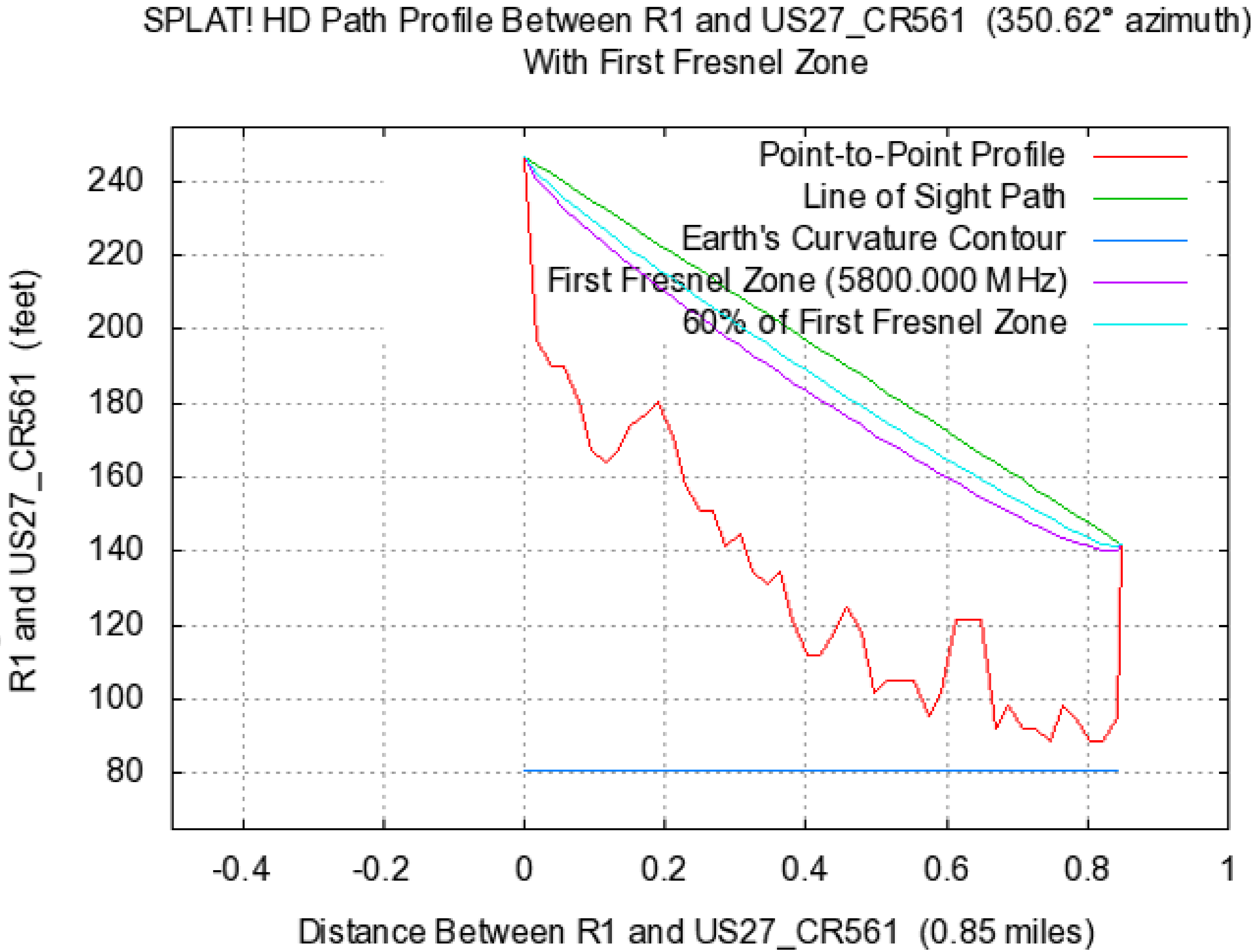
Table 2 – Link Summary Table

Link ID	From	To	Antenna Mounting Height (ft)	Link Distance (mi)	Frequency (GHz)	System Operating Margin (dB)
#1	US27 & CR 561		40	0.85	5.8	0.37
		Repeater 1	40			
#2	Repeater 1		40	0.20	5.8	8.72
		Repeater 2	40			
#3	Repeater 2		40	0.33	5.8	4.11
		US27 & Citrus Grove	40			
#4	US27 & Citrus Grove		40	0.77	5.8	3.54
		US27 & Southern Breeze	40			

2. Appendices

2.1 *Appendix A: Path Profiles*

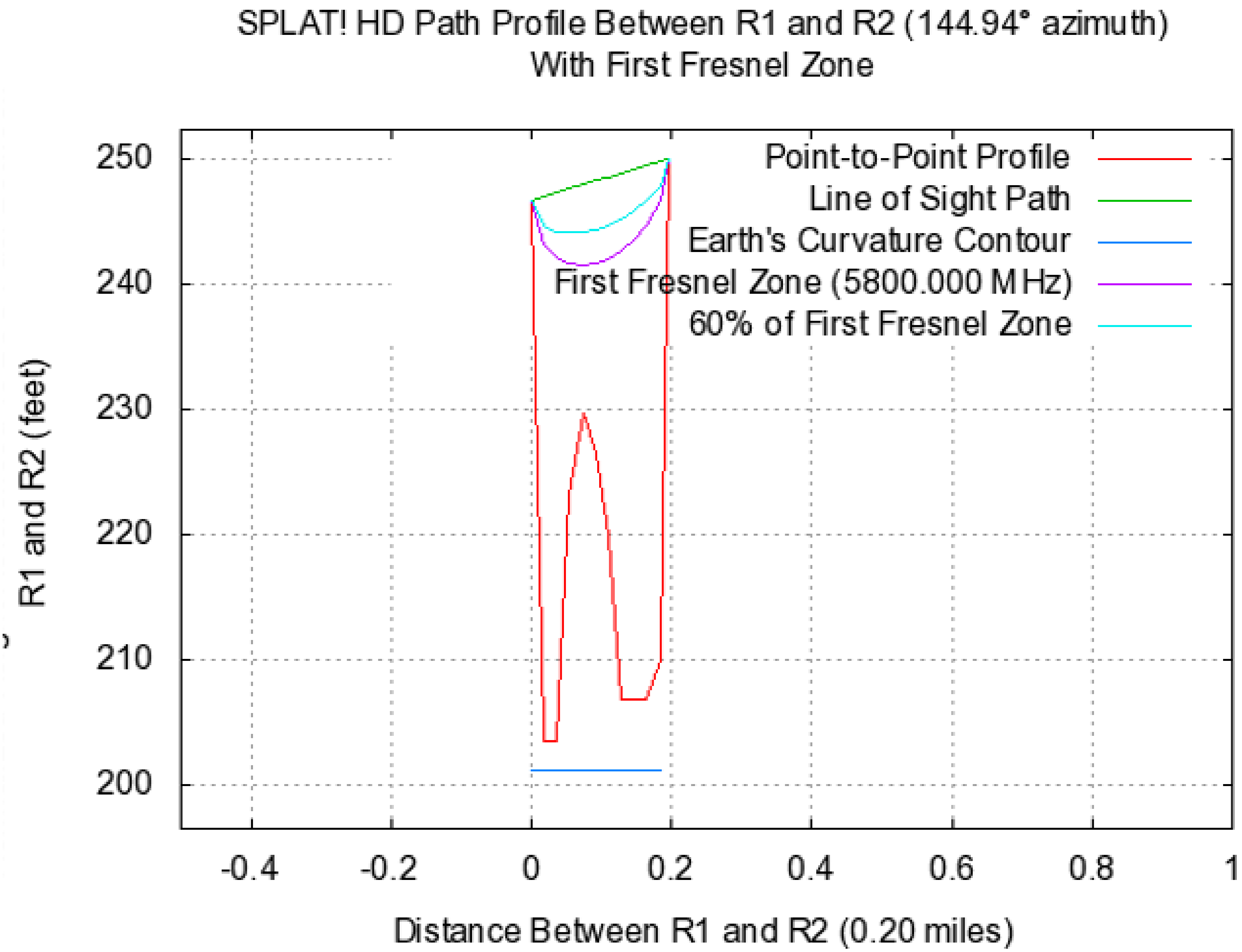
Link #1


SPLAT! HD Path Profile Between R1 and US27_CR561 (350.62° azimuth)
With First Fresnel Zone
Point-to-Point Profile
Line of Sight Path
Earth's Curvature Contour
First Fresnel Zone (5800.000 MHz)
60% of First Fresnel Zone
R1 and US27_CR561 (feet)
240
220
200
180
160
140
120
100
80
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Distance Between R1 and US27_CR561 (0.85 miles)

```
                --==[ SPLAT! HD v1.3.1 Path Analysis ]==--

---------------------------------------------------------------------------

Transmitter site: US27_CR561
Site location: 28.6202 North / 81.7602 West (28° 37' 12" N / 81° 45' 36" W)
Ground elevation: 101.71 feet AMSL
Antenna height: 40.00 feet AGL / 141.71 feet AMSL
Antenna height above average terrain: 32.35 feet
Distance to R1: 0.85 miles
Azimuth to R1: 170.62 degrees
Elevation angle to R1: +1.3356 degrees

---------------------------------------------------------------------------

Receiver site: R1
Site location: 28.6081 North / 81.7580 West (28° 36' 29" N / 81° 45' 28" W)
Ground elevation: 206.69 feet AMSL
Antenna height: 40.00 feet AGL / 246.69 feet AMSL
Antenna height above average terrain: 139.26 feet
Distance to US27_CR561 : 0.85 miles
Azimuth to US27_CR561 : 350.62 degrees
Depression angle to US27_CR561 : -1.3479 degrees

---------------------------------------------------------------------------

Longley-Rice path calculation parameters used in this analysis:

Earth's Dielectric Constant: 15.000
Earth's Conductivity: 0.005 Siemens/meter
Atmospheric Bending Constant (N-units): 301.000 ppm
Frequency: 5800.000 MHz
Radio Climate: 5 (Continental Temperate)
Polarization: 0 (Horizontal)
Fraction of Situations: 50.0%
Fraction of Time: 50.0%
Transmitter ERP: 242.7 milliwatts (+23.85 dBm)
Transmitter EIRP: 397.3 milliwatts (+25.99 dBm)

---------------------------------------------------------------------------

Summary for the link between US27_CR561  and R1:

Free space path loss: 110.45 dB
Longley-Rice path loss: 110.15 dB
Attenuation due to terrain shielding: -0.30 dB
Field strength at R1: 68.37 dBuV/meter
```

```
Signal power level at R1: -84.16 dBm
Signal power density at R1: -77.41 dBW per square meter
Voltage across 50 ohm dipole at R1: 17.73 uV (24.97 dBuV)
Voltage across 75 ohm dipole at R1: 21.71 uV (26.73 dBuV)
Mode of propagation: Line-Of-Sight Mode
Longley-Rice model error number: 0 (No error)

---------------------------------------------------------------------------


No obstructions to LOS path due to terrain were detected by SPLAT! HD

The first Fresnel zone is clear.

60% of the first Fresnel zone is clear.
```

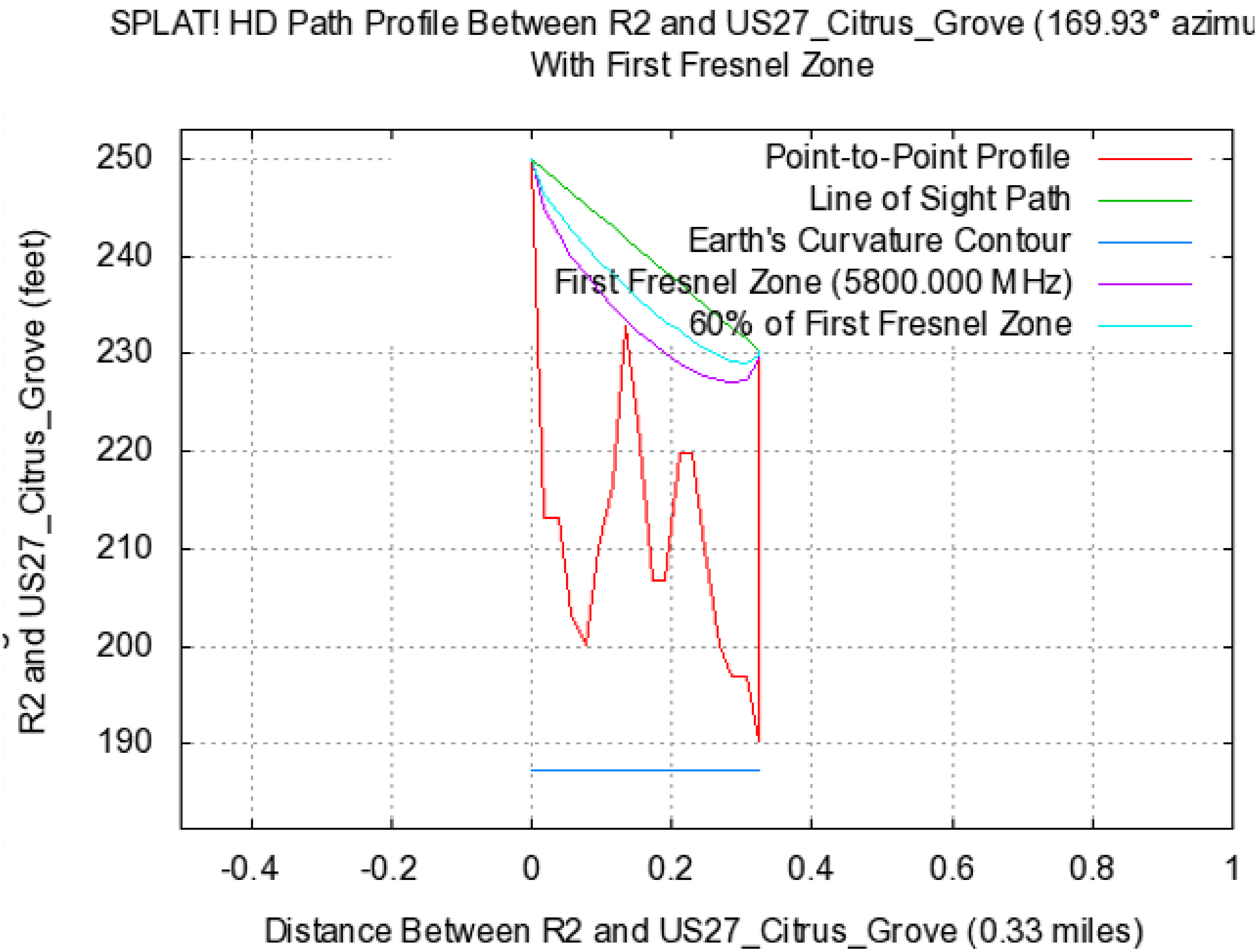
Link #2


SPLAT! HD Path Profile Between R1 and R2 (144.94° azimuth)
With First Fresnel Zone
Point-to-Point Profile
Line of Sight Path
Earth's Curvature Contour
First Fresnel Zone (5800.000 MHz)
60% of First Fresnel Zone
R1 and R2 (feet)
250
240
230
220
210
200
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Distance Between R1 and R2 (0.20 miles)

```
                --==[ SPLAT! HD v1.3.1 Path Analysis ]==--

---------------------------------------------------------------------------

Transmitter site: R2
Site location: 28.6058 North / 81.7561 West (28° 36' 20" N / 81° 45' 22" W)
Ground elevation: 209.97 feet AMSL
Antenna height: 40.00 feet AGL / 249.97 feet AMSL
Antenna height above average terrain: 141.81 feet
Distance to R1: 0.20 miles
Azimuth to R1: 324.94 degrees
Depression angle to R1: -0.1839 degrees

---------------------------------------------------------------------------

Receiver site: R1
Site location: 28.6081 North / 81.7580 West (28° 36' 29" N / 81° 45' 28" W)
Ground elevation: 206.69 feet AMSL
Antenna height: 40.00 feet AGL / 246.69 feet AMSL
Antenna height above average terrain: 139.26 feet
Distance to R2: 0.20 miles
Azimuth to R2: 144.94 degrees
Elevation angle to R2: +0.1811 degrees

---------------------------------------------------------------------------

Longley-Rice path calculation parameters used in this analysis:

Earth's Dielectric Constant: 15.000
Earth's Conductivity: 0.005 Siemens/meter
Atmospheric Bending Constant (N-units): 301.000 ppm
Frequency: 5800.000 MHz
Radio Climate: 5 (Continental Temperate)
Polarization: 0 (Horizontal)
Fraction of Situations: 50.0%
Fraction of Time: 50.0%
Transmitter ERP: 242.7 milliwatts (+23.85 dBm)
Transmitter EIRP: 397.3 milliwatts (+25.99 dBm)

---------------------------------------------------------------------------

Summary for the link between R2 and R1:

Free space path loss: 97.67 dB
Longley-Rice path loss: 96.19 dB
Attenuation due to terrain shielding: -1.48 dB
Field strength at R1: 82.33 dBuV/meter
```

```
Signal power level at R1: -70.20 dBm
Signal power density at R1: -63.46 dBW per square meter
Voltage across 50 ohm dipole at R1: 88.39 uV (38.93 dBuV)
Voltage across 75 ohm dipole at R1: 108.26 uV (40.69 dBuV)
Mode of propagation: Line-Of-Sight Mode
Longley-Rice model error number: 4
  Warning: Some parameters are out of range.
  Results are probably invalid.

---------------------------------------------------------------------------


No obstructions to LOS path due to terrain were detected by SPLAT! HD

The first Fresnel zone is clear.

60% of the first Fresnel zone is clear.
```

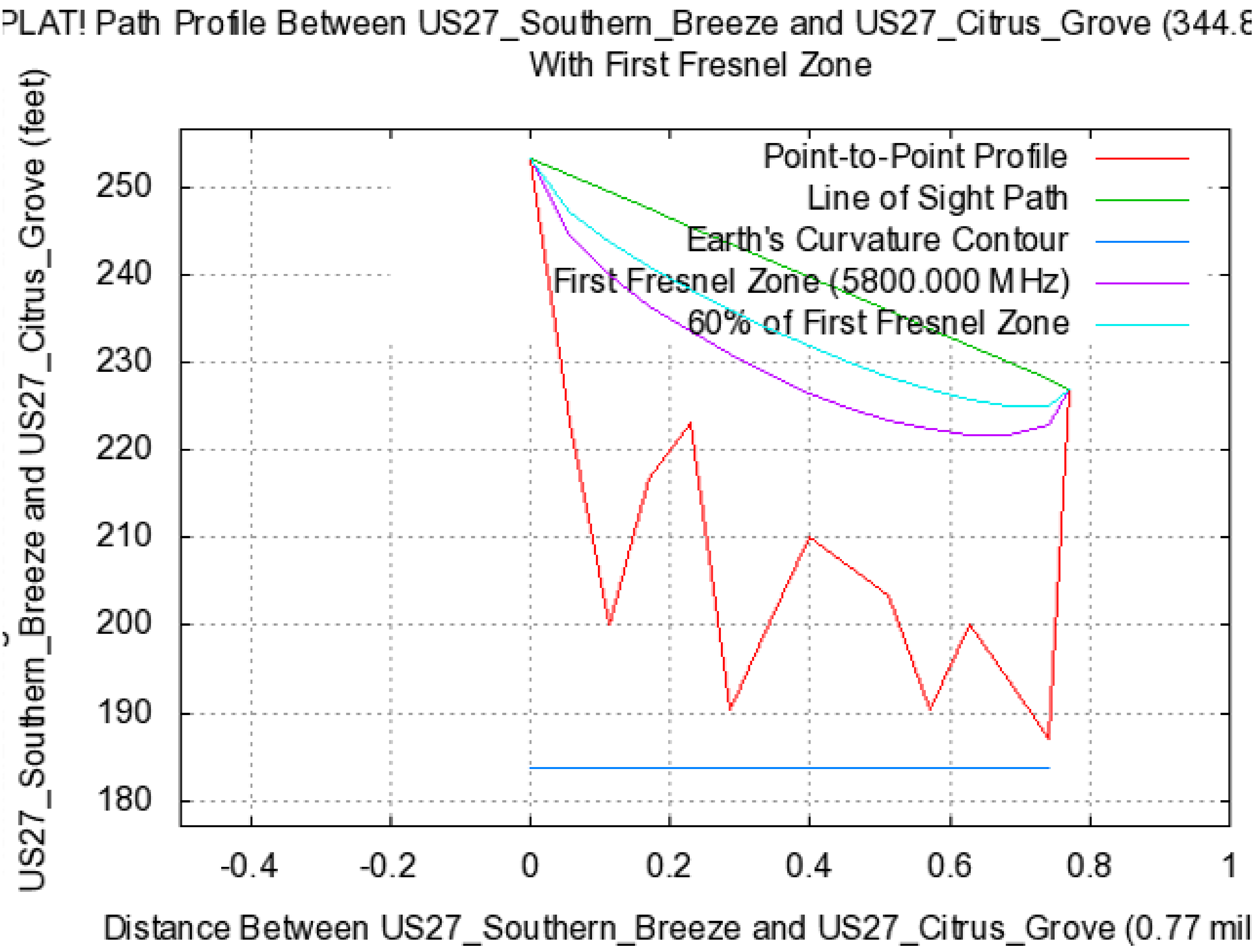
Link #3


SPLAT! HD Path Profile Between R2 and US27_Citrus_Grove (169.93° azimu
With First Fresnel Zone
Point-to-Point Profile
Line of Sight Path
Earth's Curvature Contour
First Fresnel Zone (5800.000 MHz)
60% of First Fresnel Zone
R2 and US27_Citrus_Grove (feet)
250
240
230
220
210
200
190
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Distance Between R2 and US27_Citrus_Grove (0.33 miles)

```
              --==[ SPLAT! HD v1.3.1 Path Analysis ]==--

---------------------------------------------------------------------------

Transmitter site: US27_Citrus_Grove
Site location: 28.6011 North / 81.7552 West (28° 36' 4" N / 81° 45' 18" W)
Ground elevation: 190.29 feet AMSL
Antenna height: 40.00 feet AGL / 230.29 feet AMSL
Antenna height above average terrain: 121.70 feet
Distance to R2: 0.33 miles
Azimuth to R2: 349.93 degrees
Elevation angle to R2: +0.6534 degrees

---------------------------------------------------------------------------

Receiver site: R2
Site location: 28.6058 North / 81.7561 West (28° 36' 20" N / 81° 45' 22" W)
Ground elevation: 209.97 feet AMSL
Antenna height: 40.00 feet AGL / 249.97 feet AMSL
Antenna height above average terrain: 141.81 feet
Distance to US27_Citrus_Grove: 0.33 miles
Azimuth to US27_Citrus_Grove: 169.93 degrees
Depression angle to US27_Citrus_Grove: -0.6581 degrees

---------------------------------------------------------------------------

Longley-Rice path calculation parameters used in this analysis:

Earth's Dielectric Constant: 15.000
Earth's Conductivity: 0.005 Siemens/meter
Atmospheric Bending Constant (N-units): 301.000 ppm
Frequency: 5800.000 MHz
Radio Climate: 5 (Continental Temperate)
Polarization: 0 (Horizontal)
Fraction of Situations: 50.0%
Fraction of Time: 50.0%
Transmitter ERP: 242.7 milliwatts (+23.85 dBm)
Transmitter EIRP: 397.3 milliwatts (+25.99 dBm)

---------------------------------------------------------------------------

Summary for the link between US27_Citrus_Grove and R2:

Free space path loss: 102.13 dB
Longley-Rice path loss: 101.56 dB
Attenuation due to terrain shielding: -0.57 dB
Field strength at R2: 76.96 dBuV/meter
```

```
Signal power level at R2: -75.57 dBm
Signal power density at R2: -68.82 dBW per square meter
Voltage across 50 ohm dipole at R2: 47.66 uV (33.56 dBuV)
Voltage across 75 ohm dipole at R2: 58.37 uV (35.32 dBuV)
Mode of propagation: Line-Of-Sight Mode
Longley-Rice model error number: 4
  Warning: Some parameters are out of range.
  Results are probably invalid.

---------------------------------------------------------------------------


No obstructions to LOS path due to terrain were detected by SPLAT! HD

The first Fresnel zone is clear.

60% of the first Fresnel zone is clear.
```

Link #4



PLAT! Path Profile Between US27_Southern_Breeze and US27_Citrus_Grove (344.8
With First Fresnel Zone
US27_Southern_Breeze and US27_Citrus_Grove (feet)
Point-to-Point Profile
Line of Sight Path
Earth's Curvature Contour
First Fresnel Zone (5800.000 MHz)
60% of First Fresnel Zone
250
240
230
220
210
200
190
180
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Distance Between US27_Southern_Breeze and US27_Citrus_Grove (0.77 mil

```
                --==[ SPLAT! v1.3.1 Path Analysis ]==--

---------------------------------------------------------------------------

Transmitter site: US27_Citrus_Grove
Site location: 28.6011 North / 81.7552 West (28° 36' 4" N / 81° 45' 18" W)
Ground elevation: 187.01 feet AMSL
Antenna height: 40.00 feet AGL / 227.01 feet AMSL
Antenna height above average terrain: 118.99 feet
Distance to US27_Southern_Breeze: 0.77 miles
Azimuth to US27_Southern_Breeze: 164.87 degrees
Elevation angle to US27_Southern_Breeze: +0.3634 degrees

---------------------------------------------------------------------------

Receiver site: US27_Southern_Breeze
Site location: 28.5904 North / 81.7519 West (28° 35' 25" N / 81° 45' 6" W)
Ground elevation: 213.25 feet AMSL
Antenna height: 40.00 feet AGL / 253.25 feet AMSL
Antenna height above average terrain: 140.98 feet
Distance to US27_Citrus_Grove: 0.77 miles
Azimuth to US27_Citrus_Grove: 344.88 degrees
Depression angle to US27_Citrus_Grove: -0.3746 degrees

---------------------------------------------------------------------------

Longley-Rice path calculation parameters used in this analysis:

Earth's Dielectric Constant: 15.000
Earth's Conductivity: 0.005 Siemens/meter
Atmospheric Bending Constant (N-units): 301.000 ppm
Frequency: 5800.000 MHz
Radio Climate: 5 (Continental Temperate)
Polarization: 0 (Horizontal)
Fraction of Situations: 50.0%
Fraction of Time: 50.0%
Transmitter ERP: 242.7 milliwatts (+23.85 dBm)
Transmitter EIRP: 397.3 milliwatts (+25.99 dBm)

---------------------------------------------------------------------------

Summary for the link between US27_Citrus_Grove and US27_Southern_Breeze:

Free space path loss: 109.62 dB
Longley-Rice path loss: 108.55 dB
Attenuation due to terrain shielding: -1.07 dB
Field strength at US27_Southern_Breeze: 69.97 dBuV/meter
```

```
Signal power level at US27_Southern_Breeze: -82.56 dBm
Signal power density at US27_Southern_Breeze: -75.82 dBW per square meter
Voltage across 50 ohm dipole at US27_Southern_Breeze: 21.30 uV (26.57 dBuV)
Voltage across 75 ohm dipole at US27_Southern_Breeze: 26.09 uV (28.33 dBuV)
Mode of propagation: Line-Of-Sight Mode
Longley-Rice model error number: 0 (No error)

---------------------------------------------------------------------------


No obstructions to LOS path due to terrain were detected by SPLAT!

The first Fresnel zone is clear.

60% of the first Fresnel zone is clear.
```

2.2 *Appendix B: Path Loss Calculations*

Microwave Point to Point Link Recieved Signal Strength Calculations

Project Name: SR 25/US 27 from CR 561 to N. of O'Brien Road

Project Number: 434407-1-52-01

Calculated By: ATM

Date: 2/20/17

Import the Python libraries needed to perform the calculations:

In [1]:
```
import math
```

Determine Losses Between Antenna and Transmitter or Reciever

$L_{cable} = L_0 * (d_{cable}/100)$

L_{tx} and $L_{rc} = L_{cable} + L_{misc.}$

L_0 = cable signal loss in dB per 100 ft from manufacturer data sheet
d_{cable} = length of cable in feet from antenna to transmitter or reciever
$L_{misc.}$ = all combiner/splitter or other losses in dB between antenna and transmitter or reciever

In [2]:
```
def cable_loss(L_0, d, L_misc):
    L_cable = L_0 * (d / 100.0)
    return L_cable + L_misc
```

In [3]:
```
#Link 1 - CR 561 to R1
l1_tx = 0.0 #Transmitter is inside of antenna assembly
l1_rc = 0.0
#Link 2 - R1 to R2
l2_tx = 0.0 #Transmitter is inside of antenna assembly
l2_rc = 0.0
#Link 3 - R2 to Citrus
l3_tx = 0.0 #Transmitter is inside of antenna assembly
l3_rc = 0.0
#Link 4 - Citrus to Southern
l4_tx = 0.0 #Transmitter is inside of antenna assembly
l4_rc = 0.0
```

Calculate Free Space Loss (FSL)

$$FSL = 96.6 + 20 * log(D) + 20 * log(f)$$

FSL = free space loss in decibels
D = distance between antenna in miles
f = frequency in GHz

In [4]:
```
def free_space_loss(D, f):
    return 96.6 + 20 * math.log10(D) + 20 * math.log10(f)
```

In [5]:
```
D_1 = 0.85 #Link distances in miles
D_2 = 0.20
D_3 = 0.33
D_4 = 0.77
OF = 5.8 #Operating frequency in GHz
l1_FSL = free_space_loss(D_1, OF)
print l1_FSL, 'dB'
l2_FSL = free_space_loss(D_2, OF)
print l2_FSL, 'dB'
l3_FSL = free_space_loss(D_3, OF)
print l3_FSL, 'dB'
l4_FSL = free_space_loss(D_4, OF)
print l4_FSL, 'dB'
```

```
110.456938386 dB
97.8891597845 dB
102.238838669 dB
109.598374375 dB
```

Set Mutipath Fade Margin (MFM)

Using the Barnett & Vigants Method:

$$MFM = -10 * log[(i - PR)/(2.5 * 10^{-6} * a * b * f * D^3)]$$

PR = path avaliability percentage
a = terrain factor
b = climate factor
f = frequency in GHz
D = path length in miles between antenna

Notes:

- **a** values vary according to terrain type: {**4**: for very smooth terrain (water, flat desert), **1**: average terrain with some roughness, **0.25**: for mountains and very rough terrain}
- **b** values vary according to climate: {**1**: for humid climates, **0.5**: for average climate, **0.25**: for dry climate}
- Select a **PR** based on the intended link availability percentage.

In [6]:

```
def multipath_fade_margin(PR, a, b, f, D):
    ans = (-10 * math.log10((1 - (PR / 100)) / (2.5 * (10.0 ** -6) * a * b * f
 * (D ** 3))))
    if ans > 0:
        return ans
    return 0 #Ignore where MFM is very small
```

In [7]:

```
l1_MFM = multipath_fade_margin(99.9995, 1, 1, OF, D_1)
print l1_MFM, 'dB'
l2_MFM = multipath_fade_margin(99.9999, 1, 1, OF, D_2)
print l2_MFM, 'dB'
l3_MFM = multipath_fade_margin(99.9999, 1, 1, OF, D_3)
print l3_MFM, 'dB'
l4_MFM = multipath_fade_margin(99.9995, 1, 1, OF, D_4)
print l4_MFM, 'dB'
```

```
2.50654775039 dB
0 dB
0 dB
1.21870173414 dB
```

Calculate Recieved Signal Strength (RSL)

$$RSL = P_O - L_{tx} + G_{atx} - FSL - MFM - RA - L_{rc} + G_{rc} - L_m - L_{atm} - A_{ve}$$

P_O = transmitter power output in dBm
L_{tx} = losses between transmitter and transmit antenna in dB
G_{atx} = transmit antenna gain in dB
A_{ve} = vegitation attenuation in dB
FSL = free space loss in dB
MFM = multipath fade margin in dB
$RA = \gamma_R * D$ = rain attenuation in dB
L_{rc} = losses between reciever and recieve antenna in dB
G_{rc} = recieve antenna gain in dB
L_m = micellaneous losses (obstacles, antenna misalignment, antenna aging, etc.) in dB
L_{atm} = atmospheric attenuation in dB

Rain Attenuation (from "Recommendation ITU-R P.838-2"):

$$\gamma_R = k * R^\alpha$$

γ_R = specific rain attenuation in dB/km
k & α = frequency specific coefficients from ITU-R P.838-2 tables

Atmospheric Attenuation (from "Recommendation ITU-R P.676-5"):

Simplified formula from Annex 2 for Terrestrial Paths (1 - 350 GHz), using Figure 5 values for specific attenuation:

$$L_{atm} = \gamma * r_0 = (\gamma_o + \gamma_w) * r_0$$

γ = total attenuation by atmosphere in dB/km
γ_o = attenuation due to dry air in dB/km
γ_w = attenuation due to water in atmosphere in dB/km
r_0 = link distance in km

Vegitation Attenuation (from "Recommendation ITU-R P833-4"):

For non-single vegetative obstruction:

$$A_{ve} = A_m * [1 - exp((-d * \gamma)/A_m)]$$

d = length of path within woodland in meters
γ = specific attenuation for very for vegatative paths in dB/meter
A_m = maximum attenuation for one terminal within a specific type and depth of vegetation in dB

$$A_m = A_1 * f^\alpha$$

f = frequency in MHz
A_1 & α depend on the vegitation type, density, and other factors. ITU-R P833-4 provide experimental values.

For single vegetative obstruction at or below 3 GHz:

$$A_{et} = d * \gamma$$

Notes:

- L_m is assumed to be **6.0** dB to account for attenna misalignment and system aging + **Obstacle losses**
- Obstacle losses (knife-edge approximation): {**0 dB**: no objects in 60% Fresnel Zone, **6 dB**: tip of object in middle of LOS, **16 dB** for tip of object at top of first Fresnel Zone, **20 dB**: for object tip above first Fresnel Zone}

In [8]:

```python
"""Equations required to perform RSL calculations"""

def rain_attenuation(k, alpha, D, R, D_in_miles = True, R_in_inches = True):
    if D_in_miles:
        D = D * 1.60934 #convert distance input in miles to km
    if R_in_inches:
        R = R * 25.4 #converts rainfall from inches/hr to mm/hr
    delta_R = k * R ** alpha #specific rain attenutation dB/km
    return float(delta_R * D)

def atmospheric_attenuation(atten_oxy, atten_water, D, D_in_miles = True):
    if D_in_miles:
        D = D * 1.60932 #convert distance input in miles to km
    return float((atten_oxy + atten_water) * D)

def veg_atten_multi(path_length_veg, specific_atten, A_1, alpha, frequency, D_in_miles = True, f_in_GHz = True):
    if D_in_miles:
        D = D * 1609.34 #convert distance input in miles to meters
    if f_in_GHz:
        frequency = frequency * 1000.0 #convert frequency in GHz to MHz
    max_atten = A_1 * frequency ** alpha
    return float(max_atten * (1 - math.exp((-d * specific_atten) / max_atten)))

def veg_atten_single(path_length_veg, gamma, D_in_feet = True):
    if D_in_feet:
        D = path_length_veg * 0.3048 #convert distance input in feet to meters
    return float(path_length_veg * gamma)

def RSL(P_O, L_tx, G_atx, FSL, MFM, RA, L_rc, G_rc, L_m, L_atm, A_ev):
    return float(P_O - L_tx + G_atx - FSL - MFM - RA - L_rc + G_rc - L_m - L_atm - A_ev)

def check_system(recieved_signal_strength, min_recieve_sensitivity):
    check = recieved_signal_strength > min_recieve_sensitivity
    SOM = recieved_signal_strength - min_recieve_sensitivity
    print "Recieved Signal Strength is adequate:", check
    print "Link System Operating Margin:", SOM, 'dB'
```

In [9]:

```
#Link 1 - CR 561 to Repeater
l1_Lm = 6 #For misalignment and aging 6.0 dB, no objects in first fresnel
l1_RA = rain_attenuation(0.001103, 1.2338, D_1, 4.6) #4.6 in/hr from FDOT IDF curves for Zone 7 1-hr 100-yr storm
l1_ATM = atmospheric_attenuation(0.725, 0.1, D_1)
l1_VEG = 0 #No trees in path
l1_P_O = 25 #NSM5 antenna 25 dBm EIRP
l1_G_atx = 0 #Included in EIRP
l1_G_arc = 16 #NSM5 gain per cut sheet
l1_RSL = RSL(l1_P_O, l1_tx, l1_G_atx, l1_FSL, l1_MFM, l1_RA, l1_rc, l1_G_arc, l1_Lm, l1_ATM, l1_VEG)
print l1_RSL, 'dB'
check_system(l1_RSL, -80) #NSM5 antenna -80 dBm recieve sensitivity for 36 Mbit/s
```

```
-79.6286045227 dB
Recieved Signal Strength is adequate: True
Link System Operating Margin: 0.37139547728 dB
```

In [10]:

```
#Link 2 - R1 to R2
l2_Lm = 6.0 #For misalignment and aging 6.0 dB, no objects in first fresnel
l2_RA = rain_attenuation(0.001103, 1.2338, D_2, 4.6) #4.6 in/hr from FDOT IDF curves for Zone 7 1-hr 100-yr storm
l2_ATM = atmospheric_attenuation(0.725, 0.1, D_2)
l2_VEG = 0 #No trees in path
l2_P_O = 22 #NSM5 antenna 22 dBm EIRP
l2_G_atx = 0 #Included in EIRP
l2_G_arc = 16 #NSM5 gain per cut sheet
l2_RSL = RSL(l2_P_O, l2_tx, l2_G_atx, l2_FSL, l2_MFM, l2_RA, l2_rc, l2_G_arc, l2_Lm, l2_ATM, l2_VEG)
print l2_RSL, 'dB'
check_system(l2_RSL, -75) #NSM5 antenna -75 dBm recieve sensitivity for 54 Mbit/s
```

```
-66.2809523461 dB
Recieved Signal Strength is adequate: True
Link System Operating Margin: 8.71904765386 dB
```

In [11]:

```
#Link 3 - R2 to Citrus
l3_Lm = 6.0 #For misalignment and aging 6.0 dB, no objects in first fresnel
l3_RA = rain_attenuation(0.001103, 1.2338, D_3, 4.6) #4.6 in/hr from FDOT IDF curves for Zone 7 1-hr 100-yr storm
l3_ATM = atmospheric_attenuation(0.725, 0.1, D_3)
l3_VEG = 0 #No trees in path
l3_P_O = 22 #NSM5 antenna 22 dBm EIRP
l3_G_atx = 0 #Included in EIRP
l3_G_arc = 16 #NSM5 gain per cut sheet
l3_RSL = RSL(l3_P_O, l3_tx, l3_G_atx, l3_FSL, l3_MFM, l3_RA, l3_rc, l3_G_arc, l3_Lm, l3_ATM, l3_VEG)
print l3_RSL, 'dB'
check_system(l3_RSL, -75) #NSM5 antenna -75 dBm recieve sensitivity for 54 Mbit/s
```

```
-70.8852963955 dB
Recieved Signal Strength is adequate: True
Link System Operating Margin: 4.11470360455 dB
```

In [12]:

```
#Link 4 - Citrus to Southern
l4_Lm = 6.0 #For misalignment and aging 6.0 dB, no objects in first fresnel
l4_RA = rain_attenuation(0.001103, 1.2338, D_3, 4.6) #4.6 in/hr from FDOT IDF curves for Zone 7 1-hr 100-yr storm
l4_ATM = atmospheric_attenuation(0.725, 0.1, D_3)
l4_VEG = 0 #No trees in path
l4_P_O = 25 #NSM5 antenna 25 dBm EIRP
l4_G_atx = 0 #Included in EIRP
l4_G_arc = 16 #NSM5 gain per cut sheet
l4_RSL = RSL(l4_P_O, l4_tx, l4_G_atx, l4_FSL, l4_MFM, l4_RA, l4_rc, l4_G_arc, l4_Lm, l4_ATM, l4_VEG)
print l4_RSL, 'dB'
check_system(l4_RSL, -80) #NSM5 antenna -80 dBm recieve sensitivity for 36 Mbit/s
```

```
-76.4635338355 dB
Recieved Signal Strength is adequate: True
Link System Operating Margin: 3.53646616452 dB
```

2.3 *Appendix C: Equipment Cut Sheets*

DATASHEET

NanoStation® M
NanoStation® locoM

Indoor/Outdoor airMAX® CPE

Models: NSM2, NSM3, NSM365, NSM5, locoM2, locoM5, locoM9

Cost-Effective, High-Performance

Compact and Versatile Design

Powerful Integrated Antenna

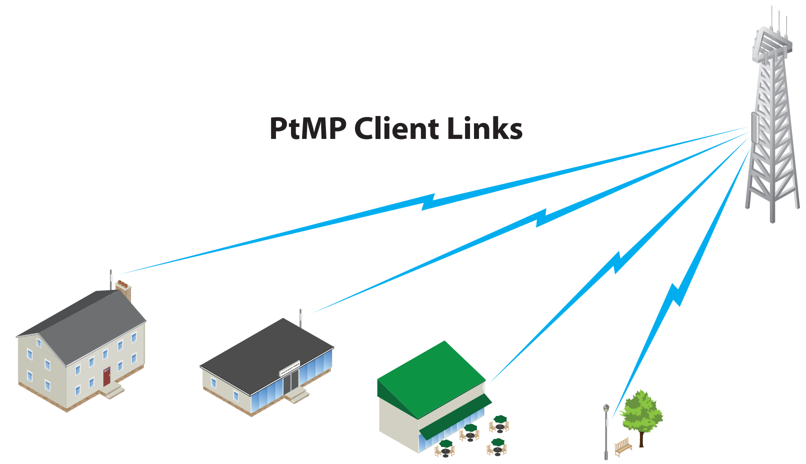
UBIQUITI®
NETWORKS

Overview

Leading-Edge Industrial Design

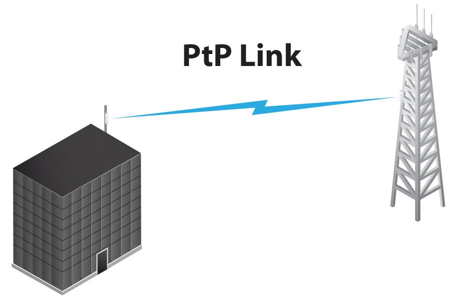
Ubiquiti Networks sets the bar for the world's first low-cost and efficient broadband Customer Premises Equipment (CPE) with the original NanoStation®. The NanoStationM and NanoStationlocoM take the same concept to the future with sleek and elegant form factors, along with integrated airMAX® (MIMO TDMA protocol) technology.

The low cost, high performance, and small form factor of NanoStationM and NanoStationlocoM make them extremely versatile and economical to deploy.



NanoStationM used as powerful clients in an airMAX PtMP (Point-to-Multi-Point) network setup.

NanoStationM as a powerful wireless client.



Use two NanoStationM to create a PtP link.

Utilize airMAX Technology

Unlike standard Wi-Fi protocol, Ubiquiti's Time Division Multiple Access (TDMA) airMAX protocol allows each client to send and receive data using pre-designated time slots scheduled by an intelligent AP controller.

This "time slot" method eliminates hidden node collisions and maximizes airtime efficiency. It provides many magnitudes of performance improvements in latency, throughput, and scalability compared to all other outdoor systems in its class.

Intelligent QoS Priority is given to voice/video for seamless streaming.

Scalability High capacity and scalability.

Long Distance Capable of high-speed, carrier-class links.

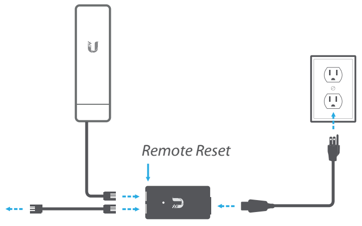
Latency Multiple features dramatically reduce noise.

Dual Ethernet Connectivity[1]

The NanoStationM provides a secondary Ethernet port with software-enabled PoE output for seamless IP video integration.

Intelligent PoE[2]

The remote hardware reset circuitry of the NanoStationM allows the device to be remotely reset from the power supply location.



The NanoStationM may also be powered by the Ubiquiti Networks® EdgeSwitch™. In addition, any NanoStationM can easily become 48V, 802.3af compliant through use of the Ubiquiti® Instant 802.3af Adapter (sold separately).

---

[1] *Only NanoStationM models*

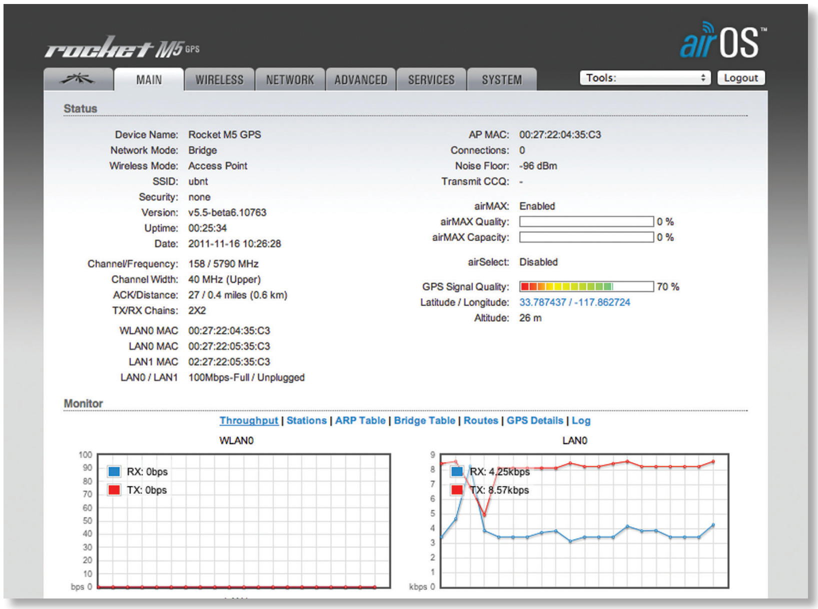
[2] *Remote reset is an option that is sold separately as the POE-24. The NanoStationM includes a 24V PoE adapter without remote reset.*

Software

airOS®

airOS® is an intuitive, versatile, highly developed Ubiquiti firmware technology. It is exceptionally intuitive and was designed to require no training to operate. Behind the user interface is a powerful firmware architecture, which enables high-performance, outdoor multi-point networking.

- Protocol Support
- Ubiquiti Channelization
- Spectral Width Adjustment
- ACK Auto-Timing
- AAP Technology
- Multi-Language Support



Status

Device Name: Rocket M5 GPS
Network Mode: Bridge
Wireless Mode: Access Point
SSID: ubnt
Security: none
Version: v5.5-beta6.10763
Uptime: 00:25:34
Date: 2011-11-16 10:26:28
Channel/Frequency: 158 / 5790 MHz
Channel Width: 40 MHz (Upper)
ACK/Distance: 27 / 0.4 miles (0.6 km)
TX/RX Chains: 2X2
WLAN0 MAC 00:27:22:04:35:C3
LAN0 MAC 00:27:22:05:35:C3
LAN1 MAC 02:27:22:05:35:C3
LAN0 / LAN1 100Mbps-Full / Unplugged

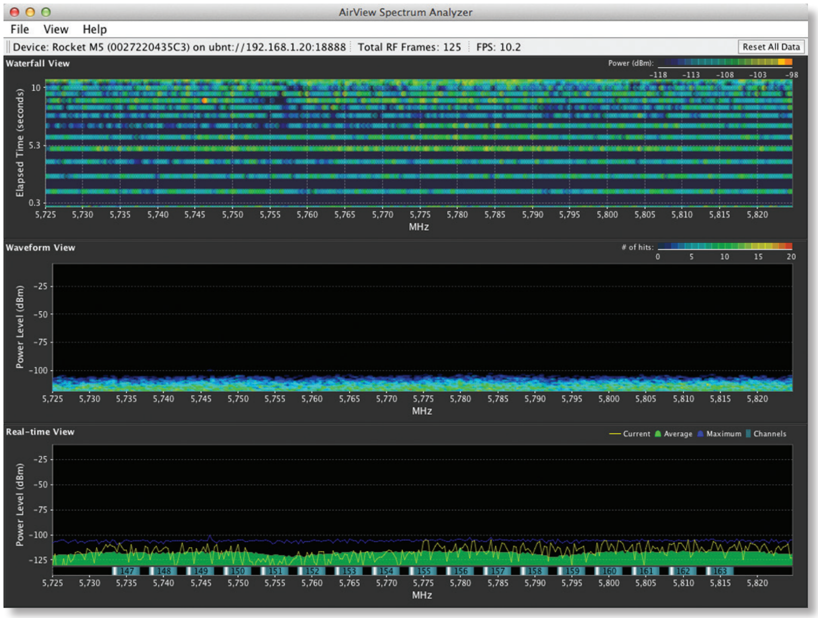
AP MAC: 00:27:22:04:35:C3
Connections: 0
Noise Floor: -96 dBm
Transmit CCQ: -
airMAX: Enabled
airMAX Quality: 0 %
airMAX Capacity: 0 %
airSelect: Disabled
GPS Signal Quality: 70 %
Latitude / Longitude: 33.787437 / -117.862724
Altitude: 26 m

Monitor

airView®

Integrated on all Ubiquiti M products, airView® provides advanced spectrum analyzer functionality: waterfall, waveform, and real-time spectral views allow operators to identify noise signatures and plan their networks to minimize noise interference.

- **Waterfall** Aggregate energy over time for each frequency.
- **Waveform** Aggregate energy collected.
- **Real-time** Energy is shown in real time as a function of frequency.
- **Recording** Automize AirView to record and report results.

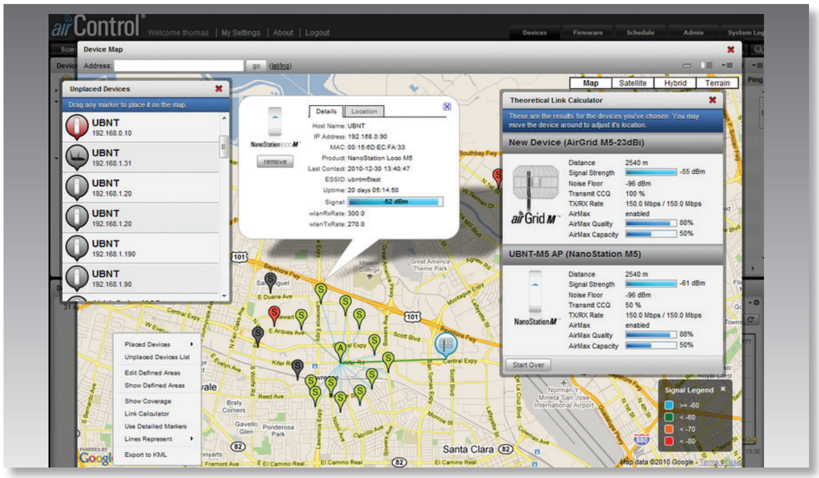


Device: Rocket M5 (0027220435C3) on ubnt://192.168.1.20:18888 Total RF Frames: 125 FPS: 10.2

airControl®

airControl® is a powerful and intuitive, web-based server network management application, which allows operators to centrally manage entire networks of Ubiquiti devices.

- Network Map
- Monitor Device Status
- Mass Firmware Upgrade
- Web UI Access
- Manage Groups of Devices
- Task Scheduling



Host Name: UBNT
IP Address: 192.168.0.90
MAC: 00:15:6D:EC:FA:33
Product: NanoStation Loco M5
Last Contact: 2010-12-30 13:40:47
ESSID: ubntm5test
Uptime: 20 days 05:14:50
Signal: -52 dBm
wlanRxRate: 300.0
wlanTxRate: 270.0

Theoretical Link Calculator

These are the results for the devices you've chosen. You may move the device around to adjust it's location.

New Device (AirGrid M5-23dBi)

Distance 2540 m
Signal Strength -55 dBm
Noise Floor -96 dBm
Transmit CCQ 100 %
TX/RX Rate 150.0 Mbps / 150.0 Mbps
AirMax enabled
AirMax Quality 88%
AirMax Capacity 50%

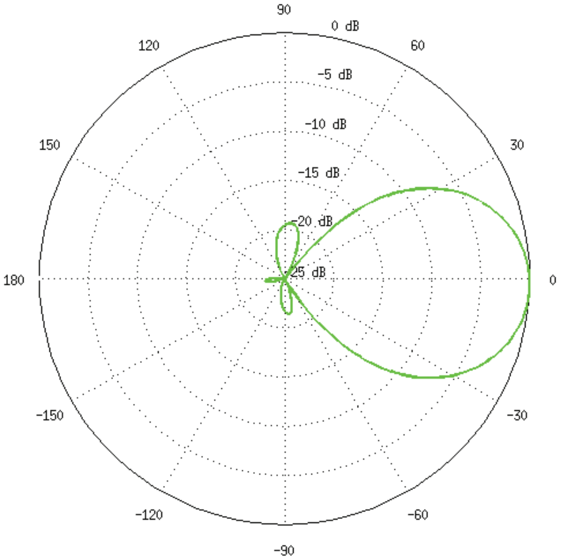
UBNT-M5 AP (NanoStation M5)

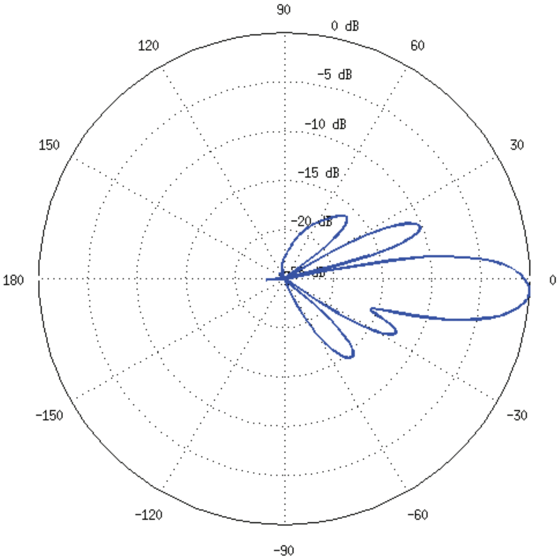
Distance 2540 m
Signal Strength -61 dBm
Noise Floor -96 dBm
Transmit CCQ 50 %
TX/RX Rate 150.0 Mbps / 150.0 Mbps
AirMax enabled
AirMax Quality 88%
AirMax Capacity 50%

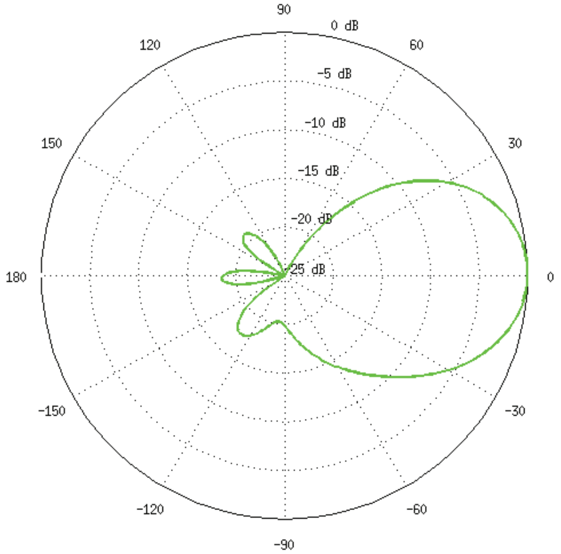
Specifications

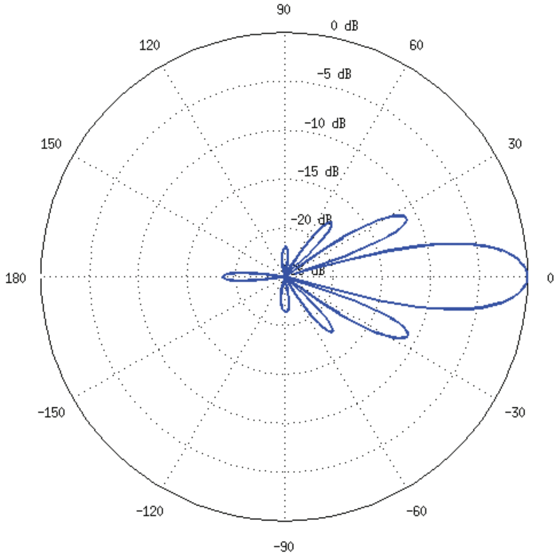
NSM5			
Dimensions	294 x 31 x 80 mm (11.57 x 1.22 x 3.15")		
Weight	400 g (14.11 oz)		
Power Supply (PoE)	24V, 0.5A		
Max. Power Consumption	8W		
Power Method	Passive PoE (Pairs 4, 5+; 7, 8 Return)		
Operating Frequency	Worldwide	USA	USA DFS
	5170-5875 MHz	5725-5850 MHz	5250-5850 MHz
Gain	14.6-16.1 dBi		
Networking Interface	(2) 10/100 Ethernet Ports		
Processor Specs	Atheros MIPS 74Kc, 560 MHz		
Memory	64 MB DDR2, 8 MB Flash		
Frequency	5 GHz		
Cross-pol Isolation	22 dB Minimum		
Max. VSWR	1.6:1		
Beamwidth	43° (H-pol) / 41° (V-pol) / 15° (Elevation)		
Polarization	Dual Linear		
Enclosure	Outdoor UV Stabilized Plastic		
Mounting	Pole-Mount (Kit Included)		
Operating Temperature	-30 to 75° C (-22 to 167° F)		
Operating Humidity	5 to 95% Noncondensing		
Wireless Approvals	FCC Part 15.247, IC RS210, CE		
RoHS Compliance	Yes		
Shock & Vibration	ETSI300-019-1.4		

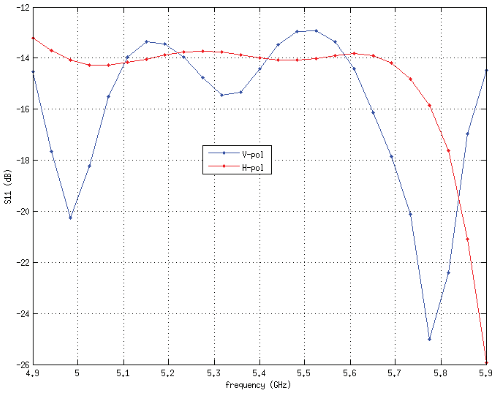
Output Power: 27 dBm							
5 GHz TX Power Specifications				5 GHz RX Power Specifications			
Modulation	Data Rate/MCS	Avg. TX	Tolerance	Modulation	Data Rate/MCS	Sensitivity	Tolerance
11a	6-24 Mbps	27 dBm	± 2 dB	**11a**	6-24 Mbps	-94 dBm	± 2 dB
	36 Mbps	25 dBm	± 2 dB		36 Mbps	-80 dBm	± 2 dB
	48 Mbps	23 dBm	± 2 dB		48 Mbps	-77 dBm	± 2 dB
	54 Mbps	22 dBm	± 2 dB		54 Mbps	-75 dBm	± 2 dB
11n/airMAX	MCS0	27 dBm	± 2 dB	**11n/airMAX**	MCS0	-96 dBm	± 2 dB
	MCS1	27 dBm	± 2 dB		MCS1	-95 dBm	± 2 dB
	MCS2	27 dBm	± 2 dB		MCS2	-92 dBm	± 2 dB
	MCS3	27 dBm	± 2 dB		MCS3	-90 dBm	± 2 dB
	MCS4	26 dBm	± 2 dB		MCS4	-86 dBm	± 2 dB
	MCS5	24 dBm	± 2 dB		MCS5	-83 dBm	± 2 dB
	MCS6	22 dBm	± 2 dB		MCS6	-77 dBm	± 2 dB
	MCS7	21 dBm	± 2 dB		MCS7	-74 dBm	± 2 dB
	MCS8	27 dBm	± 2 dB		MCS8	-95 dBm	± 2 dB
	MCS9	27 dBm	± 2 dB		MCS9	-93 dBm	± 2 dB
	MCS10	27 dBm	± 2 dB		MCS10	-90 dBm	± 2 dB
	MCS11	27 dBm	± 2 dB		MCS11	-87 dBm	± 2 dB
	MCS12	26 dBm	± 2 dB		MCS12	-84 dBm	± 2 dB
	MCS13	24 dBm	± 2 dB		MCS13	-79 dBm	± 2 dB
	MCS14	22 dBm	± 2 dB		MCS14	-78 dBm	± 2 dB
	MCS15	21 dBm	± 2 dB		MCS15	-75 dBm	± 2 dB

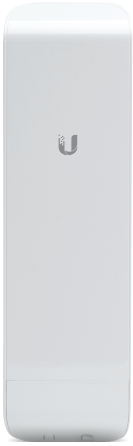

Vertical Azimuth


Vertical Elevation


Horizontal Azimuth


Horizontal Elevation


Return Loss



www.ubnt.com