NOKIA Bell Labs

# Presentation to FCC

## Measurements of Fixed Satellite Service (FSS) Earth Station Spillover Emissions to Evaluate Potential Interference Levels to Nearby 5G Systems Operating in the 28 GHz Frequency Band

Nokia Bell Labs & CTO

18-October-2016

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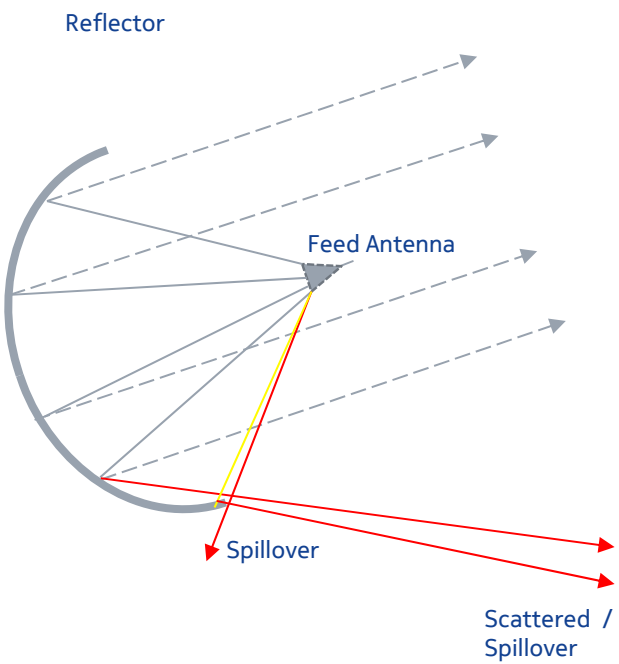
# FSS Earth Station Antenna Radiation Spill-over




- Spillover is the RF power radiated in angular regions outside the intended focal point of the reflector.
- Spillover occurs mainly due to:
  - Feed Horn energy which misses the reflector.
  - Imperfections in the Feed-Reflector focus
  - Phasing errors, i.e. real feeds vs. idealized point
  - Reflector deviation from paraboloidal shape
  - Blockages and reflections from feed support and secondary reflector support structure
  - Random surface error
  - Tradeoffs between size and desired efficiency
- Scattered energy from the feed support structure and imperfections are considered part of the total spillover for this discussion.

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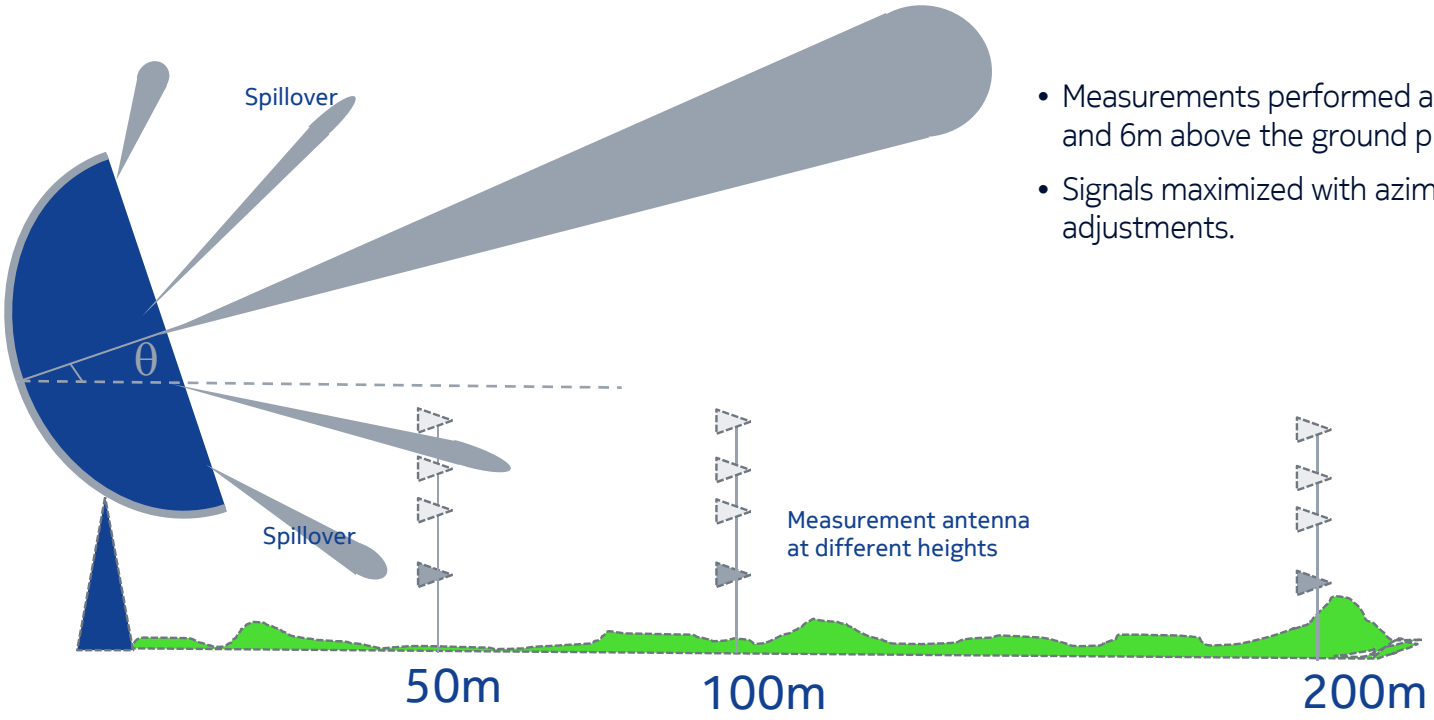
# Spill-over Radiation Measurement- Measurement Antenna above the Ground Level




- Measurements performed at 2m, 4.5m, 5m and 6m above the ground plane.
- Signals maximized with azimuth and tilt adjustments.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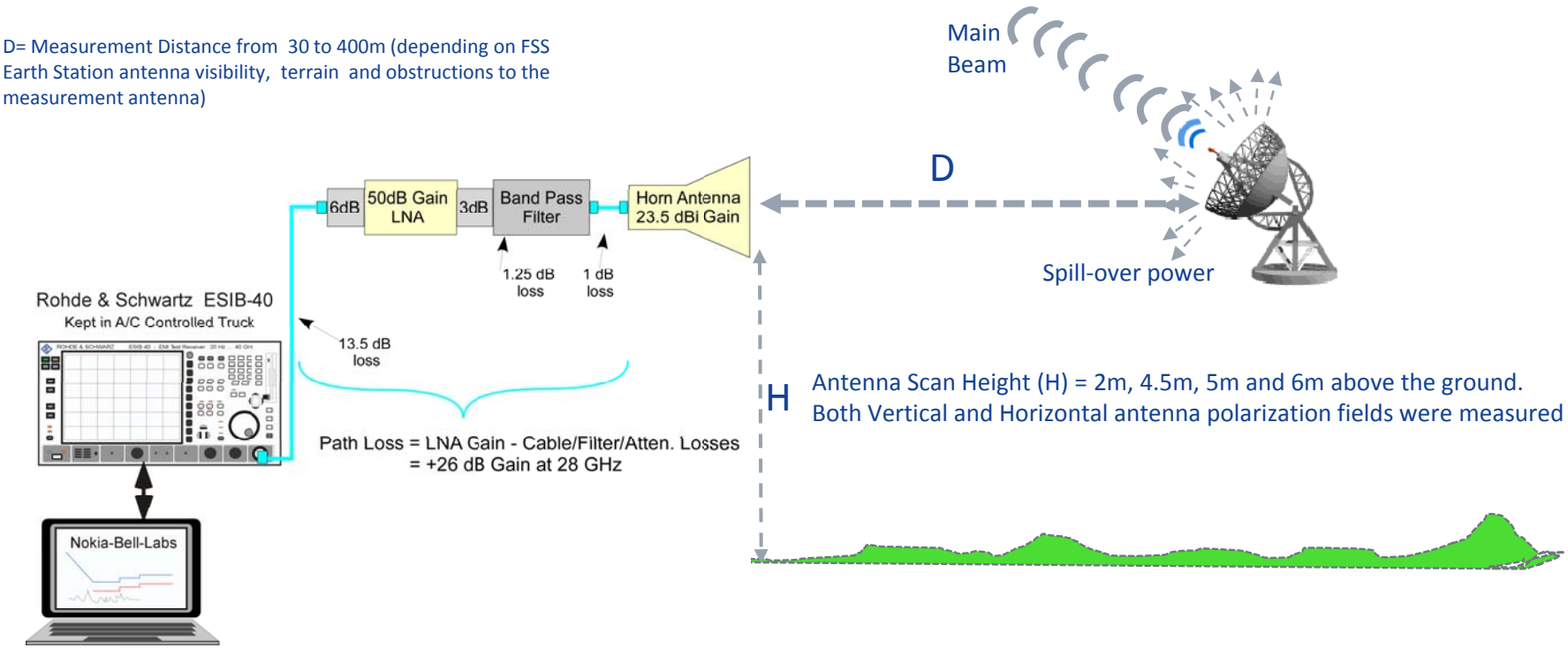
# Measurement Setup

D= Measurement Distance from 30 to 400m (depending on FSS Earth Station antenna visibility, terrain and obstructions to the measurement antenna)




Antenna Scan Height (H) = 2m, 4.5m, 5m and 6m above the ground.
Both Vertical and Horizontal antenna polarization fields were measured

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# Computational Basis for Power Flux Density at the 5G Receive Antenna Determined Using Friis Transmission Formula

*from the* Friis Transmission Formula

$$P_r = P_d \times A_{er} \text{ ---------- } (1)$$

Where:

$P_r$ = Measured power at 50 Ω analyzer input (W)

$P_{measdBm}$ = Measured power at 50 Ω analyzer input (dBm)

$P_d$ = Power flux density in W/m$^2$/MHz

$P_{d\text{-}dBm}$ = Power flux density in dBm/m$^2$/MHz

$A_{er}$ = Antenna effective aperture

G = Antenna Gain

$G_{dBi}$ = Antenna Gain in dBi

$G_{Preamp}$ = preamp gain – (cable+filter+attenuator loss) in dB

$\lambda$ = Wavelength of frequency in meters

and

$$A_{er} = G\lambda^2/4\pi \text{ ---------- } (2)$$

likewise

G = Antenna

$$G = (4\pi \times A_{er})/\lambda^2 \text{ ---------- } (3)$$

in dBm form

$$P_{d\text{-}dBm} = P_{measdBm} - G_{Preamp} - G_{dBi} - 10\mathrm{Log}_{10}(\lambda^2/4\pi) \text{ ------- } (4)$$


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## Measurement Sites

- Five Fixed Satellite Service sites were measured.
  - Eight sites were picked and visited for the test from a list of 50+ sites.
  - Three sites were not accessible due to terrain, property access and foliage.
  - Accessibility, Topography and Diversity of Operation were the selection drivers.
- All existing and pending 28GHz FSS sites were Grandfathered by the FCC.
  - The FCC grandfathered all existing and pending 28 GHz earth stations. This allows those stations to operate without regard for possible interference with 5G services.
- Measurement Site #1 is a Geosynchronous FSS Station.
  - 2 km from an mixed use National Guard / International Airport.
  - Offices and homes nearby. 100~200m
  - 3 dishes.
- Site # 2 is a Near Earth Orbit site co-located within an Geosynchronous FSS Station.
  - Within 50 Miles of Washington DC.
  - Industry and Offices nearby
  - 900+ meters to nearest homes.
  - 7 sets of dual antenna Near Earth Orbit systems set up for training and operation.
  - 18+ other FSS dish systems present.


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## Measurement Sites *continued*

- Site # 3 is a Geosynchronous FSS Station.
  - 50m to nearest business. Three additional businesses 230m away.
  - Nearest homes are 330m. Most are > 500m away.
  - 2 dishes operating in the 28 GHz Band, minimum of 4 more dishes at other frequencies.

- Site # 4 is a Geosynchronous FSS Station.
  - 5km to town center.
  - IT company located on site. Industry and Offices on left and right sides (< 400m)
  - 230+ meters to nearest homes.
  - 2 dishes operating in the 28 GHz. Third dish on site awaiting spacecraft launch.
  - 275m to Microwave Distribution System / Cellular Tower with 8 MDS antenna.

- Site # 5 is a Geosynchronous FSS Station.
  - 17 km from an Air Force Base.
  - 14 km from Regional downtown city.
  - 36 unit Apartment complex nearby starting at 70m with 12 homes beyond at 190m~300m.
  - Nearest Business 180m to rear.
  - 1 dish operating in the 28 GHz band, 3 other dishes on site operating at different frequencies.


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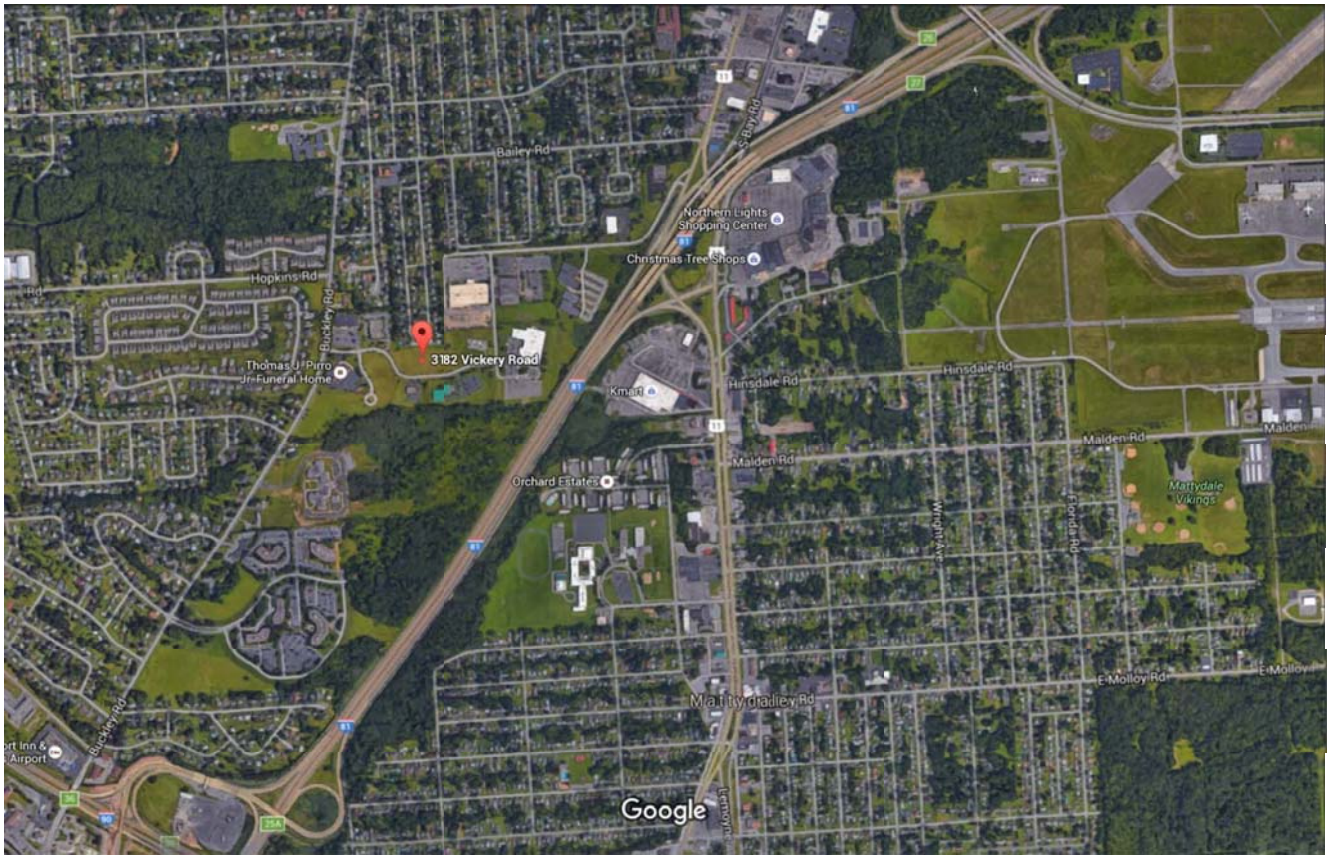
## Measurement Site #1 – Broad View

*Courtesy Google Maps*

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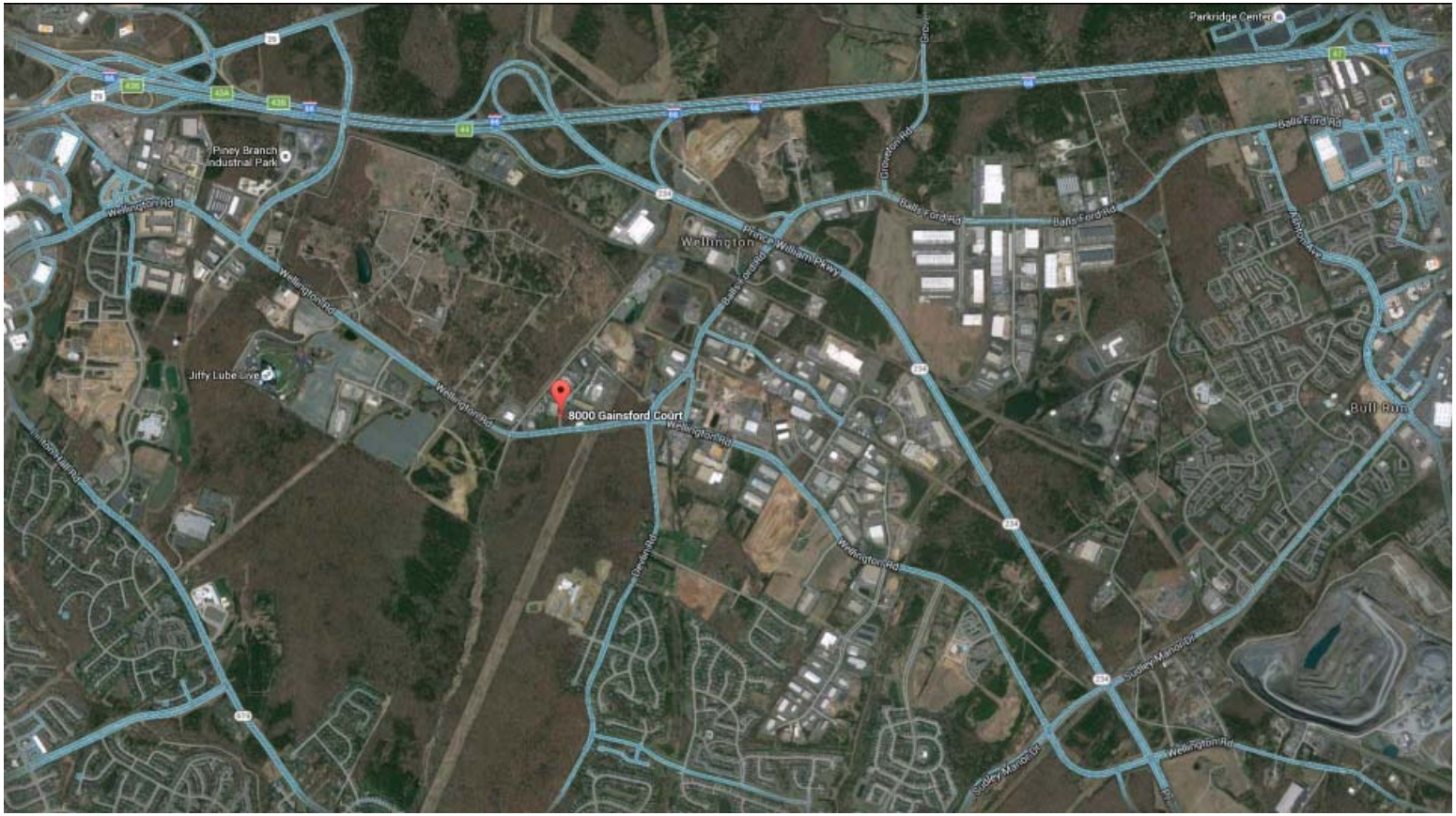
## Measurement Site #2 - Broad View

*Courtesy Google Maps*

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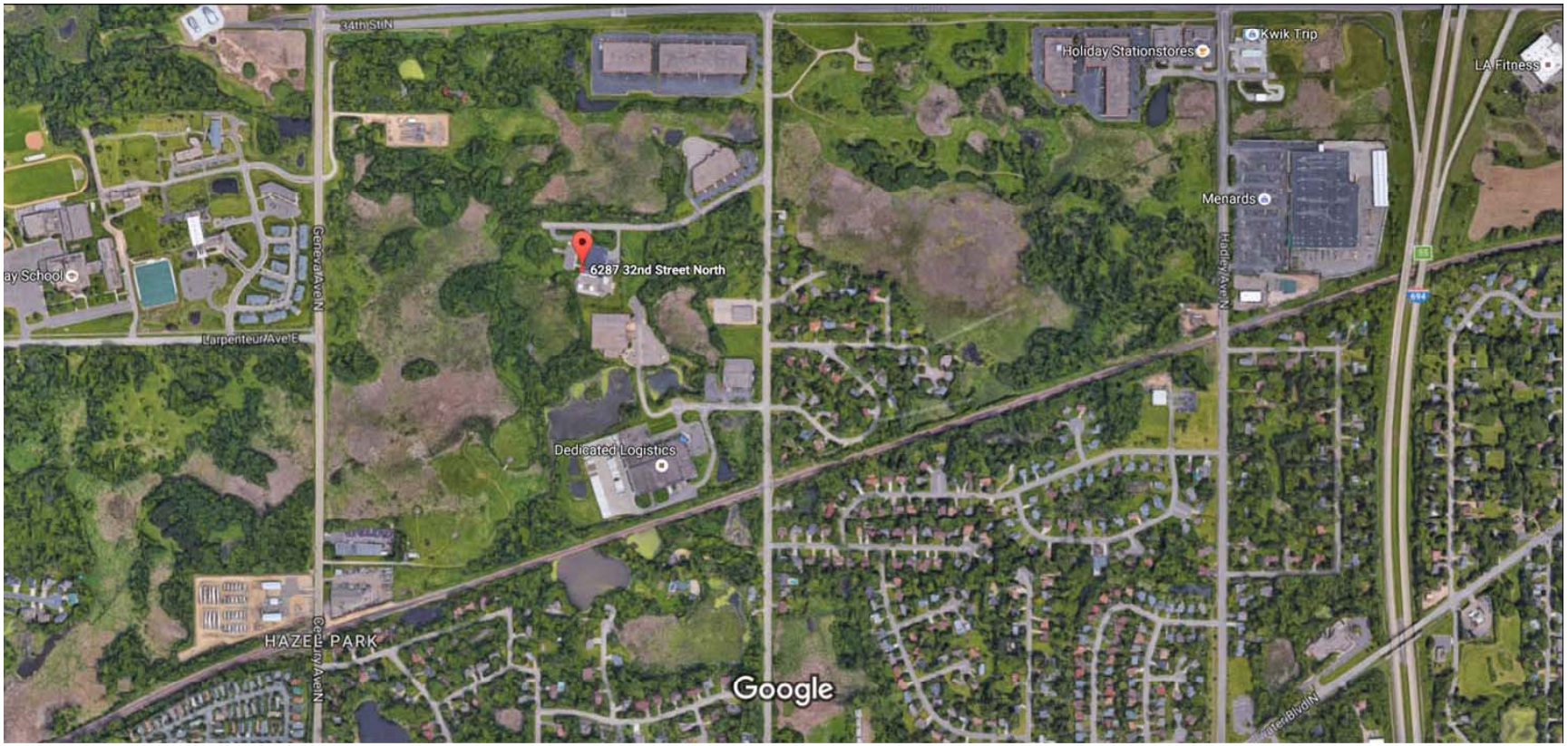
## Measurement Site #3

*Courtesy Google Maps*

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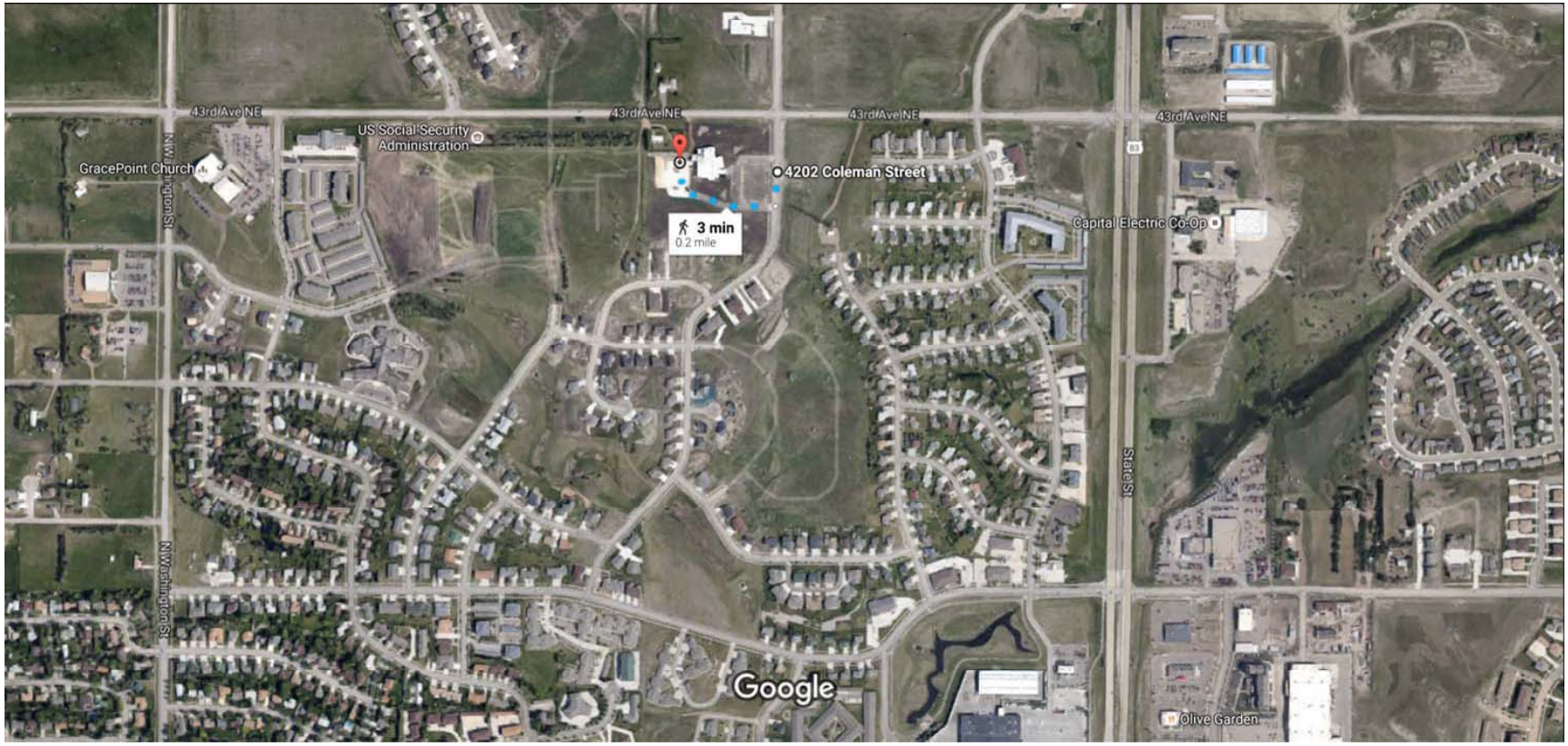
## Measurement Site #4 - Broad View

*Courtesy Google Maps*

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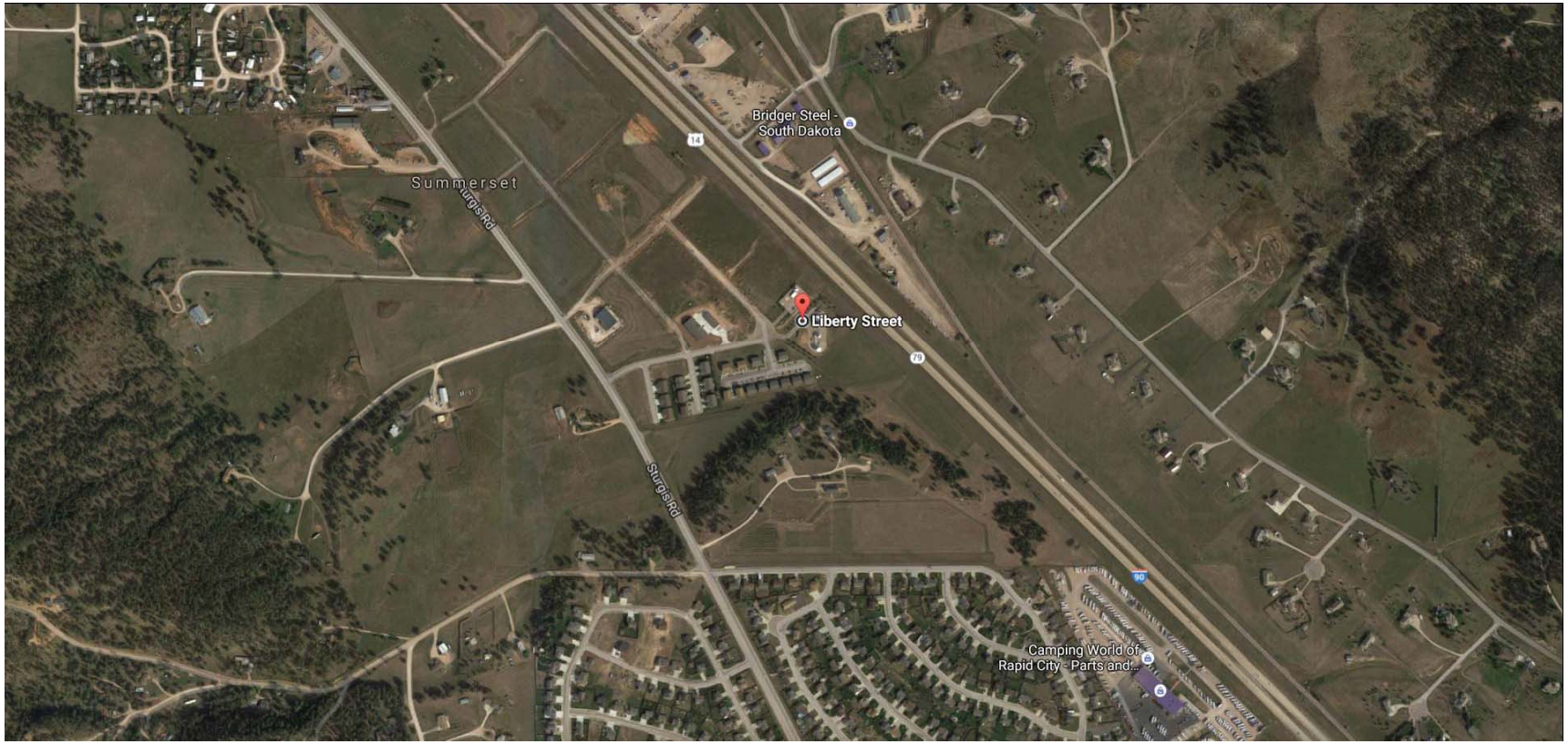
## Measurement Site #5 - Broad View

*Courtesy Google Maps*

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## Measurement Site #1

- Three active FSS Earth Station dish antenna.
  - Active Ka band transmissions from 28.35 to 28.6 GHz and 29.25 GHz to 30.0 GHz
  - The site was licensed for operation on 02/06/2012,
- Two 8.1m and a single 5.6m . All operating with Emissions Designator 22M5G7W
  - All three dish antenna are center feed sub-reflector style, circularly polarized.
    - Expected measured V & H values are 3dB down from LHP and RHP.
  - The Antennas line of focal point elevation with respect to Horizontal plane is 30.2° E – 7.4° W
  - The Antennas Azimuth limits are 223.6E - 254.5W
  - Maximum EIRP towards Horizon = -15.6 dBW/4kHz
- The two 8.1m dish antennas are Andrew Corporation ES-81-KA-1
  - Max Gains = 62.4 dBi @ 19.95 GHz and 65.6 dBi @ 29.75 GHz
  - Maximum total input power at the antenna flange = 250.6 Watts
  - Maximum aggregate output EIRP for all carriers = 89.3 dBW
- The 5.6m dish antenna is an Andrew Corporation ES-56-KA-1
  - Max Gains = 59.7 dBi @ 19.95 GHz and 62.6 dBi @ 29.75 GHz
  - Maximum total input power at antenna flange = 250.6 Watts
  - Maximum aggregate output EIRP for all carriers = 86.3 dBW

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## Measurement Site #1 *continued*

- Relatively Flat Terrain in Front of Antenna
  - Measurements were made in ideal weather conditions (cloudless clear skies)
  - Laser rangefinder used to verify distance. ( ± 0.9m accuracy)
- Measurements performed at 0°, 22.5°, 120° right and 180° with respect to middle antenna.
- All measurements were made at 2m, 4.5m, 5m and 6m measurement antenna heights.
- The 0° measurements were made at distances of 100m, 200m, 280m and 400m
  - Even Terrain (no elevation change) and Clear Line of Sight for 100m, 200m & 280m
- The 22.5 ° left measurements were made at 100m and 200m
- The 120° right measurements were made 50m, 100m and 200m
- The 180° measurements were made at 100m and 200m

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## Measurement Site #1 - Ground View - 22.5° Left, 100m Distance, 5m Height

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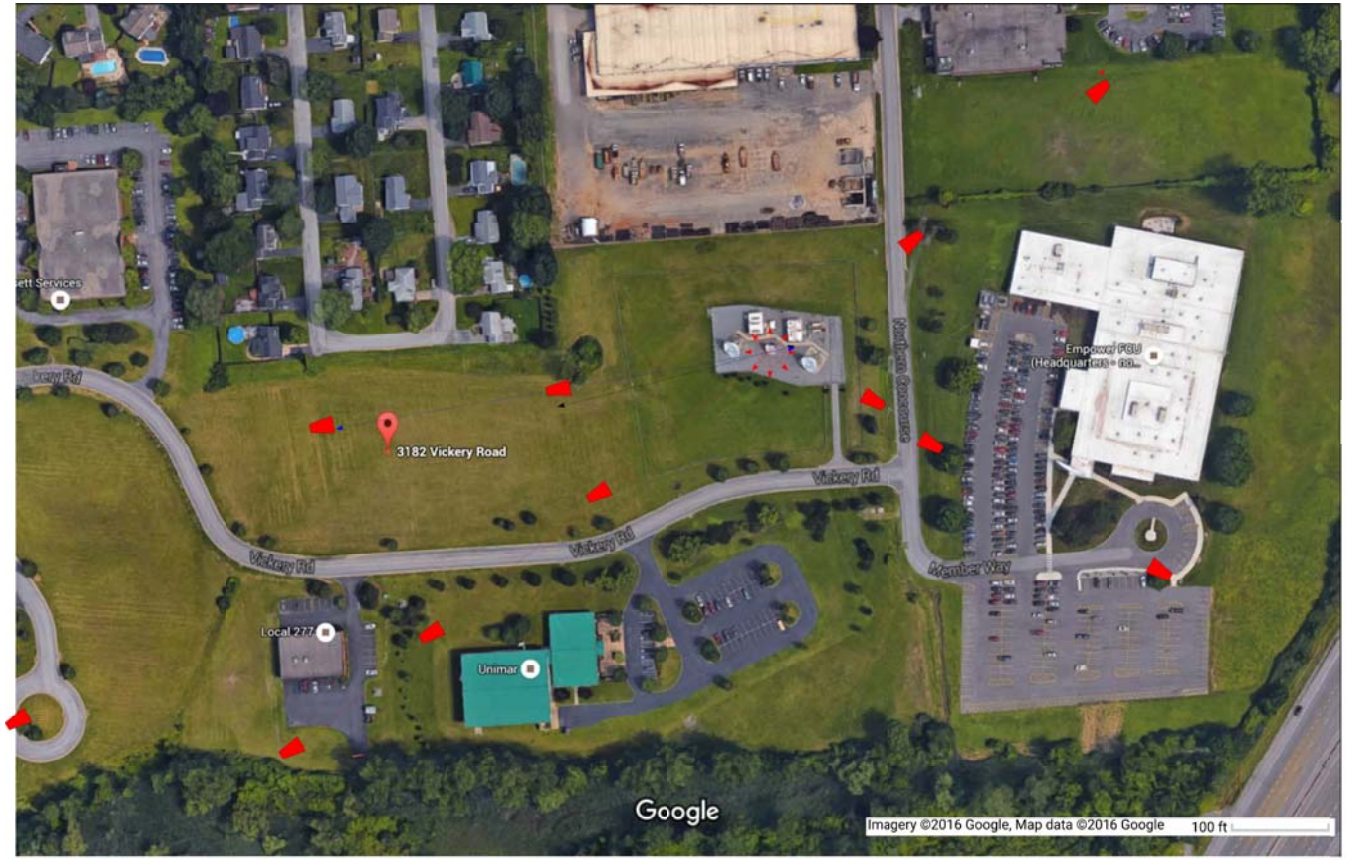
## Measurement Site #1 - Aerial View – Test Locations shown with red markers below.

*Courtesy Google Maps*

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## Measurement Site #1 - Aerial View – Distance Verification 280m, 0°

*Courtesy Google Maps*

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## Measurement Site #2 Near Earth Orbit (NEO) FSS Site

- Seven FSS Earth Station dish antenna systems were active in the 28 GHz band.
  - The 28 GHz service was operated for Near Earth Orbit Spacecraft.
  - The antenna are circularly polarized. Expected V & H values are ~3dB down from LHP and RHP.
- Seven dish antenna pairs operational at 27.5 GHz to 27.9 GHz actively tracking NEO spacecraft.
  - No other signals were present from 27 GHz -27.5 GHz or from 28 GHz -30 GHz.
    - The 1.8m diameter antennas were operating at 5W with overcast sky. Maximum feed power level is 40W.
    - The 2.4m diameter antennas listed maximum feed power = 35.9W. Max Gain = 55.2 dBi @ 28.3615 GHz
    - The 1.2m diameter antennas listed maximum feed power = 20W. Max Gain = 48.0 dBi @ 28.3 GHz
    - The minimum observed antenna focal point elevation with respect to the Horizontal plane was ~5deg.
    - The dish antennas operate in pairs. Dish #1 transmits to overhead s/c while the dish #2 waits for the next s/c.
    - Emissions Designators are 1M00G7D and 216MG7D.
    - There were >17 other active antennas at this site operating in different frequency bands.
- The 2.4m Diameter Antennas were Licensed in 2015
  - The FCC authorized max EIRP level was 70.75 W/carrier (48.5 dBm/carrier)
    - Maximum EIRP toward Horizon is 32.1 dBm/MHz (-21.9 dBw/4kHz)
    - Antenna line of focal point elevation with respect to Horizontal plane is 7.6° E – 7.0° W
- The 1.2m Diameter Antennas were Licensed in 2015
  - The FCC authorized max EIRP level was 60.6 W/carrier (47.8 dBm/carrier)
    - Maximum EIRP toward Horizon is 14.2 dBm/MHz
    - Antenna line of focal point elevation with respect to Horizontal plane is 10 deg

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## Measurement Site #2 *continued*

- Measurements were made at 0°, 90° left and 180° with respect to the middle dish antenna nominal.
  - All measurements were made at 2m, 4.5m, 5m and 6m measurement antenna heights.
  - The 0° measurements were made with ideal clear sky weather. All other measurements had overcast sky.
- The 0° measurements were made at distances of 30m, 40m, 50m, 100m and 200m.
  - These measurements had flat down-sloping terrain away from the site.
  - Elevation loss was > 5m at 200m distance.
- The 90° left measurements were made at 50m (on road), 100m and 140m.
  - The 100m and 140m measurements had even terrains with a 0.8m high roadway berm outside dish site.
- The 180° measurements were made at 30m with a 2m elevation rise.

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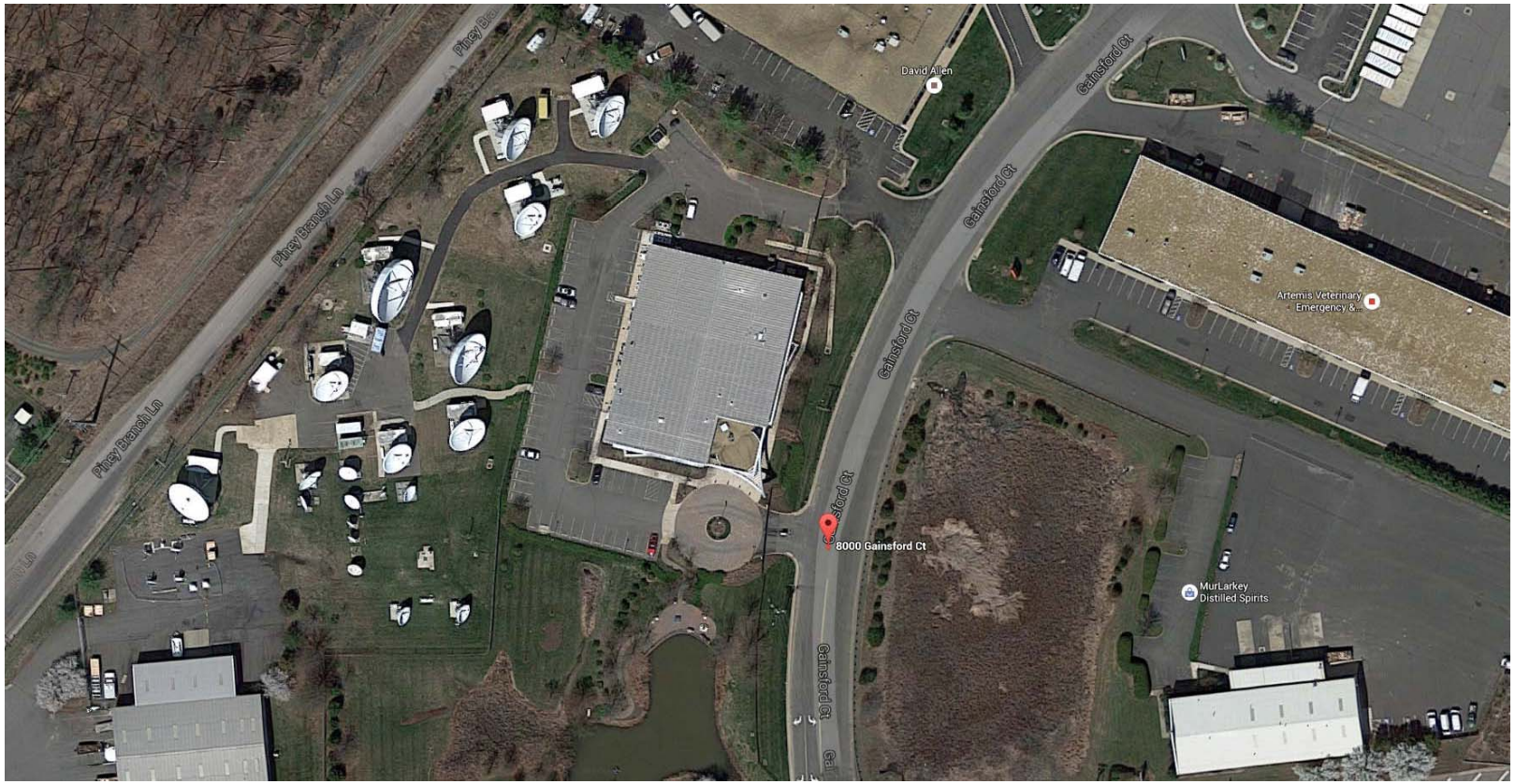
## Measurement Site #2 - Aerial View

*Courtesy Google Maps*

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## Measurement Site #2 - Ground View

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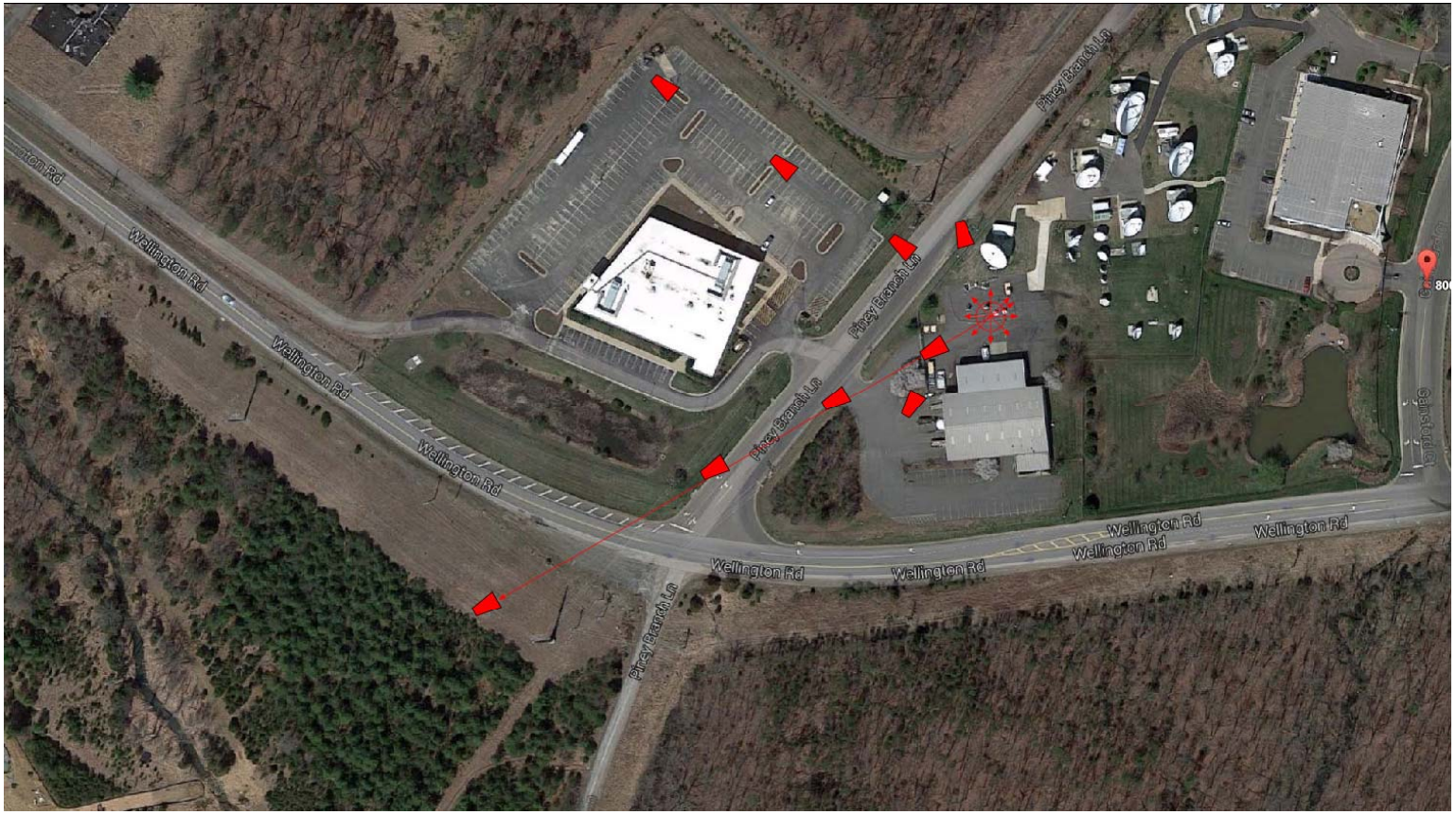
## Measurement Site #2 – Test locations shown with red markers below.

*Courtesy Google Maps*

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## Measurement Site #2 – Ground View - 90º , 140m Distance, 6m Height

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## Measurement Site #3

- Two active FSS Earth Station dish antenna.
  - Max Gain(s):70.0 dBi @ 30.0 GHz , 65.4 dBi @ 20.2 GHz
  - Maximum total input power at the antenna flange = 447.0 Watts
  - Maximum aggregate output EIRP for all carriers = 96.5 dBW
- Center feed sub-reflector style, circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP.
- Active transmissions from 28.35-29.5 GHz and 29.25-30.00 GHz.
- The 13.2m Diameter Vertex RSI Antennas were Licensed in 2014.
  - The FCC authorized max EIRP level was 85.10 W/carrier (45.60 dBm/carrier)
    - Maximum EIRP toward Horizon is 29.9 dBW/4kHz
    - Antenna line of focal point elevation with respect to Horizontal plane is 36.6° E – 31.7° W
    - Antenna Azimuth limits of 161.9° E – 215.8° W

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## Measurement Site #3

- Measurements were made in mostly cloudy skies.
- Laser rangefinder used to verify distance.

- Measurements performed at 0°, 90° right and 210° with respect to mid point of the two dish antenna.
- No elevation change for any measurement, i.e. Flat terrain.

- The 0° measurements were made at 50m only due to limited accessibility.

- The 90° right measurements were made at 85m and 125m.

- The 210° measurements were made at 50m and 80m

- All measurements were made at 2m, 4.5m, 5m and 6m measurement antenna heights.

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## Measurement Site # 3 - Aerial View - Test locations shown with red markers below.

*Courtesy Google Maps*

Imagery ©2016 Google, Map data ©2016 Google 100 ft

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## Measurement Site #3 Ground View - 210°, 50m Distance, 2m Height

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## Measurement Site #4

- Two active FSS Earth Station dish antenna.
- Center feed sub-reflector style, circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP
- Licensed for transmissions from 27.85 GHz to 30 GHz

- Two active FSS Earth Station dish antenna, licensed for the same signals.
  - Max Gain(s):62.0 dBi @ 20.2 GHz, 65.3 dBi @ 30.0 GHz
  - Maximum total input power at the antenna flange = 200.0 Watts
  - Maximum aggregate output EIRP for all carriers = 88.3 dBW

- Active transmissions from 29.5 -30.00 GHz.
- The 8.1m Diameter ASC Signal Antennas were Licensed in 2015.
  - The FCC authorized max EIRP level/carrier is 88.3 (units not listed) (44.8 ) ( units not listed)
    - Maximum EIRP toward Horizon is listed as -44.9 dBW/4kHz
    - Antenna line of focal point elevation with respect to Horizontal plane is 36.0° E – 36.0° W
    - Antenna Azimuth limits of 174.8° E – 174.8° W
    - Emission Designators range from 100KG7W to 250MG7D

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## Measurement Site #4

- Two active FSS Earth Station dish antenna.
- Active transmissions from 29.5 GHz to 30 GHz
- The antenna are circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP.

- Measurements were made at 0° and 35° right with respect to mid point of the two dish antenna.

- Both sets of measurements were made in clear skies.

- The 0° measurements were made at distances of 50m and 100m.
  - The measurement at 100m distance had an elevation gain of 4ft (1.22m).

- The 35° right measurements were made at 100m and 200m.
  - The measurement at 200m distance had an elevation loss of 12ft (3.66m) .

- All measurements were made at 2m, 4.5m, 5m and 6m measurement antenna heights.

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## Measurement Site #4 - Aerial View – Test Locations shown with red markers below.

*Courtesy Google Maps*

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## Measurement Site #4 - Ground View - 35° Right, 100m Distance, 2m Height

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## Measurement Site #4 - Ground View -35° Right, 200m Distance

day/ month/year time (EST)

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## Measurement Site #5

- Four dishes on site but only one was active in the 28 GHz band.
- One active 28GHz FSS Earth Station dish antenna.
- Center feed sub-reflector style, circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP
  - Max Gain(s): 65.5 dBi @ 30.0 GHz.
    - 62.8 dBi @ 20.2 GHz, 61.9 dBi @ 18.3 GHz, 65.3 dBi @ 28.35 GHz, 65.4 dBi @ 29.10 GHz and 65.4 dBi @ 29.50 GHz
  - Maximum total input power at the antenna flange = 200.0 Watts
  - Maximum aggregate output EIRP for all carriers = 89.0 dBW
- Active transmissions from 28.1-29.1 GHz and 29.5-30.0 GHz.
- The 7.3m Diameter Antenna was licensed in 2011.
  - Licensed to provide service to four possible spacecraft.
    - Maximum EIRP toward Horizon is -41.3 dBW/4kHz
    - Antenna line of focal point elevation with respect to Horizontal plane is 6.6° E – 7.3° W
    - Antenna Azimuth limits of 105.2E - 254.1W
    - Emissions Designators – 1K00N0N, 1M00G2D, 52M1G7D & 416MG7D

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## Measurement Site #5

- One FSS Earth Station dish antenna active in the 28 GHz band.
  - Active transmissions from 28.1-29.1 GHz and 29.5-30.0 GHz
  - The antenna is circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP

- All measurements were made with ideal clear sky weather overhead.
  - Ideal clear sky weather in the direction of transmission.

- Measurements were made at $0^o$, $90^o$ left and $180^o$ with respect to center antenna.

- The $0^o$ measurements were made at distances of 100m and 200m.
  - The measurements at 200m distance had an elevation gain of 24ft (7.32m).

- The $90^o$ left measurements were made at 100m.

- The $180^o$ measurements were made at 140m.

- All measurements were made at 2m, 4.5m, 5m and 6m measurement antenna heights.

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## Measurement Site #5 - Aerial View – Test Locations shown with red markers below.

*Courtesy Google Maps*

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## Measurement Site #5 - Ground View ~85° Left, 100m Distance, 2m Height

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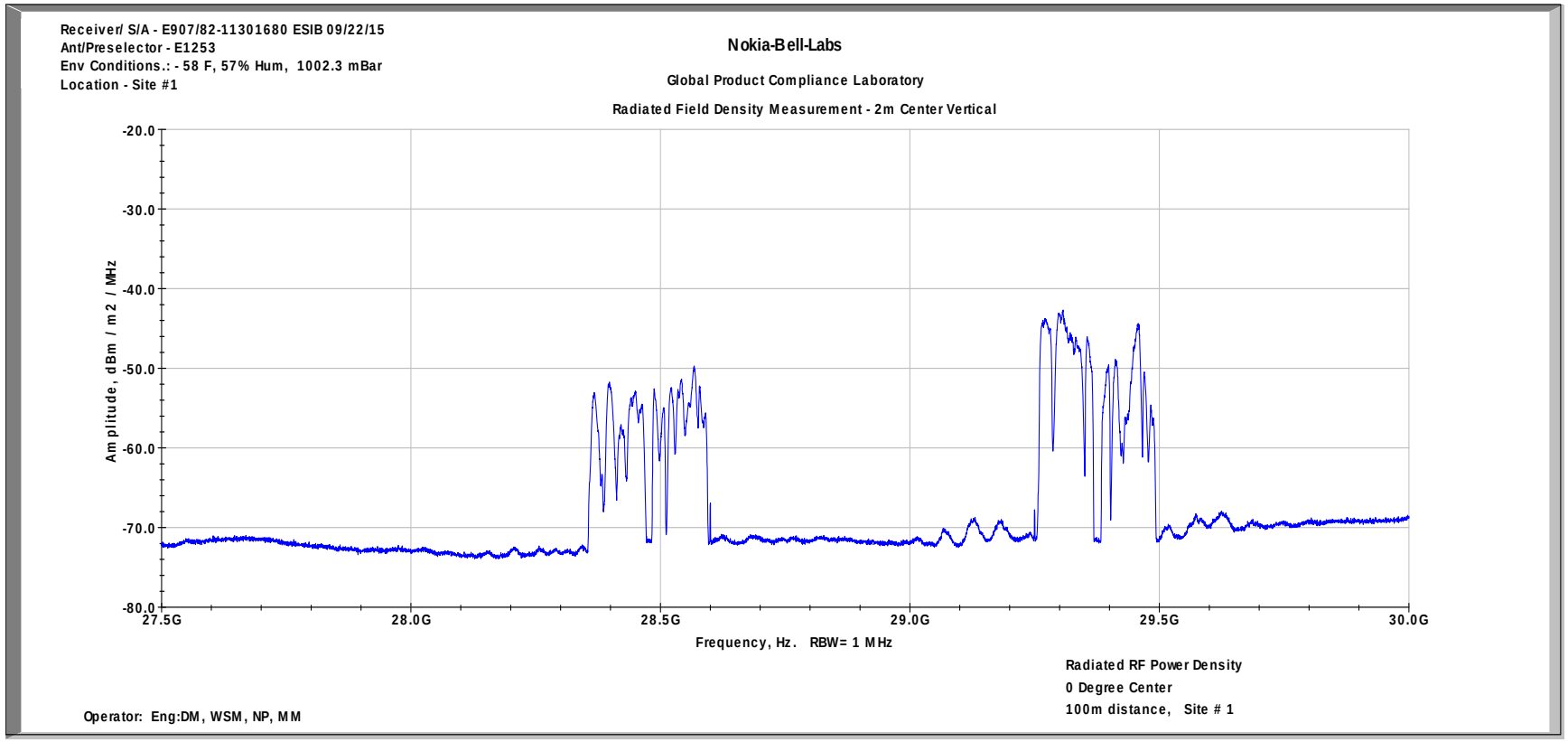
## Sample Site 1 GEO Transmit Signal Center Location 100m Distance 2m Height Vertical Polarization

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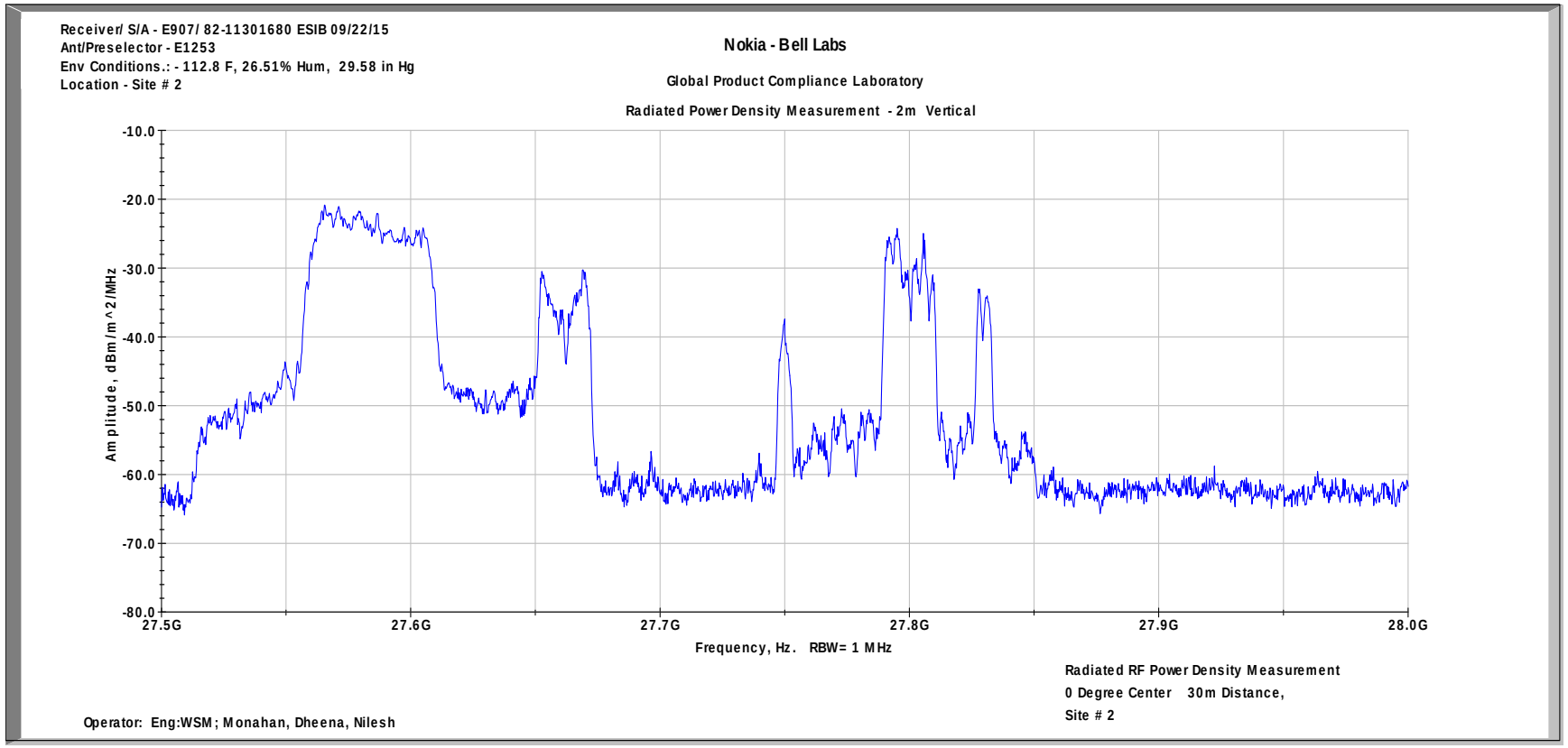
## Sample Site 2 NEO Transmit Signal Center Location 30m Distance 2m Height Vertical Polarization

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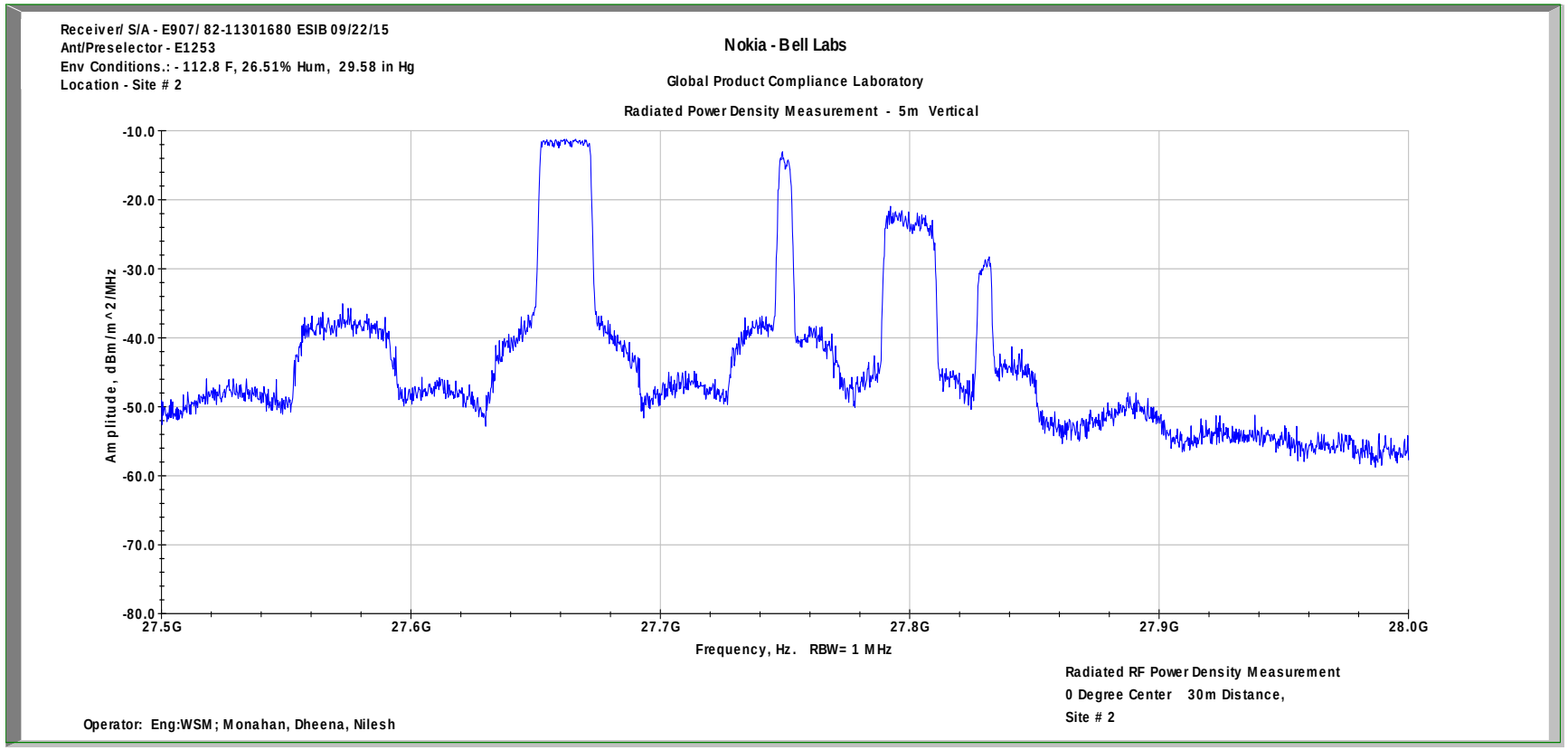
## Sample Site 2 NEO Transmit Signal Center Location 30m Distance 5m Height Horizontal Polarization

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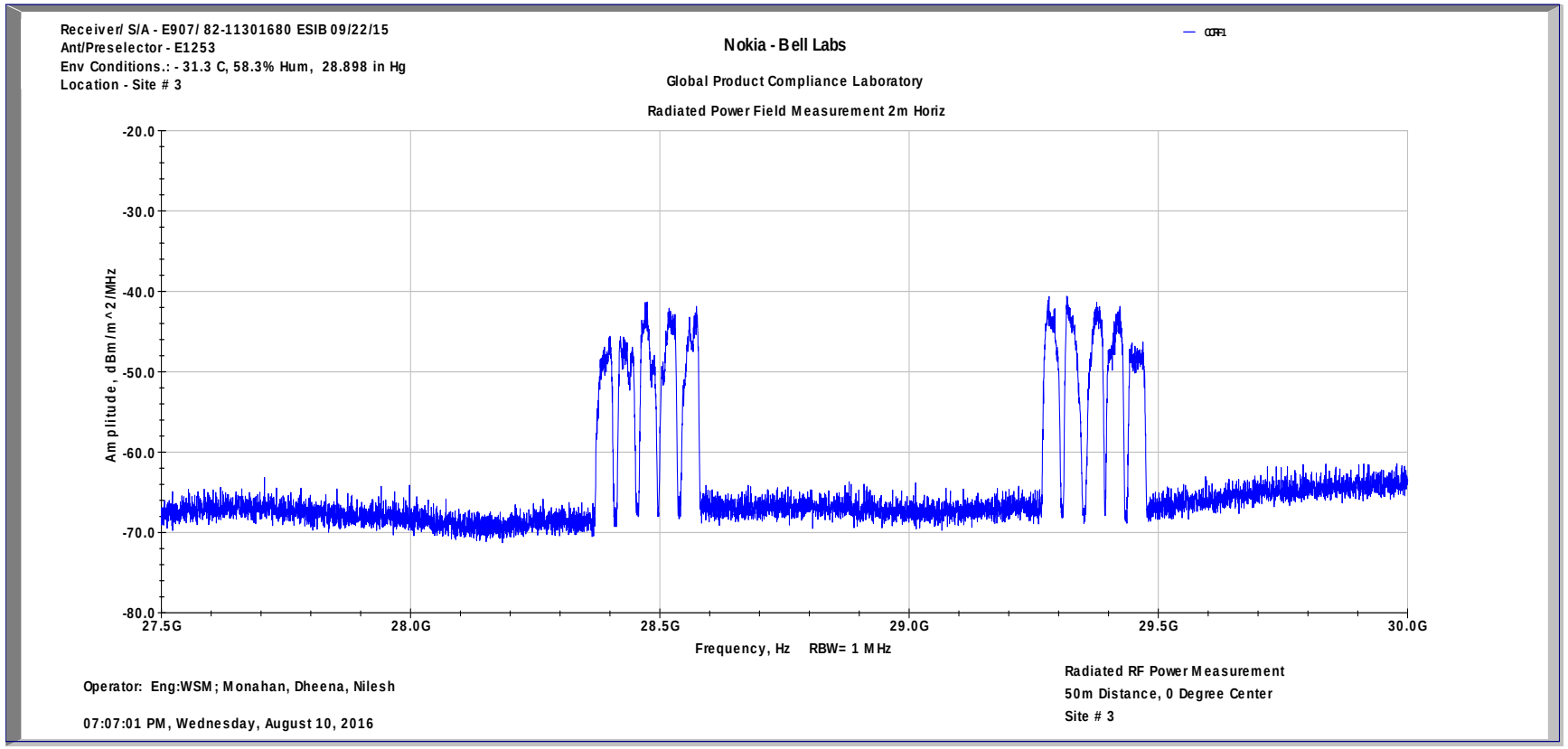
## Sample Site 3 GEO Transmit Signal Center Location 50m Distance 2m Height Horizontal Polarization

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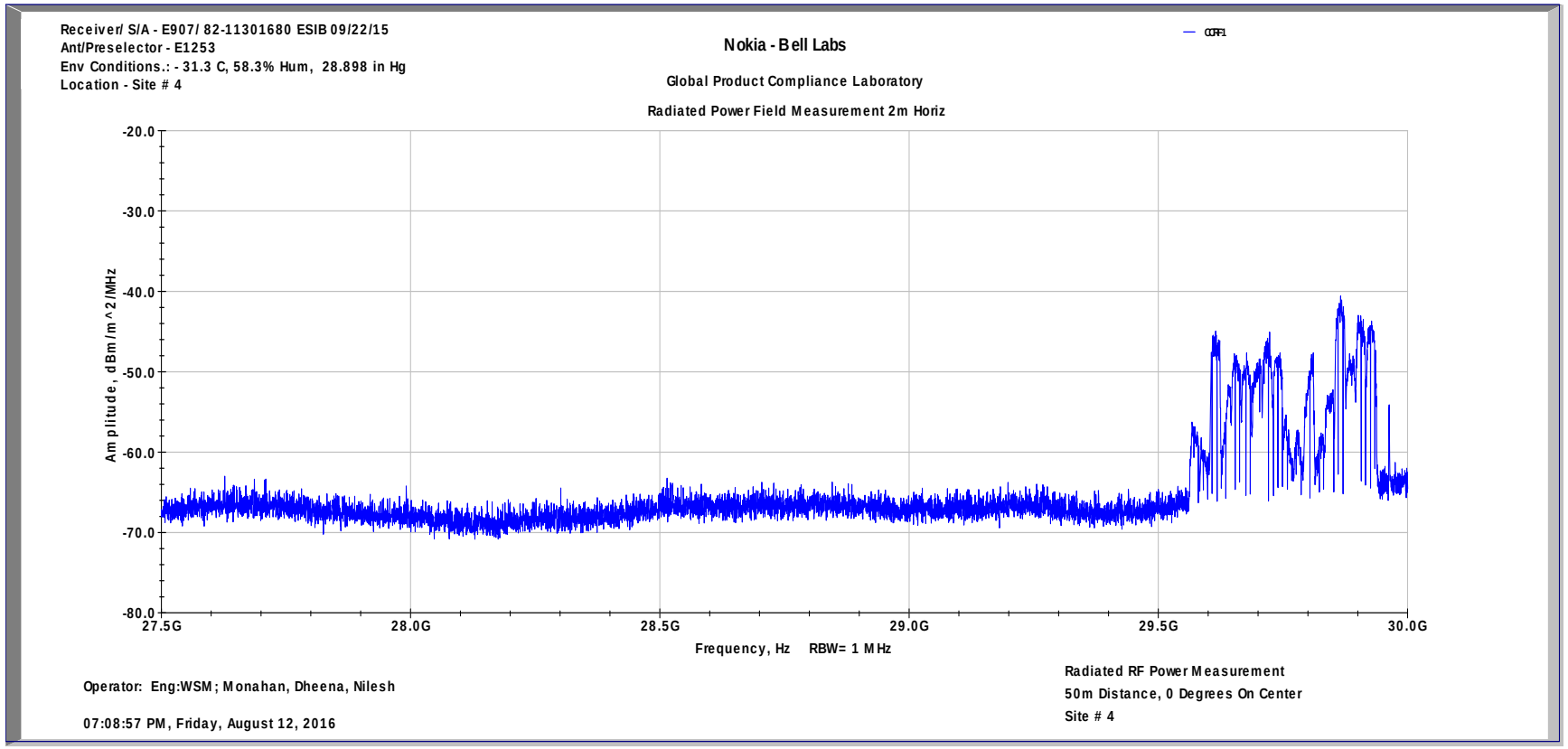
## Sample Site 4 GEO Transmit Signal Center Location 50m Distance 2m Height Horizontal Polarization

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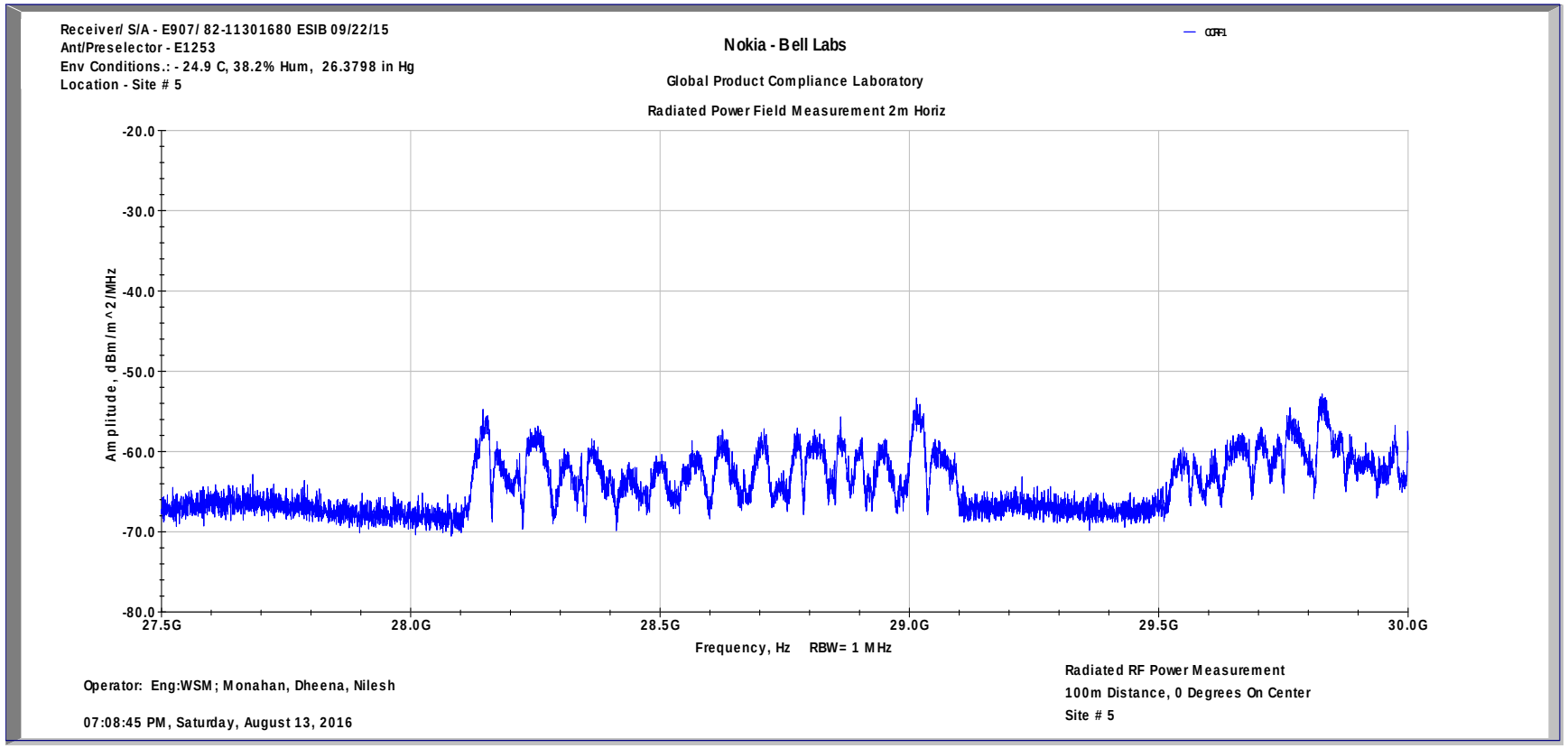
## Sample Site 5 GEO Transmit Signal Center Location 100m Distance 2m Height Horizontal Polarization

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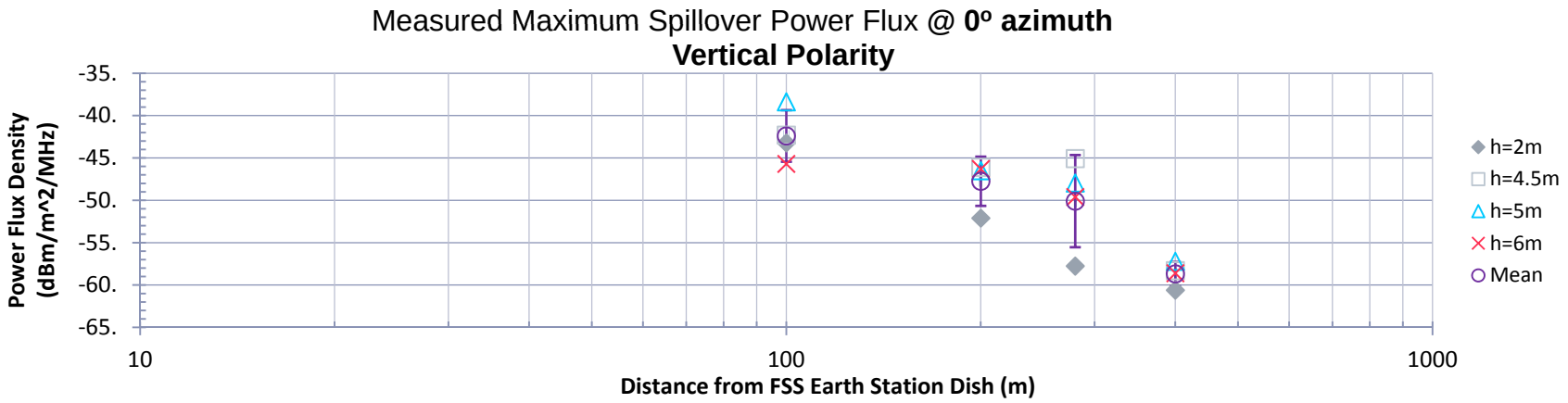
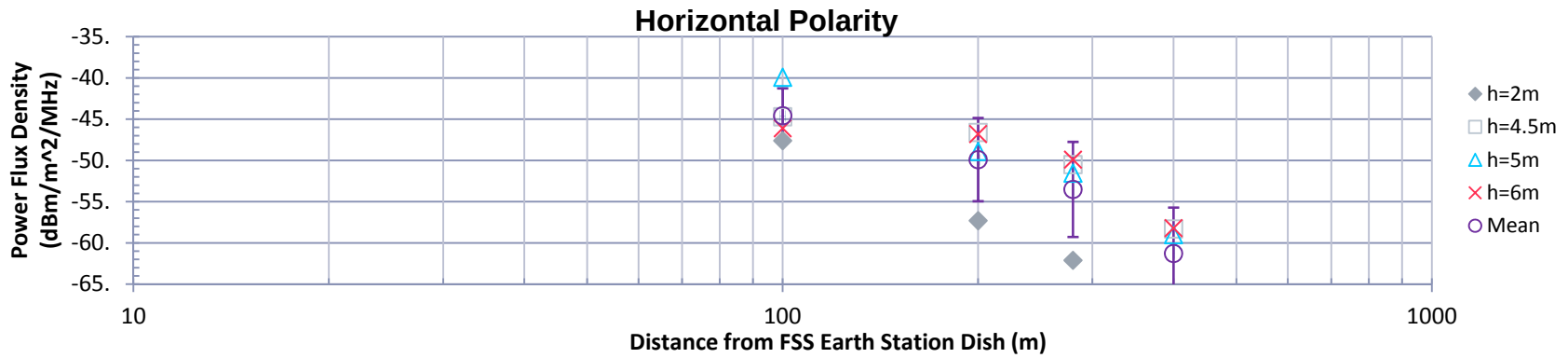
# Measurement Site #1 GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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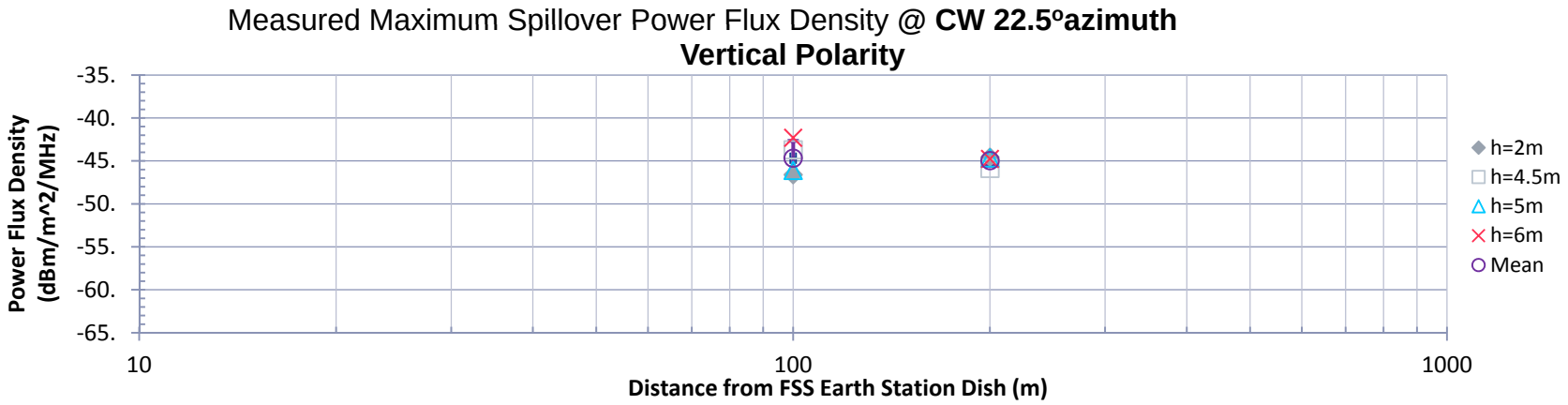
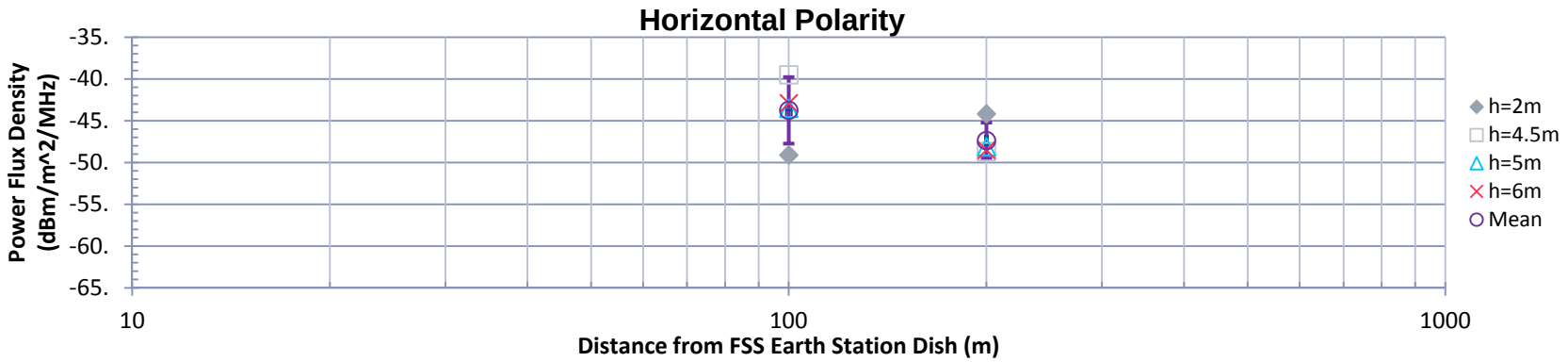
***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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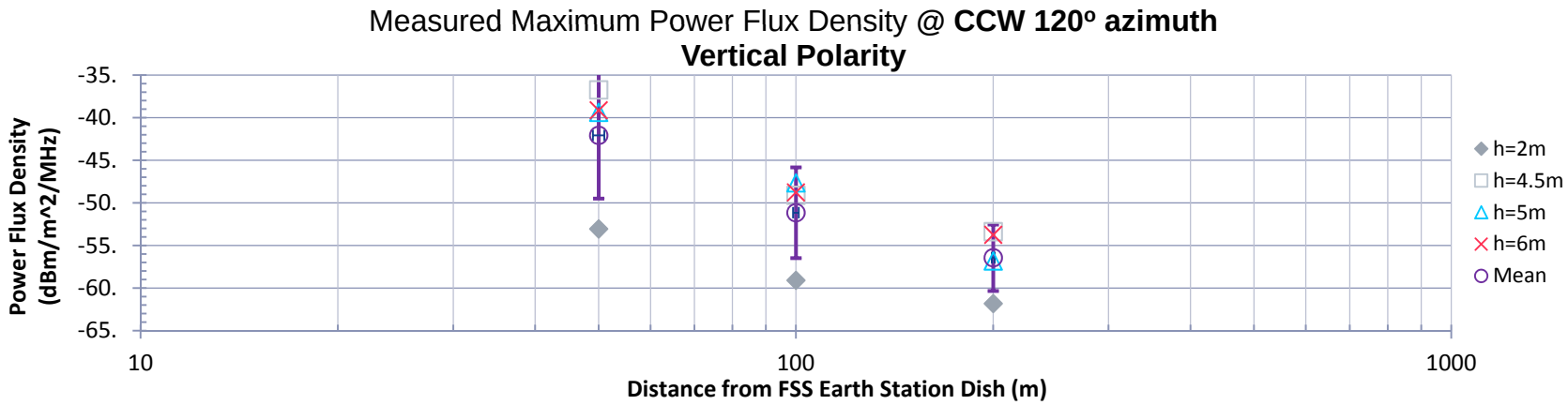
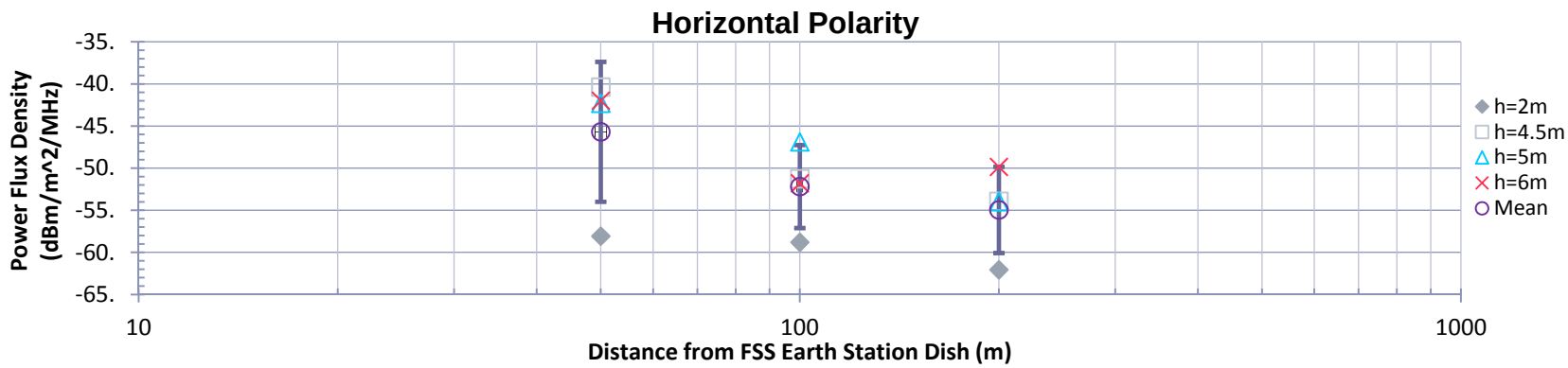
***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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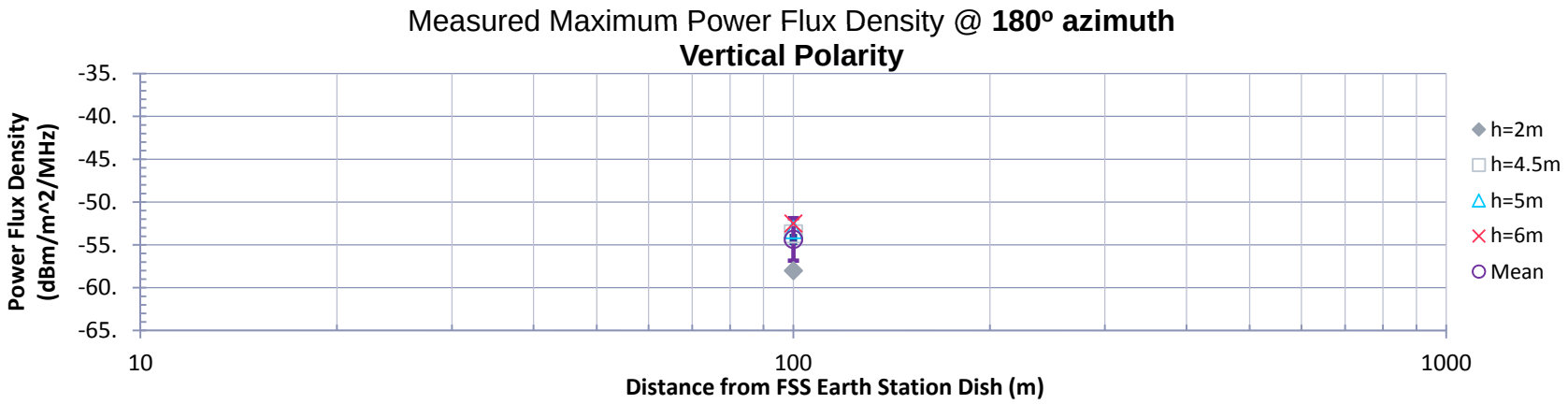
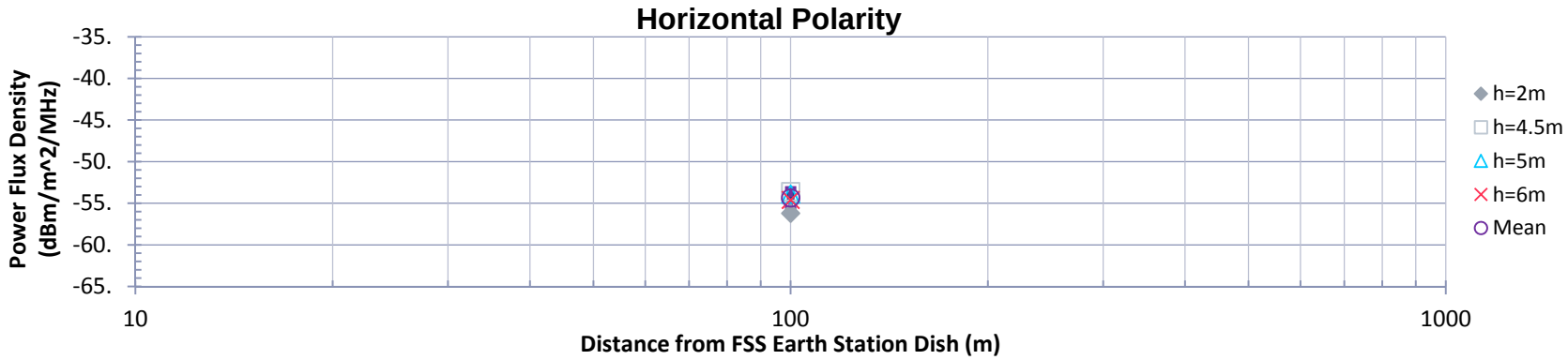
# Measurement Site #1 GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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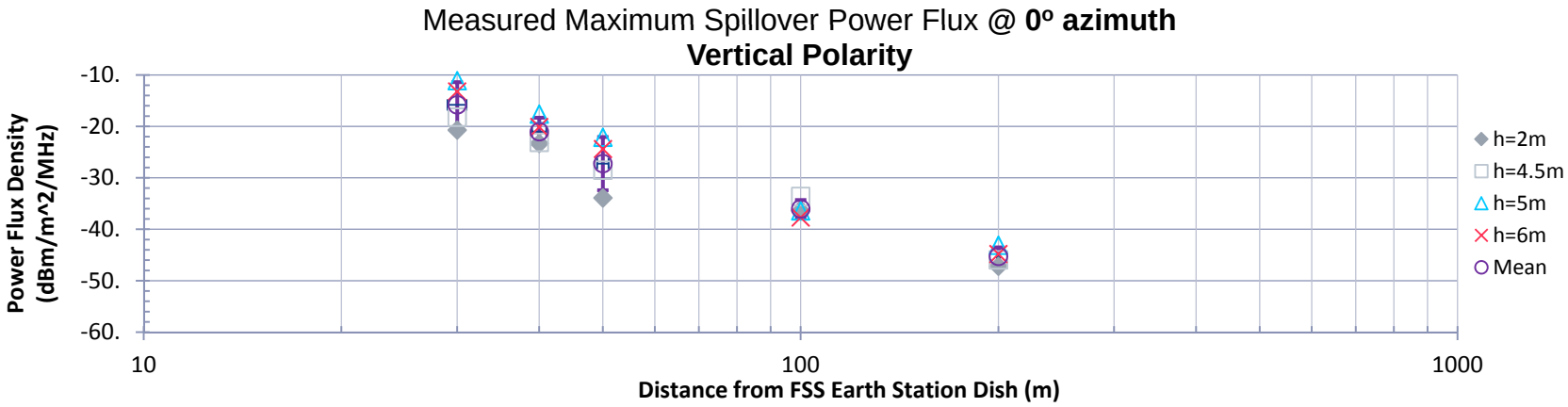
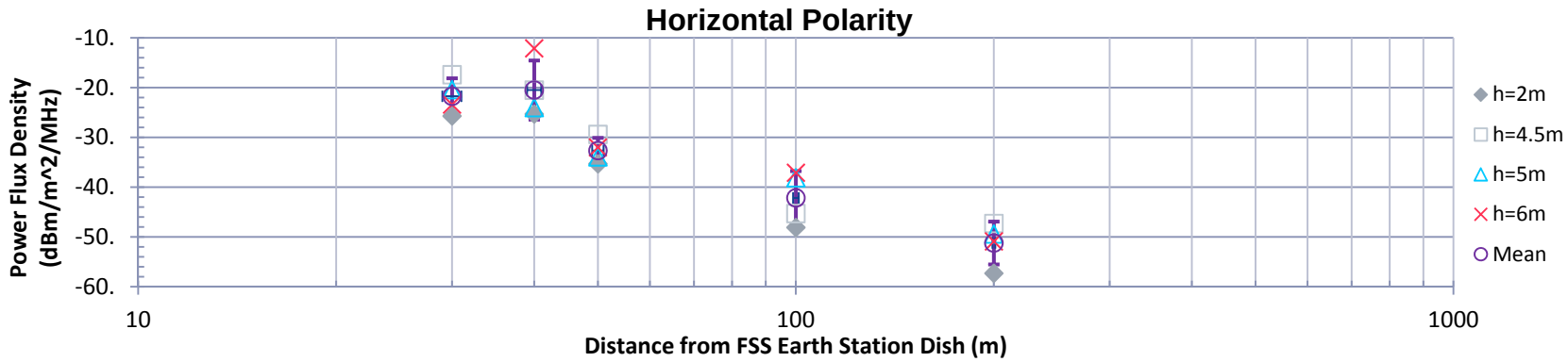
# Measurement Site #2 NEO FSS Site

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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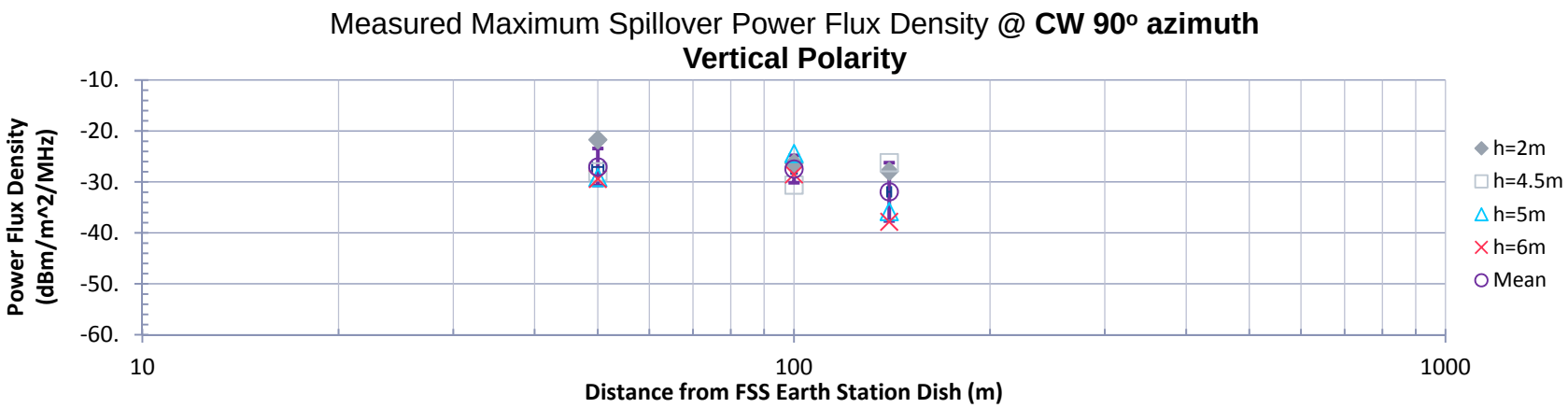
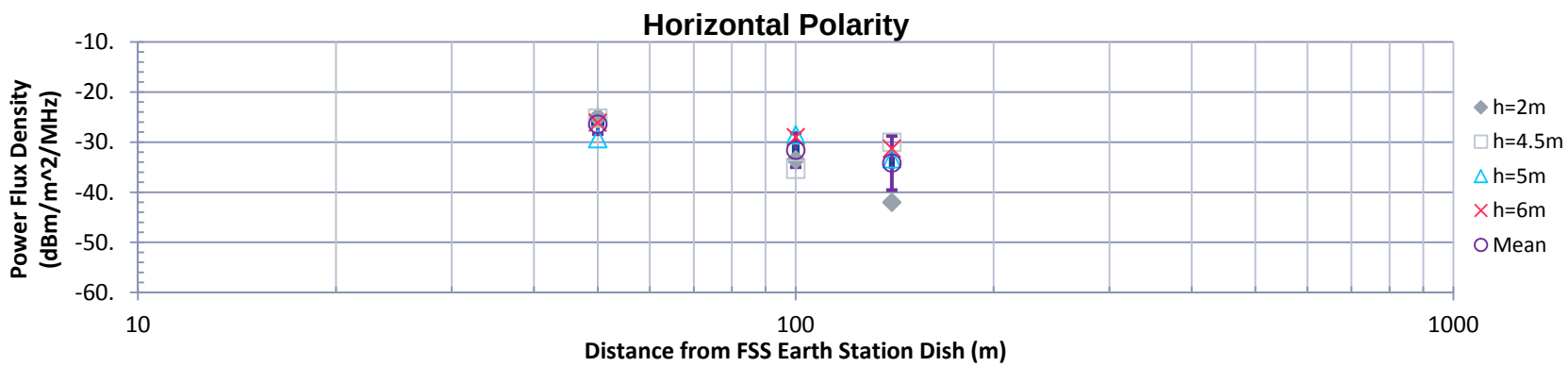
# Measurement Site #2 NEO FSS Site

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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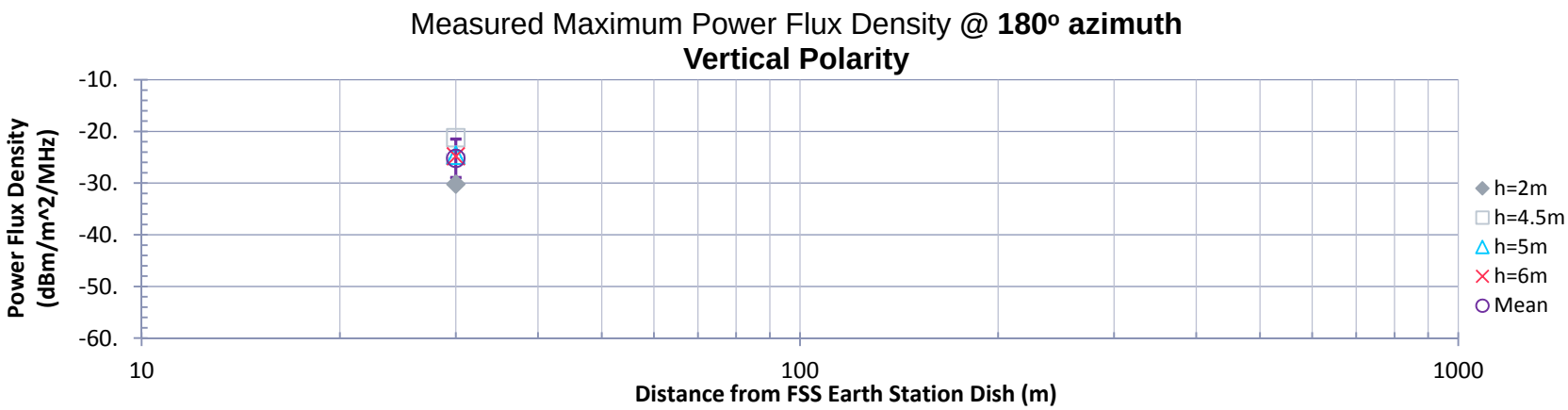
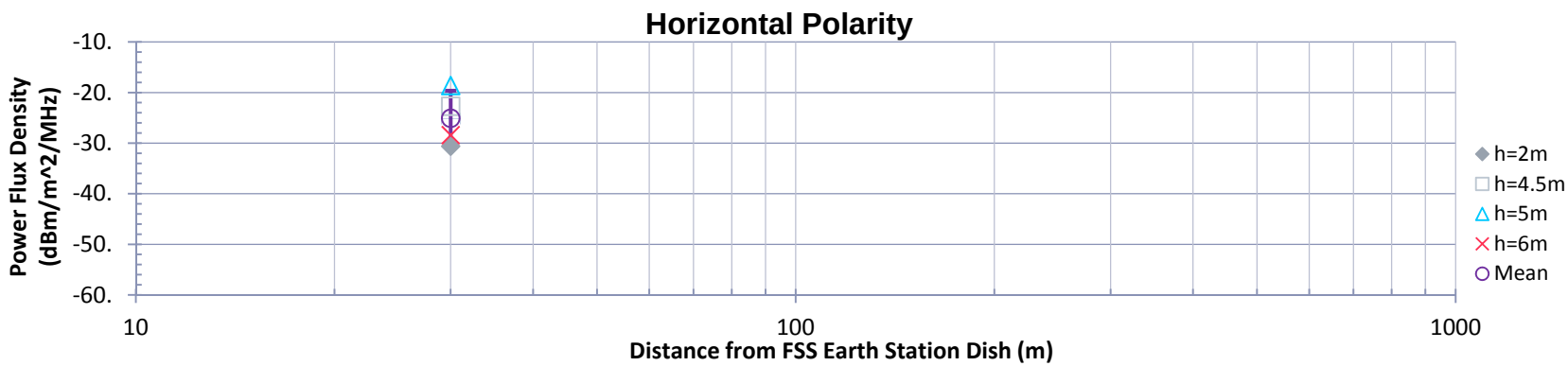
# Measurement Site #2 NEO FSS Site

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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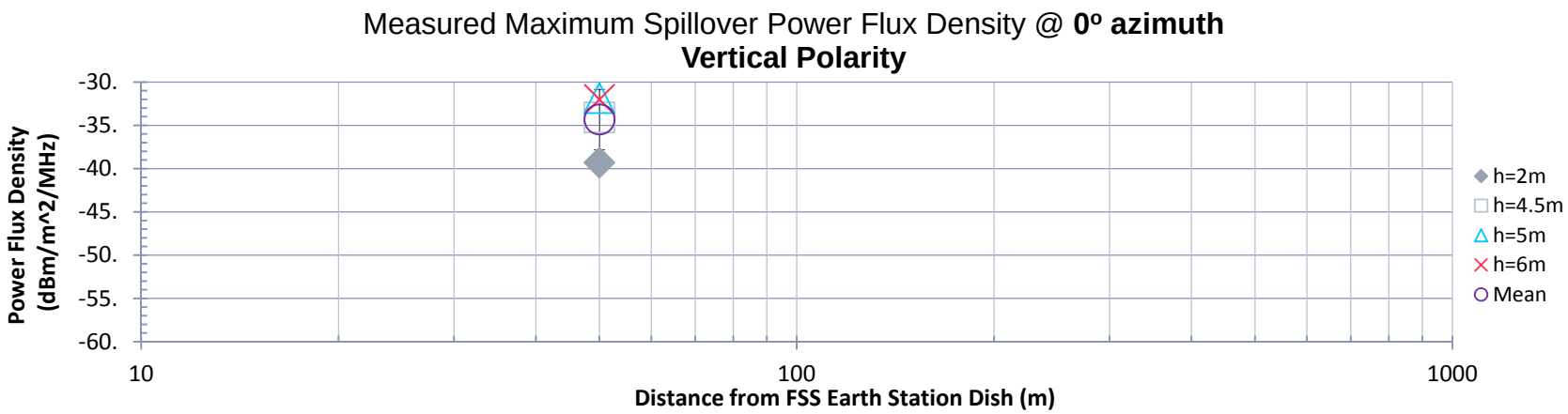
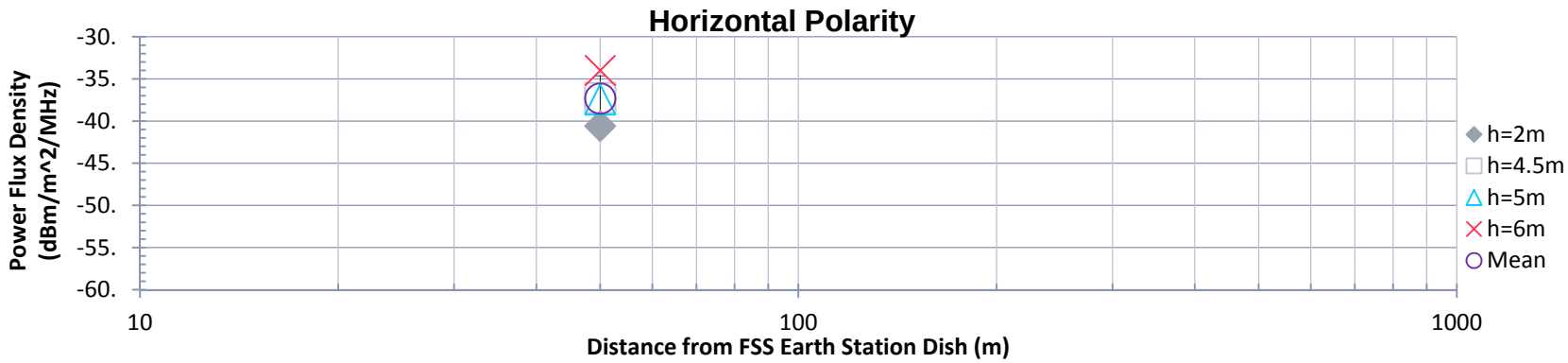
# Measurement Site #3  GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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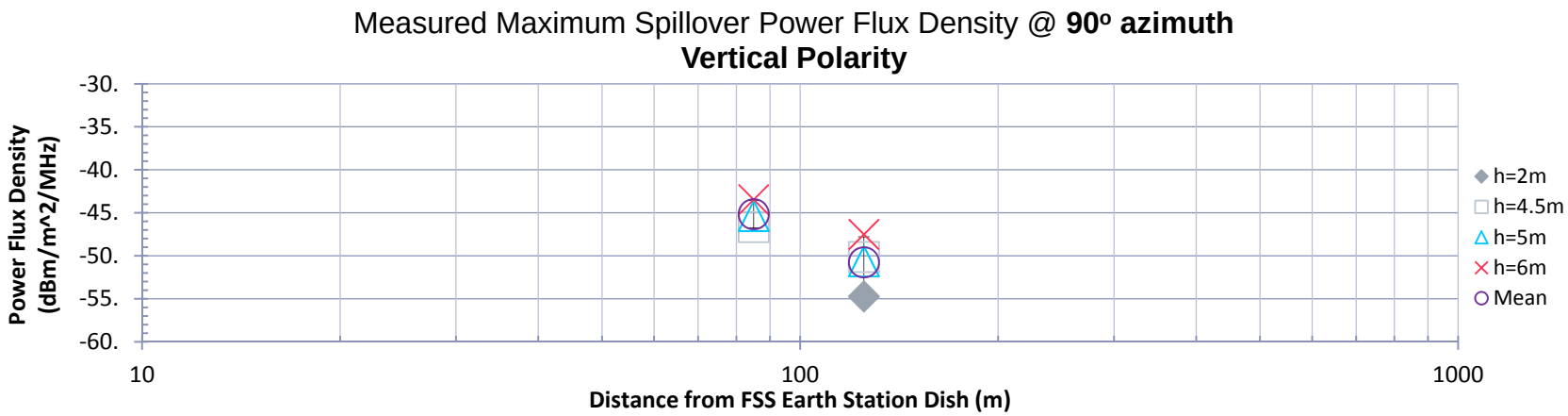
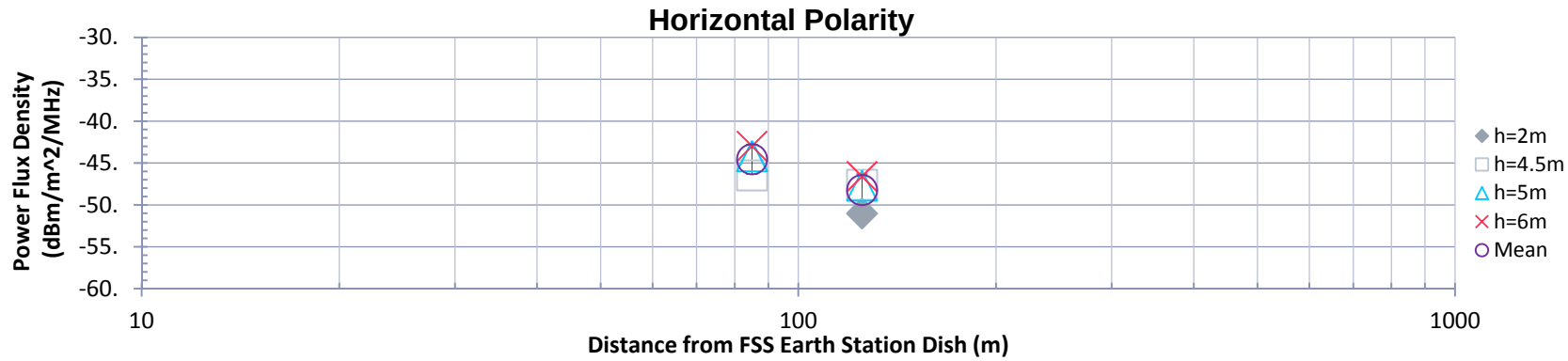
# Measurement Site #3 GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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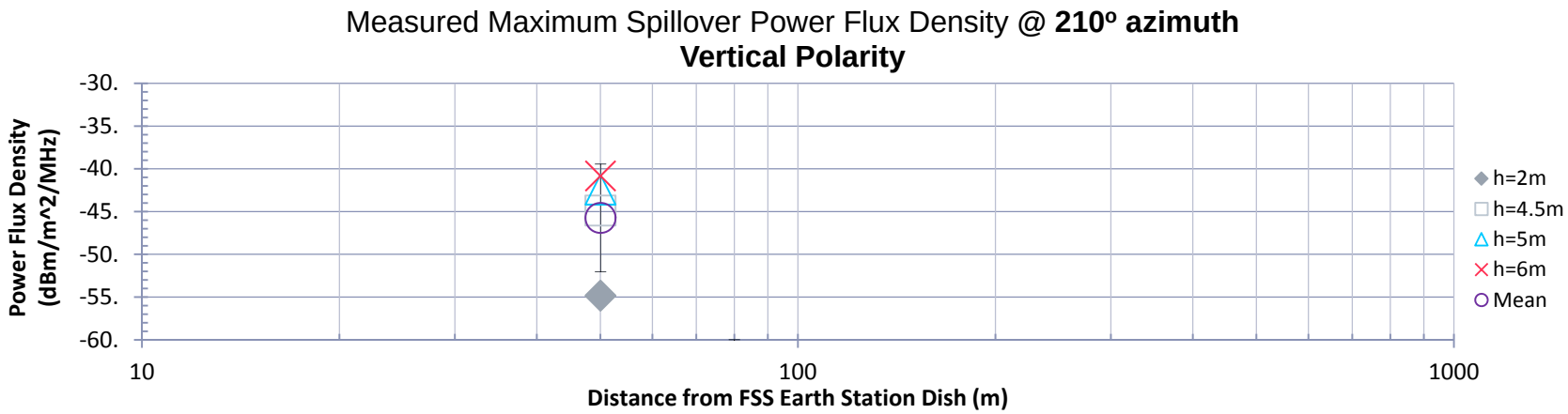
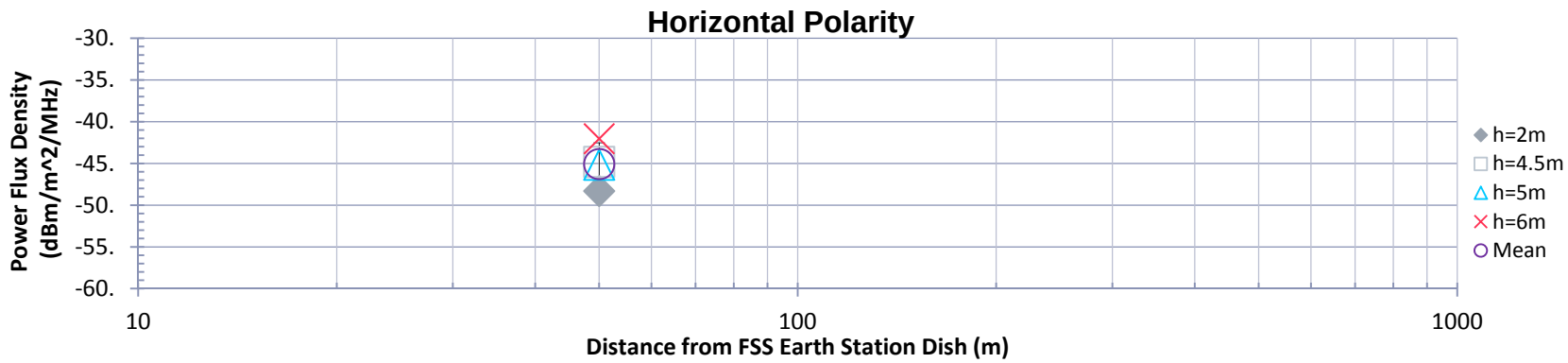
# Measurement Site #3 GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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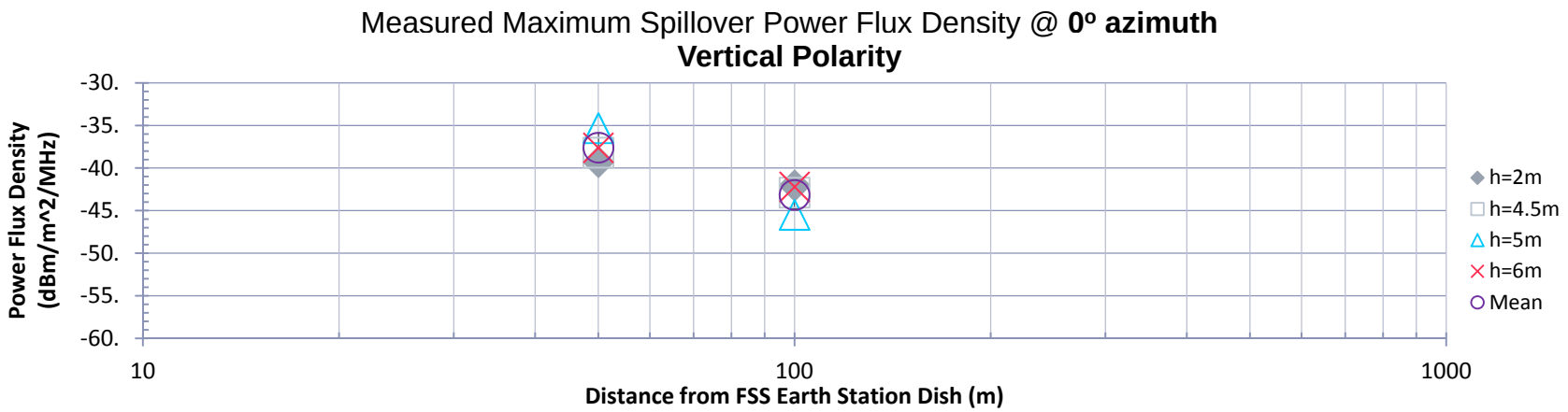
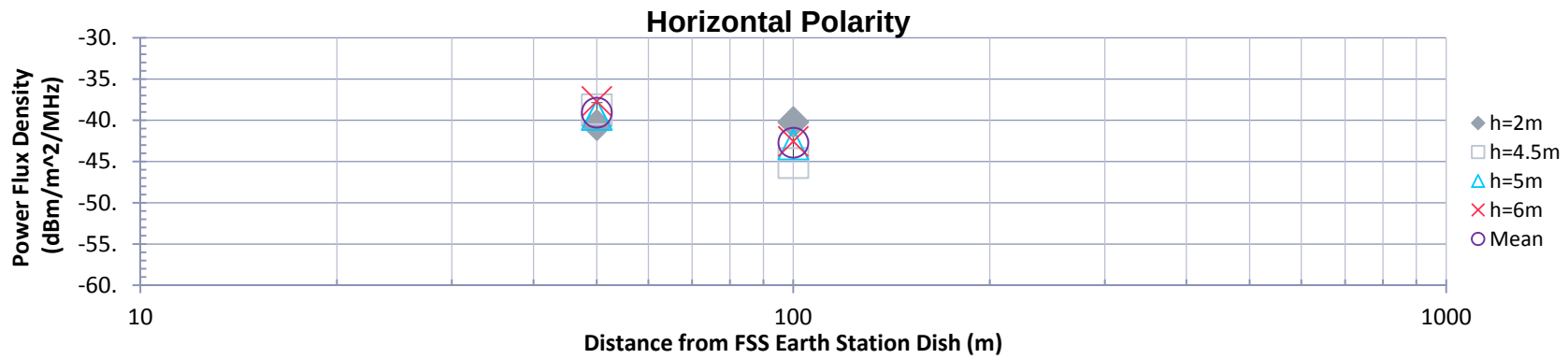
# Measurement Site #4 GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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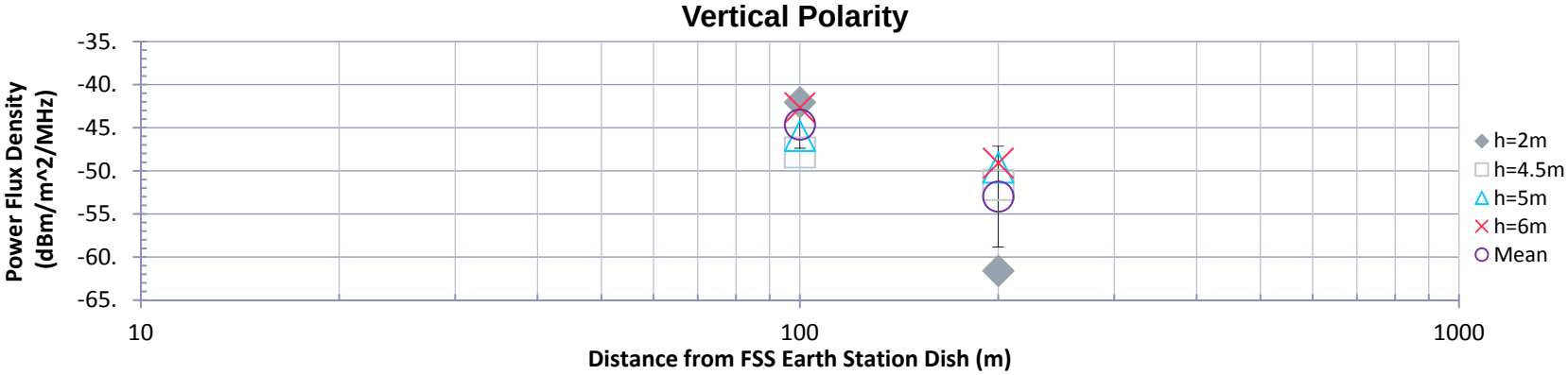
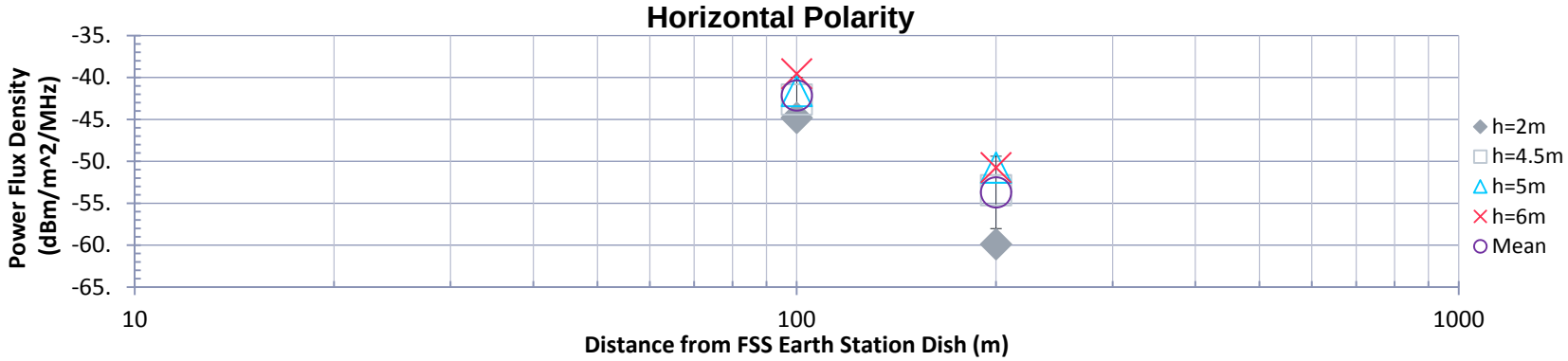
# Measurement Site #4 GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

Measured Maximum Spillover Power Flux Density @ **35º azimuth**

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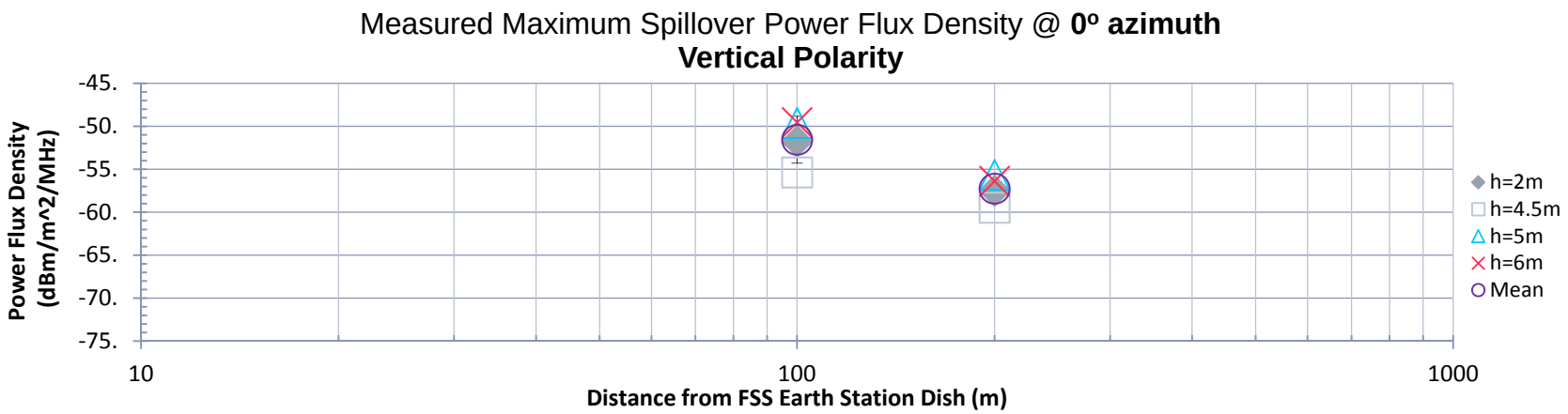
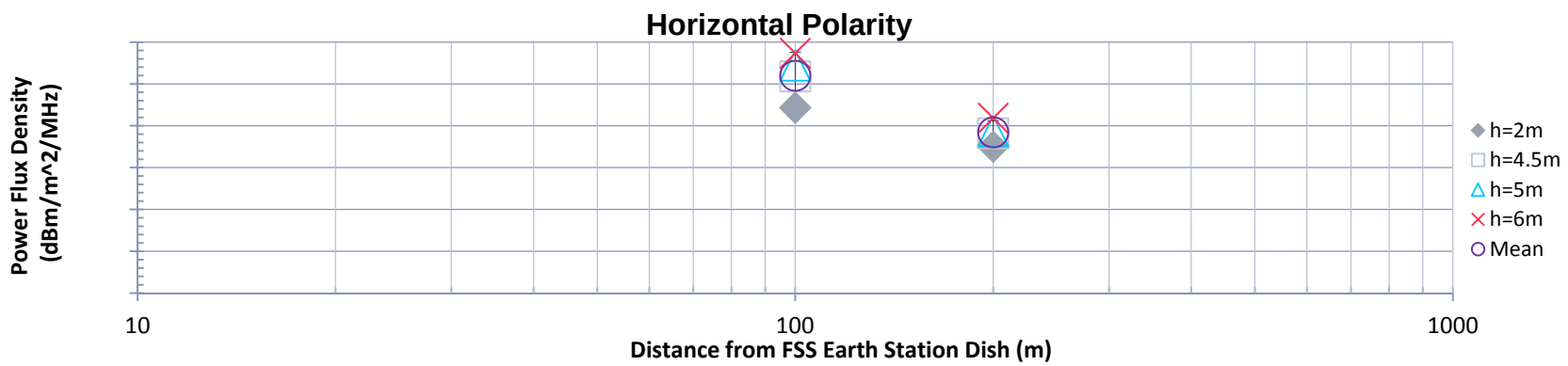
# Measurement Site #5 GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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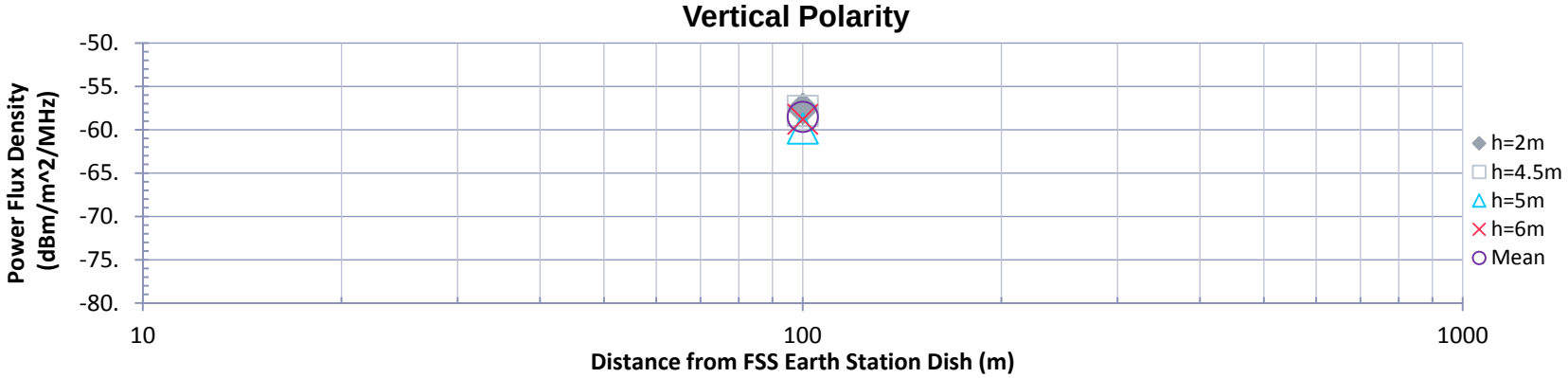
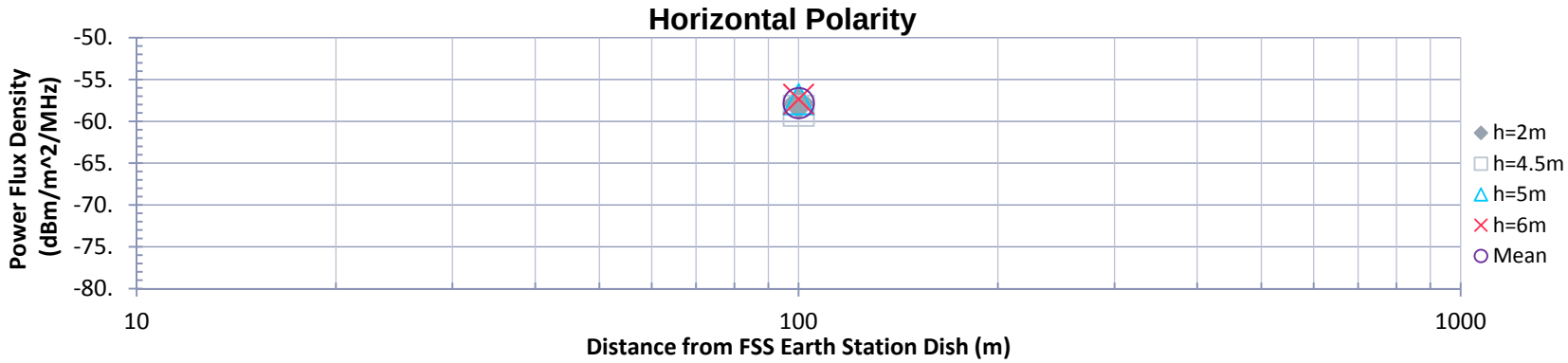
# Measurement Site #5 GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

Measured Maximum Spillover Power Flux Density @ **90º azimuth**

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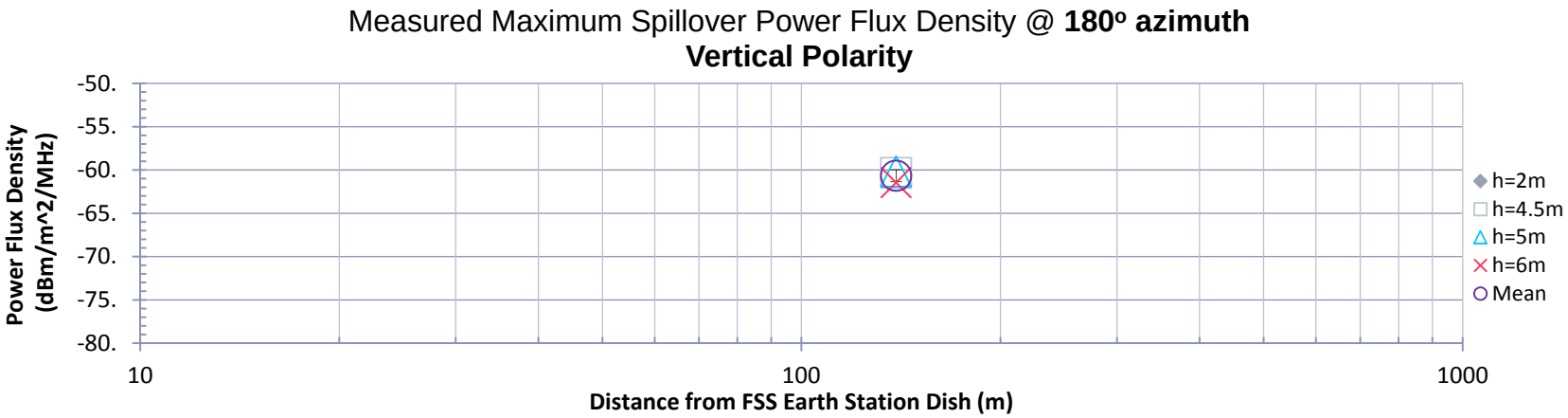
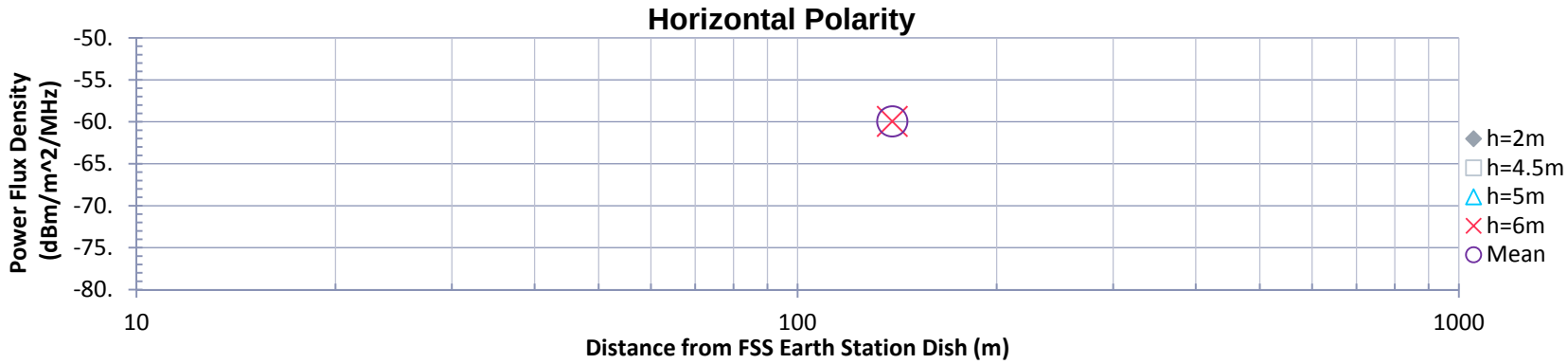
# Measurement Site #5 GEO FSS Site:

***Effect of Distance and Receive Antenna Height (h) on Measured Maximum Spillover Power Flux Density***

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## Conclusions

- The test results have qualitatively and quantitatively increased our understanding of the RF environment around the sites.
- Measurement data from site to site was consistent in showing the same data trends.
- In general, the emissions were lower as the measurement antenna was moved farther away horizontally from the source and higher as the measurement antenna was moved vertically up.
- This was expected and is supported by the simulation. AT&T, Nokia, Samsung, T-Mobile, and Verizon (collectively, the "Joint Filers") in a joint filing indicate that interference from existing transmit FSS earth stations into 5G networks can be controlled by limiting the PFD at 10 meters above ground level to -77.6 dBm/m$^2$/MHz at a distance of 200 meters.
- Based on the measured data, it can be concluded that the emission levels are higher and impact a greater angular area as compared to the information previously shared by the "Joint Filers" with the FCC.
- The measured levels were higher than expected in front of the dish and were typically 20 to 30 dB above the -77.6 dBm/m$^2$/MHz at the 200 meter distance as suggested requested by the "Joint Filers" to protect 5G systems from FSS earth stations interference. The PFD levels measured in the vertical plane were typically 1 to 2 dB higher than the Horizontal.

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## Conclusions

- The measured levels to the sides and to the rear of the sites were much higher than expected. It was also observed that there was no roll-off detected as a function of the azimuth angle as suggested by the Satellite Industry Association (SIA) in the Joint Filers letter (Exhibit E-5).
- There were relatively equal levels of power flux density (PFD) measured at all angles.
- In general there was only about a 10 dB reduction in the PFD that was detected at 22.5° , 90°, 120° and 180° as compared to that measured at 0°.
  - For example if the measurement for 100 meters at 0° was -48 dBm/m$^2$/MHz then the level measured at 100 meters / 90° angle was typically -58 dBm/m$^2$/MHz. These levels were well beyond what could have been expected in the way of spillover from the feed structure and the front of the dish.
- All Measured PFD's exceeded -77.6 dBm/m$^2$/MHz for distances up to 400m and for measurement heights up to 6m at fair weather conditions.

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## Conclusions

- Specifically, the following conclusions can be drawn:
- The source(s) of the side and rear emissions are not from spillover but are more likely due to transmitter/ transmit path leakage.
  - It is not unusual for transmitters to leak energy at their transmit frequency. This is especially true over time as the performance of shielding interfaces degrade with environmental corrosion.
- Thus, any 5G installation near a 28GHz FSS Earth Station site must be assessed for potential interference from the Earth Station. This conclusion could apply to other bands.

- See AT&T, Nokia, Samsung, T-Mobile, and Verizon May 6, Ex Parte at 1.

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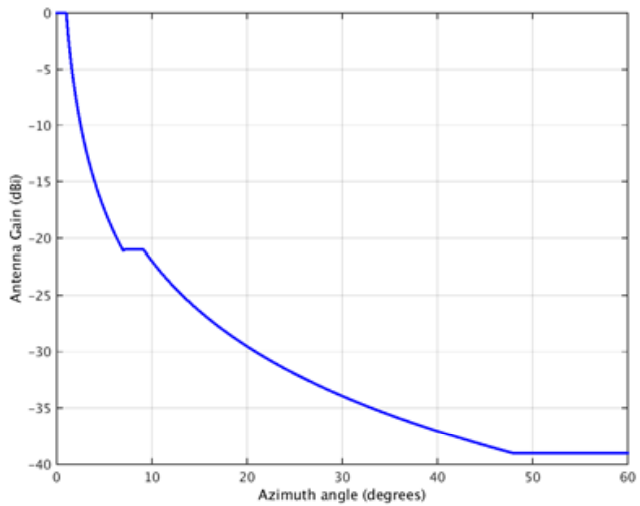
# Exhibit E-5 from Second UMFUFSS Letter

## FSS Earth Station parameters

| Parameter | Value |
|---|---|
| EIRP density towards horizon (dBm/MHz) | 12.2 (Class 1), 24.1 (Class 2), 48.0 (Class 3) |
| Antenna height | 10m AGL |

FSS Earth Station pattern in the azimuth plane

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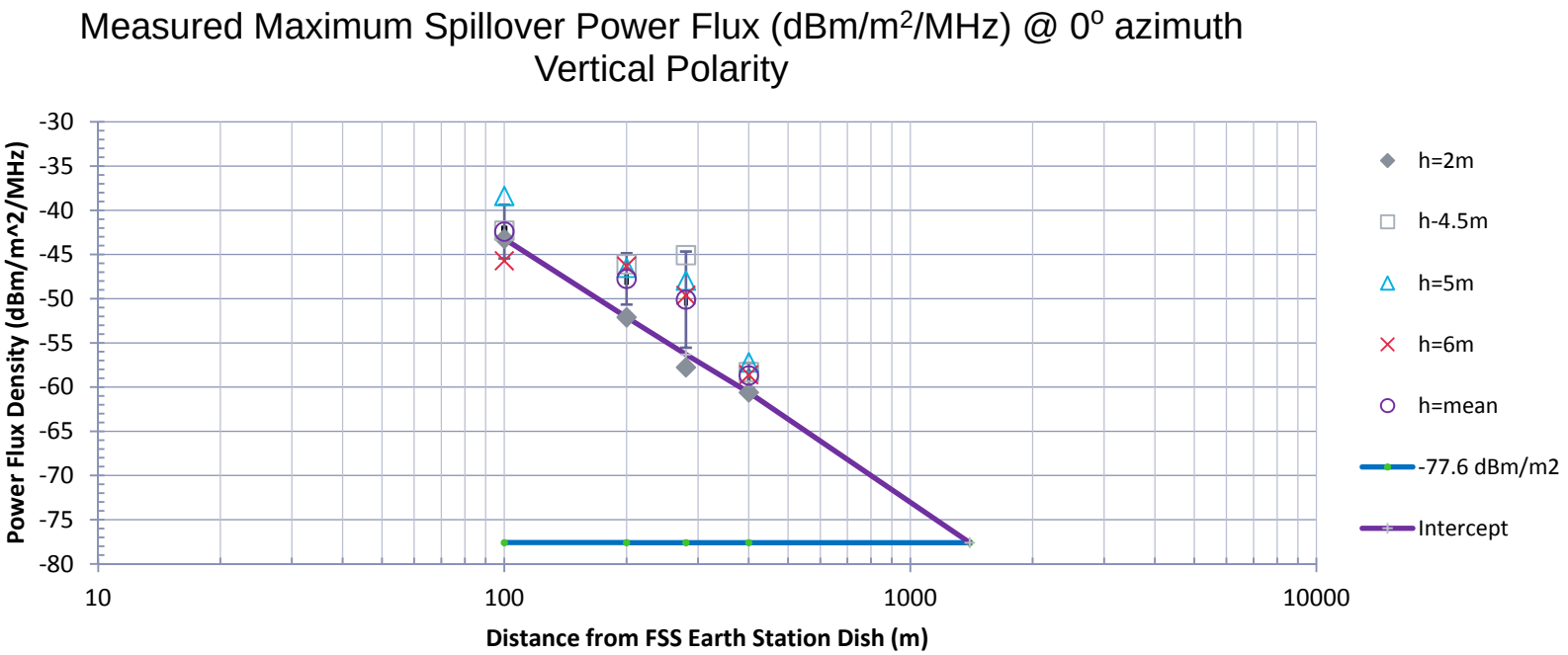
# Extrapolation of Site #1 0° Data to find the -77.6 dBm/m²/MHz crossover

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