Summary of Approach Simulations to Assess VHF Compatibility for GLS/ILS/VOR

Matt Harris, Kira Hein

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Overview

- Summary of Issue
- Simulation Description
- Scenarios
- Results

Summary of Issue

- Several navigation aids share the same VHF spectrum (108 – 118 MHz)
  - VDB – VHF Data Broadcast for GLS
  - VOR – VHF Omnidirectional Range
  - ILS – Instrument Landing System Localizer
  - VHF Comm/Data – Voice Communication and VHF Data Link

- Airborne navigation and landing equipment must be able to operate with minimum desired signal
  - with undesired signals much stronger at adjacent channels than the desired signal
  - Current ILS, VOR, VDB specification requires compatibility with -46 dB D/U at 75 kHz adjacent <u>and beyond</u>
  - Airborne antenna gain variation is allowed to be 7 to 15+ dB, specified in the horizontal direction

Summary of Issue, Continued

- Aircraft installation contributes to D/U limits
  - Antenna gain variation due to difference in direction to desired / undesired
    - Antenna gain variation is limited to ~15dB in the horizontal
    - Installed antenna gain at low elevations can be overcome by reduced transmission loss
  - Mismatch loss variation due to difference in frequency of desired / undesired
    - Mismatch loss can vary by 6dB for the worst combination of distant frequencies
    - Mismatch loss negligible at close frequency separation
- Signal-in-space D/U must have margin for aircraft installation
  - Receiver D/U limit plus installation contribution
  - Results in more stringent signal-in-space D/U limit (+10dB?, +15 dB?, +20 dB?)
  - Can required D/U performance be constrained with VDB siting constraints?

Simulation Overview and Purpose

- Model nav aid transmitters, including transmission loss (ILS, VOR, VDB)
- Model aircraft on approach, including aircraft antenna patterns (VOR antenna)

- For each scenario of desired / undesired, determine D/U power levels vs. VDB location (rough precision)
  - Can a receiver specification be feasibly determined?
  - Does the full installation gain variation margin apply for all cases?
  - Can any credit for relative location of transmitters be taken?

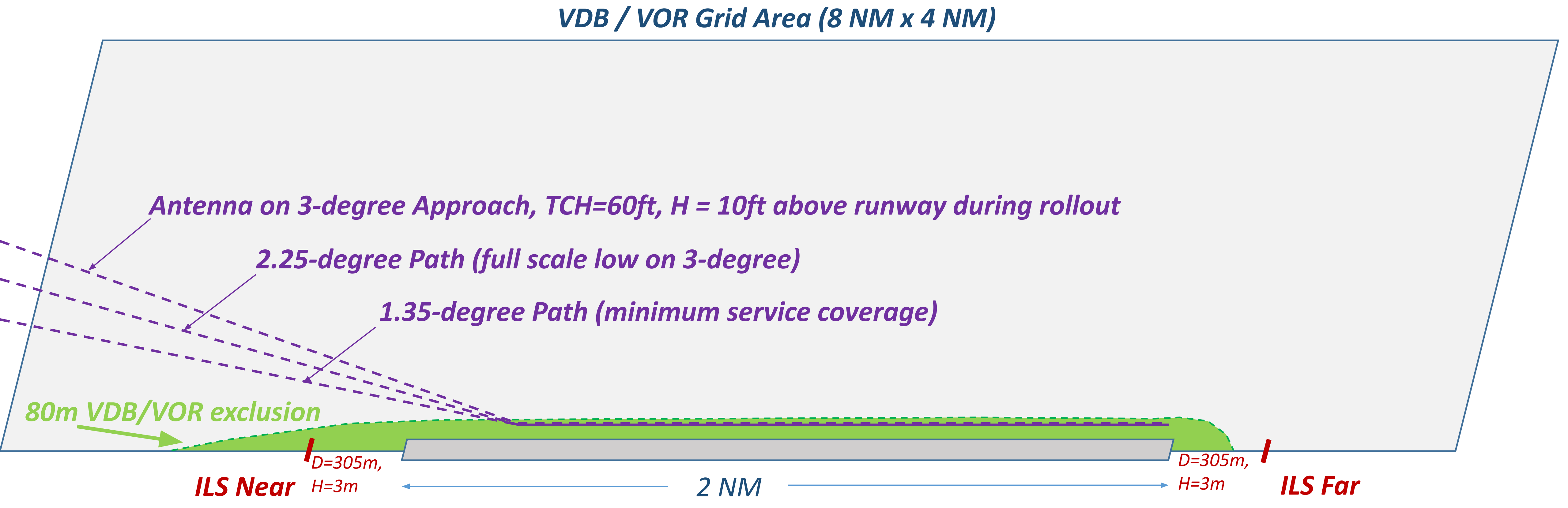
Could Study
Studied
Not Studied

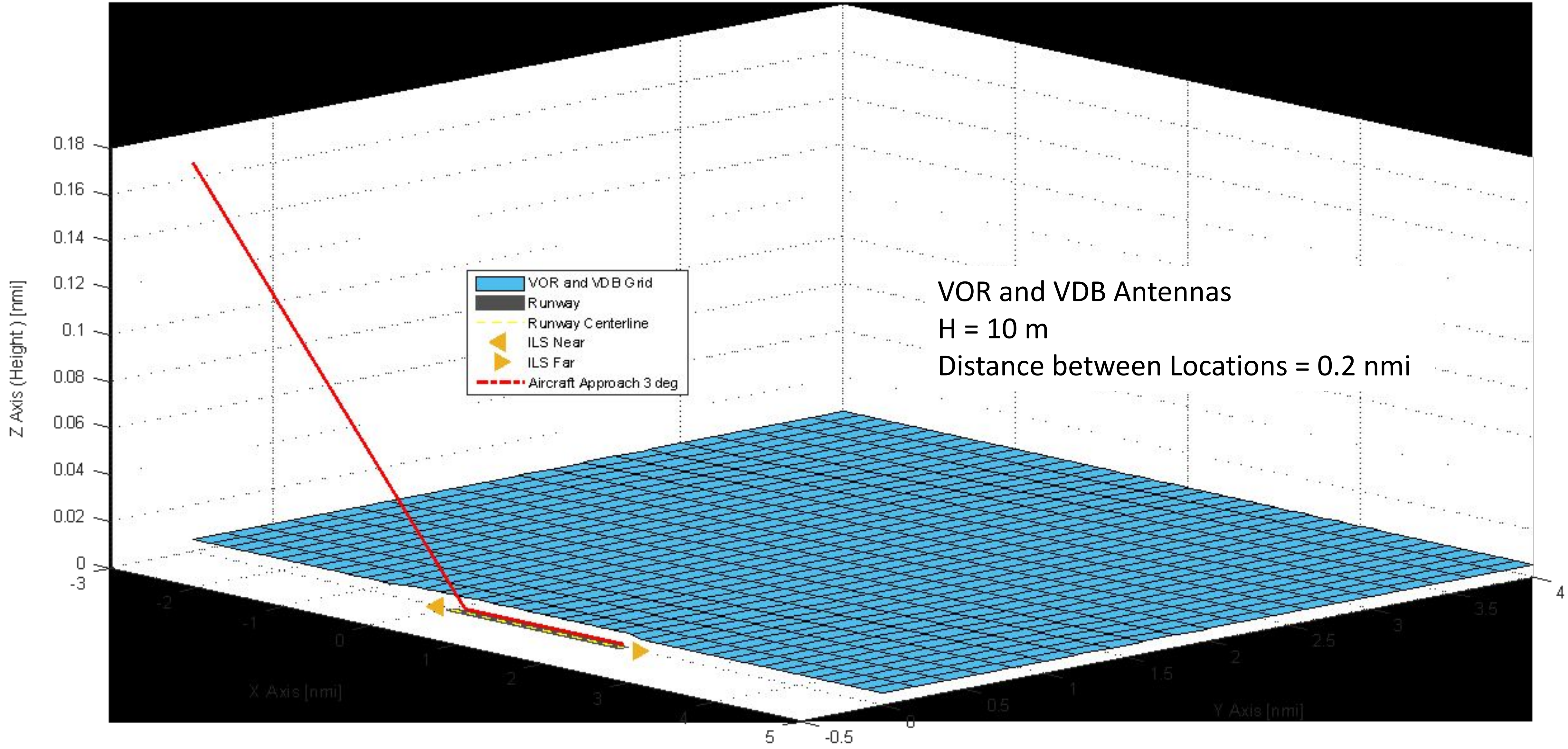
Desired \ Undesired	**VDB**	**VOR**	**ILS Overfly**	**ILS Far End**	**VHF Comm/Data**
VDB					
VOR					
ILS Far End				N/A	
VHF Comm/Data					

Simulation Description

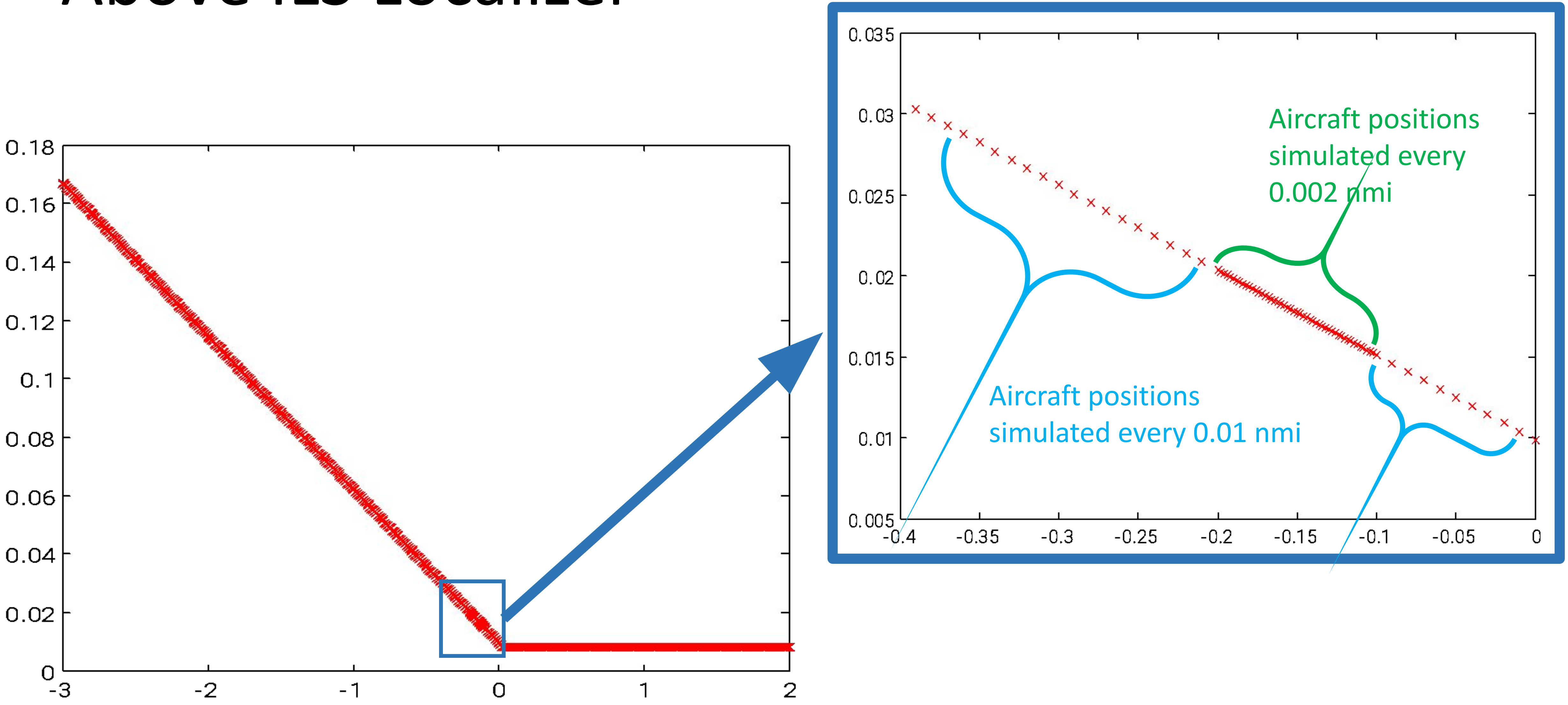
1. Simulate Aircraft on Approach
    - 3 degrees, 2.25 degrees (full scale low), 1.35 degrees (minimum service coverage)
    - 2 mile runway length
2. Simulate Airborne Receive Antenna Patterns
    - No airborne pattern (signal-in-space power level)
    - Boeing VOR antenna pattern from scale model measurements
3. Simulate VHF Nav Aids and Transmit Antenna Patterns
    - ILS near, ILS far, VDB grid, VOR grid
    - ILS antenna pattern and power levels calibrated with other data
    - VDB simplistic model calibrated against other higher fidelity models
    - VOR simplistic model (compared with flight data)
    - VOR/VDB > 80m from aircraft path

1. Simulate Aircraft on Approach (not to scale)




VOR and VDB Grid
Runway
Runway Centerline
ILS Near
ILS Far
Aircraft Approach 3 deg
VOR and VDB Antennas
H = 10 m
Distance between Locations = 0.2 nmi
Z Axis (Height) [nmi]
X Axis [nmi]
Y Axis [nmi]
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-3
-2
-1
0
1
2
3
4
5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4

Additional Position Sampling Resolution Above ILS Localizer



2. Simulate Airborne Antenna Patterns

- Simulate no Airborne Antenna Pattern
  - Provides Signal-In-Space Desired / Undesired ratio (SIS D/U)
  - Accounts for transmission loss for actual transmitter locations

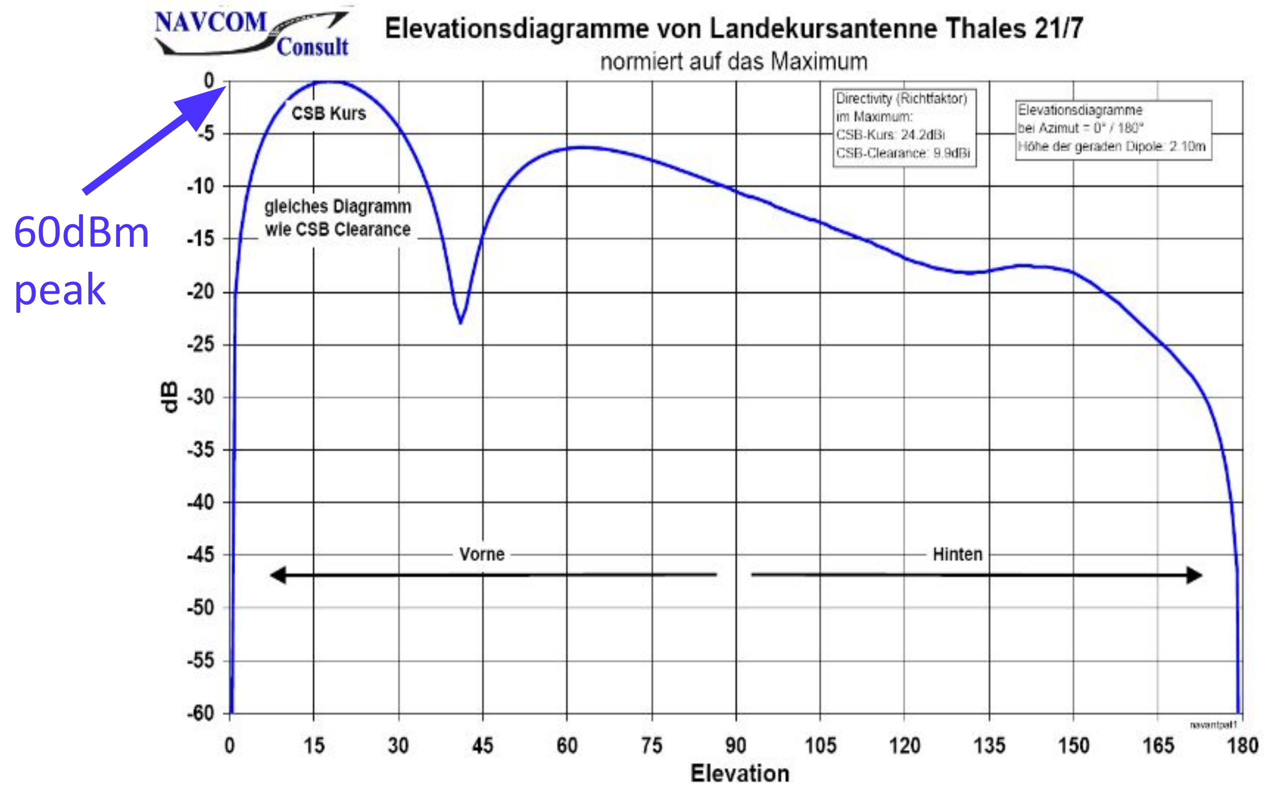
- Boeing VOR antenna pattern from scale model measurements
  - Proprietary installed patterns will not be published or shared
  - Measurements smoothed from 0.1 degree resolution to reduce spikes
    - Spikes believed to be an artifact of the scale model measurement setup
    - average of nearest values +/- 0.1 degrees
  - Max and min values in a [3-degree] az/el window were determined
  - Selected higher gain pattern for undesired, lower gain for desired signal

- Difference in D/U with and without antenna pattern

3. Simulate VHF Nav Aids and Transmit Patterns

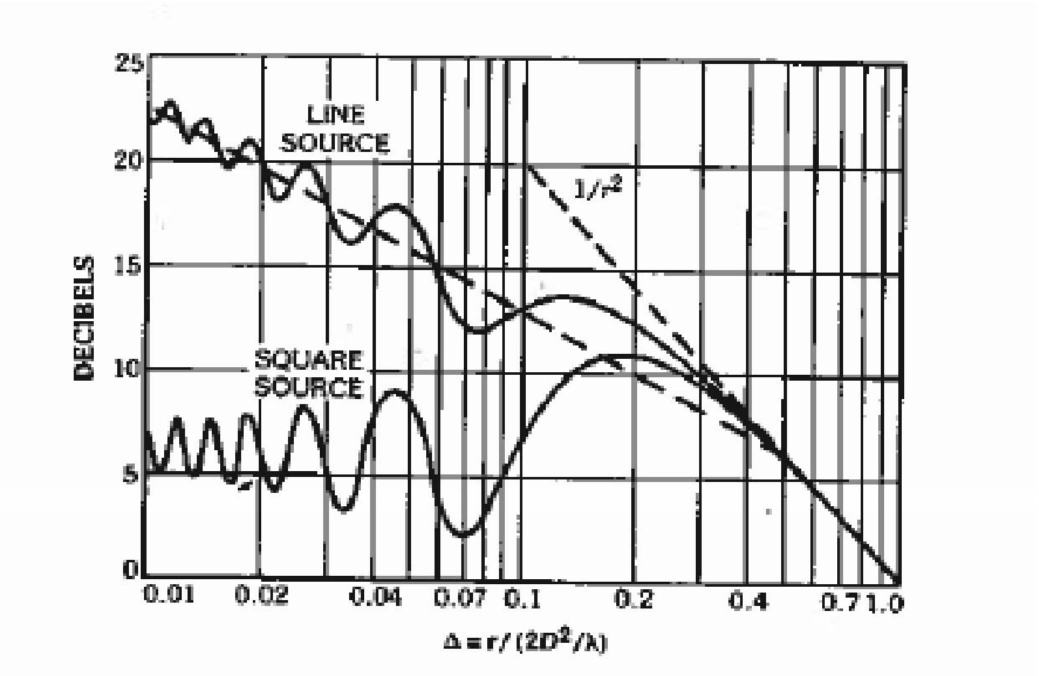
- ILS LOC
- VOR
- VDB

1. Simulate ILS LOC Signal Strength



ILS Localizer Antenna Pattern

Source: Stefan Müller and Felix Butsch and Helmut Günzel, "Investigation of GBAS frequency protection requirements at third adjacent channel and beyond," DFS Deutche Flugsicherung GmbH, Version 0.10, 13.11.2015



ILS Path Loss 1/r Behavior within ½ Far Field (One-Half Far Field Boundary ~ 2700 feet)

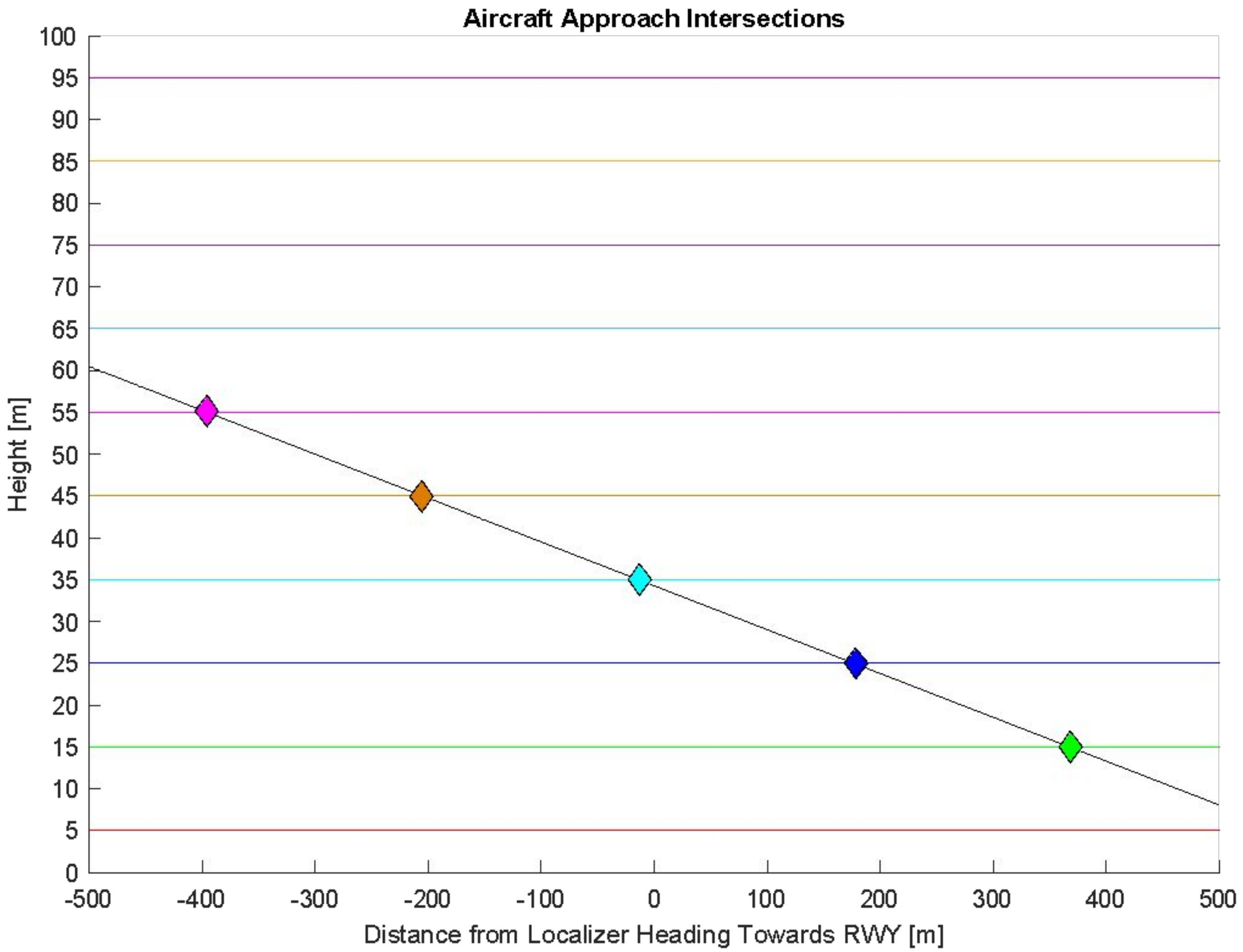
Source: Orville Nyhous letter to RTCA SC-159 WG4 VDB ad-hoc team, "Computation of Received Signal Levels in the Near Field Region of a Localizer (LOC)", May 2016 – Picture from Van Valkenburg, M. E., Reference Data for Engineers: Radio, Electronics, Computer, and Communications, Eighth Edition, SAMS, Prentice Hall, 1993, Page 32-7.

ILS Signal Strength Equation

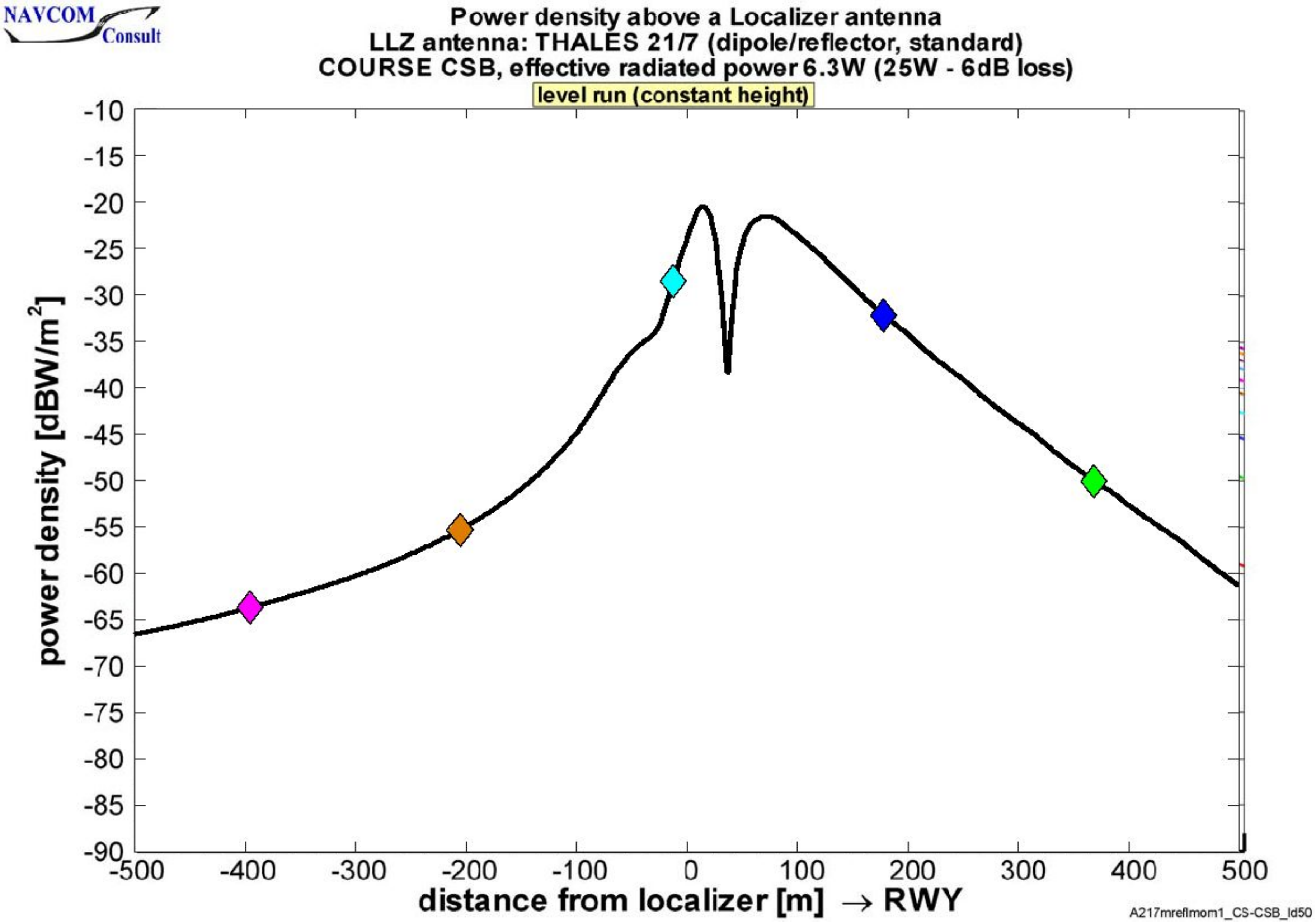
- $FSPL_{(distance < 822.7611\ m)}$
  = 10*log10(distance) + 20*log10(108 MHz) – 147.55 + 29.1527
- $FSPL_{(distance > 822.7611\ m)}$
  = 20*log10(distance) + 20*log10(108 MHz) – 147.5

- $Signal_{dBW} = P_{Tx}$ + Gain from Antenna Pattern (Relative to Main Beam)
  + Main Beam Gain + FSPL - 30
- $Signal_{dBW}$ = 47 dBm + Gain from Antenna Pattern + 13 dB + FSPL - 30

Simulated Approach Height vs. LOC Distance



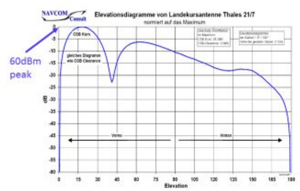
Comparing simulated antenna heights with heights above LOC antenna simulated by Jules Hermen on next slides



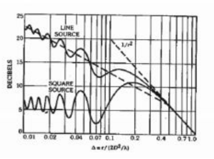
Has same general shape, differences could be due to differences in Ground Antenna Gain from the steep slope, or minor difference in the height reference (above ground or above ILS Localizer).

Recreating Navcom ILS overflight plots with Simplified Model

Simulate ILS Signal Strength

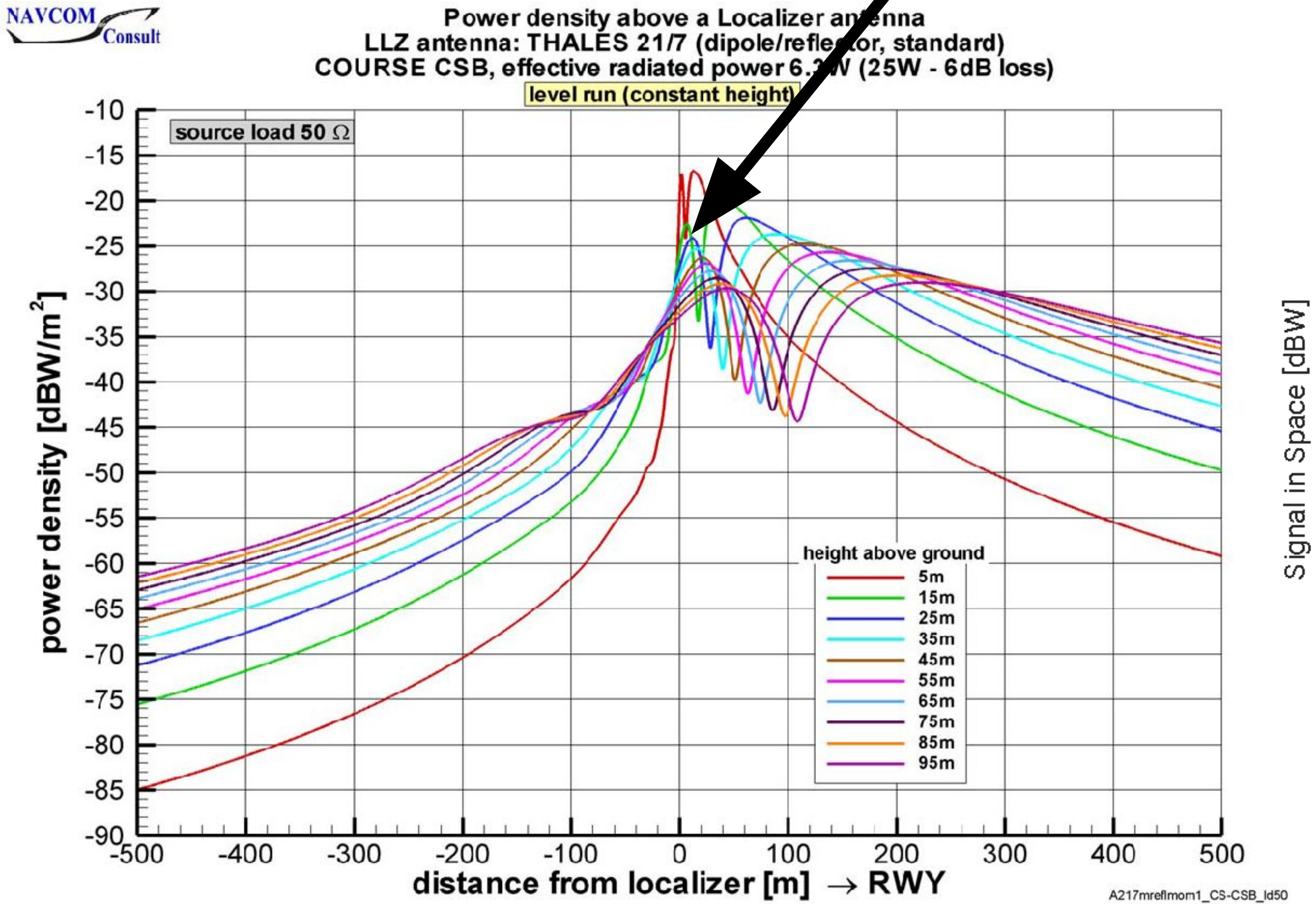


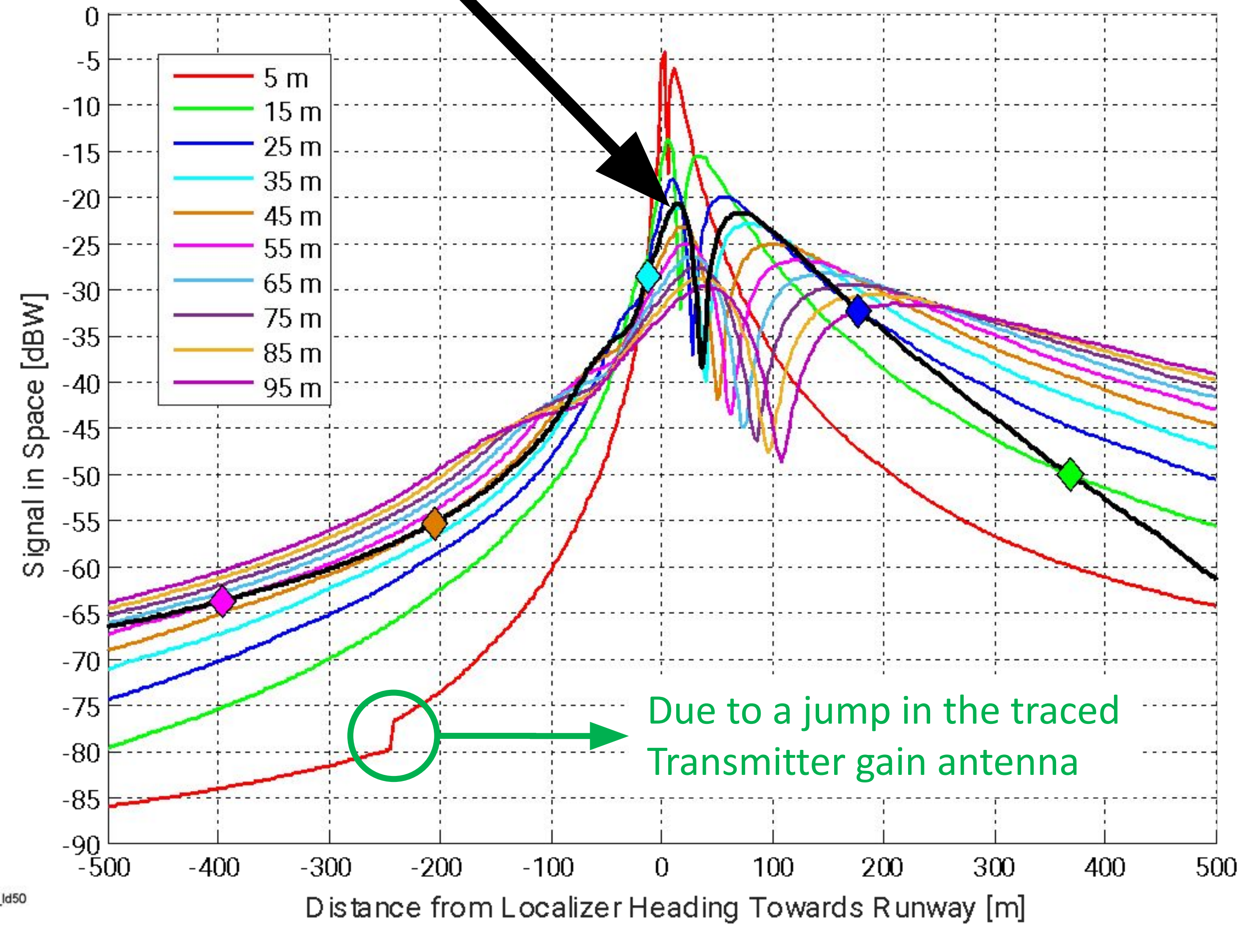
ILS Localizer Antenna Pattern



ILS Path Loss 1/r Behavior within ½ Far Field (One-Half Far Field Boundary ~ 2700 feet)

Peak near ILS LOC antenna (@100' height above LOC):
Navcom = -25dBm
Simplified Model = -22dBm



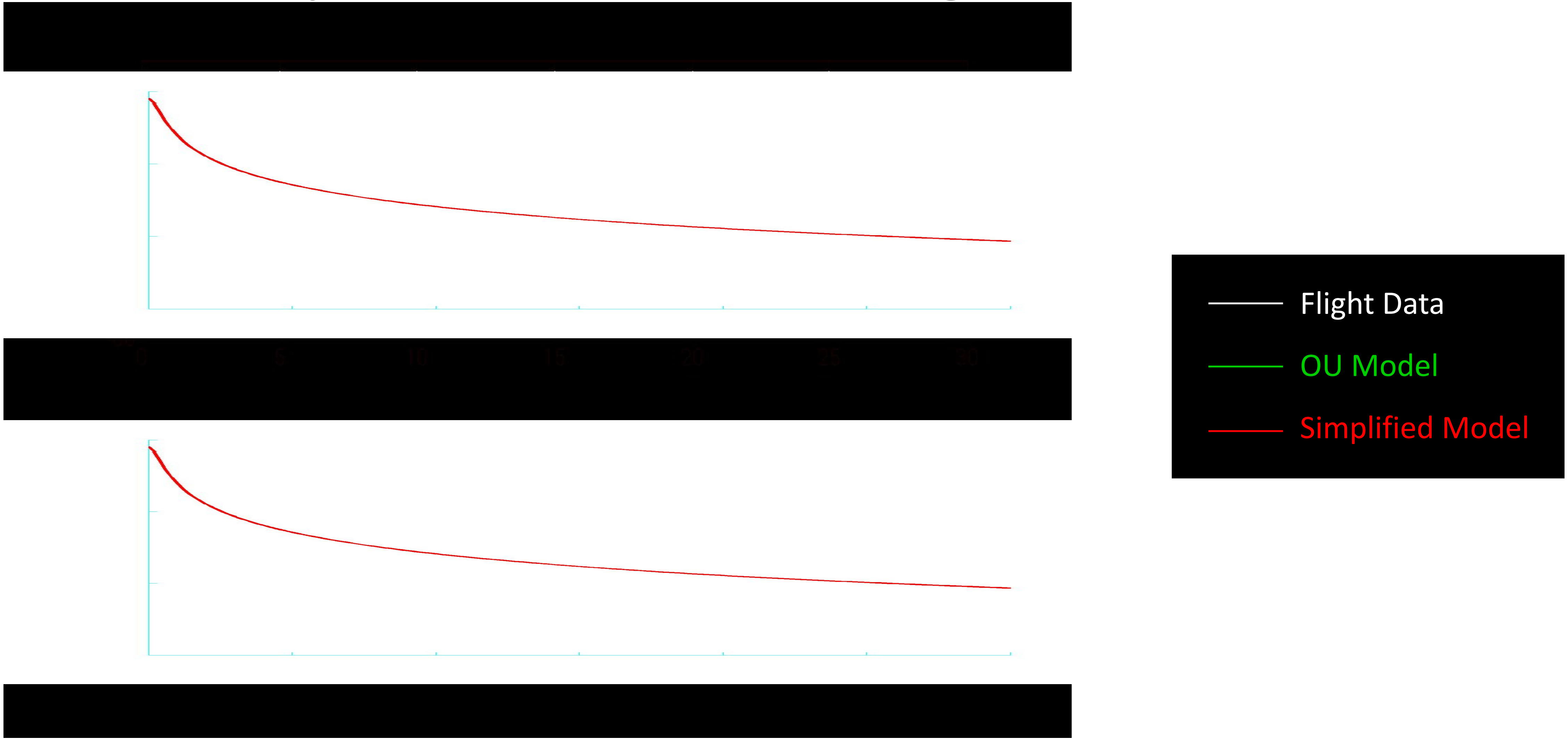


Due to a jump in the traced Transmitter gain antenna

2. Simulate VDB Signal Strength

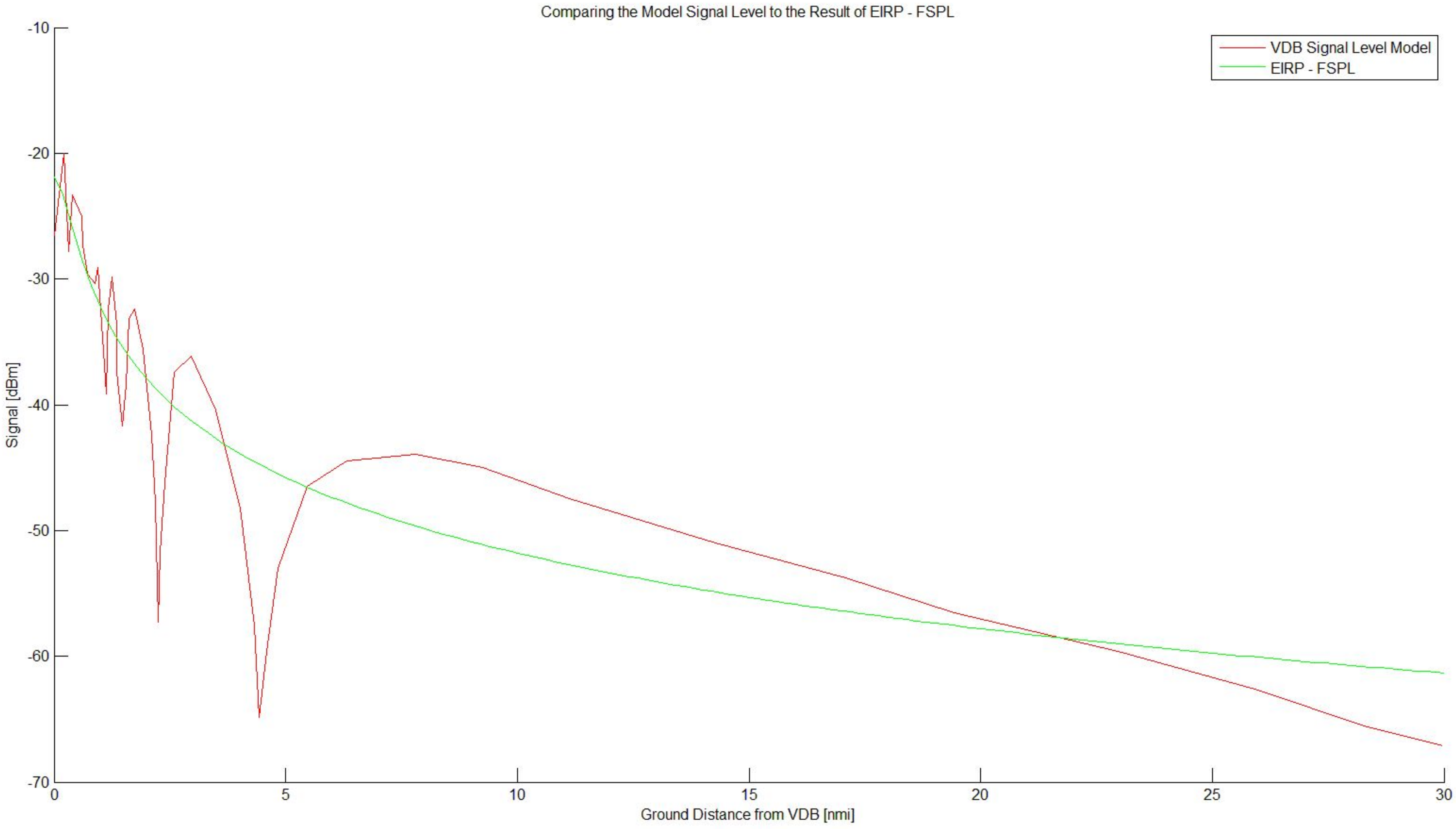
- VDB simplified model
  - Simulated as omnidirectional with transmit power of 47 dBm (50W)
  - No transmission losses assumed, path loss simulated as $1/r^2$
  - Matches Ohio University model fairly well (ignoring fades)

Compare Simple VDB Model (Red) with Ohio University EM Model and Flight Measurements

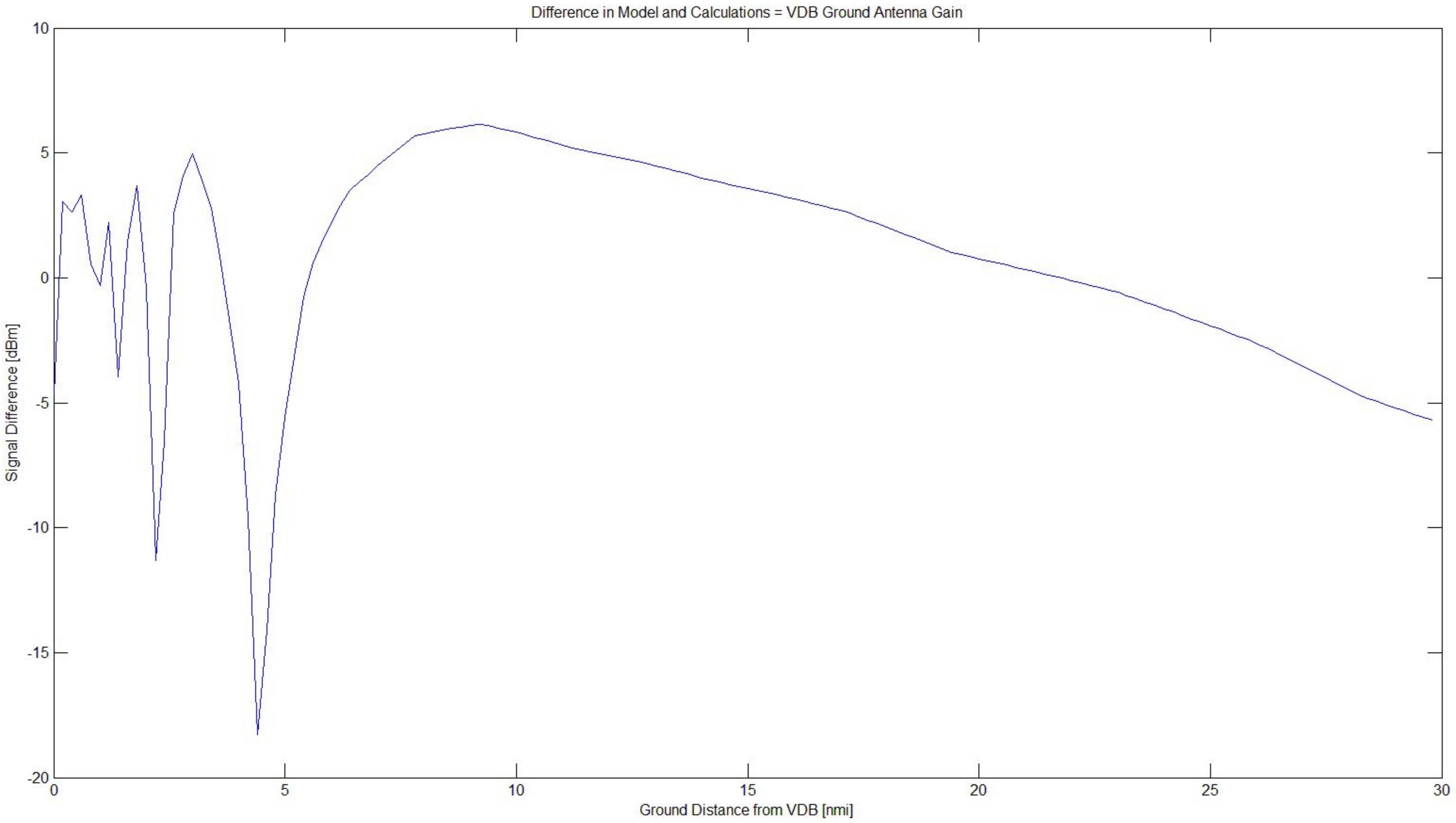


From: Skidmore, Wilson, Dickinson, Nyhus, “The LAAS VHF Data Broadcast Modeling, Siting, Flight Inspection, and Flight Test Results”, ION GPS 2001, Salt Lake City, Utah

Comparing HPOL Results



Difference OU HPOL Sim and Simple Model



Matches roughly well within +/-5dB, not accounting for fades up to 18 dB
These simulation results will only work as a guideline for validation - actual VDB levels must be used in practice

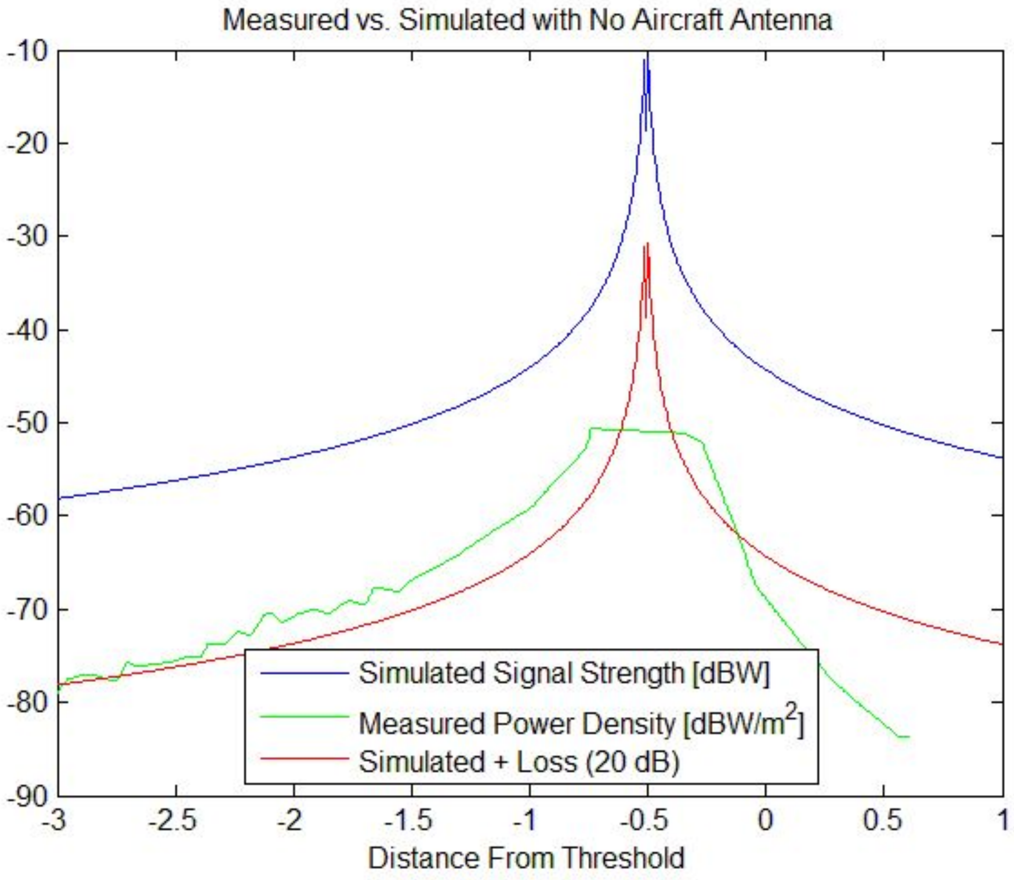
3. Simulate VOR Signal Strength

- VOR simplified model
  - Simulated as +6dB gain below 60 degrees elevation, -3dB above 60 degrees
  - No transmission losses assumed, path loss simulated as $1/r^2$
  - Transmit power set to 50 dBm (100W) for D/U calculations
  - Compared with Bremen flight inspection, setting power to 200W, SIS power levels using this simple model result in SIS power levels ~15dB too high

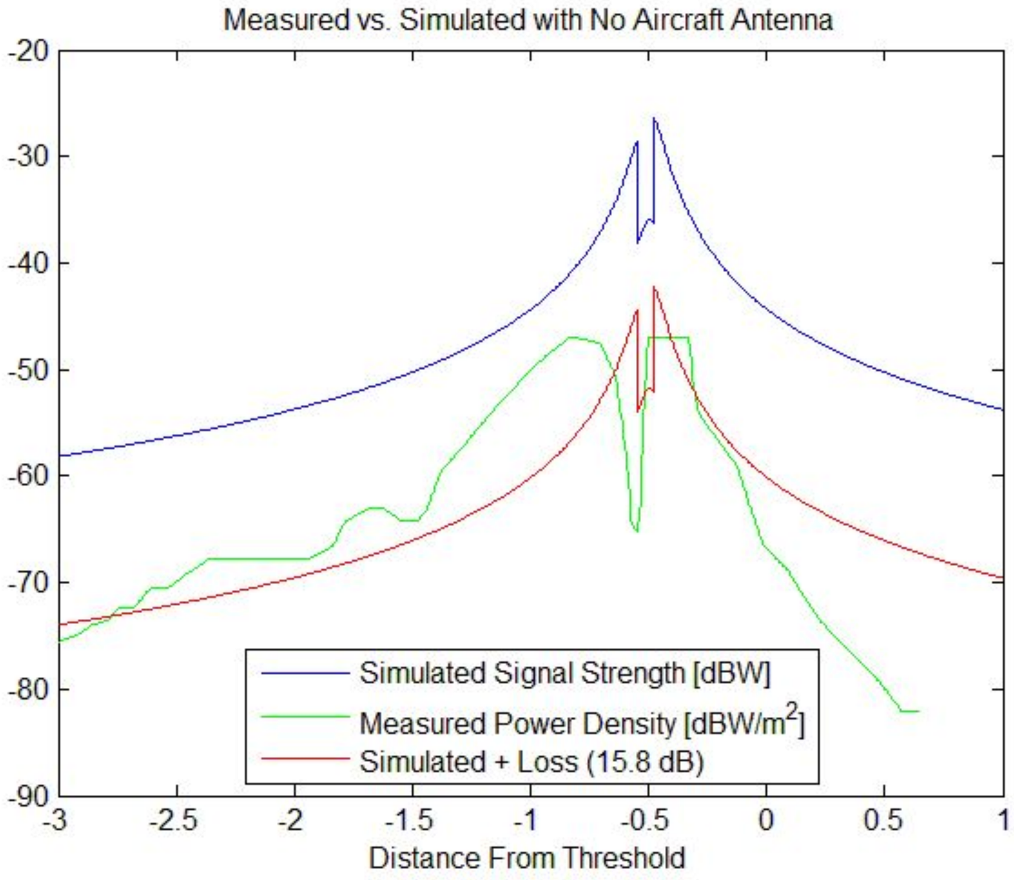
Compare Simple VOR Model with Bremen Flight Inspection Measurements

- The EIRP is set as 53 dBm (200 W) to match Bremen VOR power
- Ground Antenna Gain is simulated as:
  - -4 dB in the Cone of Silence (elevation > 60 degrees)
  - 6 dB elsewhere
- FSPL = $20*\log_{10}(\text{distance}_{\text{meter}}) + 20*\log_{10}(117.45\text{ MHz}) - 147.55$
- Signal Strength (dBW/m^2) = EIRP (dBm) + $\text{Gain}_{\text{GroundAntenna}}$ – FSPL – 30

Bremen test data vs Simulated VOR Signal (No Simulated Aircraft Antenna)

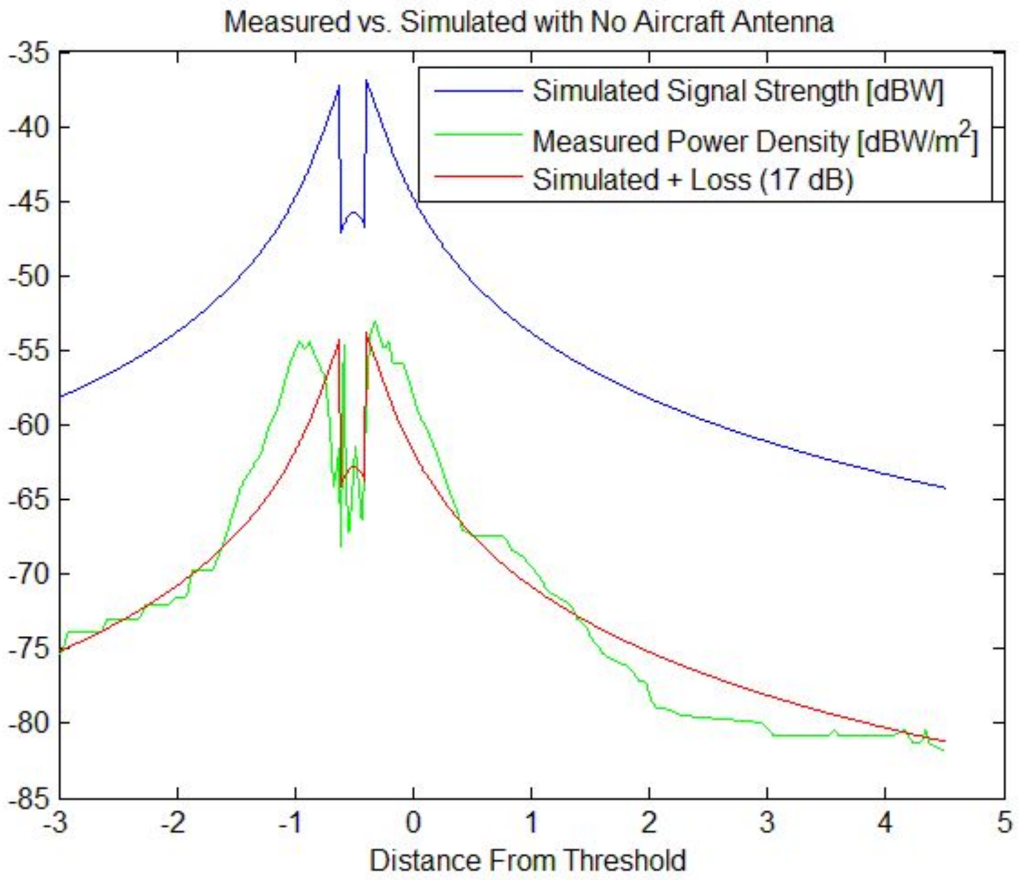


27 Approach, Go Around – VOR overflight at 50'

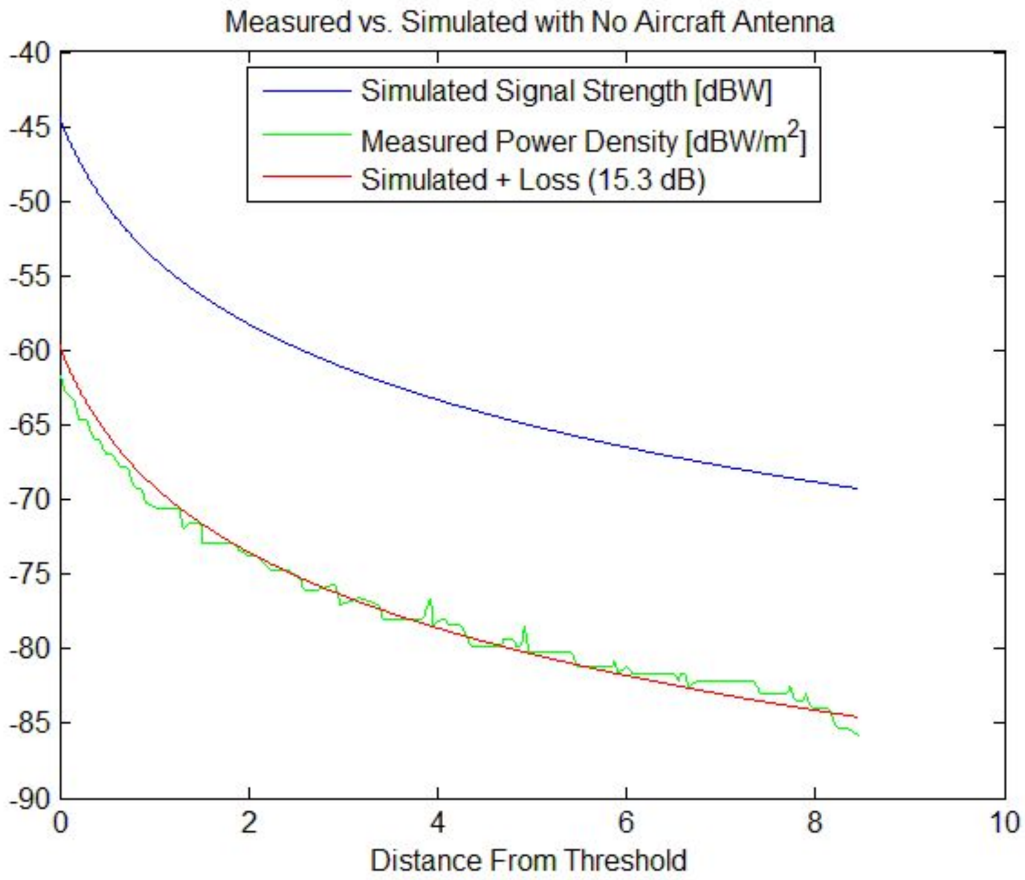


27 Approach Go Around – VOR overflight at 400'

Bremen test data vs Simulated VOR Signal (No Simulated Aircraft Antenna)



09 Approach – VOR overflight at 400'



27 Approach – No VOR overflight

Transmit Simplified Models Summary

1. ILS LOC
   - Simplified model based on NavCom gain vs. el and 1/R, $1/R^2$ losses
   - Matches well with other NavCom results, but may be a few dB too high for close overflights
2. VDB
   - Simplified model is isotropic
   - Does not account for up to 15dB fades in real life
   - Actual SIS power levels will be accounted for during inspection
3. VOR
   - Simplified model has 10dB reduced gain above 60 degrees
   - Produces power levels that are about 15dB higher than flight inspection results
   - 15dB increase in undesired VOR coincidentally covers lack of VDB fade modeling

D/U Simulation Results

D/U Simulation Scenarios

1. VDB Desired / ILS Near Undesired
2. VDB Desired / ILS Far Undesired
3. VDB Desired / VOR Undesired (and VOR / VDB)

VDB Desired / ILS Near Undesired

VDB Location Grid and ILS Near Stable Location

Scatter plots for VDB Location

Formulas

- $EIRP_{VDB}$ = 47 dBm [1]
- $EIRP_{ILS}$ in the main beam = 60 dBm [1]
- $G_{transmitter,VDB}$ = 0 dB (Isotropic Antenna)
- $FSPL_{ILS,D > 822\ m} = 20*\log_{10}(D) + 20*\log_{10}(108) – 147.55$
  - Frequency for the undesired chosen to yield the smaller FSPL
- $FSPL_{ILS,D < 822\ m} = 10*\log_{10}(D) + 20*\log_{10}(108) – 147.55 + 29.15$
- $FSPL_{VDB} = 20*\log_{10}(D) + 20*\log10(117.95) – 147.55$
  - Frequency for the desired chosen to yield the bigger FSPL
- $P_{VDB} = EIRP_{VDB} + G_{transmitter,VDB} + G_{Receiver,VDB} – FSPL_{VDB}$
- $P_{ILS} = EIRP_{ILS} + G_{transmitter,ILS} + G_{Receiver,ILS} – FSPL_{ILS}$
- $D/U = P_{VDB} – P_{ILS}$

[1] Source: Stefan Müller and Felix Butsch and Helmut Günzel, “Investigation of GBAS frequency protection requirements at third adjacent channel and beyond,” DFS Deutche Flugsicherung GmbH, Version 0.10, 13.11.2015

Explanation on the Scatter plots

- Each circle corresponds with a GBAS antenna location.
- If the dot is green then no VDB antenna location causes the D/U for that GBAS location to go below the threshold.
- If VDB antenna locations cause the D/U to go below the threshold then the color corresponds with the worst case.
- If the color is not green, the size of the dot corresponds with how many times a VDB antenna on the grid was less than the threshold.
- The color bar on the right only appears if there is a GBAS antenna location that is not green.

Full A/C Flight Path

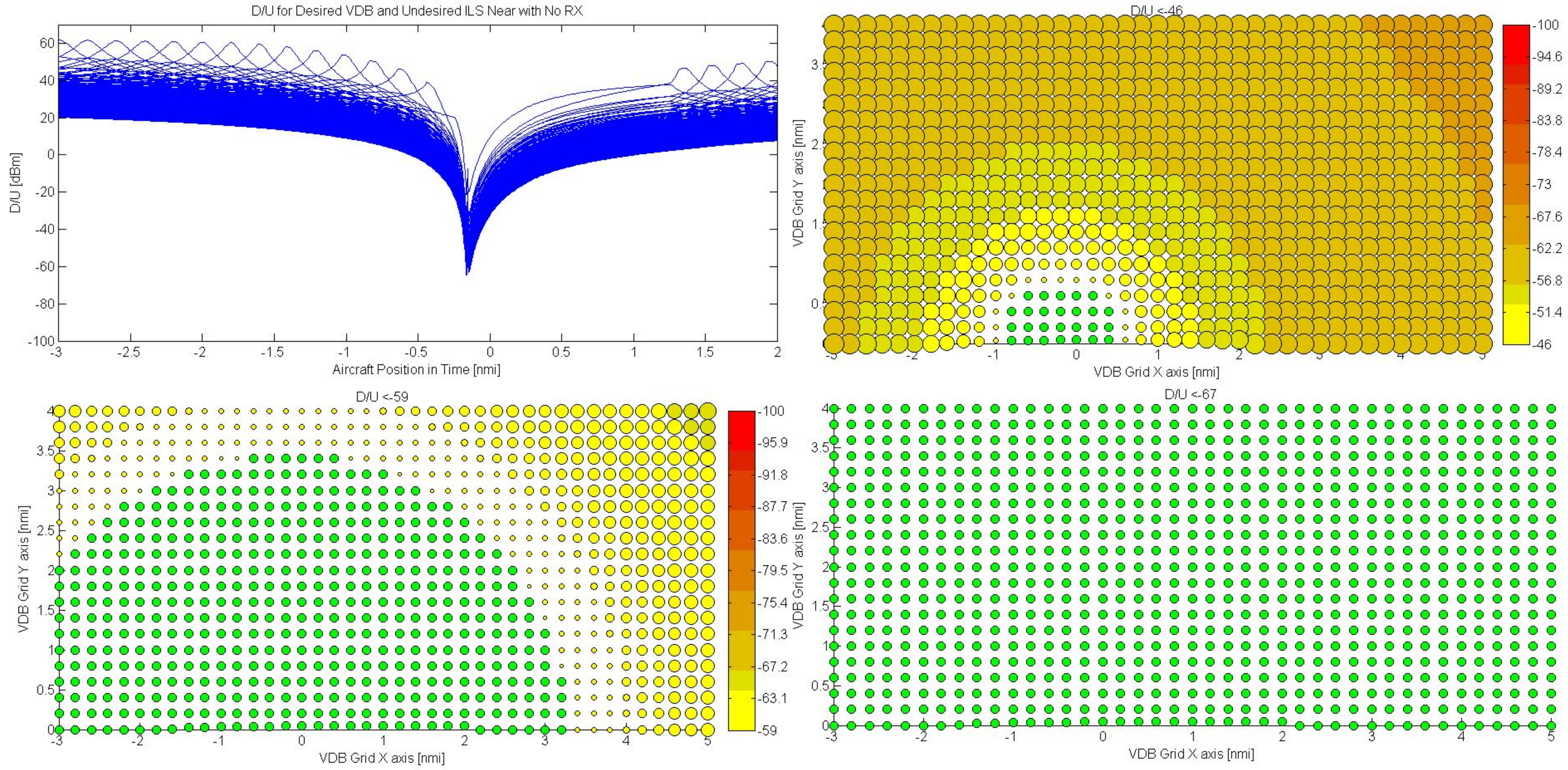
FPA = 1.35 degrees (lower edge of coverage)

- Plot 1 : Plots of the D/U vs. Position
- Plot 2 : Scatterplot of Threshold = -46
- Plot 3 : Scatterplot of Threshold = -59
- Plot 4 : Scatterplot of Threshold = -67

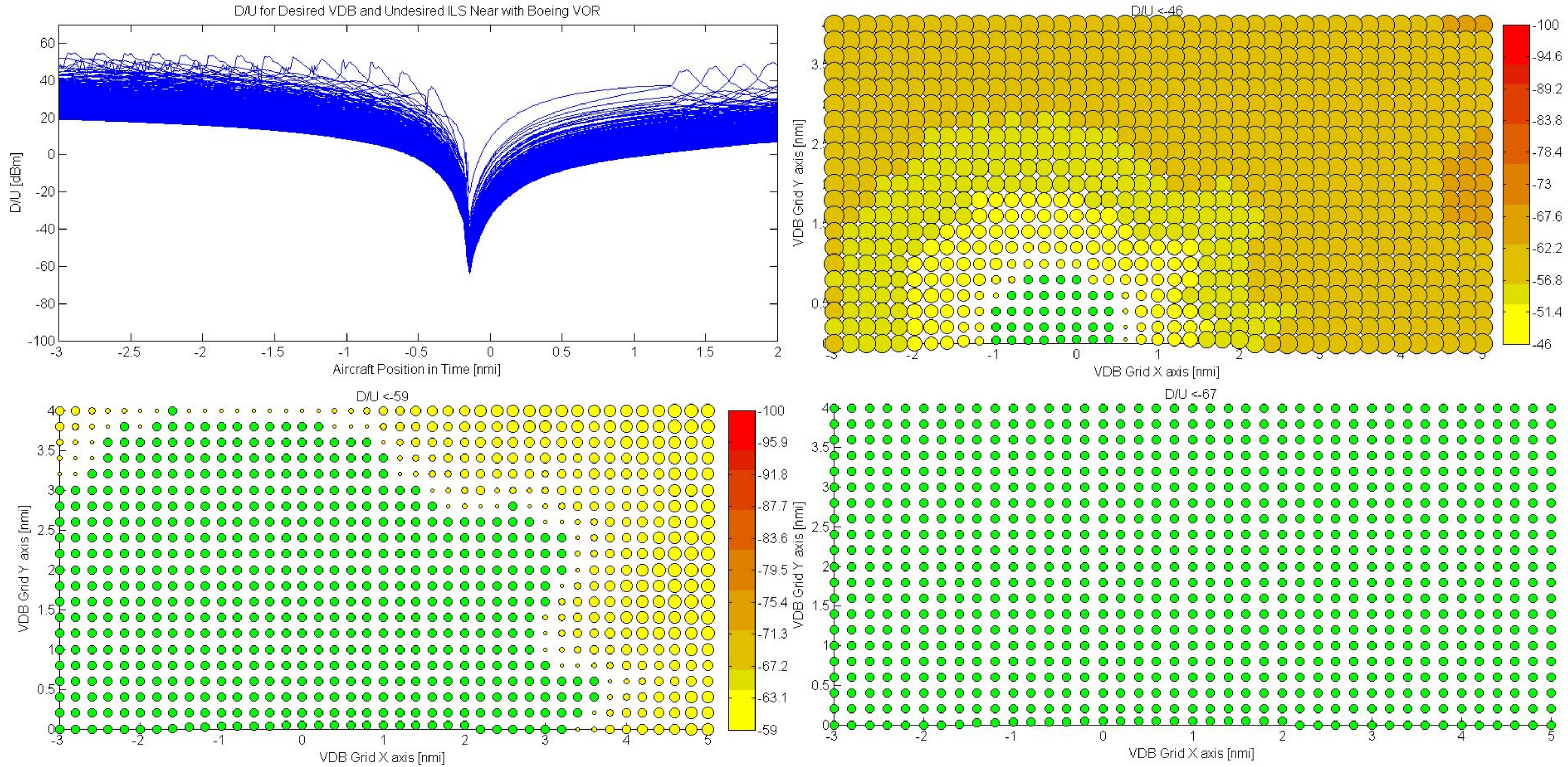
1	2
3	4

Threshold = *the limit of the D/U required to be tolerable at the receiver input*

1.35 Degrees, No Antenna , U = ILS Near



1.35 Degrees, Boeing VOR , U = ILS Near



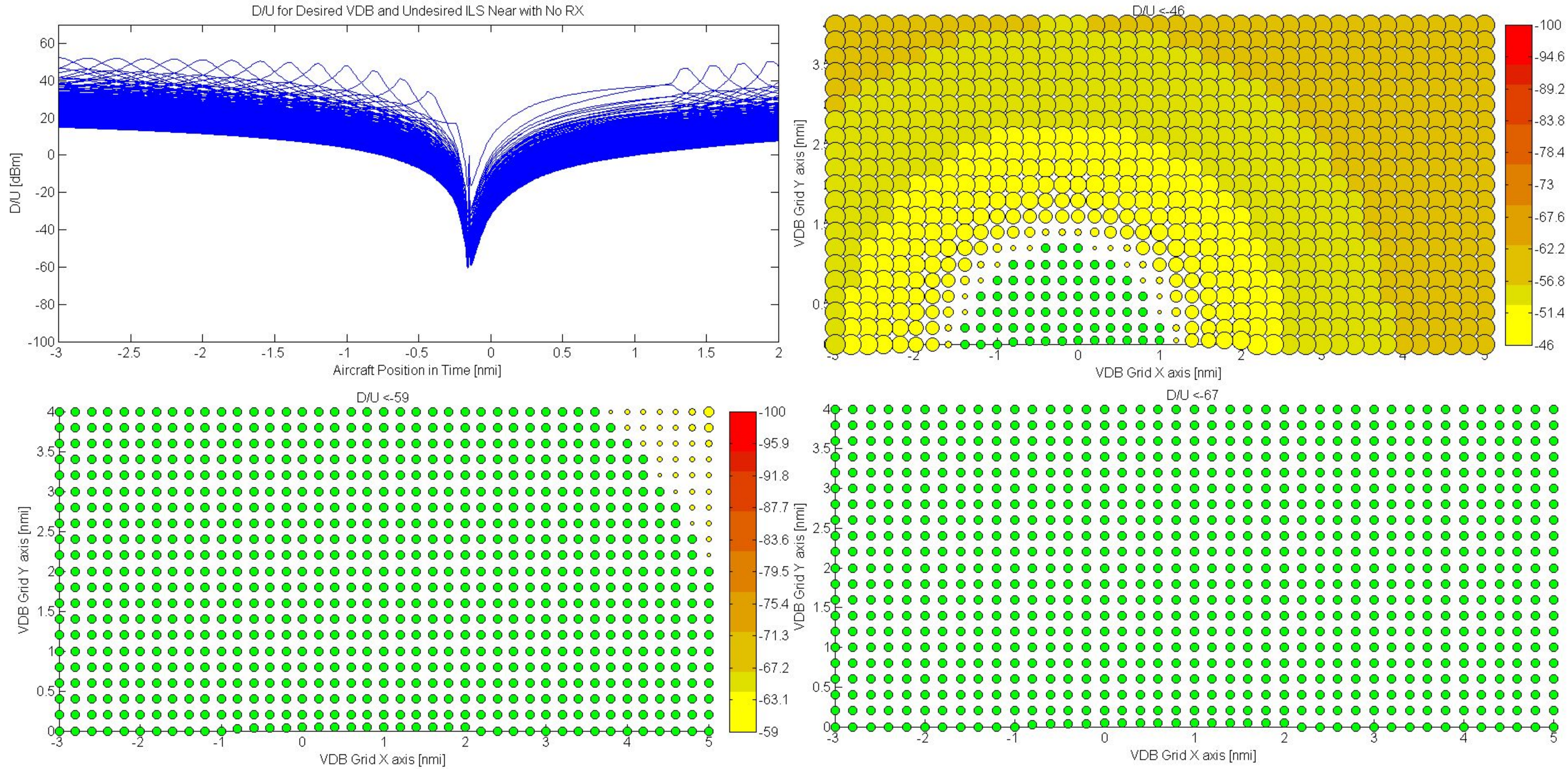
FPA = 2.25 degrees (full scale low)

- Plot 1 : Plots of the D/U
- Plot 2 : Scatterplot of Threshold = -46
- Plot 3 : Scatterplot of Threshold = -59
- Plot 4 : Scatterplot of Threshold = -67

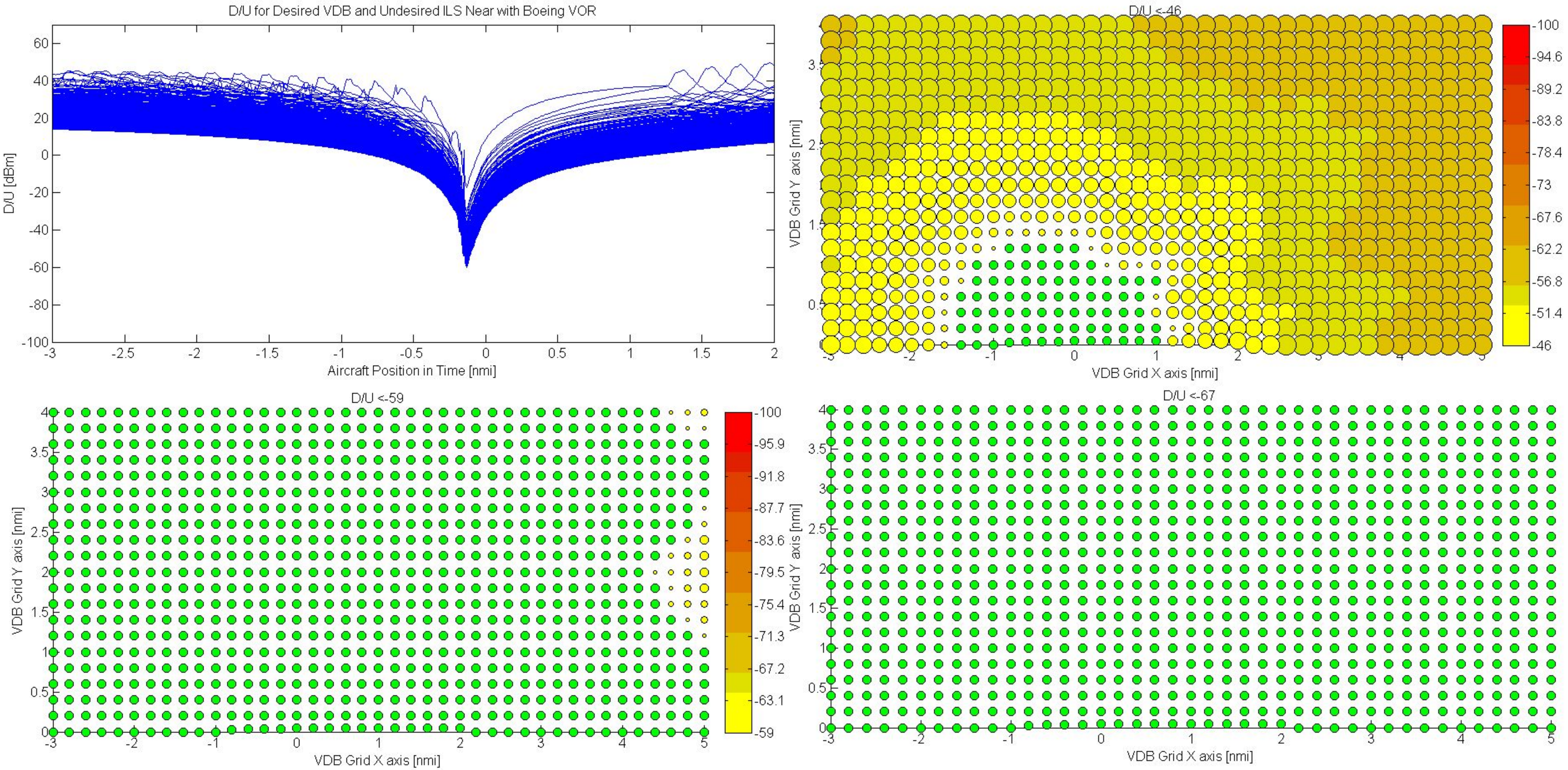
1	2
3	4

Threshold = *the limit of the D/U required to be tolerable at the receiver input*

2.25 Degrees, No Antenna , U = ILS Near



2.25 Degrees, Boeing VOR , U = ILS Near



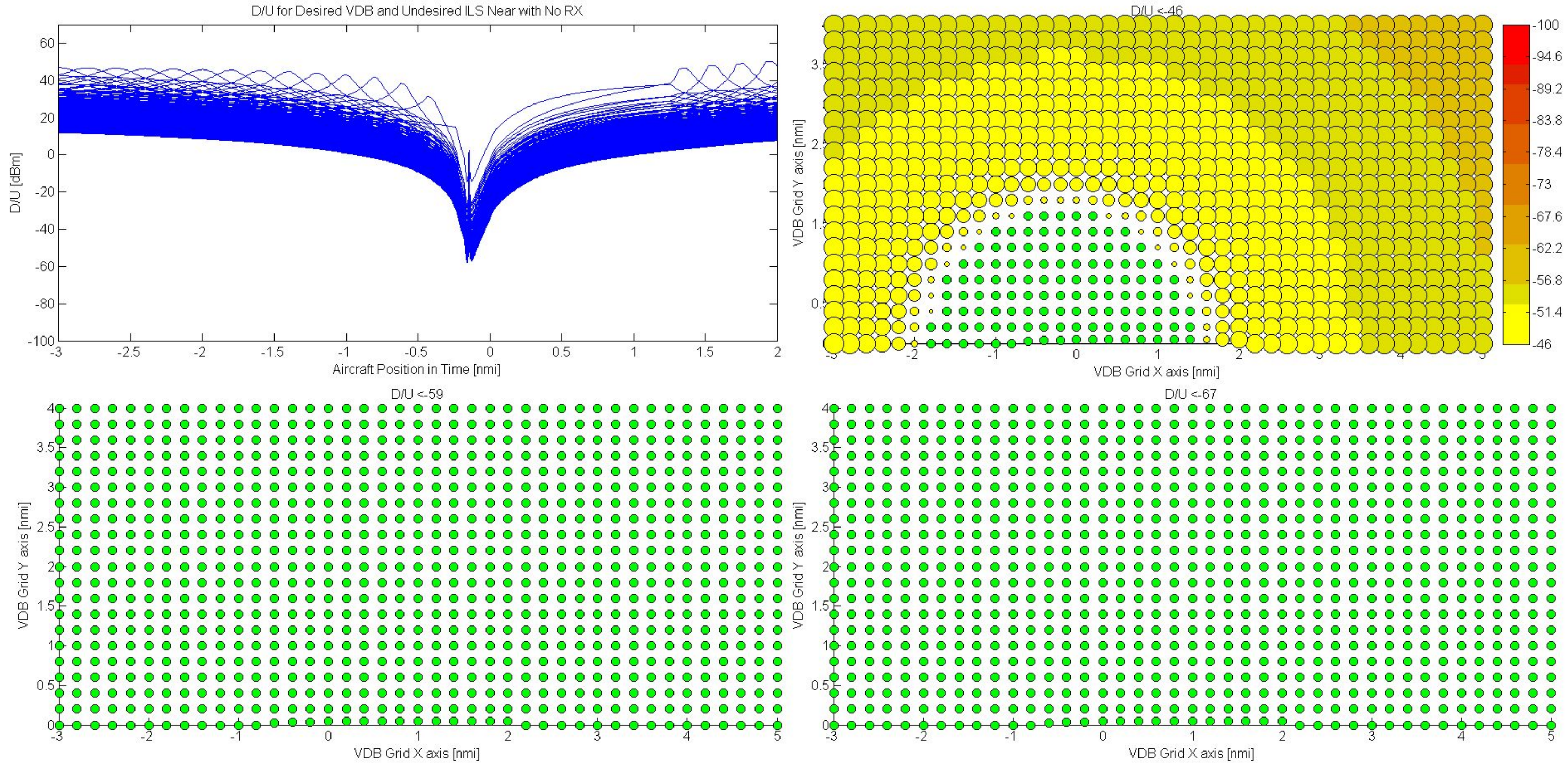
FPA = 3 degrees (On Glideslope)

- Plot 1 : Plots of the D/U
- Plot 2 : Scatterplot of Threshold = -46
- Plot 3 : Scatterplot of Threshold = -59
- Plot 4 : Scatterplot of Threshold = -67

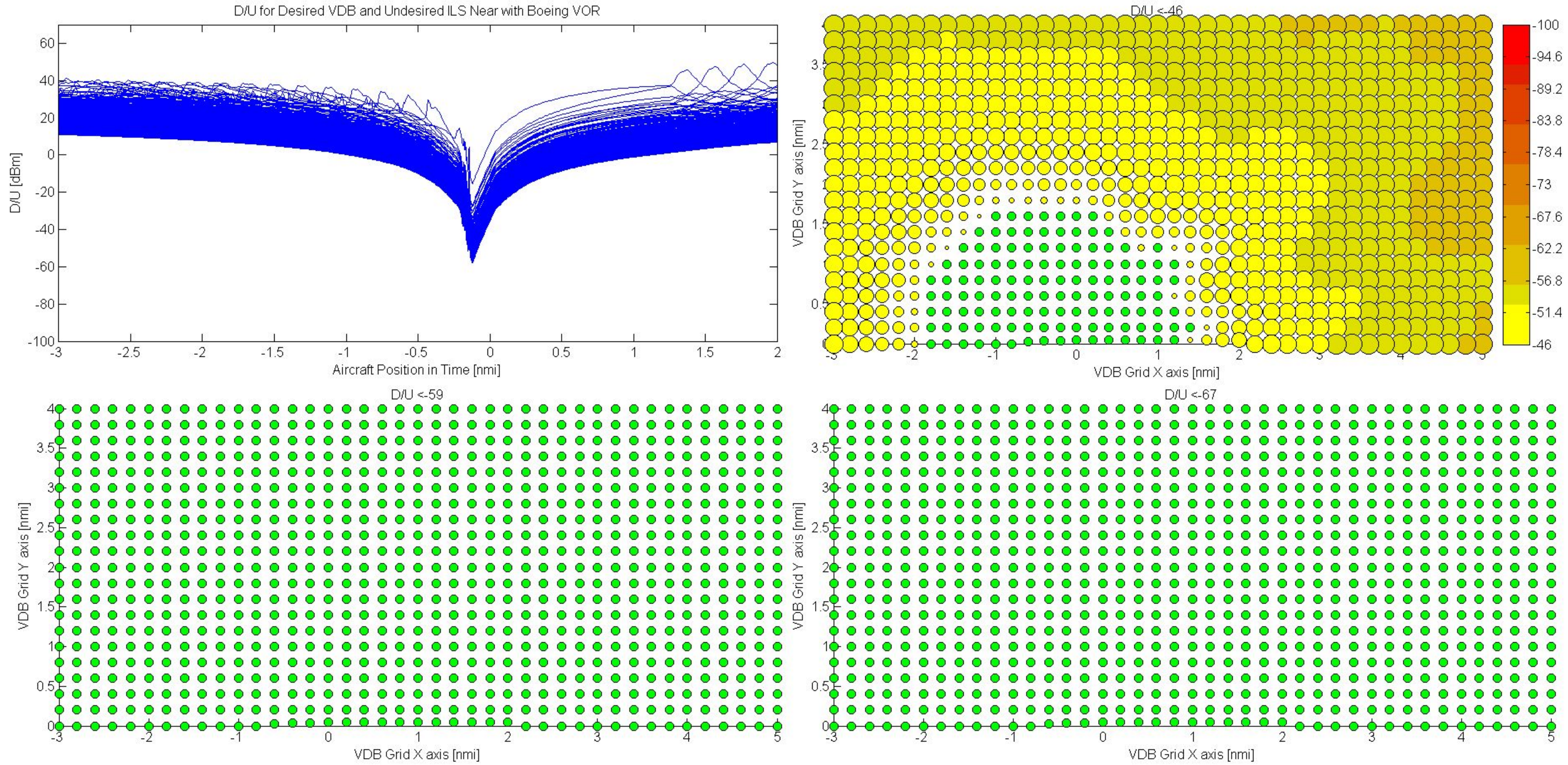
1	2
3	4

Threshold *= the limit of the D/U required to be tolerable at the receiver input*

3 Degrees, No Antenna , U = ILS Near



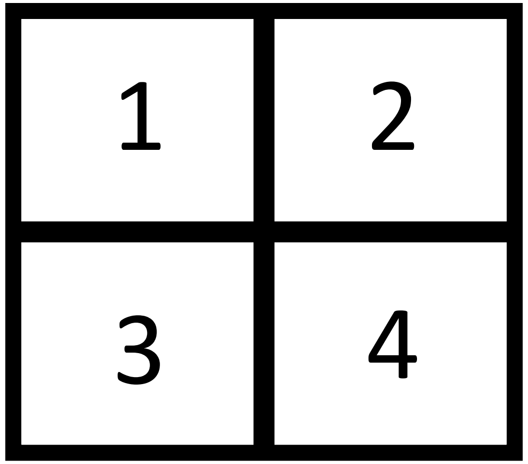
3 Degrees, Boeing VOR , U = ILS Near



A/C Flight Path to 200 ft

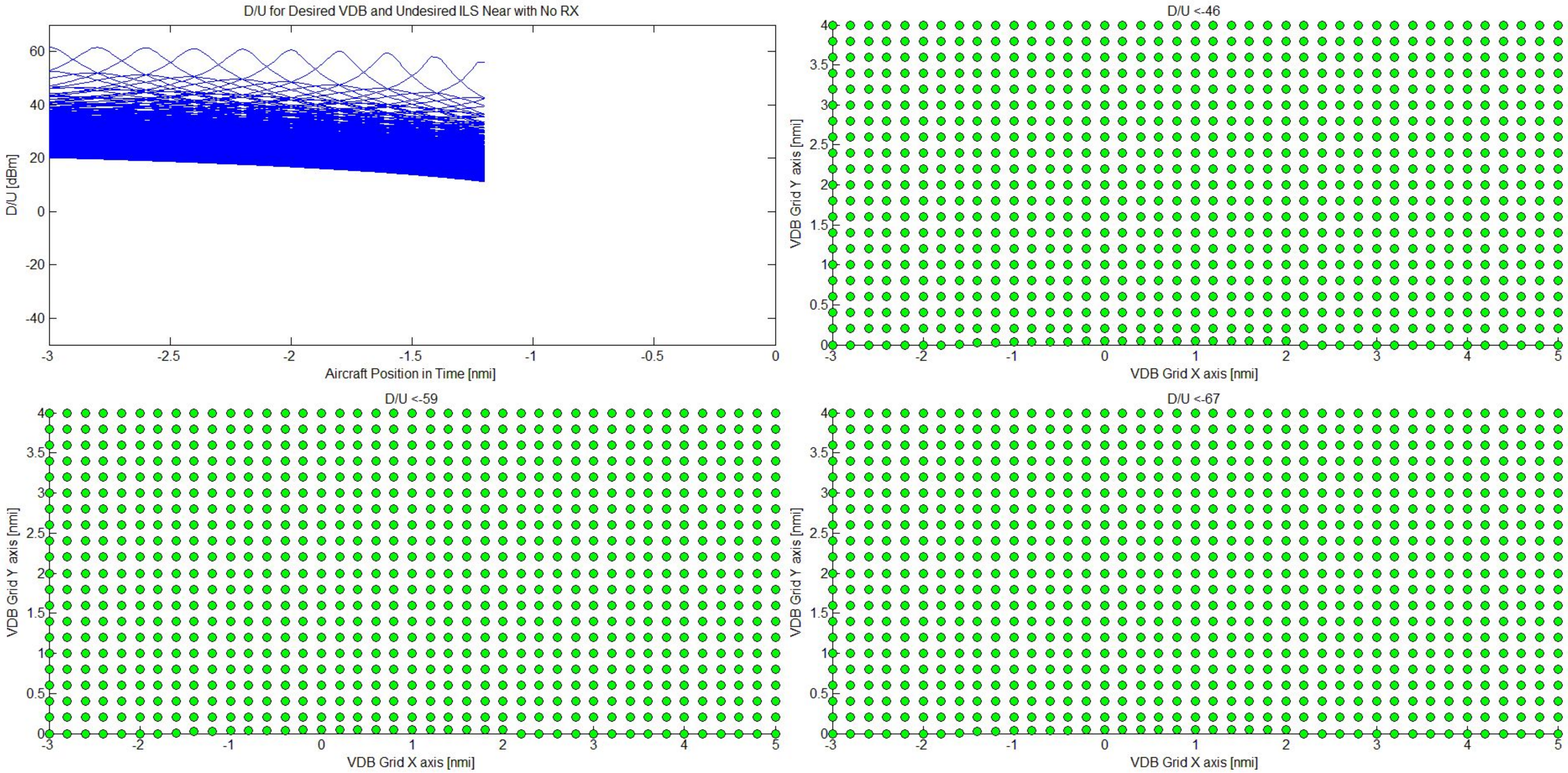
FPA = 1.35 degrees (Lowest Coverage)

- Plot 1 : Plots of the D/U
- Plot 2 : Scatterplot of Threshold = -46
- Plot 3 : Scatterplot of Threshold = -59
- Plot 4 : Scatterplot of Threshold = -67

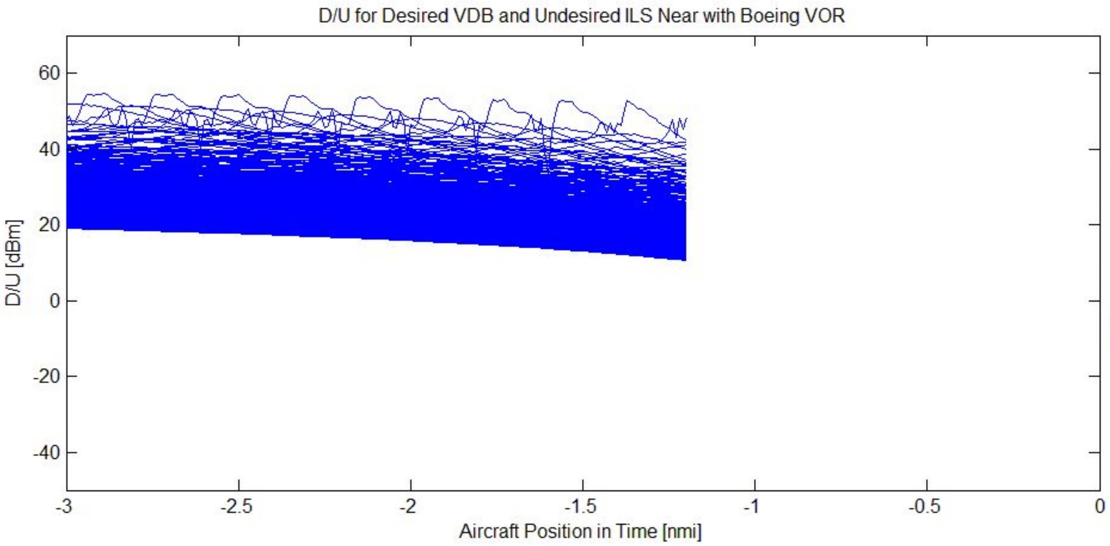


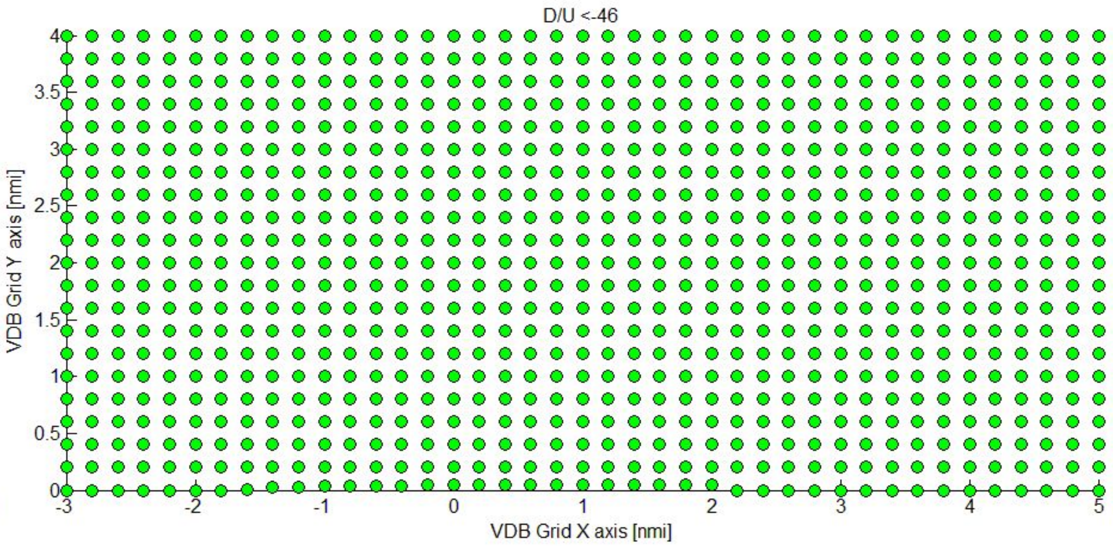
Threshold = *the limit of the D/U required to be tolerable at the receiver input*

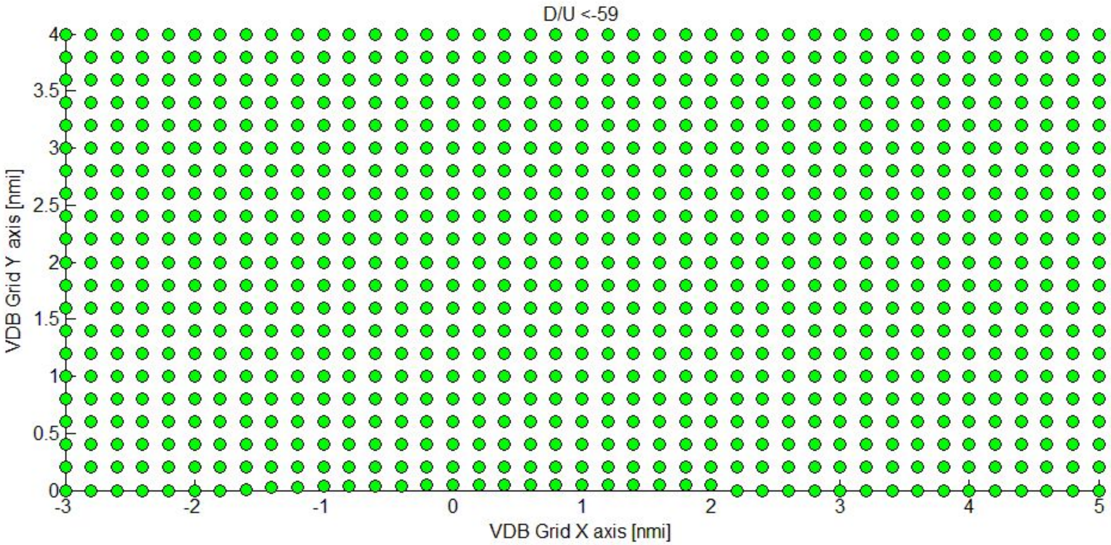
1.35 Degrees, No Antenna, U = ILS Near

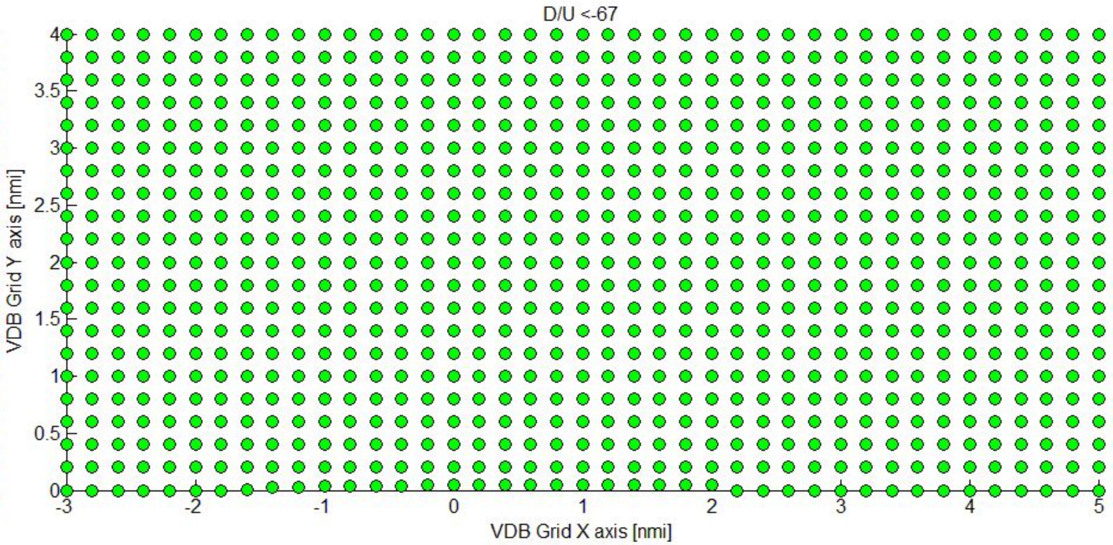


1.35 Degrees, Boeing VOR, U = ILS Near









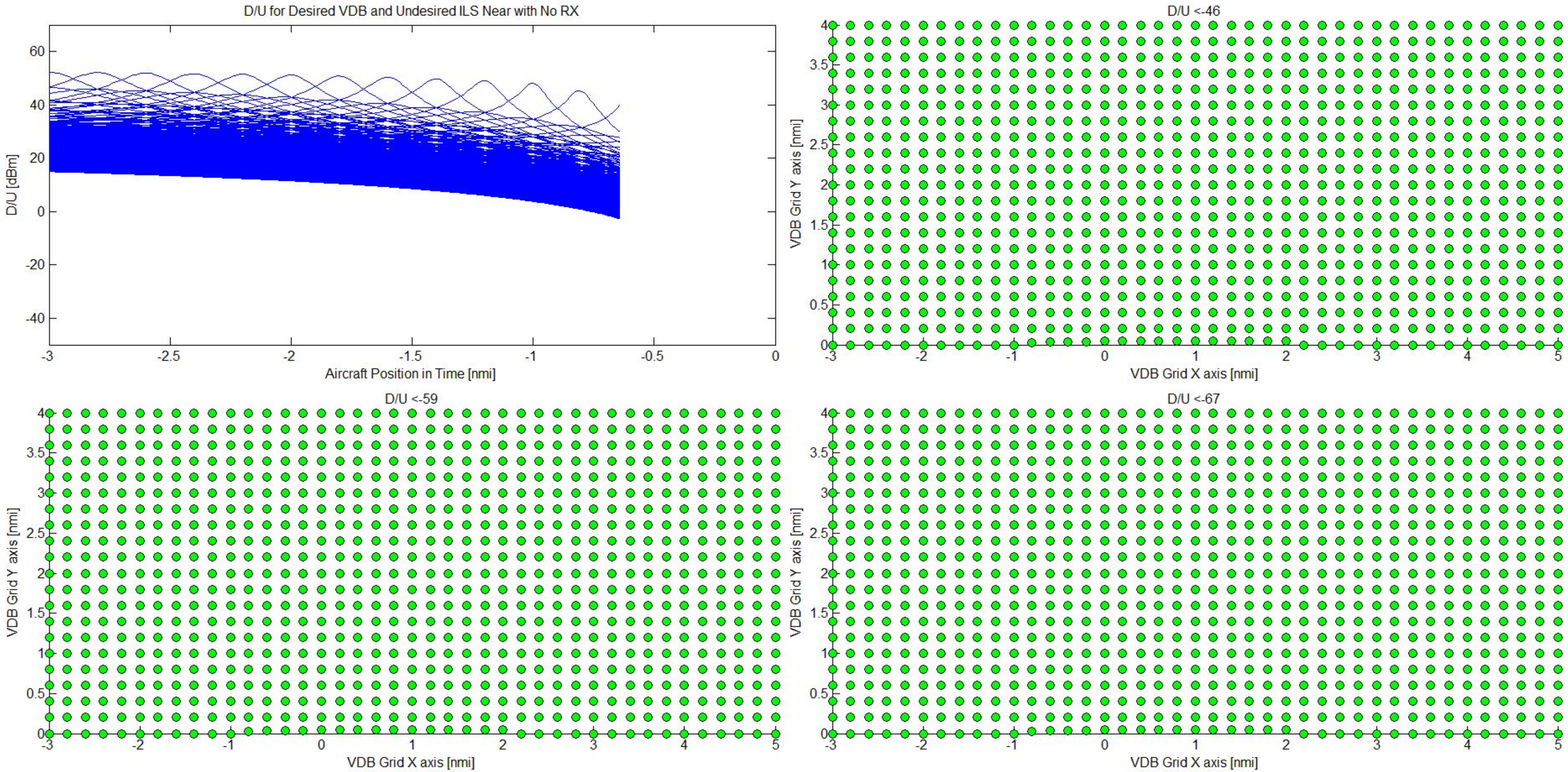
FPA = 2.25 degrees (Full Scale Low)

- Plot 1 : Plots of the D/U
- Plot 2 : Scatterplot of Threshold = -46
- Plot 3 : Scatterplot of Threshold = -59
- Plot 4 : Scatterplot of Threshold = -67

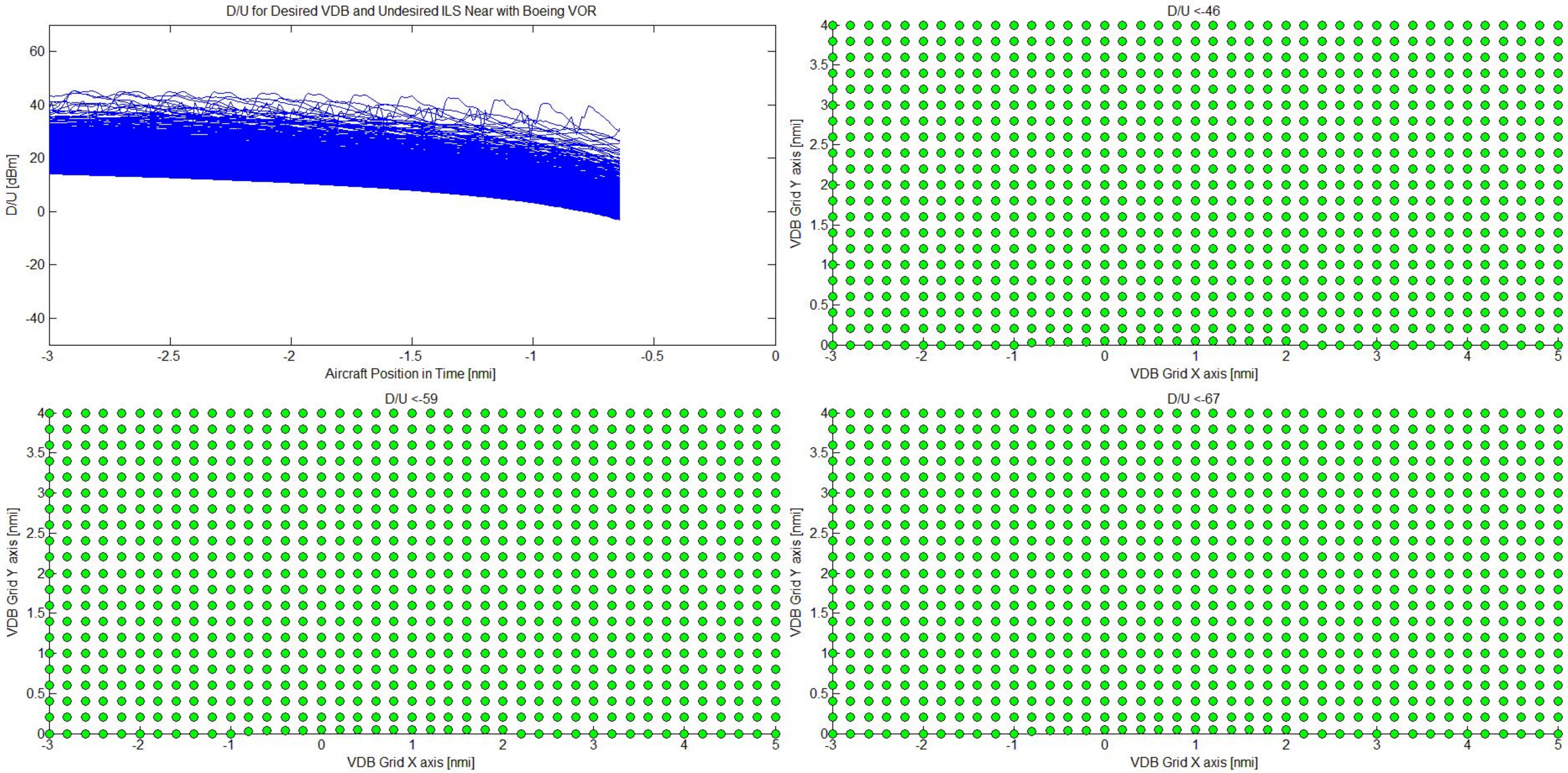
1	2
3	4

Threshold *= the limit of the D/U required to be tolerable at the receiver input*

2.25 Degrees, No Antenna, U = ILS Near



2.25 Degrees, Boeing VOR, U = ILS Near



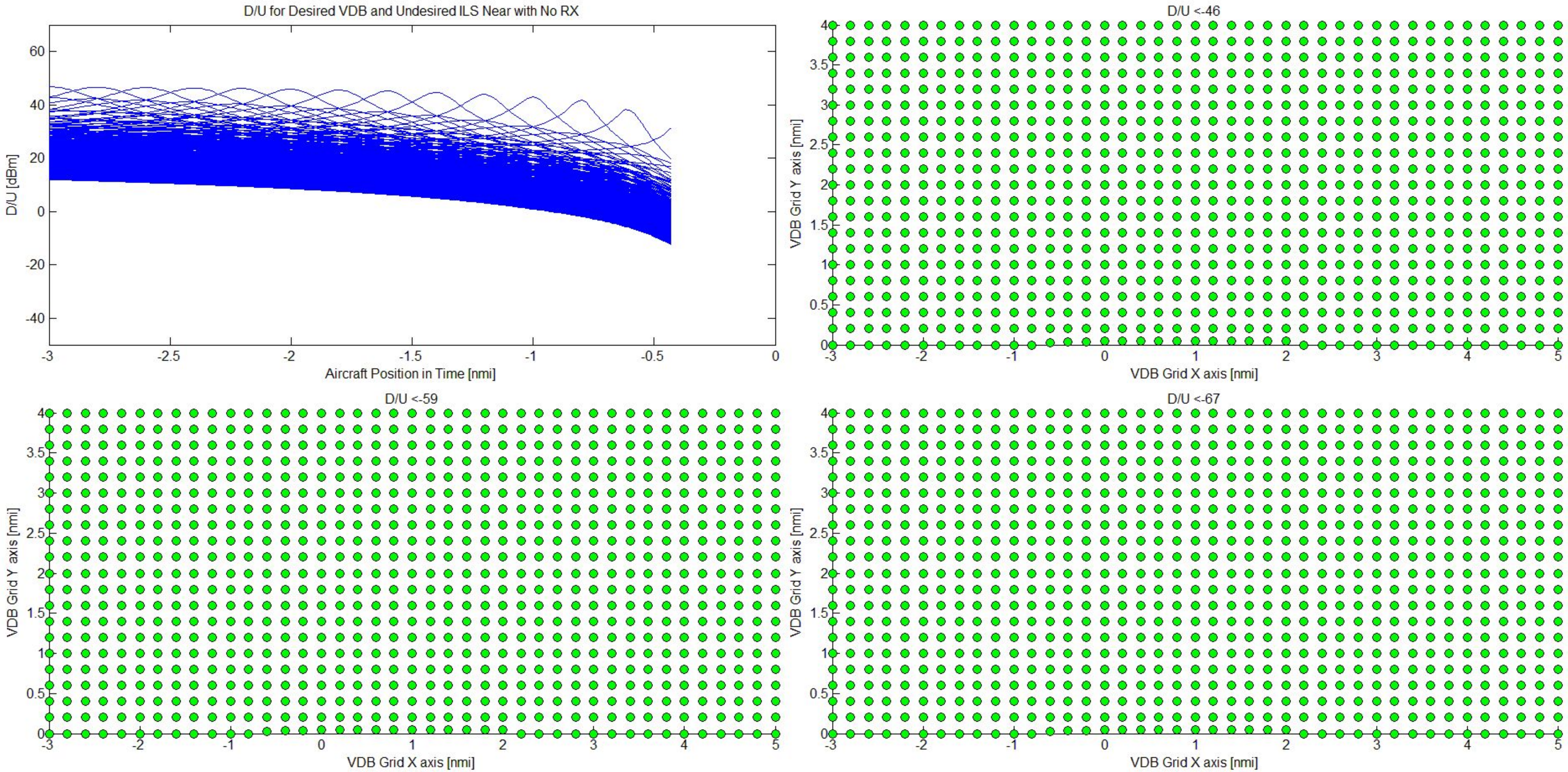
FPA = 3 degrees (On Glideslope)

- Plot 1 : Plots of the D/U
- Plot 2 : Scatterplot of Threshold = -46
- Plot 3 : Scatterplot of Threshold = -59
- Plot 4 : Scatterplot of Threshold = -67

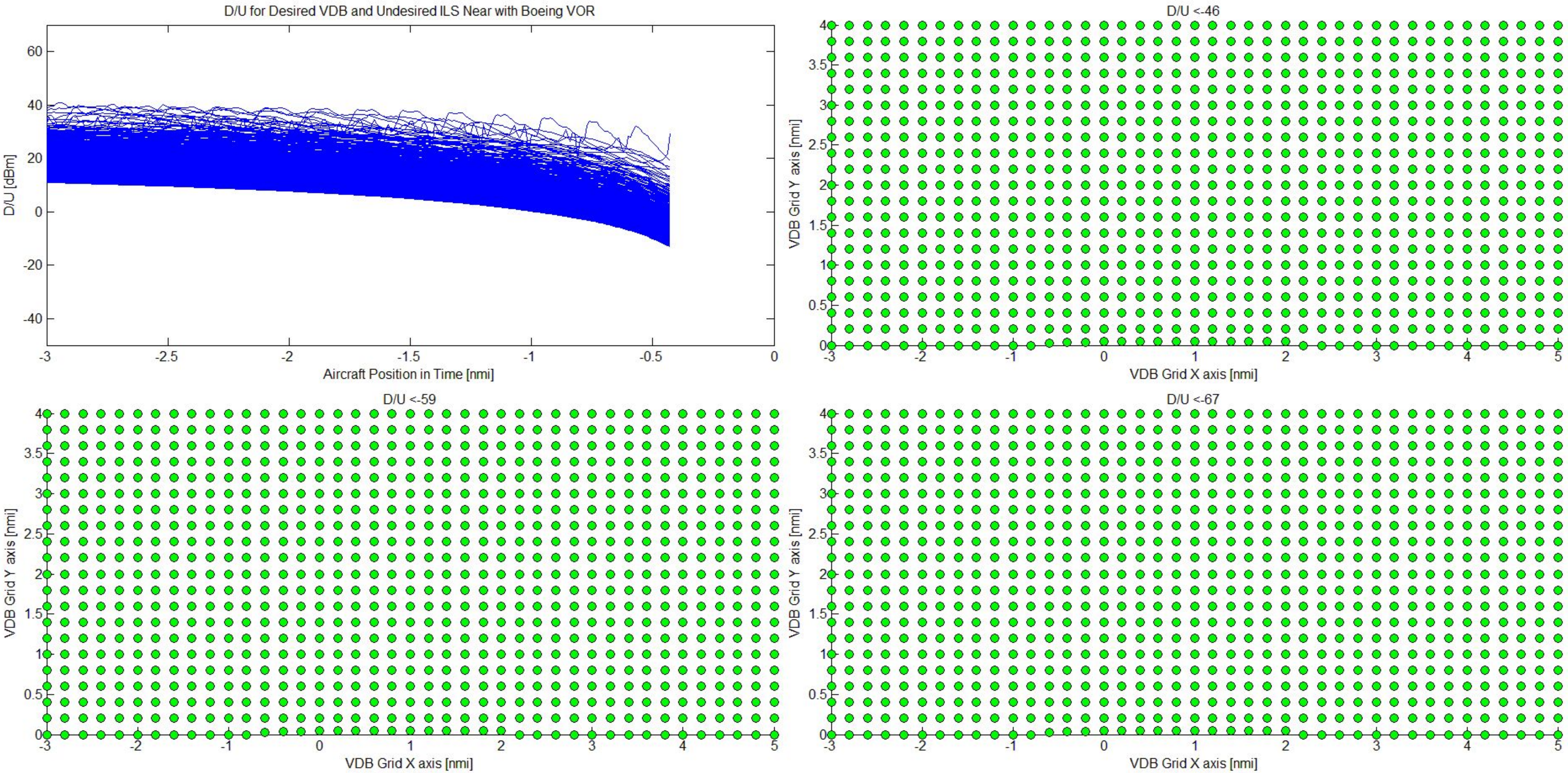
1	2
3	4

Threshold *= the limit of the D/U required to be tolerable at the receiver input*

3 Degrees, No Antenna, U = ILS Near



3 Degrees, Boeing VOR, U = ILS Near



Summary VDB / ILS Near D/U

- Antenna Gain Variation Contribution to worst case D/U at the receiver input is <<15dB for Boeing VOR antenna
  - Worst D/U with Boeing VOR antenna is within 3dB of SIS D/U for any VDB location
    - Comparable results for other similar VOR antennas
    - Even adding mismatch loss variation would only increase D/U by ~10dB
  - This result should be invariant with corrections for real SIS power levels
    - Antenna gain variation contribution is only a function of transmitter directions
    - VDB overflight = closer to VDB, ILS overflight = VDB not lower antenna gain
  - SIS D/U for aircraft above 200 feet HAT is never less than -15 dB
    - Even adding 10dB margin for VOR antenna and mismatch variation, and 20 dB for model simplicity, the VDB/ILS Near D/U above 200 feet is within -46dB

VDB Desired / ILS Far Undesired

VDB Location Grid and ILS Far Stable Location

Scatter plots for VDB Location

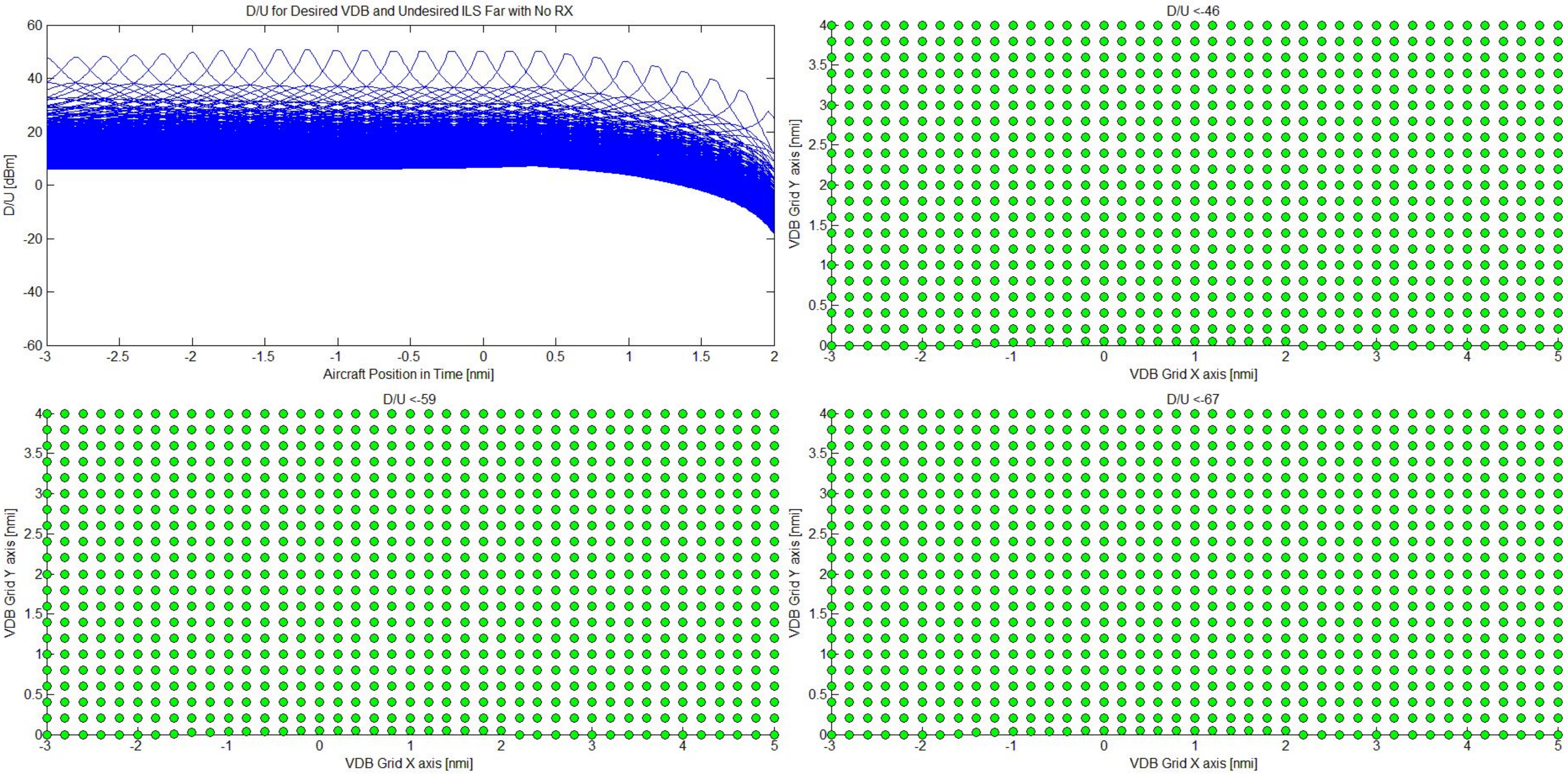
Formulas

- $EIRP_{VDB}$ = 47 dBm [1]
- $EIRP_{ILS}$ in the main beam = 60 dBm [1]
- $G_{Transmitter,VDB}$ = 0 dB (Isotropic Antenna)
- $FSPL_{ILS,D > 822\ m} = 20*\log_{10}(D) + 20*\log_{10}(108\ MHz) – 147.55$
- $FSPL_{ILS,D < 822\ m} = 10*\log_{10}(D) + 20*\log_{10}(108\ MHz) – 147.55 + 29.15$
- $FSPL_{VDB} = 20*\log_{10}(D) + 20*\log10(117.95\ MHz) – 147.55$
- $P_{VDB} = EIRP_{VDB} + G_{Transmitter,VDB} + G_{Receiver,VDB} – FSPL_{VDB}$
- $P_{ILS} = EIRP_{ILS} + G_{Transmitter,ILS} + G_{Receiver,ILS} – FSPL_{ILS}$
- $D/U = P_{VDB} – P_{ILS}$

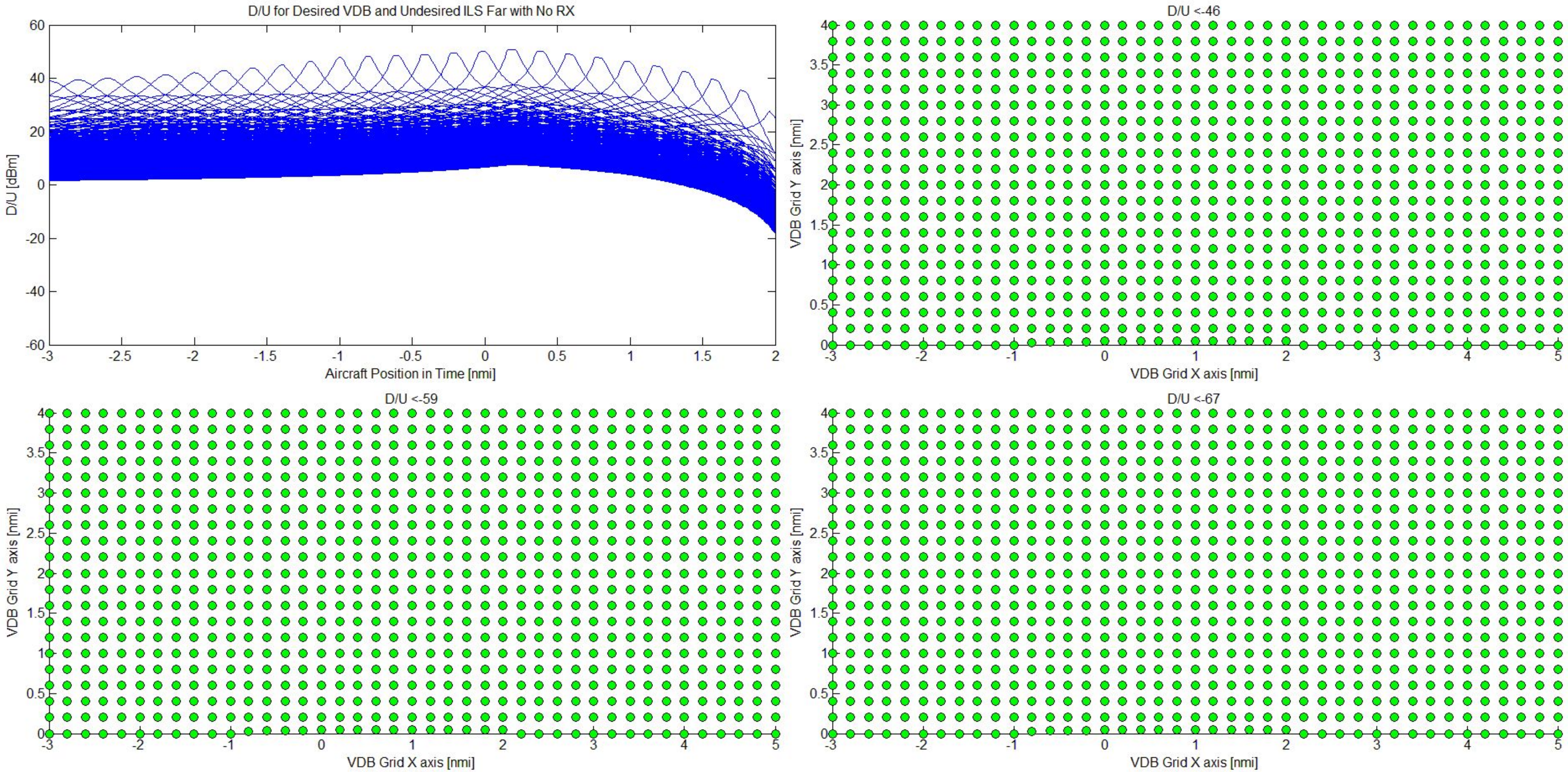
[1] Source: Stefan Müller and Felix Butsch and Helmut Günzel, “Investigation of GBAS frequency protection requirements at third adjacent channel and beyond,” DFS Deutche Flugsicherung GmbH, Version 0.10, 13.11.2015

Full A/C Flight Path

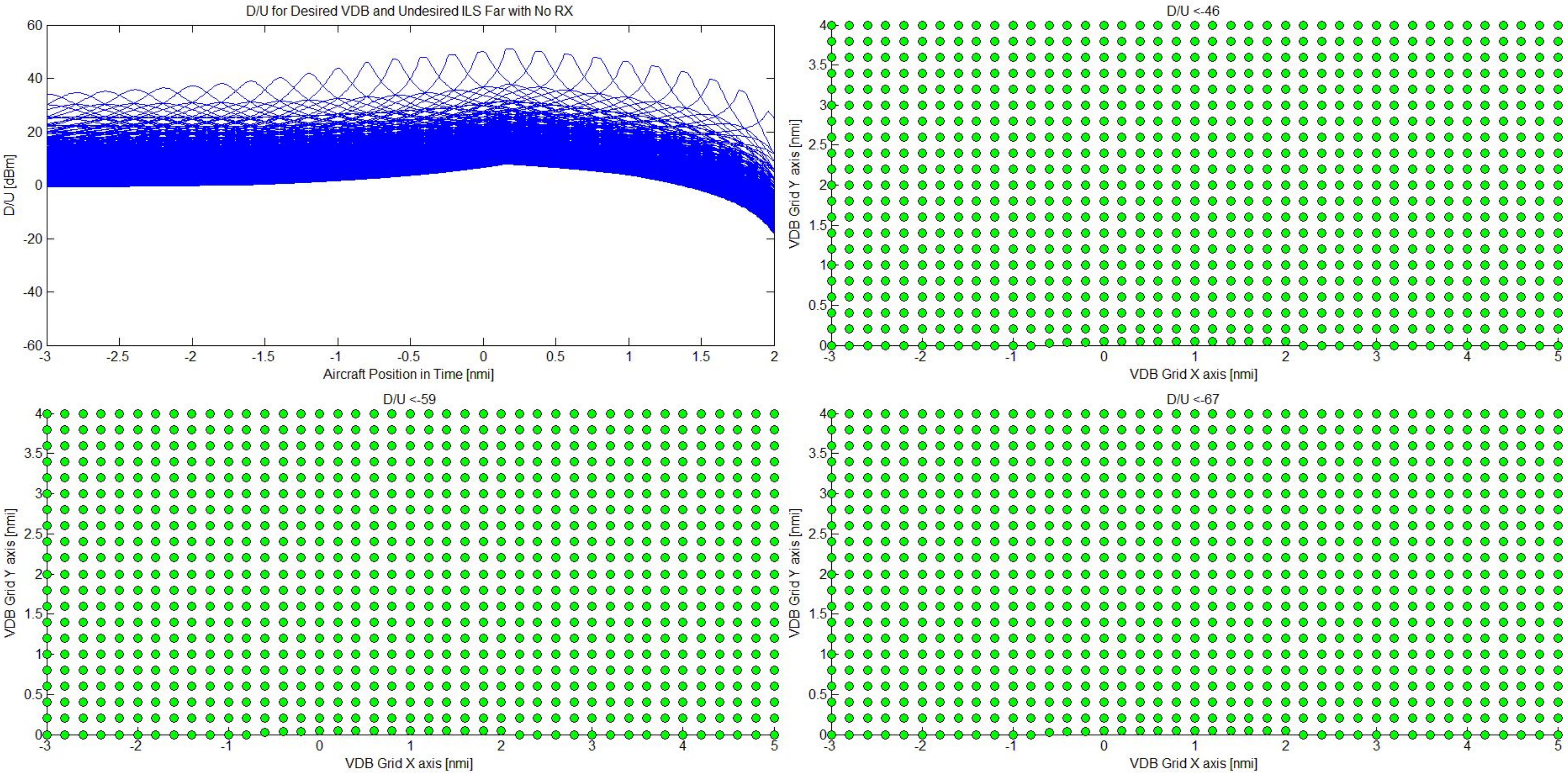
1.35 Degrees, No Antenna, U = ILS Far



2.25 Degrees, No Antenna, U = ILS Far

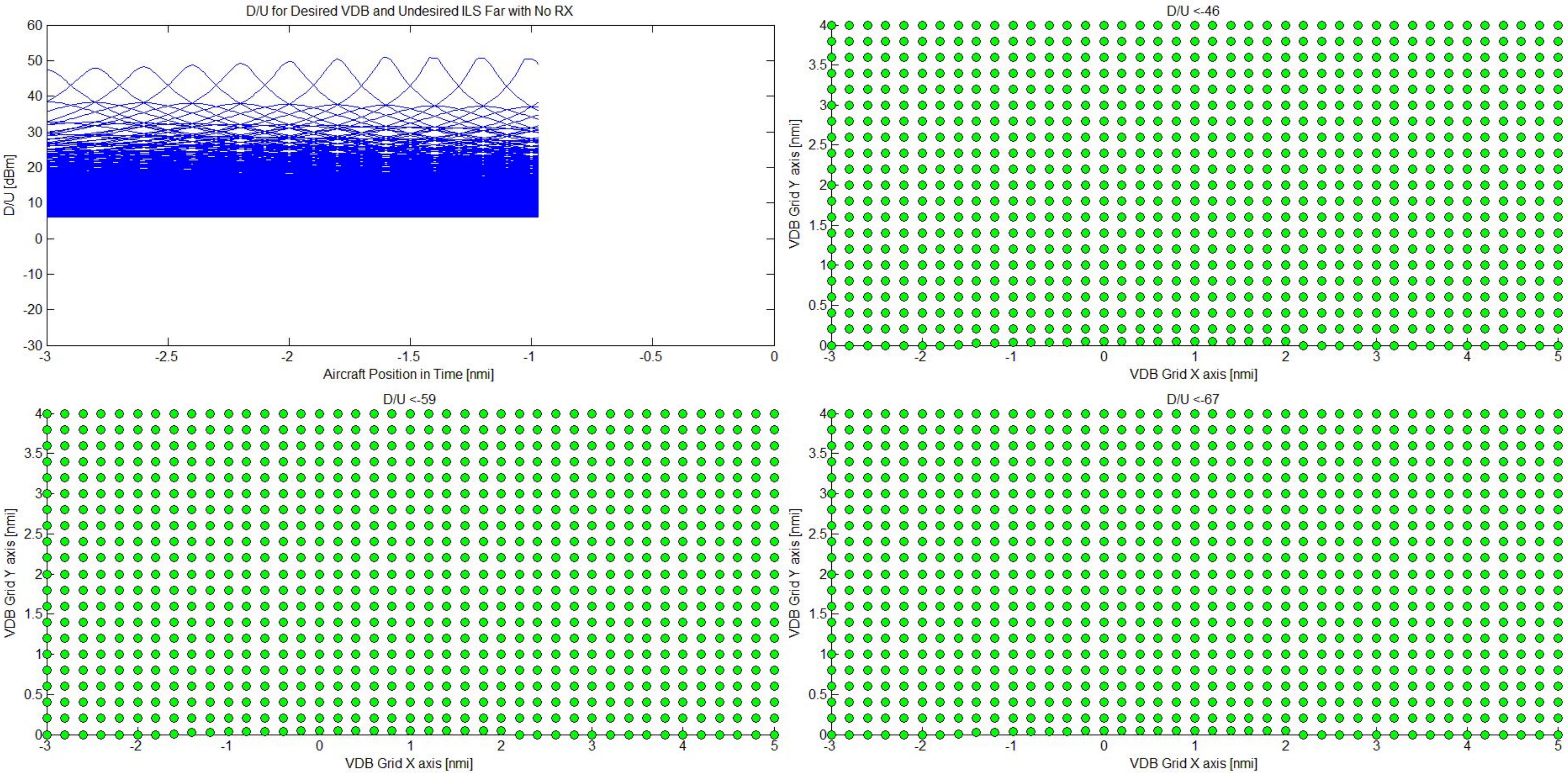


3 Degrees, No Antenna, U = ILS Far

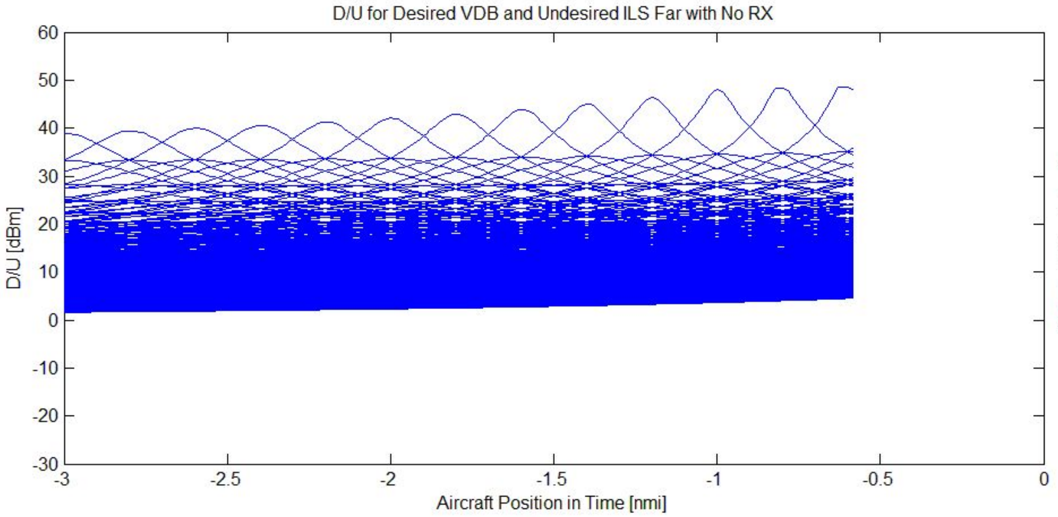


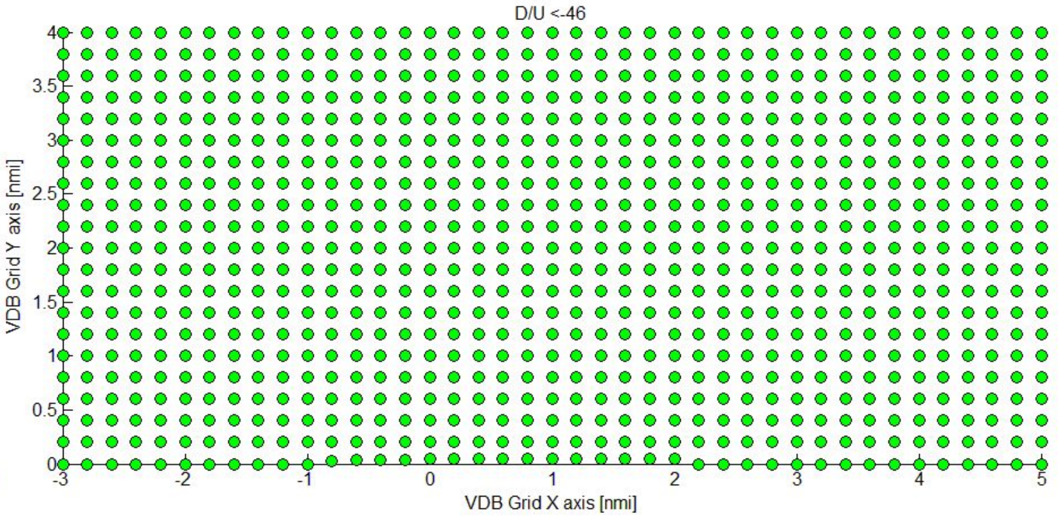
A/C Flight Path to 200 ft

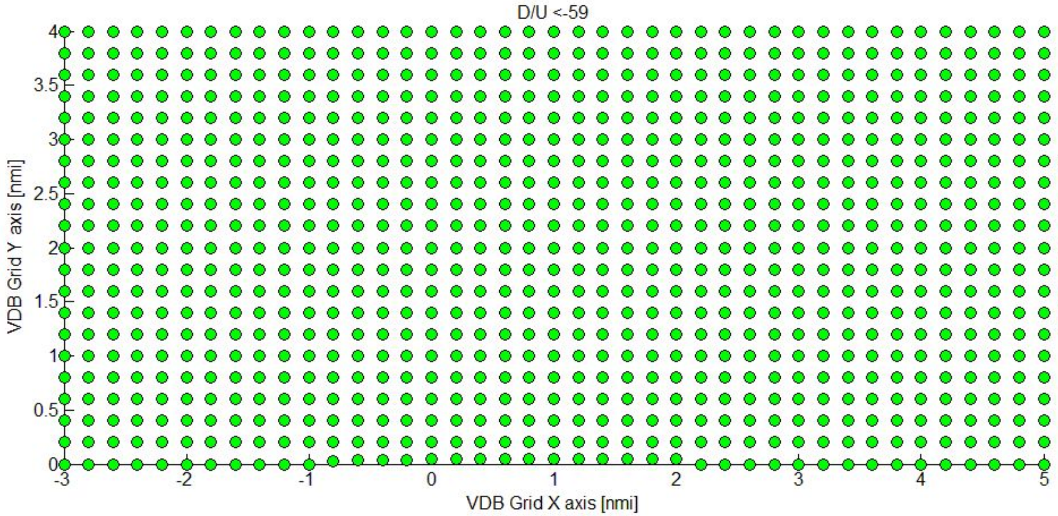
1.35 Degrees, No Antenna, U = ILS Far

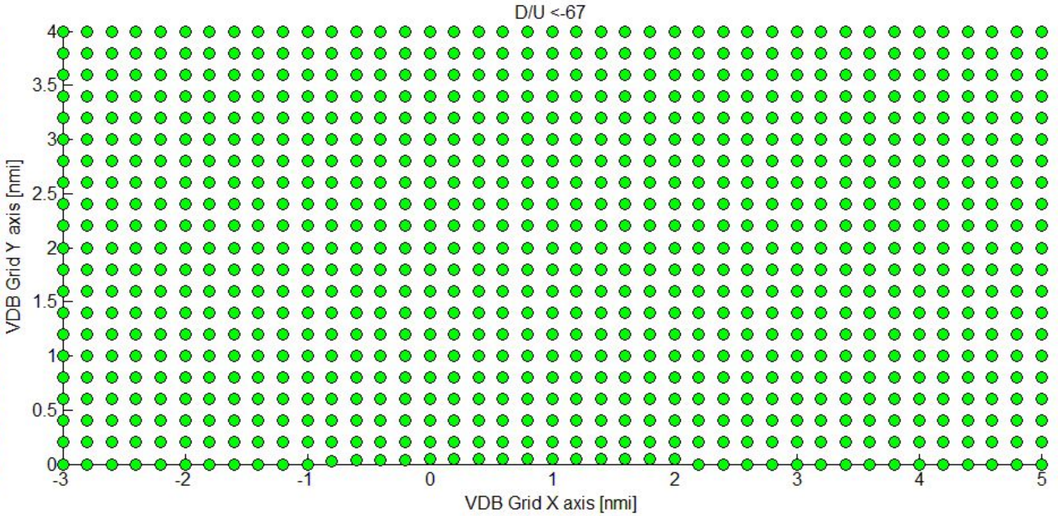


2.25 Degrees, No Antenna, U = ILS Far

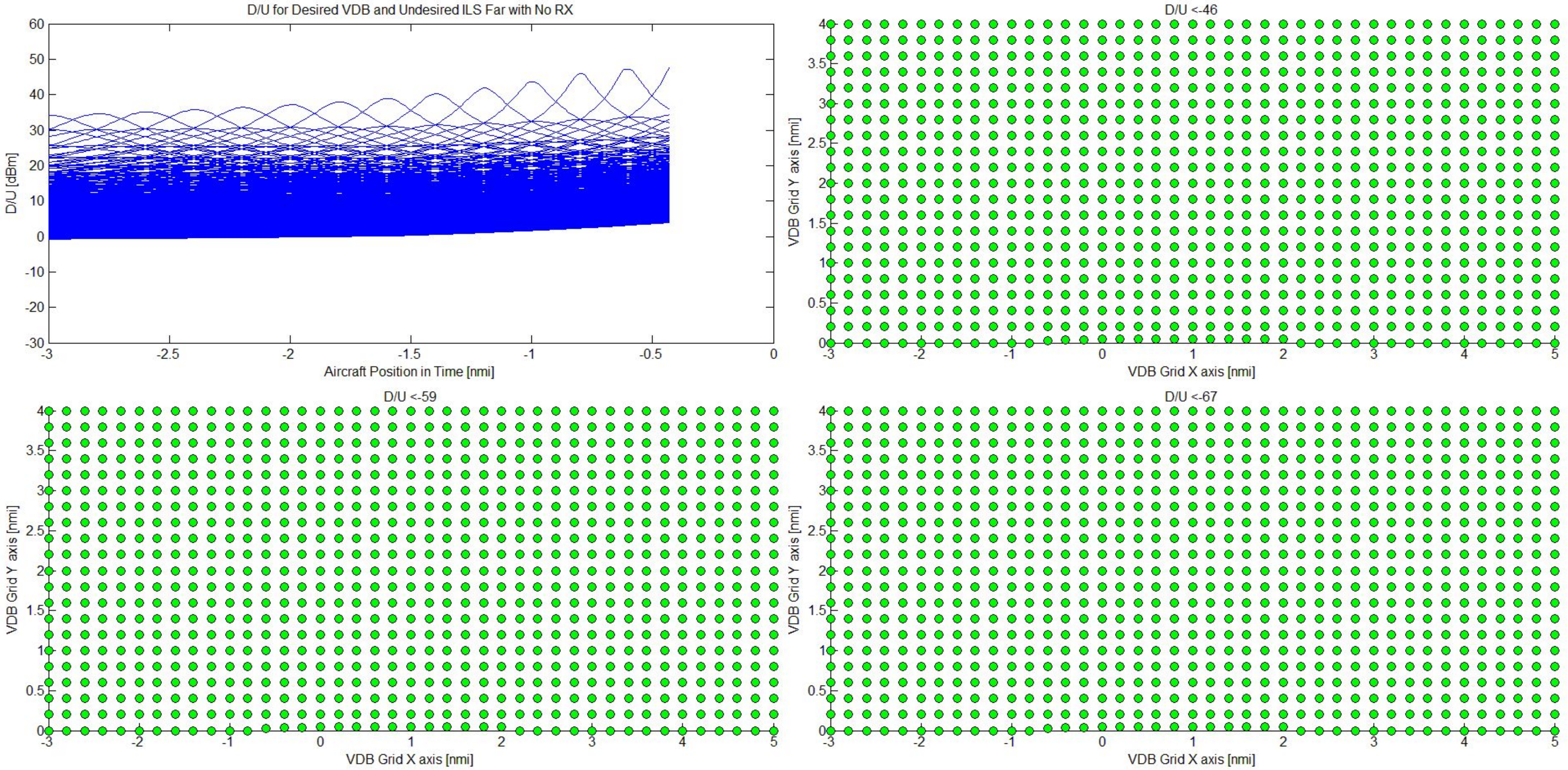








3 Degrees, No Antenna, U = ILS Far



Summary VDB / ILS Far D/U

- Antenna Gain Variation Contribution to worst case D/U at the receiver input is <<15dB for Boeing VOR antenna
  - Worst D/U with Boeing VOR antenna is within 3dB of SIS D/U for any VDB location
    - Comparable results for other similar VOR antennas
    - Even adding mismatch loss variation would only increase D/U by ~10dB
    - Takeoff heading away from ILS Far using LOC antenna not studied
    - Takeoff heading away from ILS Far using VOR antenna should be similar
  - This result should be invariant with corrections for real SIS power levels
    - Antenna gain variation contribution is only a function of transmitter directions
    - VDB overflight = closer to VDB
  - SIS D/U for aircraft above 200 feet HAT is never less than 0 dB
    - Even adding 21dB margin for antenna and mismatch variation, and 20 dB for VDB fades, the VDB/ILS Far D/U above 200 feet is within -46dB for approaches to 200ft
  - SIS D/U for aircraft below 200 feet HAT is only less than 0 dB within ~0.5 miles from Localizer

VDB Desired / VOR Undesired

VDB Location Grid and VOR Location Grid

Scatter plots for VDB Location and VOR Location

Assumptions

- VOR antenna is 10 meters above the ground
- VDB antenna is 10 meters above the ground
- The airplane height above threshold = 60 ft
- The airborne antenna is 10 ft above the ground once the aircraft is rolling on the runway
- The runway is 2 nmi long
- The grid extends 3 nmi out from both ends of the runway and 4 nmi out from one side
- The aircraft's flight path begins 3 nmi ground distance from the runway end
- The VDB positions are every 0.2 nmi
- The aircraft steps 0.01 nmi
- The VDB positions less than 80 m from the aircraft flight path were moved in the Y direction so that there is 80 m separation
- The Undesired VOR had a frequency of 108.025 MHz.
- The Desired VDB had a frequency of 117.95 MHz.

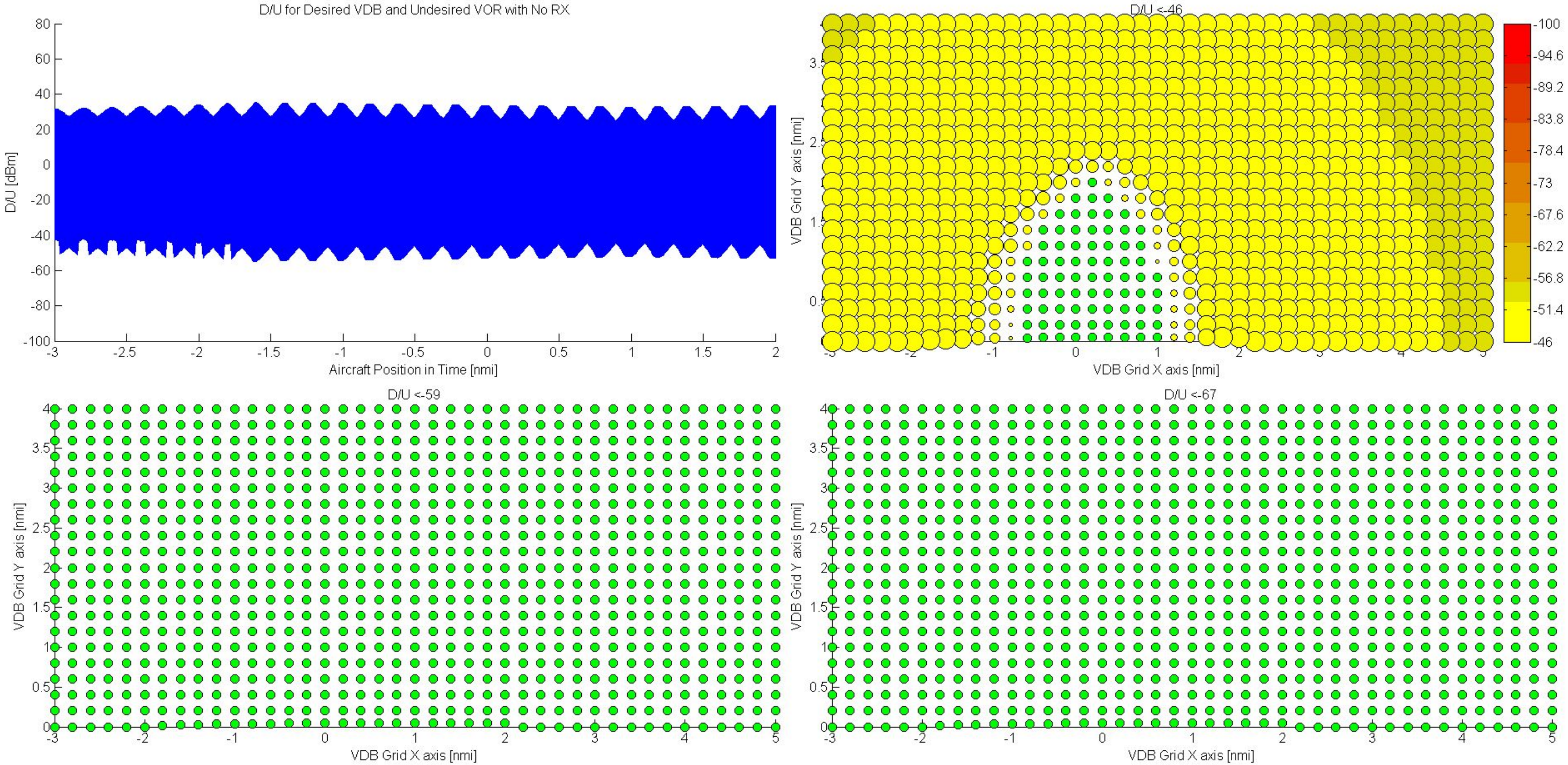
Formulas

- $EIRP_{VDB}$ = 47 dBm [1]
- $EIRP_{VOR}$ = 50 dBm [1]
- $G_{Transmitter,VDB}$ = 0 dB (Isotropic Antenna)
- $G_{Transmitter,VOR}$ = -4 dB in the “cone of silence” [1]
  6 dB elsewhere
- $FSPL_{VOR} = 20*\log_{10}(D) + 20*\log10(108) – 147.55$
- $FSPL_{VDB} = 20*\log_{10}(D) + 20*\log10(117.95) – 147.55$
- $P_{VDB} = EIRP_{VDB} + G_{Transmitter,VDB} + G_{Receiver,VDB} – FSPL_{VDB}$
- $P_{VOR} = EIRP_{VOR} + G_{Transmitter,VOR} + G_{Receiver,VOR} – FSPL_{VOR}$
- $D/Points = P_{VDB} – P_{VOR}$

[1] Source: Stefan Müller and Felix Butsch and Helmut Günzel, “Investigation of GBAS frequency protection requirements at third adjacent channel and beyond,” DFS Deutche Flugsicherung GmbH, Version 0.10, 13.11.2015

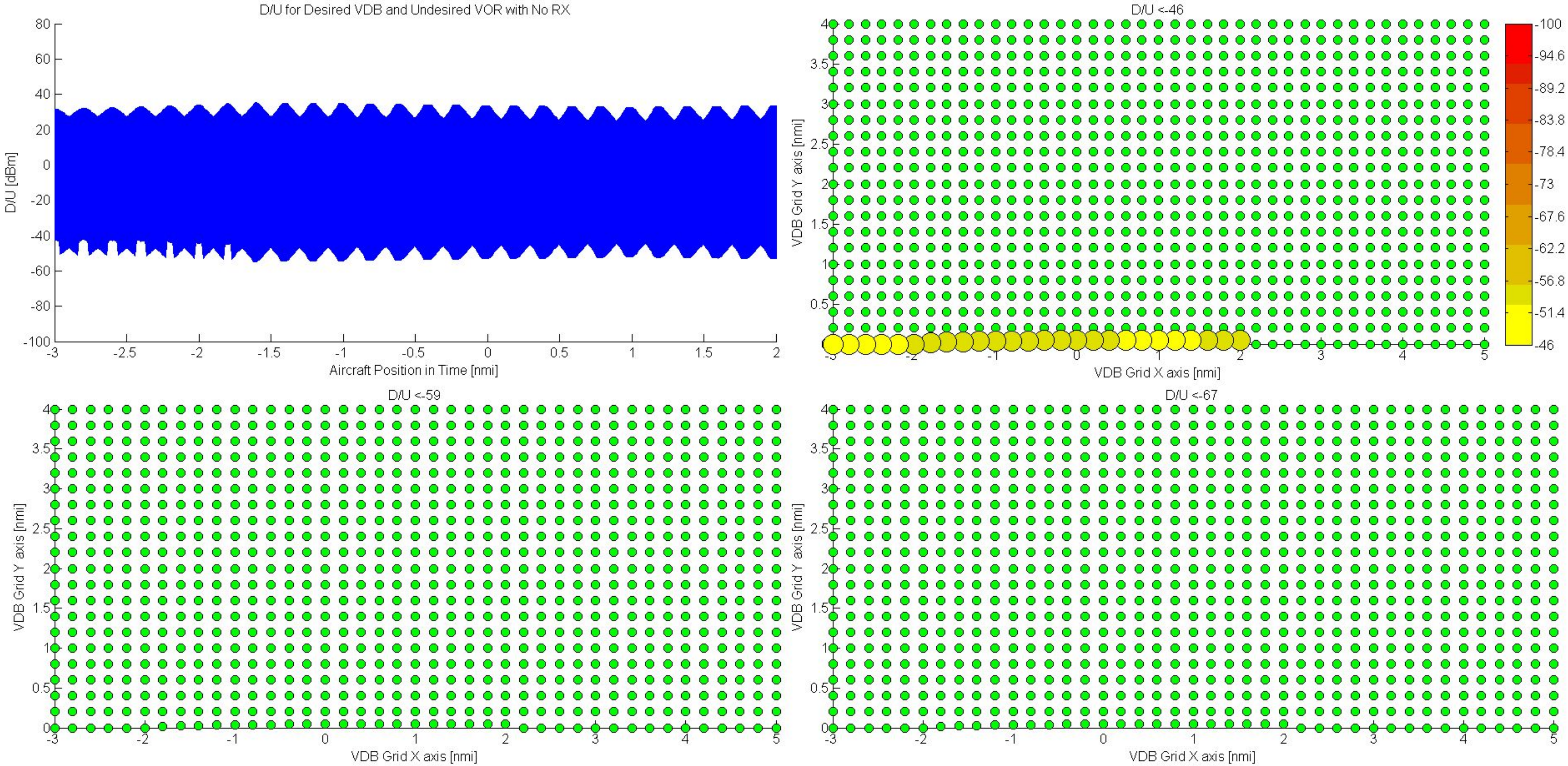
Full A/C Flight Path

1.35 Degrees, No Antenna, Points = VDB



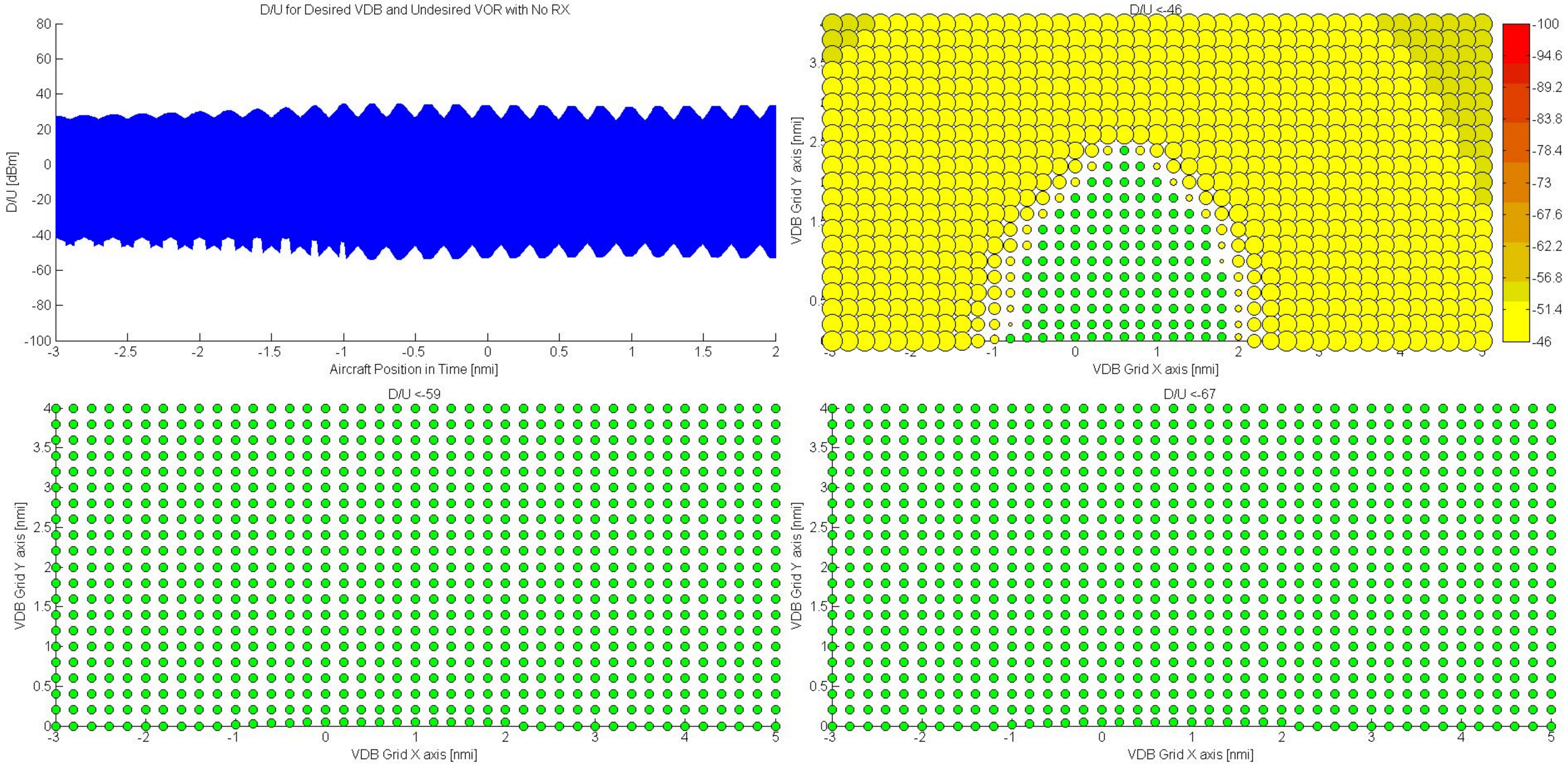
Note: The size for locations with the number of cases greater that 25 are clipped to improve readability

1.35 Degrees, No Antenna, Points = VOR



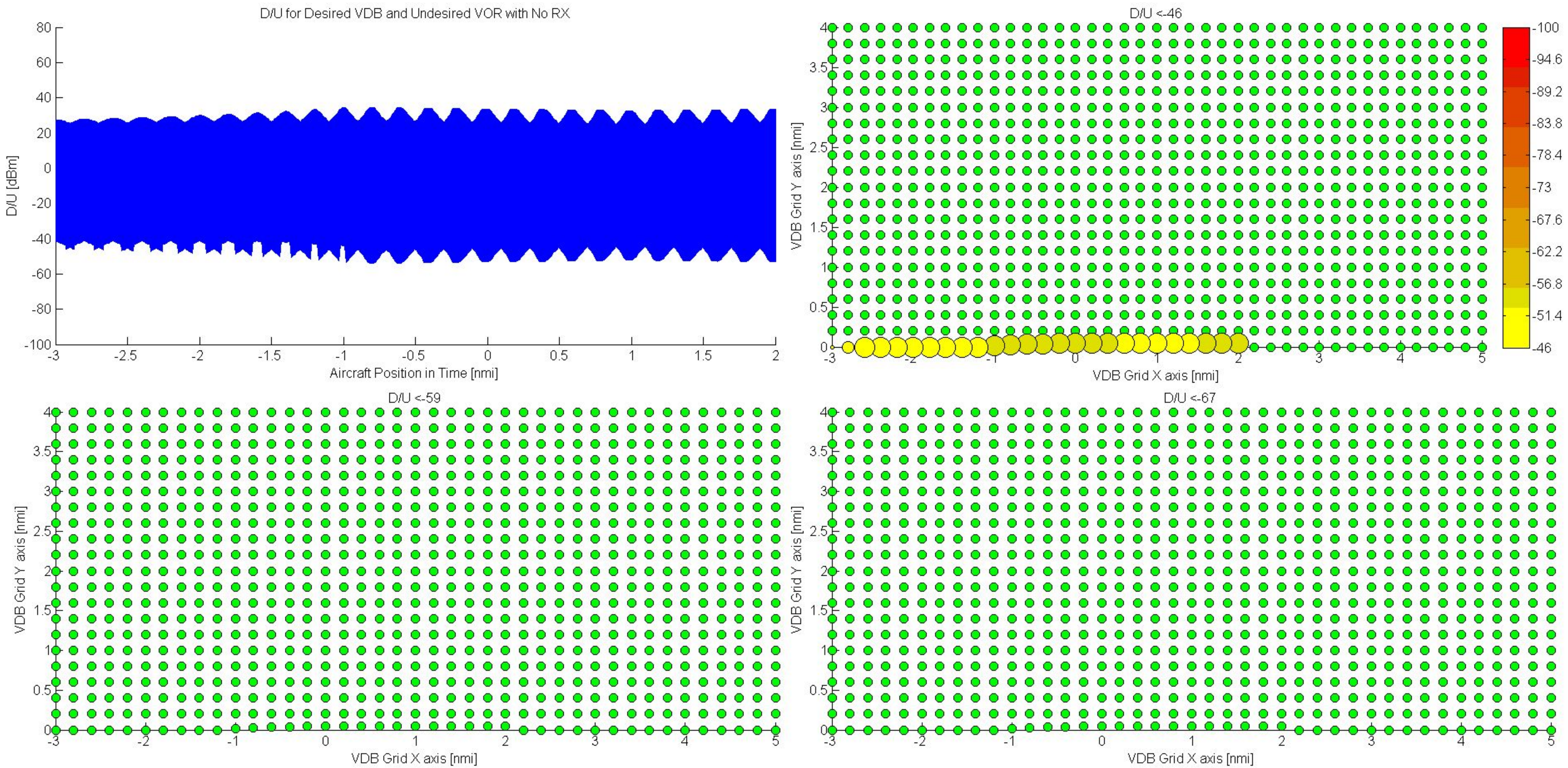
Note: The size for locations with the number of cases greater that 25 are clipped to improve readability

2.25 Degrees, No Antenna , Points = VDB



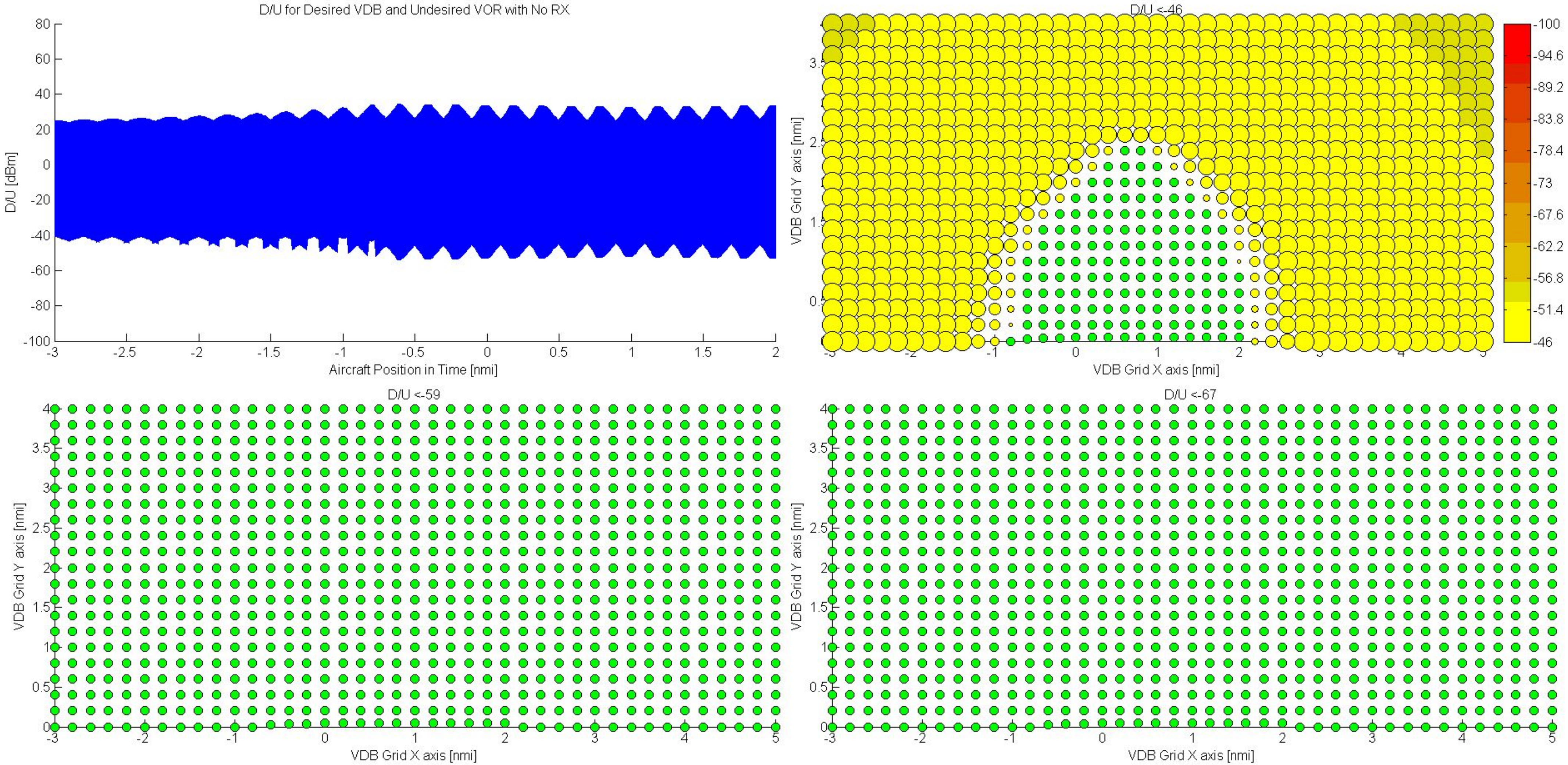
Note: The size for locations with the number of cases greater that 25 are clipped to improve readability

2.25 Degrees, No Antenna , Points = VOR



Note: The size for locations with the number of cases greater that 25 are clipped to improve readability

3 Degrees, No Antenna , Points = VDB



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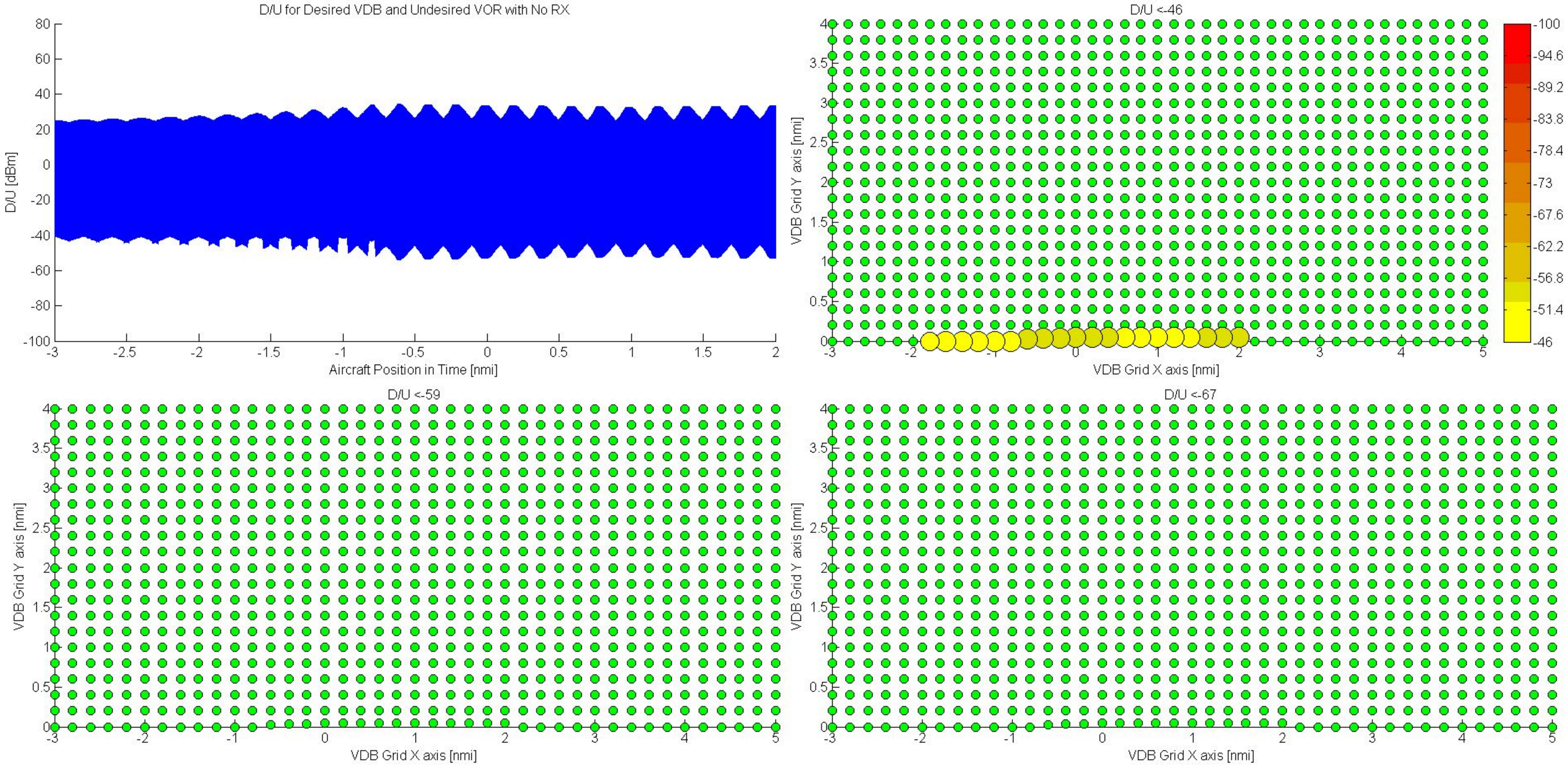

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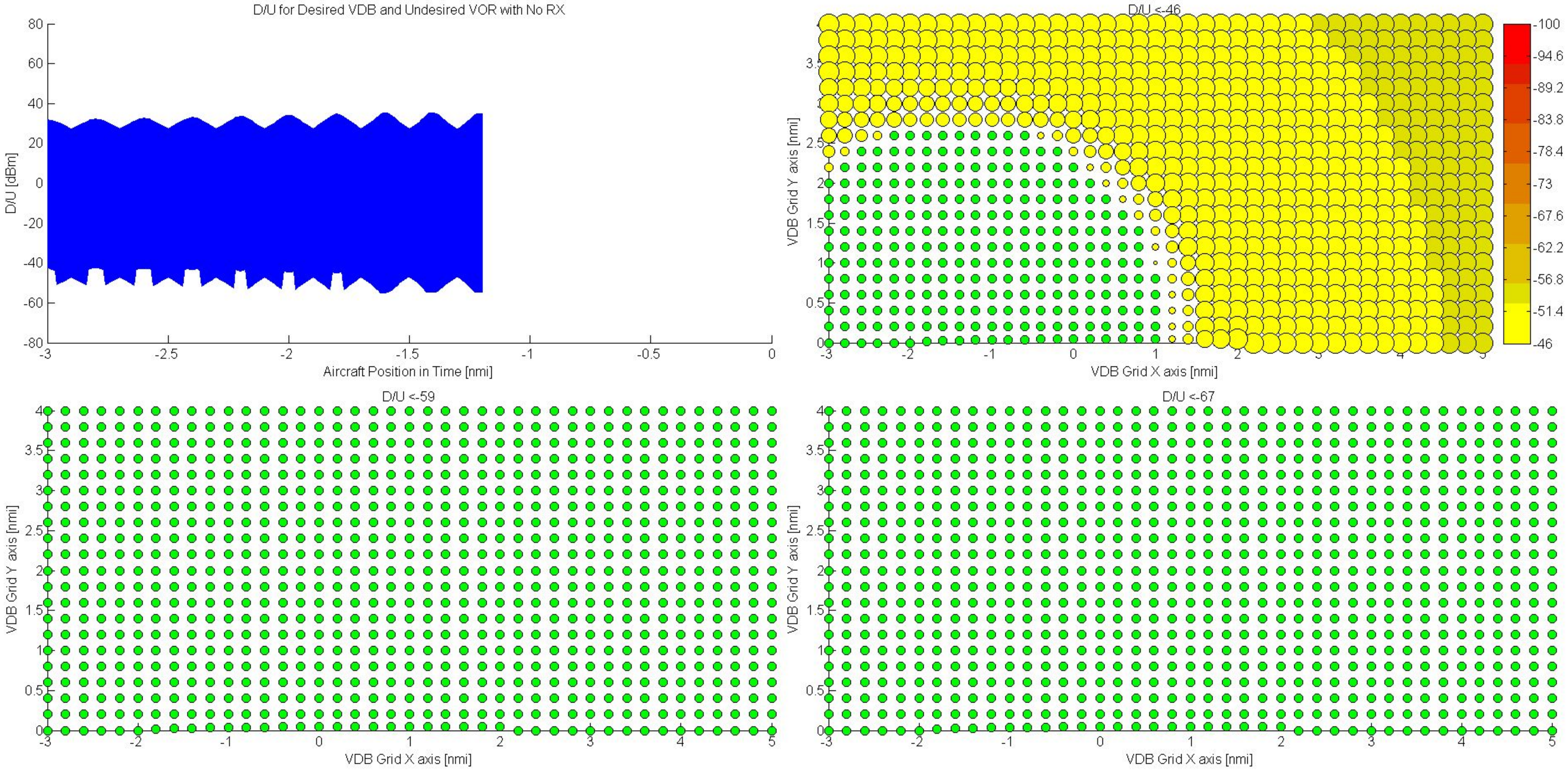
A/C Flight Path to 200 ft

A/C Flight Path to 200 ft

1.35 Degrees, No Antenna , Points = VDB



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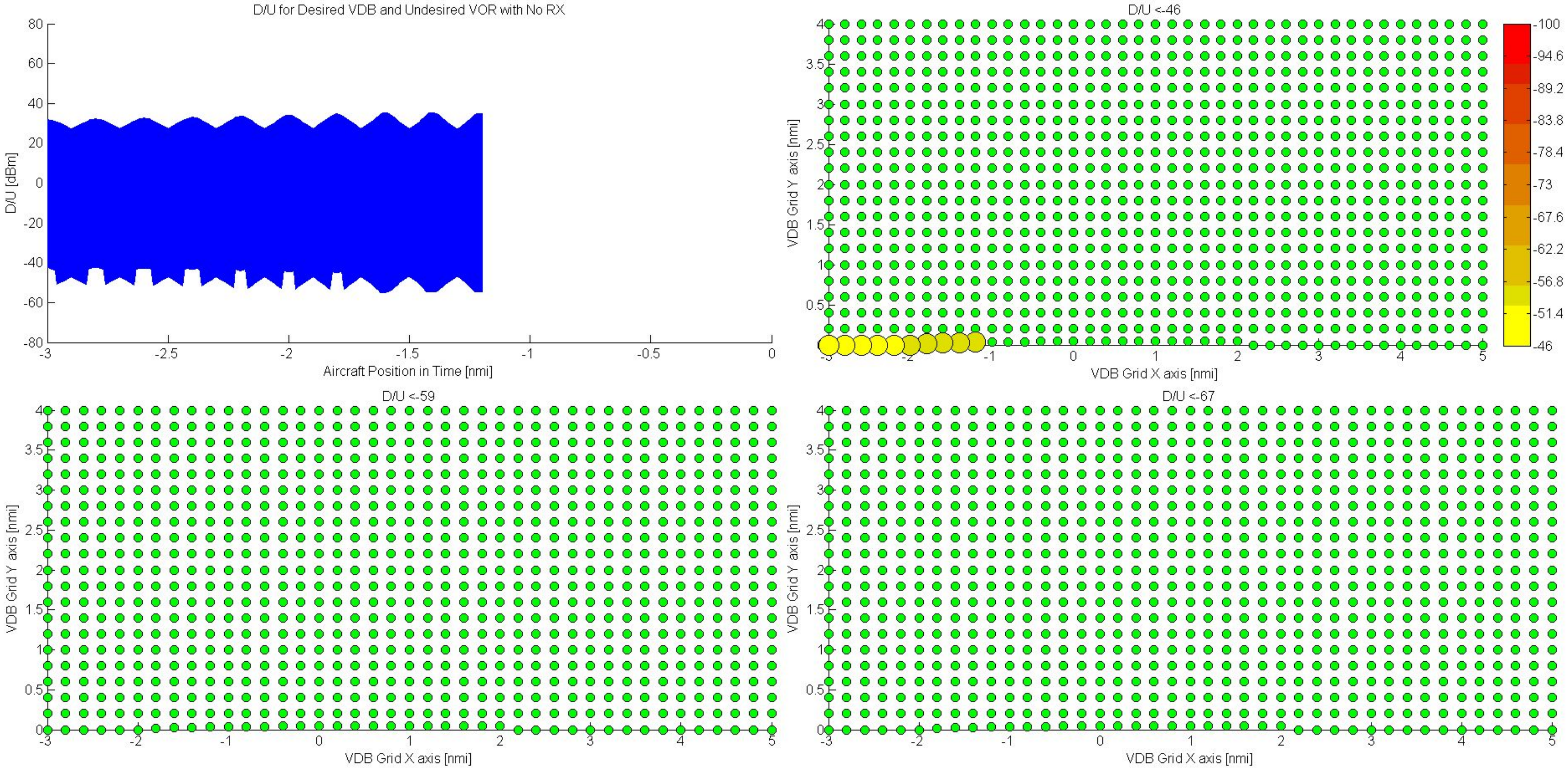
1.35 Degrees, No Antenna , Points = VOR



Note: The size for locations with the number of cases greater that 25 are clipped to improve readability

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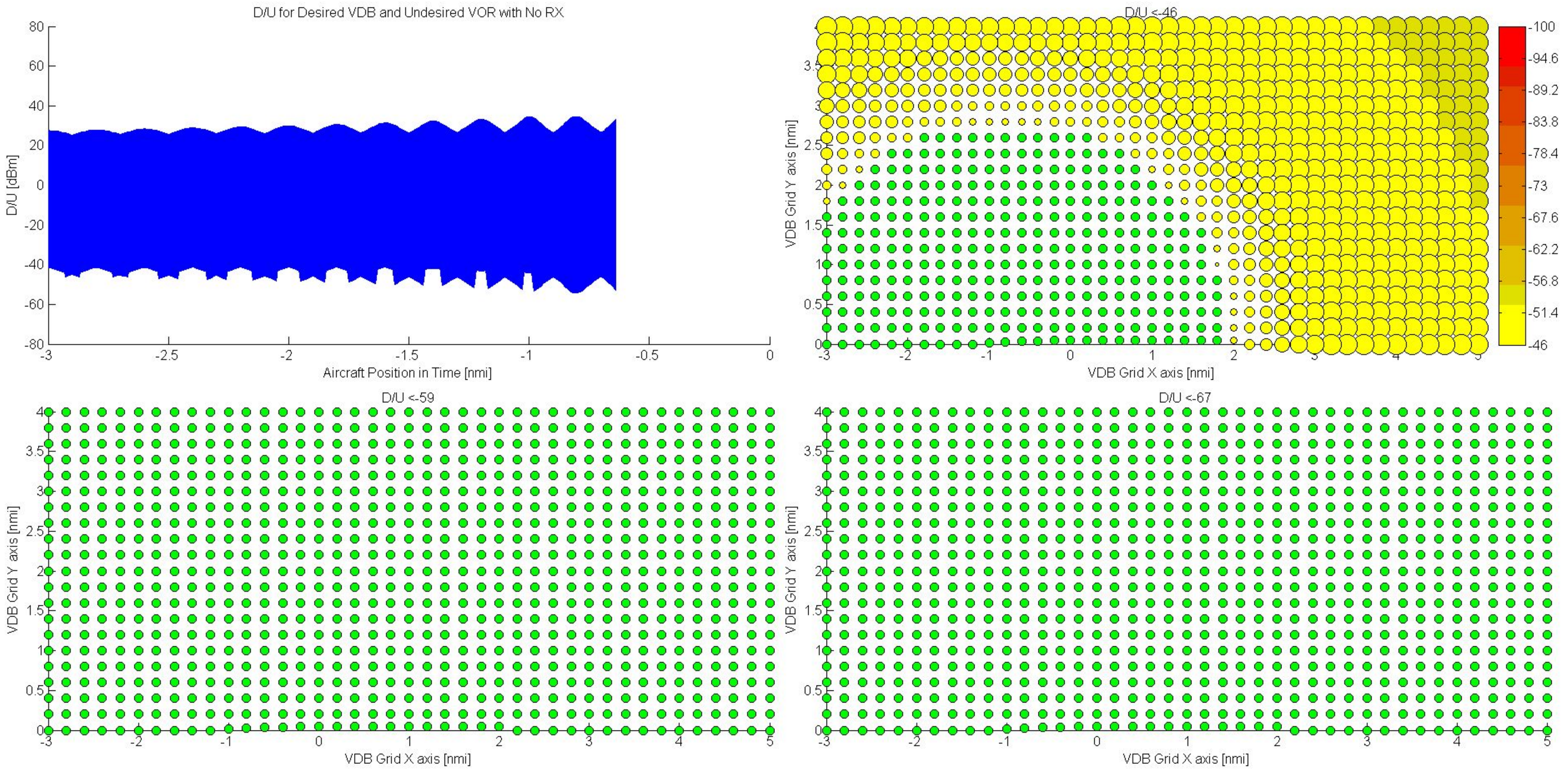

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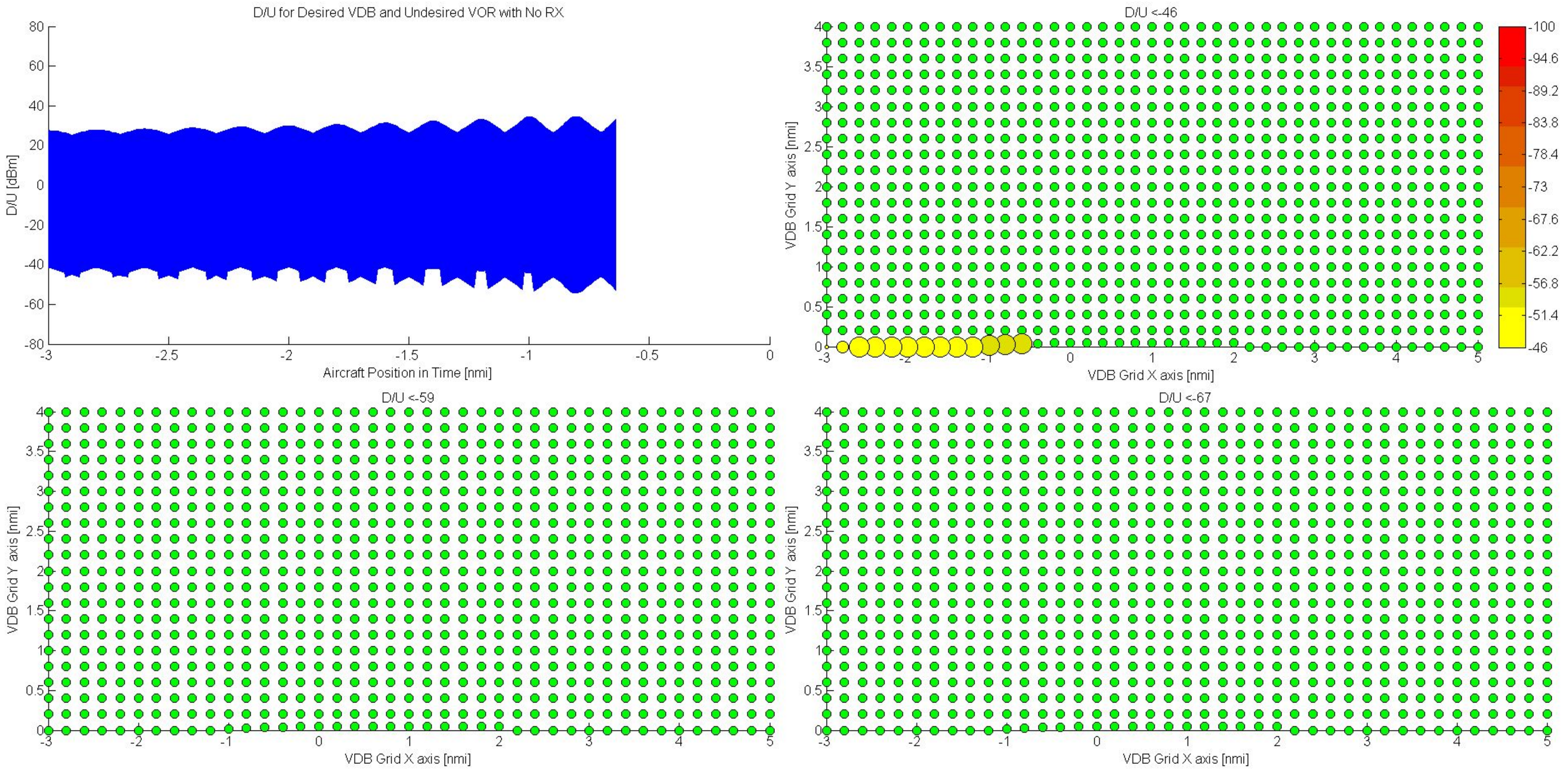

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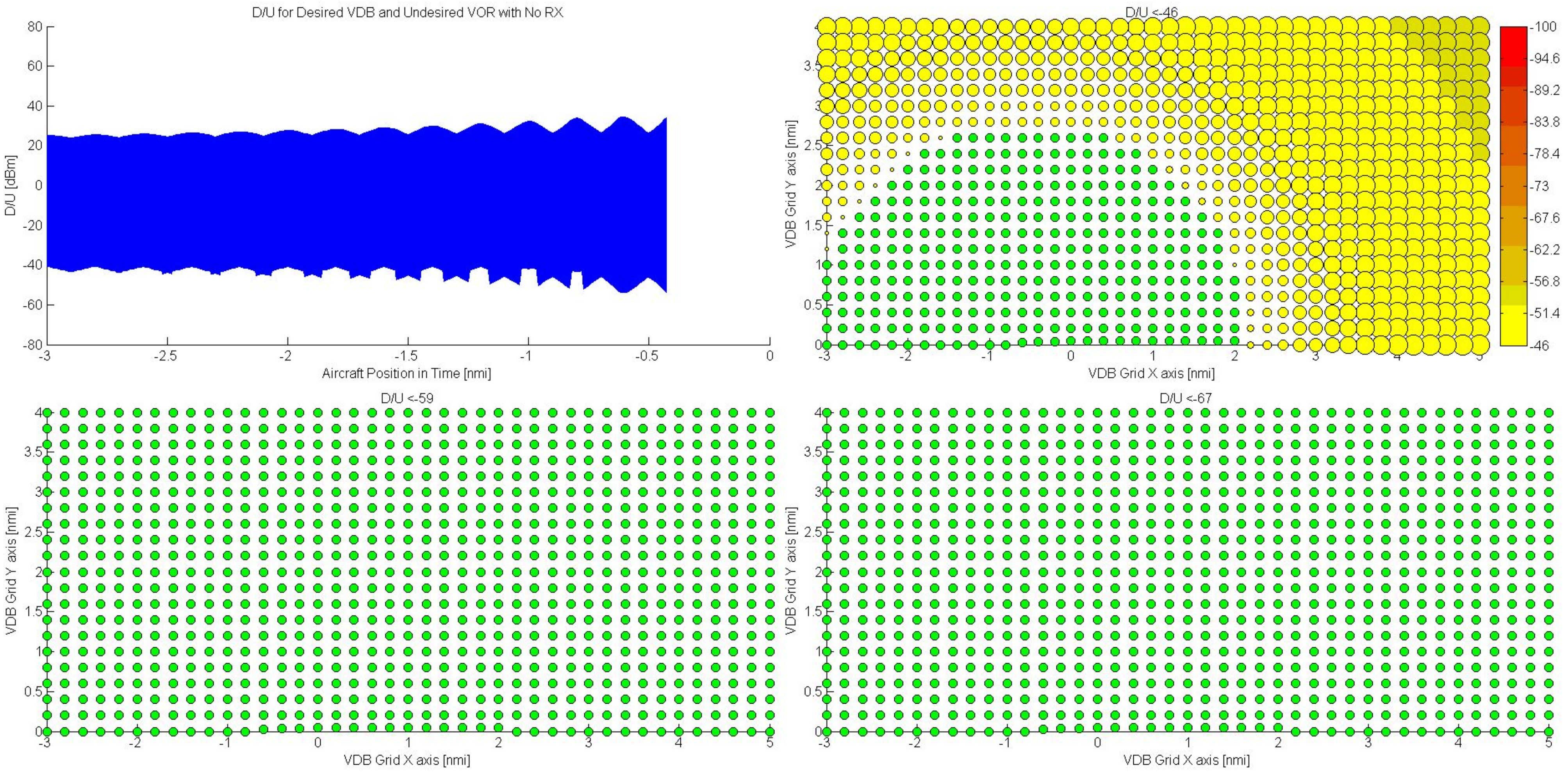

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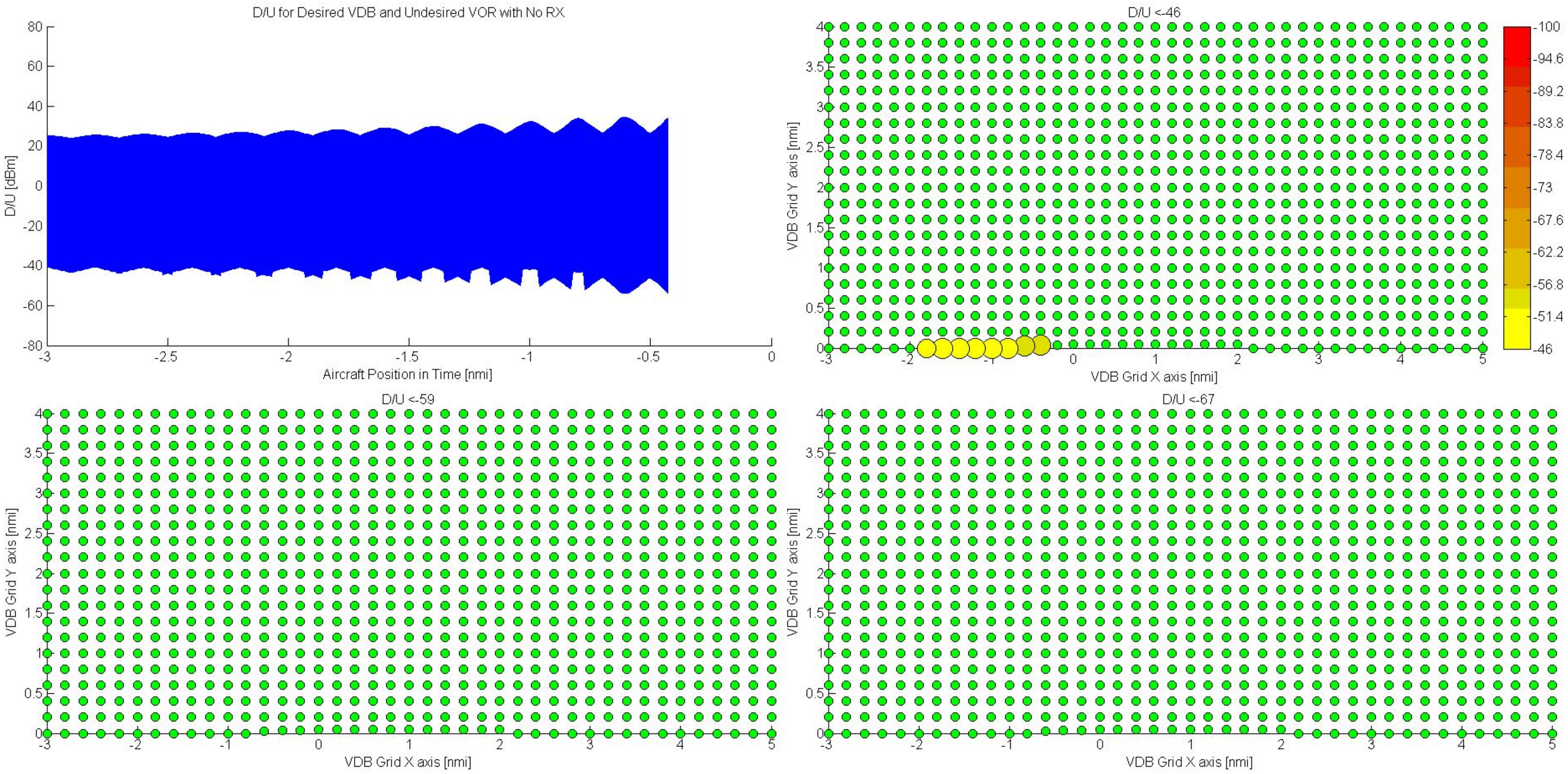
A/C Flight Path to 200 ft

3 Degrees, No Antenna , Points = VOR



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