ADVANCED TECH ENGINEERING INC.

Where Performance and Technical Integrity Matters

Communications IPT

Ku-Band Antenna UAV Optimization Trade Study – Preliminary

Rev D

February 17, 2009

Advanced Tech Engineering, Inc.

Frank A. Lucchesi

Contents

Purpose of the Study

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- Evaluate alternative locations for Ku-Band & UHF Antennas
- Rev D study addresses Ku-band antenna
- UHF trade study in progress

Caveats & Tasks

- The overall EM gain/coverage trades & coupling analyses are considered preliminary pending completion and commencement of the following tasks:
  1) Incorporate realistic UAV EM material properties

     Narrative: Present model assume perfect EM PEC conductor for UAV material which results in high number of multipath reflections and strong antenna-to-antenna coupling. This is worse case and provides pessimistic results. Need to update material EM properties ASAP.
  2) Validate Ku-band Antenna Model

     Narrative: An ideal Ku-band Omni-directional antenna is currently modeled. The Ku-band antenna provided by vendorX requires near field (Xfdtd) validation prior to importing into the overall far field (Xgtd) model. The antenna has greater directivity in theta than the theoretical model. However, the trend is valid which shows relative performance of locating the antenna at various locations
  3) Quantitative Gain / Coverage Assessment

     Narrative: The present PBS states unobstructed coverage which is unrealizable. We expect that the final PBS will quantify the requirement. Pending completion of 1 and 2 above, Gain / coverage Vs geometry will be assessed to close the link at specified ranges
  4) Locating other data link antennas

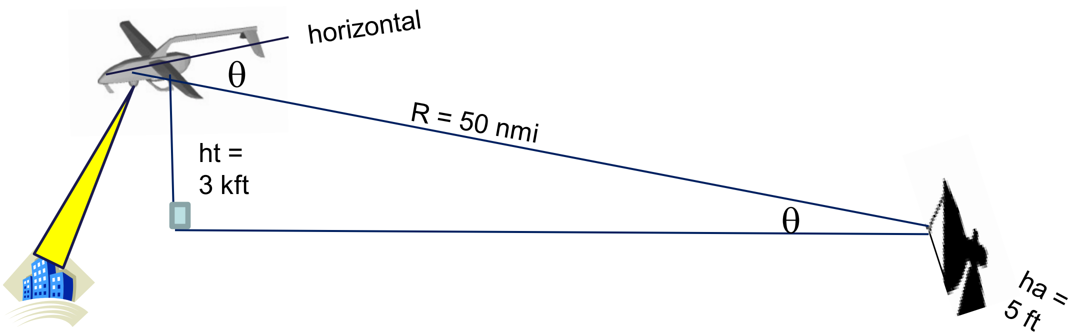
     Narrative: Trades to select location for the other antenna are pending the outcome of selecting Ku-band location. The antenna gain patterns over desired coverage (geometry driven) must support link closure at 50 nmi, 3 kft, in clear and rain environmental conditions for Ku-band and 100 nmi, etc. for UHF band per MEUAS RFP response.
  5) Complete coupling and commence co-site analysis

     Narrative: Coupling and co-site analysis is pending the selection of all data link antenna locations. This outcome of this analysis drives link analysis and data link design (e.g., filters, materials, etc.)

Top-level Take-Away

- The location recommended for Ku-Band antenna provides the best antenna gain over desired coverage volume for the Spiral-1 UAV configuration
- Additional information as defined in the caveat/tasks slide are required improve model fidelity and predictions for demo UAV and Tier II UAV
- Based on current EM analyses, the Spiral-1 UAV configuration does not support Tier II UAS link closure over required /assumed geometries at range and AGL altitude
- Path forward for Spiral-1 Demo UAV:
  - Choose acceptable location and carefully construct scenario based on physical and performance constraints
- Path forward for Tier II UAV:
  - Continue improving the fidelity of the EM models
  - Consider UAV modifications that supports data link apertures and closure requirements (e.g., two switched apertures)
  - Consider CDL increment III transmit power improvements
  - Custom electronically steerable directional antenna

UAV to GDT Geometry
50nmi slant range, 3 kt AGL altitude



<u>Finding Target Elevation θ</u> $_t$ (Flat Earth Calculation)

Sin θ = $(h_t - h_a)/R$

θ = Arcsin (3000 ft/6080 ft /nmi)/50 nmi

= 0.57 degrees

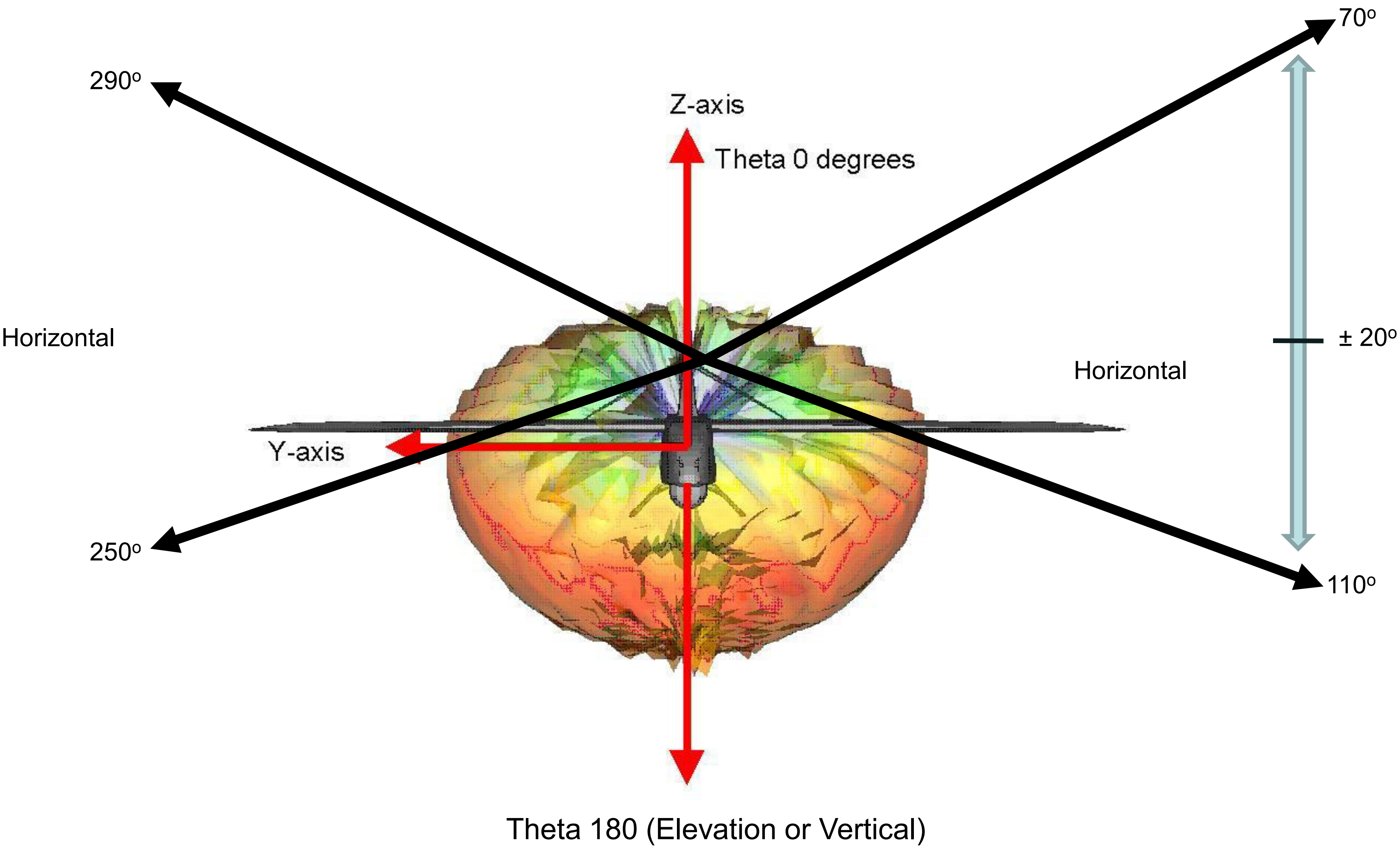
Aircraft level flight (e.g., no roll or pitch) @ 50 nmi slant range and 3 kft Altitude AGL

= - 0.57° below horizontal axis

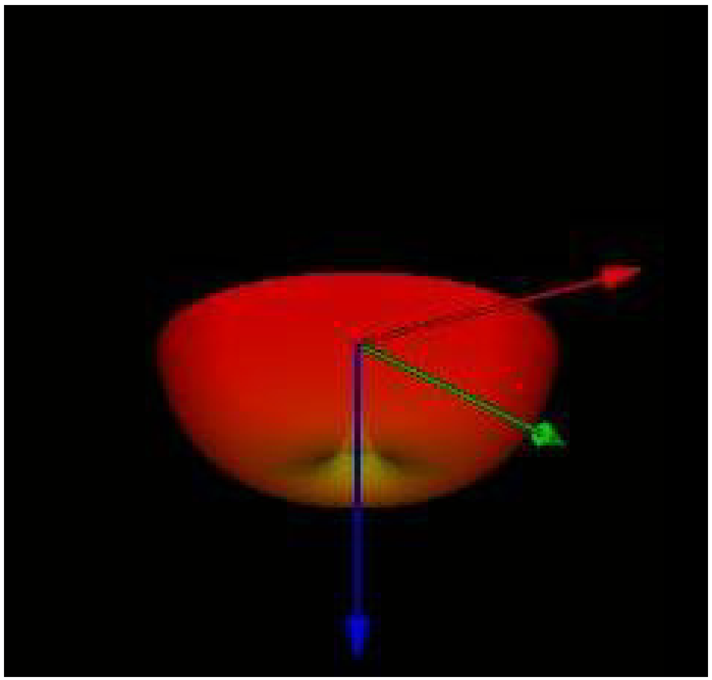
Aircraft normal flight (assumes 20° max roll angle during orbits or flight conditions)

= +19.43° (above horizontal axis) to 20.57° (below horizontal axis)

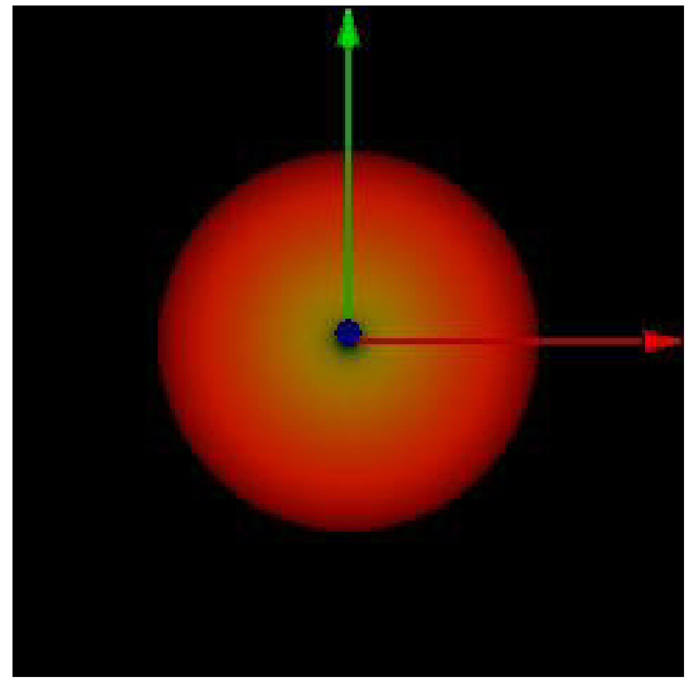
Reference Diagram



Ku-Band
Ideal Monopole Transmitter in Free Space
“No Platform EM Interaction”

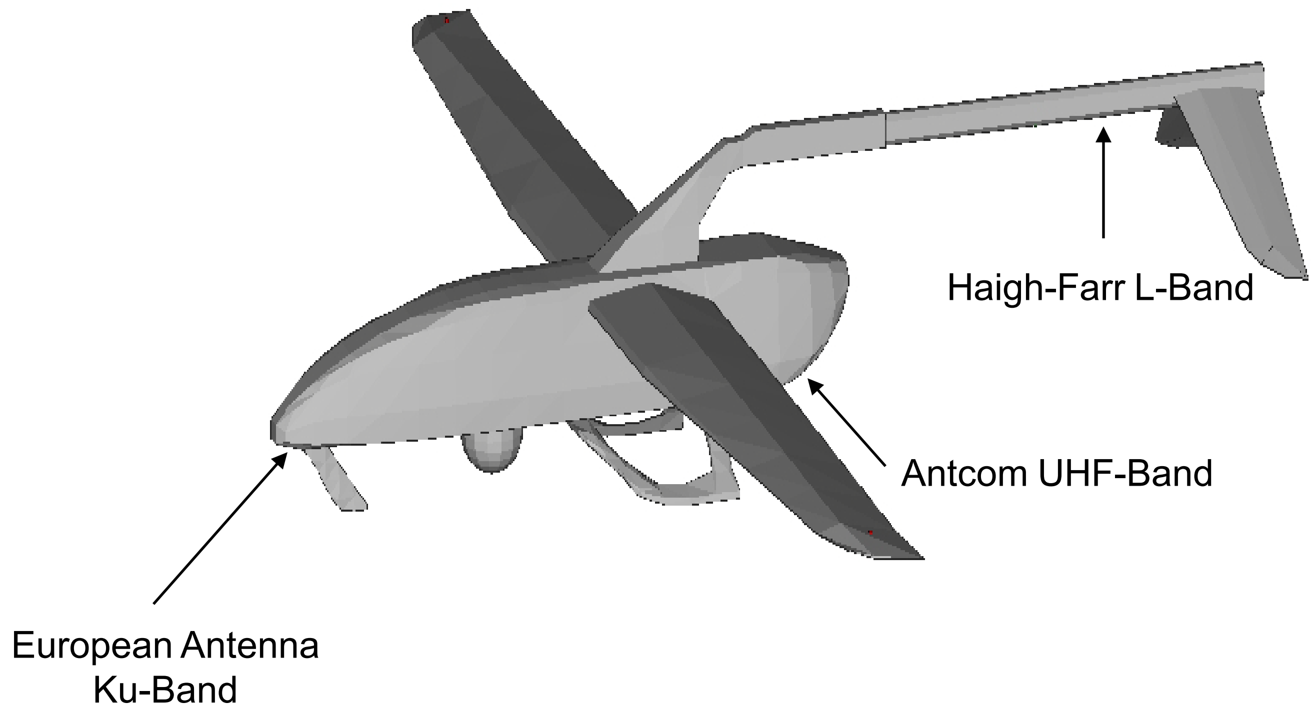


Side view of monopole radiation pattern.

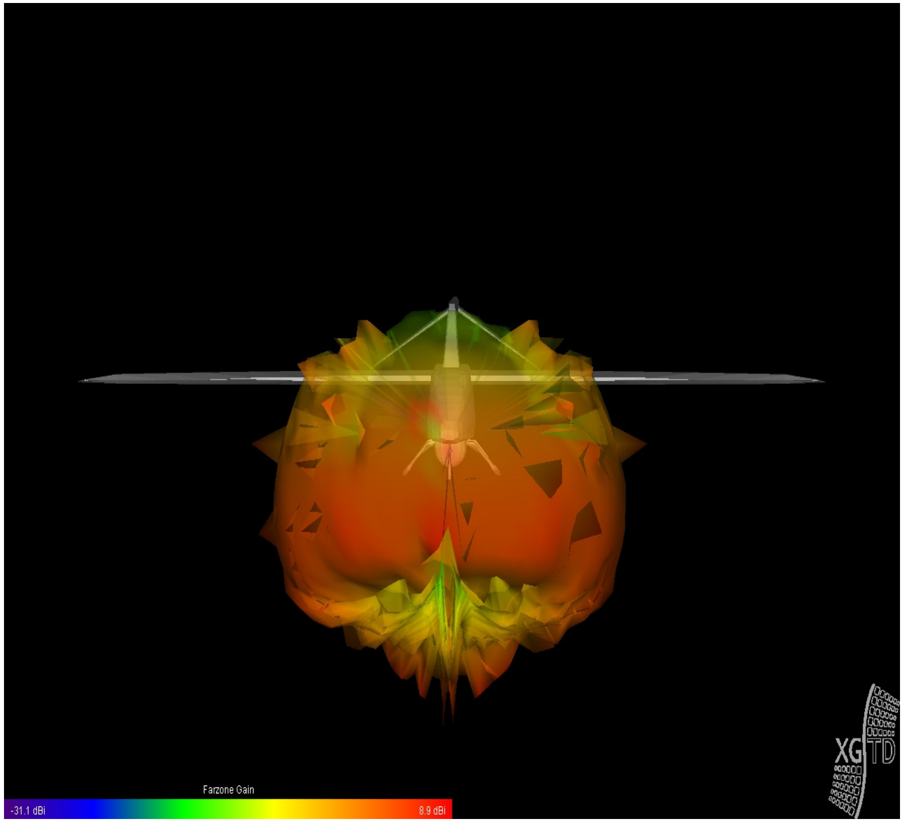


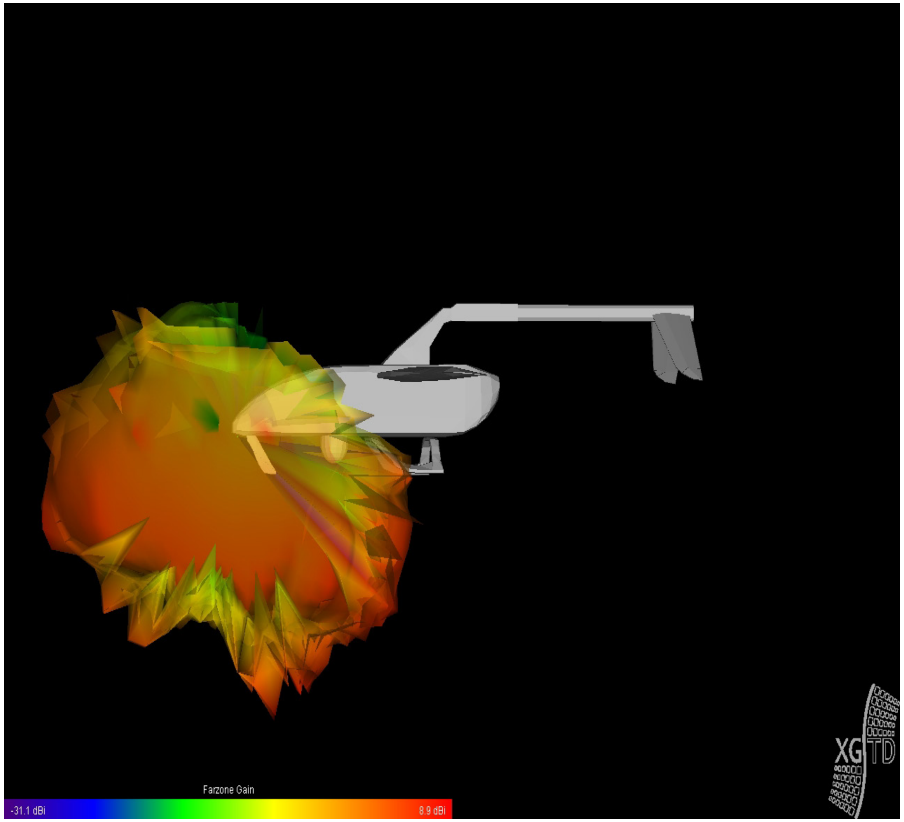
Bottom view of monopole radiation pattern.

Recommended Antenna Placements

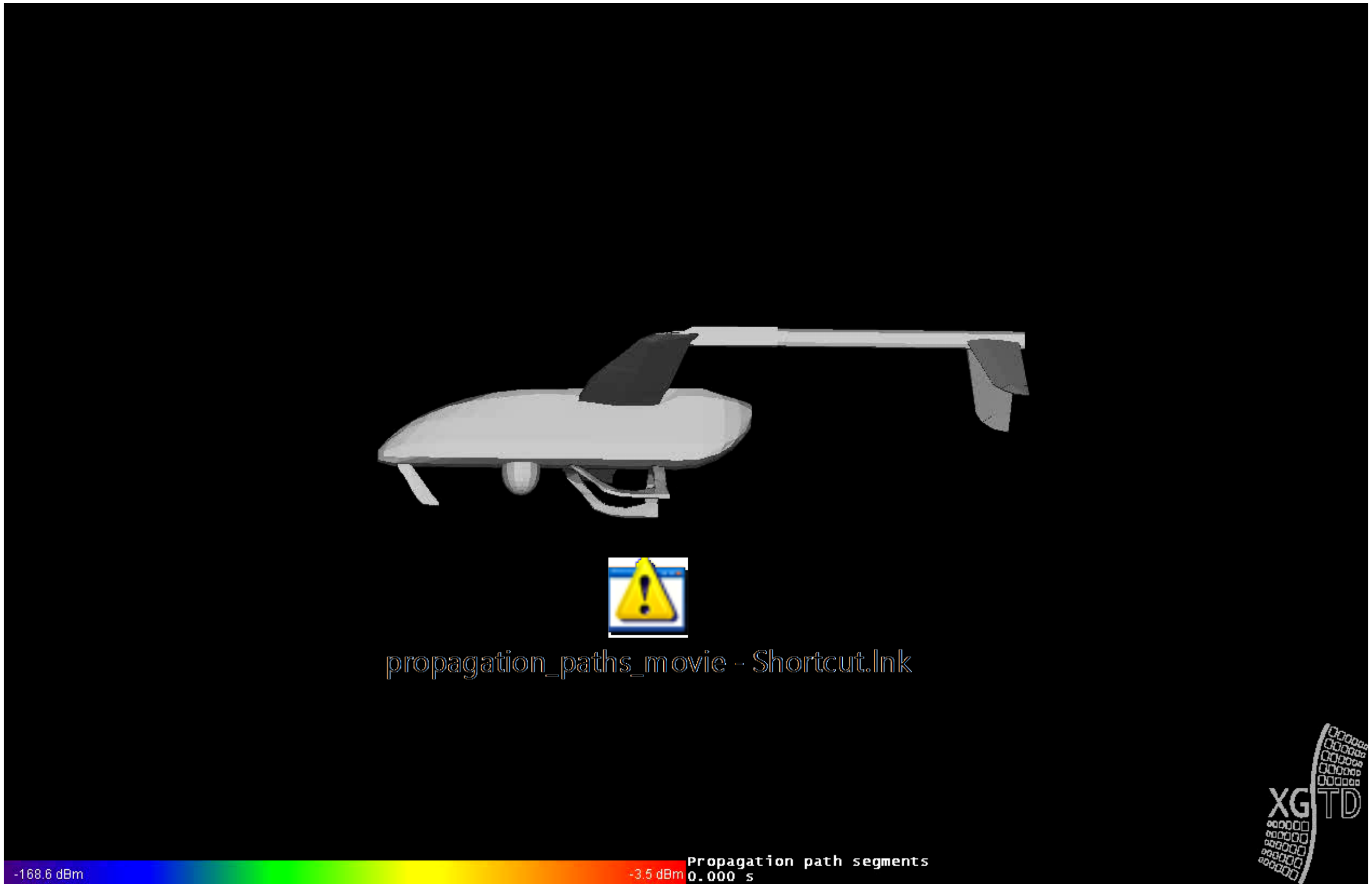


Ku-Band Antenna Placement on Front

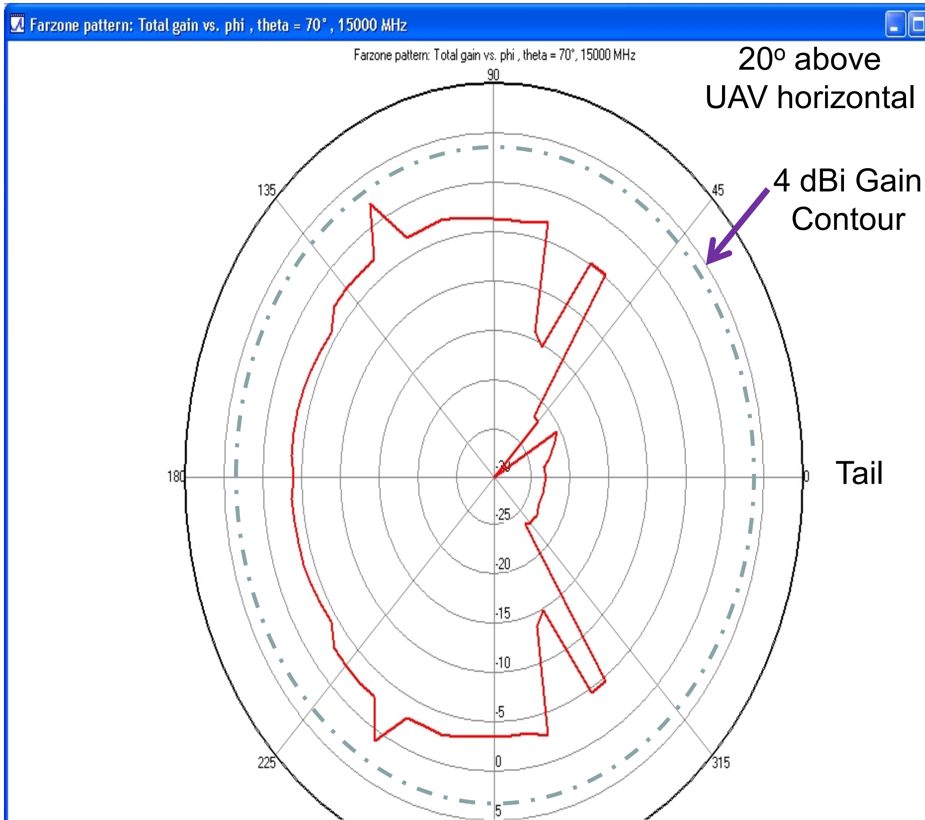




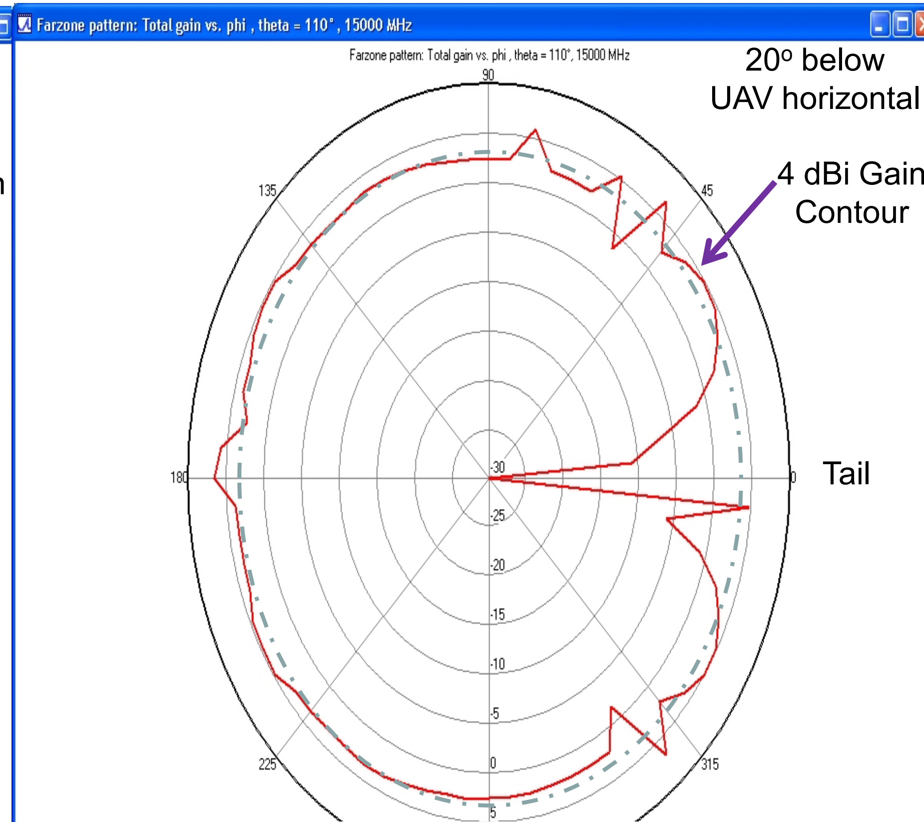
Movie Illustrating RF Propagation Paths



Ku-Band Antenna Placement on Front – Pitch / Roll 20° Cut



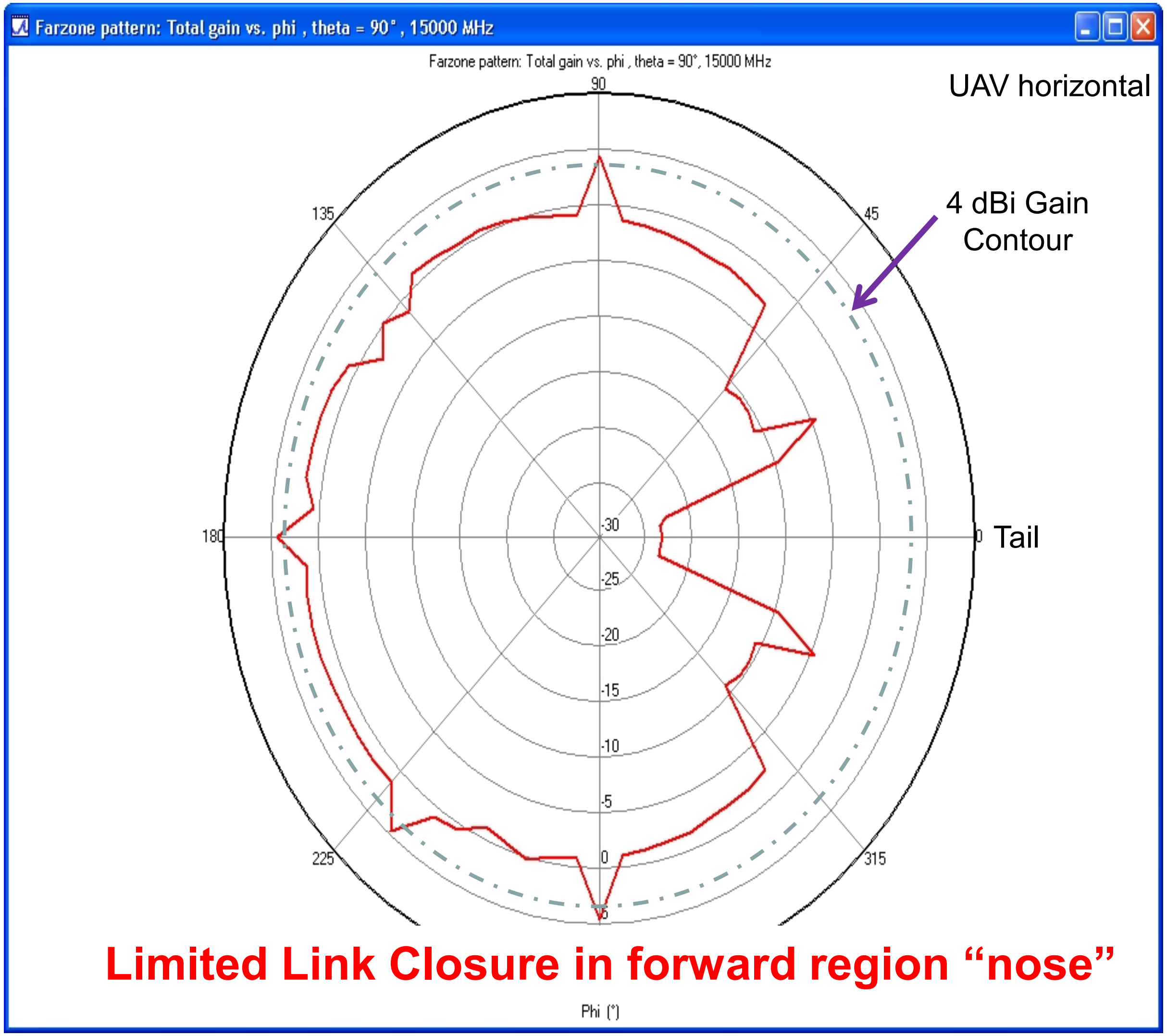
No Link Closure



Link Closure over 95% over region

Antenna Gain > 3.4 dBi to close links at 50 nmi and 3 kft (95% availability, clear environmental conditions)

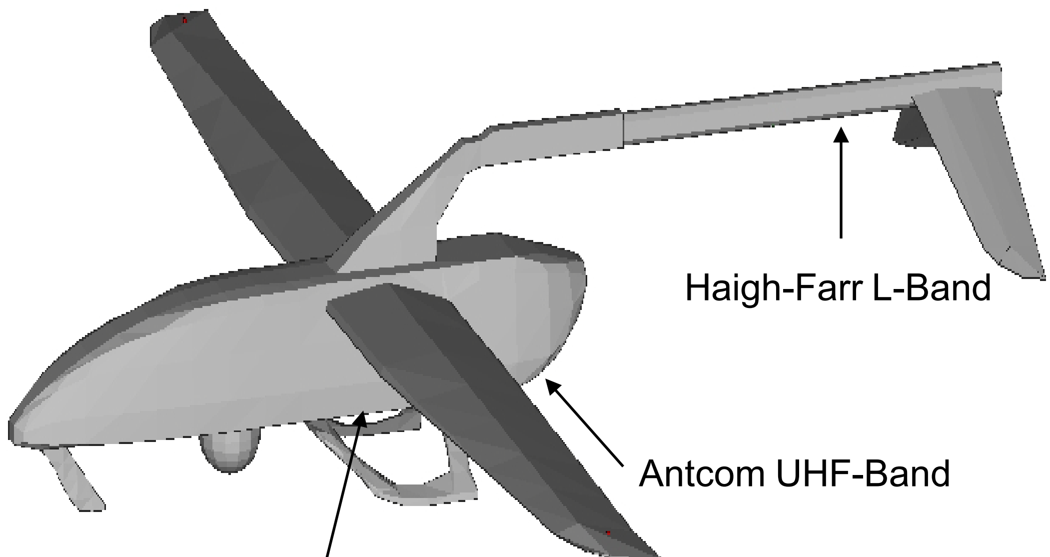
Ku-Band Antenna Placement on Front – Horizontal Cut



Limited Link Closure in forward region "nose"

Cautionary Note:
Gain > 4 dBi implies multiple platform reflections occurs which results in greater inter-symbol interference

Alternative Ku-Band Antenna Placement Between the Skids



Ku-Band Antenna Placement Between Skids

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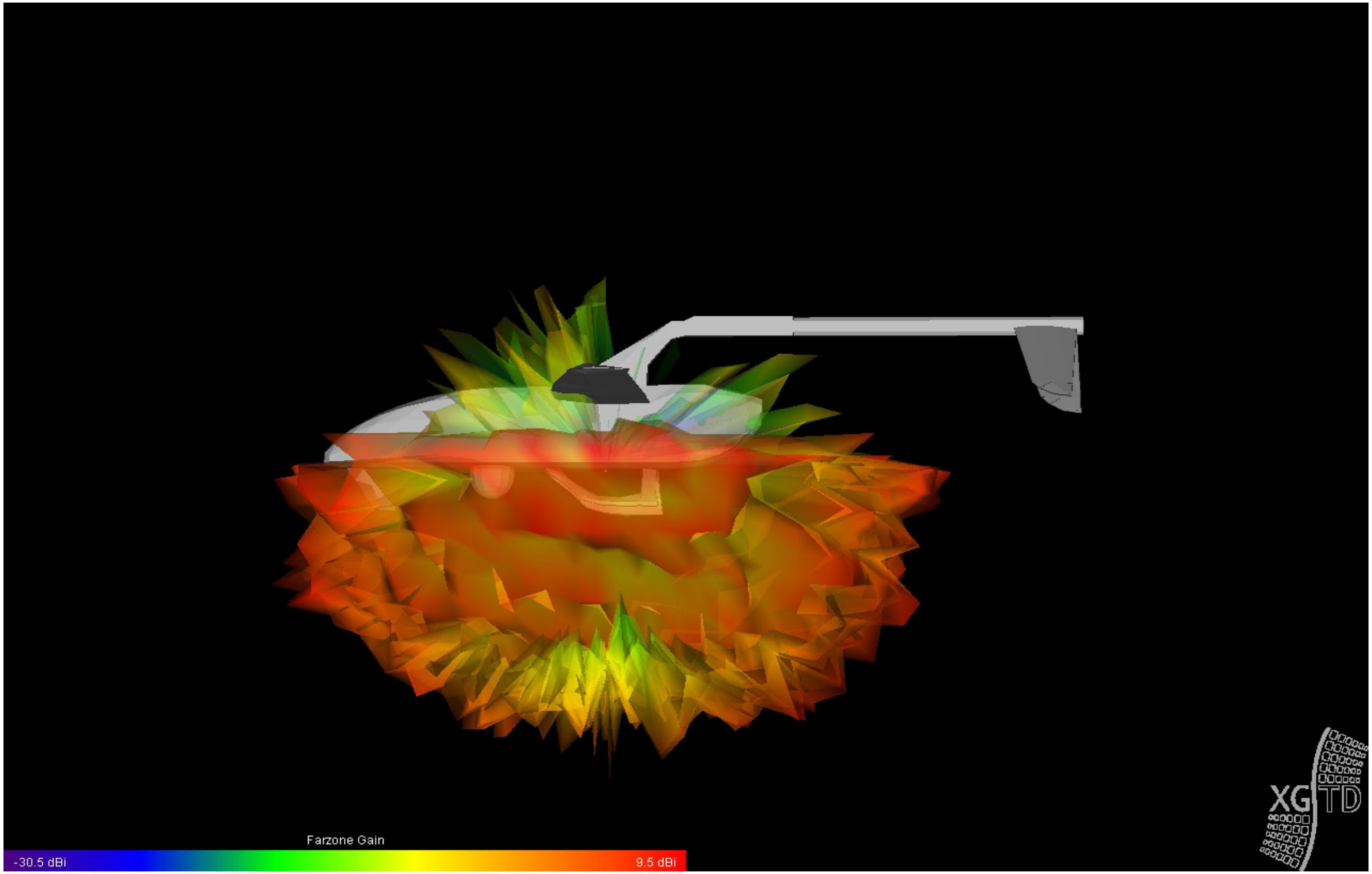
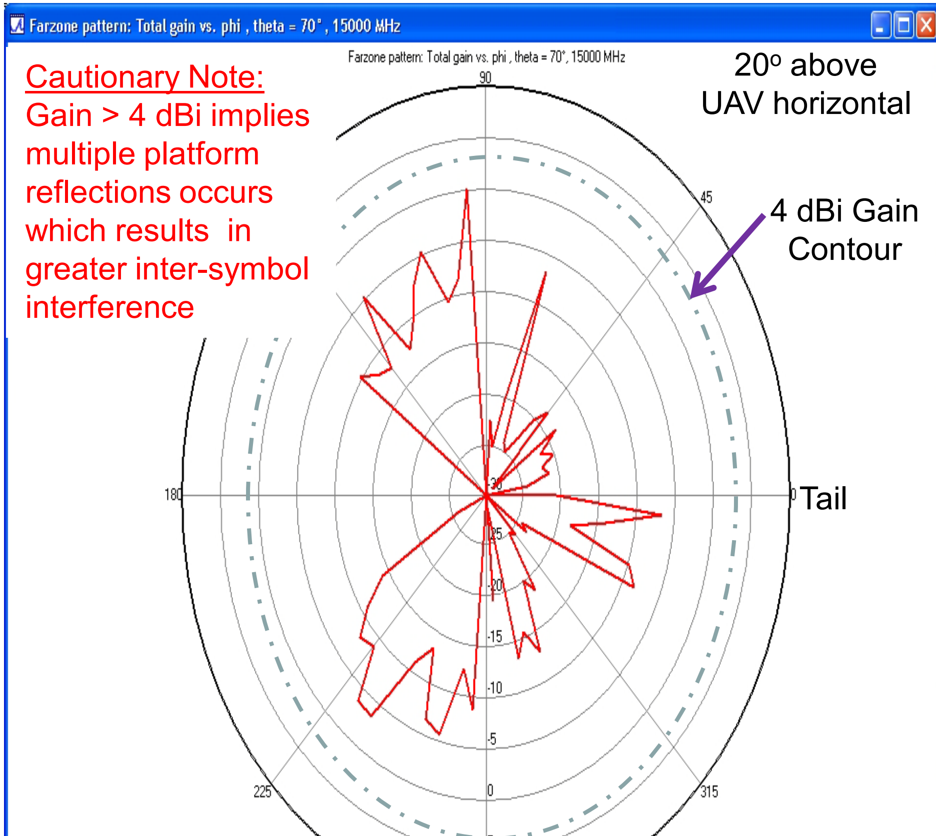
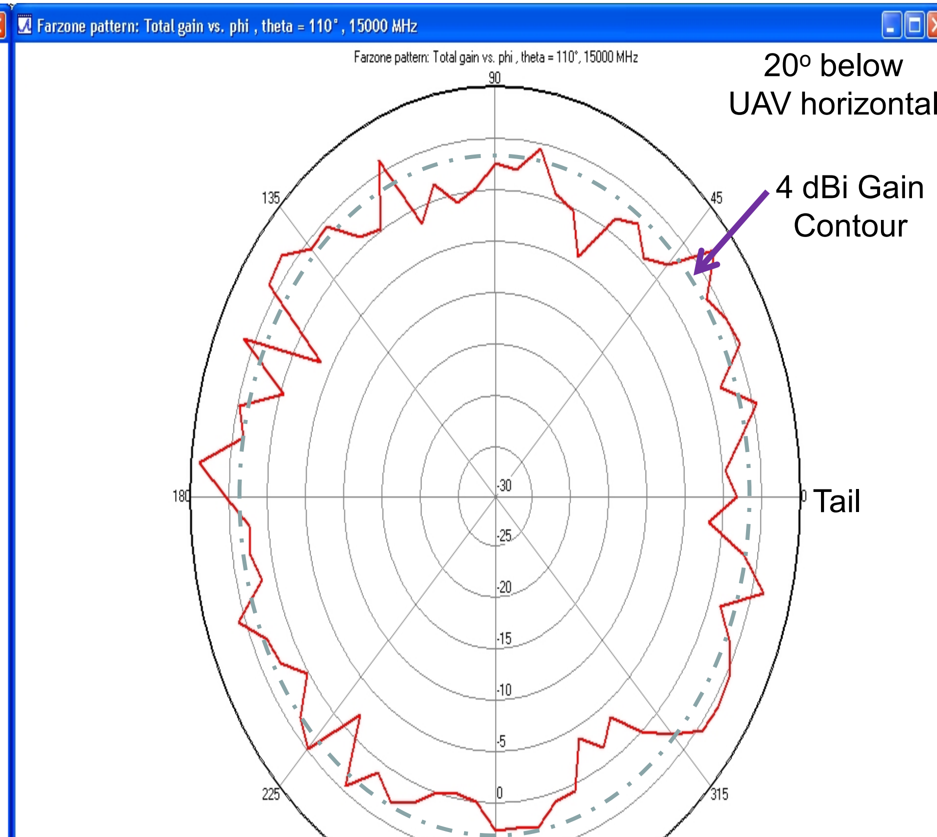


Ku-Band Antenna Placement Between Skids – Pitch / Roll 20° Cut



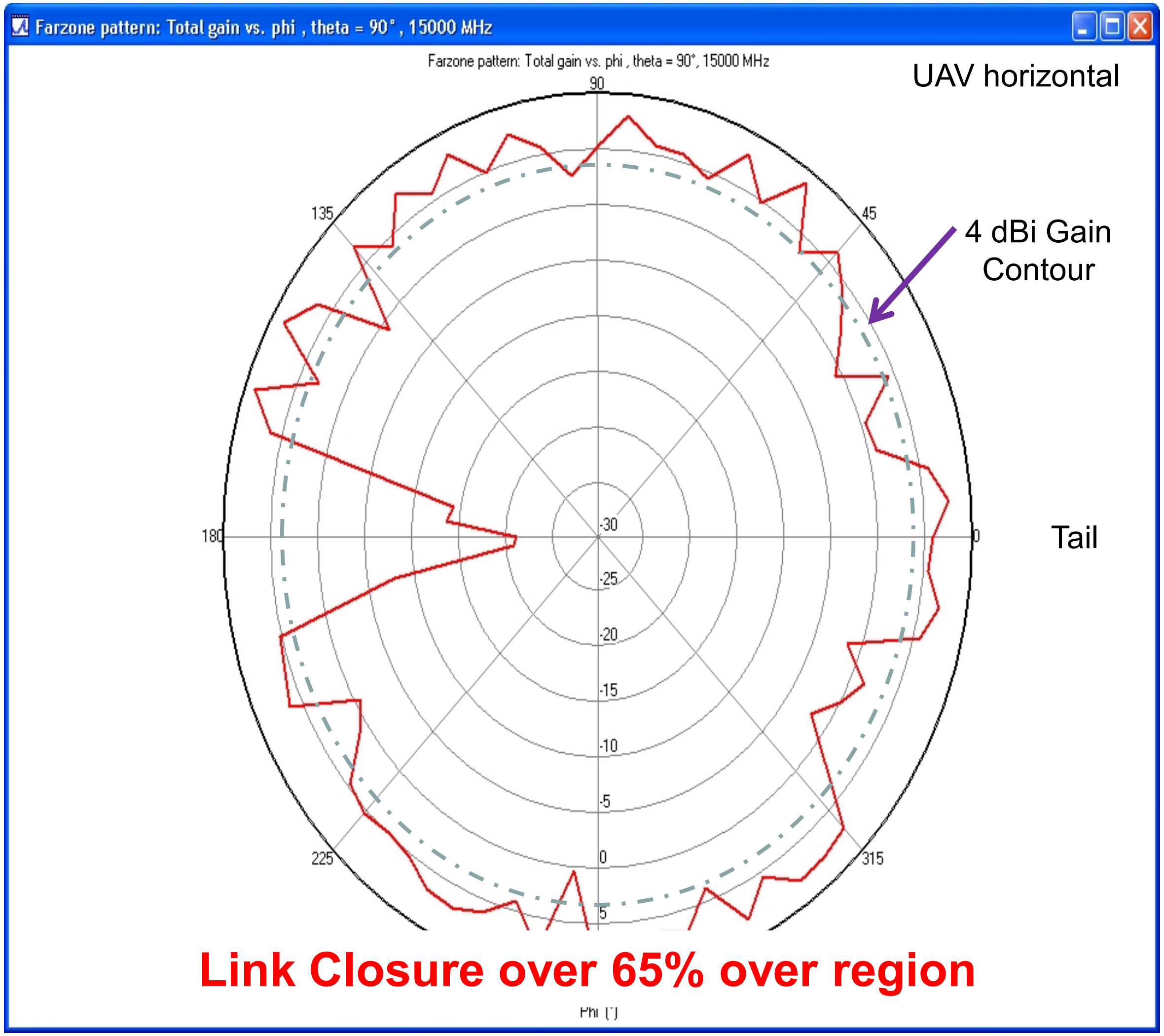
No Link Closure over region



Link Closure over 45% over region

Antenna Gain > 3.4 dBi to close links at 50 nmi and 3 kft (95% availability, clear environmental conditions)

Ku-Band Antenna Placement Between Skids – Horizontal Cut



Cautionary Note:
Gain > 4 dBi implies multiple platform reflections occurs which results in greater inter-symbol interference

Alternative Ku-Band Antenna Placement on Top of Aircraft Fuselage

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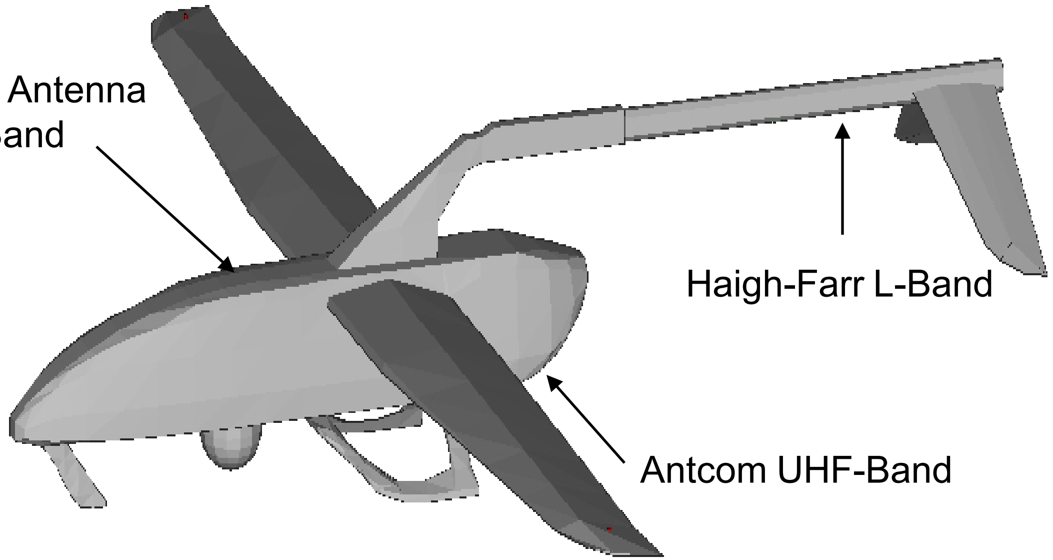

Ku-Band Antenna Placement on Top of Aircraft Fuselage

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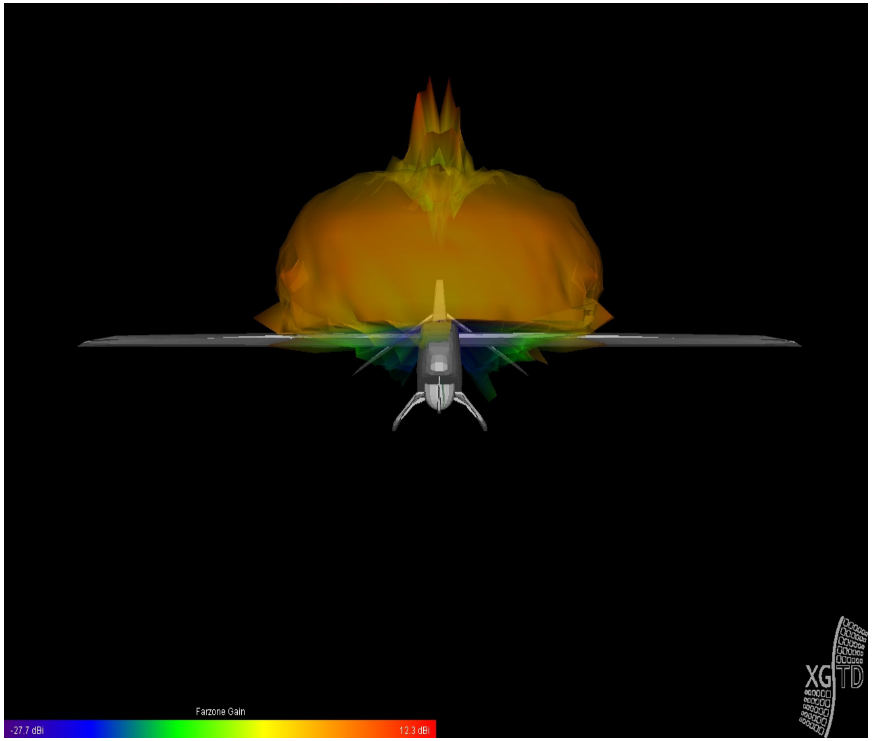
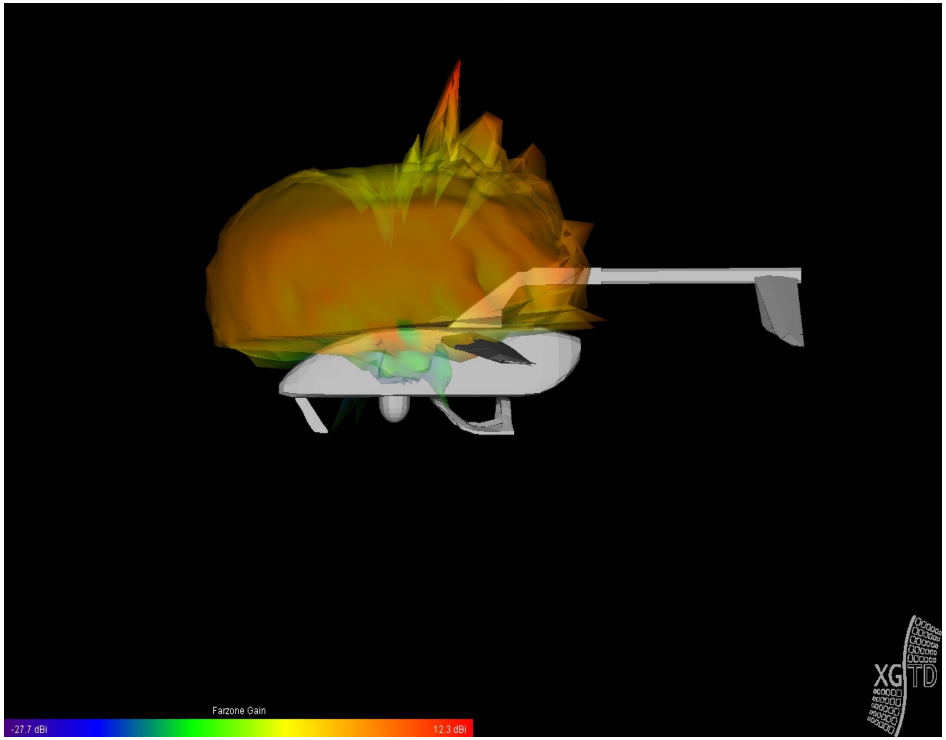
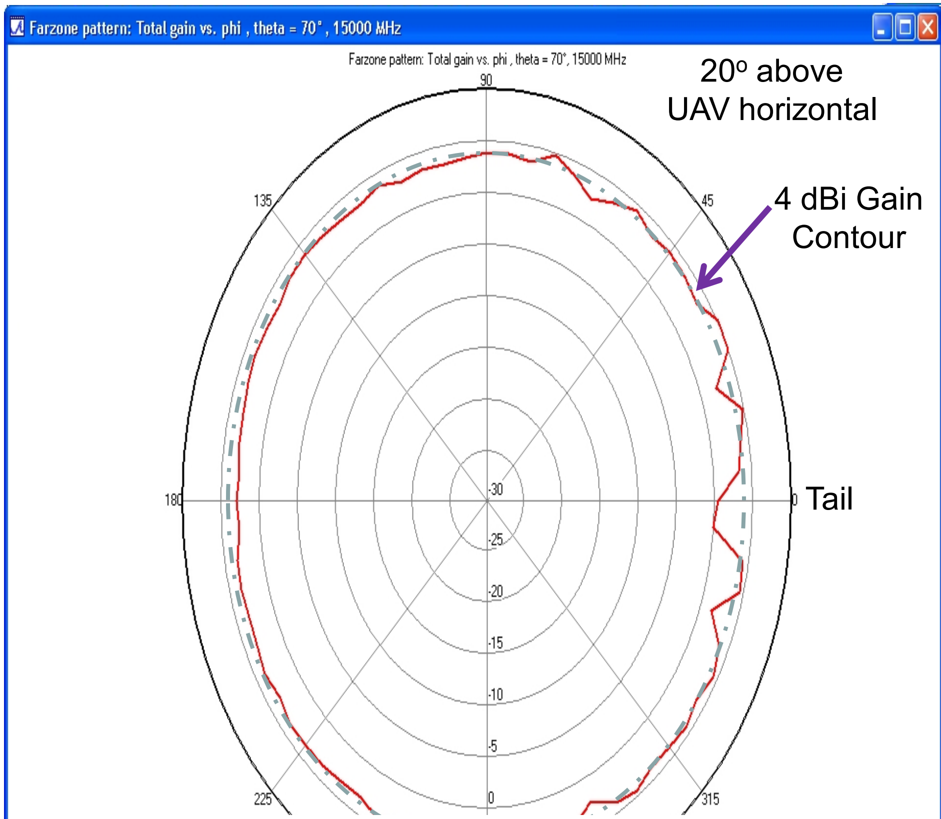
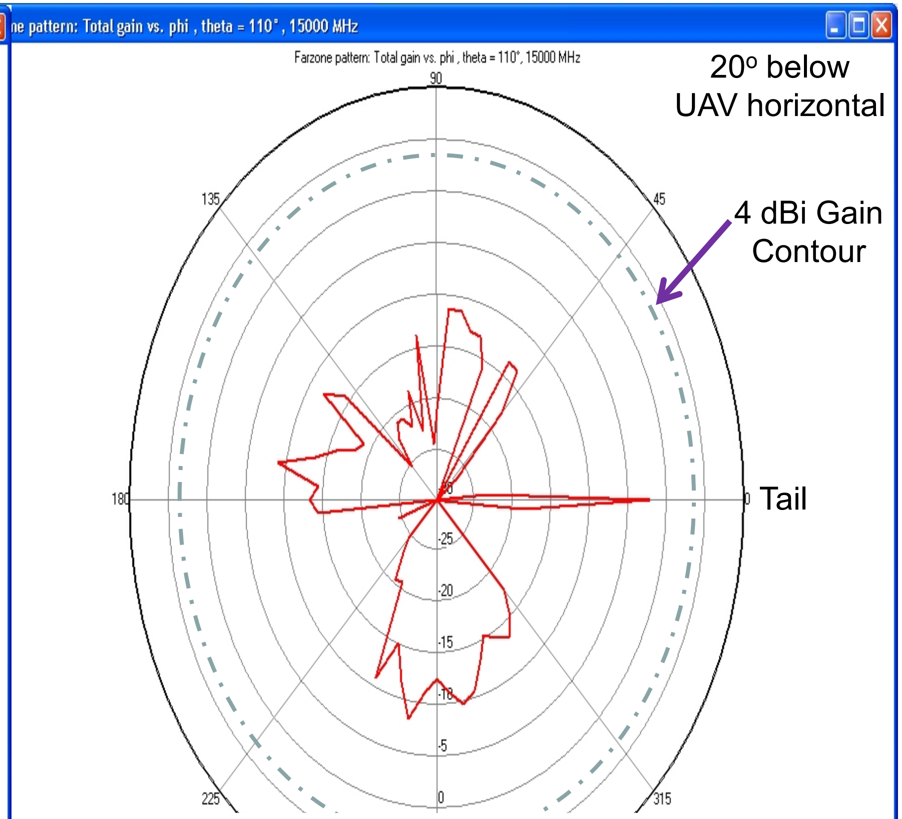




Ku-Band Antenna Placement on Top of Aircraft Fuselage – Pitch / Roll 20º Cut



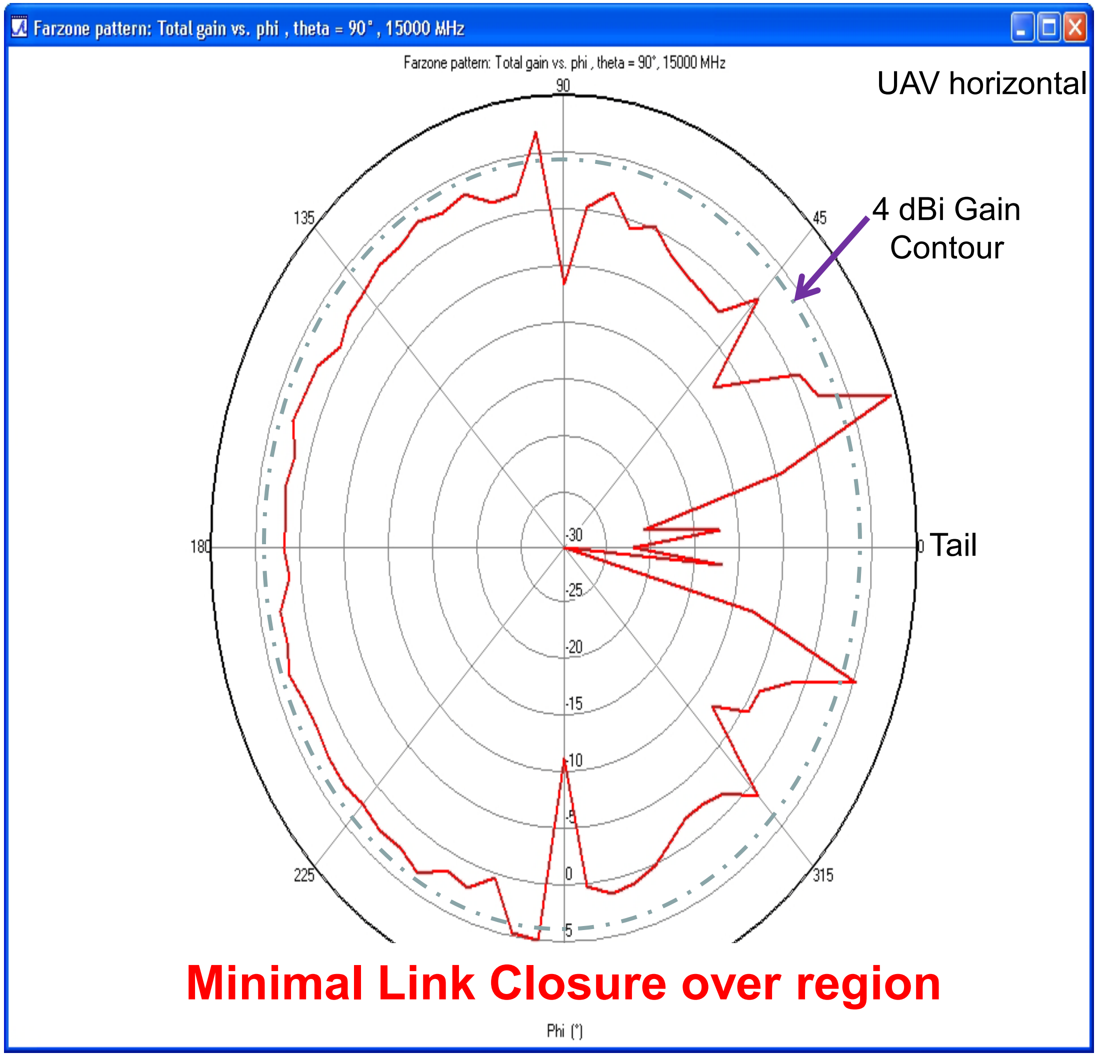
Link Closure over 98% over region



No Link Closure

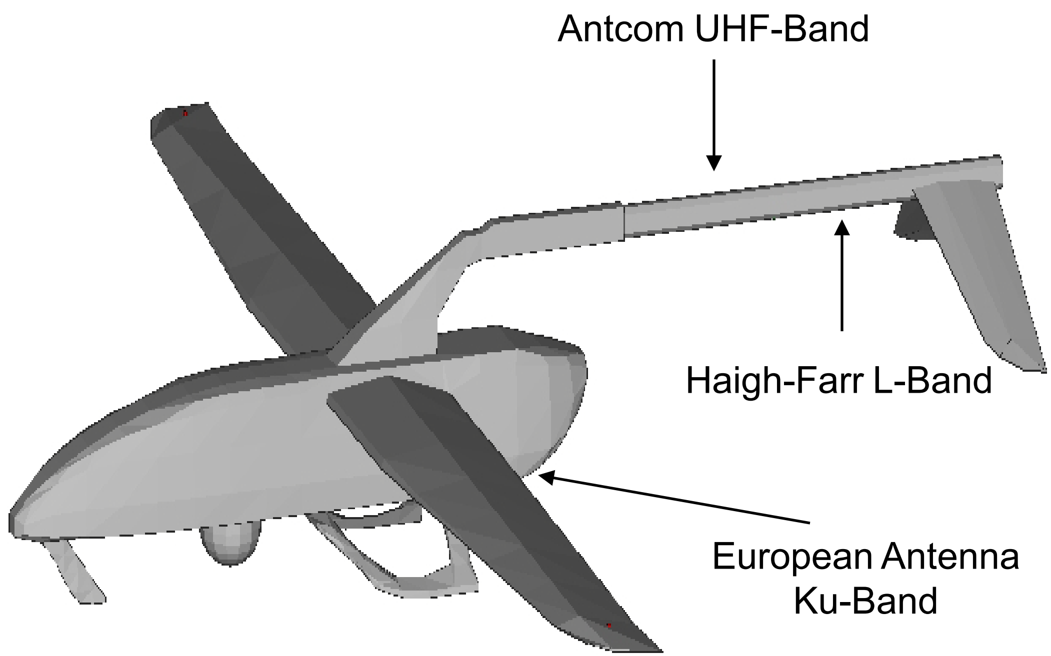
Antenna Gain > 3.4 dBi to close links at 50 nmi and 3 kft (95% availability, clear environmental conditions)

Ku-Band Antenna on Top of Aircraft Fuselage – Horizontal Cut

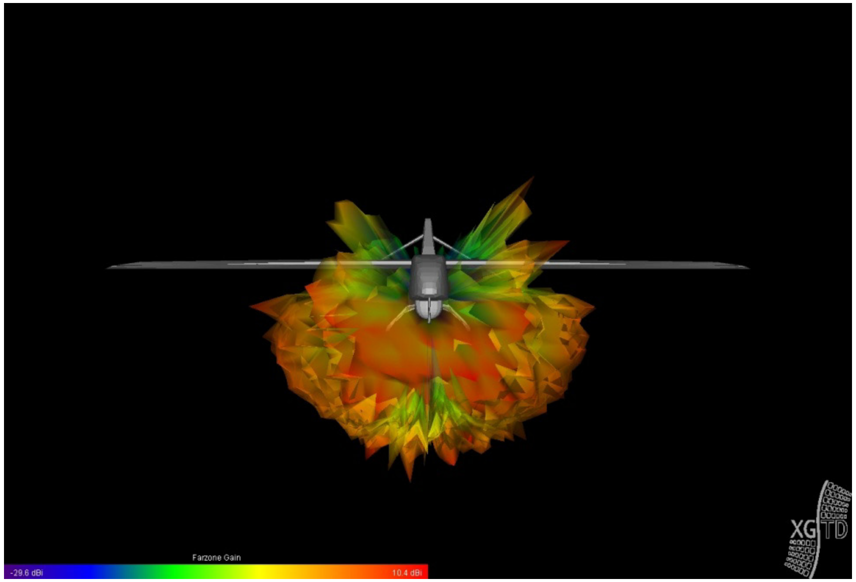


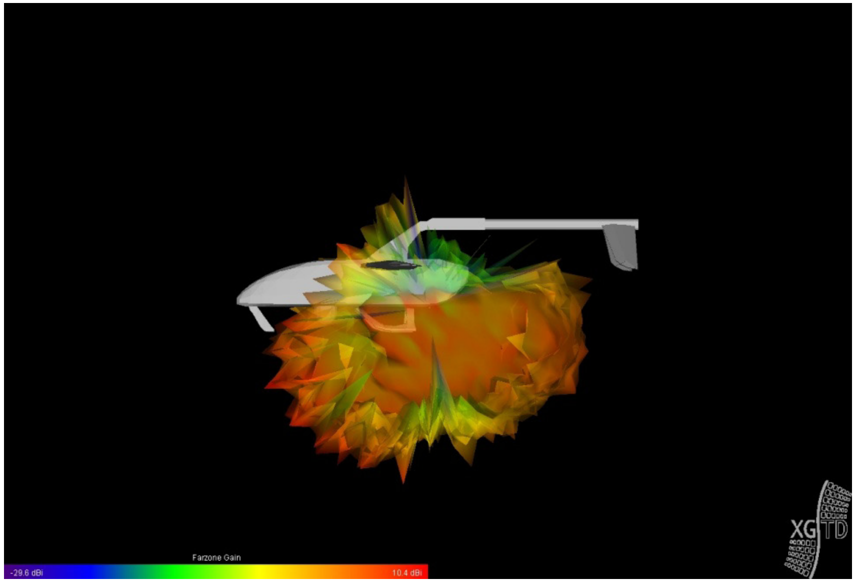
Cautionary Note:
Gain > 4 dBi implies multiple platform reflections occurs which results in greater inter-symbol interference

Alternative Antenna Placement Near Aft Fuselage



Ku-Band Antenna Placement Aft Fuselage





Ku-Band Antenna
Placement Aft Fuselage- Pitch / Roll 20º Cut

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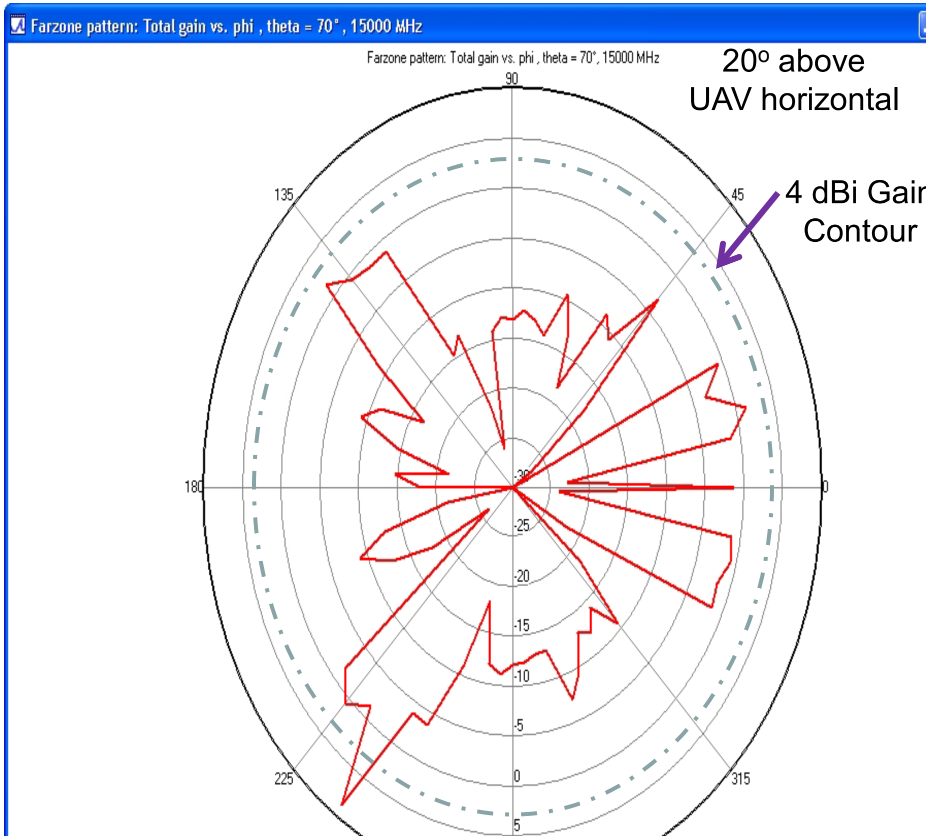
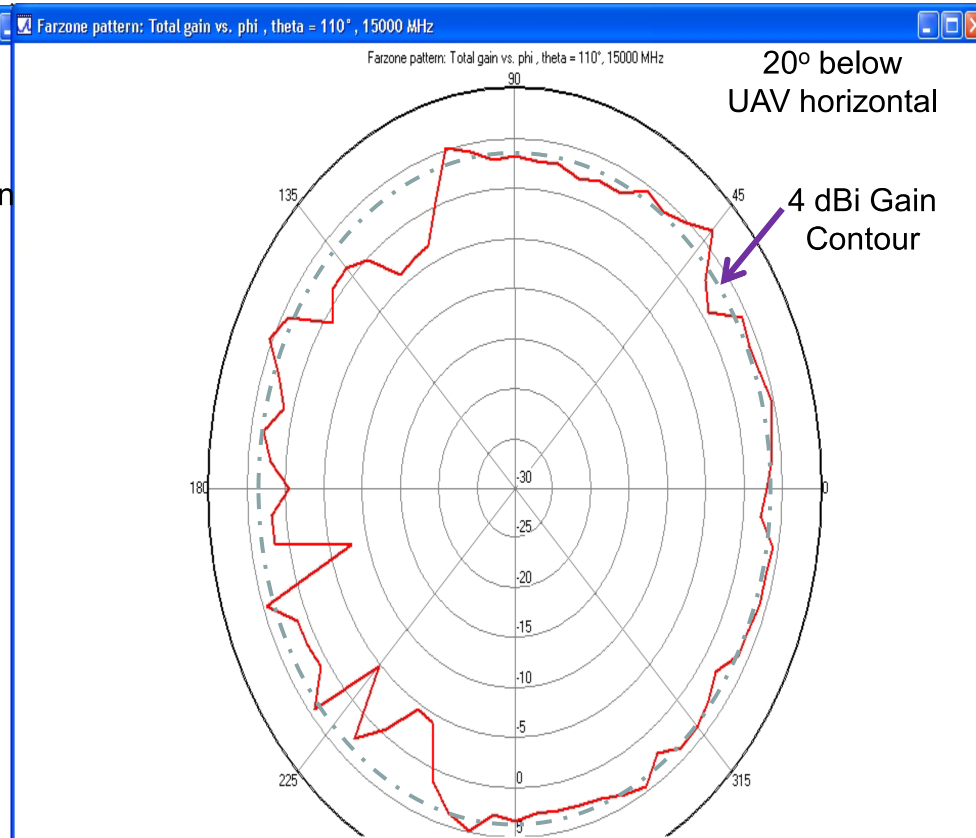


Link Closure over 1% over region



Link Closure over 89% over region

Antenna Gain > 3.4 dBi to close links at 50 nmi and 3 kft (95% availability, clear environmental conditions)

Ku-Band Antenna Placement Aft Fuselage Horizontal Cut

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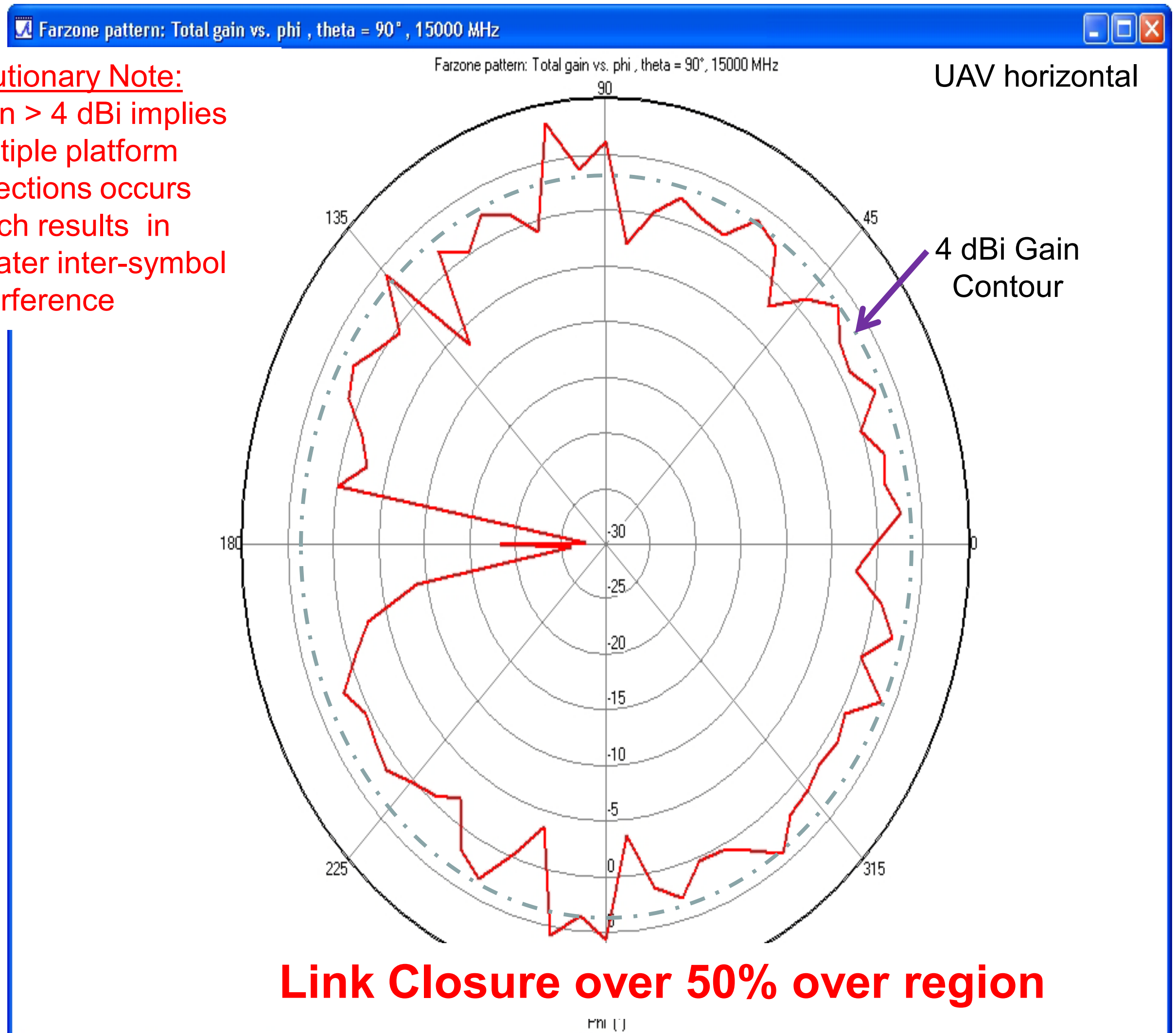
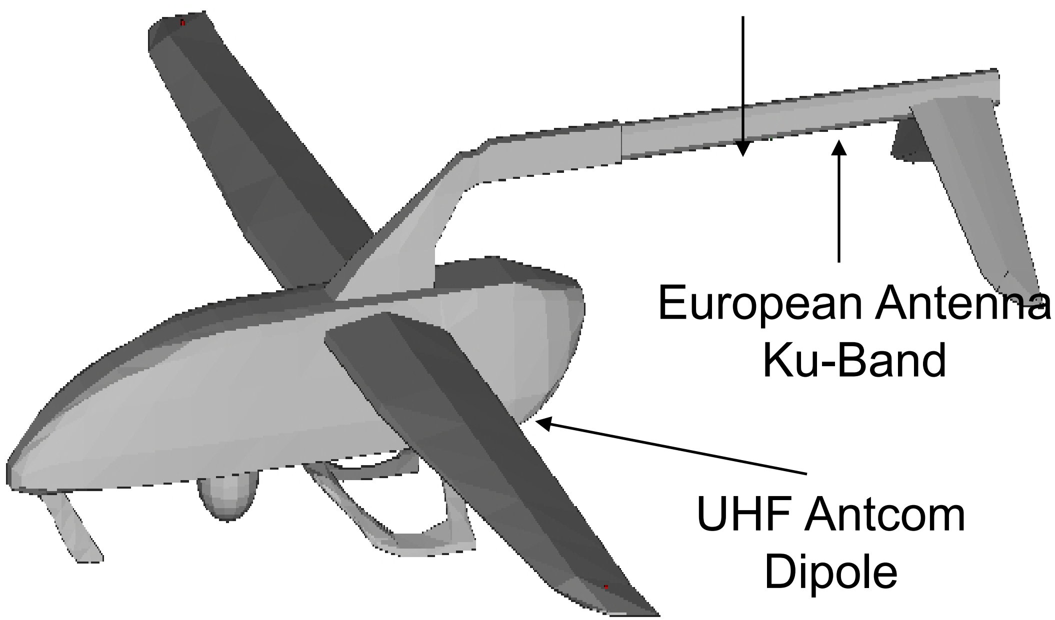
Cautionary Note:
Gain > 4 dBi implies multiple platform reflections occurs which results in greater inter-symbol interference

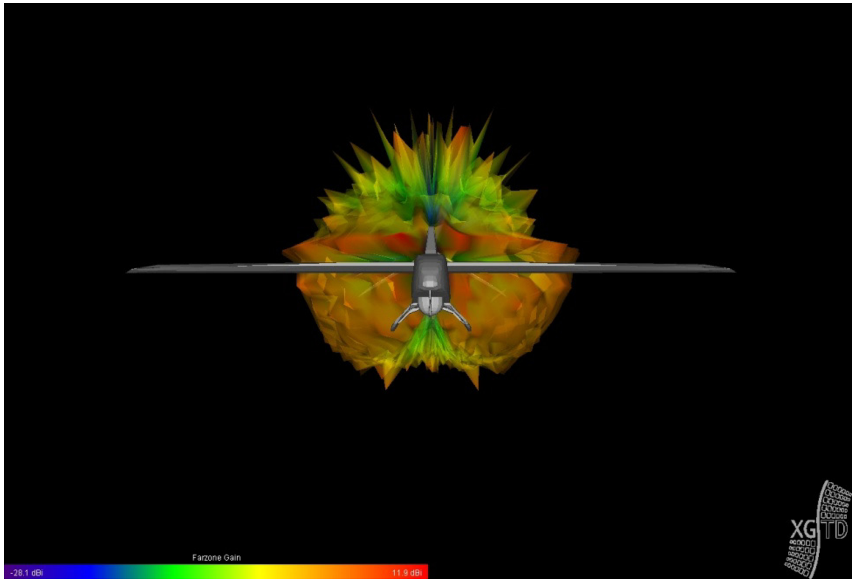


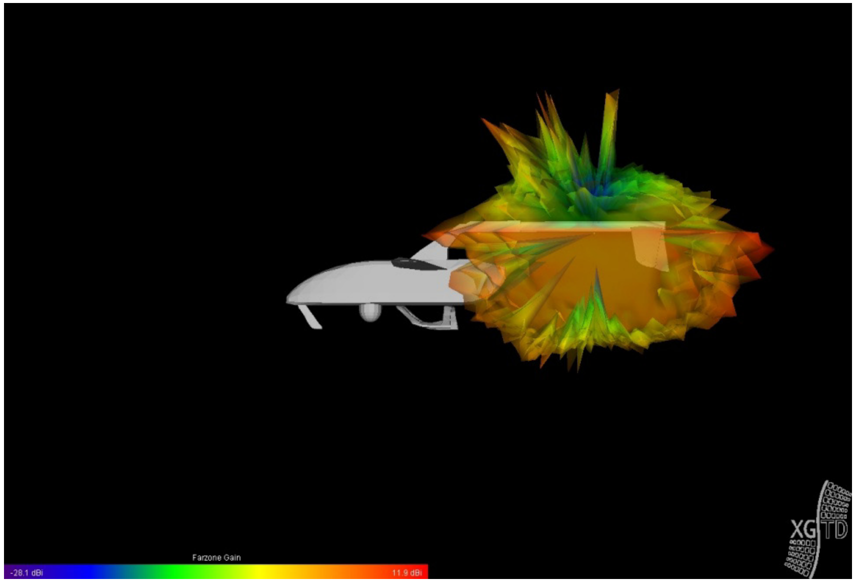
Link Closure over 50% over region

Alternative Antenna Placement Bottom Tail Boom

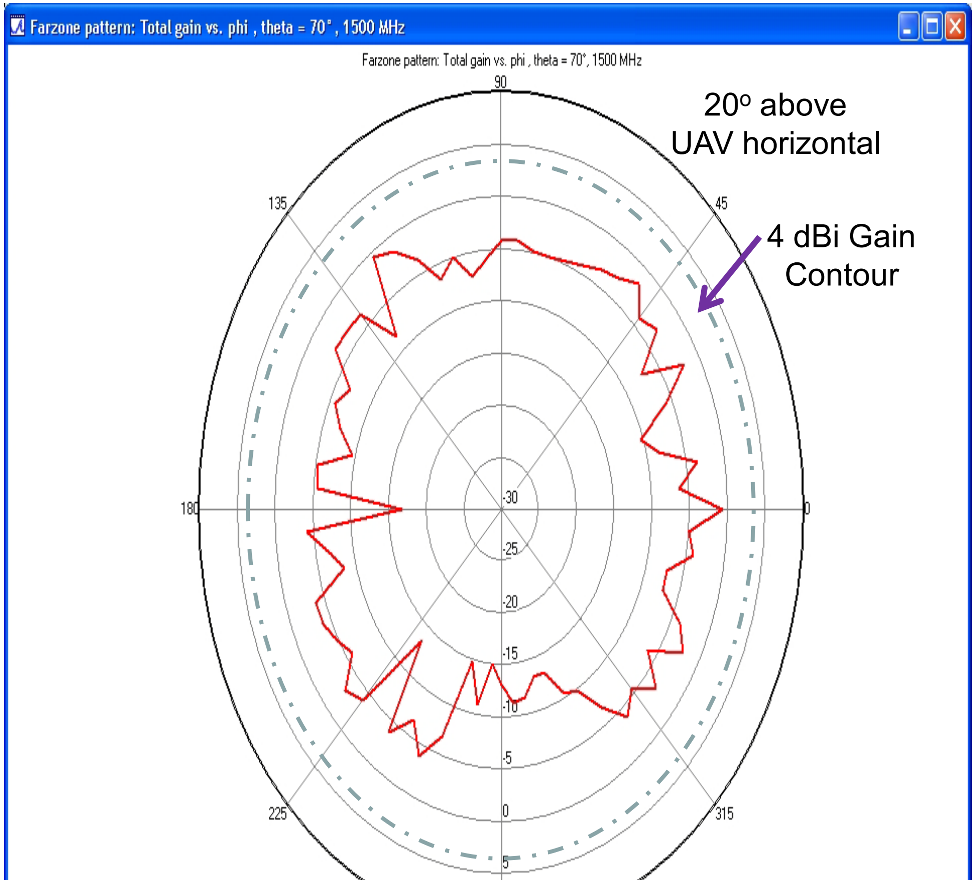


Ku-Band Antenna Placement Bottom Tail Boom

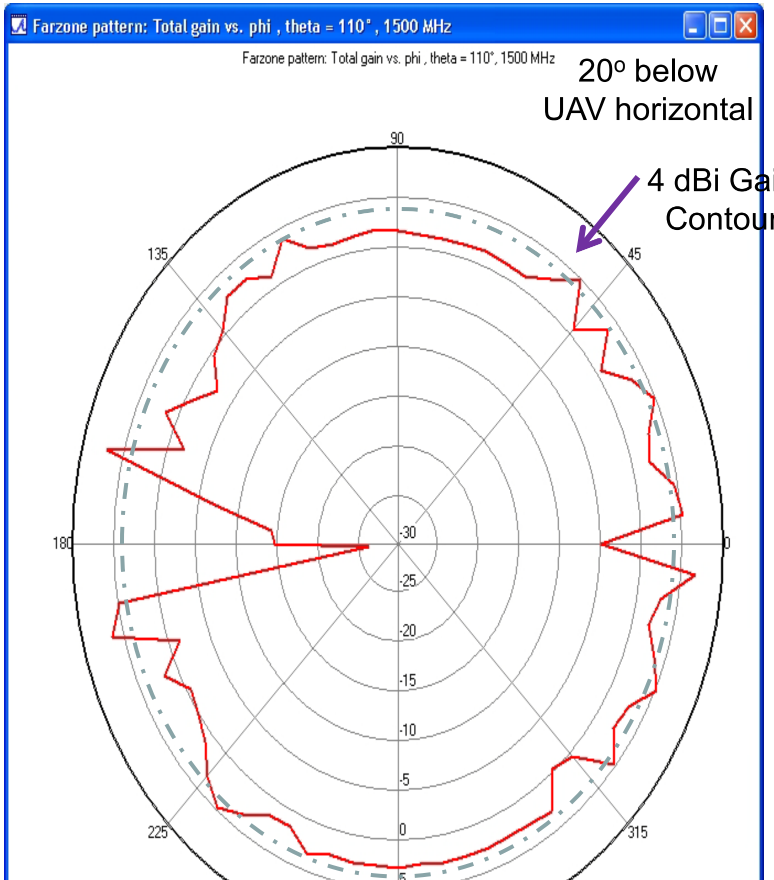




Ku-Band Antenna Placement Bottom Tail Boom - Pitch / Roll 20º Cut



No Link Closure

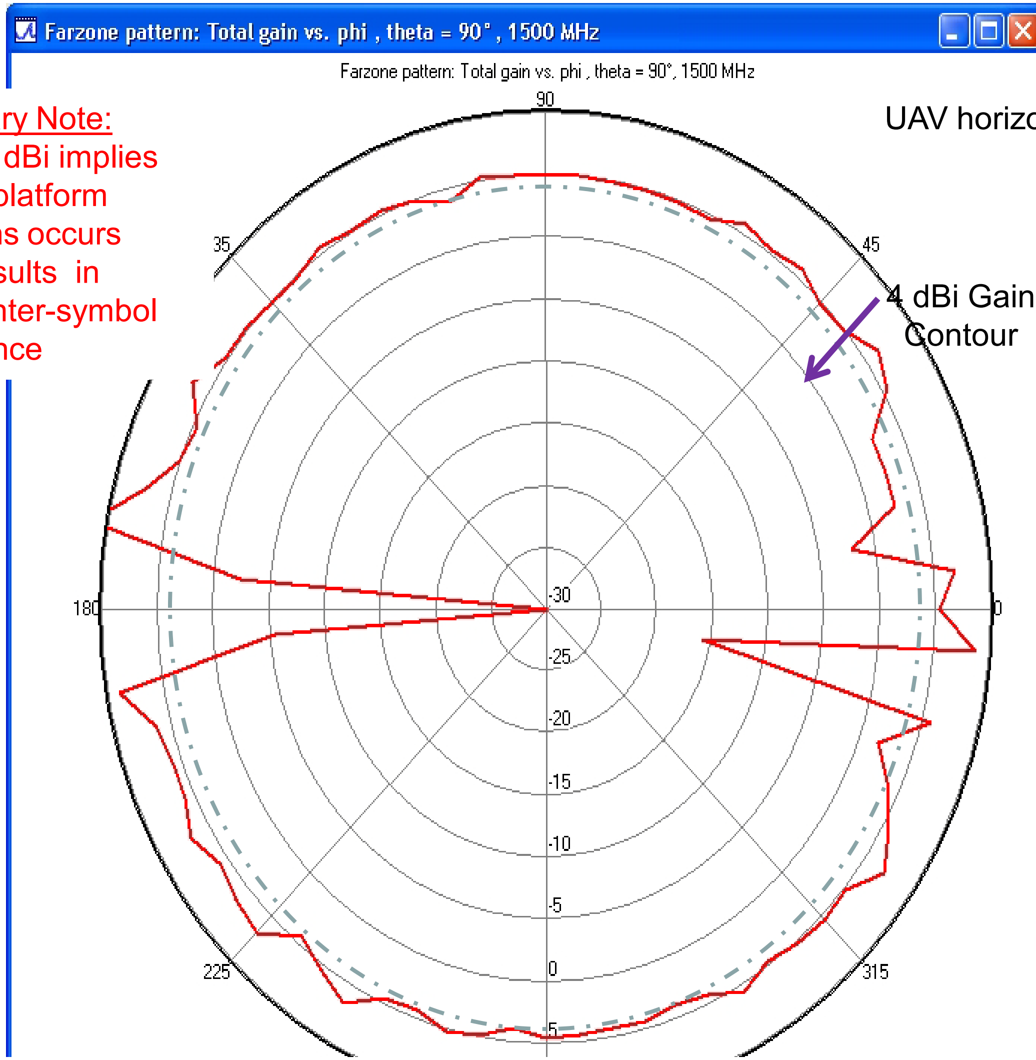


Link Closure over 75 % over region

Antenna Gain > 3.4 dBi to close links at 50 nmi and 3 kft (95% availability, clear environmental conditions)

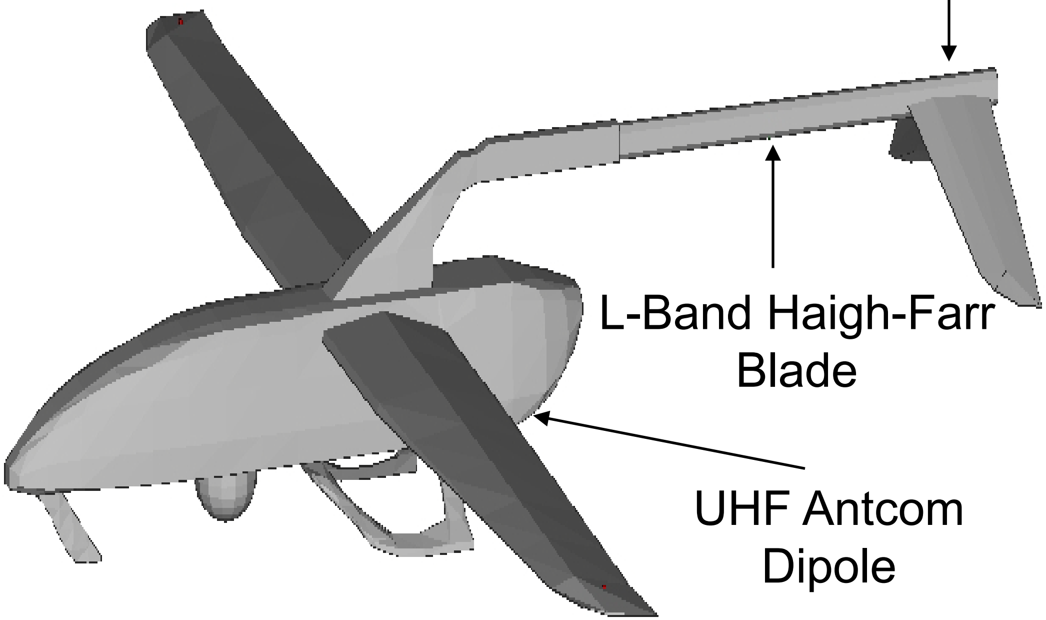
Ku-Band Antenna Placement Bottom Tail Boom– Horizontal Cut

Cautionary Note:
Gain > 4 dBi implies multiple platform reflections occurs which results in greater inter-symbol interference

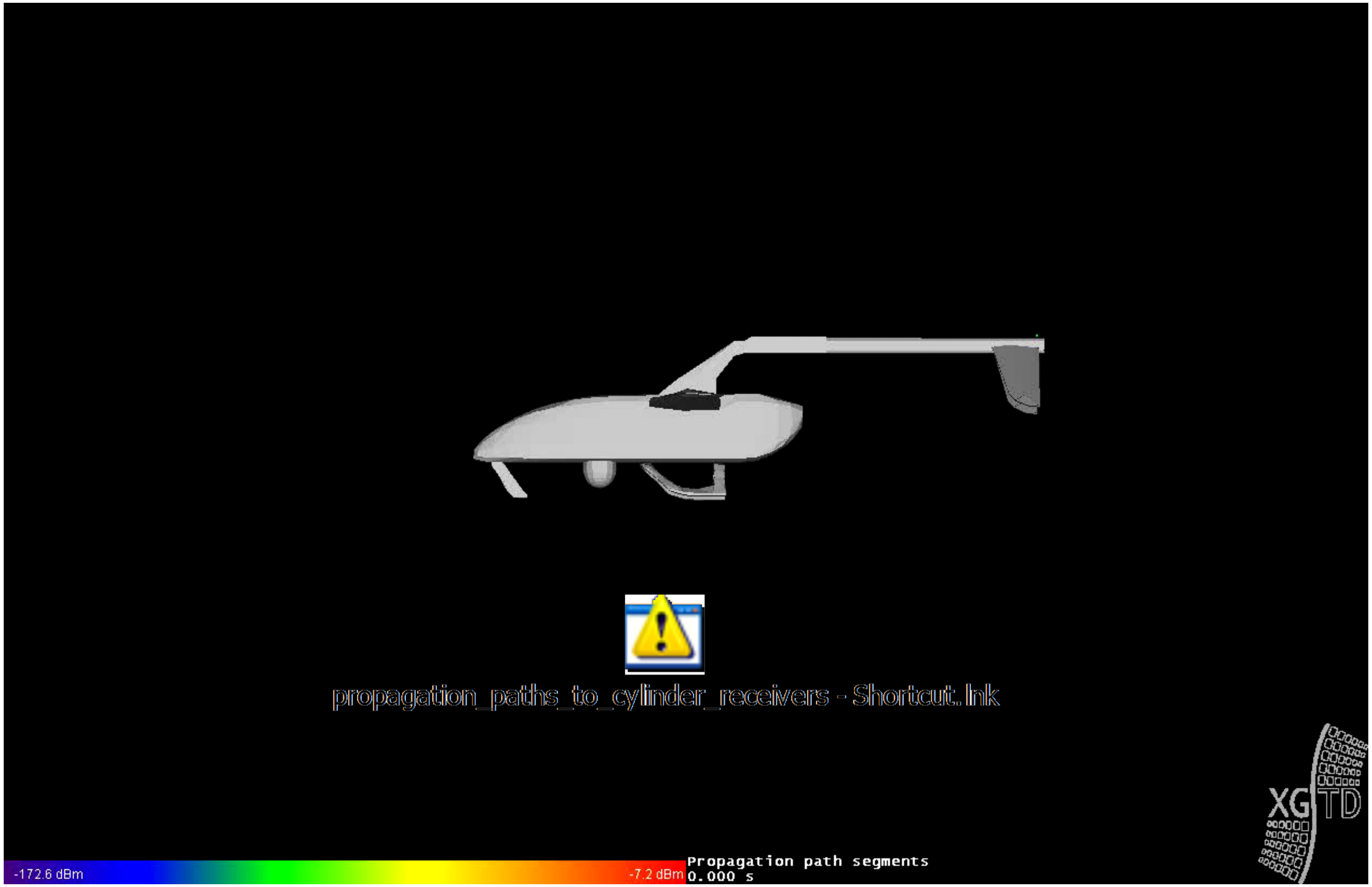


Link Closure over 80% over region (See Cautionary Note)

Antenna Placement Top Tail Boom (1.5 inches from end)



Movie Illustrating RF Propagation Paths and Significant Multipath Reflections from Tail Boom Design



Ku-Band Antenna Placement Top Tail Boom (1.5 inches from end)

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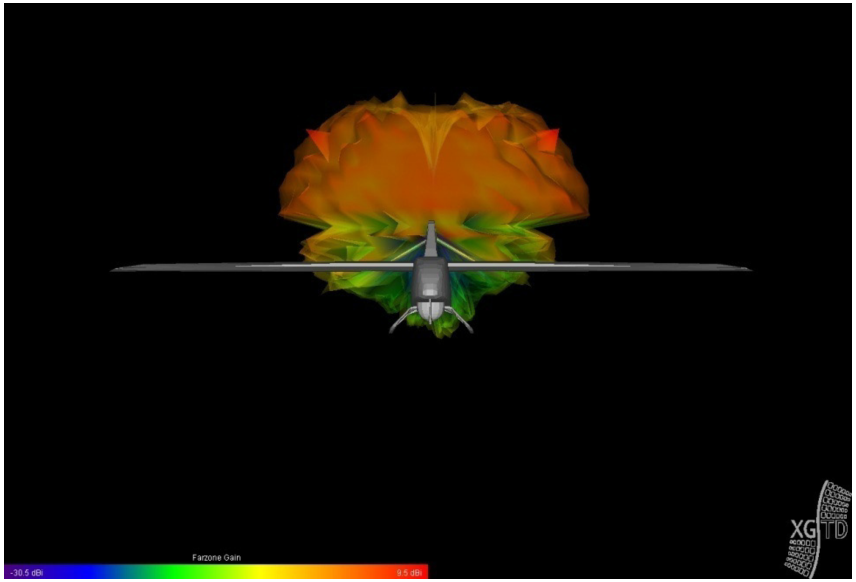

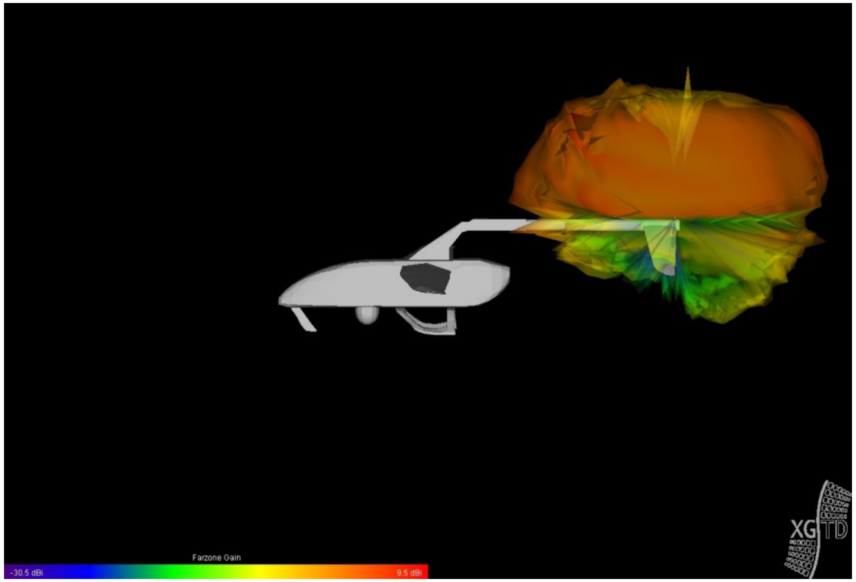

Ku-Band Antenna Placement Top Tail Boom (1.5 inches from end)- Pitch / Roll 20° Cut

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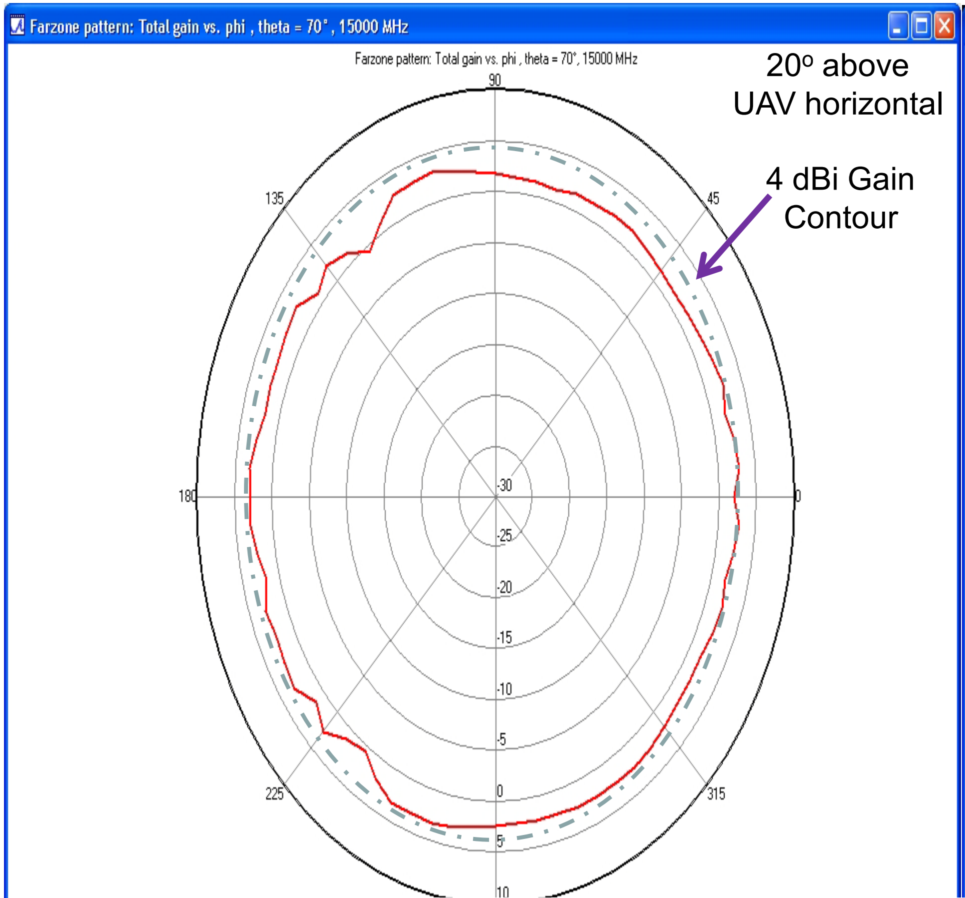
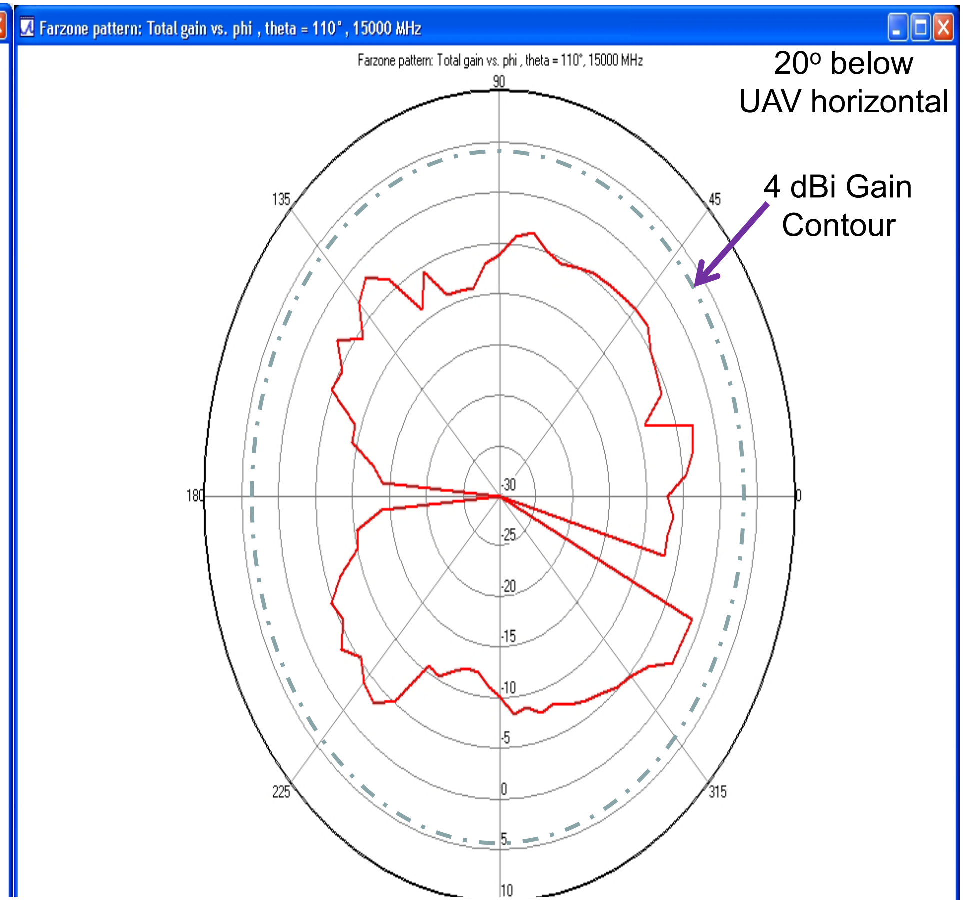
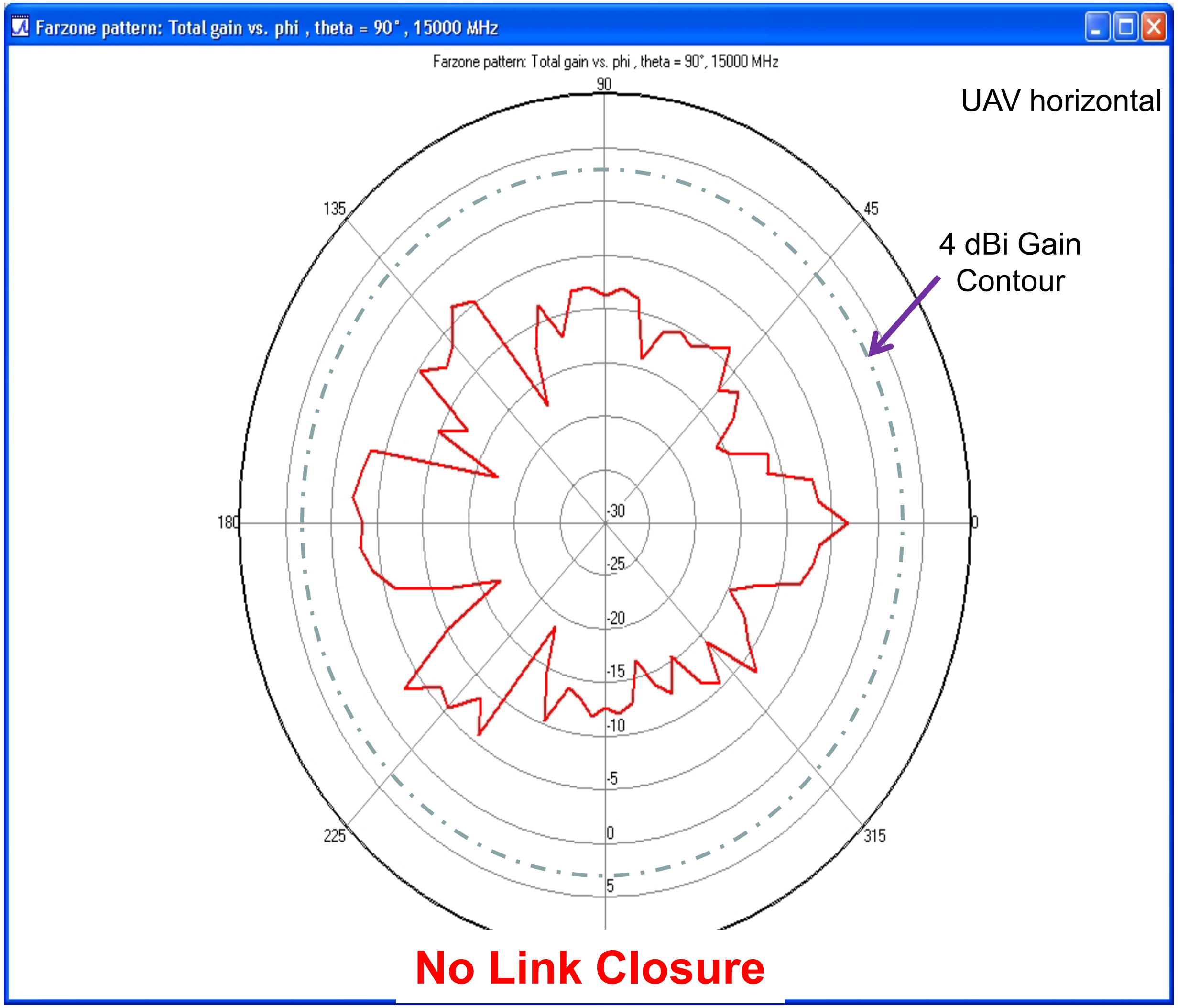




Link Closure less than 95% over region — **No Link Closure**

Antenna Gain > 3.4 dBi to close links at 50 nmi and 3 kft (95% availability, clear environmental conditions)

Ku-Band Antenna Placement Top Tail Boom (1.5 inches from end)- Horizontal Cut



No Link Closure

Isolation Results Between Ku-Band Transmitter and UHF & L-Band Receivers

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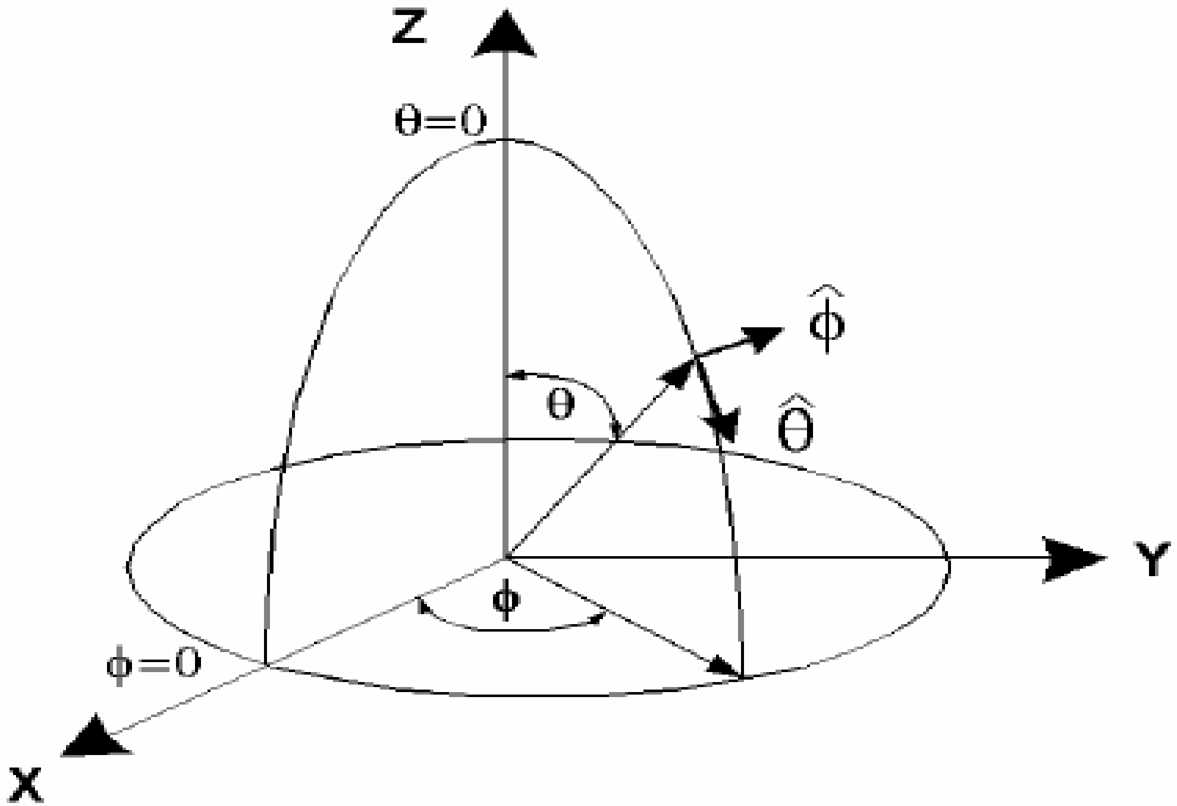
Ku-Band Antenna Placement on nose of aircraft	
Ku-Band Transmitter Received Power (dBm) at victim receivers	
UHF Antenna Receiver	-250
L Band Antenna Receiver	-250
Ku-Band Antenna Placement in between skids	
Ku-Band Transmitter Received Power (dBm) at victim receivers	
UHF Antenna Receiver	-24.8
L Band Antenna Receiver	-250
Ku-Band Antenna Placement on top of aircraft	
Ku-Band Transmitter Received Power (dBm) at victim receivers	
UHF Antenna Receiver	-63.55
L Band Antenna Receiver	-28.14
Ku-Band Antenna Placement on bottom of aircraft near aft fuselage	
Ku-Band Transmitter Received Power (dBm) at victim receivers	
UHF Antenna Receiver (top of boom)	-250
L Band Antenna Receiver (bottom of boom)	-50.06

Isolation Results Between Ku-Band Transmitter and UHF & L-Band Receivers

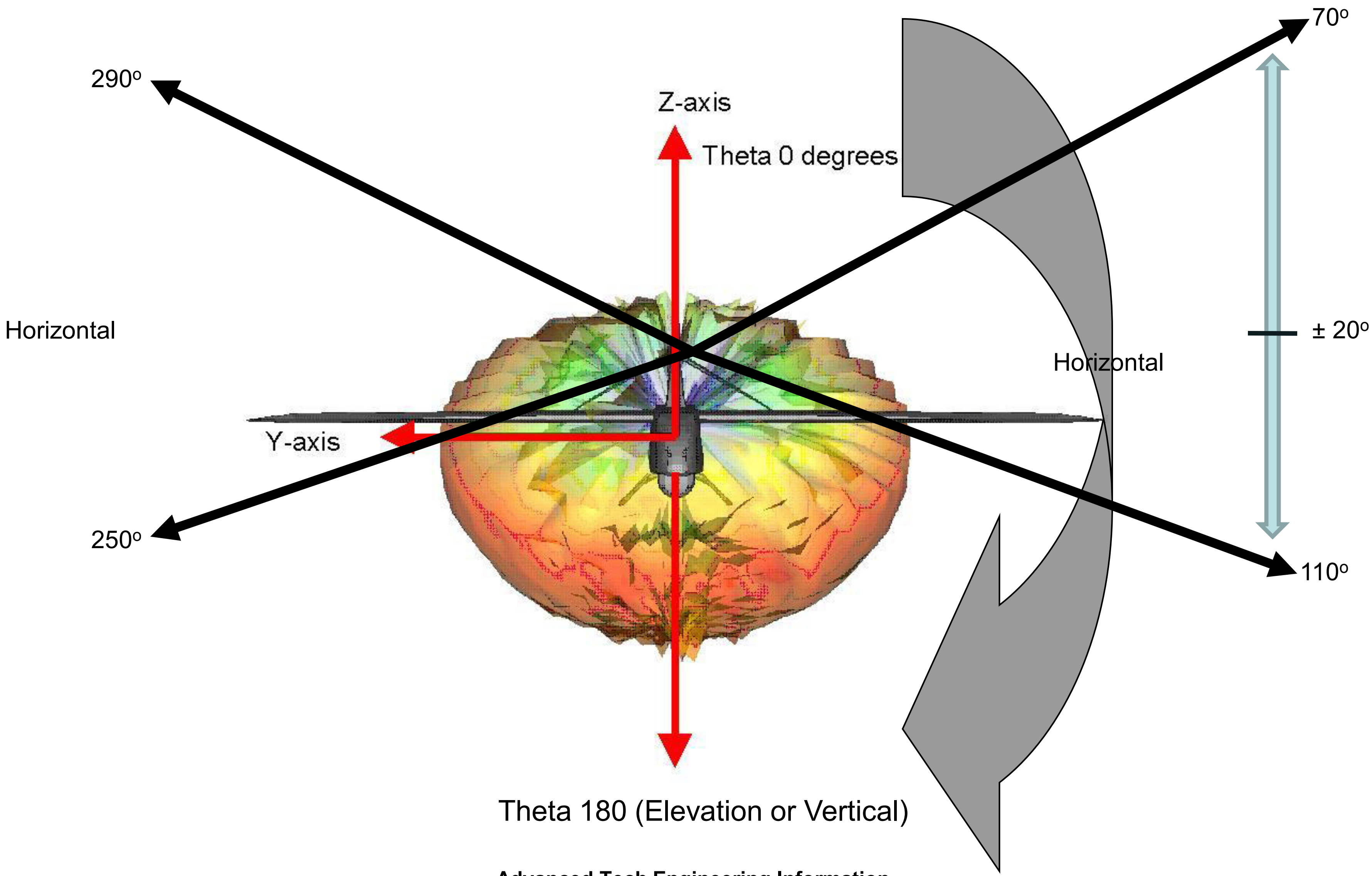
Ku-Band Antenna Placement on bottom of tail boom 12" from tail	
Ku-Band Transmitter Received Power (dBm) at victim receivers	
UHF Antenna Receiver (top of boom)	1.74
L Band Antenna Receiver (bottom of boom)	7.68
Ku-Band Antenna Placement on top of tail boom 1.5" from tail	
Ku-Band Transmitter Received Power (dBm) at victim receivers	
UHF Antenna Receiver (top of boom)	-22.82
L Band Antenna Receiver (bottom of boom)	-10.86

Coordinate System Reference Diagrams

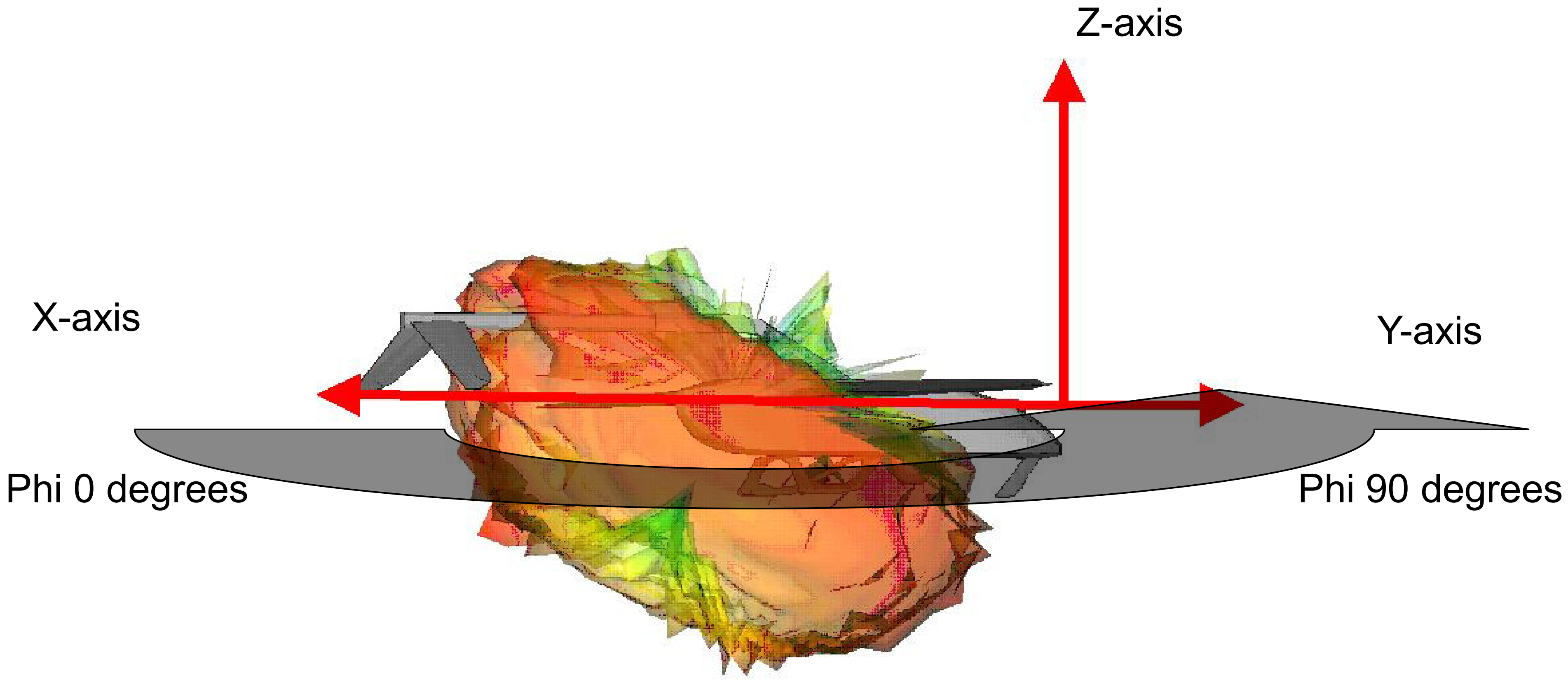
Coordinate Frame Reference



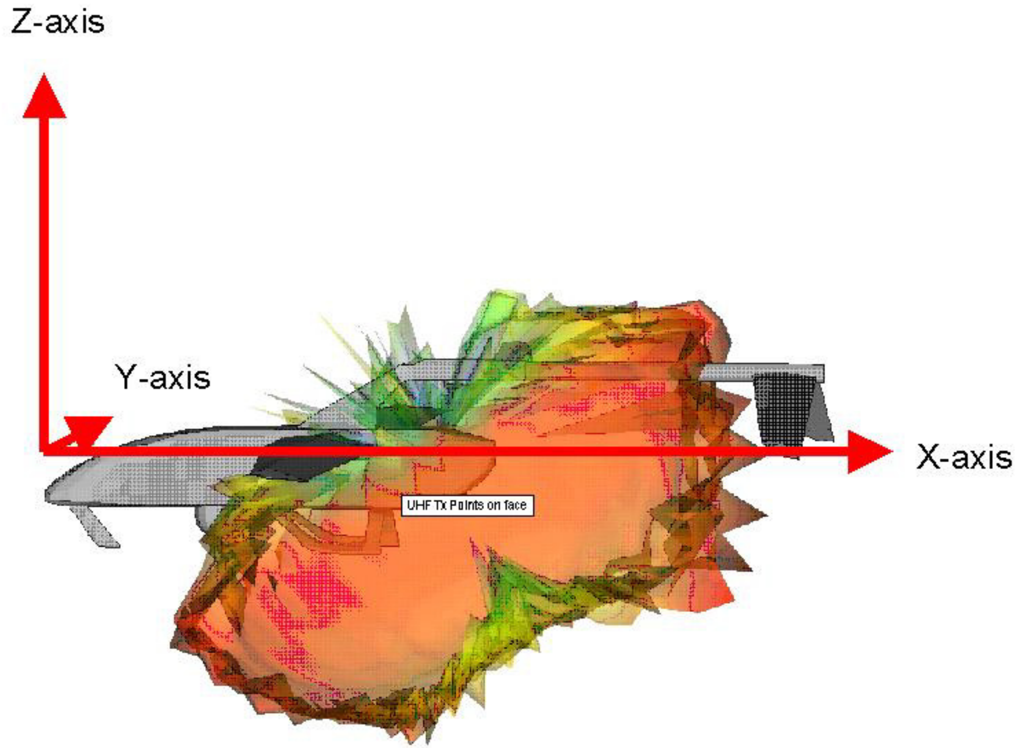
Reference Diagram



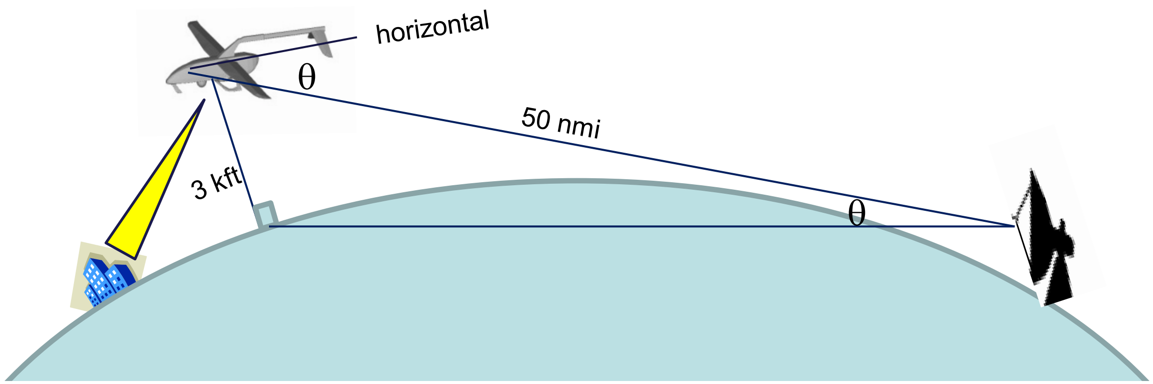
Reference Diagram



Reference Diagram



UAV to GDT Geometry @ 50 nmi



Finding θ

Sin θ = Opposite / hypotenuse

θ = Arcsin (3000 ft/6080 ft /nmi)/50 nmi

= 0.57 degrees

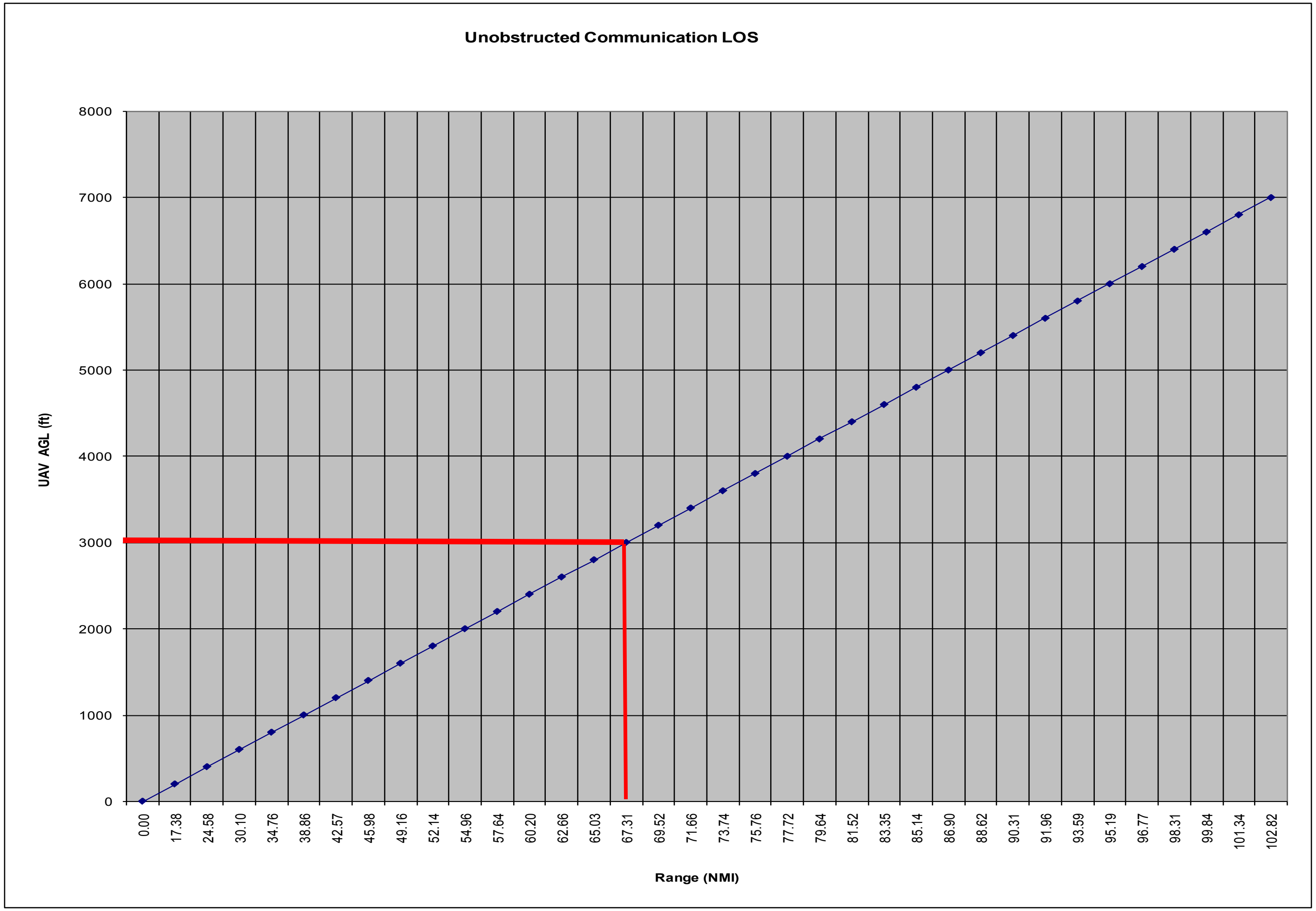
Aircraft level flight (e.g., no roll or pitch) @ 50 nmi slant range and 3 kft Altitude AGL

= - 0.57° below horizontal axis

Aircraft normal flight (assumes 20° max roll angle during orbits or flight conditions)

= +19.43° (above horizontal axis) to 20.57° (below horizontal axis)

Radio / Radar Unobstructed LOS



Radio / RADAR Horizon Reference

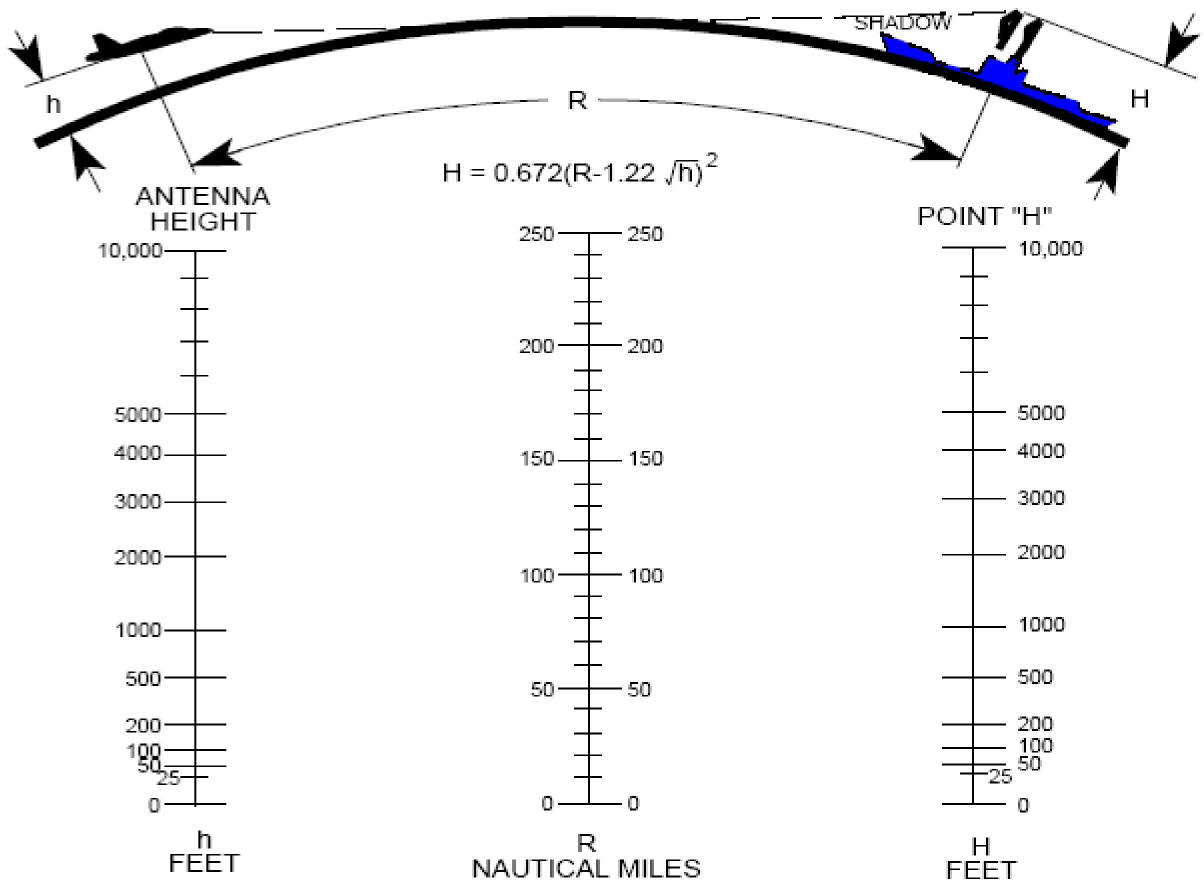


Figure 2. Earth Curvature Nomograph