Simulation of Test Zone Scattering in a RCS Compact Range

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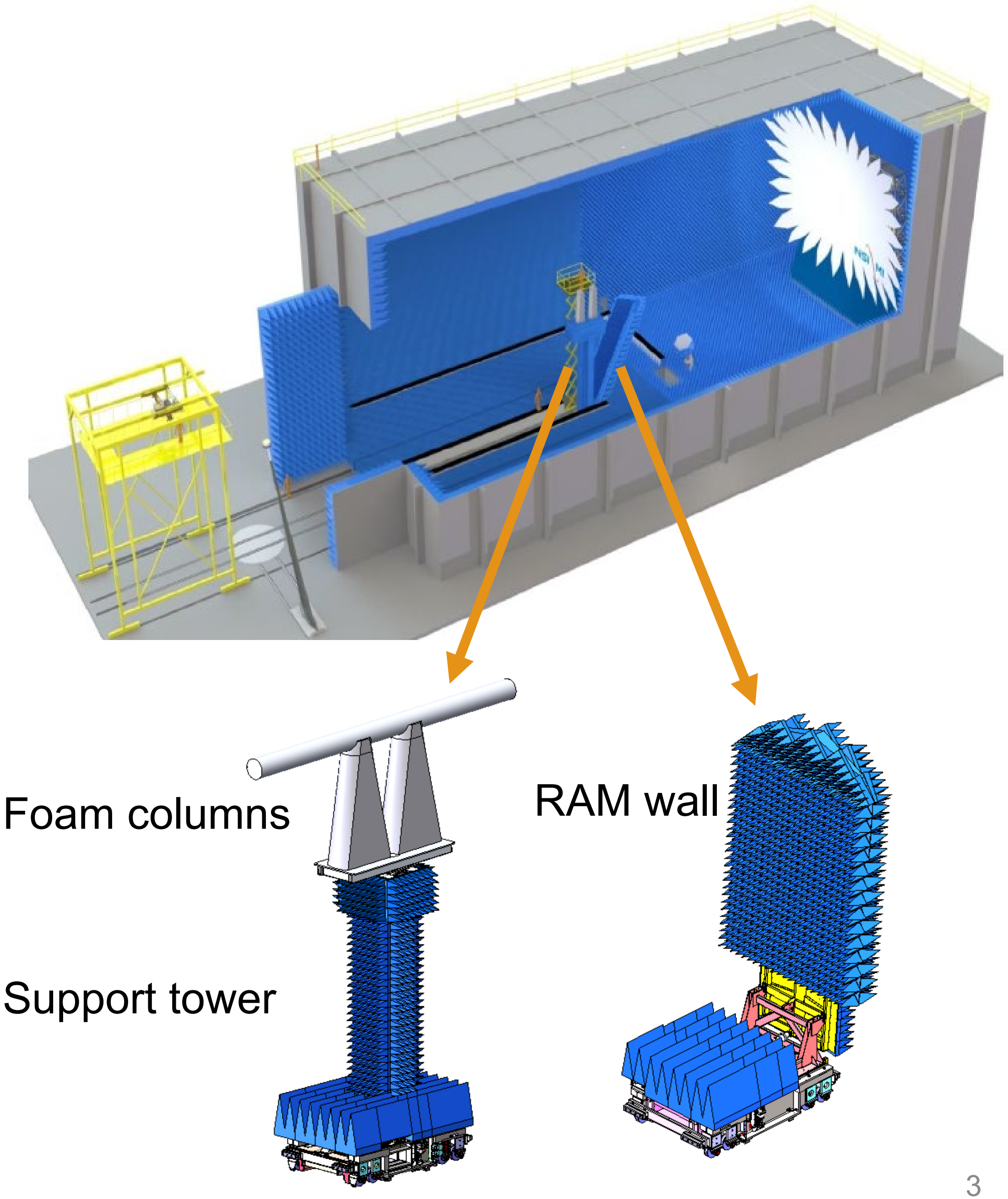
Acknowledgement

- The RCS chamber images and all of the measurement system design details were provided by NSI-MI Technologies

Problem

- Foam columns are needed to support targets in an RCS compact test range because some targets cannot be mounted on pylons
  - The height of the columns is driven by fabrication and mechanical limitations of tall foam columns
  - We also want to limit the height of columns to minimize RCS that can’t be canceled out with background subtraction
- A wall of Radar Absorbing Material (RAM) was introduced to reduce the impact of the foam column support tower on measurements
- The RAM wall effectively shadows the tower and base of columns, but creates unacceptable edge diffraction in the compact range quiet zone
- We need to preserve the quiet zone performance relative to the case without the RAM wall present



Initial Thoughts

- The top & side edges of the RAM wall represent discontinuities that will scatter energy
  - This scattering will be worse at lower frequencies, where absorber scattering is more diffuse
  - Absorber material properties (and therefore scattering properties) are frequency dependent
- Post-processing editing of the ripples introduced to the quiet zone will be difficult because they will be in the range gate
- Diffraction can be minimized with shaping
  - Serrated top edge to direct scattering out of the quiet zone
  - Tapered resistive card (R-card) can smooth out the transition

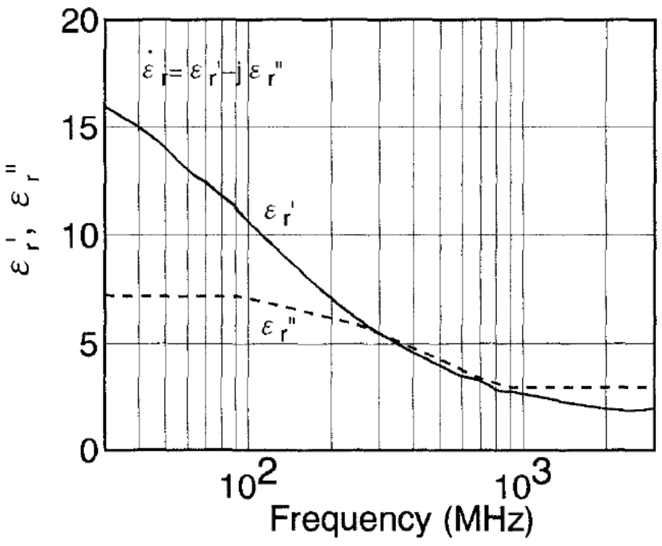
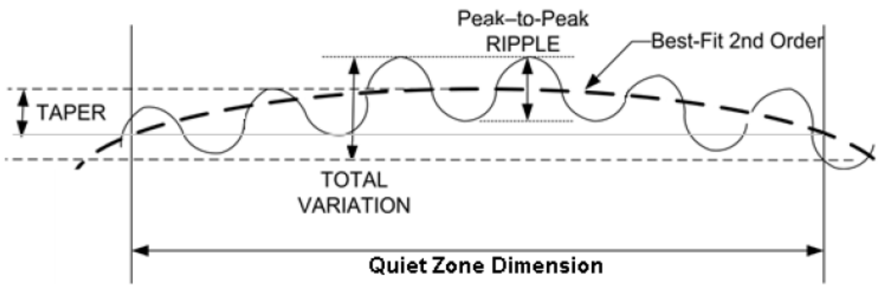


Fig.2. The complex relative permittivity of lossy dielectric.

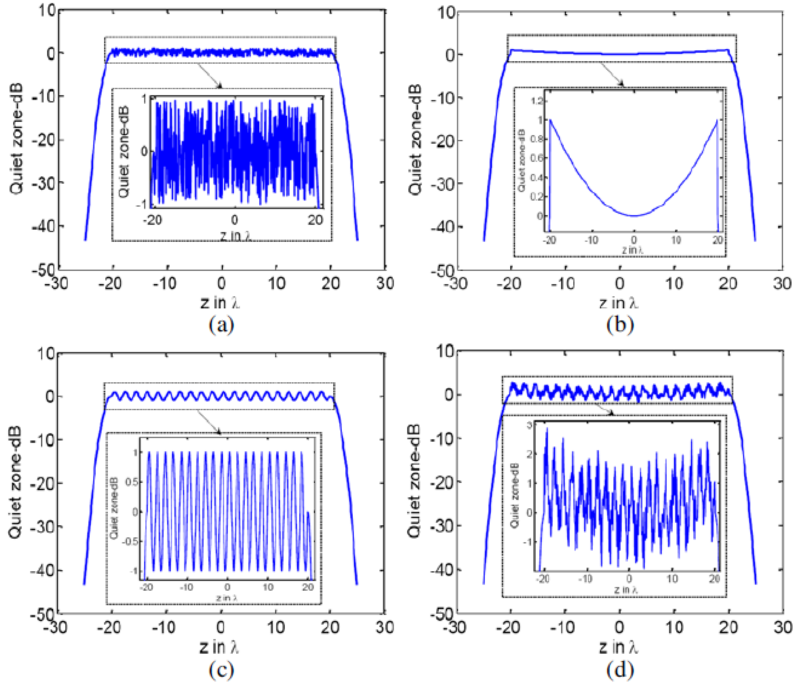
The complex relative permittivity $\dot{\varepsilon}_r = \varepsilon_r' - j\varepsilon_r''$ of urethane containing carbon powder is measured in the frequency range from $30MHz$ to $3000MHz$. The measured permittivity shown in Fig.2 is used throughout the calculation presented in this paper.

Ripple Impacts on Measurements

- The measurement impacts of QZ amplitude taper, amplitude ripple, and phase ripple on antenna pattern measurements have been studied previously [1-3]
- For RCS measurements, incident field amplitude & phase variations represent imperfect illumination of the target under test [4-6]
  - Impact is highly dependent on target under test scatting centers; some examples
    - Specular (Sin(x)/x) scatters will have reduced max response, and wider main lobe
    - Leading edge response (i.e. surface mismatch, lead edge airfoils, etc.), similar to above specular
    - Point scatters – while specific aspect to aspect correlation to theoretical plane wave much less impact when comparing sector statistics
      - Will have filling in of nulls and shifting of peaks for constructive interference



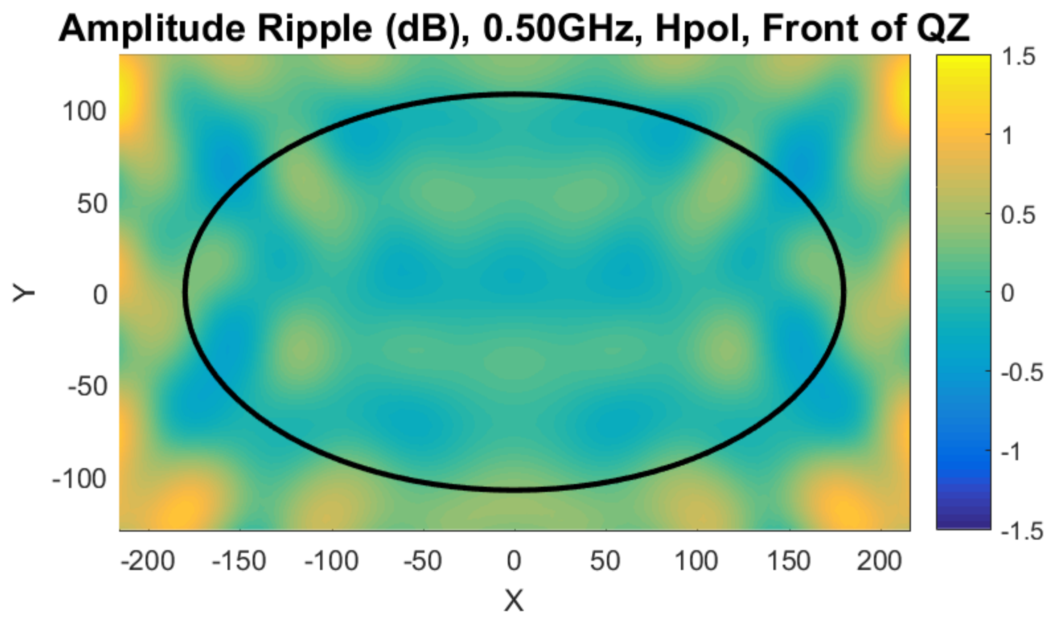
QZ ripple description taken from [1]



QZ ripple models presented in [2] for (a) uniform distribution, (b) taper, (c) sinusoidal distribution, and (d) a combination of the others

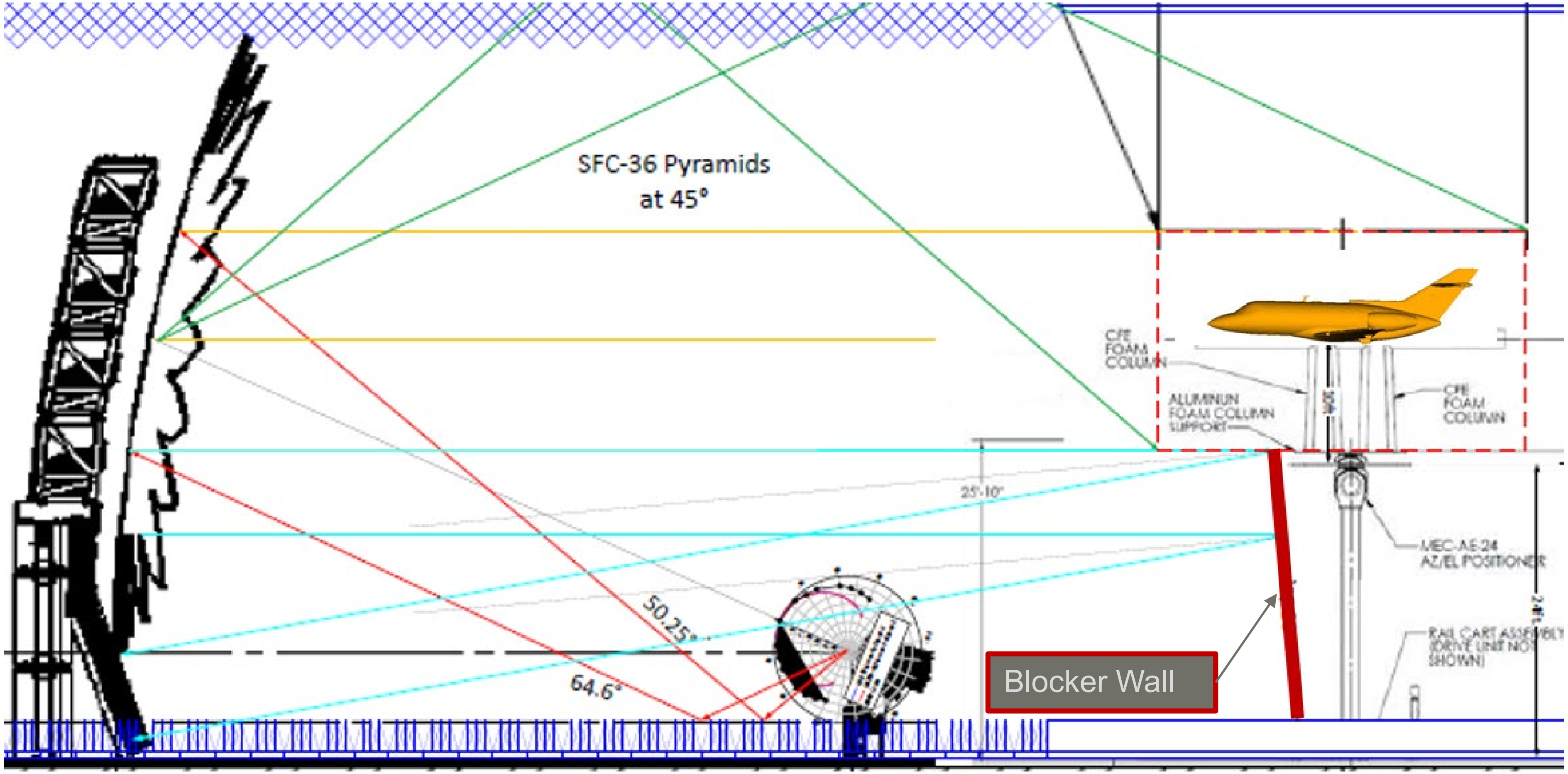
Goal

- Optimize the height of the RAM wall to provide maximum shadowing of the Unit Under Test (UUT) tower and foam column without unacceptable degradation of the quiet zone illumination
- Quantify phase and amplitude variations across the entire quiet zone including the effects of the RAM wall
- Establish acceptable level of quiet zone degradation



Beginning the Modeling Effort

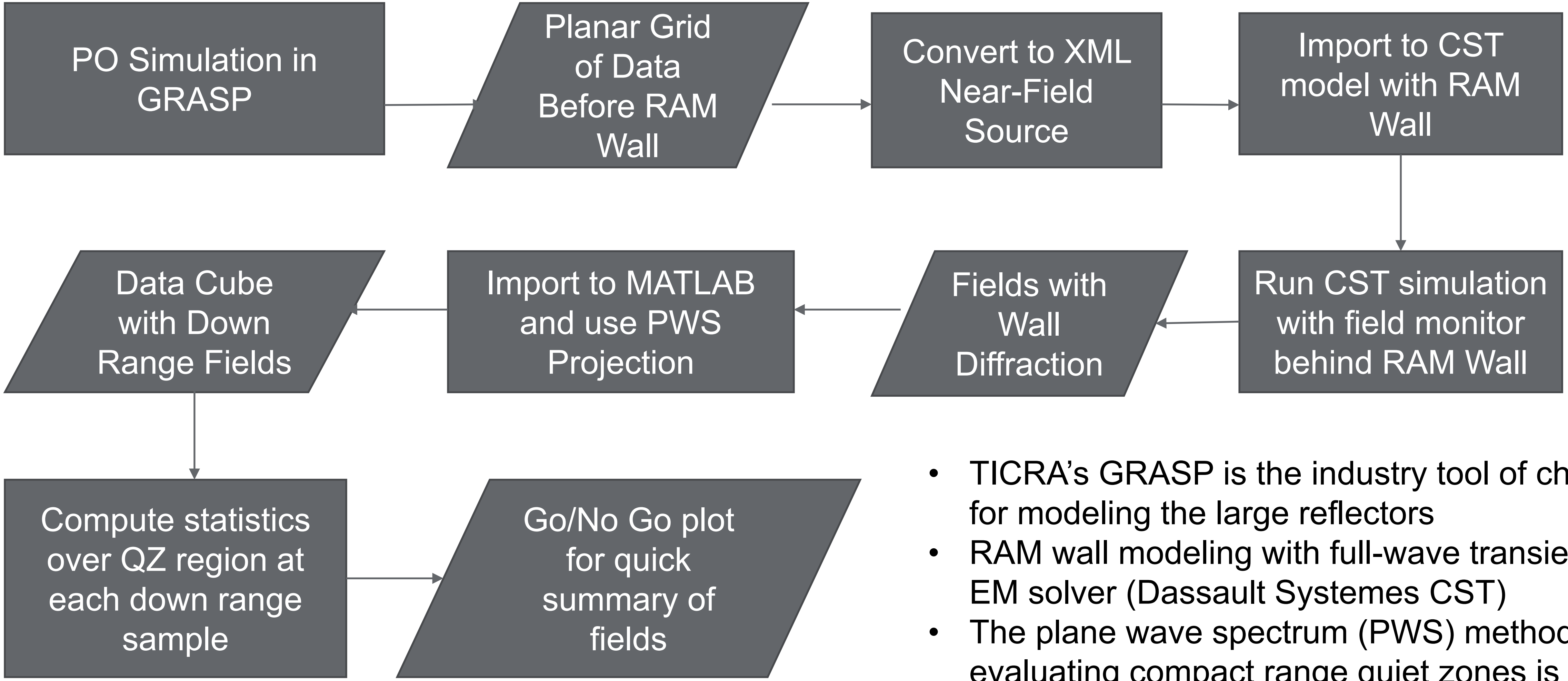
- Ray tracing provides a “big picture” view of the scattering environment, but doesn’t provide quantitative results



Beginning the Modeling Effort

- GRASP simulations have previously shown the un-distorted fields in the quiet zone
  - GRASP is a computationally efficient method to model the feed+reflector
- However GRASP is not well-suited to modeling the RAM wall due to the complex dielectric properties; a full-wave solver is preferred for this portion of the solution
  - A full-wave model of the RAM wall is electrically large; incorporating the full quiet zone would make the problem impractical to solve
- A hybrid modeling approach is needed

Simulation Workflow

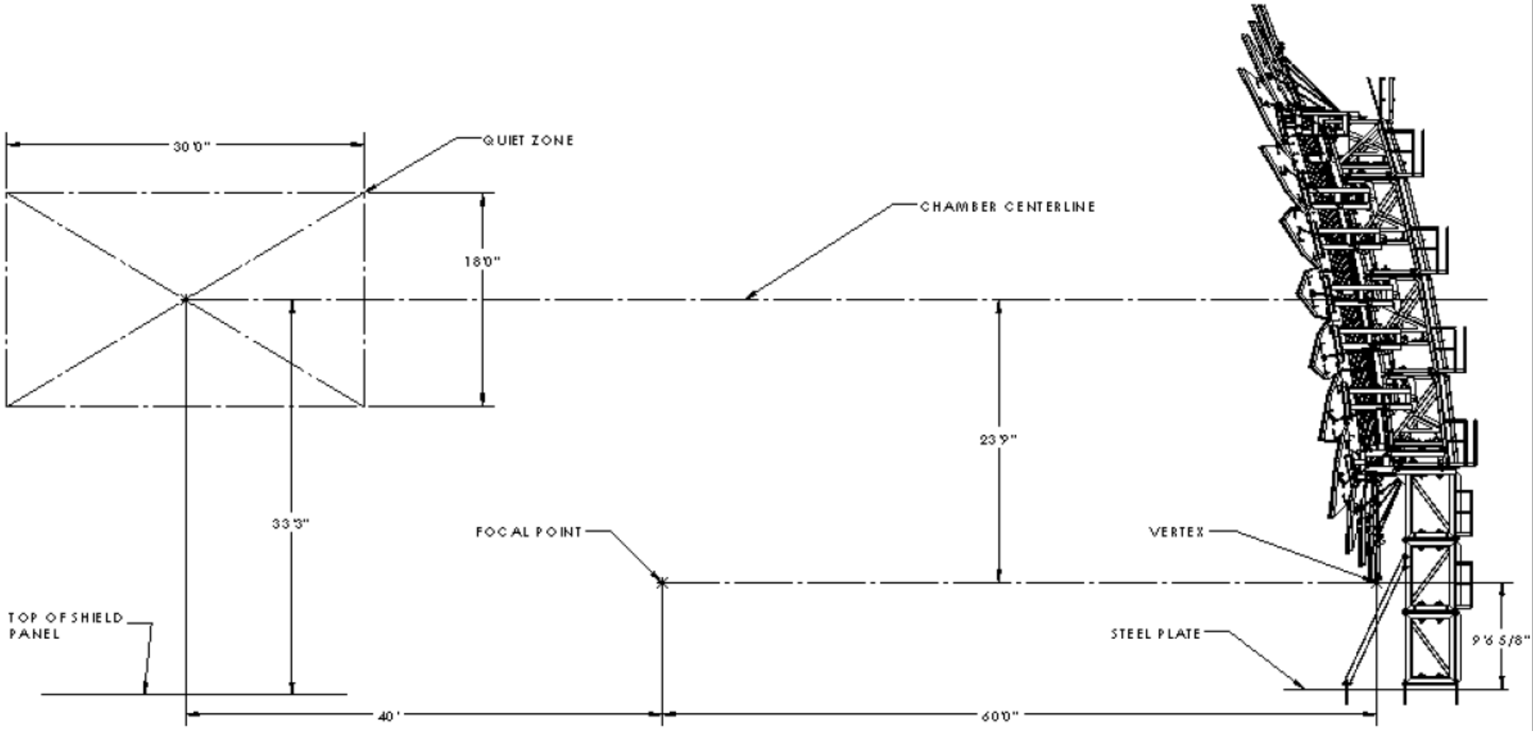


- TICRA's GRASP is the industry tool of choice for modeling the large reflectors
- RAM wall modeling with full-wave transient EM solver (Dassault Systemes CST)
- The plane wave spectrum (PWS) method of evaluating compact range quiet zones is well established [3],[4]

Chamber Geometry

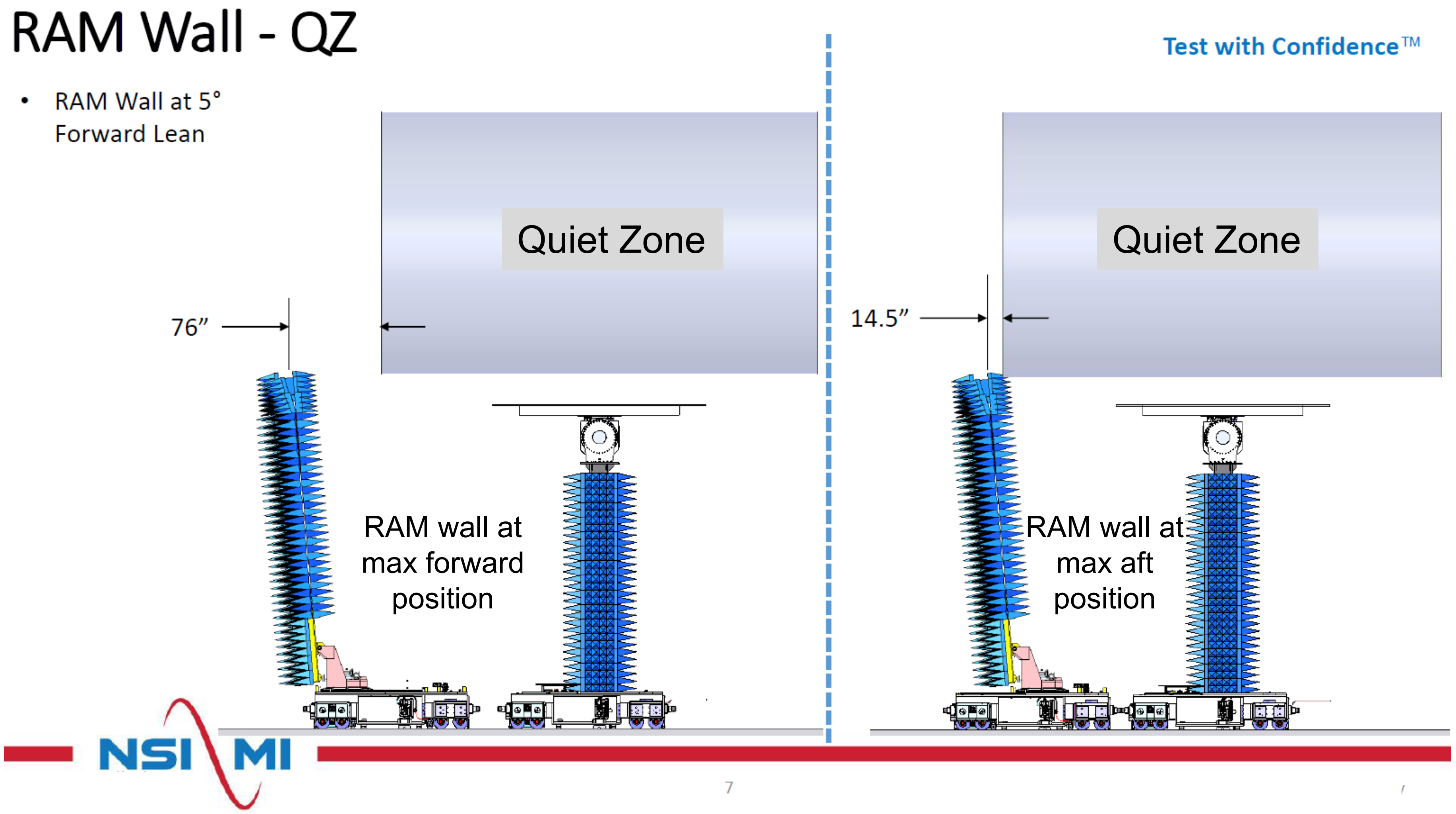
- Quiet Zone:
  - Oval cross section with major axis of 30’, minor axis of 18’, and depth of 30’
  - Center: (0, 33’3”, 100’)
    - This will map to (0,0) in the field plots shown later
- Room:
  - X: -39’ to +39’
  - Y: -33.25’ to +33.25’
- Room plane for fields at front of QZ:
  - X: -468” to +468”
  - Y: -399” to +399”
  - Z: 85’

Anechoic Chamber Dimensions			
Parameter	**Length**	**Width**	**Height**
Inside Shield	185’	78’	66’-6”

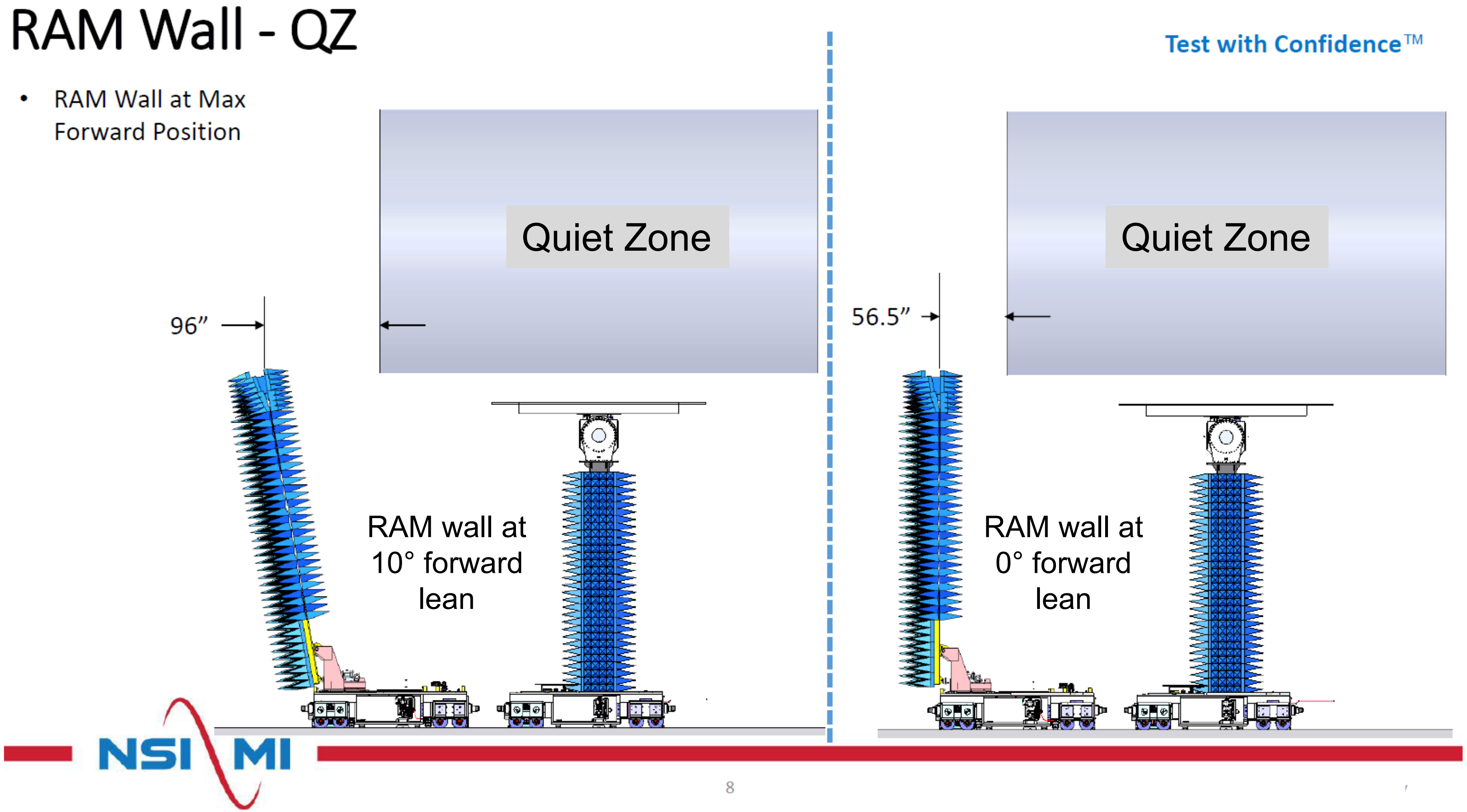


RAM wall not shown

Wall Position Options

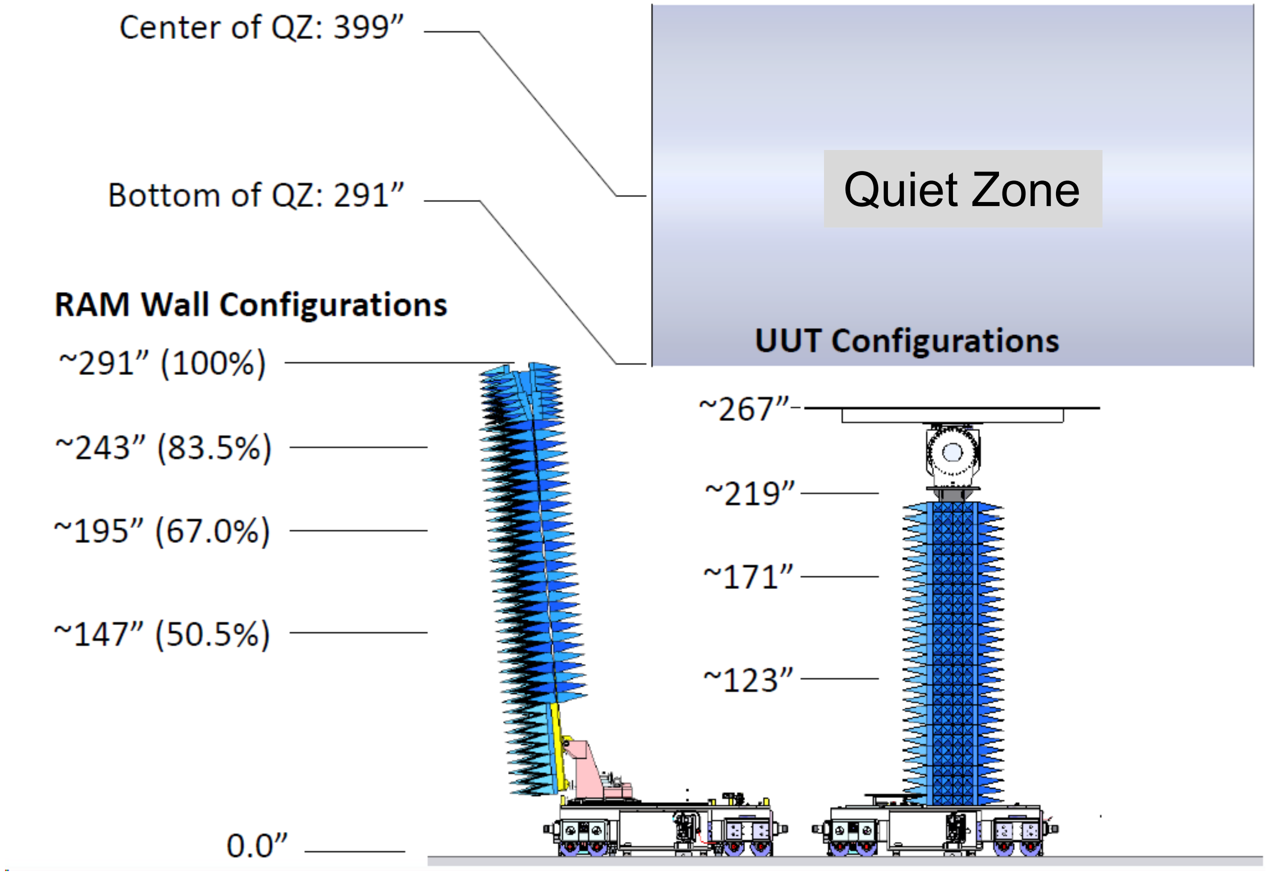


Wall Tilt Options



Wall & Tower Height Configurations

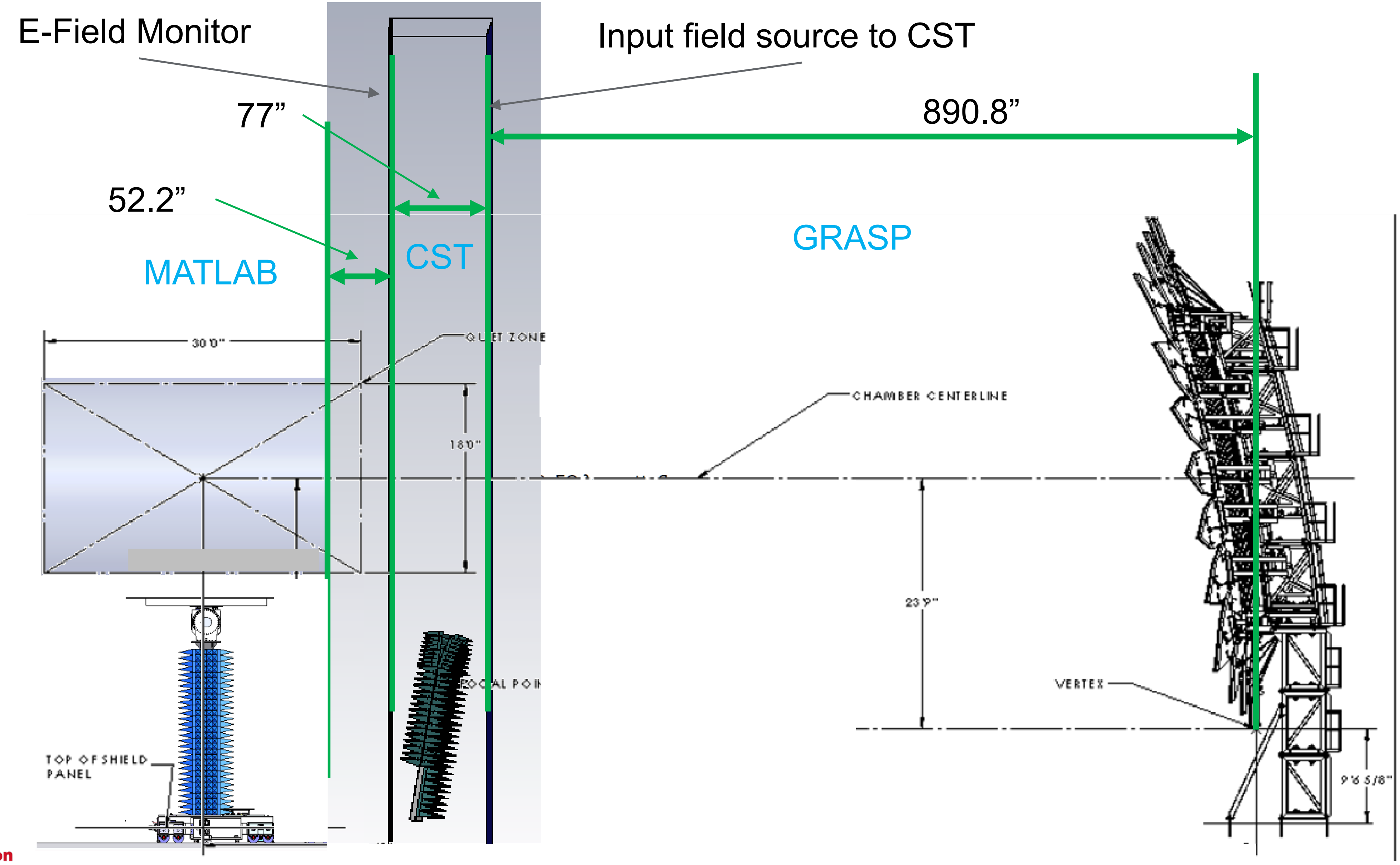
- The wall diffraction problem was anticipated before detailed analysis was performed
- As a risk mitigation strategy, the RAM wall was designed to come in multiple sections to vary the height
- The wall could also be tilted in attempt to mitigate backscatter



Modeling Assumptions and Approximations

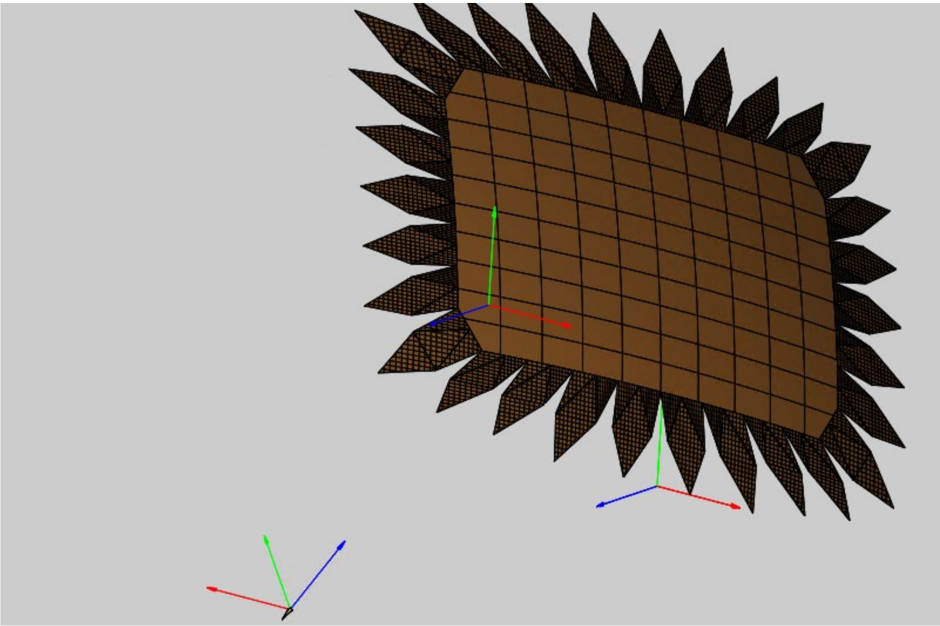
- The NSI-MI provided GRASP model assumes an ideal, Gaussian feed
- The number of field points exported from GRASP meets the λ/2 Nyquist criterion to avoid aliasing in the plane wave spectrum
- GRASP fields on a plane provide sufficient accuracy for this application
- The solution fields generated by CST meet the λ/2 Nyquist criterion to avoid aliasing in the plane wave spectrum
- The sled that the RAM wall is mounted on is in an area where the field amplitude is weak and can be left un-modeled without significantly impacting results

Graphical Overview of Modeling Process



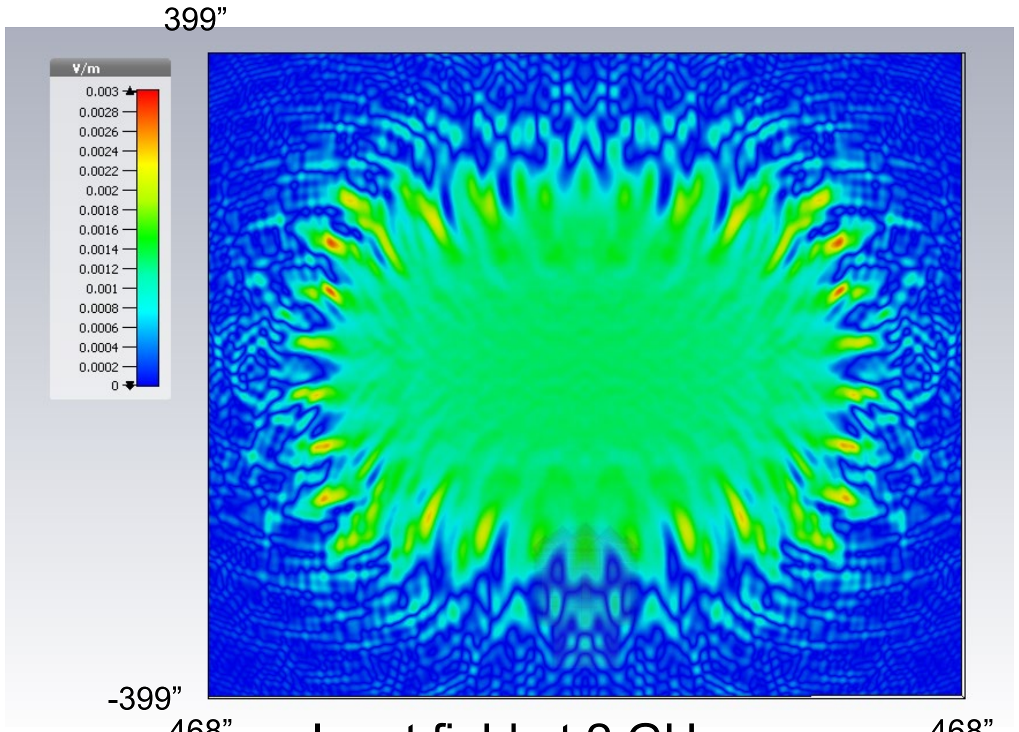
PO/PTD GRASP Simulation

- GRASP model of reflector provided by NSI-MI Technologies
  - Feed horn pattern modeled as a Gaussian Beam
  - Simulation with physical optics
- Monitor fields on a Planar Grid with half wavelength steps at the highest frequency (10 GHz for our case)
- Export *.grd files

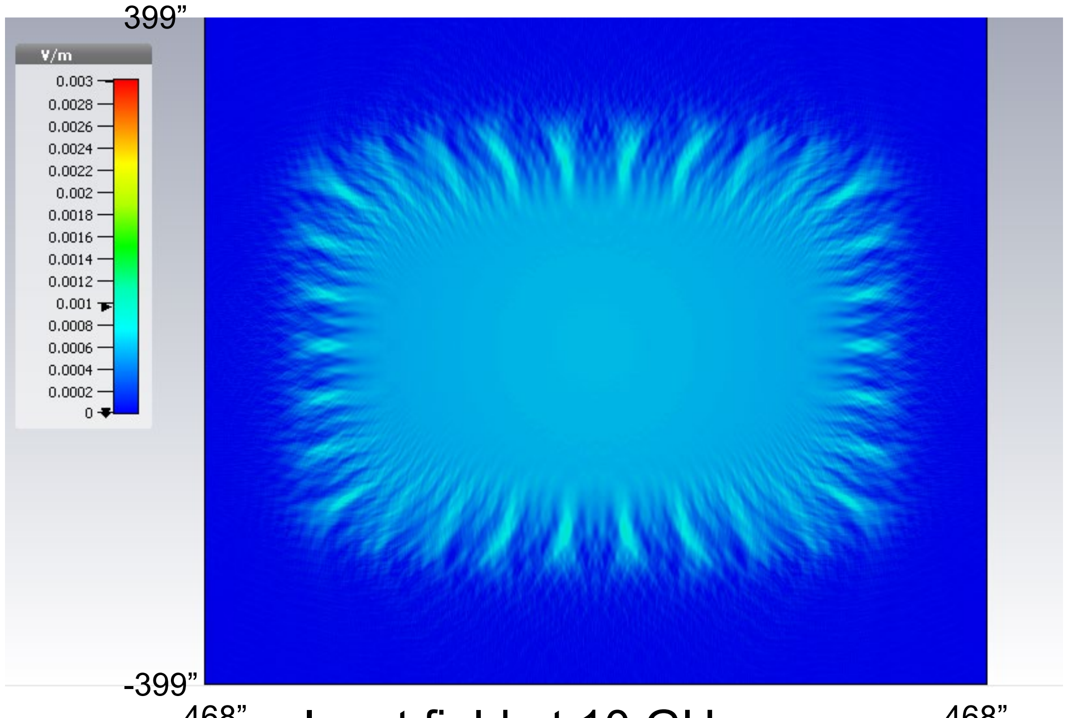


Convert GRASP Output to CST Input

- GRASP results were converted to a XML CST field source
- The field source excites the absorber wall using CST's time domain solver
- The fields can be monitored at any down-range position after the wall
  - This reduces the required mesh



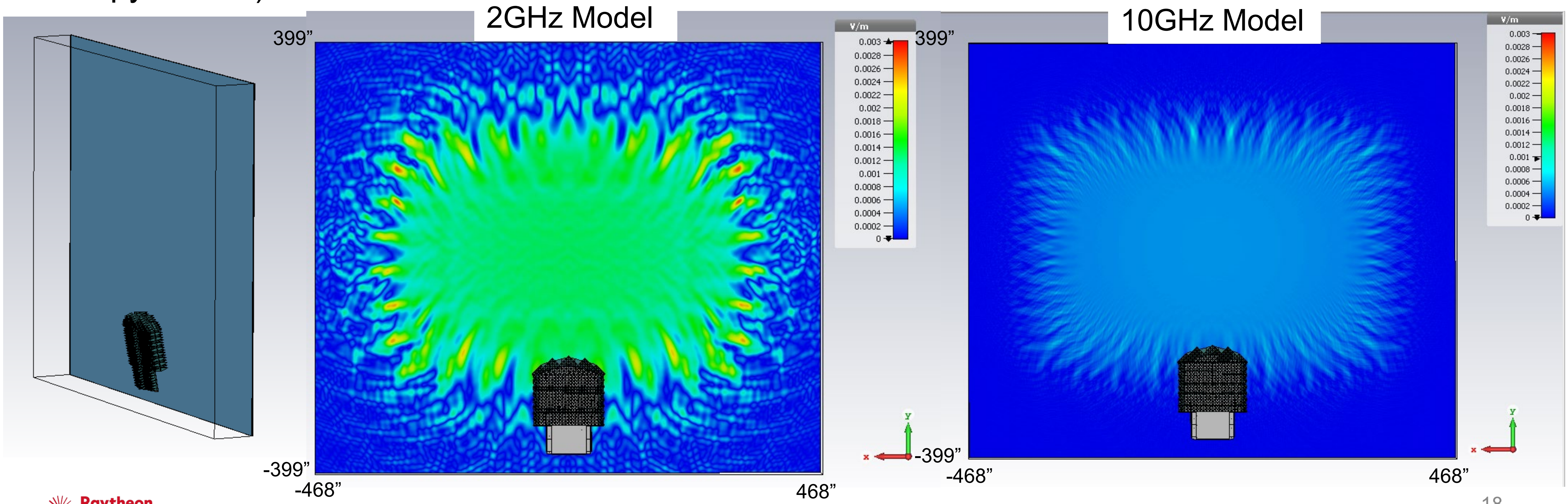
Input field at 2 GHz



Input field at 10 GHz

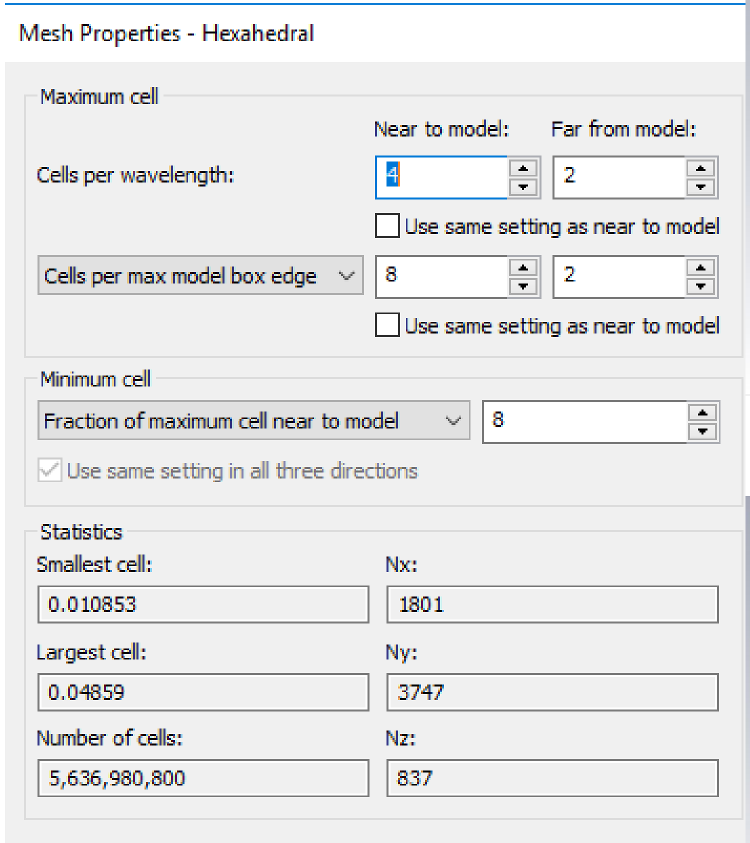
CST RAM Wall Model

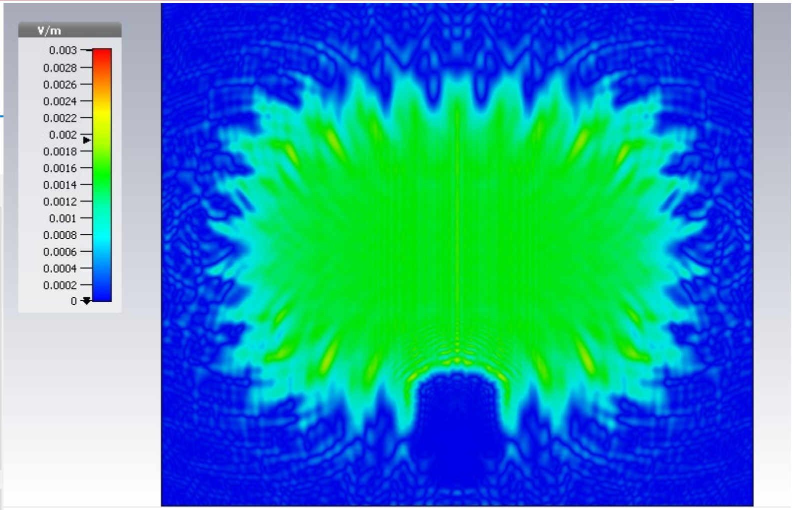
- Structure modeled as PEC
- Wall modeled in sections – most analysis focused on the case with 1x4ft, 1x2ft, and a 10° canted crown section installed
- Absorber modeled as PPG/Cuming Microwave SFC-18 (18” pyramidal) and SFC-24 (24” pyramidal)



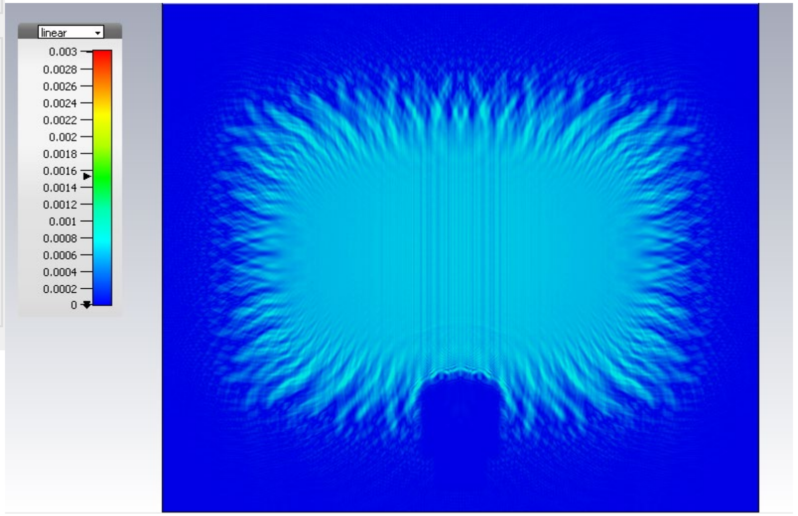
CST Output

- 6 hours to complete one simulation
  - Single frequency, single polarization field source
- MPI computing on 8 nodes with
  - 256 GB RAM
  - 2 CPUs
  - 28 Cores
- CST 2018 Transient Solver
  - Accuracy set to -25 dB
  - One symmetry plane
    - Simulations with no symmetry planes were also run with similar results, but the solving time nearly doubled
  - Subvolume field monitor on XY plane
  - Mesh as shown to the right
- Results exported to ASCII files at a step size sufficient to meet Nyquist criteria





2 GHz Results

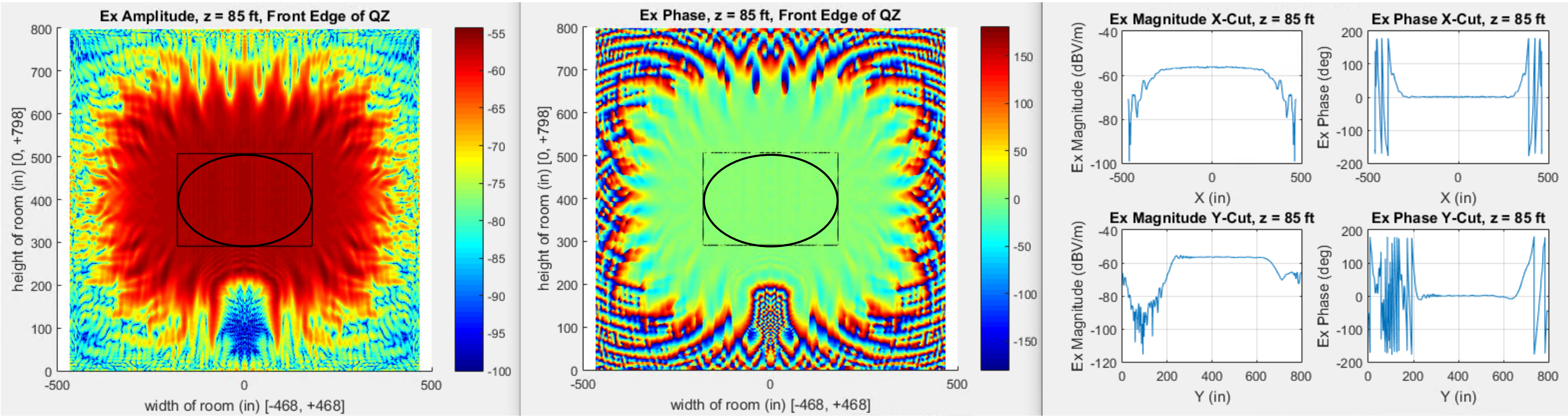


10 GHz Results

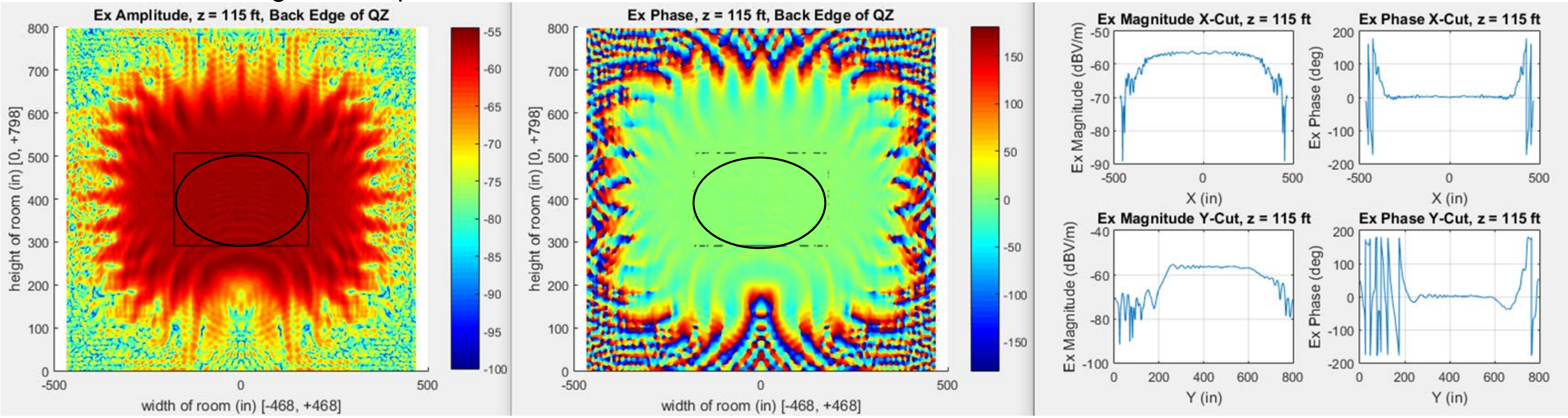
Propagate Fields Downrange in PWS

- Import fields to MATLAB
- Convert the fields to plane-wave spectrum (PWS)
  - $\boldsymbol{F_T}\left(k_x, k_y, z = 0\right) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \boldsymbol{E_T}(x, y, z = 0)e^{j(k_x x + k_y y)}dxdy$
- Convert PWS at desired downrange position to fields
  - $\boldsymbol{E_T}(x, y, z = Z_{DR}) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \left[\boldsymbol{F_T}\left(k_x, k_y\right) - \hat{\boldsymbol{e}}_{\boldsymbol{z}} \frac{\boldsymbol{k_T}\cdot\boldsymbol{F_T}\left(k_x,k_y\right)}{k_z}\right] e^{-j(k_x x + k_y y + k_z Z_{DR})}dk_x dk_y$
- pnfSim MATLAB package contains functions that do this efficiently

2 GHz Quiet Zone Field Examples

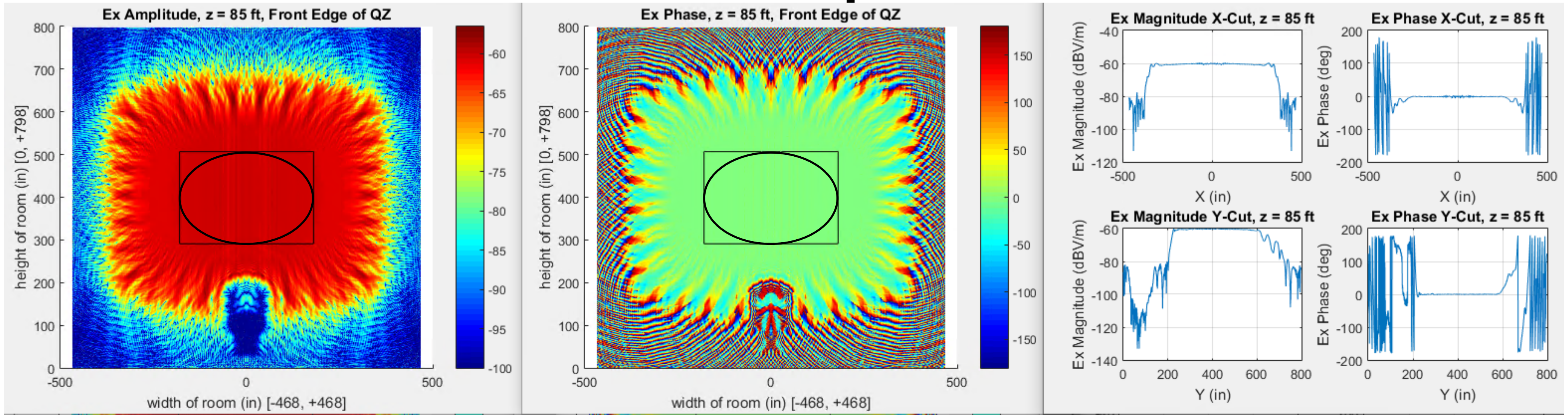


Fields at the front edge of the quiet zone

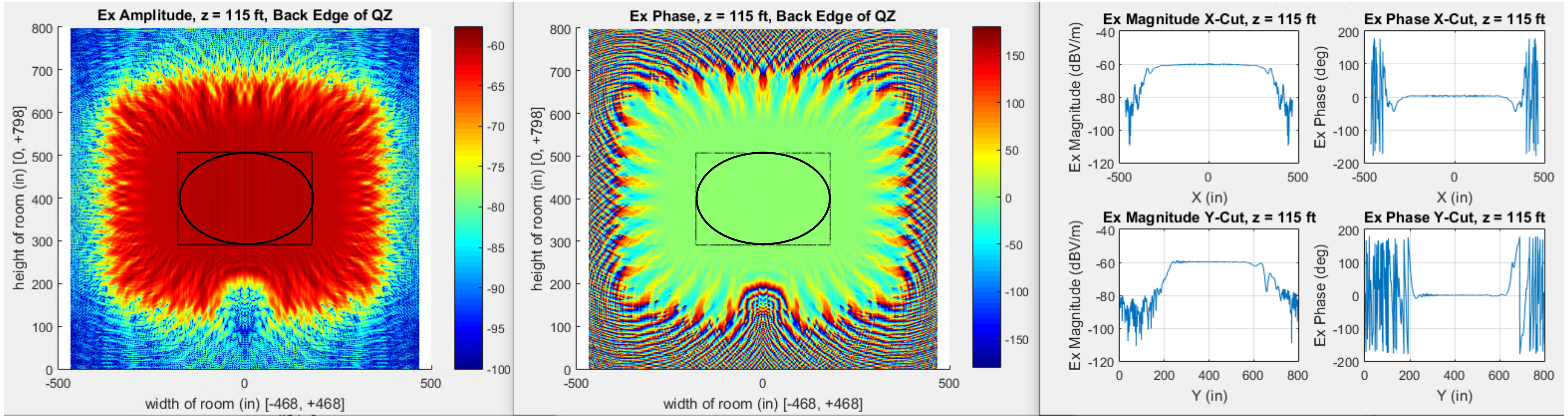


Fields at the back edge of the quiet zone

10 GHz Quiet Zone Field Examples



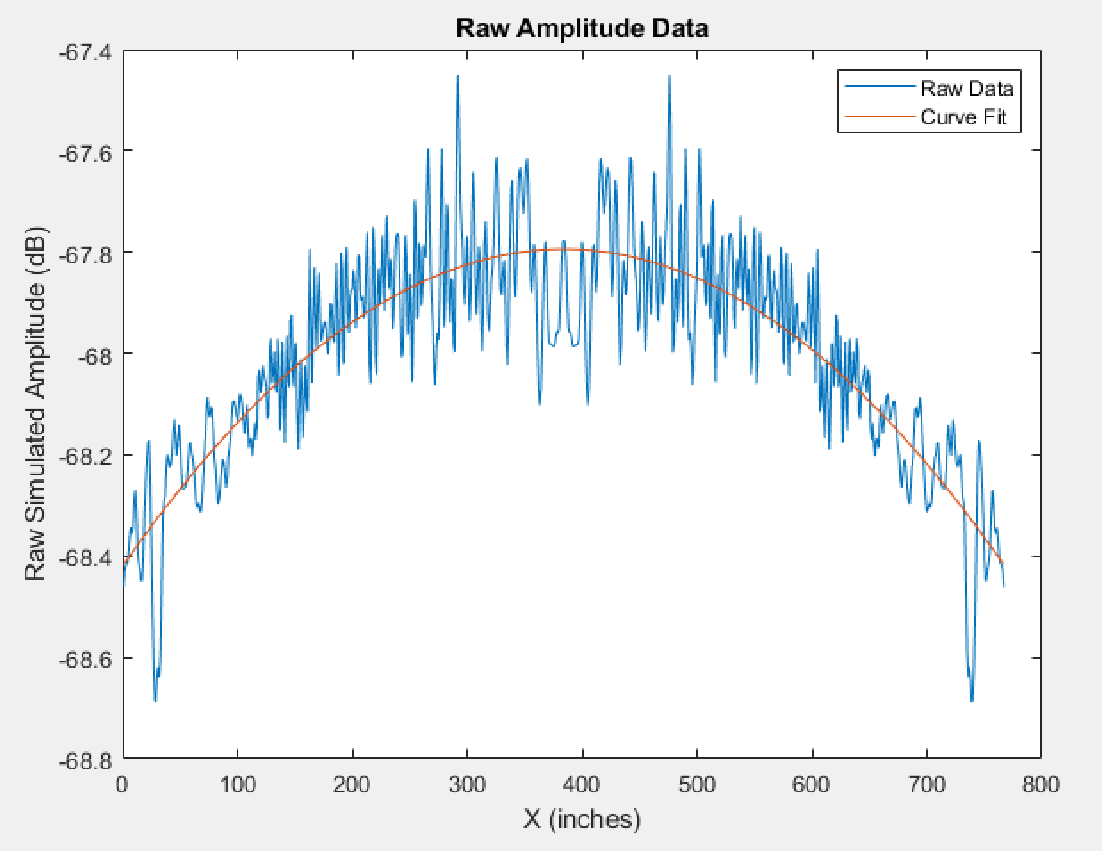
Fields at the front edge of the quiet zone

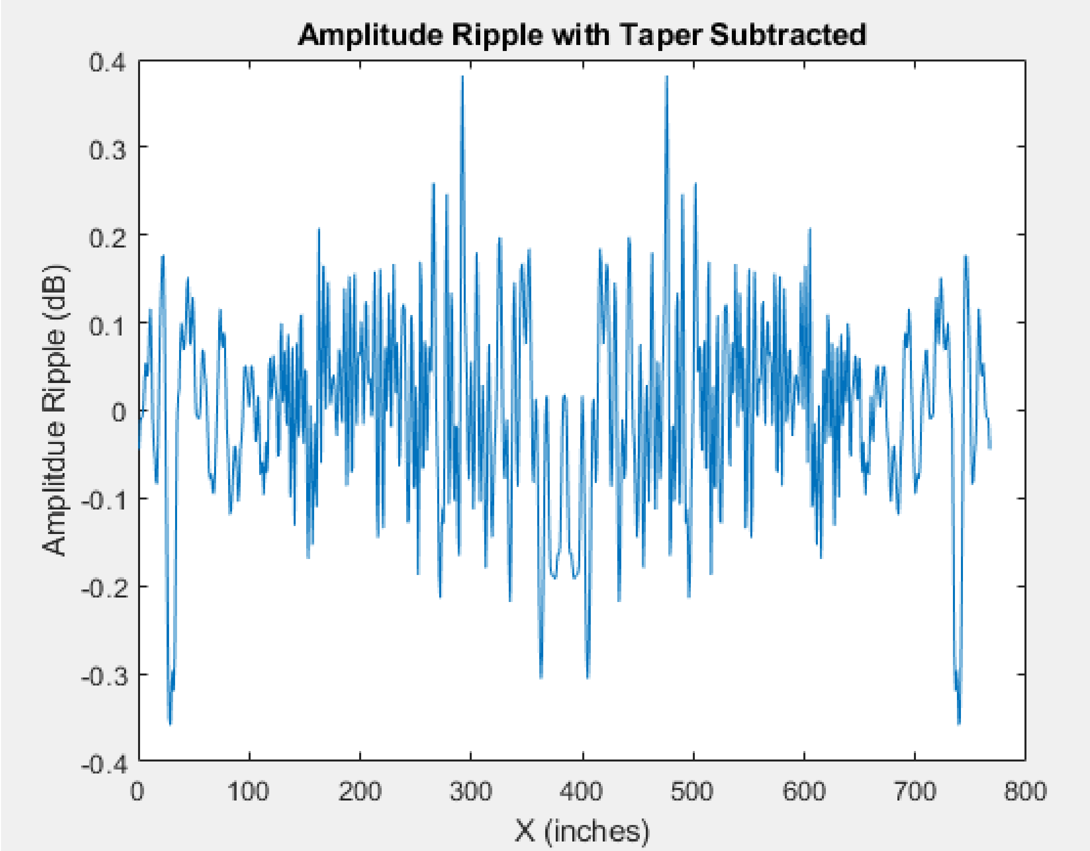


Fields at the back edge of the quiet zone

QZ Field Cut Metrics

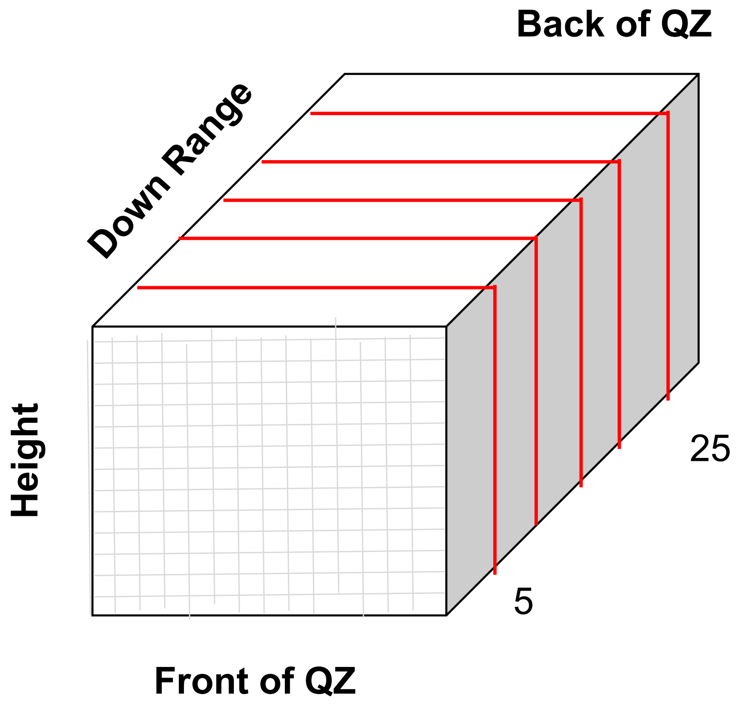
- Extract the ripple from each cut by fitting a 2nd order polynomial to the raw cut and subtracting that bias
  - MATLAB: poly2 fit with LinearLeastSquares
- Generate statistics on the resultant ripple plot for each horizontal cut at a given downrange location



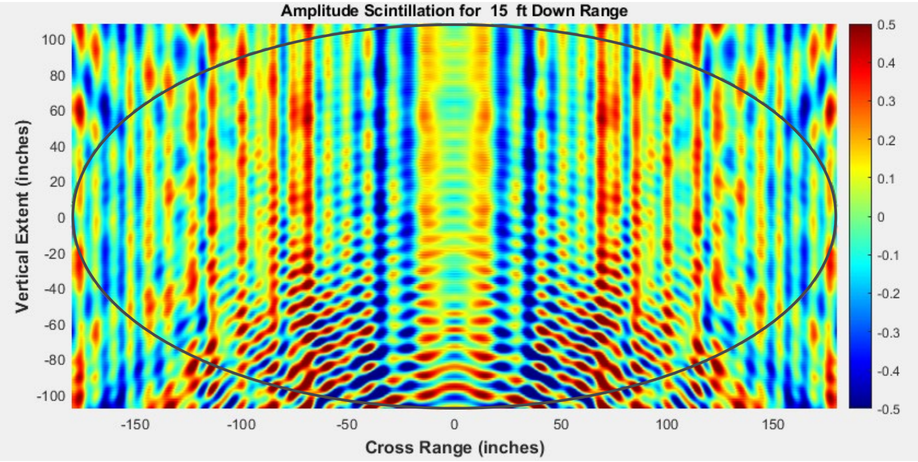


Quiet Zone Analysis

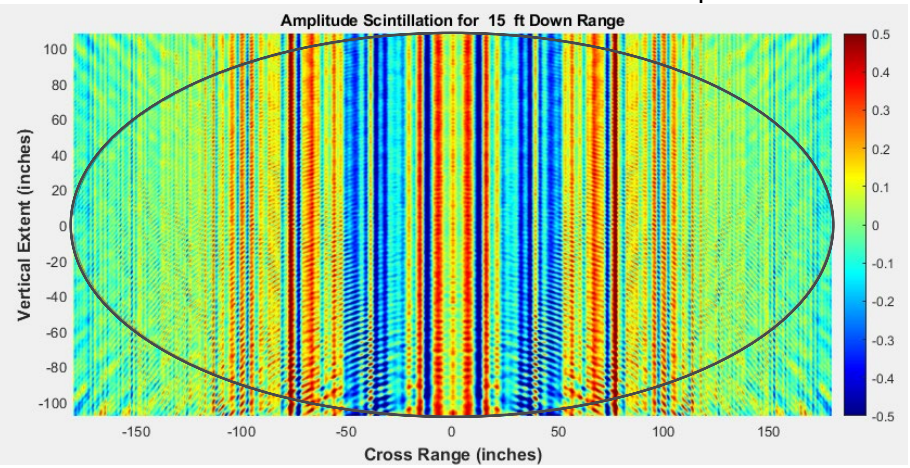
- The quiet zone is analyzed in down range stations – every 5' down range (7 total stations)
- The field at each station the field is sampled at 0.5" increments in each direction
- Loop over rows in quiet zone
- Loop over down range stations in 5' intervals from 0' to 30'
- Compute statistics on scintillation
- Determine whether the ripple is acceptable for all down range stations



Simplified illustration of QZ, QZ is elliptical



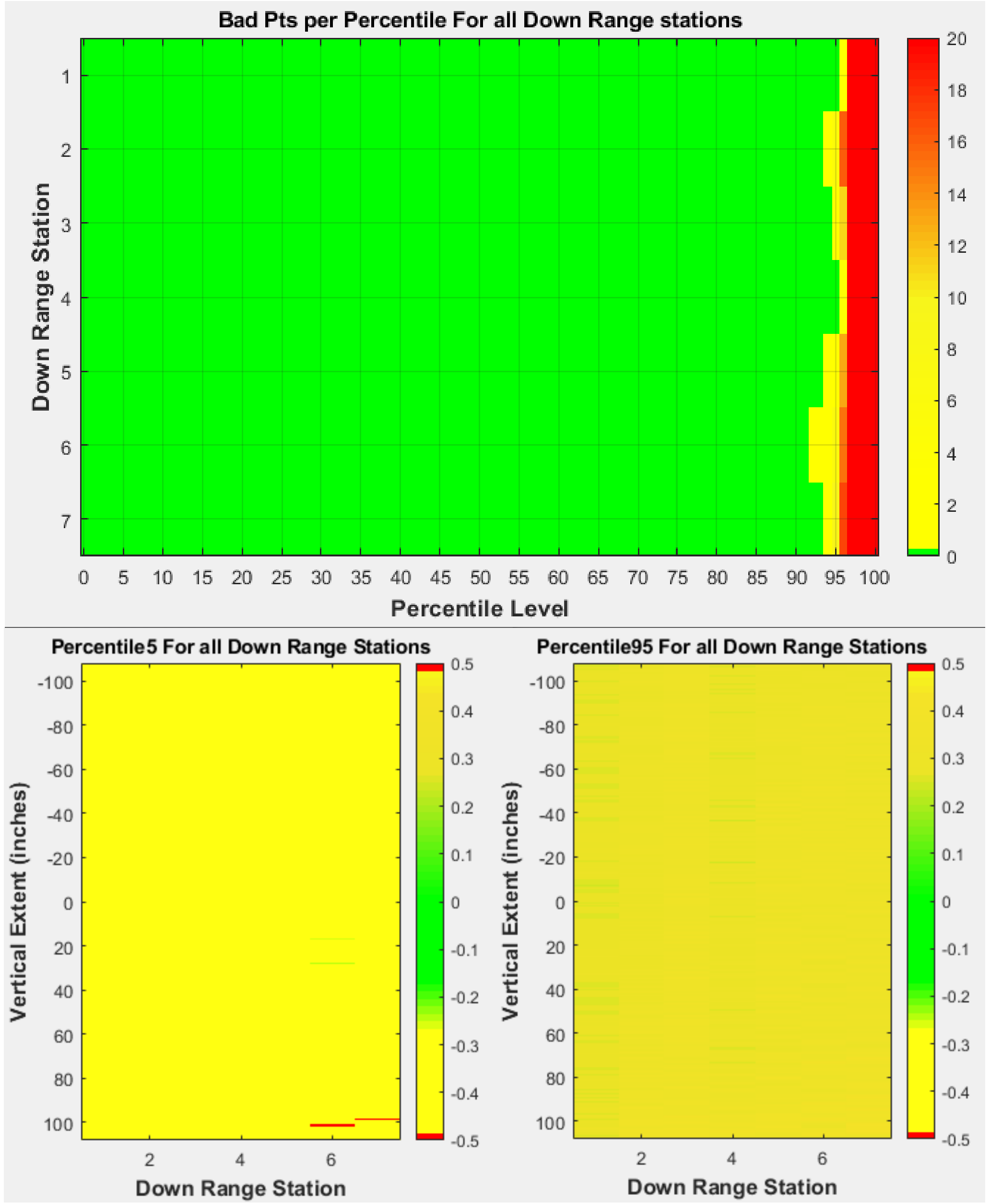
Amplitude scintillation, 15' down range, 2 GHz H-pol



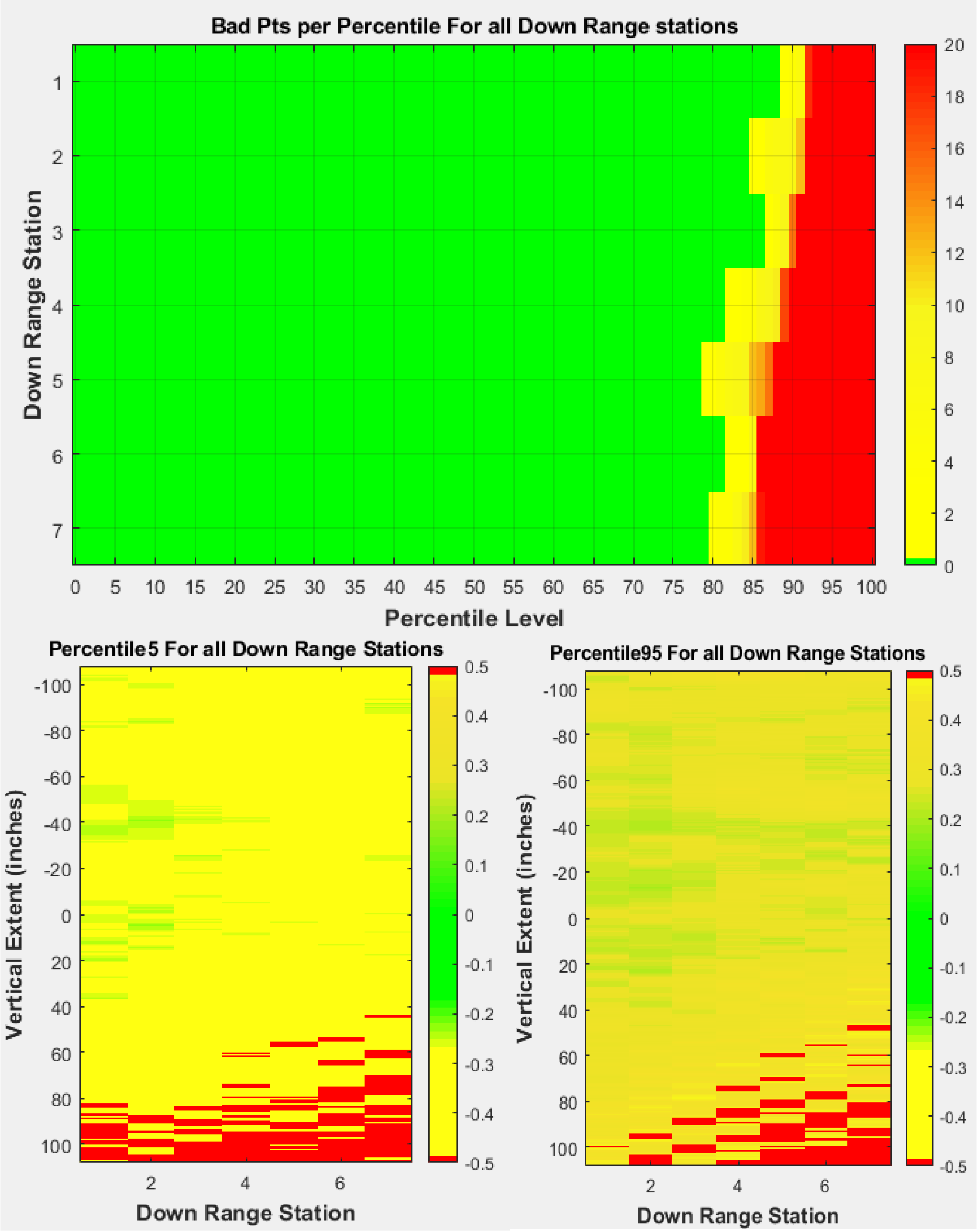
Amplitude scintillation, 15' down range, 10 GHz H-pol

Acceptance Criteria – Amplitude Ripple

- 90% acceptance criteria allows a total of 10% of points in field to be out-of-spec
- Top plot shows the number of points in the QZ exceeding the ripple spec
- Bottom plots show the 5th and 95th percentiles of the ripple for each down range station
  - 5th percentile contains negative ripple points
  - 95th percentile contains positive ripple points
- 90% of the QZ is within spec at all down range samples for this model
  - Shown is the 10 GHz HH simulation of a 6' section of wall with 18" SFC-18 absorber, 10° tilt



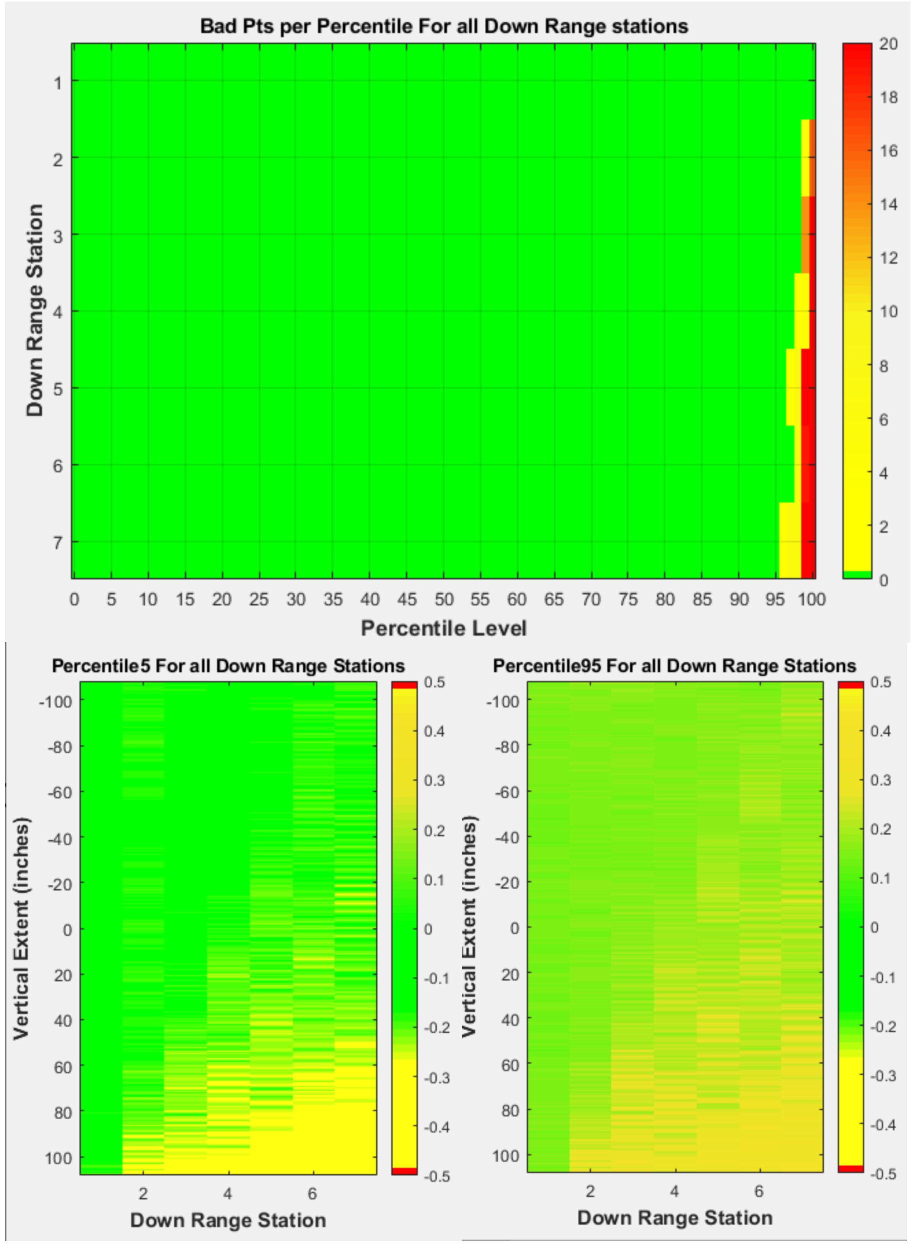
Acceptance Criteria – Amplitude Ripple, Comparison



- As a comparison with the results from the previous slide, shown here is the result for the previous case at 2GHz

Acceptance Criteria – Amplitude Ripple, Comparison

- Shown here is a 10 GHz case, but with an R-card taper on top of the RAM wall crown



Conclusions

- We developed and demonstrated a workflow for simulating the quiet zone fields in a large compact range, including the effects of diffraction from a RAM wall
- This simulation was used to asses and optimize the RAM wall configuration to minimize scattering in the quiet zone
- The simulation workflow will allow Raytheon to pre-select test configurations, saving hundreds of hours in experimentation with field probing

References

- [1] S. F. Gregson and C. G. Parini, "Examination of the effect of common CATR quiet zone specifications on antenna pattern measurement uncertainties," *Loughborough Antennas & Propagation Conference (LAPC 2017)*, Loughborough, 2017, pp. 1-5, doi: 10.1049/cp.2017.0276.
- [2] Xiaoming Liu and Junsheng Yu, "Effect of Quiet Zone Ripples on Antenna Pattern Measurement," *Progress In Electromagnetics Research M*, Vol. 75, 49-60, 2018.
- [3] C. G. Parini, R. Dubrovka and S. F. Gregson, "Computational electromagnetic modelling of compact antenna test range quiet zone probing: A comparison of simulation techniques," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, Switzerland, 2016, pp. 1-5, doi: 10.1109/EuCAP.2016.7481234.
- [4] C. H. Currie and N. C. Currie, “Radar Reflectivity Measurement: Techniques and Applications”, Chapter 9, MA, Boston: Artech House, 1989.
- [5] G. T. Ruck et al., “Radar Cross Section Handbook”, New York & London: Plenum Press, 2002.
- [6] J. Sorgnit et al., “Uncertainty Analysis Procedures for Dynamic Radar Cross Section Measurements at the Atlantic Test Range,” National Institute of Standards and Technology, Boulder, CO, 1998.
- H. Anzai et. al, “The Equivalent Representation of Pyramidal Absorbers and its Application to the Analysis of Electromagnetic Wave Absorber’s Characteristics”, 1995 IEEE International Symposium on Electromagnetic Compatibility

Thank you.