Power Density Calculations

- The following slides summarize the expected power density levels with respect to human exposure and aircraft susceptibility. Results show no hazard exists for aircraft. Minimal controls for personnel will be established, as described herein.
- Power density levels will be verified to be within safe limits (per 47 CFR 1.1310) for personnel at the initial turn-on of the RF equipment, and at any time test setup changes are made that affect power density levels of the test or surrounding areas.
- Electromagnetic energy exposure control measures will be documented in an RF safety control plan describing elements such as signage, procedures, personnel training, and RF survey measurements.

Objective of Prototype Demonstration System (PDS) RF Emissions Analysis

- Conduct analysis to determine if RF emission levels will exceed safety levels accessible to personnel and aircraft
- Approach is to determine if RF emission levels outside the radome enclosure side walls are below most stringent safety standards
  - If, directly outside the radome enclosure side walls, RF emission levels are below Maximum Permissible Exposure (MPE) limits, then all RF emission levels in areas accessible to personnel will be below MPE limits
- Conduct a power density calculation on the vertical sides of the metal box
- Conduct a power density calculation along the peak of the beam from the antenna face to 4 km above the antenna
  - Confirm legitimacy of the analysis by comparing results against theory
  - Determine minimum safe aircraft altitude (confirm no impact to aircraft)

Overview of Prototype Demonstration System (PDS)

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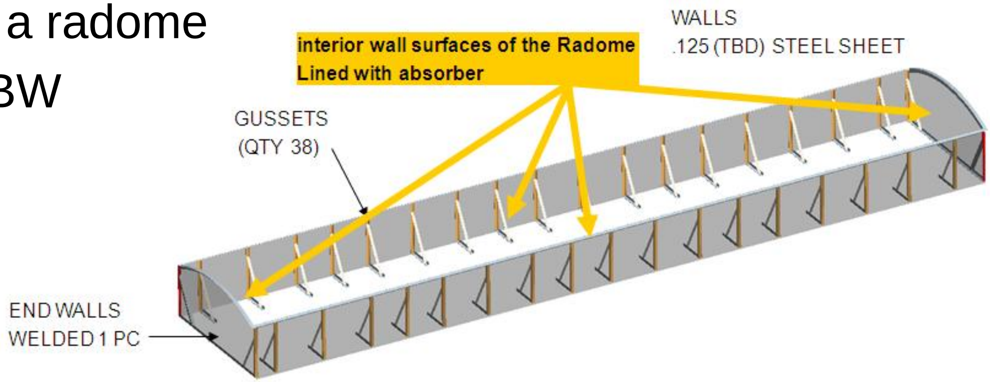
- Conducted outdoors at IADC
  - Area of Antenna: 4.66 m^2
  - Gain of Array: 38 dBi
  - Transmit Power: 67 dBm (worst case, does not include COAX losses from transmitter to antenna)
  - 2.45 ms pulse, 30% duty
- Transmit array is enclosed on five sides in a RF absorber lined metal box that is located on top of a 53' metal isocontainer roughly 4.2 meters above the ground
- The array will transmit a fixed pulsed LFM waveform skyward through a radome
  - 13 deg AZ BW, 0.37 EL BW
  - +/- 50 deg AZ
  - +/- 50 deg EL

Radome Structure

RF absorber lined Metal side walls, floor below array is metal



Power Density Analysis Calculation Methodology

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$\text{Vector from element } (\mathrm{x}_{\mathrm{elem}}, y_{elem}, z_{elem}) \text{ to observation point } (\mathrm{x}_{\mathrm{obs}}, y_{obs}, z_{obs})$

$M = \#\, of\ elements\ in\ array\ antenna$

$R_{vec} = (x_{obs} - x_{elem})\hat{x} + (y_{obs} - y_{elem})\hat{y} + (z_{obs} - z_{elem})\hat{z}$

$R = \sqrt{(x_{obs} - x_{elem})^2 + (y_{obs} - y_{elem})^2 + (z_{obs} - z_{elem})^2}$

$normal = \hat{z}$

$$\cos(\theta) = \frac{normal \bullet R_{vec}}{R}$$

$\text{Power Density at observation point } (\mathrm{x}_{\mathrm{obs}}, y_{obs}, z_{obs})$

$$\mathrm{P}_{\mathrm{density}} = \frac{P_{TX} \bullet Area}{\lambda^2} \left| \frac{1}{M} \sum_{n=1}^{M} \frac{\cos^{0.5}\theta \bullet e^{jkR_n}}{R_n} \right|^2$$

$R_n = R\ \ from\ element\ n\ to\ observation\ point$

$P_{TX} = total\ transmitted\ power;\ \ Area = total\ array\ antenna\ area$

Calculation Description

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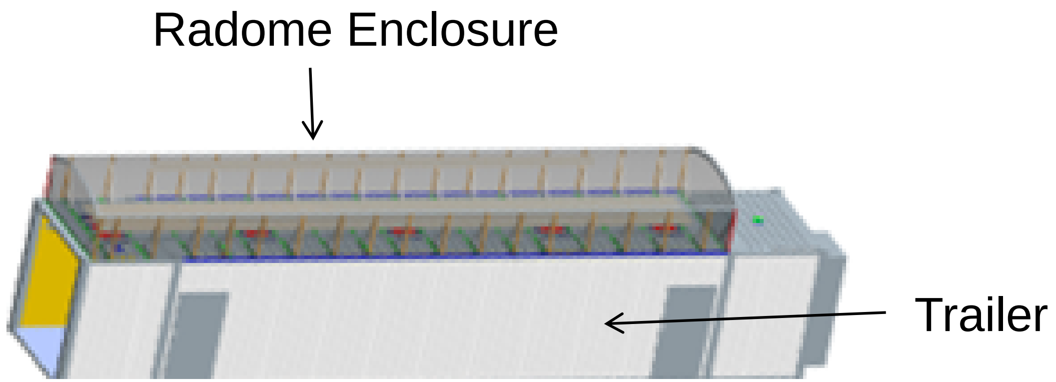
- Set up antenna source
  - Antenna source consists of M active elements
- Select a region in which to calculate the power density
  - Region is subdivided into unit cells
- Using the equation on previous slide calculate the power density on each unit cell
  - Power density is a vector summation of all the signals from each of the active elements

PDS Analysis Parameters

- Transmit frequencies 3.1 – 3.4 GHz
- Power density calculation:
  – Along a radial vector from the center of the array face to 4 km above the array
  – On a plane co-located with the side of the radome enclosure
- Radome Enclosure Dimensions:
  – 102” (2.591 m) in x-dimension
  – 540” (13.7164 m) in y-dimension
  – 52.7” (1.339 m) in z-dimension

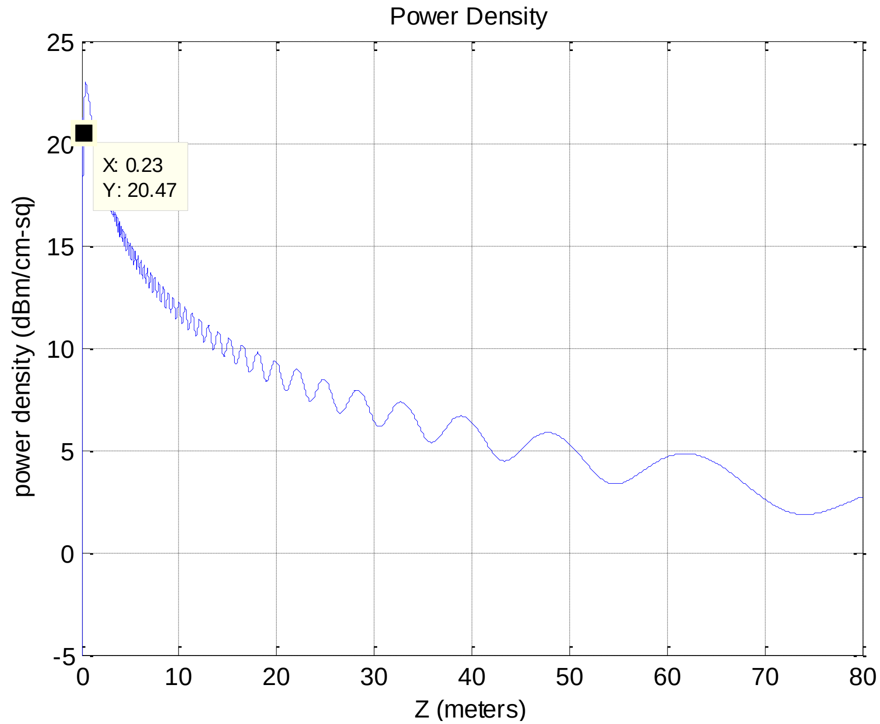


Power Density Predictions From Theory

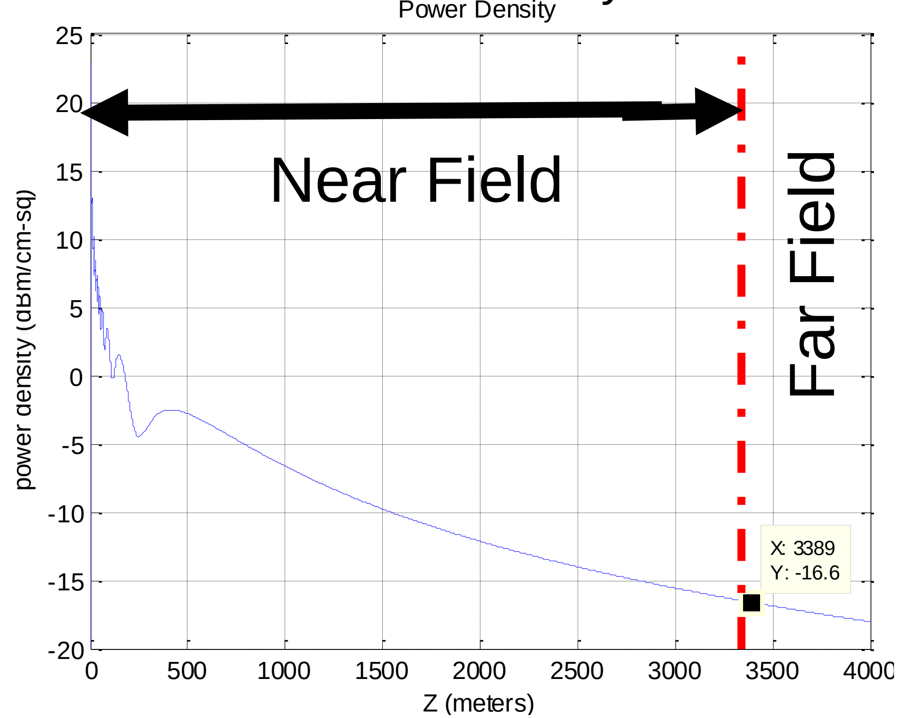
- Power Density at Array Face
  - $P_D = (P_{TX} * DF) / Area_{array}$
    - P_{TX} = 5120 Watts
    - DF = 1 (Duty Factor set to 1 for peak power analysis)
    - $Area_{array} = 4.66\ m^2$
    - $P_D = 1099.6\ W/m^2$ (20.41 dBm/cm^2)
- Power Density in Far Field
  - $P_D = P_{TX}\ G_{TX}\ DF / (4\pi R^2)$
    - P_{TX} = 5120 Watts
    - G_{TX} = 38 dBi
    - R = Far Field Distance = 3389 m
    - DF = 1 (Duty Factor set to 1 for peak power analysis)
    - $P_D = 0.2238\ W/m^2$ (-16.54 dBm/cm^2)

PDS Power Density Calculations Along Boresite

Near Field Power Density



Near Field to Far Field Power Density



Near Field and Far Field Power Density Levels Comply With Predictions

Aircraft & Personnel RF Emissions Requirements

Document	Comments	MPE (dBm/cm-sq)	PDS Predicted Performance
IEEE C95.1	Human Exposure (Uncontrolled)	0	-6.4 dBm/cm-sq (worst case at radome height)
	Human Exposure (Controlled)	10	-6.4 dBm/cm-sq (worst case at radome height)
AFMAN 91-201	EED on Aircraft	10	Below this limit from 20 meters and above
14 CFR 23.1308, 25.1317, 27.1317, 29.1317 (Environment I)	Civil Aircraft (Peak)	34	Meets more stringent AFMAN 91-201 at 20 meters and above
	Civil Aircraft (Average)	10	Below this limit peak from 20 meters and above
14 CFR 23.1308, 25.1317, 27.1317, 29.1317 (Environment II)	Civil Aircraft (Peak)	34	Meets more stringent AFMAN 91-201 at 20 meters and above
	Civil Aircraft (Average)	6	Below this limit from 20 meters and above
47 CFR 1.1310	Human Exposure (average)	0	-6.4 dBm/cm-sq (worst case at radome height)

PDS poses not RF emissions issues to aircraft or personnel

Aircraft Minimum Safe Altitude

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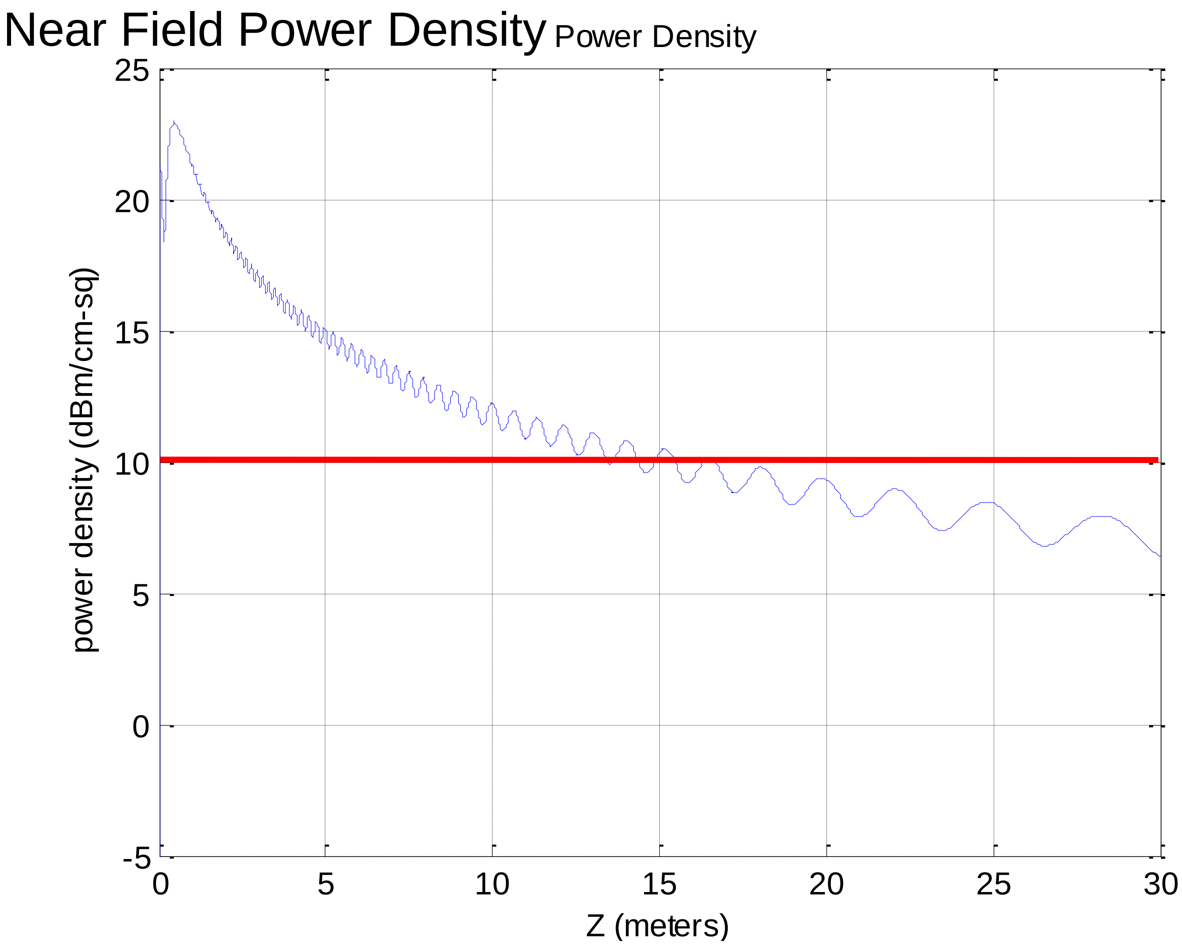
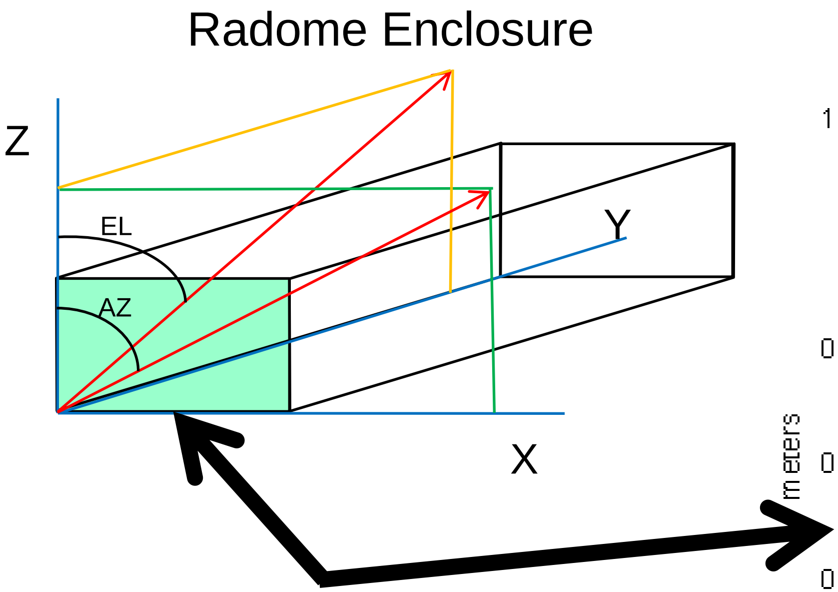
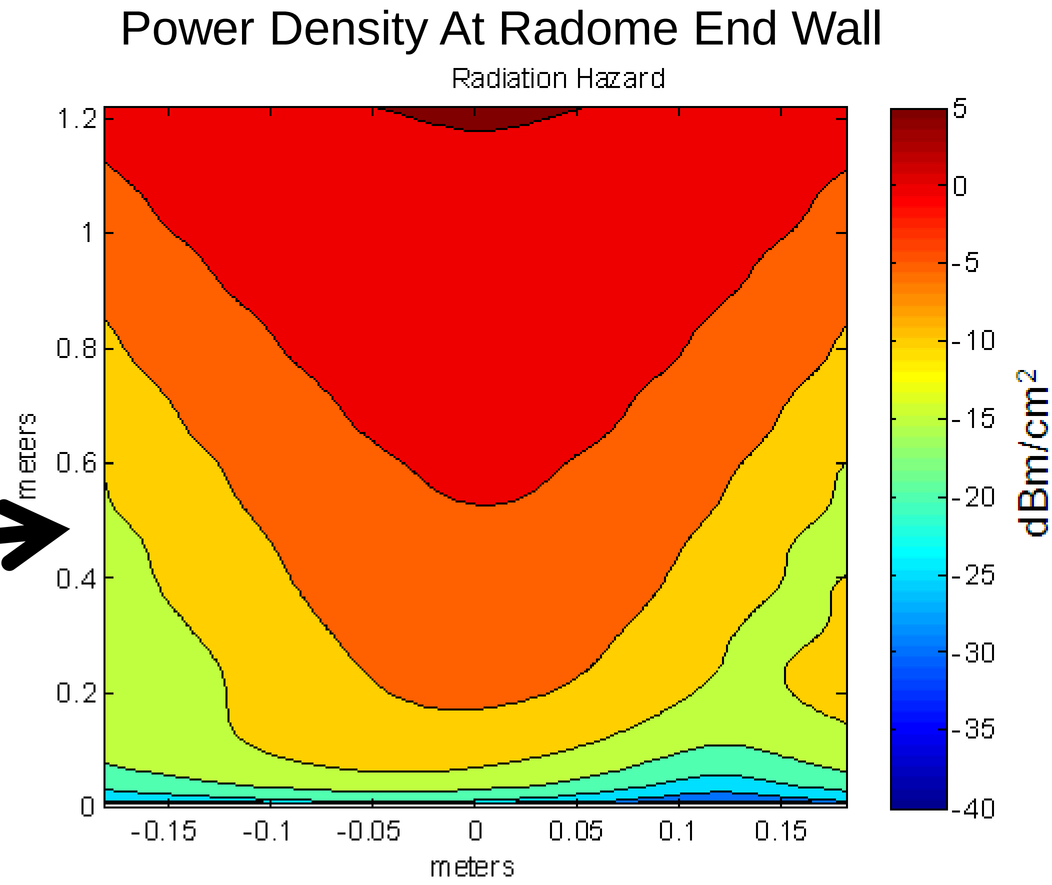


Power Densities are Below The Requirement Specified in AFMAN 91-201 from 20 meters and above

Personnel RADHAZ Analysis

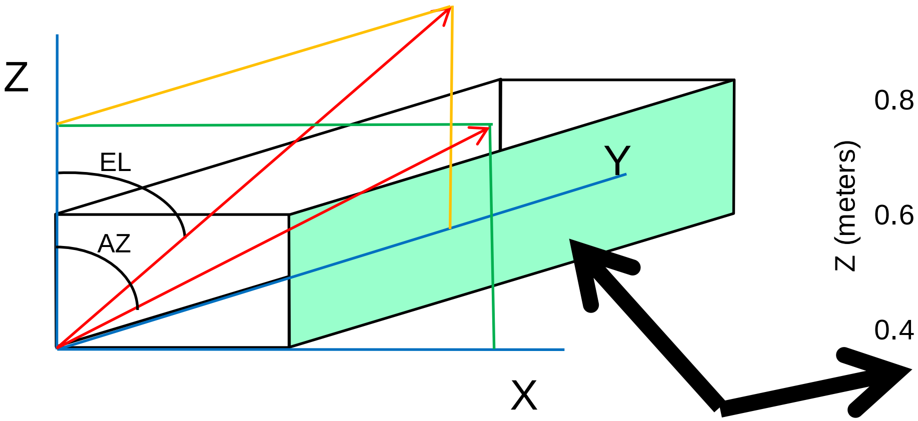
Power Density on XZ Plane 3.1 GHz (AZ: 0.0˚, EL: Max)



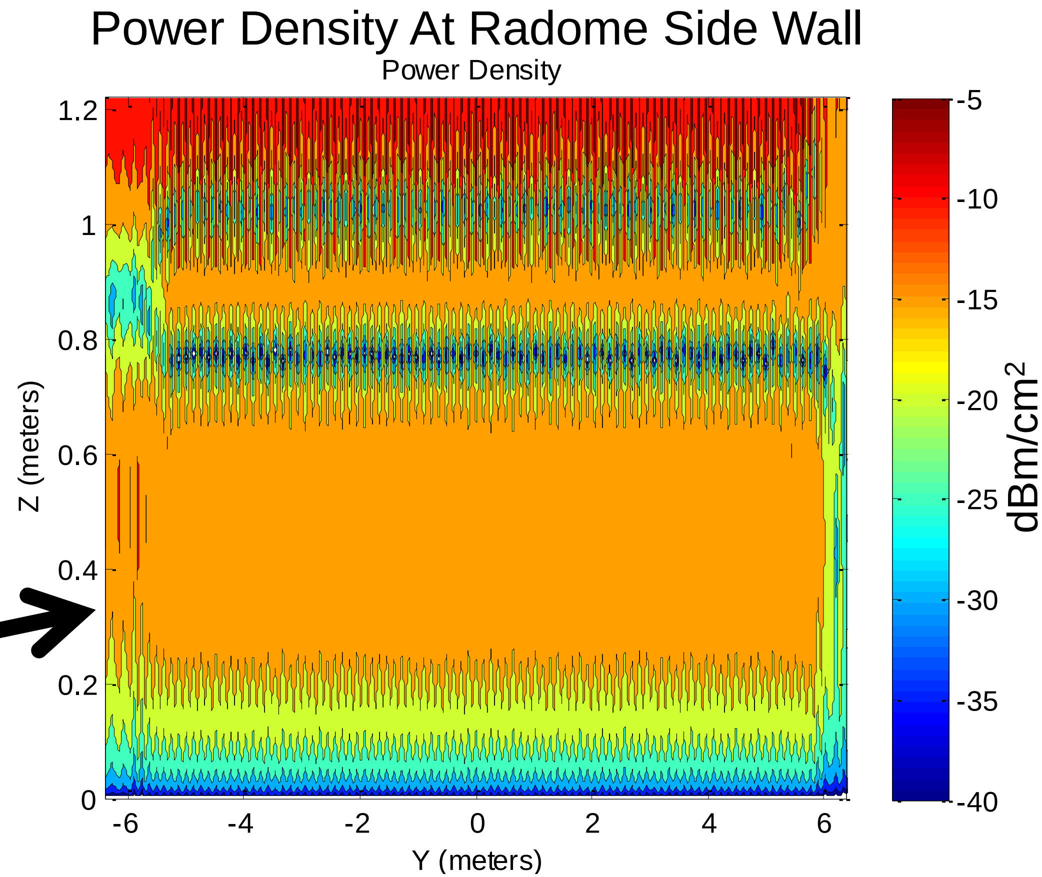


Peak Power Density on Metal End Wall (without absorber) is 5.29 dBm/cm^2

Personnel RADHAZ Analysis
Power Density on YZ Plane 3.1 GHz (AZ: 0.0˚, EL: Max)



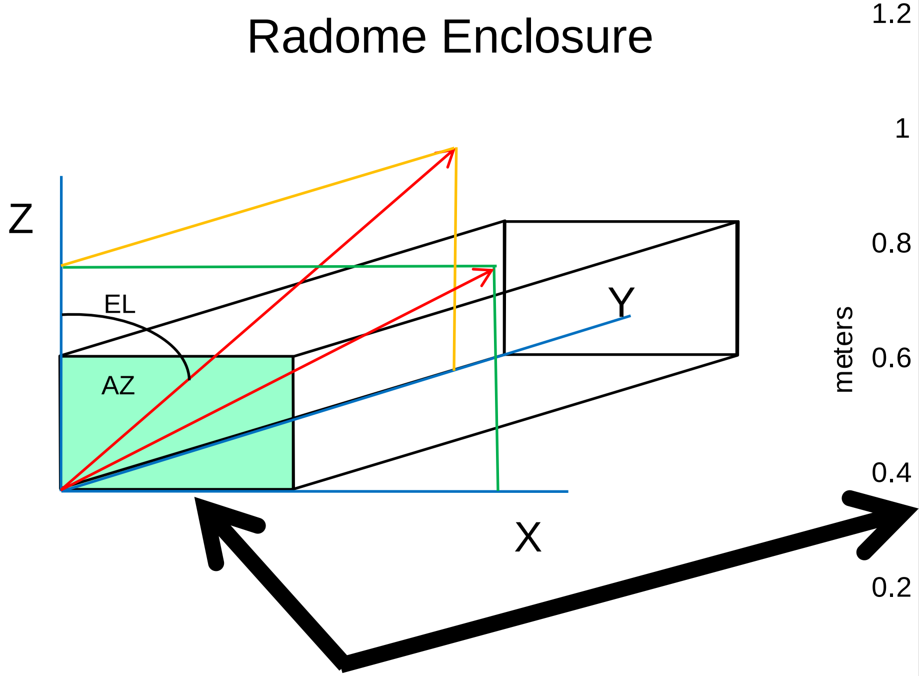
Radome Enclosure

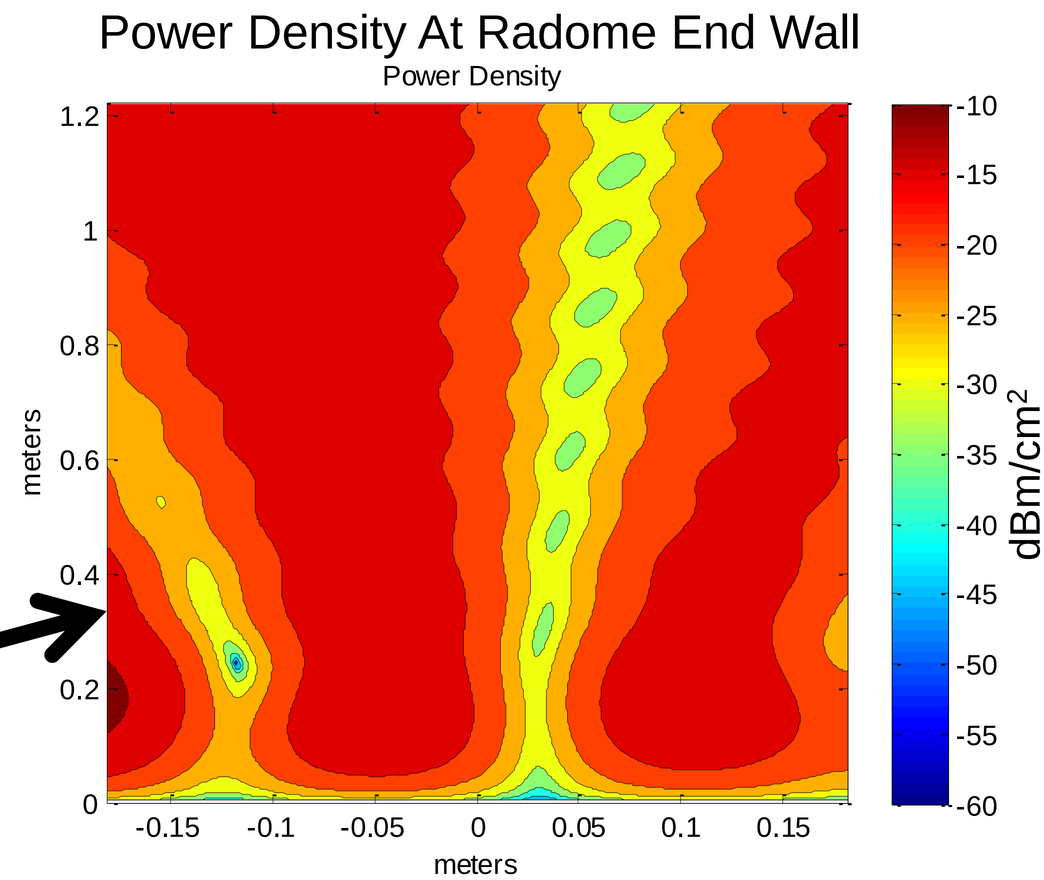


Peak Power Density on Side Metal Wall (without absorber) is -3.07 dBm/cm^2

Personnel RADHAZ Analysis

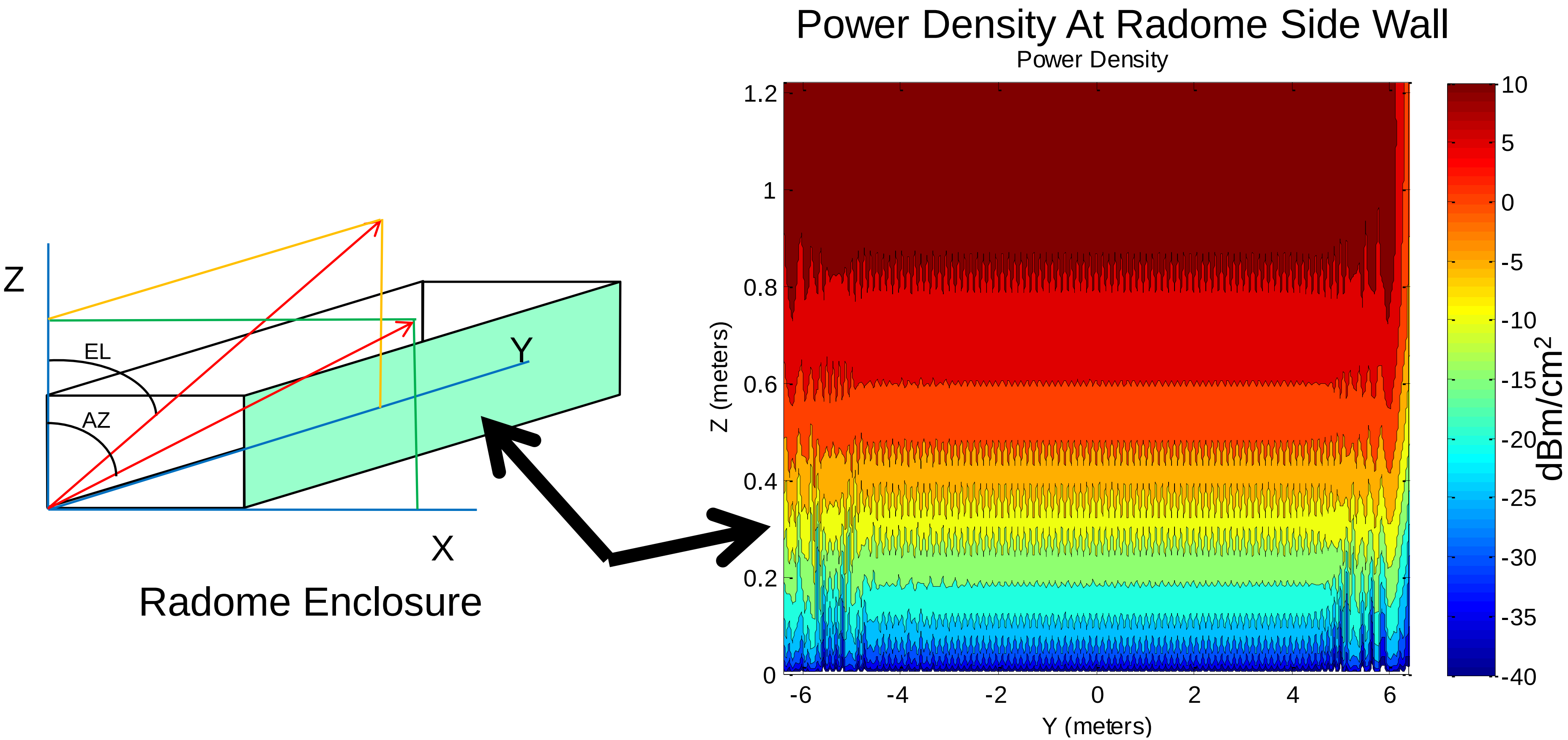
Power Density on XZ Plane 3.1 GHz (AZ: 50.0˚, EL: Max)





Peak Power Density on Radome End Metal Wall (without absorber) is $-9.11\ dBm/cm^2$

Personnel RADHAZ Analysis
Power Density on XZ Plane 3.4 GHz (AZ: 50.0˚, EL: Min)



Peak Power Density on Metal Wall (without absorber) is 13.60 dBm/cm^2

Return Loss of Radome Enclosure RF Absorber

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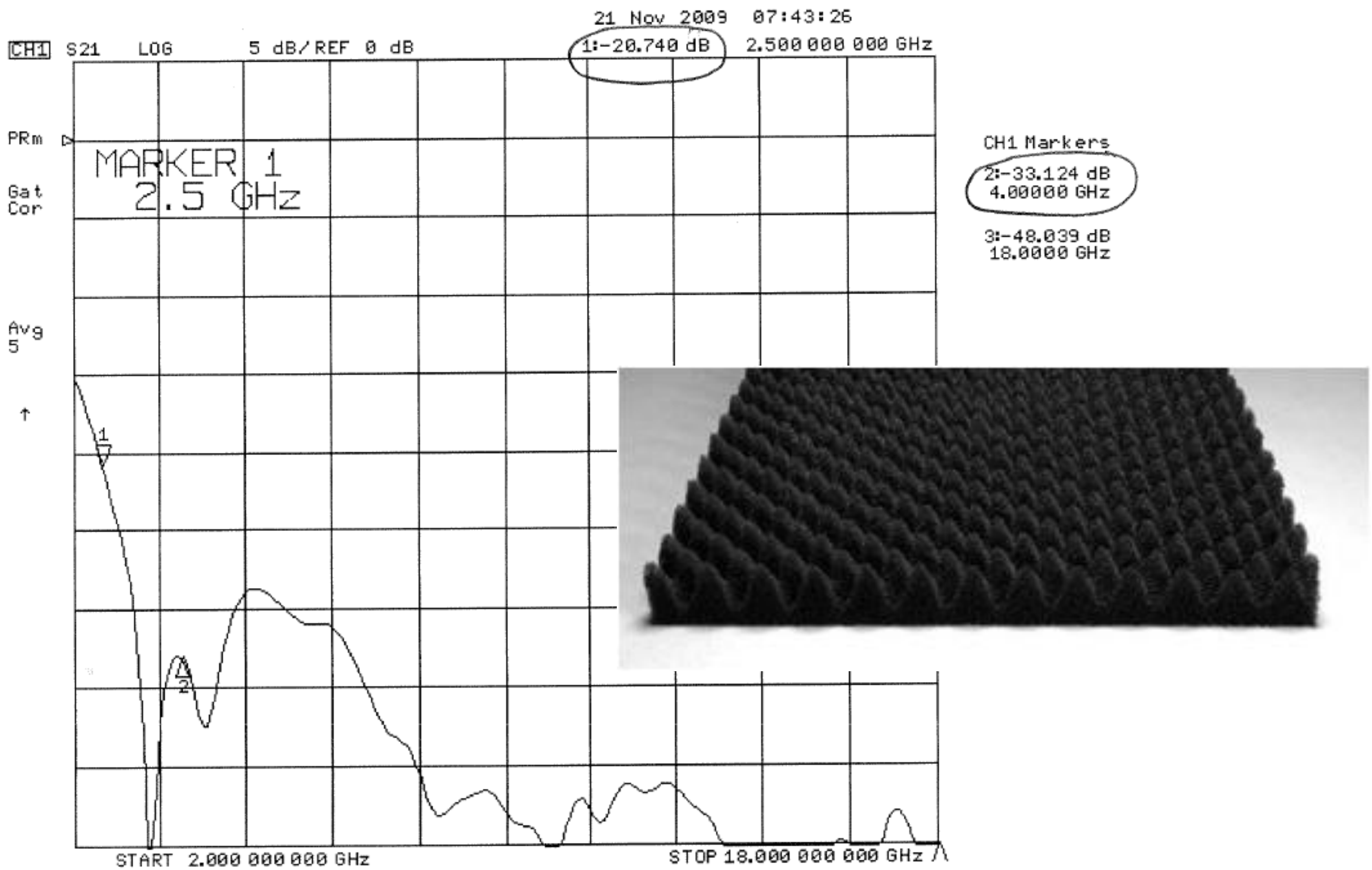

Return Loss of 30 dB and 40 dB at the Band Edges
Translate into 15 dB and 20 dB One Way Insertion Loss.

RF Transmission Through Absorber

Frequency (GHz)	Plane	Scan AZ	Scan EL	Peak Power Density Inside (dBm/cm-sq)	Insertion Loss (dB)	Peak Power Density Outside (dBm/cm-sq)
3.1	XZ	0.0	Max	5.29	15	-9.71
3.1	YZ	0.0	Max	-3.07	15	-18.07
3.1	XZ	50.0	Max	-9.11	15	-24.11
3.4	YZ	50.0	Min	13.60	20	-6.40

- Insertion Loss of absorber was measured at boresite
- Shielding of Radome Enclosure is unknown (but should be at least 50 dB)
- We can make an assumption that the difference in Insertion Loss of the RF absorbing material from boresite to an incident angle off-boresite is, at worst case, equivalent to the shielding of the metal radome enclosure.

Worst Case Power Density Outside Side Walls of Radome Enclosure is – 6.40 dBm/cm^2 (well below requirement 0 dBm/cm^2) without considering additional shielding of radome enclosure

PDS RF Emissions Summary

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- Calculated power density along Z axis.
  - Very good agreement between basic equations and detailed analysis
  - Power densities are below most stringent requirements from 20 meters on up which verifies no hazard to aircraft
- Calculated power density on planes co-located with sides of radome enclosure.
  - Power densities were better than 6 dB below most stringent requirements even when the ohmic losses of the Transmit feed network were not included in the analysis, and sidewall shielding
- Results show that as long as personnel do not have access to the radome enclosure (lock out/tag out procedure) when the Transmit array is radiating, there is no risk of exposure to RF emissions above the most stringent safety limits

No Personnel Radiation Hazard Exists Outside of Radome Enclosure