Responding to Unintended Public Policy Consequences – Assessing Electromagnetic Emissions from the L3-Comm Pro-vision Airport Body Scanner System

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October 30-31, 2018

Acknowledgements

- ARA-BRD Research Team Members
  - Computations & Signal Processing:
    - Mr. Ton Van, Dr. Tri Van, Ms. Jennifer Westoven
  - RF Measurement Design, Build, Test, TSA Field Tests
    - Mr. Kevin Hamblin and Mr. Kevin LaVoy
- L3-Comm
  - Detailed ProVision 1 & 2 Design Information
    - Mr. Scott Trosper

This was a great team effort – my thanks to all!

Outline of Briefing Paper

- Technology, Engineers and Public Policy – The need for root cause analysis
- Airport Body Scanner Introduction and Background
- General Description of Pro-Vision Scanner System
- Previous Field Strength Assessment and Need for Follow-on work
- NAS Sponsored Test Objectives
- Field Probe Test Apparatus and Validation Approach
- Theoretical Development and Incident Field Predictions
- Remote Airport Testing Results
- Comparison of Theoretical and Measured fields
- Summary and Conclusions

When Technology Collides with the General Public

- When Technology "works", the **public hardly notices**
  - Cell phones, ubiquitous availability of electricity, water, transportation, food….
- When Technology "*fails*", **the public screams for immediate answers**
  - Plane/Car/Bus/Train crashes
  - Flint water crisis
  - Identity Theft/Data Spills
  - Space Shuttle Columbia Disaster

- Role of the Engineer as Arbiters in a crisis
  - Unsought, thankless roles to be embraced and executed - If asked, **<u>just do it</u>**!
  - Performing transparent technical assessments, writing unbiased opinions, advocating for technical reason when emotions and politics can drive poor decisions
- Technology advancement absolutely depends on public safety perceptions

Case 1: The Columbia Accident

- A Small, suitcase sized piece of polyurethane foam destroyed the left leading edge thermal protection system, causing the Shuttle to break up on re-entry
- Hundreds of Engineers pursued multiple accident theoretical threads to resolve the "root cause" of the accident - *I was one of them*

"Foamologist" Theory

- Though *technical root cause* was the foam release impact, the *system root cause* included a NASA culture at the time blind to the possibility that a feather-light piece of foam had the kinetic energy to destroy a carbon- carbon edge

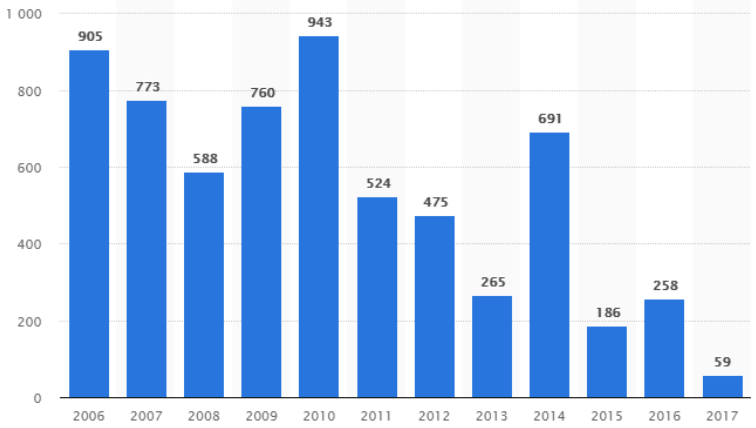
Commercial Space Fallout

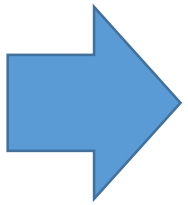
- A Redesigned Shuttle completed the ISS, then was retired well before its vehicle lifetime - perceived as “unsafe” and “expensive”)
  - (135 missions, 2 Accidents, 1.48% accident rate, 14 fatalities)
- The bulk of manned space lift is shifting to “private” companies funded by USG and private capital
  - Space-X, Virgin Galactic, etc. – *none who have flown ast*ronauts
- The working assumption is that innovative “private” space development will be safer than “NASA” space when flying astronauts
  - Space-X unmanned rocket accidents (16 successes, 5 failures, 23% accident rate)
  - Virgin Galactic (3 successes, 1 failure, 25% accident rate, 2 fatalities, <u>suborbital</u>)
- Remains to be seen if “private” is safer when astronauts begin to fly…

Case 2: Airline Safety Improvements

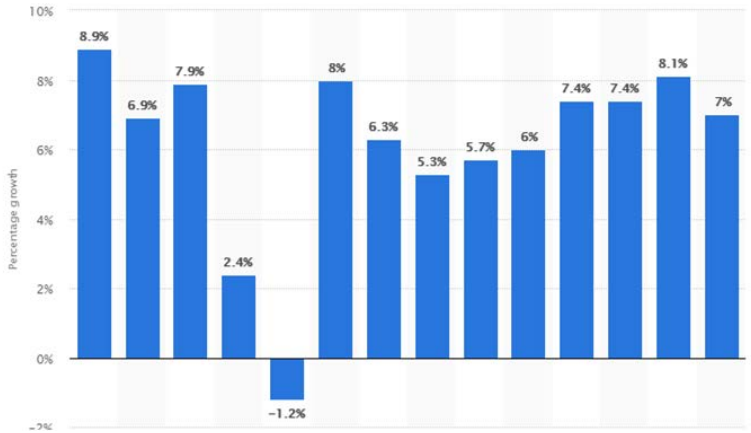
- Privatizing airliner construction doesn't prevent air travel fatalities either
- Systematic Studies of Air Accident by NTSB/Others aims to reduce system failures to the limits of human operators (pilots)

Worldwide Air Fatalities 2006-2017[1]





Annual growth in global air traffic passenger demand from 2005 to 2018



Why? – Aerospace system engineers study accidents and failures to <u>Learn and Fix!</u>

[1] https://www.statista.com/statistics/263443/worldwide-air-traffic-fatalities/

Which Brings us to Todays Topic…

- After 9/11, the DHS adopted enhanced security scanning protocols throughout the US Airport System. These changes included (but were not limited to)….
  - **Enhanced baggage screening – every piece of Luggage flown to be inspected**
  - **Enhanced personnel screening – every person goes through …**
    - Metal Detector ("Trusted traveler")
    - Airport ProVision mm wave Body Scanner
    - Pat-down
    - Maybe all three of the above

- Intrusive screening had unintended consequences
  - **Long Airport Lines, accusations of racial profiling**
  - **Claims of illnesses caused by screening devices**

When technology "*fails*", the public screams for immediate answers

Pro-Vision Airport Body Scanner

- There are 793 full-body scanners at 157 airports worldwide
- ***Millions*** of passengers walk through these annually
- ***Many*** passengers claim the body scanner is not safe for humans
- ***Some*** passengers have filed formal complaints in the US Courts, TSA, DHS, and with or through their congressional representatives
- ***One*** *complaint* by a *single passenger* to his local Congressman stated they developed (or was diagnosed) with **Stage 4 cancer** shortly after walking through a Provision Body Scanner
- ***This*** *Public complaint* caused Congress to have the PV2 scanner's safety re-assessed by the **National Academy of Science and Engineering**
  - ***…and ARA found itself in the middle of a technical and political firestorm***

Why did ARA become involved?

ARA - Panama City, FL, DM = Brian Heimbuch

Explosives and Equipment Characterization
($15.2M/48 mos.)

Customer: DHS S&T HSARPA EXD

Tyndall AFB, FL

ARA Operates DHS testbed….

(1) Baggage Screening Devices
(2) Explosive Detection Algorithms
(3) Identifies evolving IED devices
(4) Create/Detonate/Measure yields of new IED chemical compositions
(1) Assures baggage screening detects evolving explosive threats

Pro-Vision Airport Body Scanner

Not the First Time….

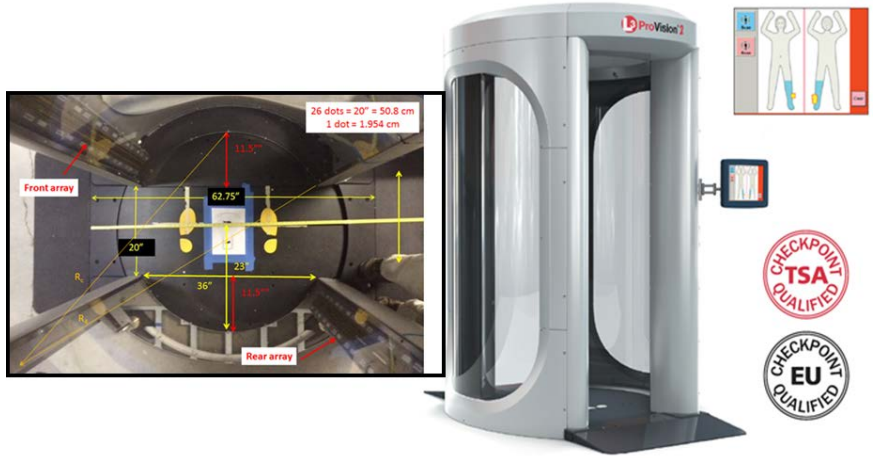
- DHS Executed an In-House study in 2012 to evaluate the radiated field strength of the Provision Body Scanner
- *Field Emissions included "all" frequencies, including out-of-band from electronics and computers*
- *In-Band (24-30 GHz) field measurements were done using a simple crystal detector, a power meter, and <u>two</u> sample points within the Provision scanner. Calibration was very questionable.*
- *The "Test Machine" was a dedicated lab research machine in a TSA Laboratory. No operational airport machines were tested.*
- *The "calibrated field measurements" of the two points varied by over a factor of 50.*
- *Documented in a report: " Compilation of Emission Safety Reports on the L3 Communications ProVision 100 Active Millimeter Wave Advanced Imaging System, DHS/ST/TSL-12/118, 1 Sept 2012"*

TSA Airport Body Scanner Background

- What drove these emission measurements?

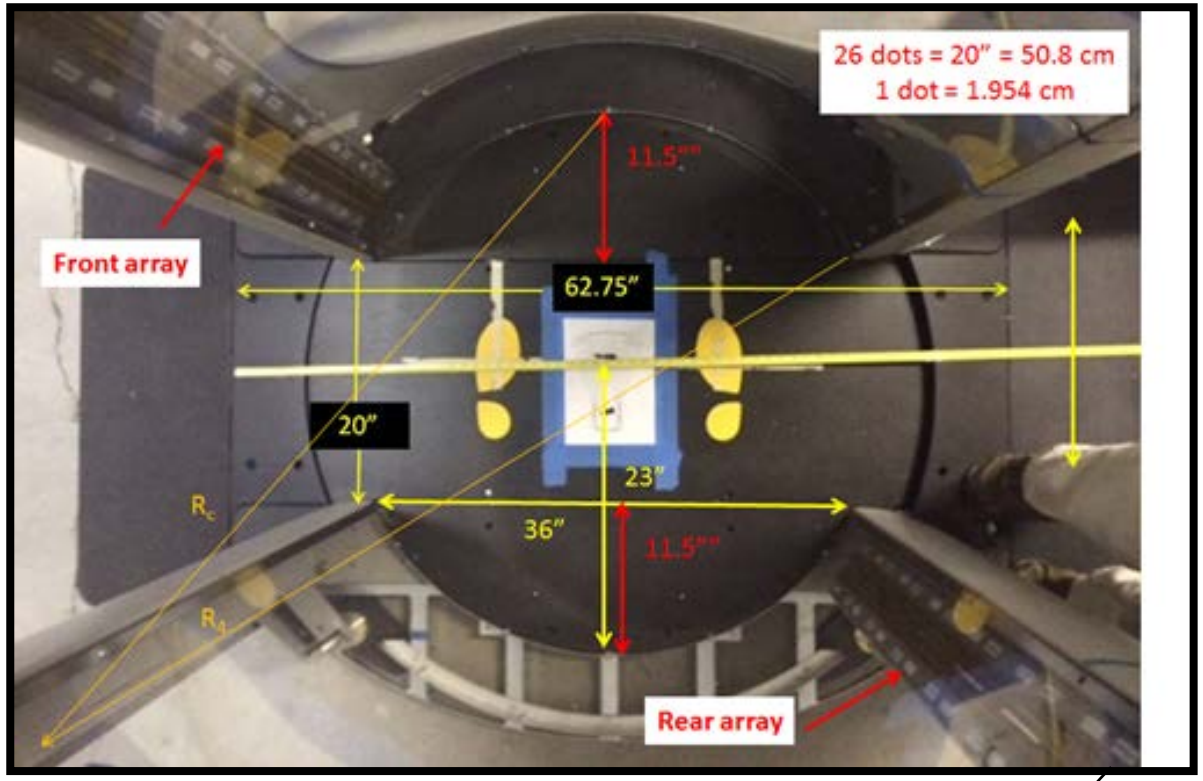
L3Comm Provision 1 Airport Body Scanner

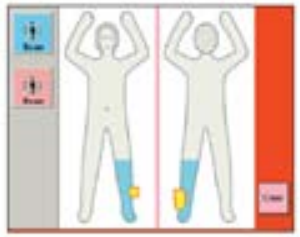
- Congressional Inquiry – Does the TSA body scanner present any RF Hazard to Public Passengers and/or TSA Operators?



- Tasking: CI ➡DHS ➡TSA ➡NAS (Agent)
  - NAS – Committee to evaluate safety from calibrated RF emissions data
  - ARA(BRD) – Contracted to Provide Emission data

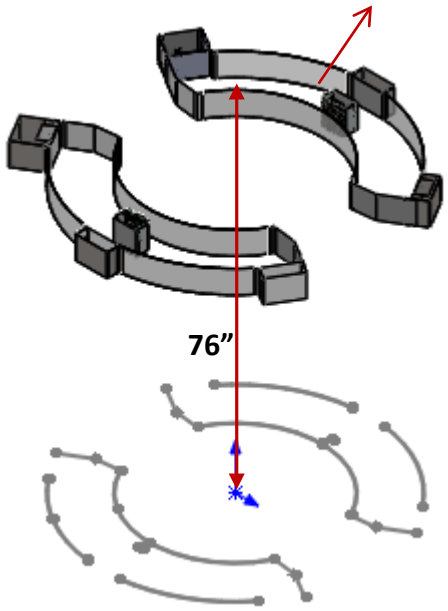
Provision 1.0 Interior



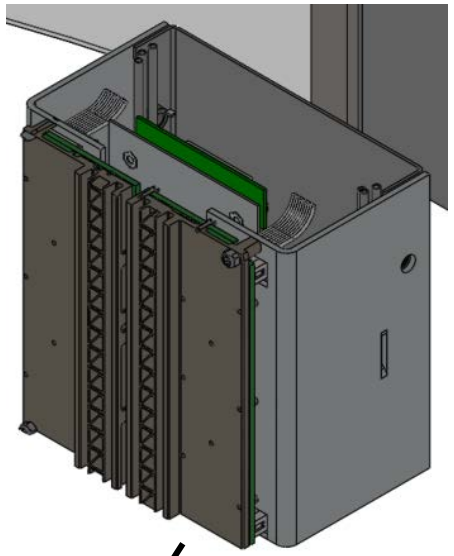


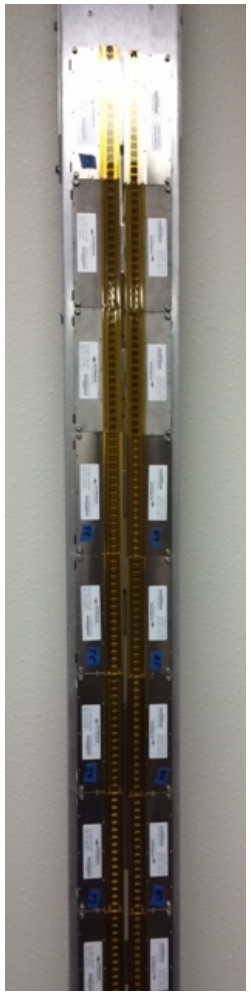
Provision Detail Drawings

Linear Antenna arrays
(1 Tx, 1 Rx, Sequentially fired)

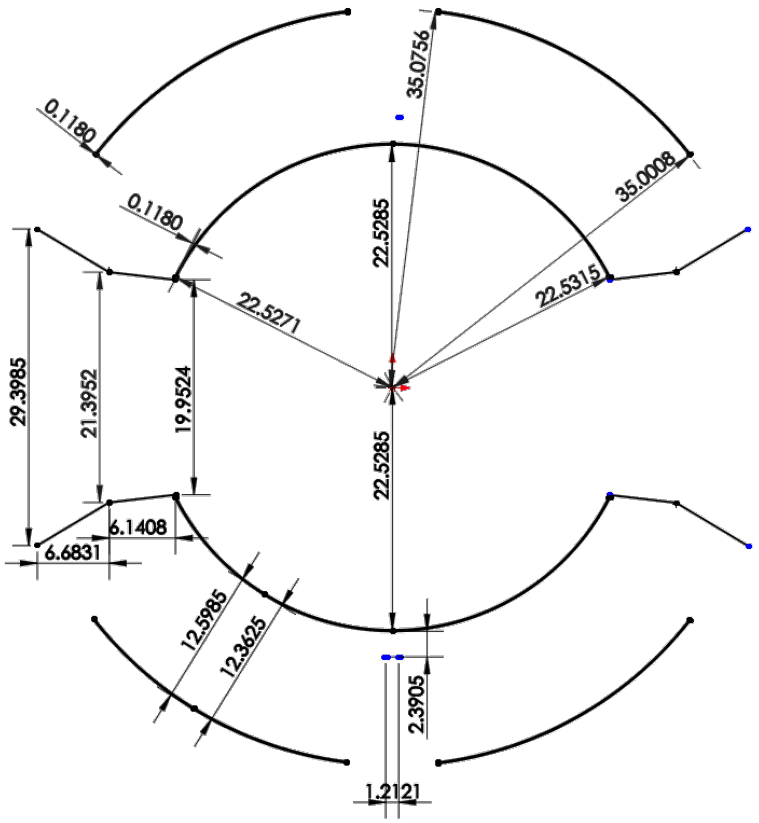


Added lines for measurements.





Chamber Dimensions

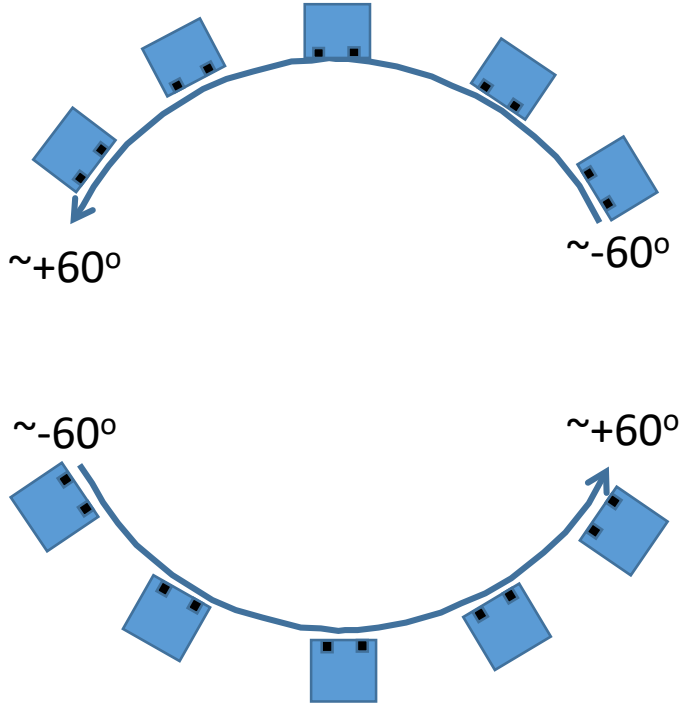


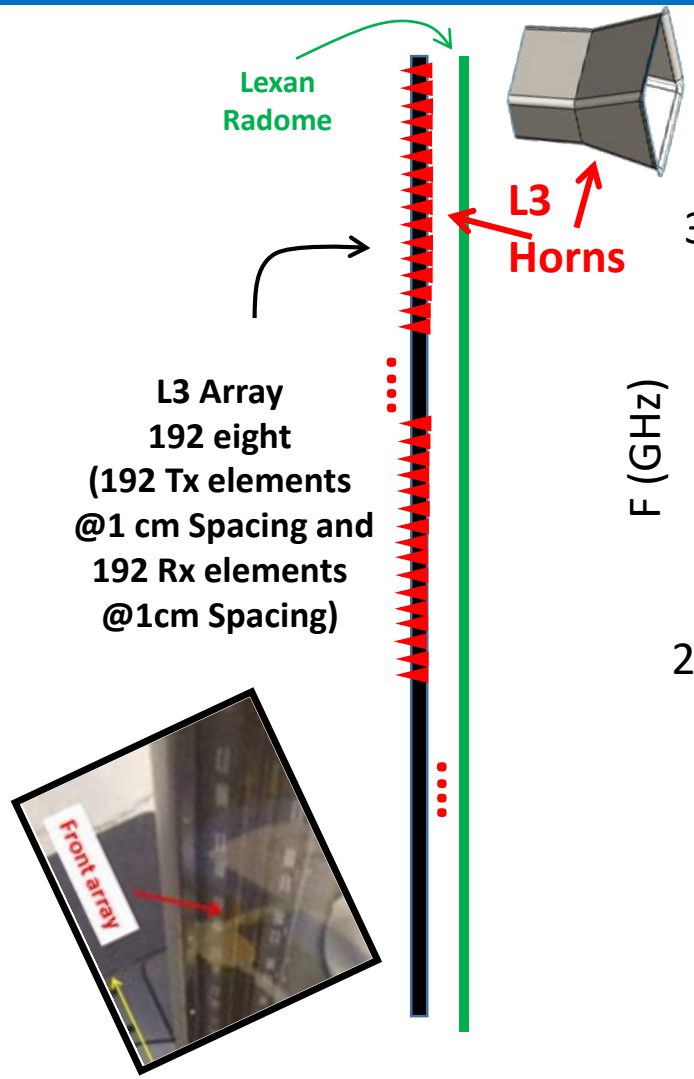
Units are in inches.

More Background on ProVision Scanner

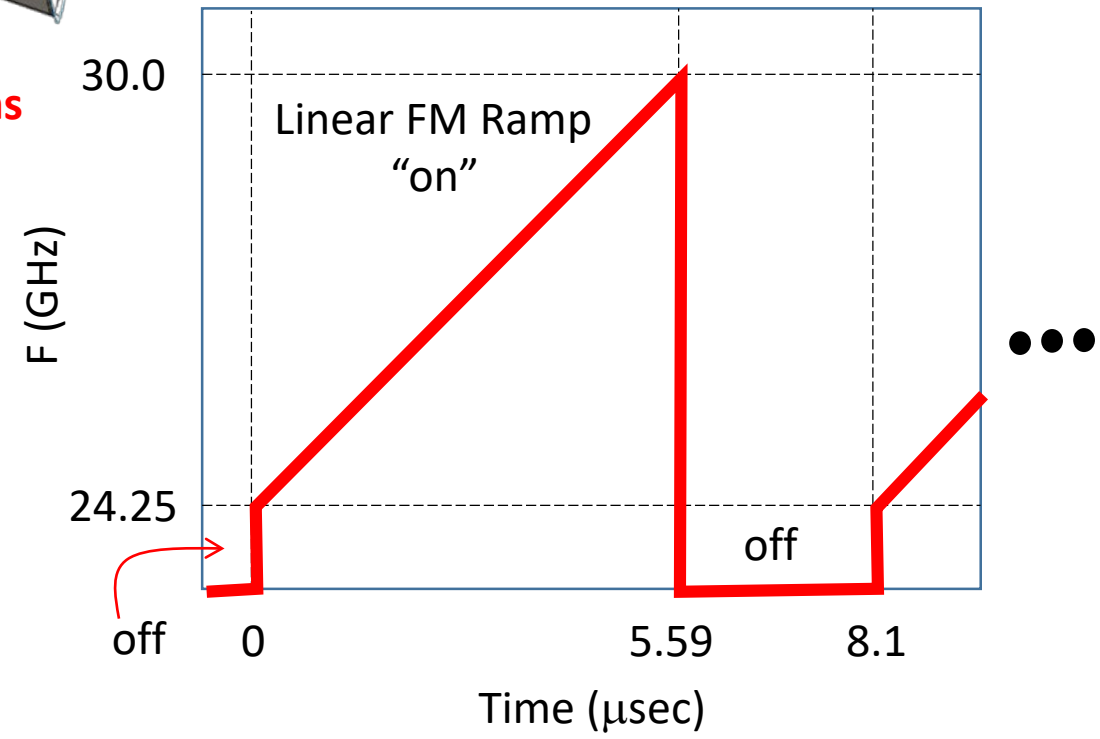
- Very Fast 3-D Dual Transmit/Receive Array Scanner using cylindrical array geometry
  - Electronic-Scan in (linear) Elevation, Mechanical Scan in (rotational) Azimuth
  - 2 Separate set of TX/RX arrays (one scanning passenger front, the other rear)
  - 192 elements Tx, 192 Rx, each element is energized twice during a sequential linear scan
  - Very fast 24.25-30.00 GHz Linear FM Swept Waveforms
  - Acquires all data in 1.5 seconds – built for millions of iterations!
- NAS tasked ARA to provide the following:
  - What are the ***calibrated*** **radiated Electric Field Strengths** where a passenger stands (front and back) *with measurement uncertainty*
  - Same question – but outside where the "next passenger" and "TSA Operators" stand
- Why is this not trivial?
  - The frequency sweep is very fast, the waveform radiated powers are very low by design, the geometry constantly changes during the sweep, the space is very small, and all measurements *must be made on production operational machines already deployed in the field "over the air" only!*

Provision Scanner detail – How it works





Radiated Waveform



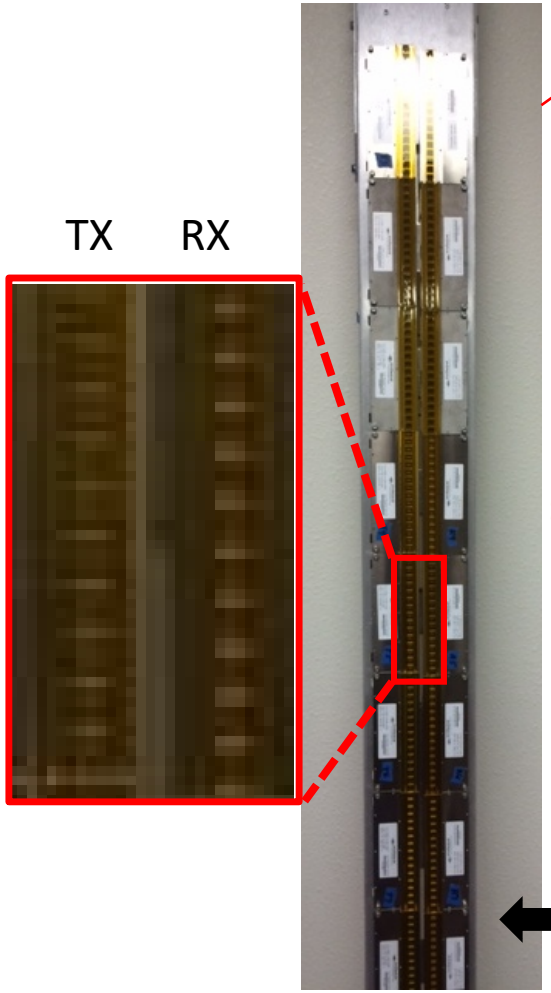
Electrically Scanned Top to Bottom
Mechanically Scanned about +/-60°
Linear FM Front and Rear Facing Array
Raw Data Product –
Front/Rear "ISAR" Image
(L3 Prefers the term "Holograph")

Overall ProVision Duty Cycle is
(5.59 µsec "on"/2.51 µsec"off)
Dc = 5.59/8.1 = 69%
Each Element is radiated twice, for
A total of 192 x 2 = 384 waveforms per angle

L3 Horn **Antenna** Total Gain Patterns

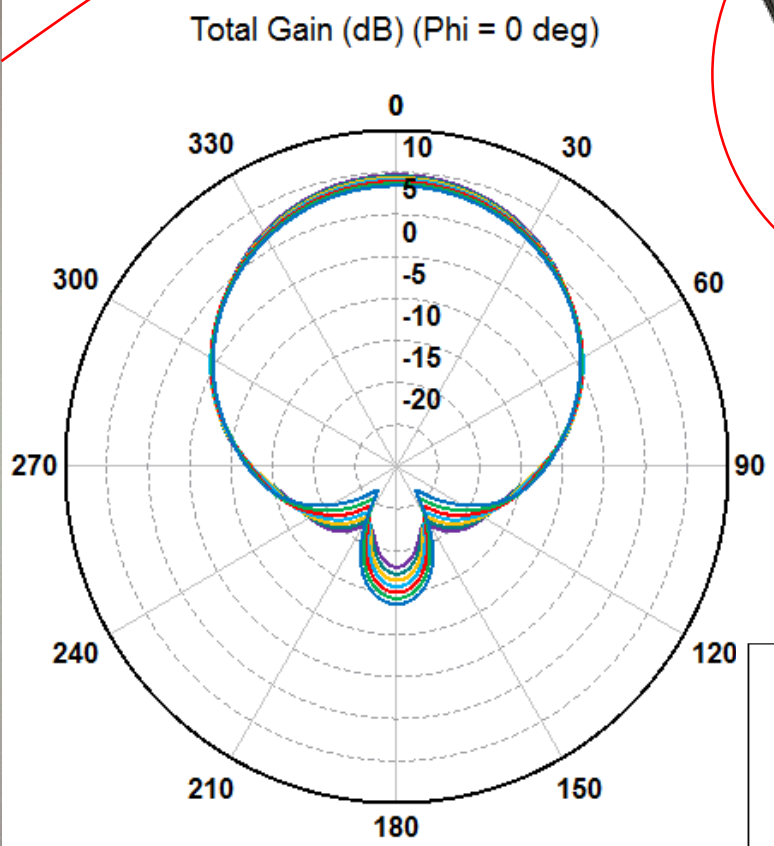
Computed by Dr. Tri Van – ARA-BRD

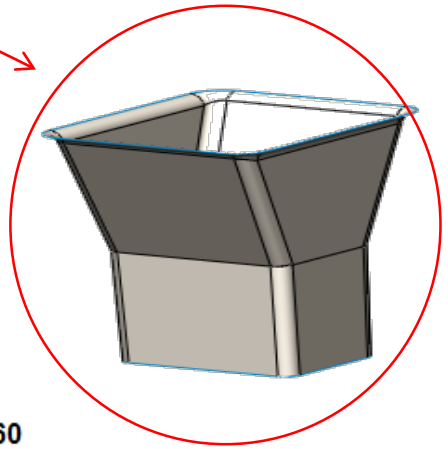
TX/RX Linear Arrays - Front View



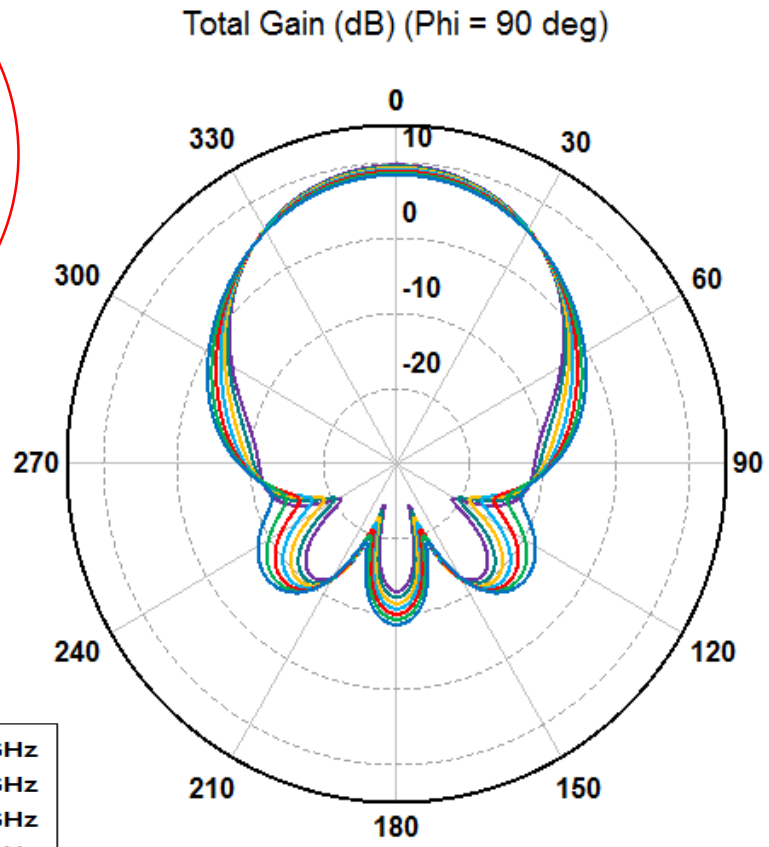
192 cm total Height
(192 elements @ 1 cm Spacing)

E-plane



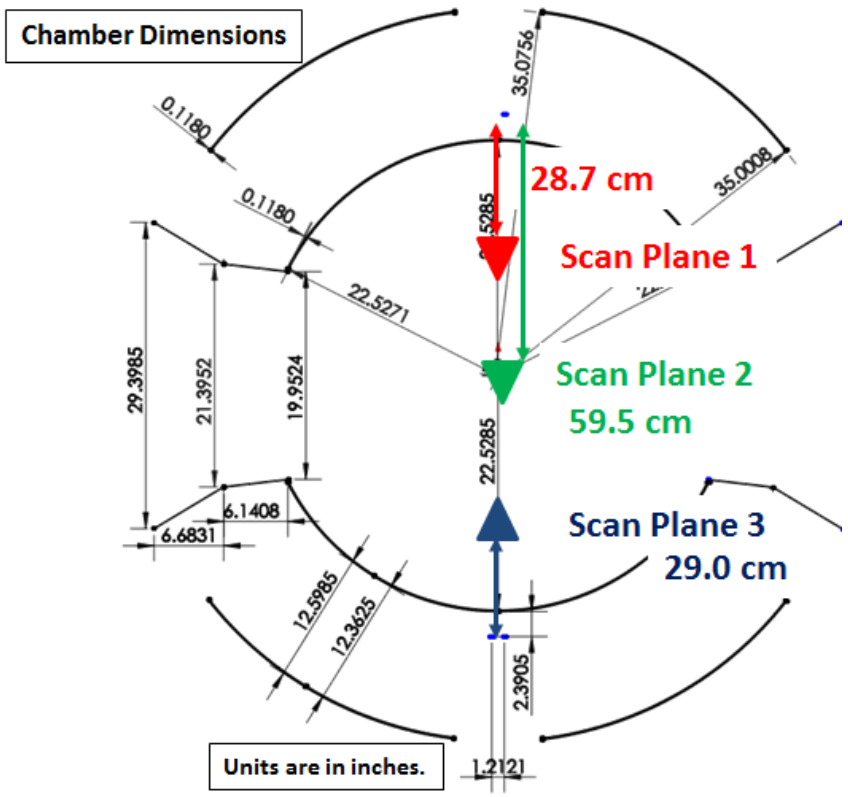


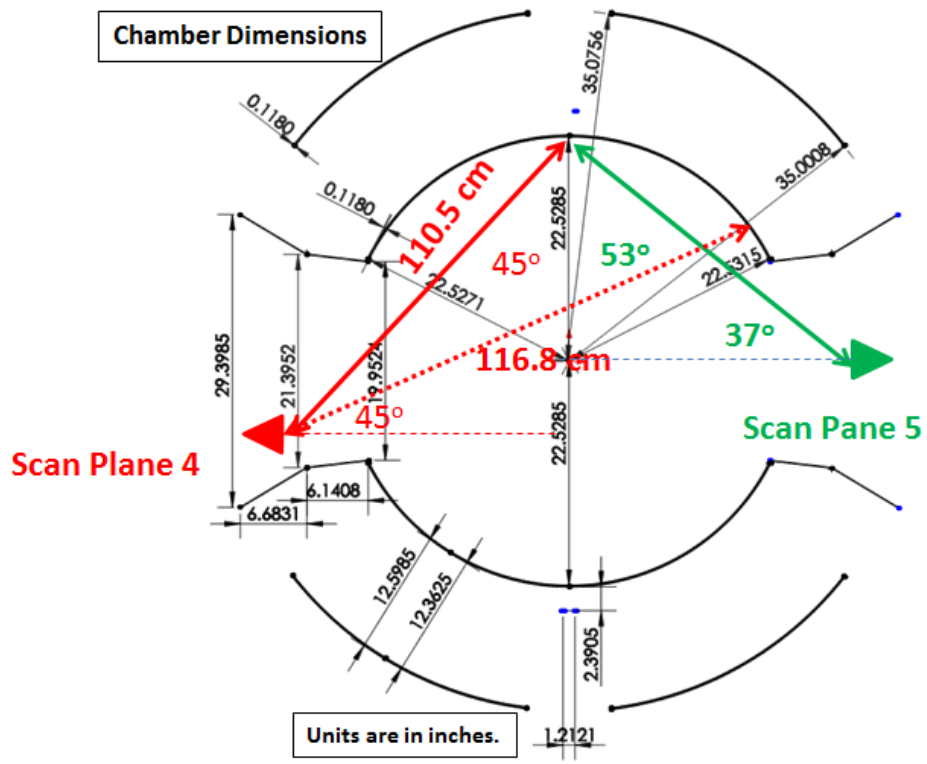
H-plane



Frequency = 24 GHz
Frequency = 25 GHz
Frequency = 26 GHz
Frequency = 27 GHz
Frequency = 28 GHz
Frequency = 29 GHz
Frequency = 30 GHz

Internal/External Scan Plane Details





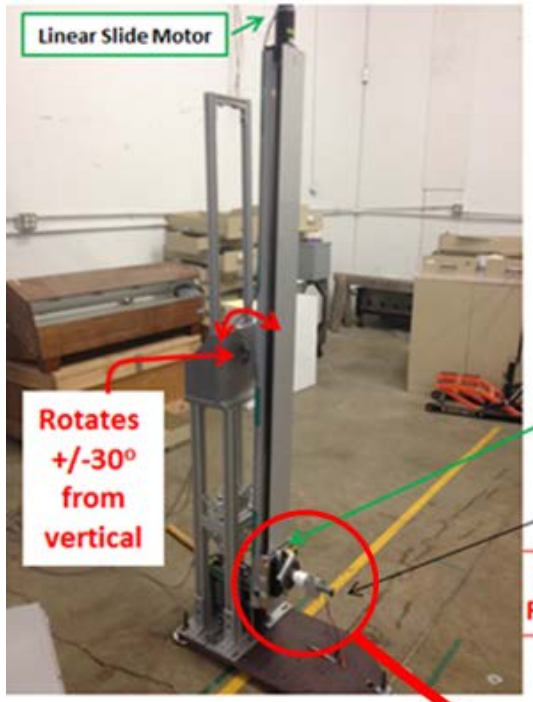
ProVision Diagnostic Mode

Sets the Front and rear arrays In the center scan position and free runs the RF Sweep Waveforms

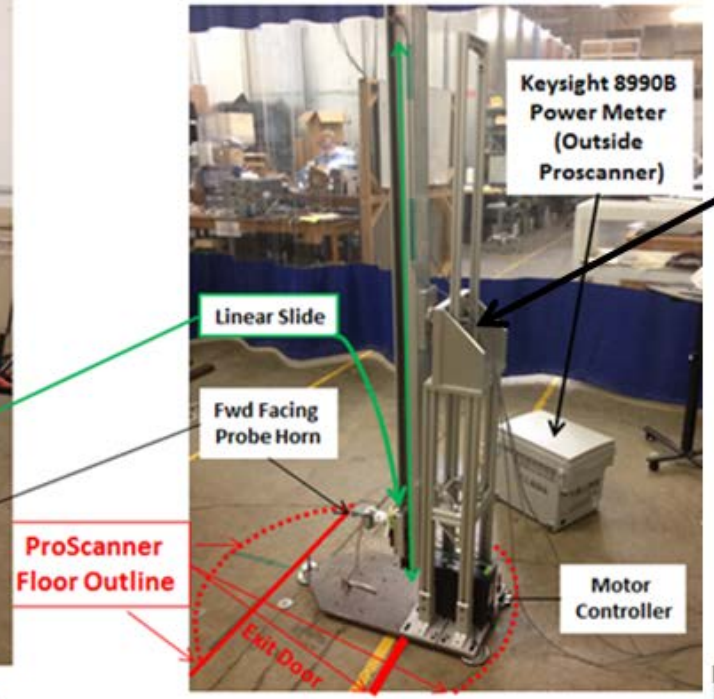
Allows accurate capture of RF energy without worrying About array cylindrical Movement during test (Scan Planes 1,2,3)

Scan Plane 1 (front array) and **Scan Plane 3** (Rear) are symmetrical and should have similar field strengths
Scan Plane 2 should be similar to **Scan Plane 1** data *reduced by additional 30.8 cm spread loss vs frequency*
Scan Plane 4 is where the TSA Operator sits, while **Scan Plane 5** is the closest a "next passenger" stands

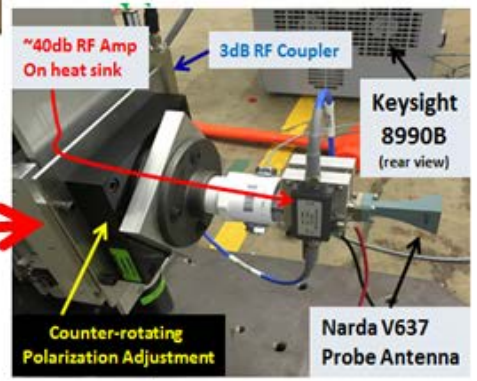
ProVision Interior and Field Probe Equipment

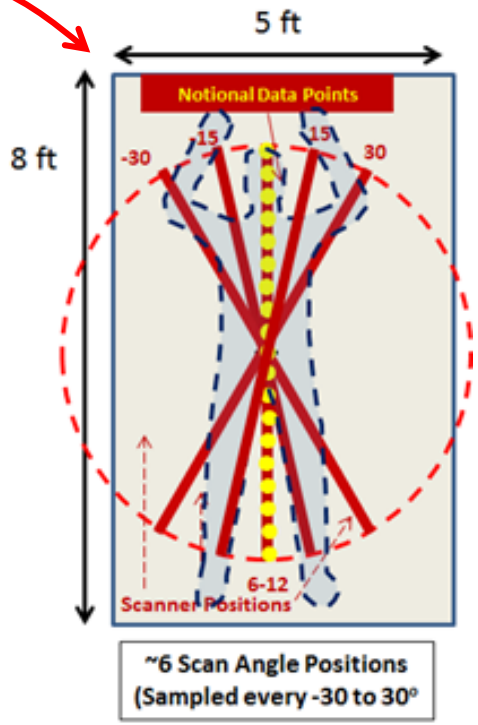


Front Perspective View



Rear Perspective View

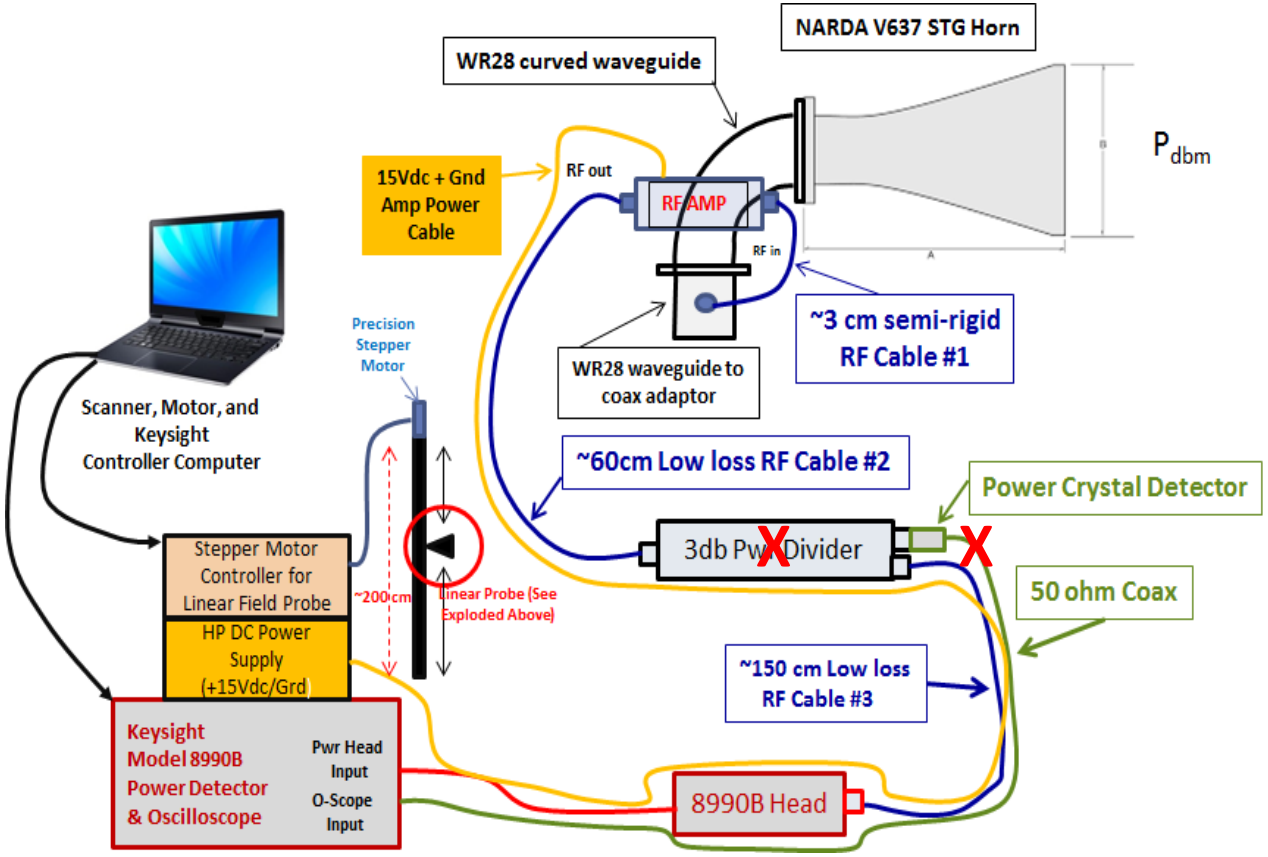




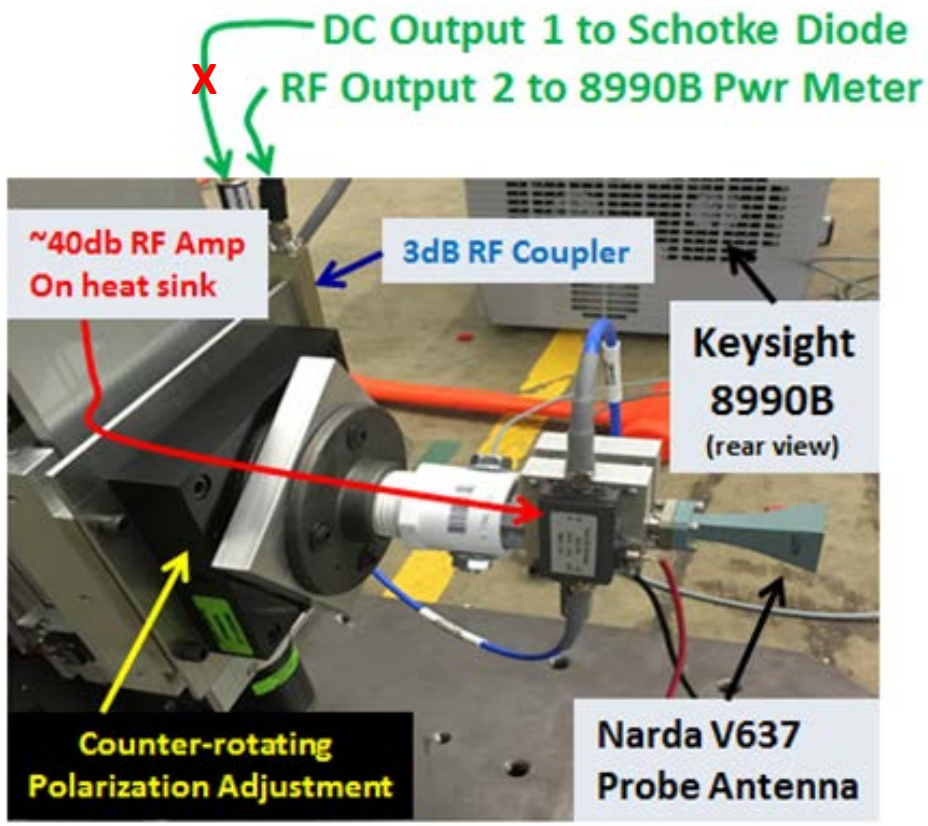
Radial Probe was a compromise to accommodate limited space

RF Microwave Sensor Head Design

X – Dropped After DAY

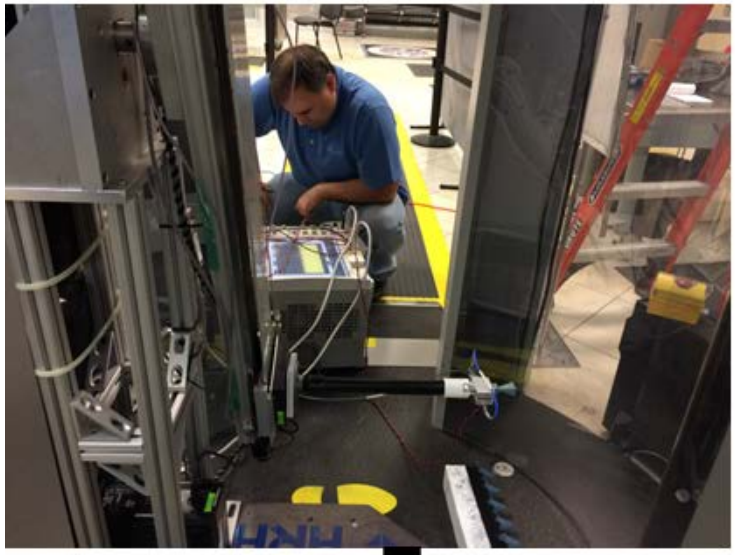


Dayton Airport NAS Detector Signal Flow
(CVG/MEM/TYS Dropped Schottky Signal Path for Extra Gain)



RF Microwave Scanner Deployed in Dayton

Scan Plane 1



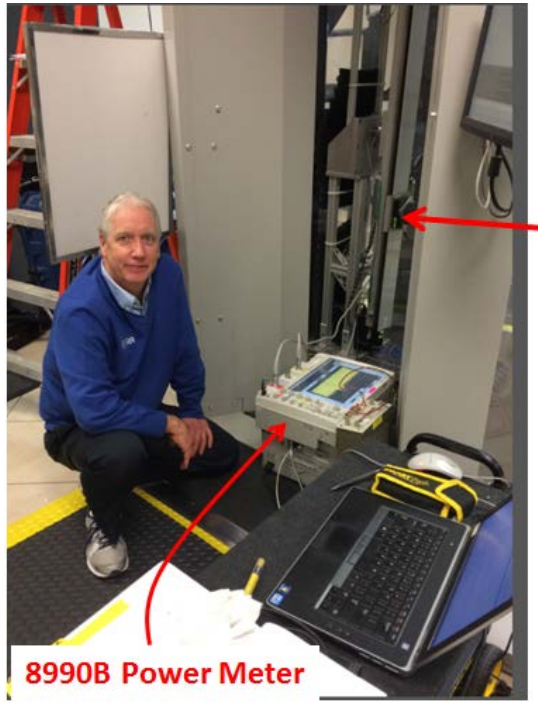
Scan Plane 2 is the same field probe position with Probe Antenna 12" further back from front array.

Scan Plane 5

Scan Plane 5 Where Next Passenger Stands

Scan Plane 4

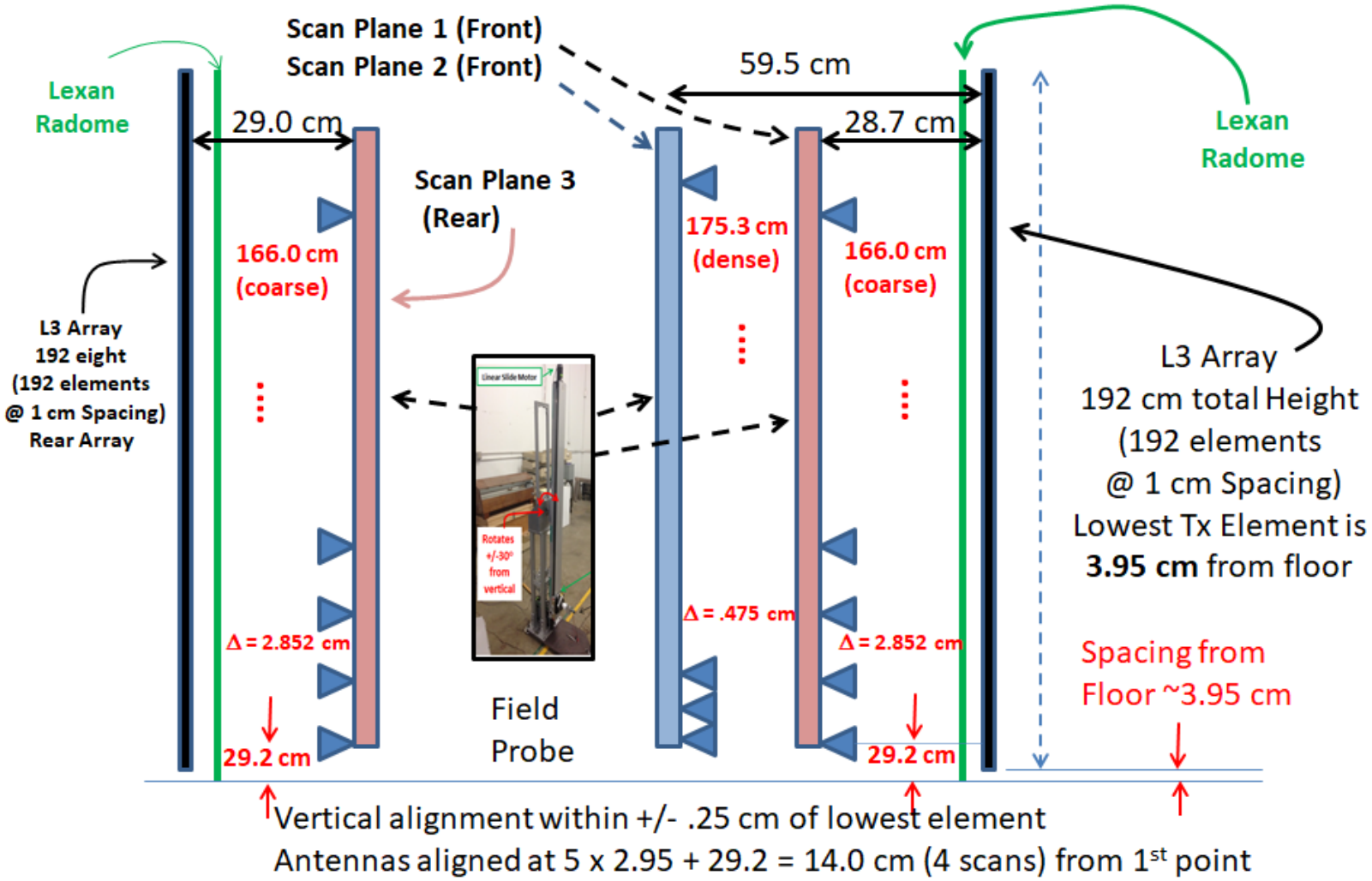
Scan Plane 4 Where TSA Operator Stands



Scan Plane 3 Field Probe Staring at Rear ProVision Scanner Array (DAY)

Dayton 0° Scan Measurement Geometry

Not to scale



Field Probe Height Samples

- Course Δ=2.852 cm (48 samples)
- Fine Δ=0.475 cm (299 samples)

Angular Field Samples

- Primary: 0° (Vertical)
- Some Off:+/-15°, +/- 30°
- Rapid field off-angle falloff

Polarization

- Primarily VV
- Some HH (Low X-Pol Antenna)

8990B Power Meter

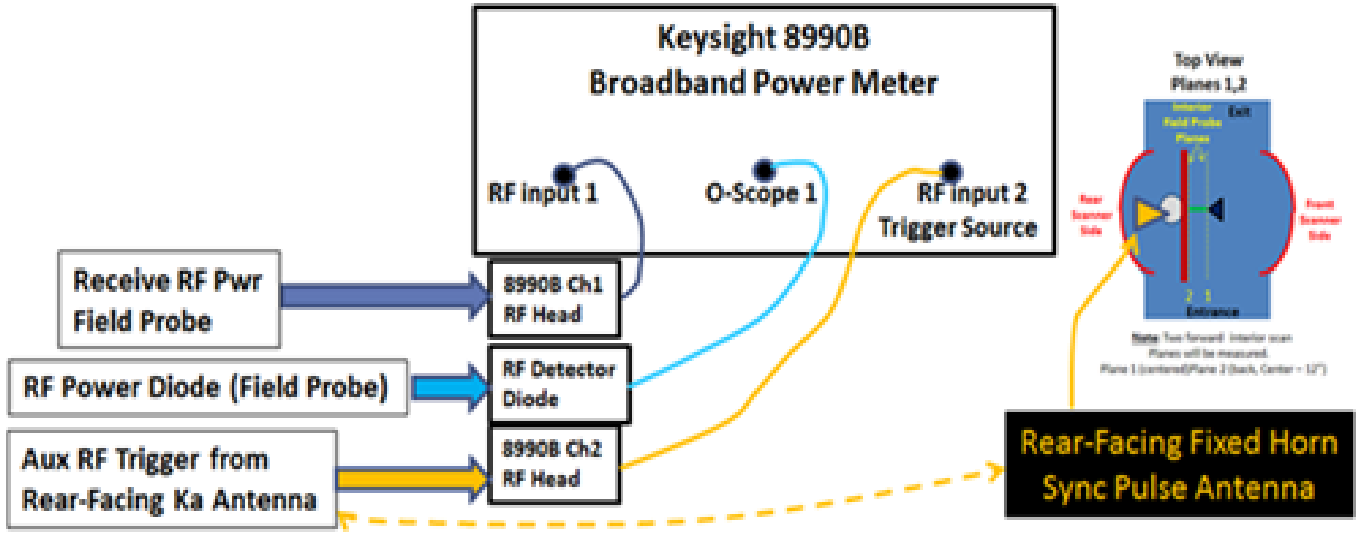
- 10,000 time domain pts/sweep
- Raw Output: Power (dBm)

NAS Imposed Limitation
No Direct Airport Scanner Timing Pulse

Measurement Imposed Limitation from NAS

- NAS directed ARA ***not*** to modify Operational ProVision ***in any way***
- No direct timing pulse (therefore) available to sync 8990B[1]
- Timing had to be acquired "over the air" with regular waveforms
- Limitation was added to prevent operational airport scanner systems from having to be removed from service and recalibrated after test

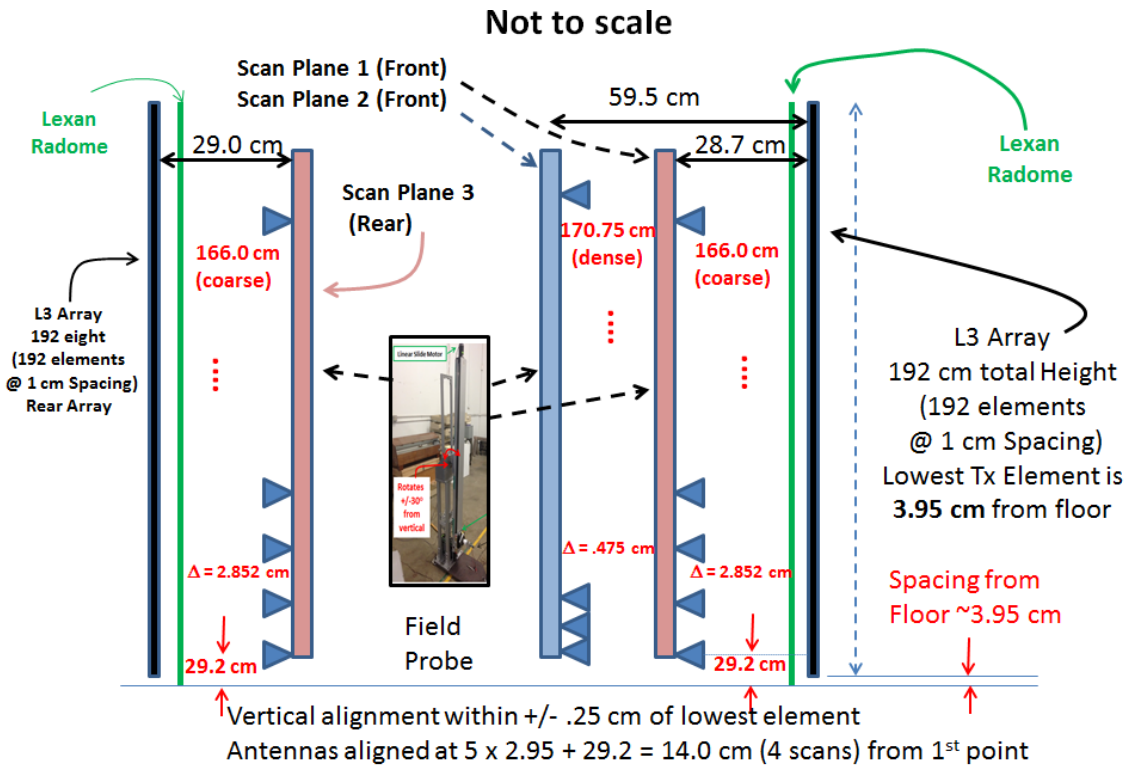
[1] The only timing pulse was a BNC connector on top of the mechanically swinging array which would have been difficult to get to and involved disassembling machine to access



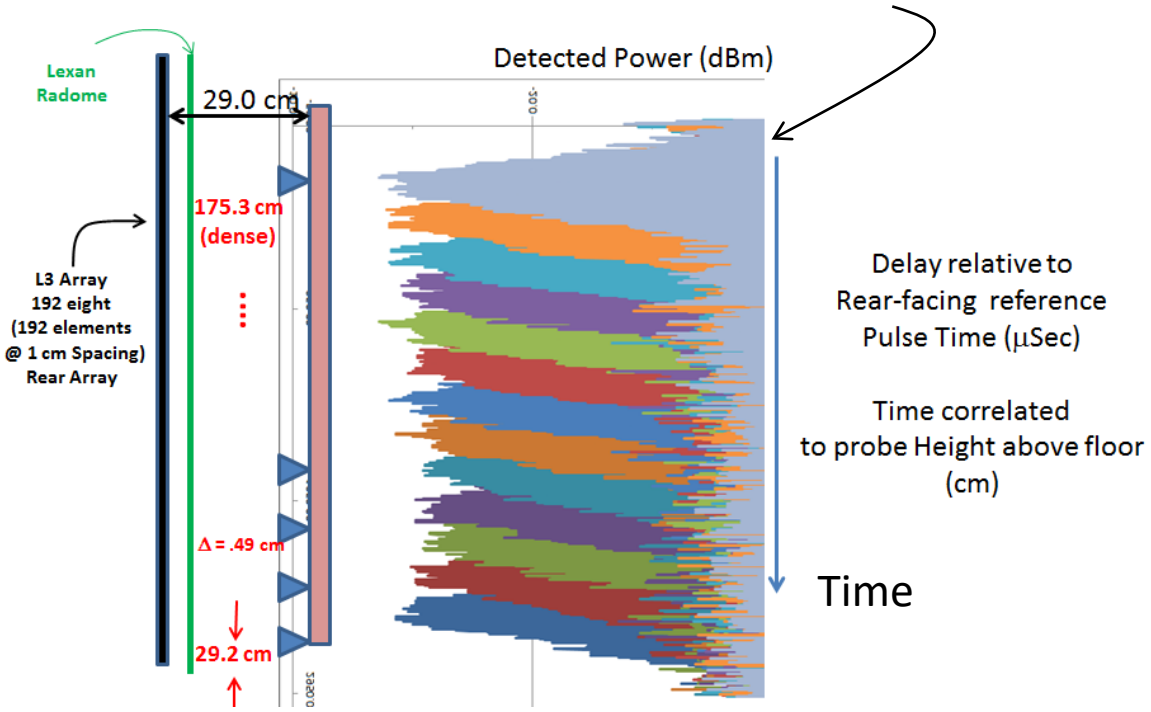
Solution: Rear Facing Horn Sync Antenna

Worked exceptionally well and was a very reliable trigger!

Dayton Measurement Geometry



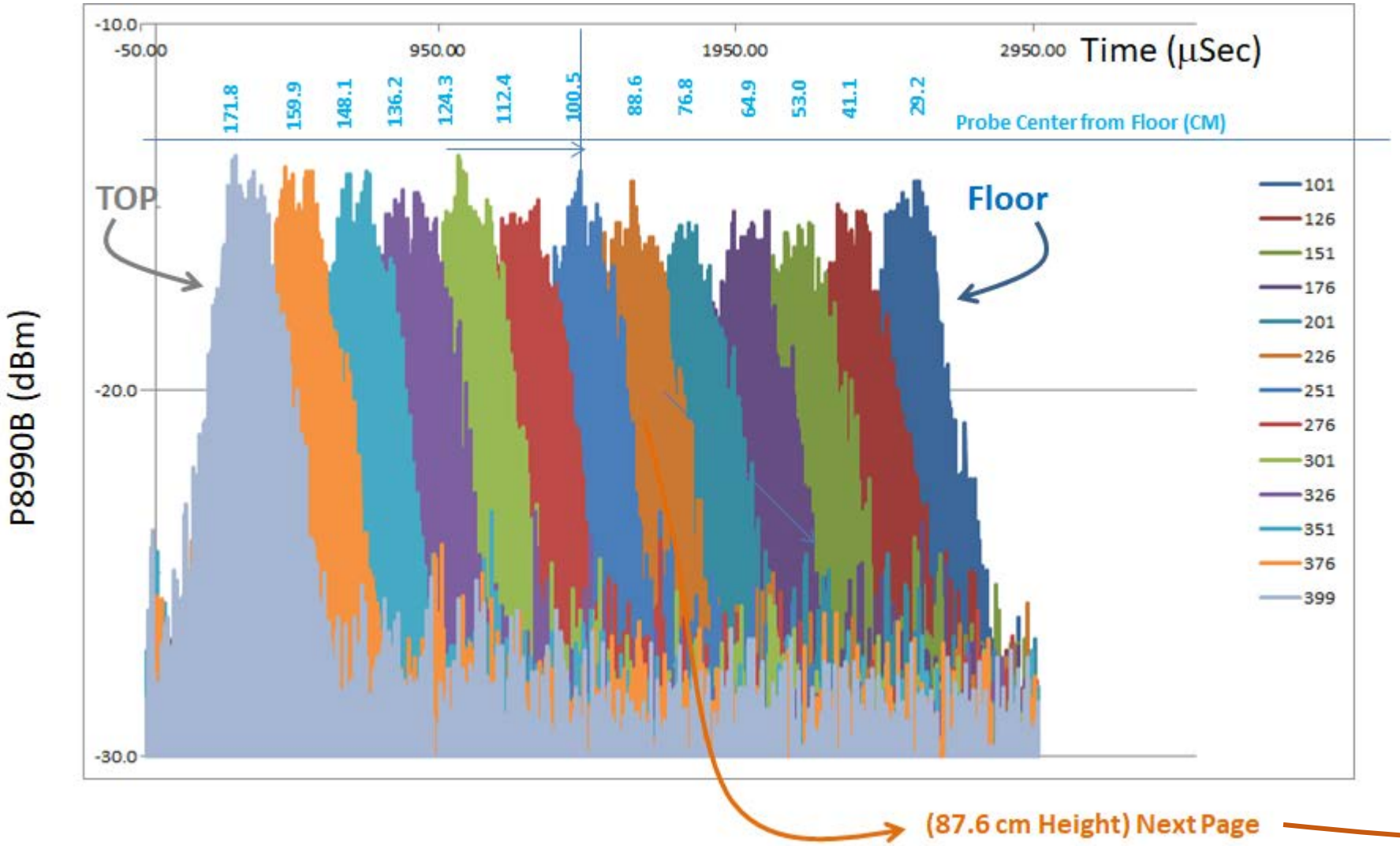
Dayton Configuration 1.7(h), 12 of 45 files shown
This collection gathered 130,000 samples



Ground Rules: (1) We were **not allowed** to physically Connect to machines (i.e. no hard wired trigger pulses available)
(2) Vertical Array was set at mid-sweep position
(so called TSA diagnostic mode)

Configuration 1.7.h Raw Power Data

Scan Plane 3, Course, (13 of 45 files shown) from 29.2-175.3 cm from floor
(There are 130,000 raw data points in just these 13 plots – 10,000 each)



Provision takes **3100 µsec** to complete entire array sweep

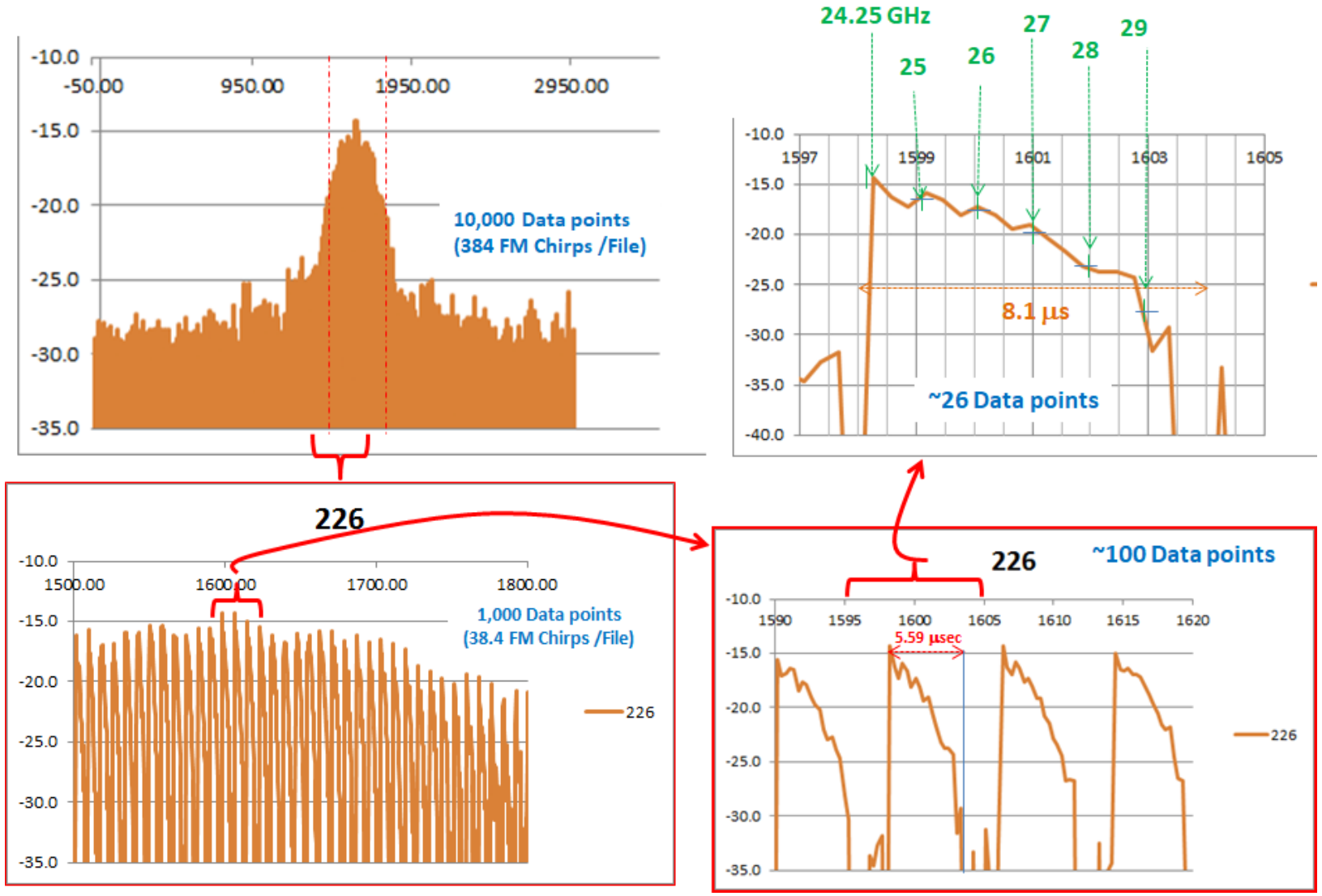
We therefore set 8990B time base sweep to **3500 µsec**

Next Page Focuses on the scan at 87.6 cm above the floor of the scanner, file number **226**[2]

[2] **Note: File # not related to height**

Raw scan data #226 before system calibration

Scan Plane 3 (DAY)

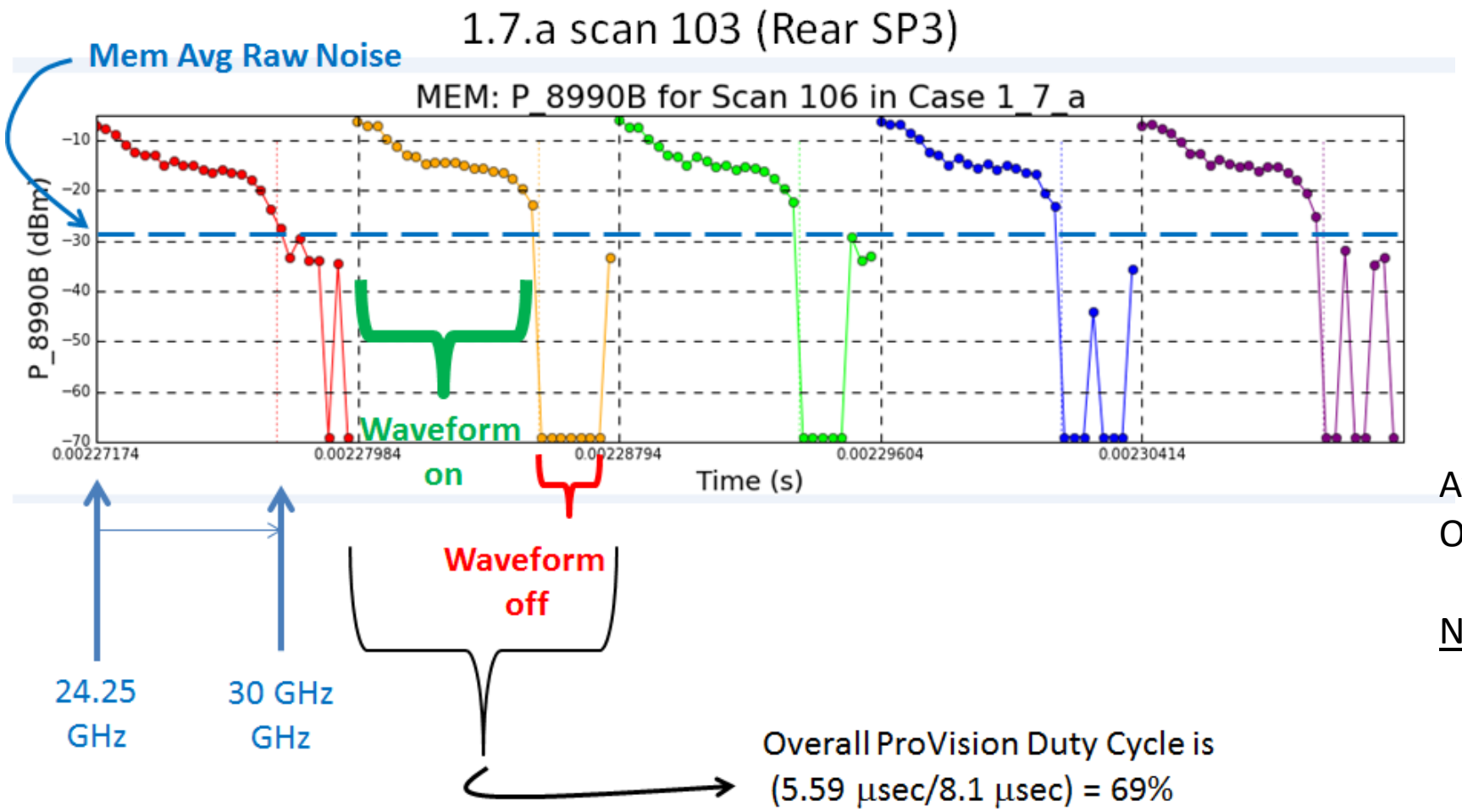


Linear FM Chirp

f_{low} = 24.25 GHz
f_{high} = 30 GHz
Sweep Period = 5.59 µsec
(Note: waveform is not linear in dB)

$$f_{GHz}(t) = 24.25 + \left(\frac{5.75}{5.59}\right) t \ (\mu sec)$$

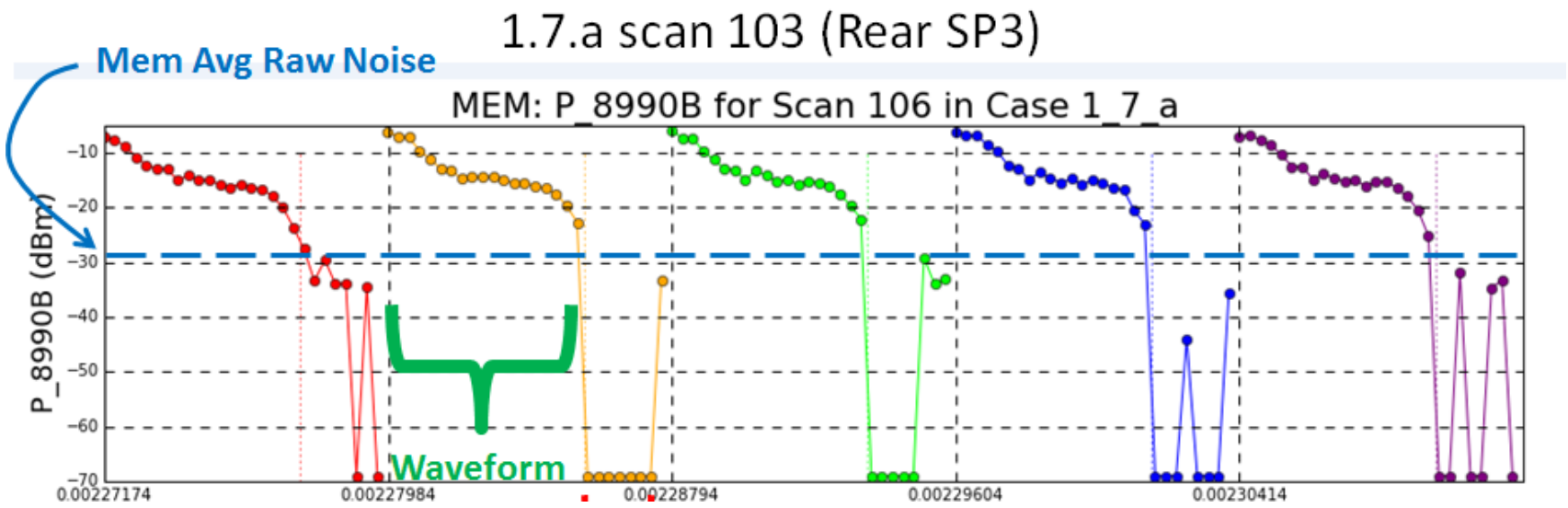
Blow-Up of Detected Waveforms (MEM)



Averaged the 5 Peak Waveforms
Of every scan, every configuration

<u>Note</u>: Waveform not linear in dB

Blow-Up of Detected Waveforms (MEM)



Averaged the 5 Peak Waveforms
Of every scan, every configuration

Note: Waveform not linear in dB

(a) We are *measuring raw* un-calibrated receive power with the Keysight 8990B vs time….

(b) The NAS wants Frequency Based Incident Field Strength versus scan plane location

How do we get from (a) to (b)…?

Manipulation of Friis Formula

$$P_{rcv} = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \; [Watts]$$

$$P_{8990B}(f) = P_{rcv}(f) \cdot NGain_{rf\#1}(f) \quad [Watts]$$

$$P_{rcv}(f) = P_{8990B}(f) / NGain_{rf\#1}(f) \quad [Watts]$$

<u>Next</u>: $$P_d(f) = \frac{P_{rcv}(f)}{A_e(f)} \quad \left[\frac{Watt}{m^2}\right]$$

$$A_e(f) = G_r(f) \cdot \frac{\lambda^2}{4\pi} \quad [m^2]$$

$$P_d(f) = \frac{4\pi P_{8990B}(f)}{NGain_{rf\#1}(f) G_r(f) \lambda^2} \quad [Watts/m^2]$$

$$\boxed{|E_i(f)| = \sqrt{120\pi P_d(f)} \quad [Volts/m]}$$

Manipulation of Friis Formula – $NGain_{rf\#1}$

$$P_{rcv} = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \quad [Watts]$$

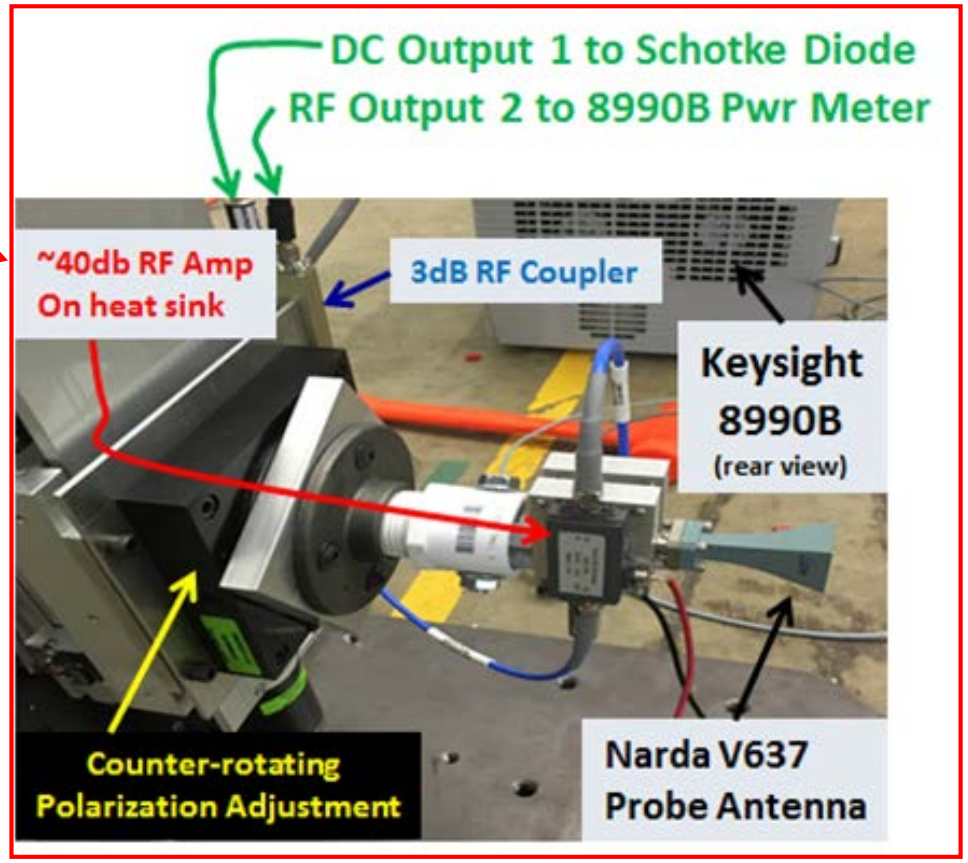
$$P_{8990B}(f) = P_{rcv}(f) \cdot NGain_{rf\#1}(f) \quad [Watts]$$

$$P_{rcv}(f) = P_{8990B}(f) / NGain_{rf\#1}(f) \quad [Watts]$$

Next: $$P_d(f) = \frac{P_{rcv}(f)}{A_e(f)} \quad \left[\frac{Watt}{m^2}\right]$$

$$A_e(f) = G_r(f) \cdot \frac{\lambda^2}{4\pi} \quad [m^2]$$

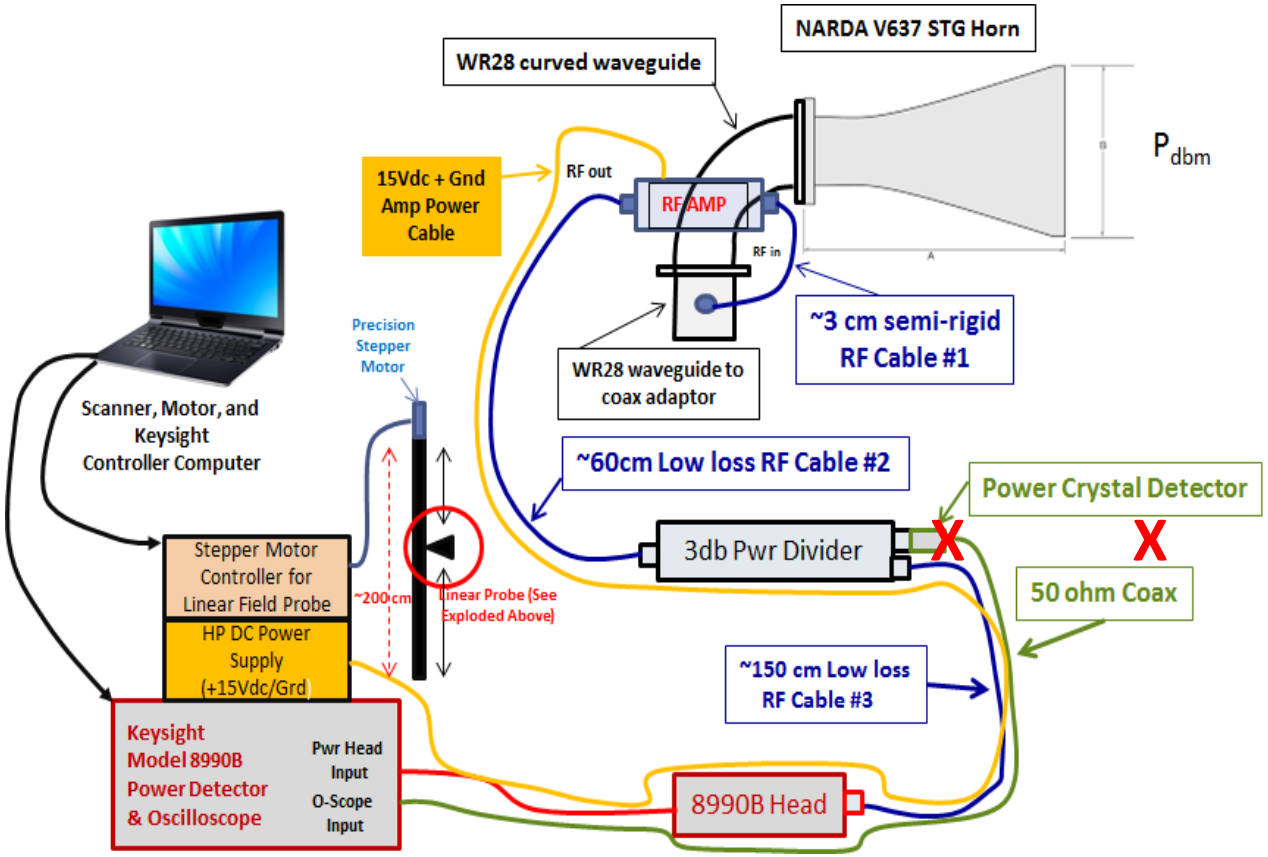
$$P_d(f) = \frac{4\pi P_{8990B}(f)}{NGain_{rf\#1}(f) G_r(f) \lambda^2} \quad [Watts/m^2]$$



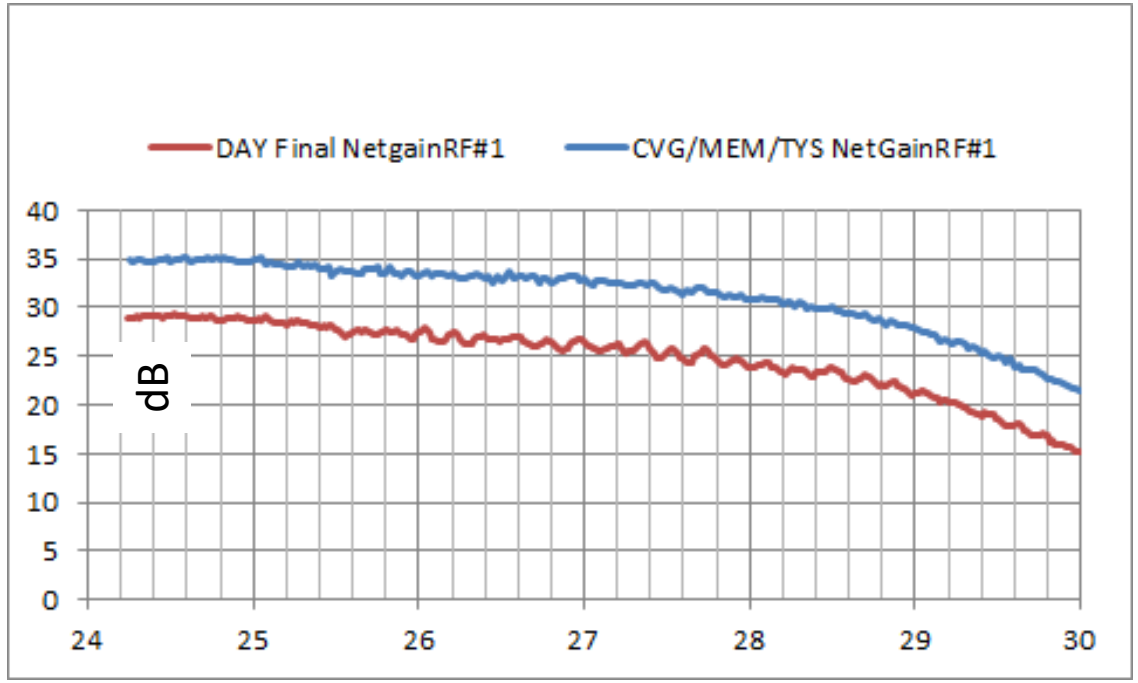
$$|E_i(f)| = \sqrt{120\pi P_d(f)} \quad [Volts/m]$$

RF Microwave Sensor Head Cal - $NGain_{rf\#1}$

X – Dropped After DAY



Dayton Airport NAS Detector Signal Flow
(CVG/MEM/TYS Dropped Schottky Signal Path for Extra Gain)



Freq (GHz)

$$P_d(f) = \frac{4\pi\, P_{8990B}(f)}{NGain_{rf\#1}(f)\, G_r(f)\, \lambda^2}$$

Manipulation of Friis Formula (Receive Gain, G_r)

$$P_{rcv} = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \quad [Watts]$$

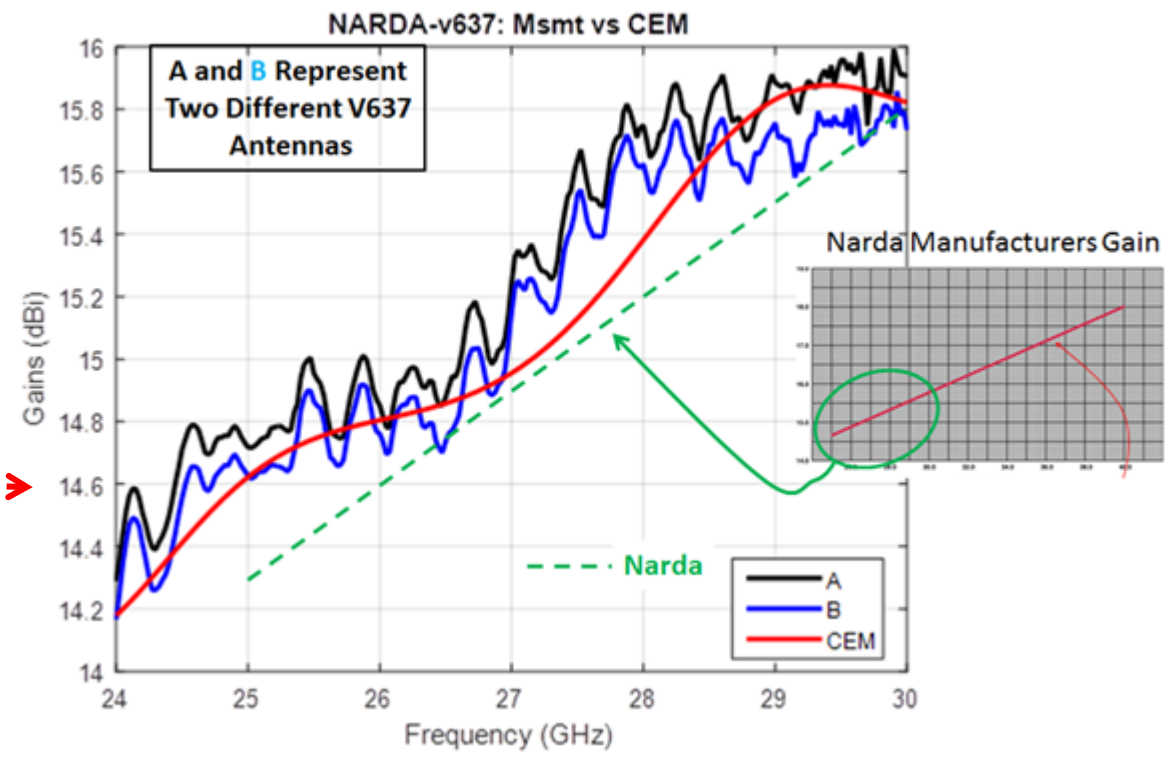
$$P_{8990B}(f) = P_{rcv}(f) \cdot NGain_{rf\#1}(f) \quad [Watts]$$

$$P_{rcv}(f) = P_{8990B}(f) / NGain_{rf\#1}(f) \quad [Watts]$$

Next: $$P_d(f) = \frac{P_{rcv}(f)}{A_e(f)} \quad \left[\frac{Watt}{m^2}\right]$$

$$A_e(f) = G_r(f) \cdot \frac{\lambda^2}{4\pi} \quad [m^2]$$

$$P_d(f) = \frac{4\pi P_{8990B}(f)}{NGain_{rf\#1}(f) G_r(f) \lambda^2} \quad [Watts/m^2]$$



$$|E_i(f)| = \sqrt{120\pi P_d(f)} \quad [Volts/m]$$

Manipulation of Friis Formula to get $|E_i(f)|$

$$P_{rcv} = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \quad [Watts]$$

$$P_{8990B}(f) = P_{rcv}(f) \cdot NGain_{rf\#1}(f) \quad [Watts]$$

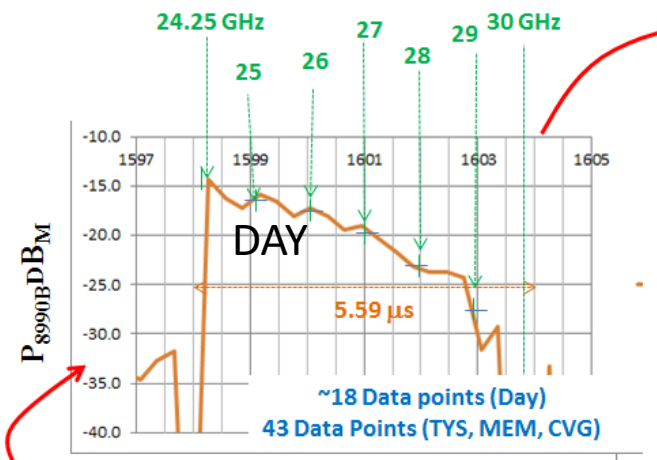
$$P_{rcv}(f) = P_{8990B}(f) / NGain_{rf\#1}(f) \quad [Watts]$$

Next: $$P_d(f) = \frac{P_{rcv}(f)}{A_e(f)} \quad \left[\frac{Watt}{m^2}\right]$$

$$A_e(f) = G_r(f) \cdot \frac{\lambda^2}{4\pi} \quad [m^2]$$

$$P_d(f) = \frac{4\pi P_{8990B}(f)}{NGain_{rf\#1}(f) G_r(f) \lambda^2} \quad [Watts/m^2]$$

$$|E_i(f)| = \sqrt{120\pi P_d(f)} \quad [Volts/m]$$



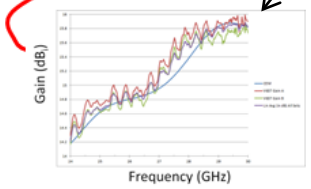
RAW 226 Before System Calibration
1.7.h, VV, Middle of Scan, 11.3" from Source array

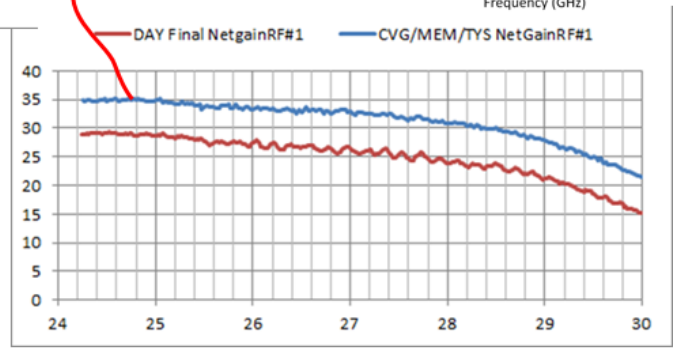
Compute P_d above, then E Field:

$$|E_i(f)| = \sqrt{120\pi P_d(f)}$$

Narda SGH $G_r(f)$

$$P_d(f) = \frac{4\pi P_{8990B}(f)}{NGain_{rf\#1}(f)\, G_r(f)\, \lambda^2}$$





Manipulation of Friis Formula

$$P_{rcv} = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \quad [Watts]$$

$$P_{8990B}(f) = P_{rcv}(f) \cdot NGain_{rf\#1}(f) \quad [Watts]$$

$$P_{rcv}(f) = P_{8990B}(f) / NGain_{rf\#1}(f) \quad [Watts]$$

Next: $$P_d(f) = \frac{P_{rcv}(f)}{A_e(f)} \quad \left[\frac{Watt}{m^2}\right]$$

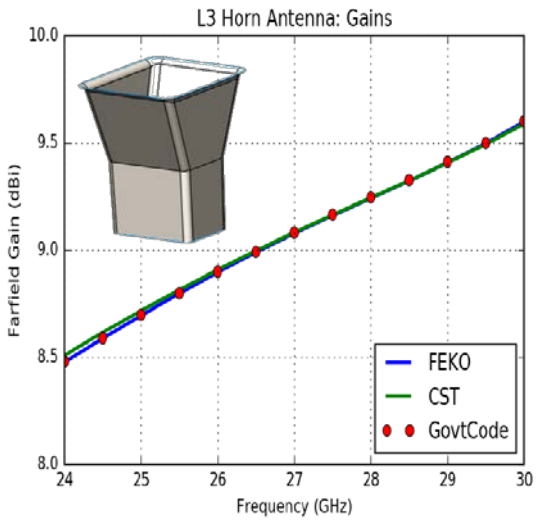
$$A_e(f) = G_r(f) \cdot \frac{\lambda^2}{4\pi} \quad [m^2]$$

$$P_d(f) = \frac{4\pi P_{8990B}(f)}{NGain_{rf\#1}(f) G_r(f) \lambda^2} \quad [Watts/m^2]$$

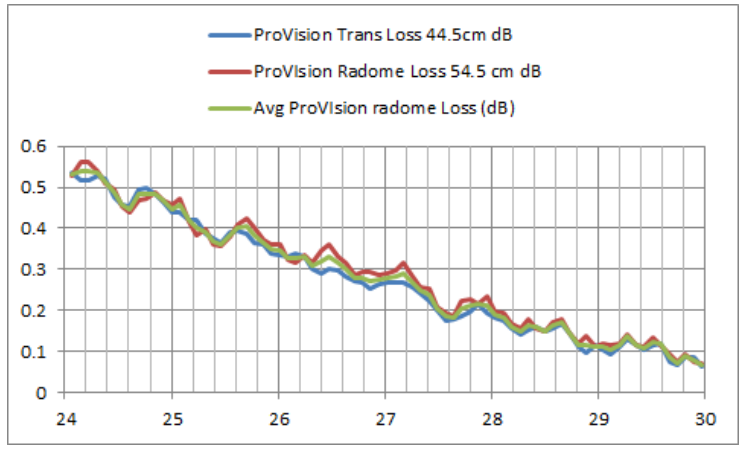
$$\boxed{|E_i(f)| = \sqrt{120\pi P_d(f)} \quad [Volts/m]}$$

Added CEM Predictions:

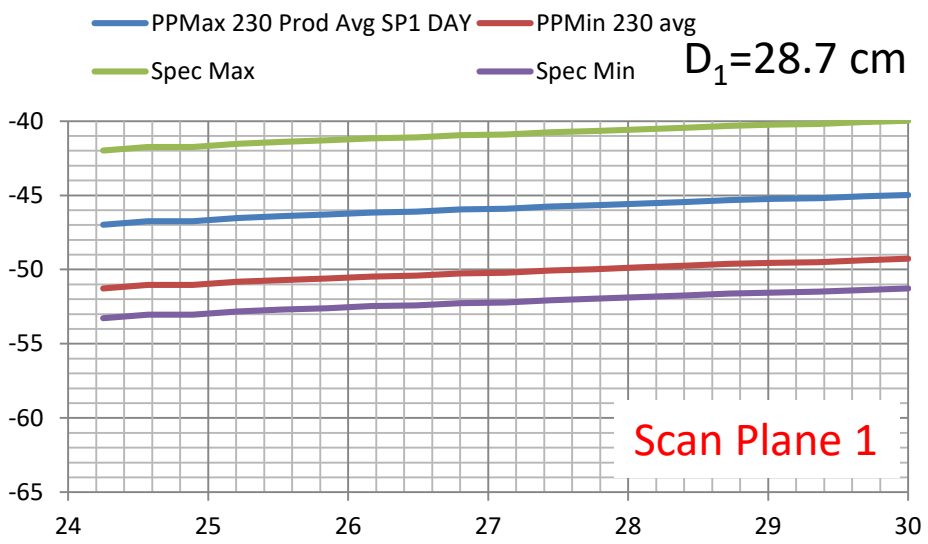
L^3 P_tG_t vs f based on L3 ProVision Transmitter Specs *and* Tri-Van Modelling of L3 Antennas as a cross check

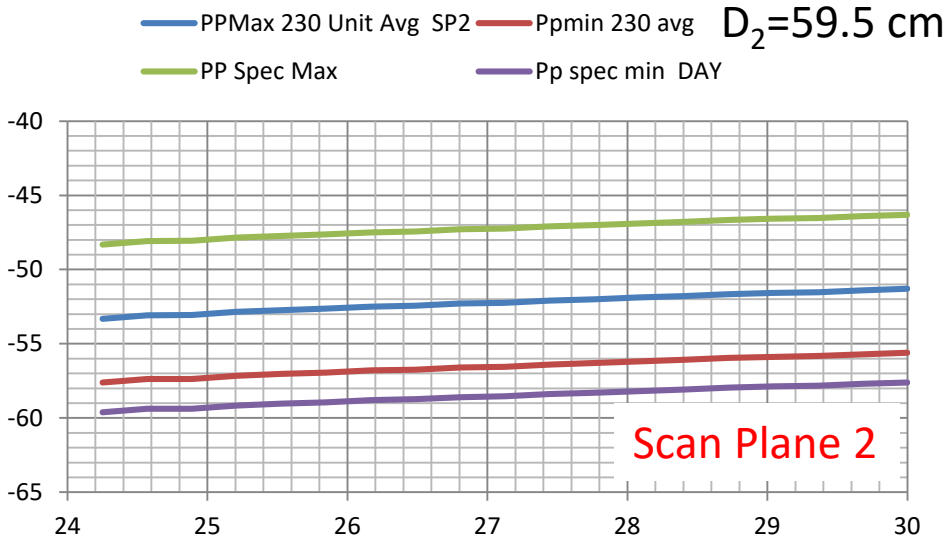


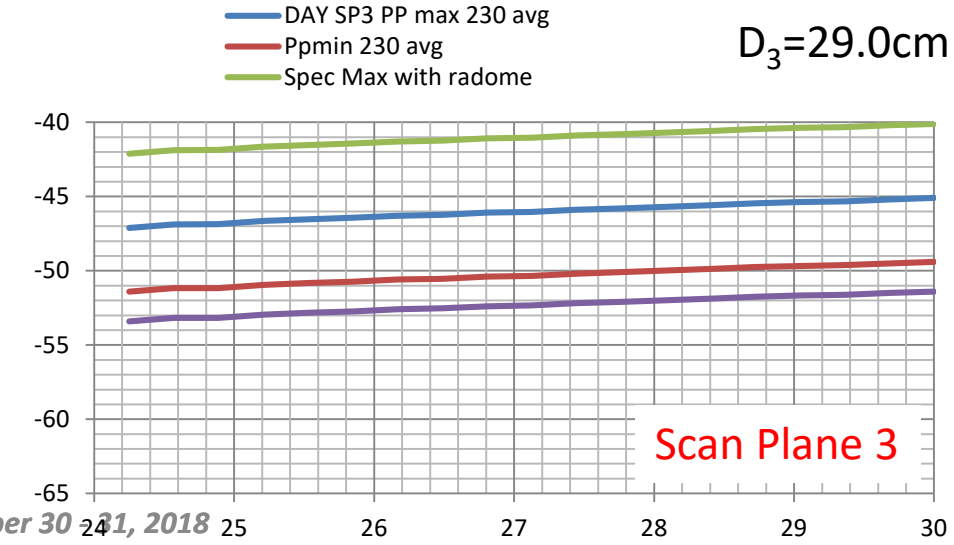
Lexan Radome Loss



Bounding the ProVision Min/Max Transmit Power

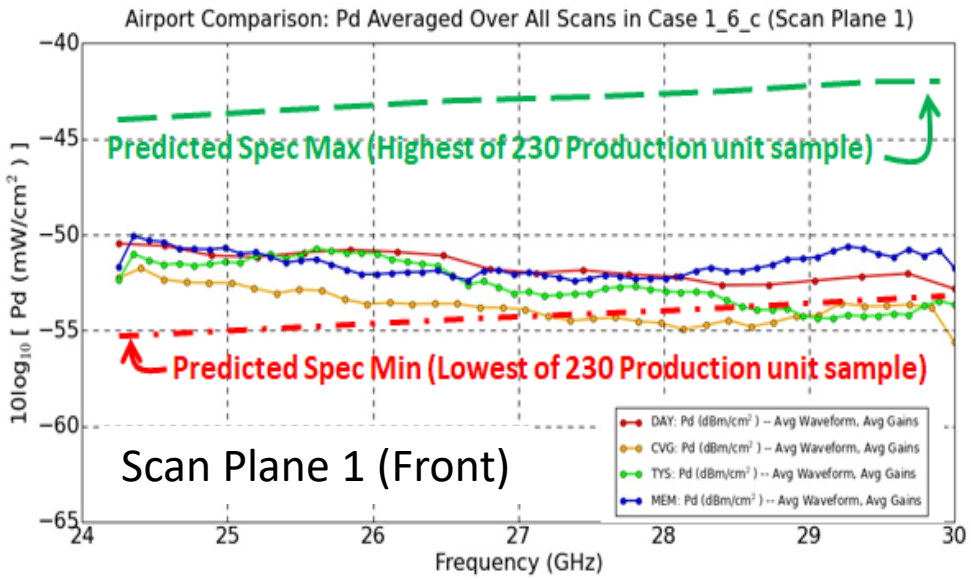


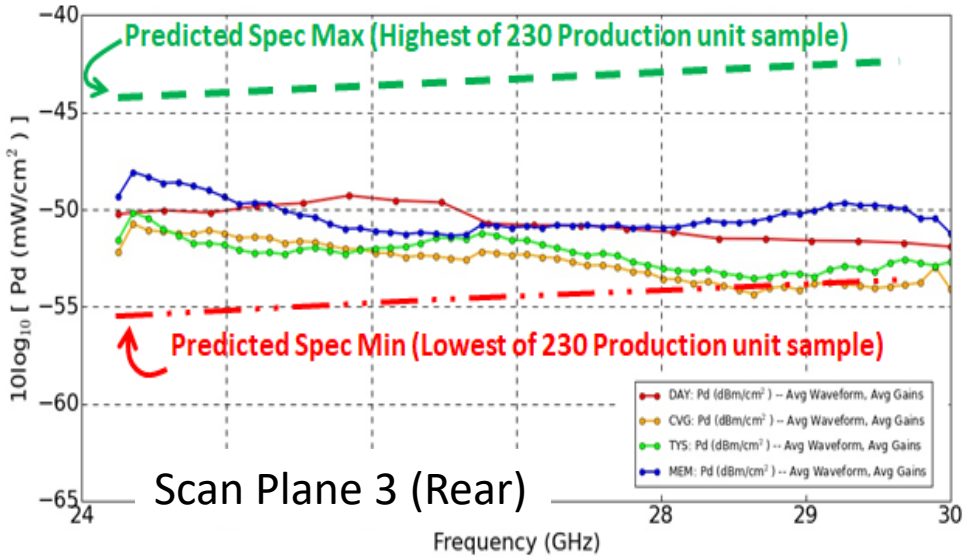


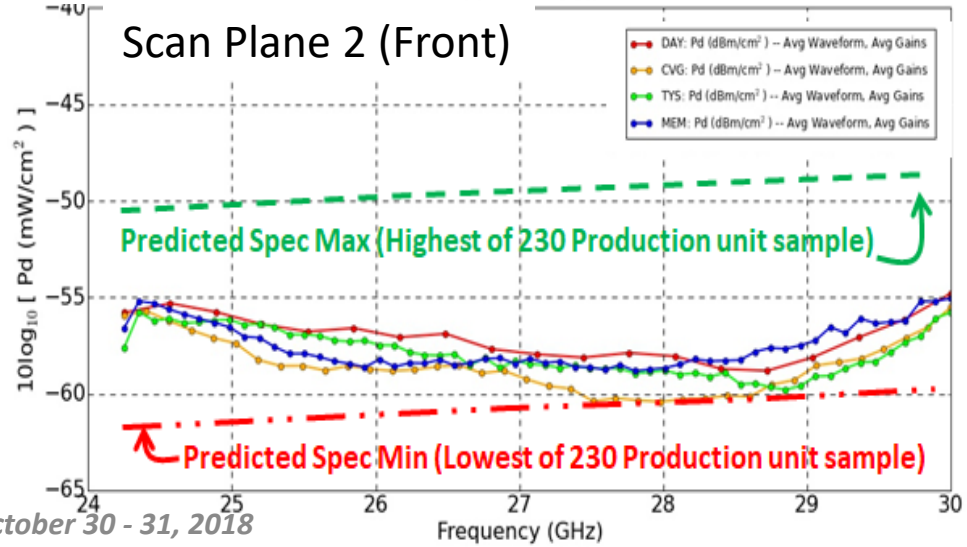


PP Spec Max = **maximum** CW power specification for L3 Xmt Module
Pp Spec Min = **minimum** CW power specification for L3 Xmt Module
PP Max 230 = *average* of CW maximum power of 230 production units
Pp Min 230 = *average* of CW minimum power of 230 production units
Comparing to field measurements requires reduction to 69% duty cycle

Composite Airport Scan Plane 1,2,3 Averages



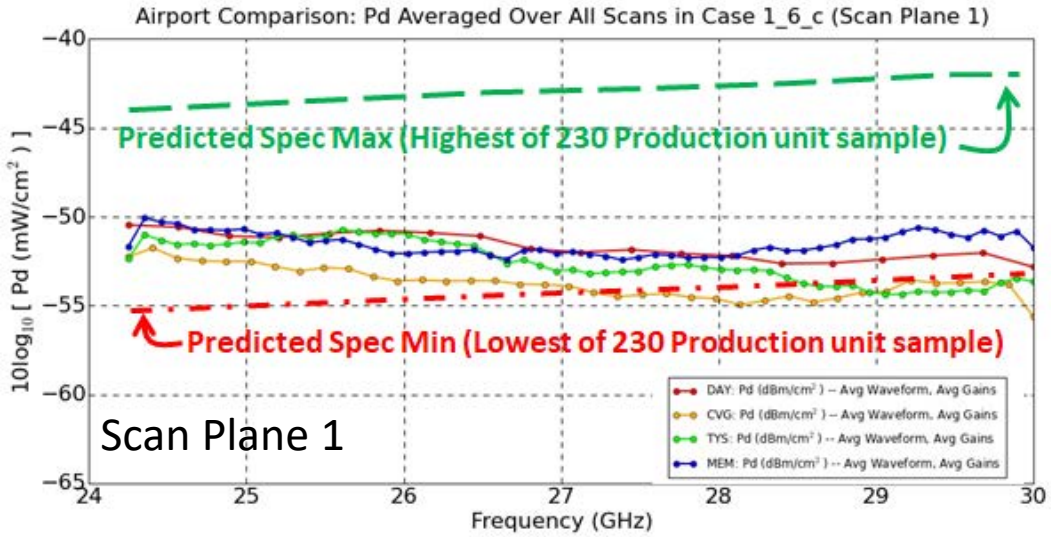


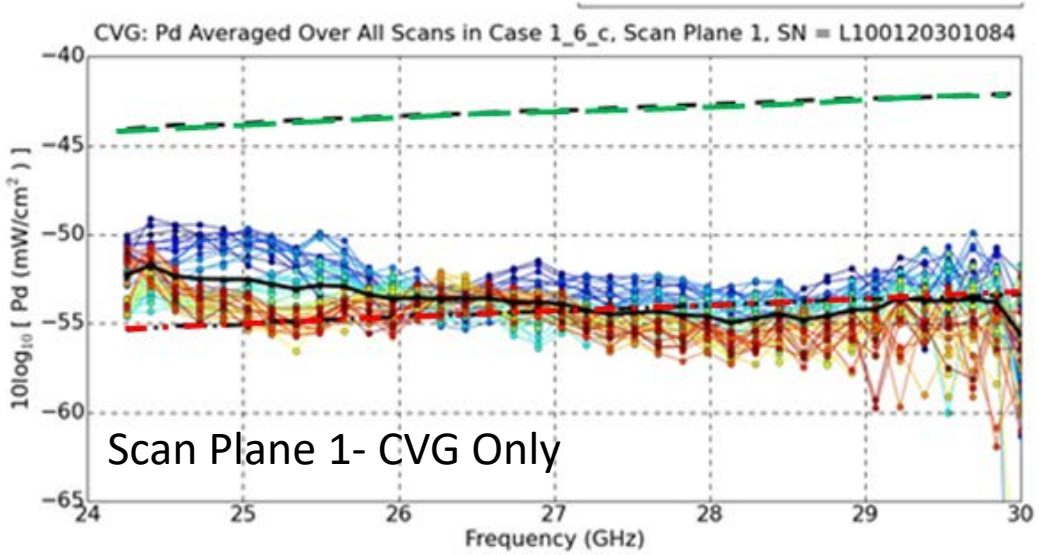


- Predicted Max and Min were based on Tri-Van CEM Analysis of L3 Antenna Array combined with L3Comm Production Acceptance Transmitter Variability Test Data For 230 Production Provision Machines
- Team Tested 4 machines, 2 Model Provision 1, and 2 of the newer, slightly smaller Provision 2 at 4 airports

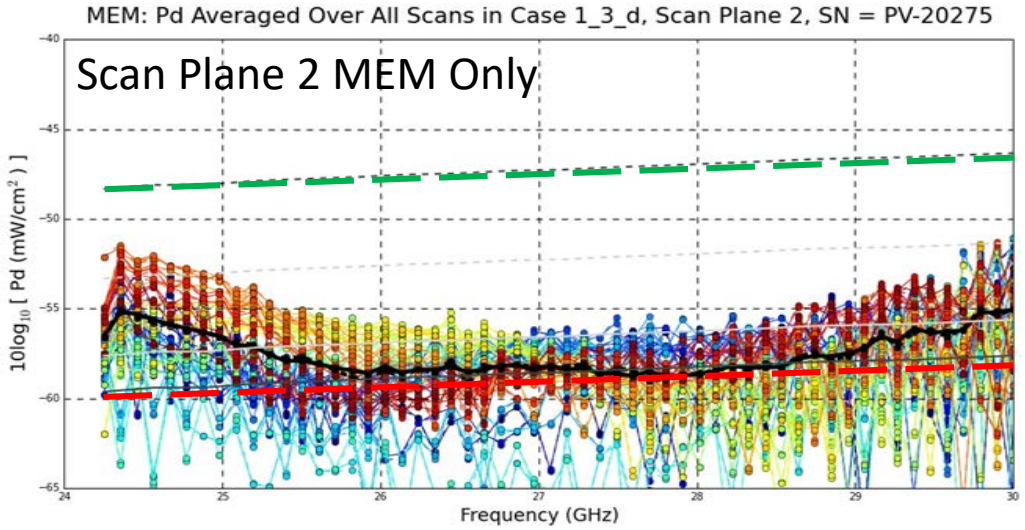
Airport Scan Full Dataset Samples

CVG SP1 and MEM SP2





Note Scan Plane 2 has lower S/N because of additional R^2 spread losses

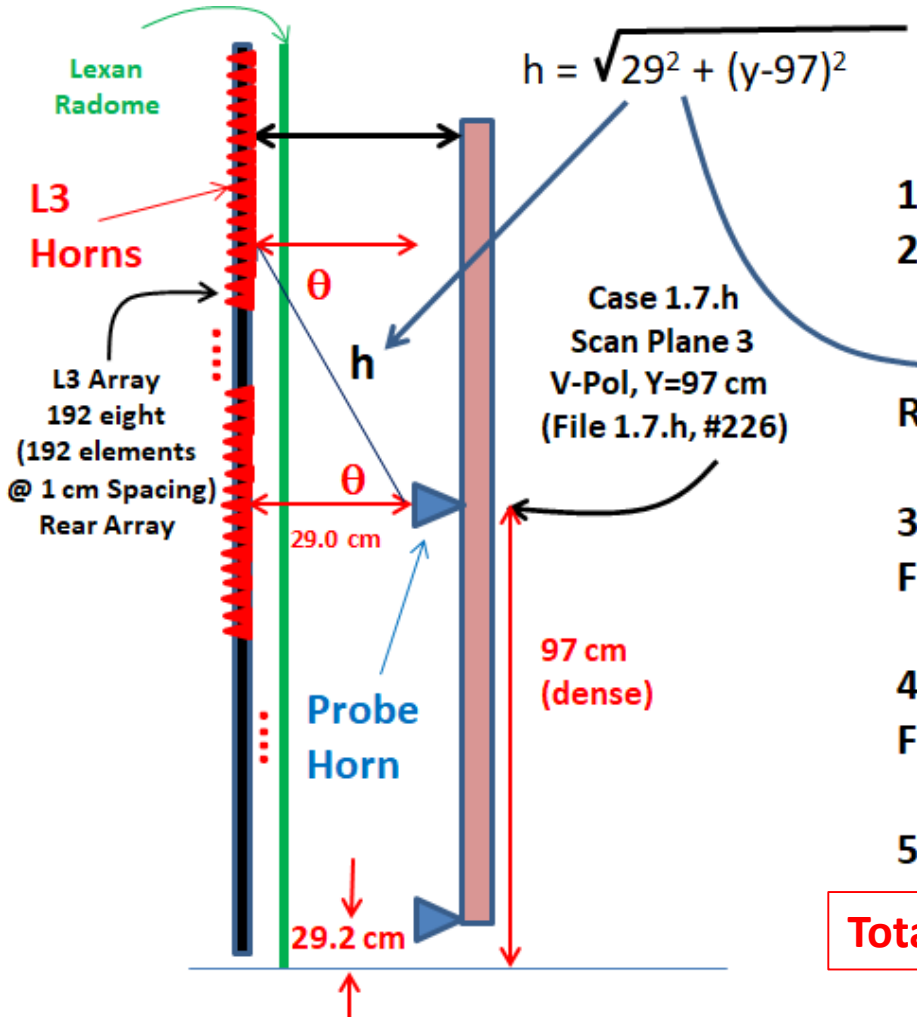


Characterizing L3 Transmit Array Elevation Spread Loss

Representative Analysis performed at 27 GHz (Near Center of Frequency Band)

Elevation Spread Loss Measurement (1 of 3)

(27 GHz, Scan Plane 3, Dayton, 97 cm height, File 226(1.7.h)



$h = \sqrt{29^2 + (y-97)^2}$

Technique for Computing Spread losses

1. Use direct path at y=97 cm as base power
2. Calculate range spread loss component Using the following formula:

R^2 Range Loss (dB) = 20 log [29 / h]

3. Extract Probe Elevation pattern loss From measured probe pattern at θ, 27 GHz

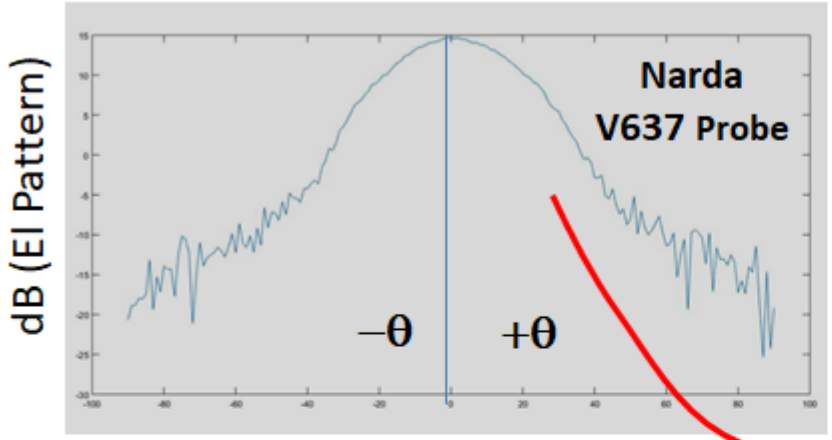
4. Extract L3 Elevation Pattern loss From L3 supplied 27 GHz data at θ, 27 GHz

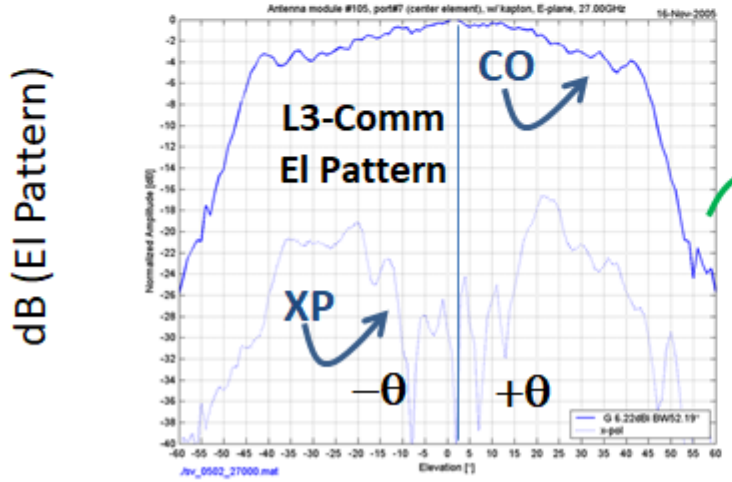
5. Total Spread Loss Calculated by:

Total EL Spread Loss (dB) = R^2 Loss (dB) + Probe El (θ) (db) + L3 El (θ) (dB)

Elevation Spread Loss Measurement (2 of 3)

(27 GHz, Scan Plane 3, Dayton, 97 cm height, File 226 (1.7.h)



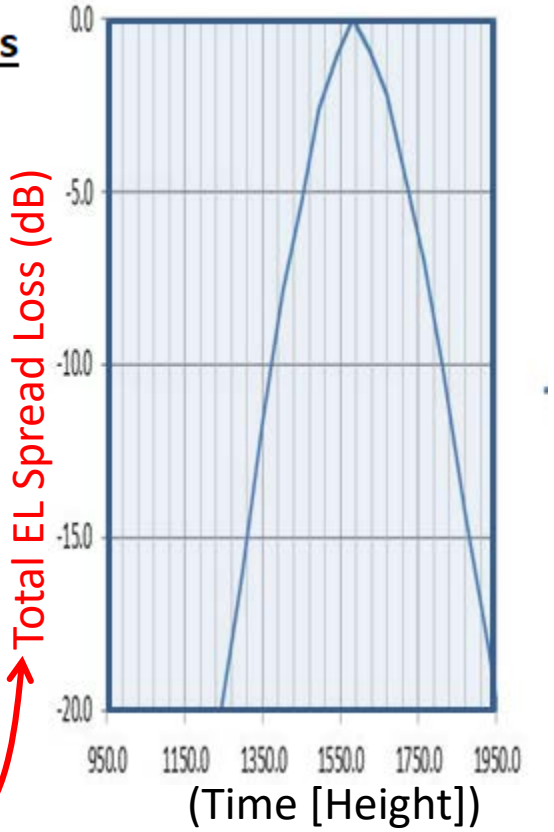


Technique for Computing Spread losses

1. Use direct path at y=97 cm as base power
2. Calculate range spread loss component Using the following formula:

R^2 Range Loss (dB) = 20 log [29 / h]

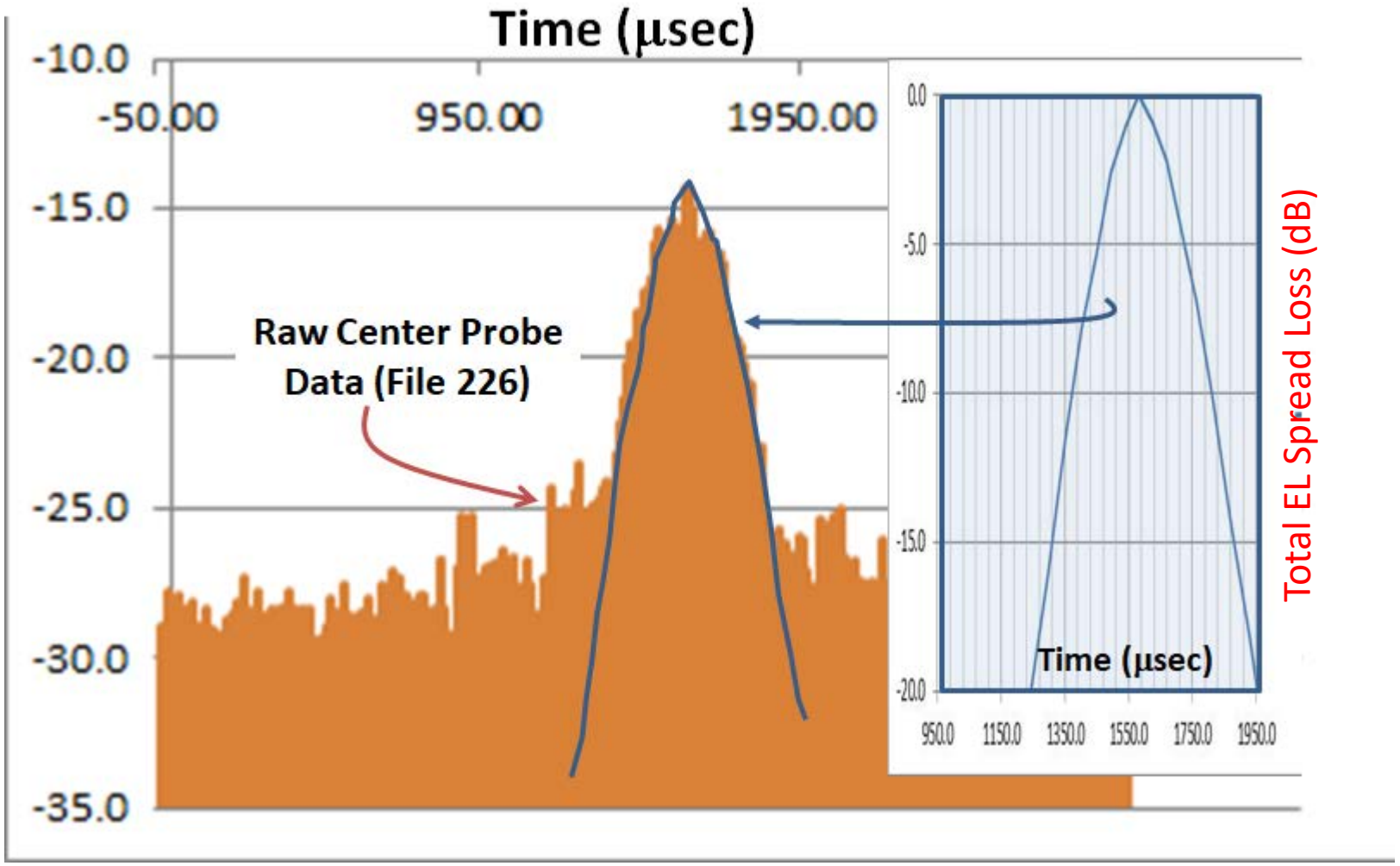
3. Extract Probe Elevation pattern loss From measured probe pattern at θ, 27 GHz
4. Extract L3 Elevation Pattern loss From L3 supplied 27 GHz data at θ, 27 GHz
4. Total Spread Loss Calculated by:



Total EL Spread Loss (dB) = R^2 Loss (dB) + Probe El (θ) (db) + L3 El (θ) (dB)

Elevation Spread Loss Measurement (3 of 3)

(27 GHz, Scan Plane 3, Dayton, 97 cm height, File 226 (1.7.h)



Conclusion:

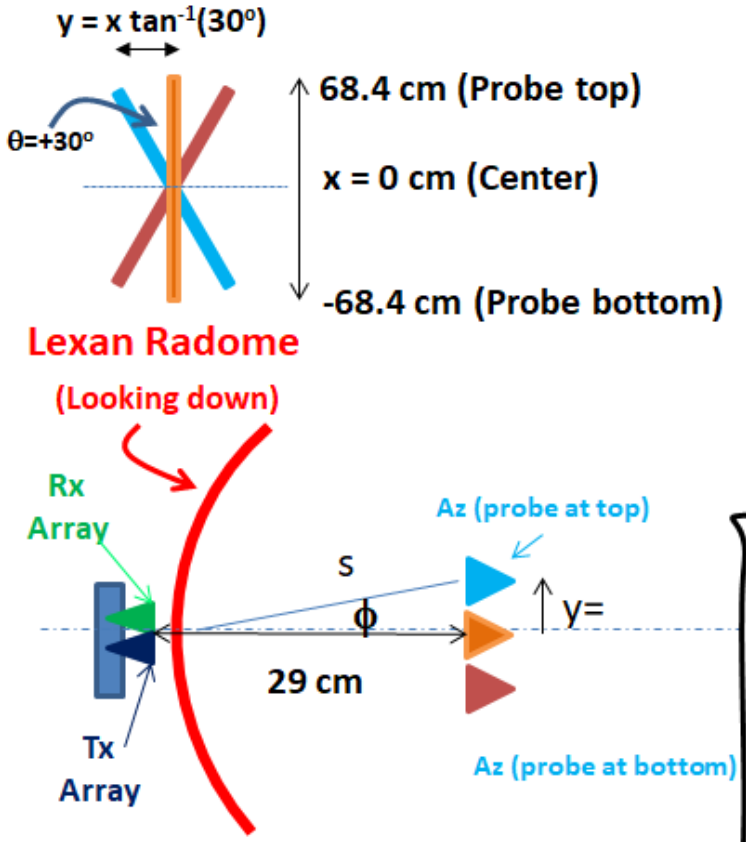
L3 Linear Array Element antenna pattern falls off as predicted in the elevation (height) plane as one proceeds away from the active radiating element

Characterizing L3 Transmit Array Azimuth Spread Losses “Off Centerline”

Representative Analysis performed at 27 GHz (Near Center of Frequency Band)

Azimuth Spread Loss Measurement (1 of 3)

(27 GHz, Scan Plane 3, Dayton, +30°, Files 114/119/124 (Case 1.7.g)



$\phi = \mathrm{Tan}\,(y/28.07)$ where $y = x \tan^{-1}(30^\circ)$
And x is the +/- probe position from center
where

$$s = \sqrt{29^2 + (x \tan^{-1}(30^\circ))^2}$$

Technique for Computing Spread losses

1. Use direct path at x=0 cm as base power
2. Calculate range spread loss component
   Using the following formula:

R^2 Range Loss (dB) = 20 log [29 / s]

3. Extract Probe Azimuth pattern loss
   From measured probe pattern at ϕ, 27 GHz

4. Extract L3 Az Pattern loss
   From L3 supplied 27 GHz data at ϕ, 27 GHz

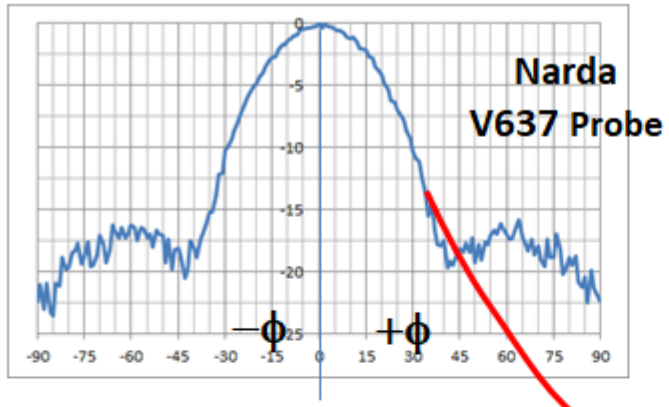
5. Total Spread Loss Calculated by:

Total AZ Spread Loss (dB) = R^2 Loss (dB) + Probe Az (ϕ) (db) + L3 Az (ϕ) (dB)

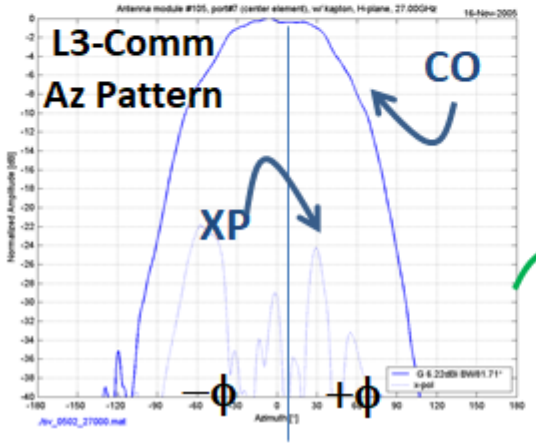
Azimuth Spread Loss Measurement (2 of 3)

(27 GHz, Scan Plane 3, Dayton, +30°, Files 114/119/124 (Case 1.7.g)

dB (Az Pattern)



dB (El Pattern)



Technique for Computing Spread losses

- Use direct path at x=0 cm as base power

2. Calculate range spread loss component Using the following formula:

Range Loss (dB) = 20 log [29 / s]

3. Extract Probe Azimuth pattern loss From measured probe pattern at ϕ, 27 GHz

4. Extract L3 Az Pattern loss From L3 supplied 27 GHz data at ϕ, 27 GHz

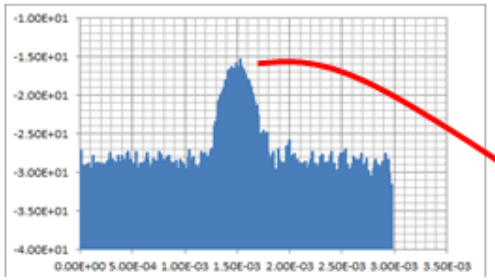
5. Total Spread Loss Calculated by:

Total AZ Spread Loss (dB) = R^2 Loss (dB) + Probe Az (ϕ) (db) + L3 Az (ϕ) (dB)

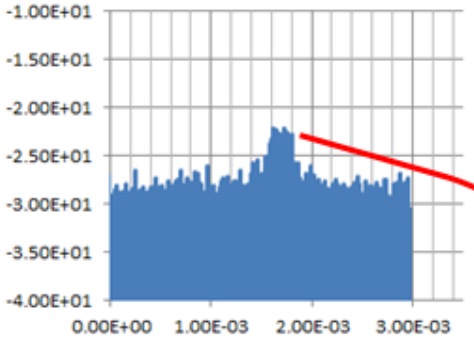
Azimuth Spread Loss Measurement (3 of 3)

(27 GHz, Scan Plane 3, Dayton, +30°, Files 114/119/124 (Case 1.7.g)

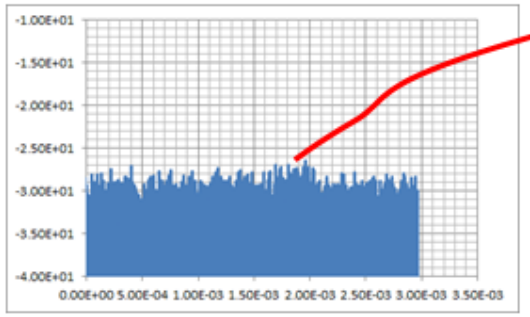
File 1.7g 124
Center x=0 cm



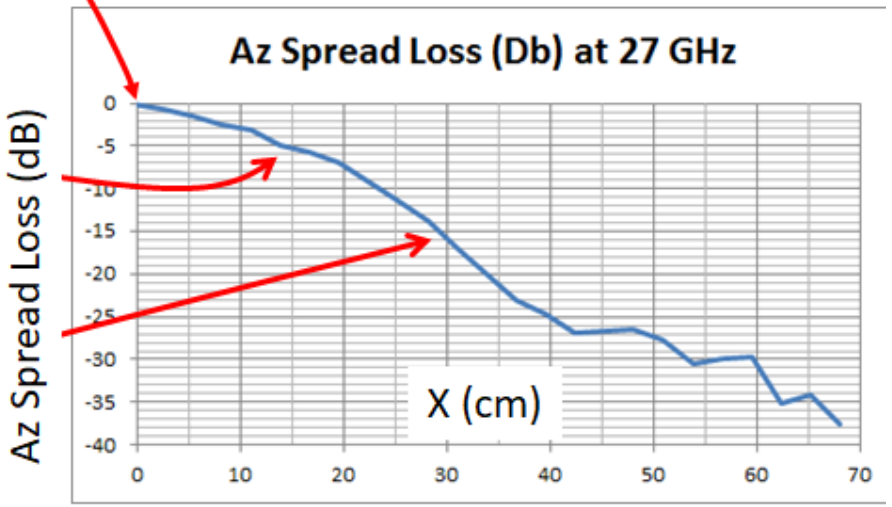
File 1.7g 119
x= 14.26 cm



File 1.7g 114
x= 28.52 cm

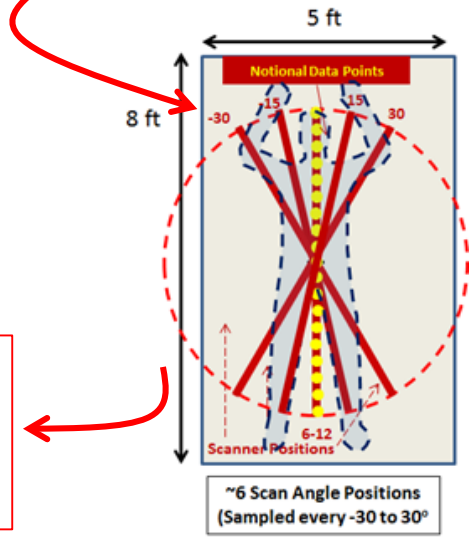


V637+L3 antenna Az pattern + spatial Spread Loss (dB)
(27 GHz)



Conclusion:

L3 Linear Array Element antenna pattern falls off as predicted in the Azimuth (width) plane as one proceeds away from the principle linear plane



Very Few Off-Axis Measurements were ultimately collected after this analysis was complete as the maximum incident fields were in the vertical plane

Uncertainty Analysis for Dayton Airport Data (1/4)

- NAS asked that *one data set* from the 4 airports be used to estimate overall measurement uncertainty
- Uncertainty performed with original Dayton dataset
  - Results ultimately drove changes to improve S/N ratio for MEM, TYS, and CVG Measurements
- Outline of Uncertainty Analysis Follows….

Uncertainty Analysis for Dayton Airport Data (2/4)

$$P_d = \frac{(4\pi f^2 P_8)}{(c^2 N G_r)}$$

- Partially differentiating the base P_d term with respect to each variable in turn (f,θ,ϕ,R), then normalizing by P_d and separating into fractional error terms we get:

$$\left[\frac{\partial P_d}{P_d}\right] = \left[\frac{2}{f}\right] + \left[\frac{\partial P_8}{P_8\ \partial f}\right] + \left[\frac{\partial P_8}{P_8\ \partial R}\right] +$$

$$\left[\frac{\partial P_8}{P_8\ \partial \theta}\right] + \left[\frac{\partial P_8}{P_8\ \partial \phi}\right] - \left[\frac{\partial N}{N\ \partial f}\right] - \left[\frac{\partial G_r}{G_r\ \partial f}\right]$$

Uncertainty Analysis for Dayton Airport Data (3/4)

The fractional RSS errors are…

$$\left[\frac{\partial P_d}{P_d}\right]^2 = \underbrace{\left[\frac{4}{f^2}\right]}_{\text{Term 1}} + \underbrace{\left[\frac{\partial P_8}{P_8\,\partial f}\right]^2}_{\text{Term 2}} + \underbrace{\left[\frac{\partial P_8}{P_8\,\partial R}\right]^2}_{\text{Term 3}} +$$

$$\underbrace{\left[\frac{\partial P_8}{P_8\,\partial \theta}\right]^2}_{\text{Term 4}} + \underbrace{\left[\frac{\partial P_8}{P_8\,\partial \phi}\right]^2}_{\text{Term 5}} + \underbrace{\left[\frac{\partial N}{N\,\partial f}\right]^2}_{\text{Term 6}} + \underbrace{\left[\frac{\partial G_r}{G_r\,\partial f}\right]^2}_{\text{Term 7}}$$

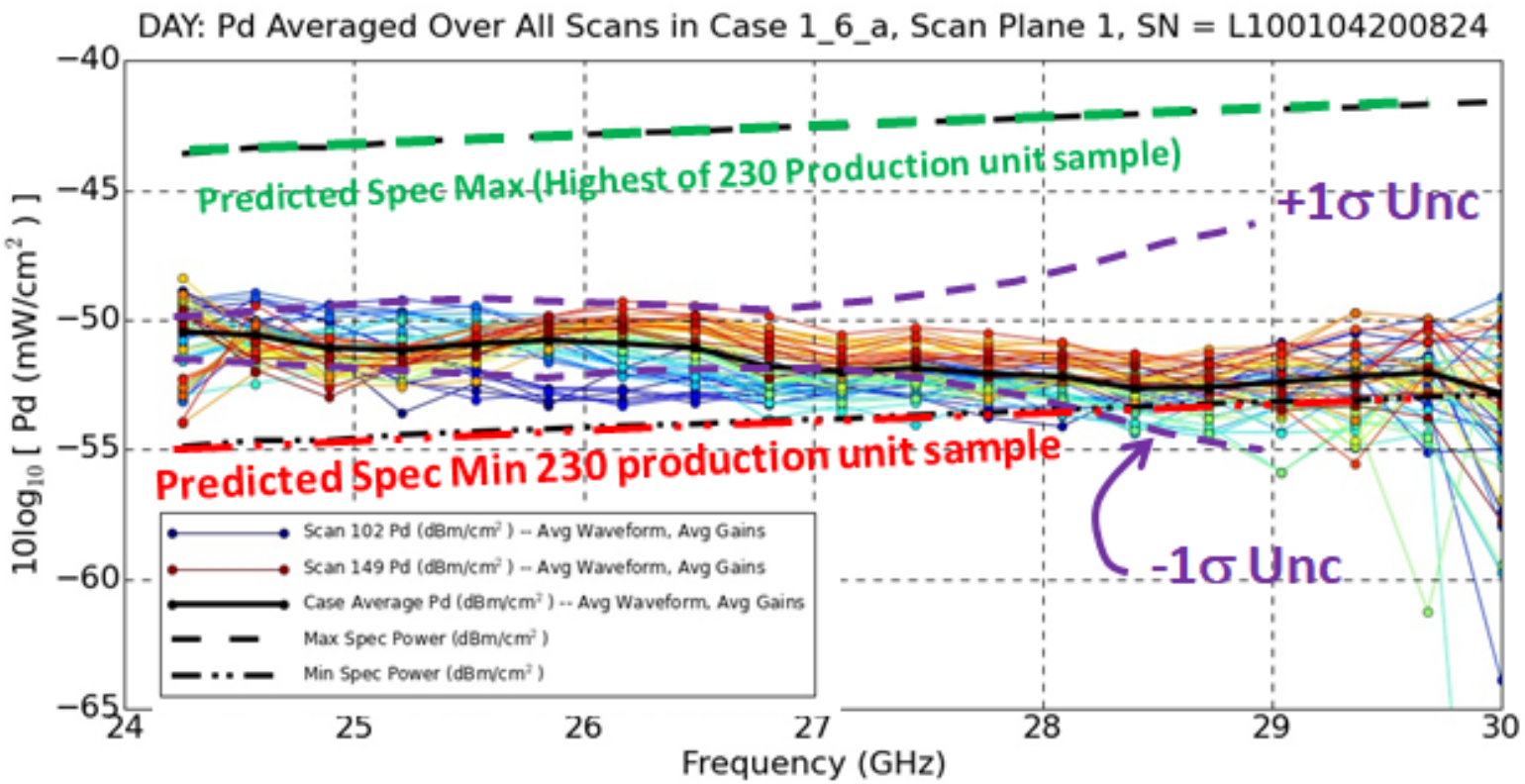
- Term 1 - Absolute frequency Uncertainty
- **Term 2** – P_8 Uncertainty (raw instrument+ S/N vs f)
  - Term 2 is normally *dominated* by S/N error
- Term 3 – P_8 due to range uncertainty (probe to array)
- Term 4 – P_8 due to azimuth boresight uncertainty
- Term 5 – P_8 due to elevation boresight uncertainty
- **Term 6** – P_d due to $\text{NetGain}_{\text{RF\#1}}$ uncertainty vs f
- **Term 7** – P_d due to receive gain G_r Uncertainty vs f

BOLDED Terms are the highest contributors to Overall Measurement Uncertainty

Uncertainty Analysis for Dayton Airport Data (4/4)

…and a lot of analysis and data reduction later….

DAY Scan Plane 1 (Front)



NOTE

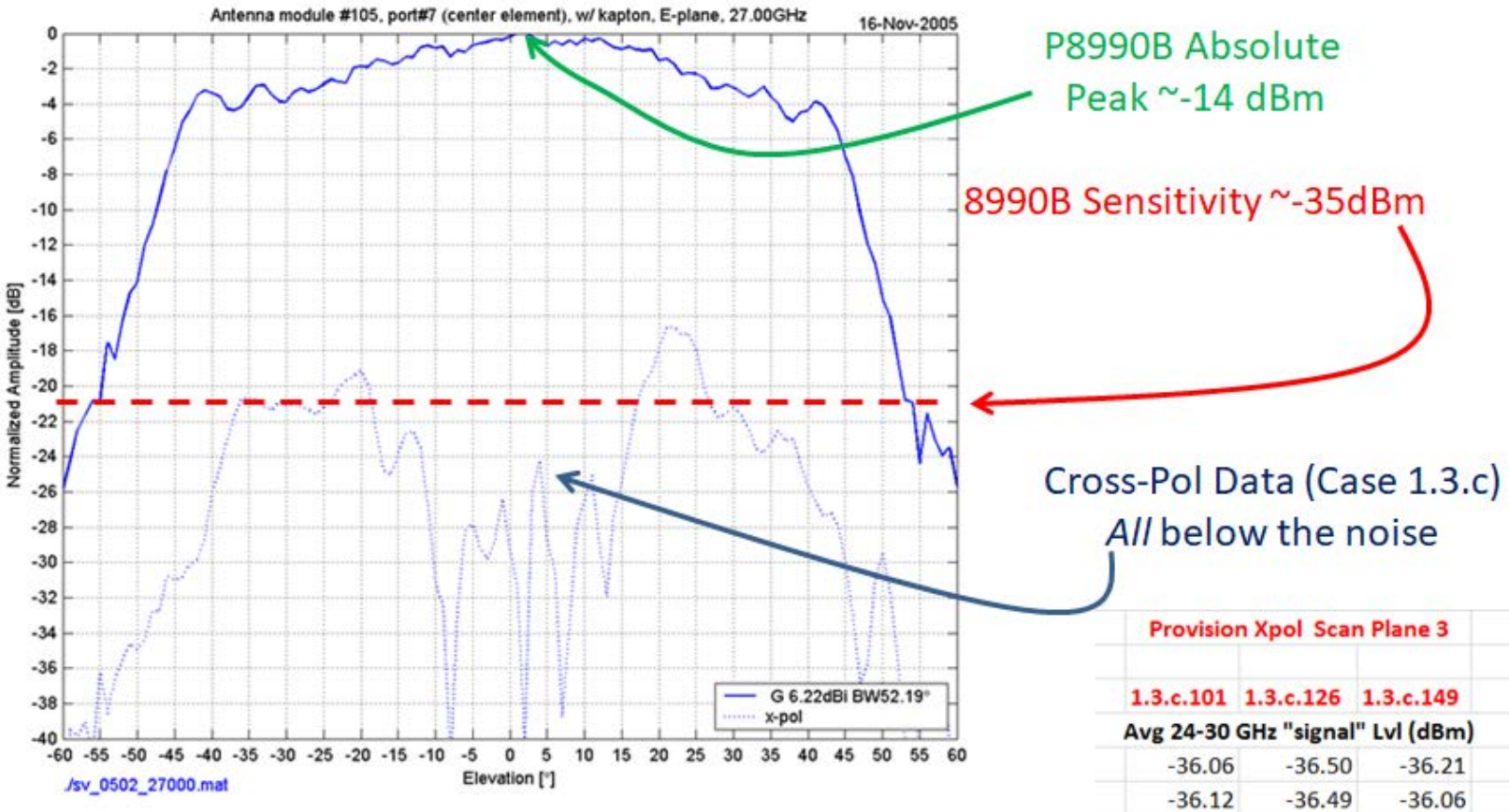
Dayton $Ngain_{RF}(f)$ system sensitivity dramatically fell off above 29 GHz

CVG/MEM/TYS Used modified Front-end sensor to increase S/N Above 29 GHz

Uncertainty only performed in DAY For Scan Plane 1

What about Body Scanner Cross Polarization (VH)?

Scan Plane 1 (Front)



Provision Xpol Scan Plane 3		
1.3.c.101	1.3.c.126	1.3.c.149
Avg 24-30 GHz "signal" Lvl (dBm)		
-36.06	-36.50	-36.21
-36.12	-36.49	-36.06
-36.32	-38.52	-36.74
-35.42	-38.72	-39.81

NOTE

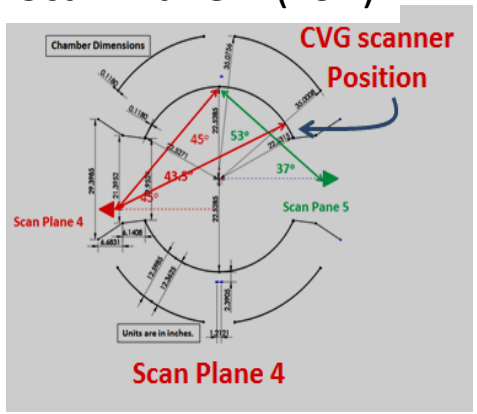
No further X-Pol Tests performed at MEM, CZVG, or TYS as a result of DAY data

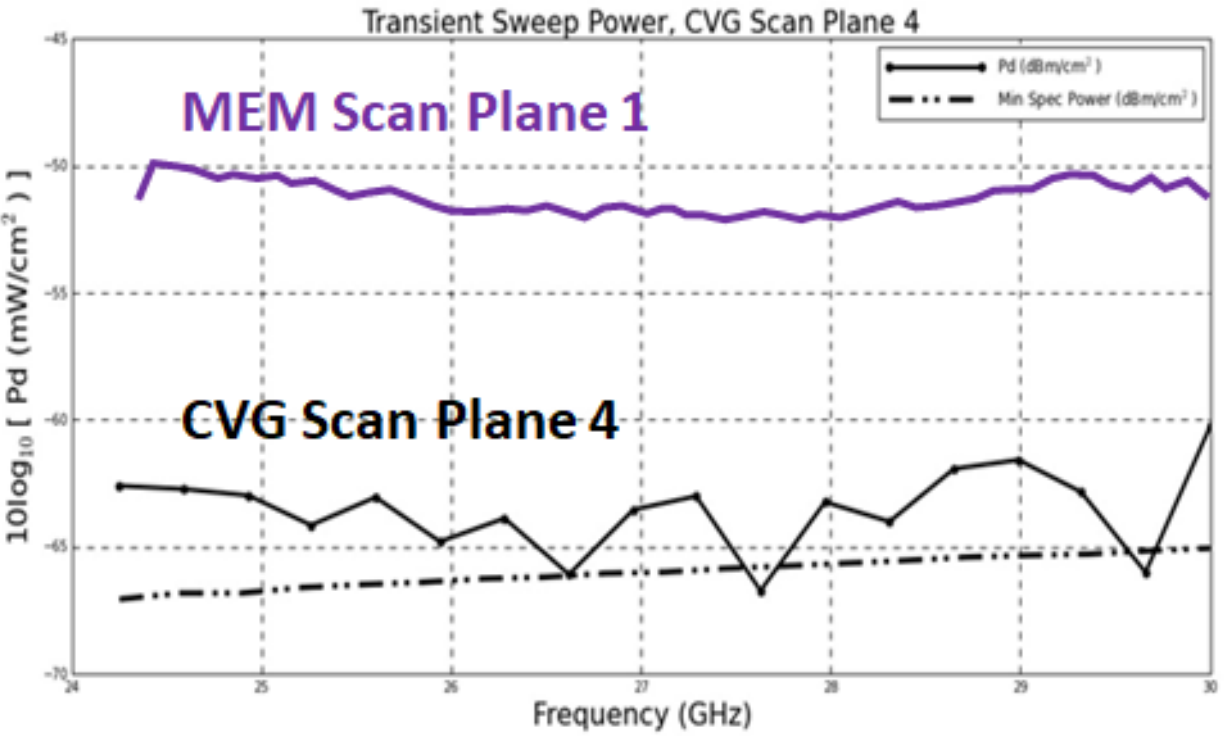
27 GHz Data shown

Power Level Measurements at TSA Operator Position

(TSA Operator Scan Plane 4 Transient, CVG Measurement)

Scan Plane 4 (TSA)





NOTE

This is the only mechanical Transient measurement performed

Field Probe Array placed just outside The ProVision Scanner Exit door center, Slightly closer than where TSA operator Stands during operation

<10 dB Lower than Passenger Scan Plane 1

Scan Plane 4 results to left must be reduced by ~8.2 dB to account for mechanical Swing-arm illumination duty cycle (30%)

ARA Pro-Vision Airport Body Scanner Measurements

(Hopefully the LAST Time)

- *In-Band (24-30 GHz) field measurements were done using a highly sophisticated, fully calibrated time domain power meter*
- *The "Test Machines" were chosen by NAS from operational airport machines in Dayton, Cincinnati, Memphis, and Tyson.*
- Several *Million* individual test points were measured in three internal and 2 external scan plans.
- *ARA Documented all measurements in a report: "Radiated Transmit Field Power Density Measurements of the ProVision Version 1 and 2 Millimeter Wave Body Scanners, NAS Final Report under contract NAS 002004737 3 May 2016"*
- *NAS Compiled all final data and issued their own final safety analysis and report incorporating ARA results: "Airport Passenger Screening Using Millimeter Wave Machines: Compliance with Guidelines, ISBN 978-0-309-46744-5*

And the NAS Measurement Conclusions…?

ALL CONCLUSIONS AND RECOMMENDATIONS [3] 135

CHAPTER 6. COMMITTEE-LED MEASUREMENTS

Finding 6.1: The committee-led measurements at airports indicate that even an "out of position" person will receive an average pulsed power density during a scan that is 270,000 times below the applicable standard exposure limit of 10 W/m^2 and most likely will receive even less standing correctly in the center of the portal.

Finding 6.2: The committee-led measurements at airports indicate that even at the entry position of the portal, the power density is several million times below the acceptable limit, even for a continuous signal.

Finding 6.3: The committee finds that during normal operation of the ProVision ATD and ProVision 2 systems there is no risk to a person being screened to receive the applicable standard exposure limit of 10 W/m^2; instead, the exposure is hundreds of thousands times less.

[3] Paraphrased after 185 pages and 2 years….

It's Safe

[3] "Airport Passenger Screening Using Millimeter Wave Machines: Compliance with Guidelines, ISBN 978-0-309-46744-5. PP135

Questions?