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WARFARE CENTERS
NEWPORT

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Software Defined Wireless Systems
Enabling technology for

Wireless CYBER Conflicts in a Highly Contested Electromagnetic Environment

SDRF14 March 12, 2014

Dr. Donald H. Steinbrecher, Chief Scientist, NUWCDIVNPT

"Cognitive & Software-Defined RF Technology: Achieving Spectral Dominance for the United States Warfighting Forces of the Future"

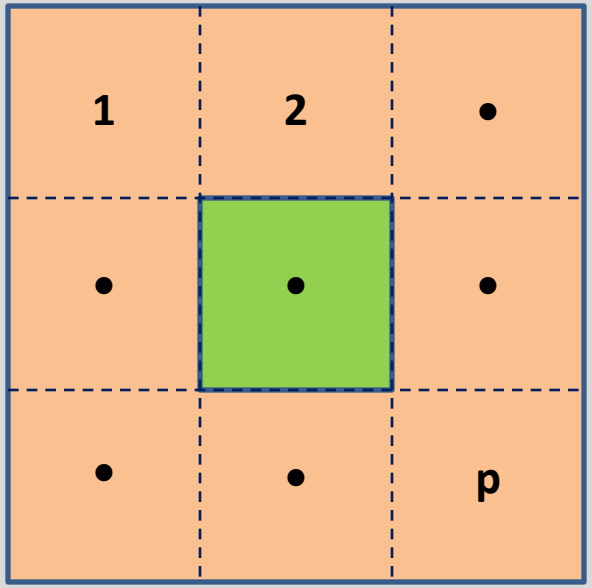
Definitions for an Ideal Partitioned Air Interface (Antenna)

Eplane:

Partitioned planar surface designed to capture EM energy. The effective aperture is equal to the physical area and the RF efficiency is 100% within measurement error.

Epixel:

One of the p equal-area partitions each with an effective aperture equal to the Epixel physical area. Thus, the capture area of the Eplane is p-times the capture area of one Epixel.



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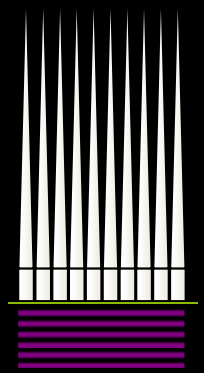

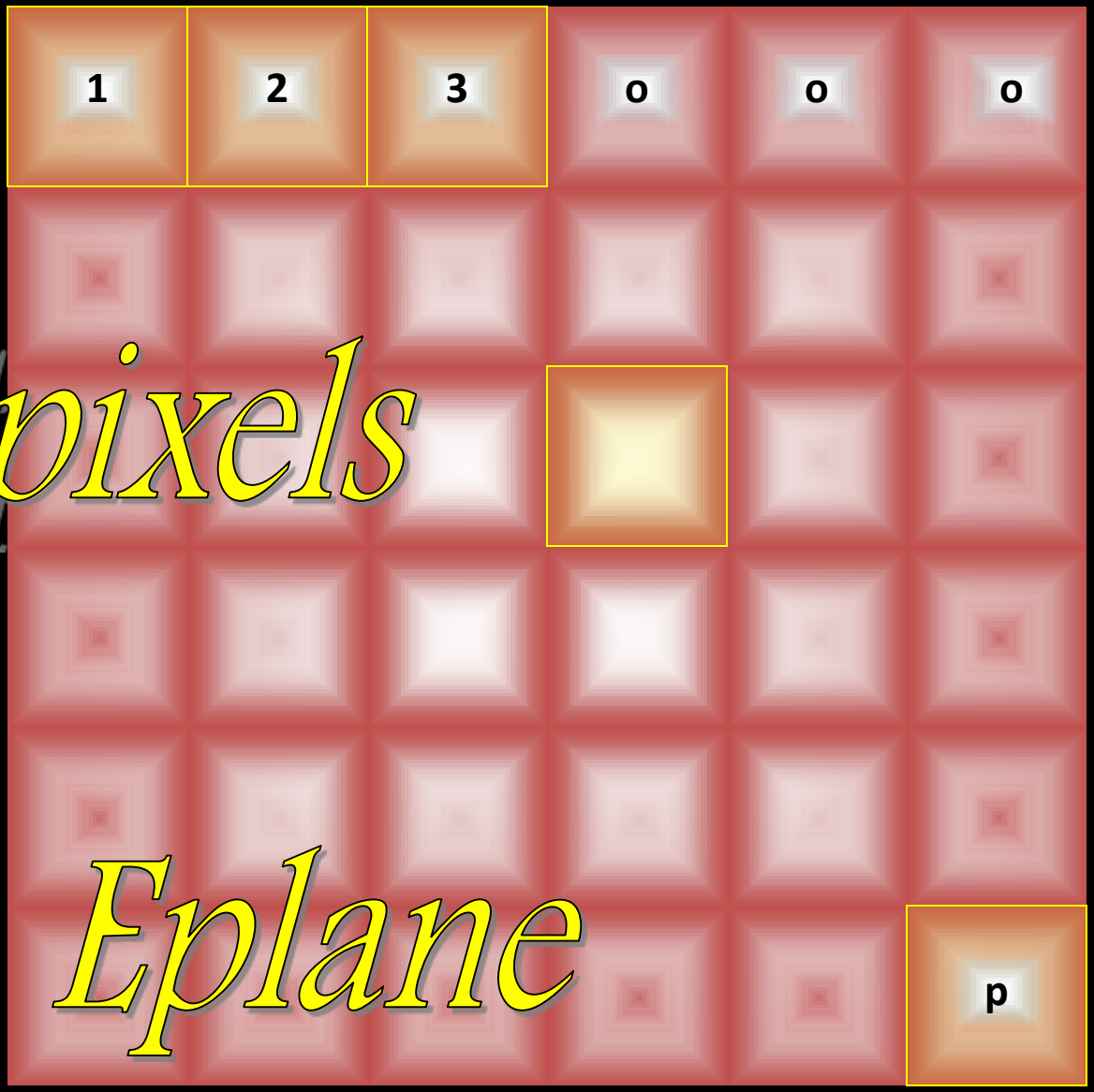

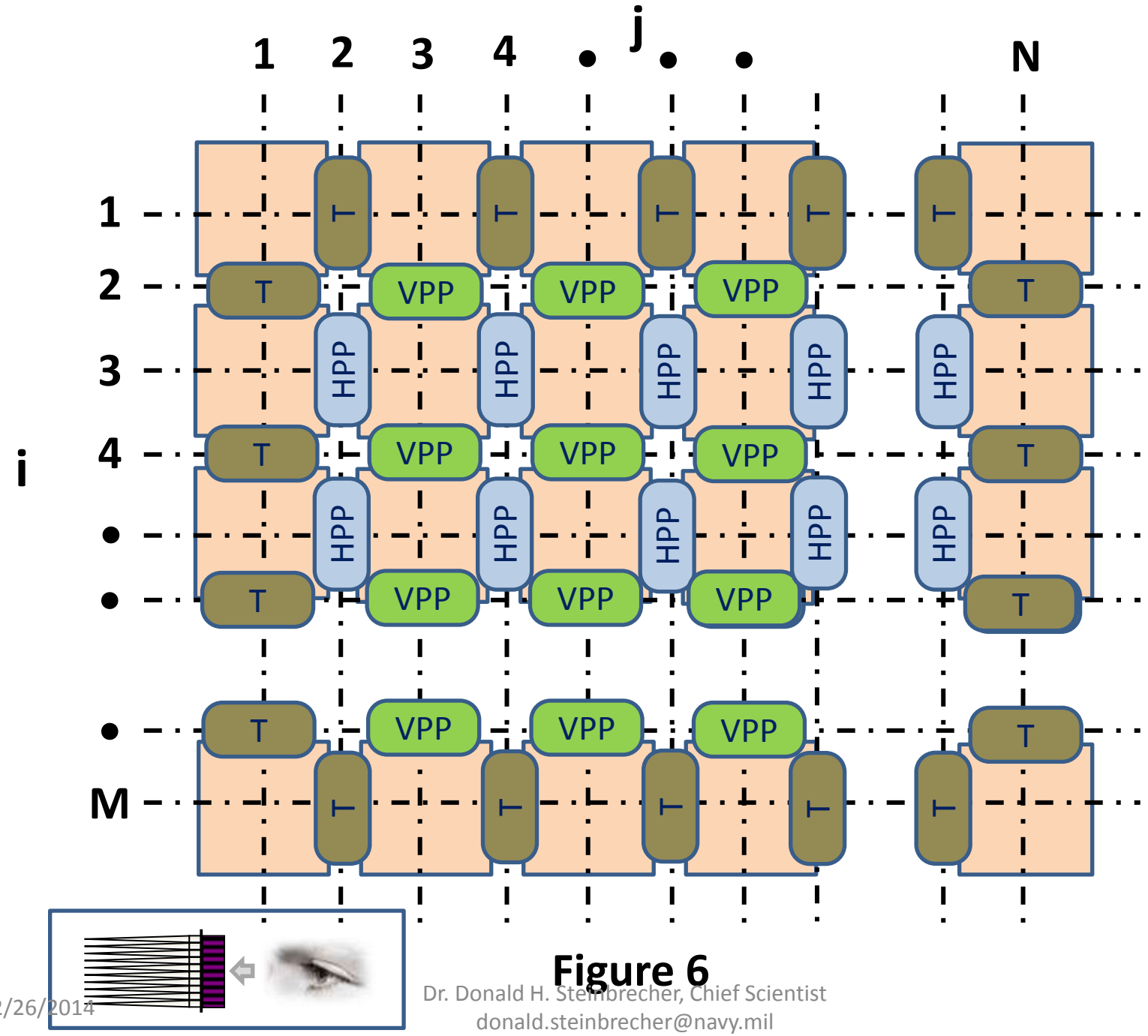

Figure 6

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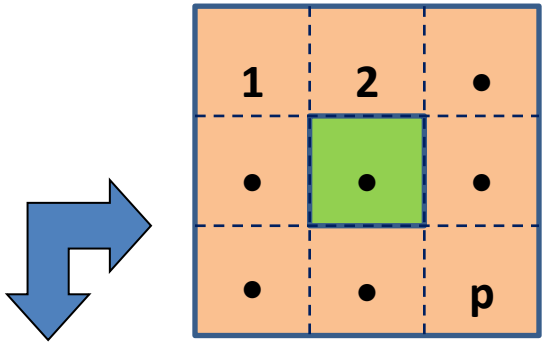
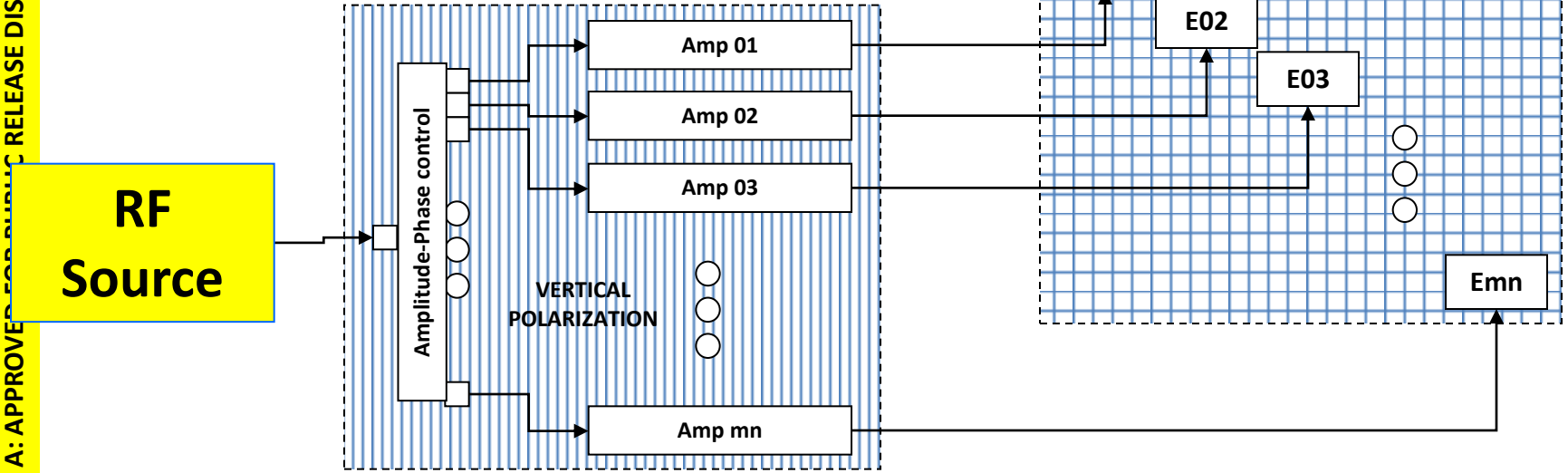
Partitioned Air Interface Spatially Combined Transmitter





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Each time the number of driven Epixels is doubled, the spatially combined far-field EIRP is expected to increase by 6 dB

Expected EIRP Relative to 32 Epixel EIRP	
Number of Driven Epixels	EIRP Relative to 32 Driven Epixels
Count	dB
16	-6
8	-12
4	-18
2	-24
1	-30

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Spatially Combined Far Field EIRP for a Wideband Partitioned Air Interface Transmitter

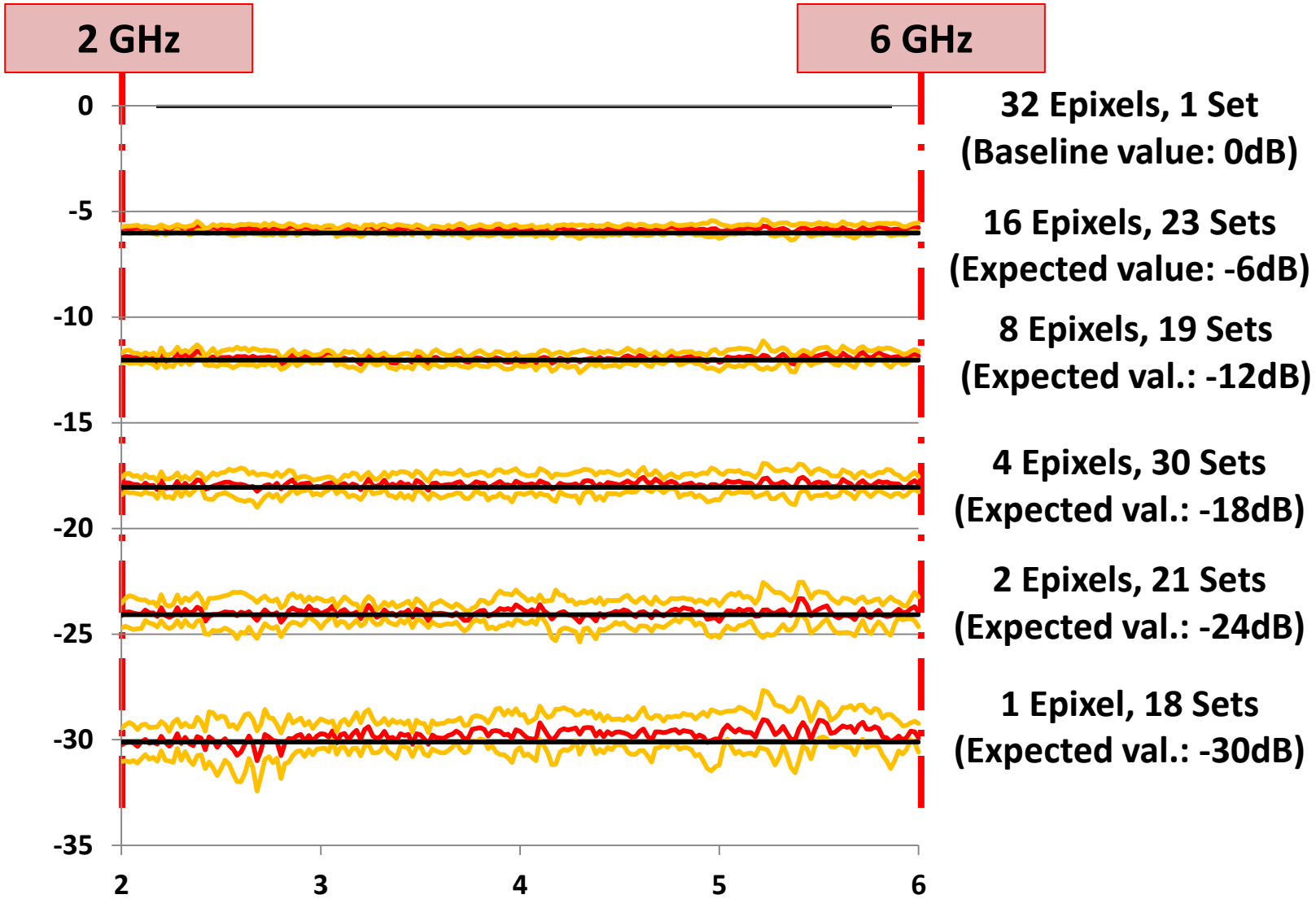

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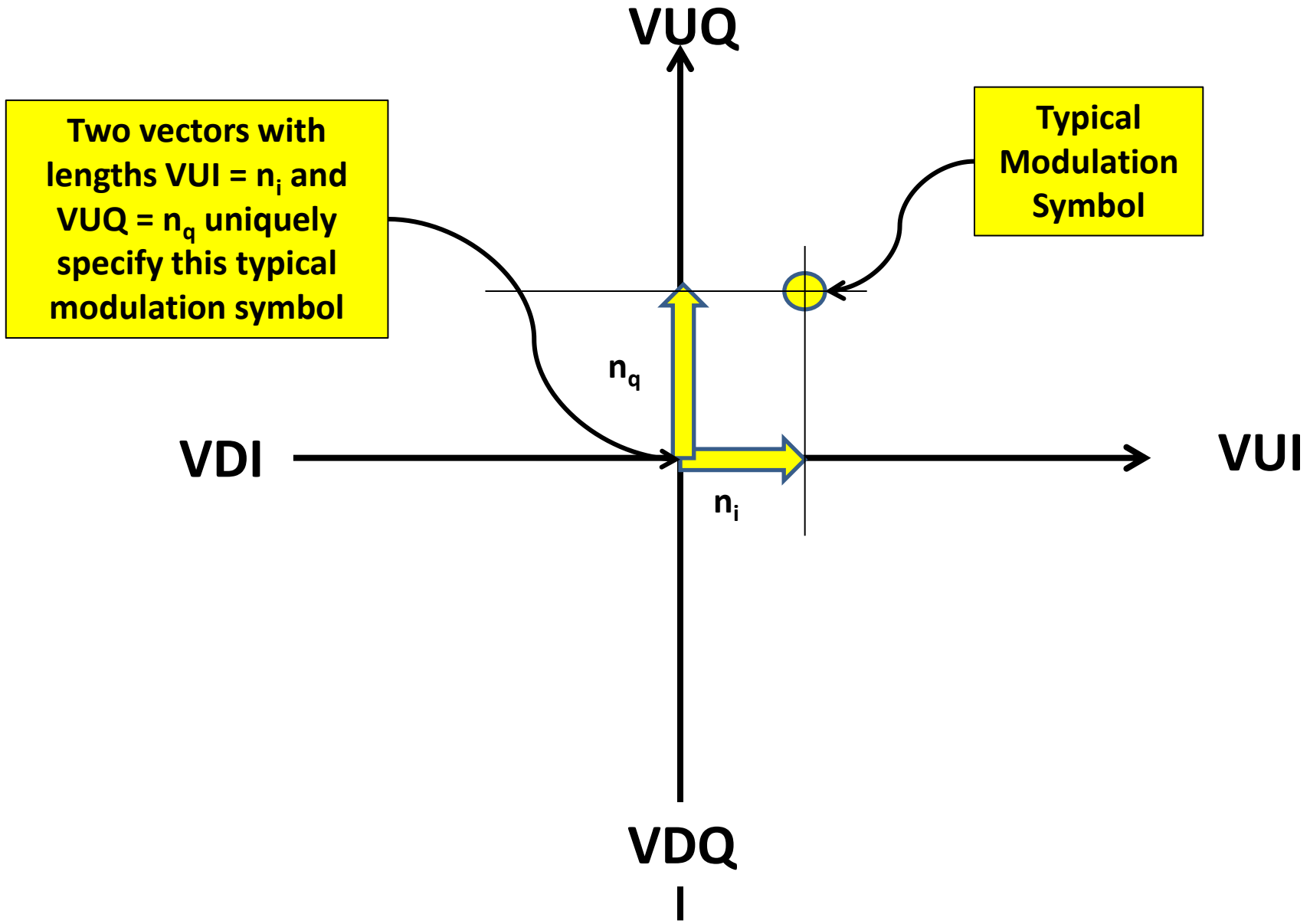
Figure 01. White Nail Modulation Symbol Space Defined



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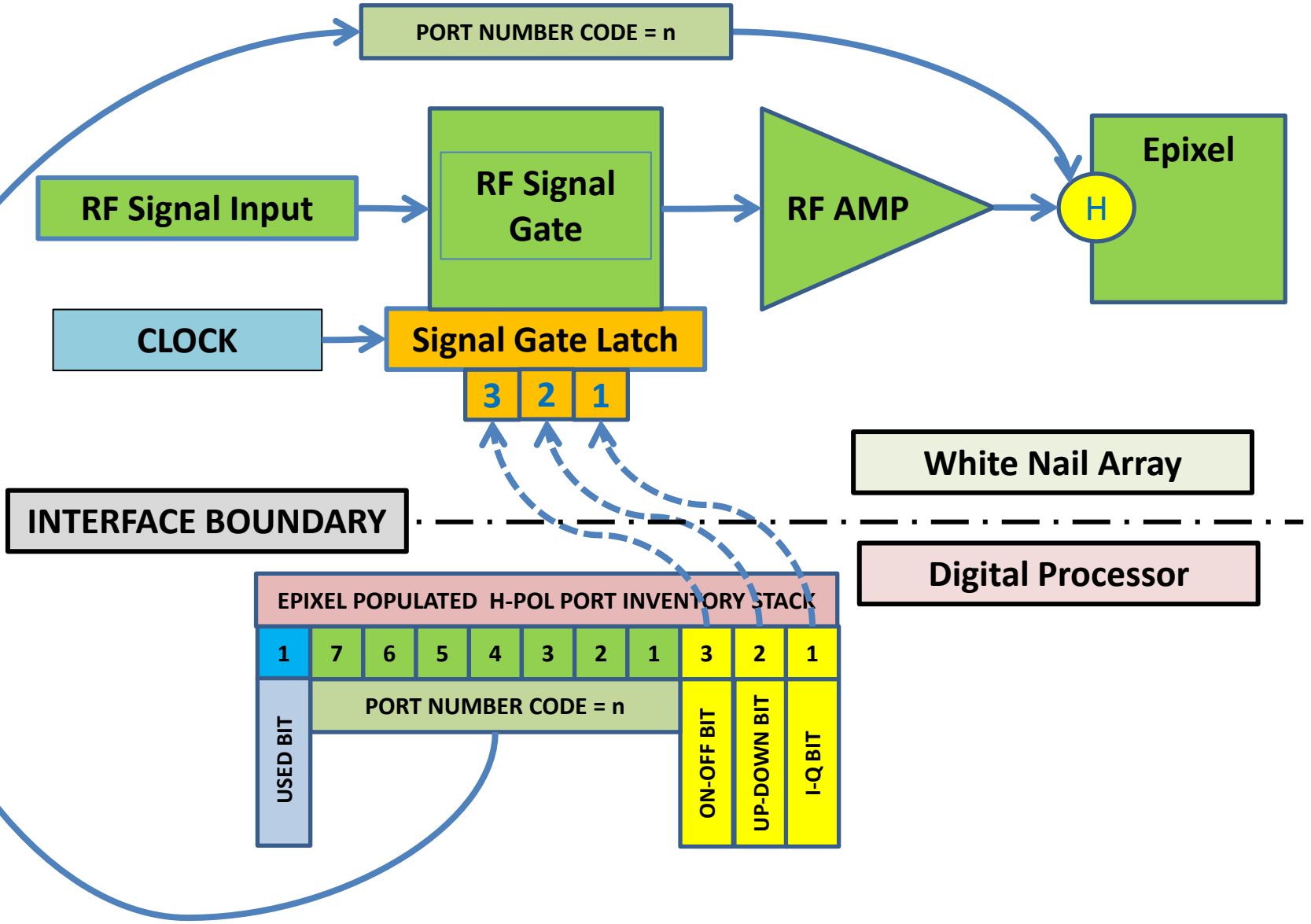

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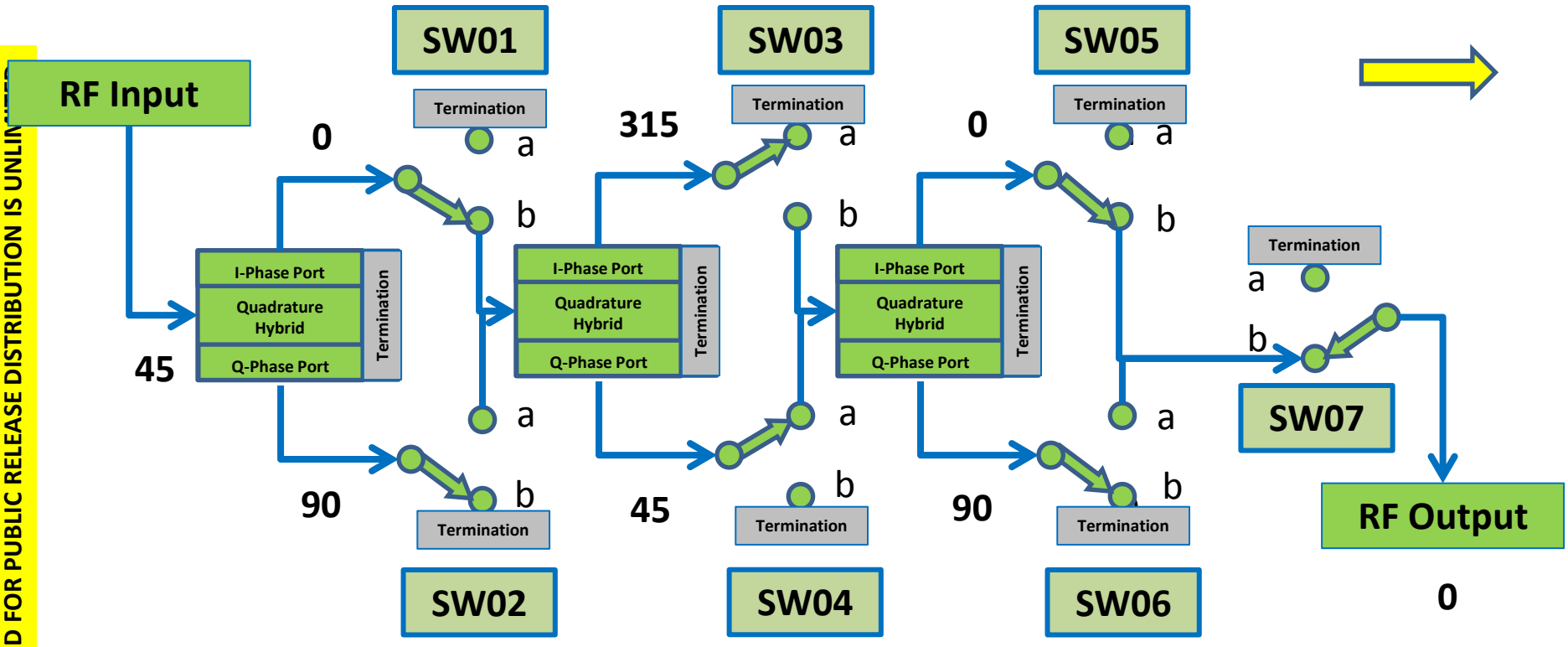
RF Signal Gate Architecture(IU)



RF Signal Gate Switching Plan to Establish Each State									
RF Signal Gate State			SW01	SW02	SW03	SW04	SW05	SW06	SW07
ON-OFF	UP-DOWN	I-Q							
OFF			a	b	a or b	a or b	a or b	a or b	a
ON	UP	I	b	b	a	a	b	b	b
ON	UP	Q	b	b	a	a	a	a	b
ON	DOWN	I	a	a	a	a	a	a	b
ON	DOWN	Q	b	b	b	b	b	b	b

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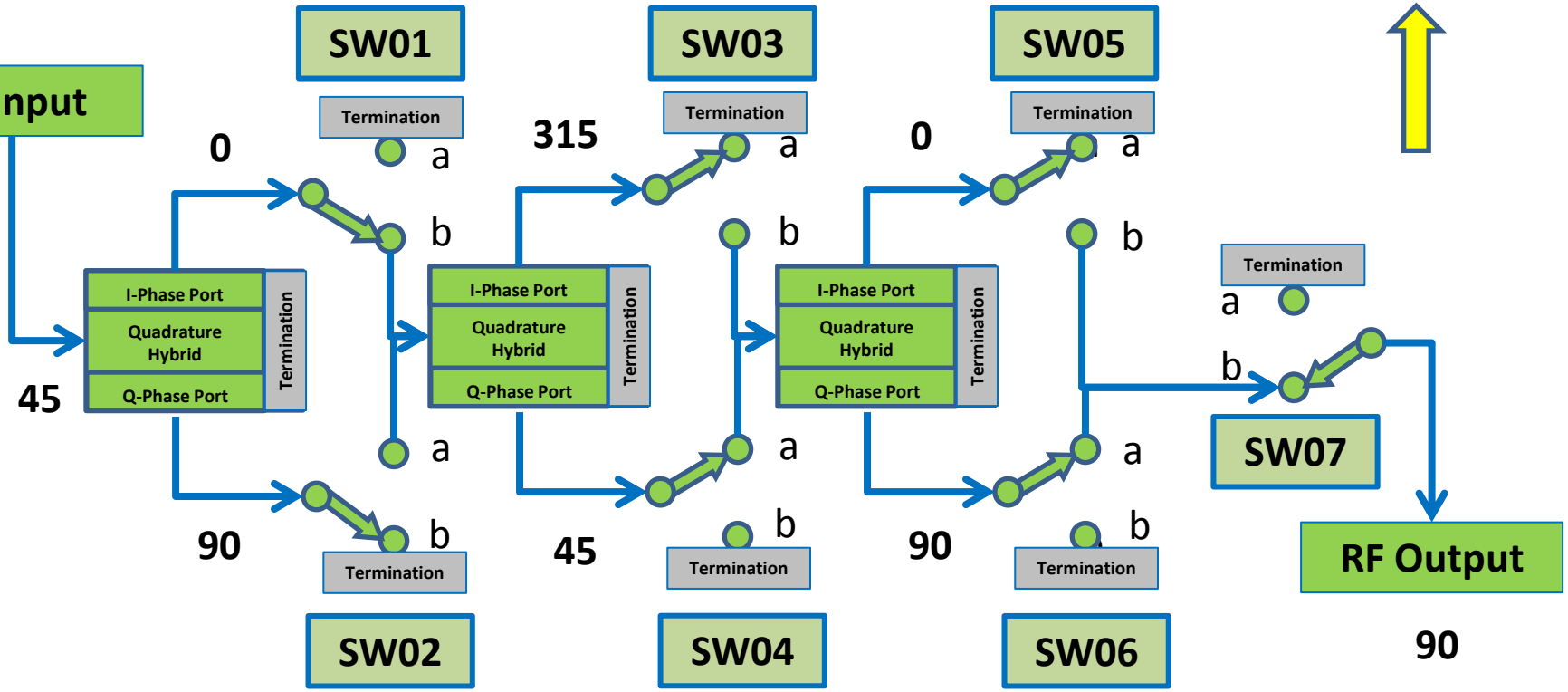
RF Signal Gate Architecture(QU)



RF Signal Gate Switching Plan to Establish Each State								
RF Signal Gate State			SW01	SW02	SW03	SW04	SW05	SW06	SW07
ON-OFF	UP-DOWN	I-Q							
OFF			a	b	a or b	a or b	a or b	a or b	a
ON	UP	I	b	b	a	a	b	b	b
ON	UP	Q	b	b	a	a	a	a	b
ON	DOWN	I	a	a	a	a	a	a	b
ON	DOWN	Q	b	b	b	b	b	b	b

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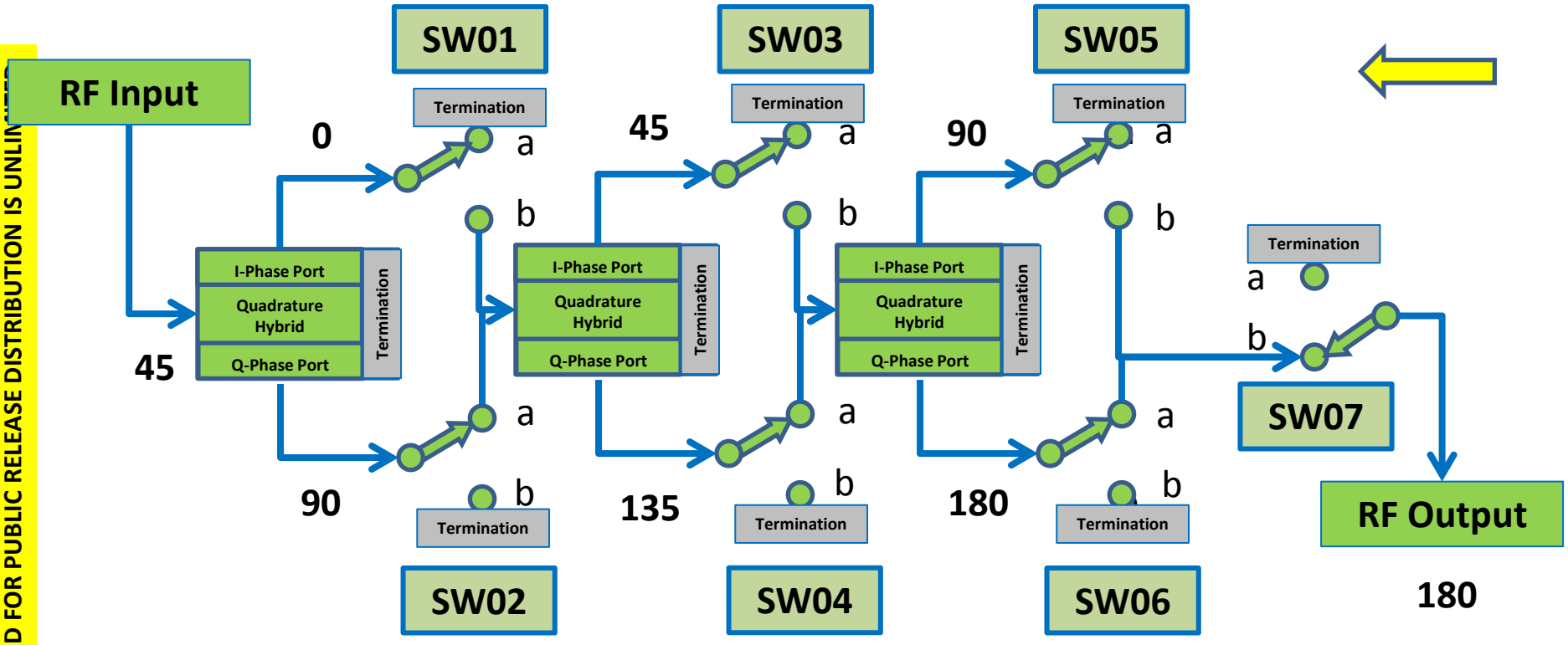
RF Signal Gate Architecture (ID)



RF Signal Gate Switching Plan to Establish Each State								
RF Signal Gate State			SW01	SW02	SW03	SW04	SW05	SW06	SW07
ON-OFF	UP-DOWN	I-Q							
OFF			a	b	a or b	a or b	a or b	a or b	a
ON	UP	I	b	b	a	a	b	b	b
ON	UP	Q	b	b	a	a	a	a	b
ON	DOWN	I	a	a	a	a	a	a	b
ON	DOWN	Q	b	b	b	b	b	b	b

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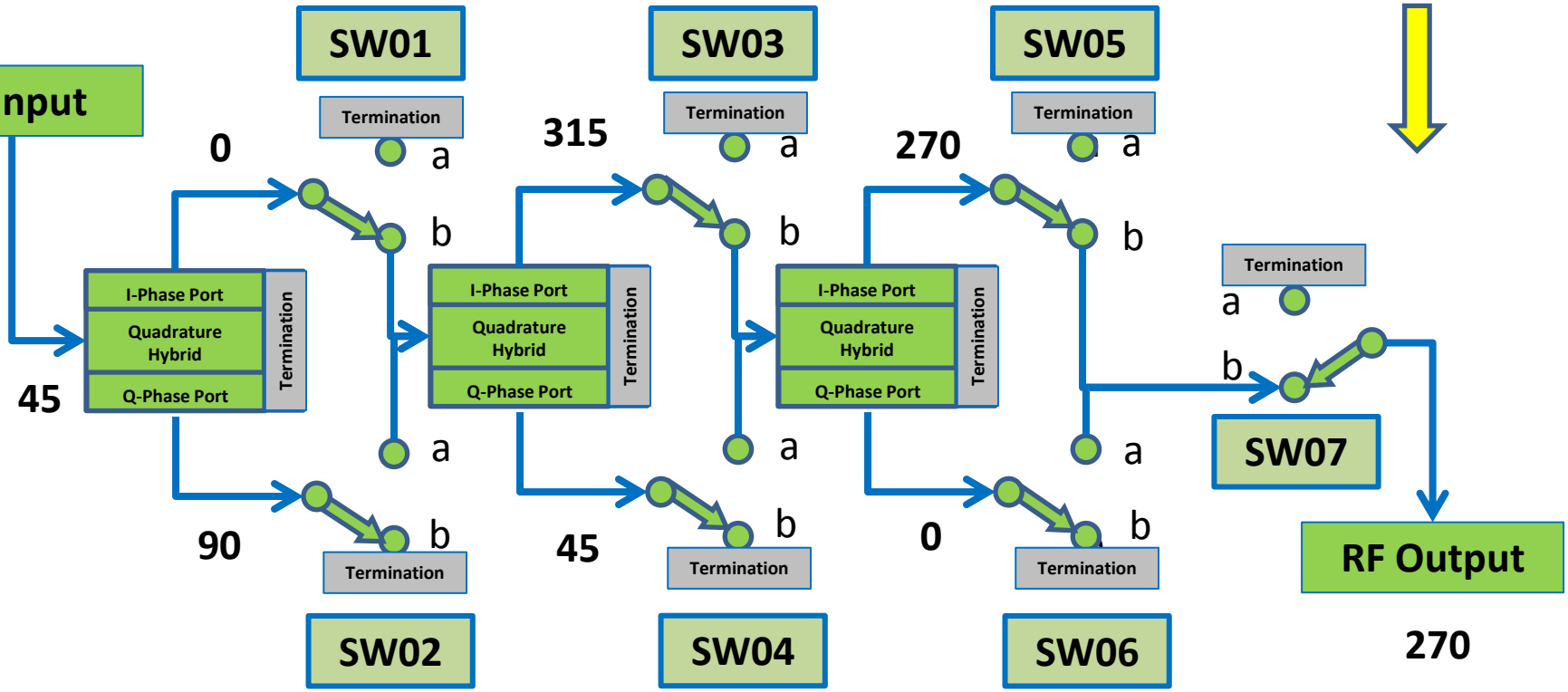
RF Signal Gate Architecture(QD)



RF Signal Gate Switching Plan to Establish Each State								
RF Signal Gate State			SW01	SW02	SW03	SW04	SW05	SW06	SW07
ON-OFF	UP-DOWN	I-Q							
OFF			a	b	a or b	a or b	a or b	a or b	a
ON	UP	I	b	b	a	a	b	b	b
ON	UP	Q	b	b	a	a	a	a	b
ON	DOWN	I	a	a	a	a	a	a	b
ON	DOWN	Q	b	b	b	b	b	b	b

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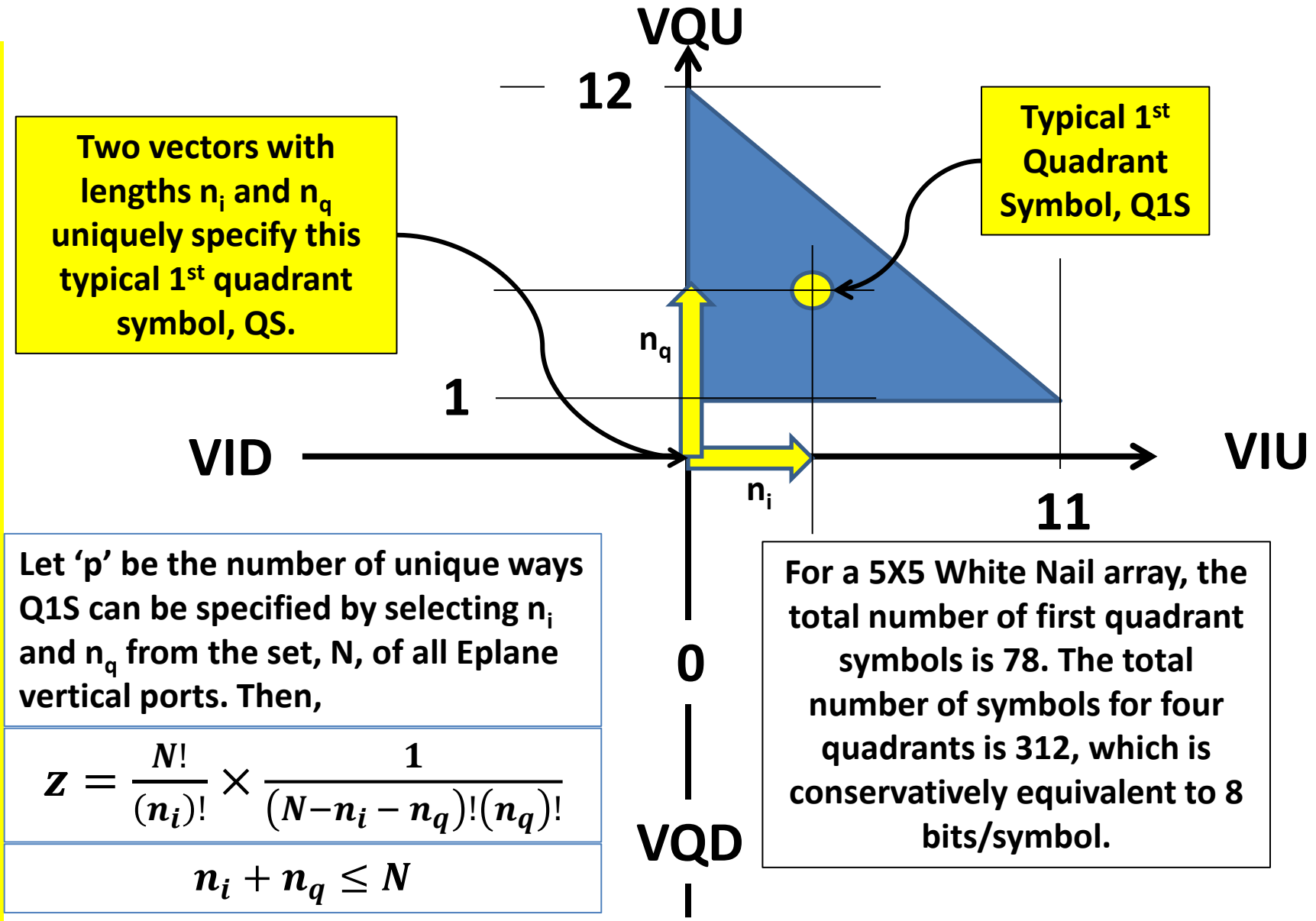
Figure 04. White Nail 5 X 5 Array Modulation Symbol Space



Let 'p' be the number of unique ways Q1S can be specified by selecting n_i and n_q from the set, N, of all Eplane vertical ports. Then,

$$z = \frac{N!}{(n_i)!} \times \frac{1}{(N - n_i - n_q)!(n_q)!}$$

$$n_i + n_q \leq N$$

For a 5X5 White Nail array, the total number of first quadrant symbols is 78. The total number of symbols for four quadrants is 312, which is conservatively equivalent to 8 bits/symbol.

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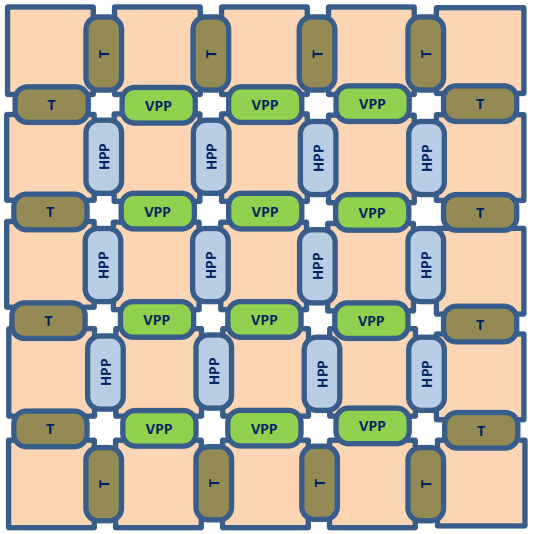
5 X 5 Eplane Showing 24 Active RF Ports



$$z = \frac{N!}{(n_i)!} \times \frac{1}{(N-n_i-n_q)!(n_q)!}$$

$$n_i + n_q \leq N = 12$$

The Number of Different Ways to Form the Sets ni and nq when Synthesizing a Symbol Vector													
z	0	1	2	3	4	5	6	7	8	9	10	11	12
0	1	12	66	220	495	792	924	792	495	220	66	12	1
1	12	132	660	1,980	3,960	5,544	5,544	3,960	1,980	660	132	12	
2	66	660	2,970	7,920	13,860	16,632	13,860	7,920	2,970	660	66		
3	220	1,980	7,920	18,480	27,720	27,720	18,480	7,920	1,980	220			
4	495	3,960	13,860	27,720	34,650	27,720	13,860	3,960	495				
5	792	5,544	16,632	27,720	27,720	16,632	5,544	792					
6	924	5,544	13,860	18,480	13,860	5,544	924						
7	792	3,960	7,920	7,920	3,960	792							
8	495	1,980	2,970	1,980	495								
9	220	660	660	220									
10	66	132	66										
11	12	12											
12	1												
Total:	Total number of Symbols												
91	13	12	11	10	9	8	7	6	5	4	3	2	1

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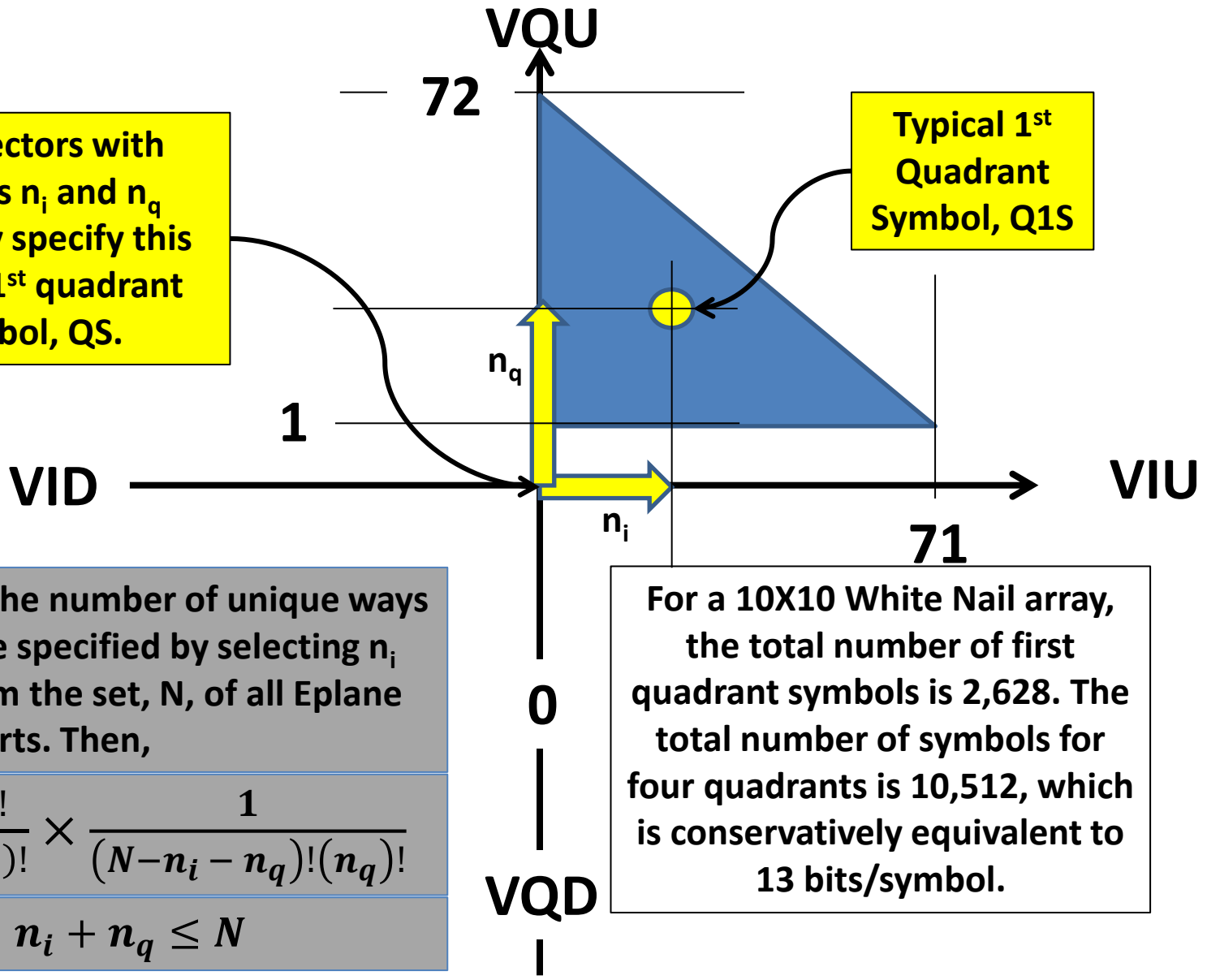
10 X 10 Array Modulation Symbol Space



Let 'p' be the number of unique ways Q1S can be specified by selecting n_i and n_q from the set, N, of all Eplane vertical ports. Then,

$$z = \frac{N!}{(n_i)!} \times \frac{1}{(N-n_i-n_q)!(n_q)!}$$

$$n_i + n_q \leq N$$

For a 10X10 White Nail array, the total number of first quadrant symbols is 2,628. The total number of symbols for four quadrants is 10,512, which is conservatively equivalent to 13 bits/symbol.

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White Nail

A Partitioned Air Interface Solution for Enabling

Software Defined Electromagnetic Systems Designed to Operate in Hostile EM Environments

"Cognitive & Software-Defined RF Technology: Achieving Wide Bandwidth and High Signal Dynamic Range"

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The White Nail Innovation Project

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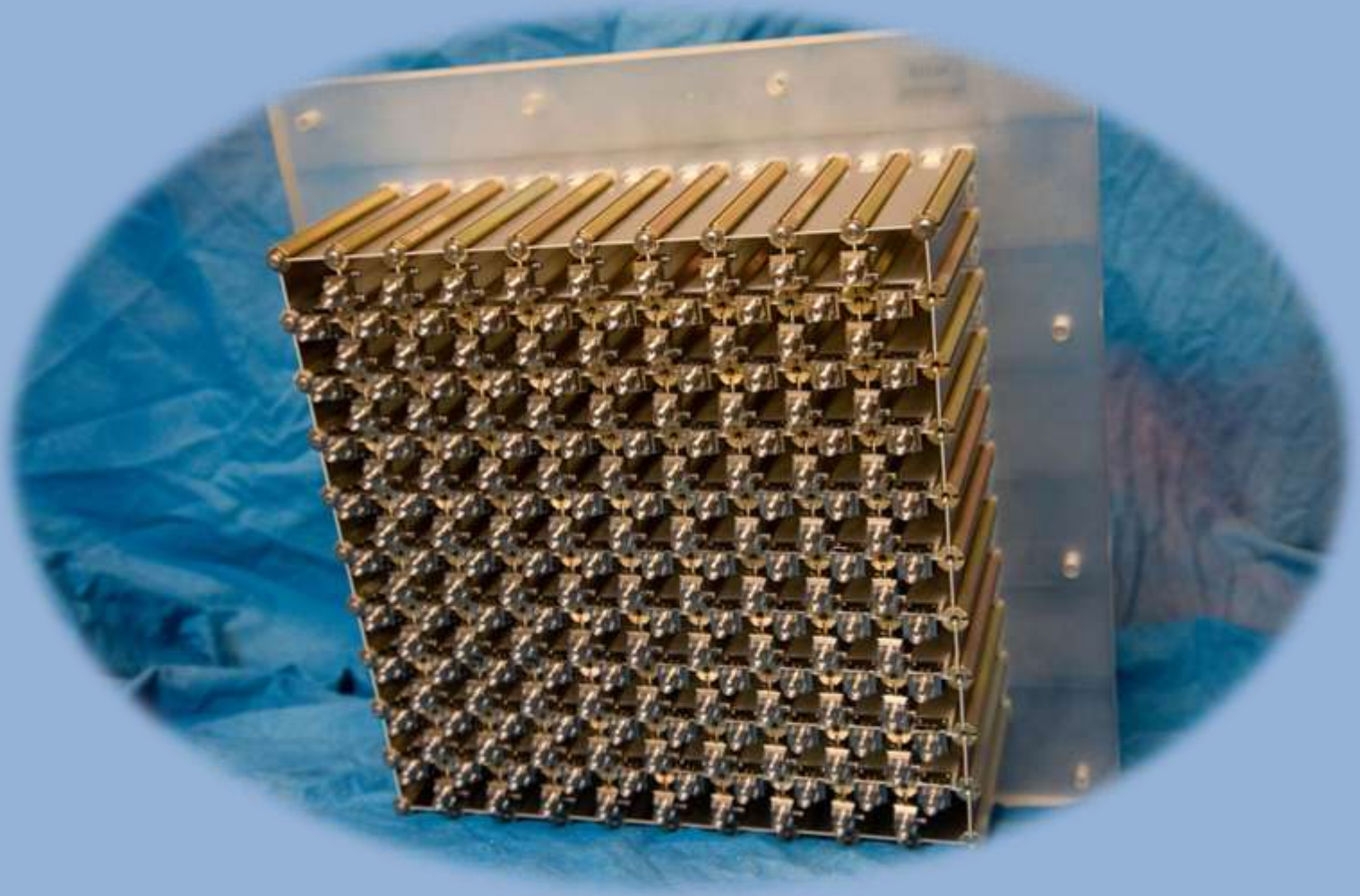

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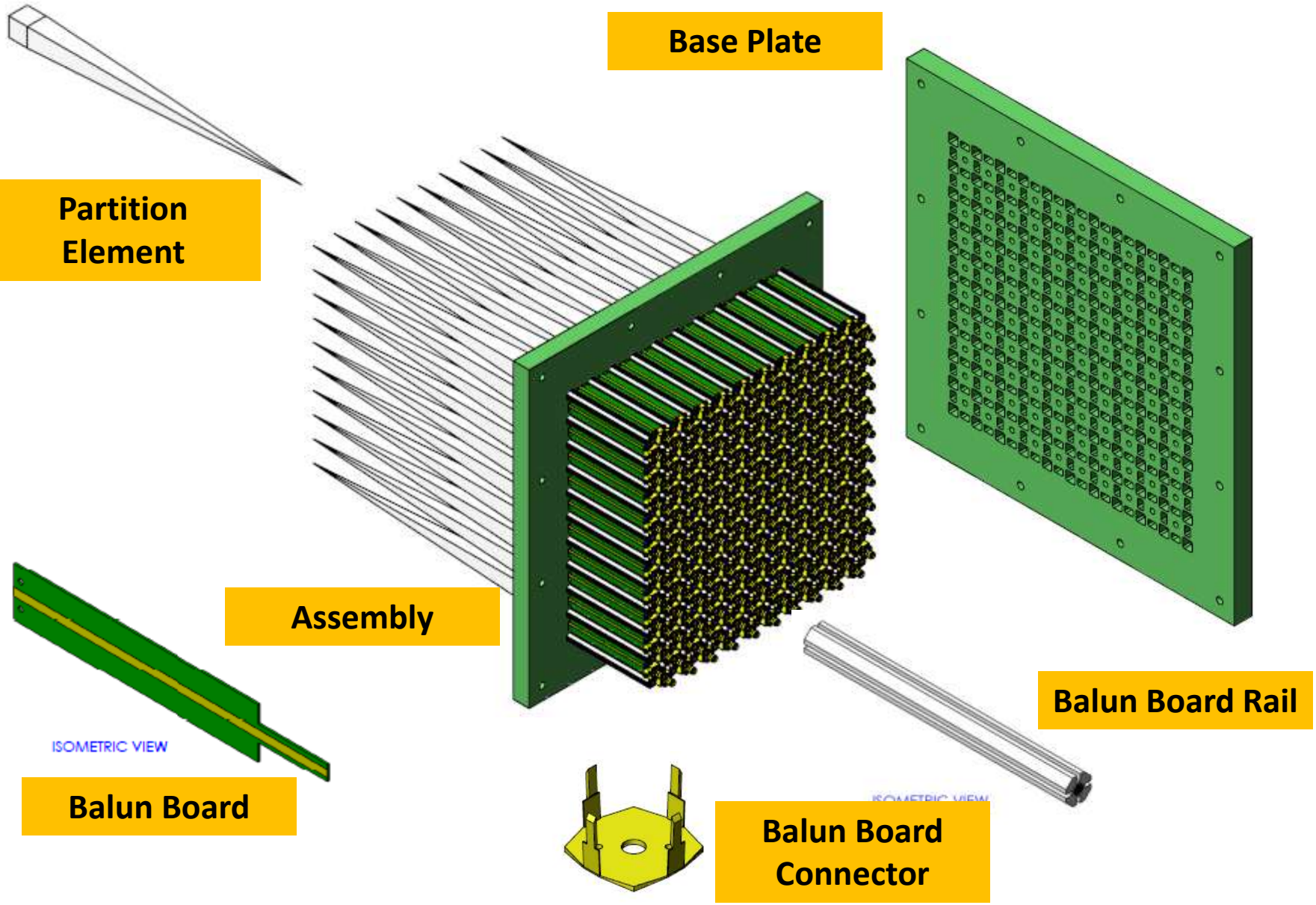

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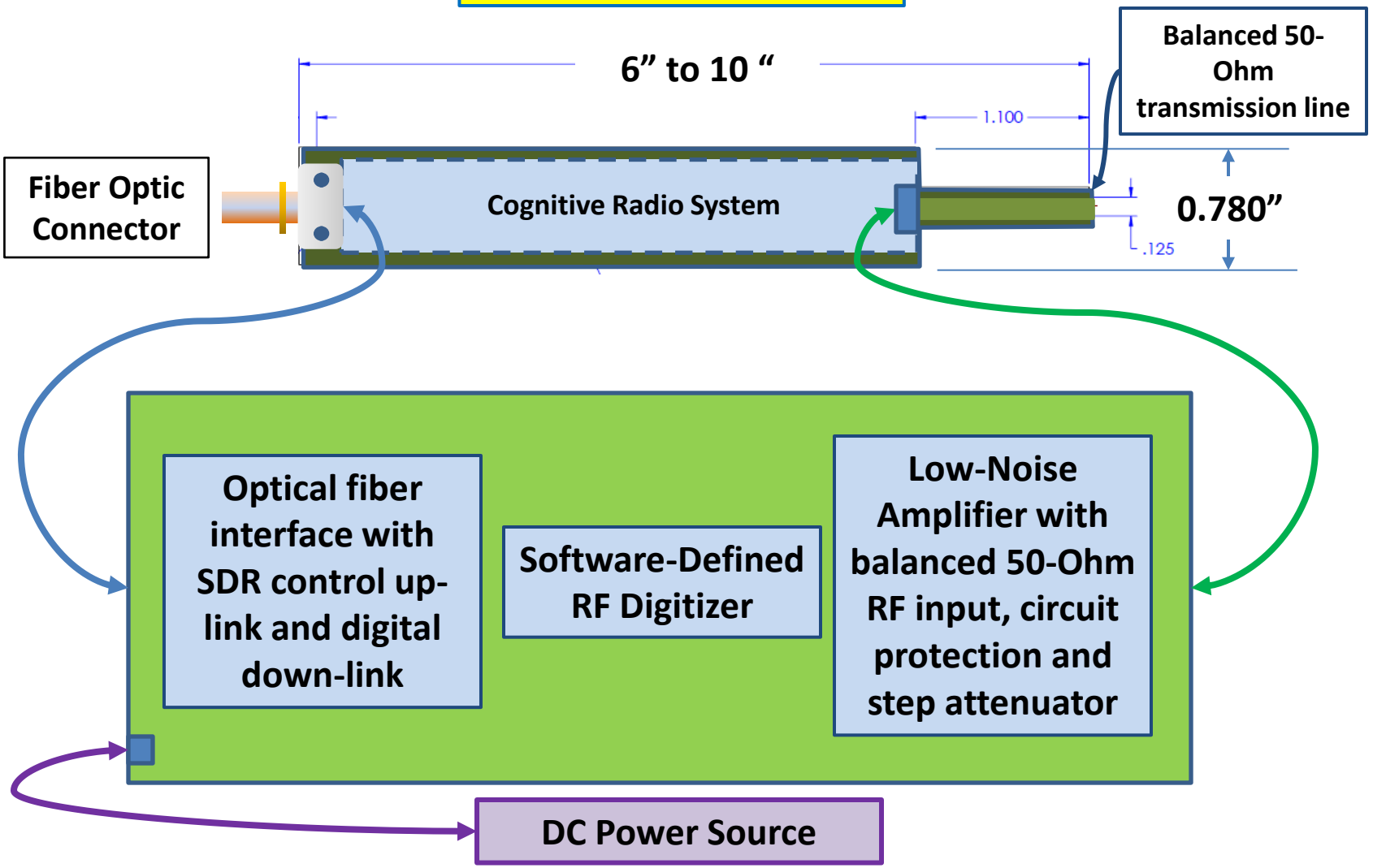
White Nail Vision



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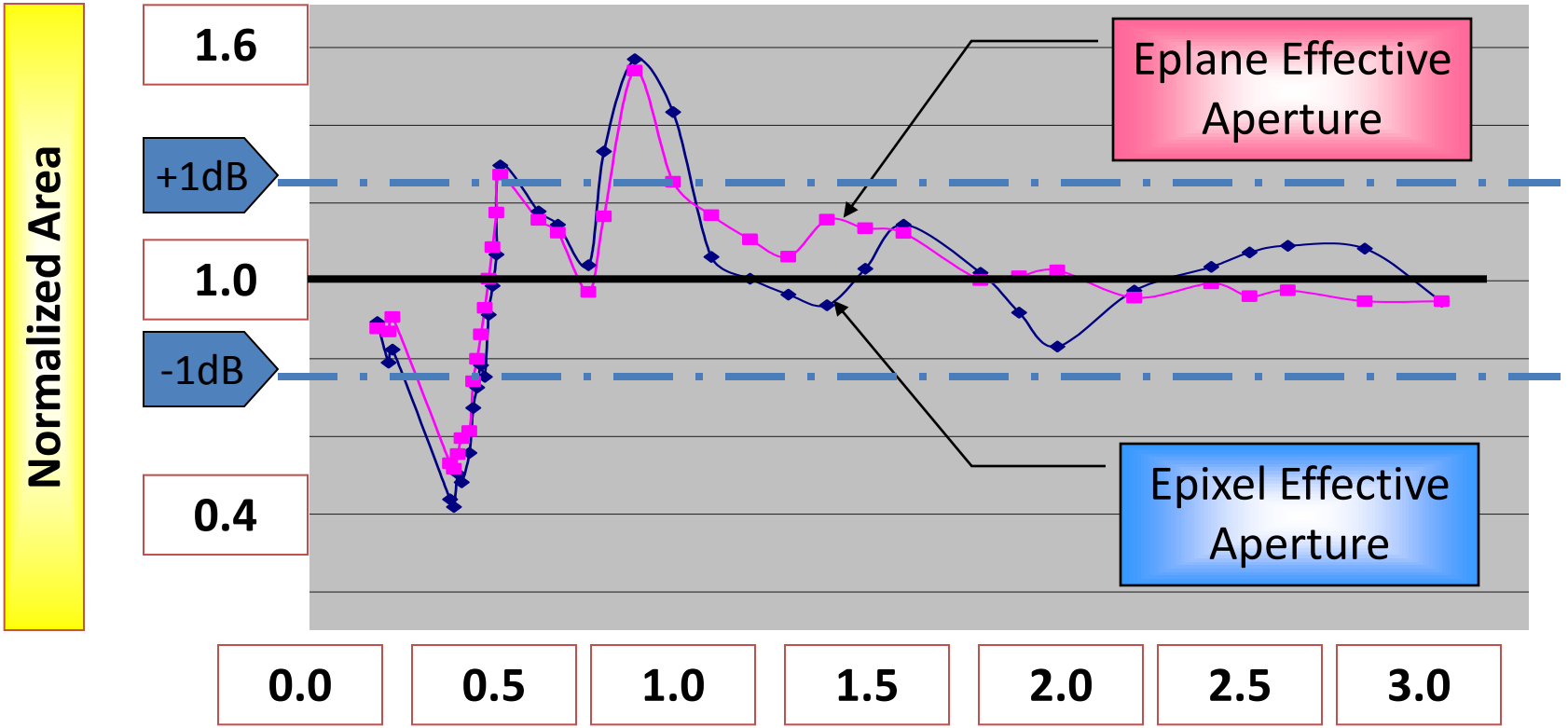
Eplane, Epixel Measured Effective Aperture vs Frequency, GHz



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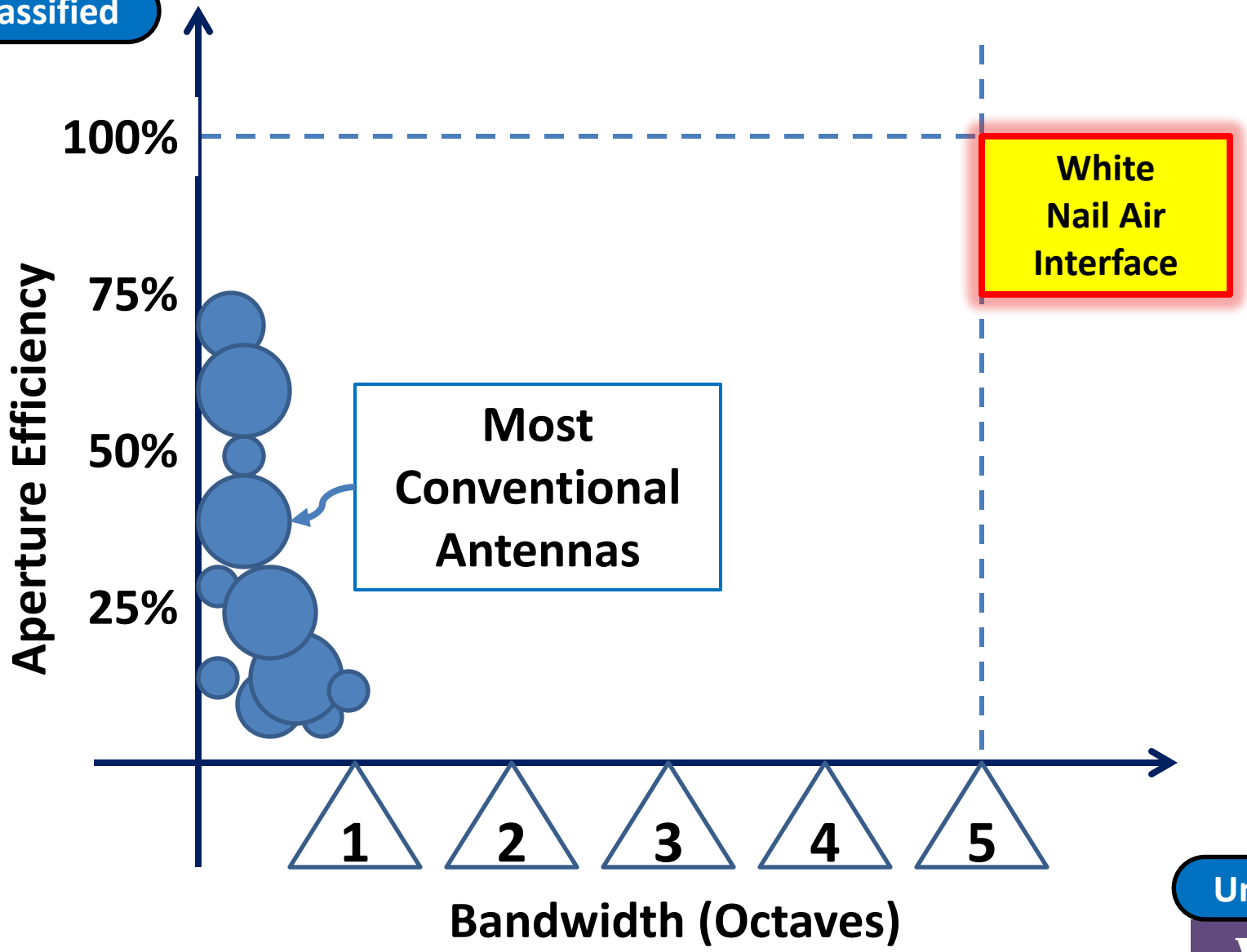

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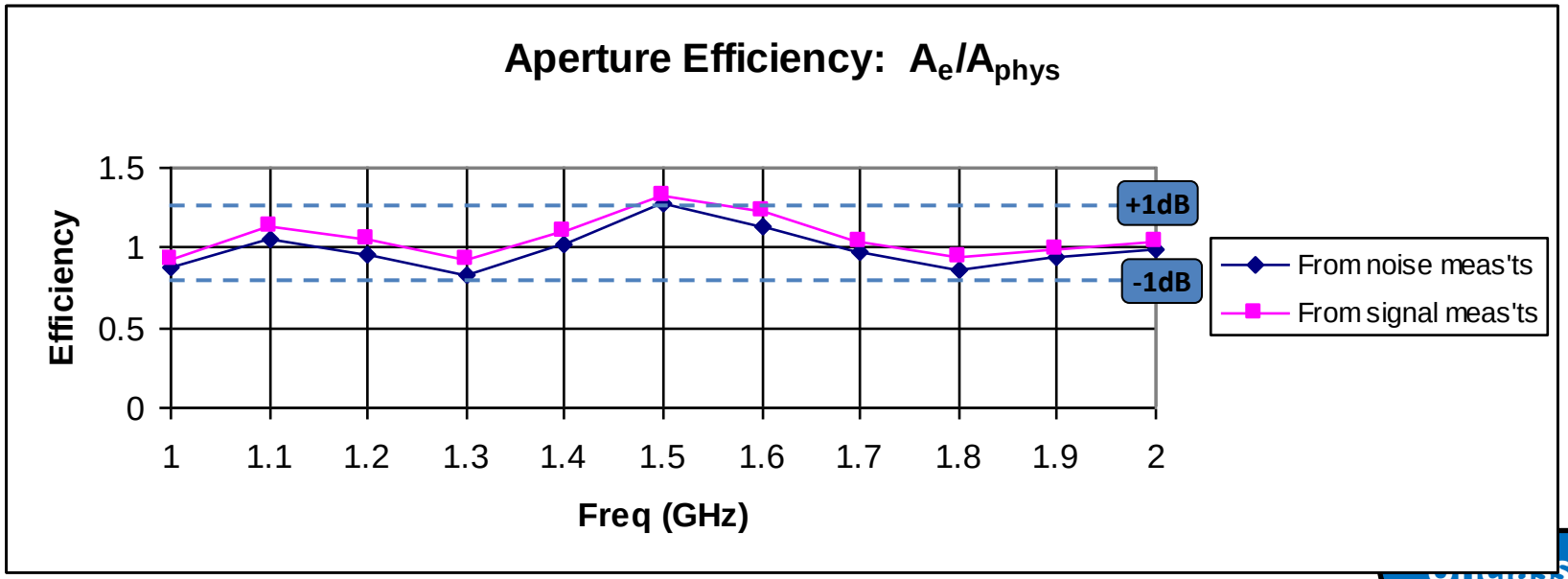
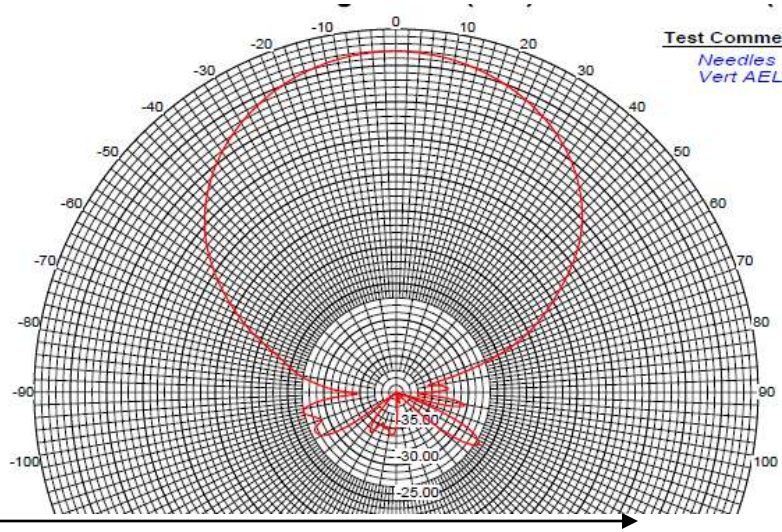
Aperture Efficiency Attributes

- Approaches 100%
- Virtually Frequency Independent
- **White Nail Effective Aperture can be made as large as desired**



White Nail Effective Aperture is the independent variable

White Nail Air Interface Can Have Almost Any Shape



Air Interface Gain

Air Interface Effective Aperture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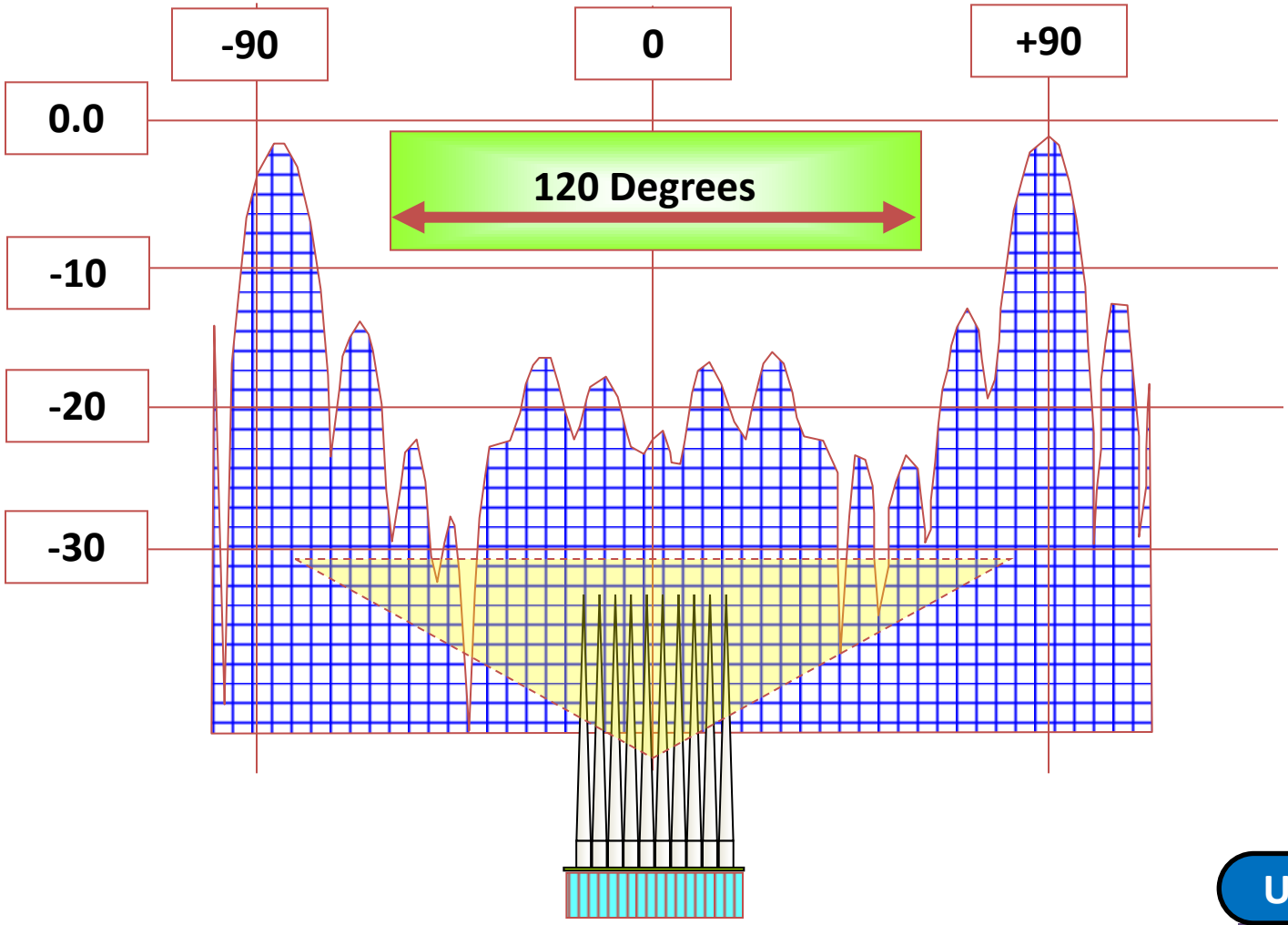
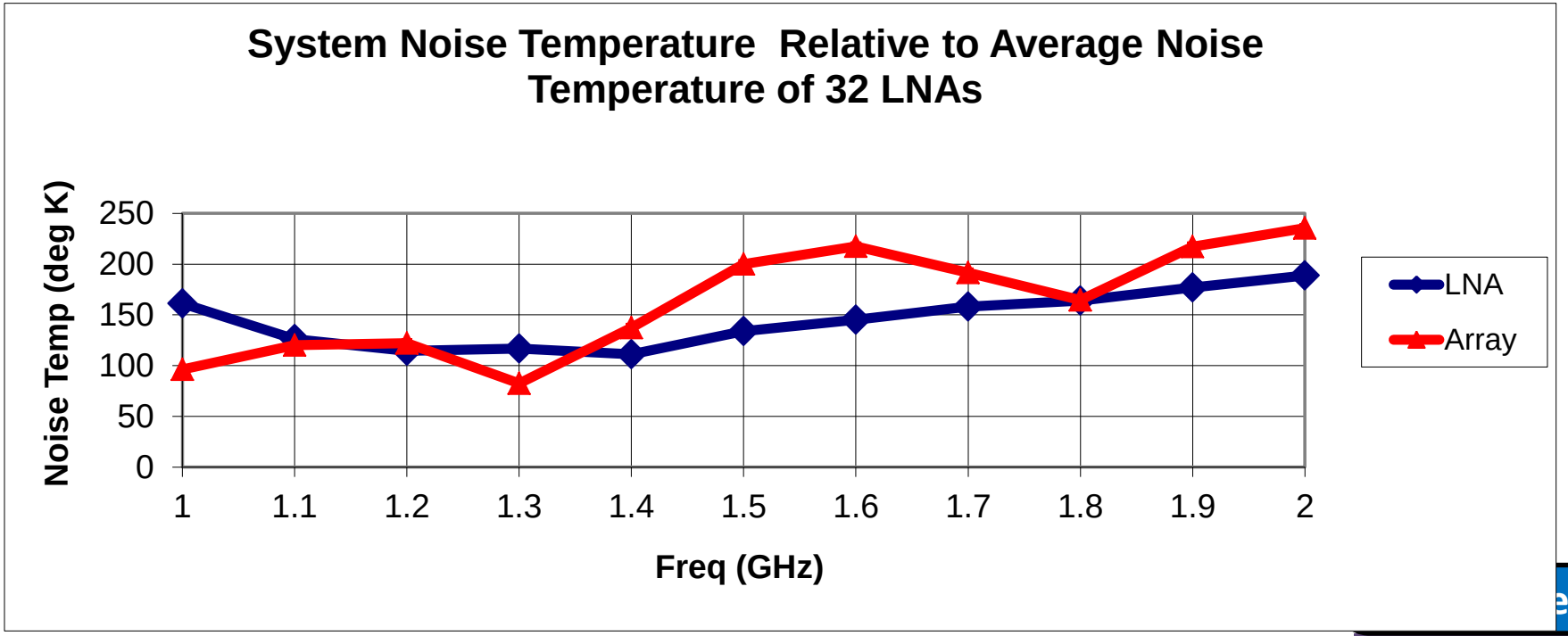
Less than 1% of incident energy is reflected

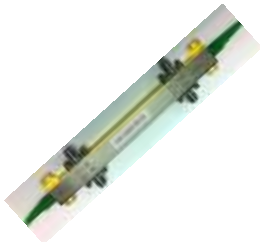


System Noise Temperature Attributes

- Partitioned aperture preserves noise temperature of LNA
- Small additional temperature contribution from aperture losses
- Essentially frequency independent system noise temperature

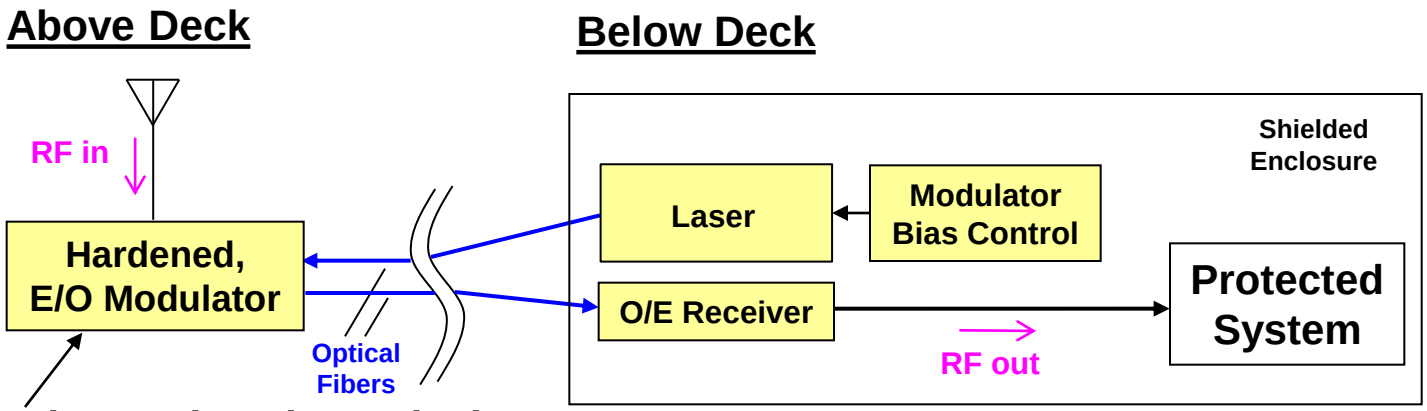


Electro-Magnetic-Attack (EMA)-Resistant RF Over Fiber Optic Link



EMA-resistant modulator withstands high power pulses

Goal: Withstand all known EMA threats up to 10 kW pulse



No electronics above deck!

- Low NF photonic link eliminates LNA
- All control functions are done below deck
- Optical fibers eliminate any conductive path between antenna and shielded enclosure

RF Parameter	Projected Link Performance
Noise Figure (dB)	6
Bandwidth (GHz)	> 20
SFDR (dB-Hz$^{2/3}$)	> 115

Achieved Goals of ONR SBIR Phase I

DC Results
- Voltage limit meets 10kW pulse goal
- Thermal limit is 2x the 10kW pulse goal

RF Results
- Withstood 1 kW pulse at 10 GHz
- Phase II will extend to 10 kW pulse at 10 GHz

PHOTONICSystems, Inc.
www.photonicsinc.com

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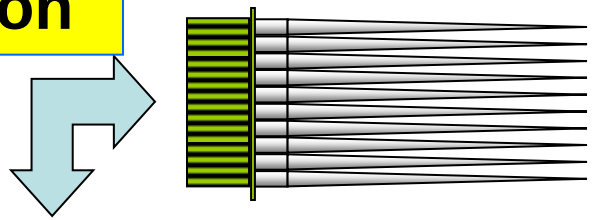
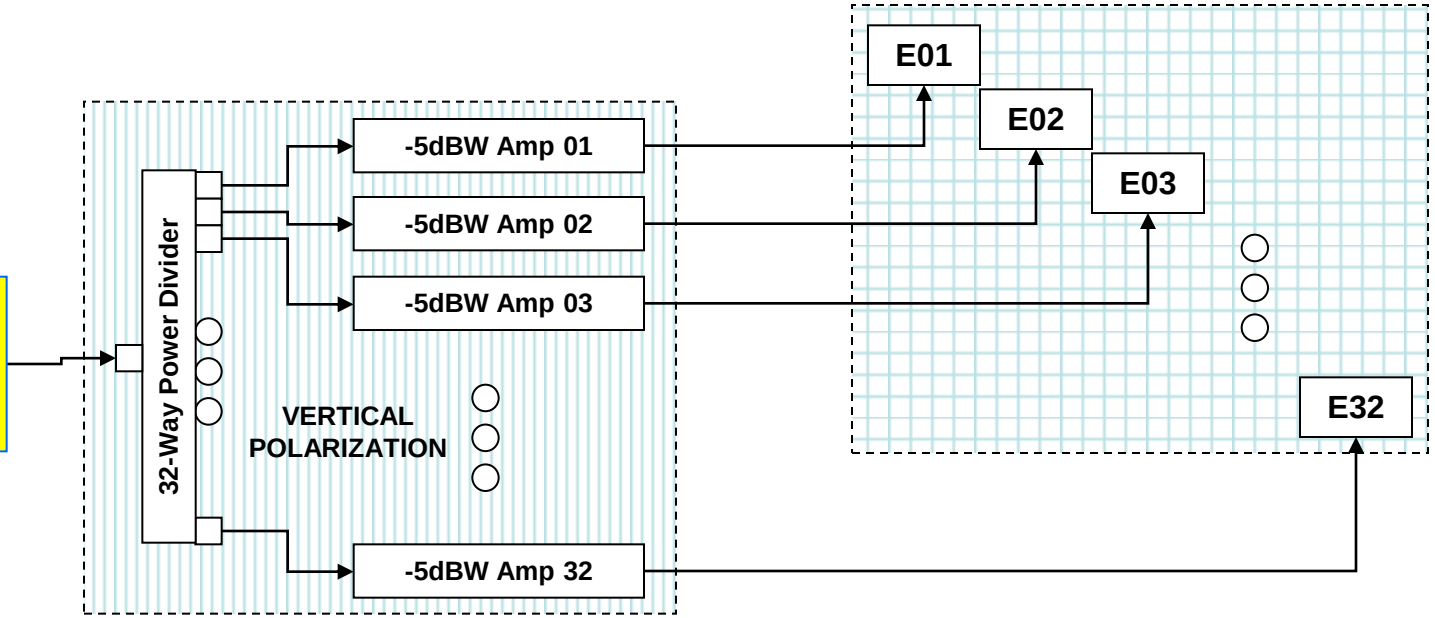
White Nail Transmitter Functionality Demonstration





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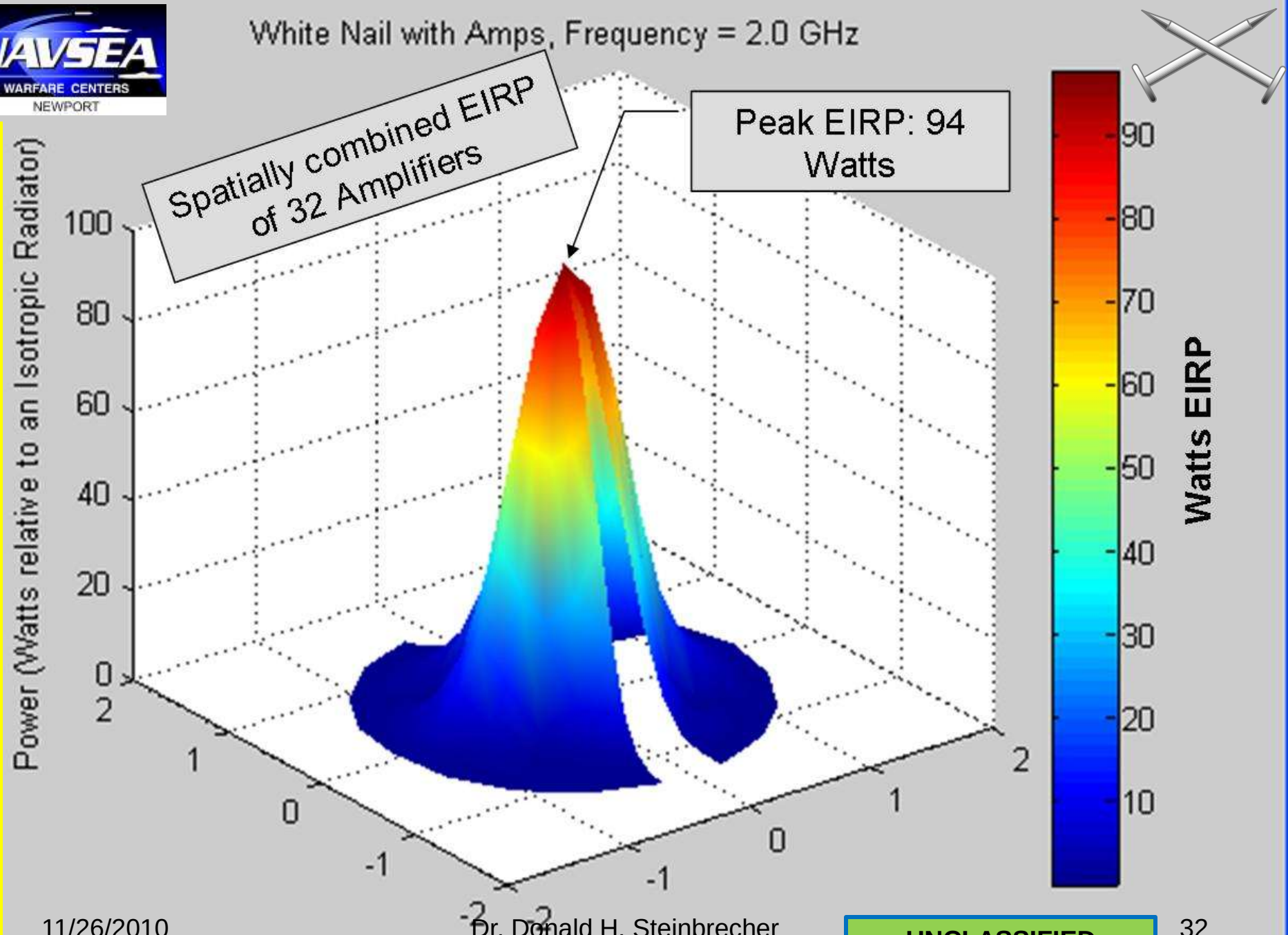

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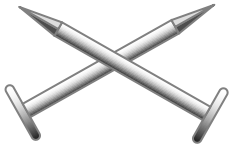

White Nail Spatially Combined Transmitter Functionality

Measured EIRP:	Watts	94	
Measured EIRP:	dBW	19.7	
Amplifier Output:	dBW	-5	
Transmit System Gain:	dB	24.7	
Spatial Combine Gain:	dB		15
Focus Gain(measured):	dB		10
Expected System Gain:	dB	25	25
Expected EIRP	dBW		20
Variance:	dB	-0.3	

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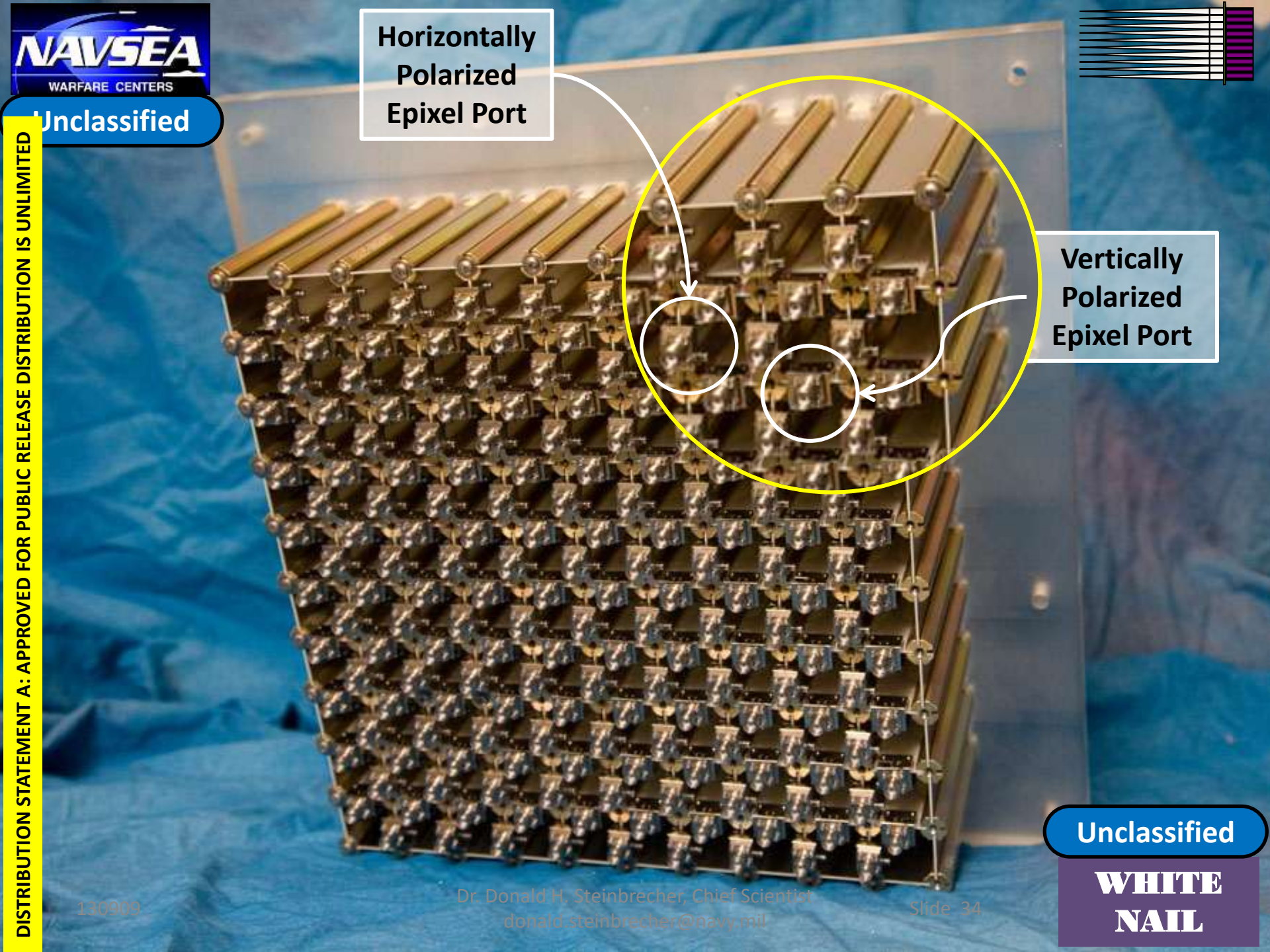
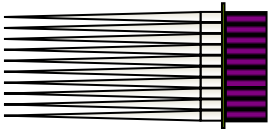
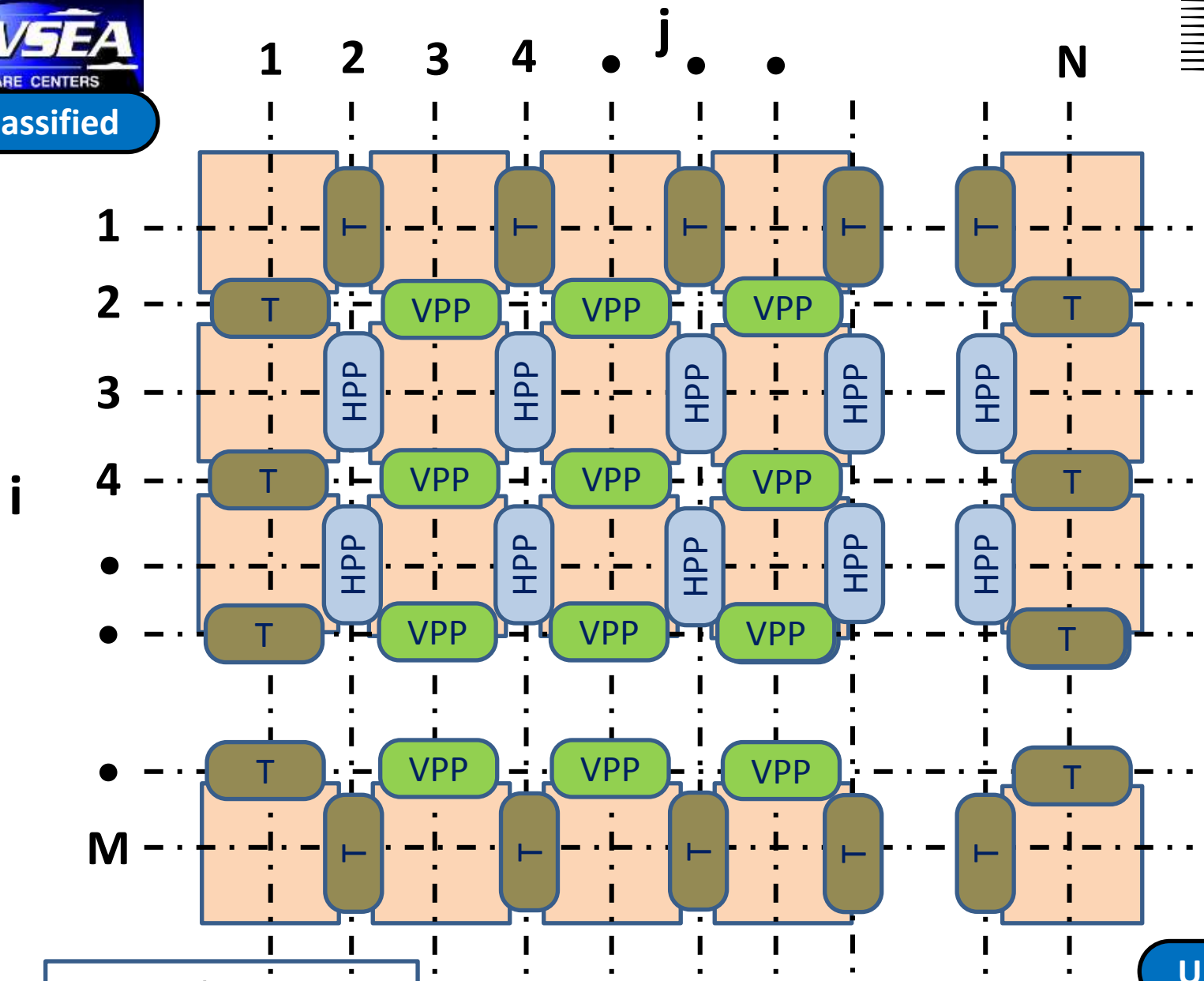






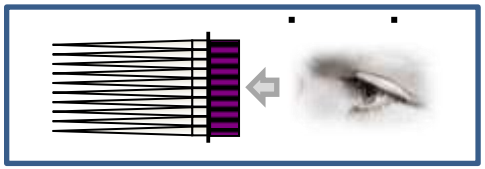
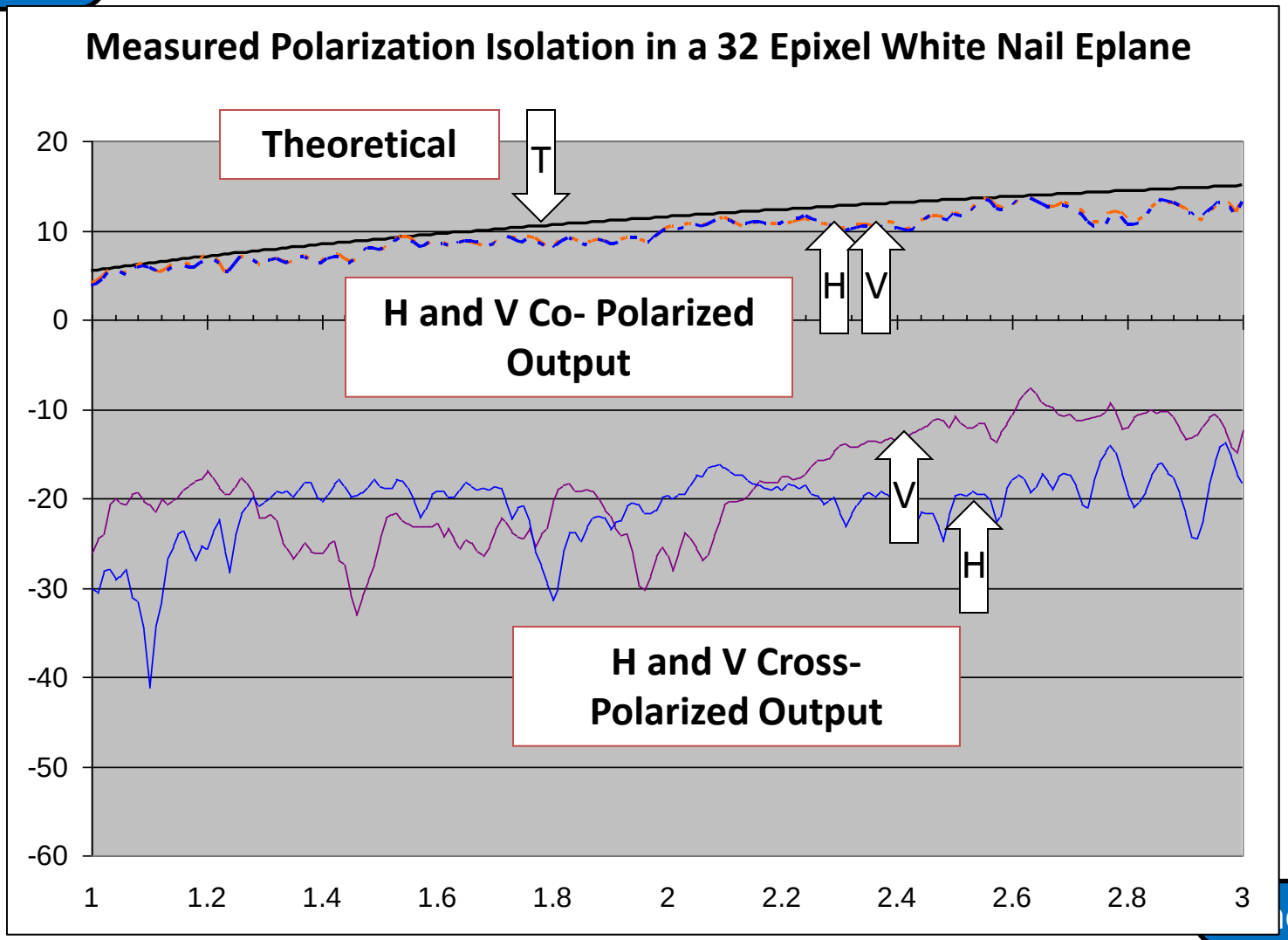
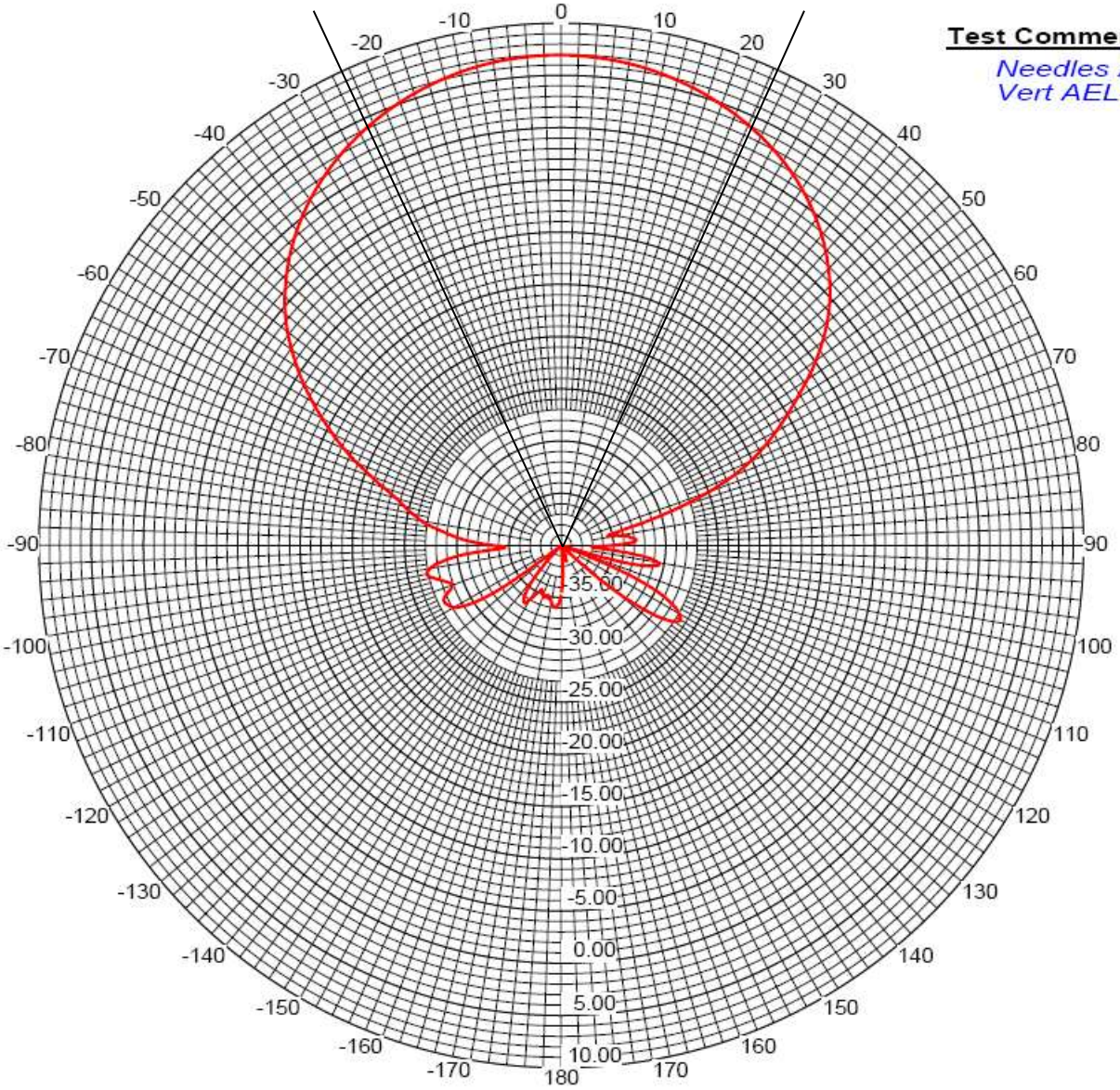


Figure 6

Measured Polarization Isolation in a 32 Epixel White Nail Eplane



Magnitude (dB) vs. Elevation (Degs)



Test Comments:

Needles Ant-3 (Elevation Co-Pol)
Vert AEL-H1734 0.65-3.0 GHz @ 10 MHz

File: EL 1.0-3.0 _AEL-H_Co-Pol.dat
Ser. no.: Ant-3
Date: 16-Oct-06
Time 10:22
Operator: BB
Channel: ch 1
Tx pol: Vert Rx pol: Vert
Frequency: 2.000 GHz

Cal. status:
File: EL 1.0-3.0 AEL-H
Table: ETS 3149 BiConiLog
Chan.: ch 1
Units: dBi

Co-Polarized 32-Epixel 2-GHz antenna pattern. Measured Beamwidth is about 50 degrees.

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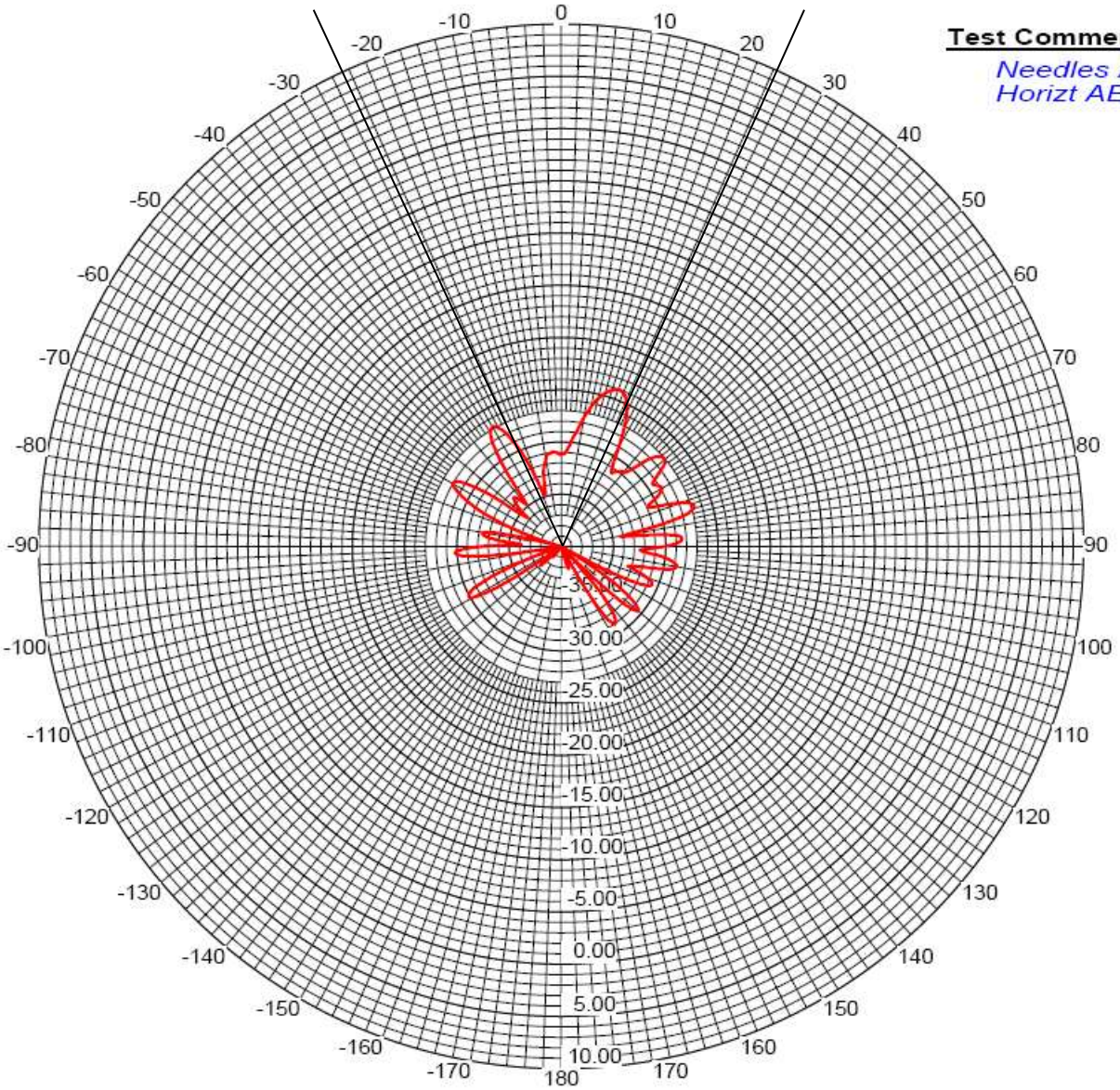
NAVSEA Newport
Undersea Warfare Center Division
RF Tapered Anechoic Chamber

Magnitude (dB) vs. Elevation (Degs)



Test Comments:

Needles Ant-3 (Elevation X-Pol)
Horizt AEL-H1734 0.65-3.0 GHz @ 10 MHz

File: EL 1.0-3.0 _AEL-H_X-Pol.dat
Ser. no.: Ant-3
Date: 16-Oct-06
Time 11:02
Operator: BB
Channel: ch 1
Tx pol: Hori Rx pol: Hori
Frequency: 2.000 GHz

Cal. status:
File: EL 1.0-3.0 AEL-H
Table: ETS 3149 BiConiLog
Chan.: ch 1
Units: dBi

X-Polarized 32-Epixel 2-GHz antenna pattern. X-pol isolation is generally better than 30 dB within the main beam.

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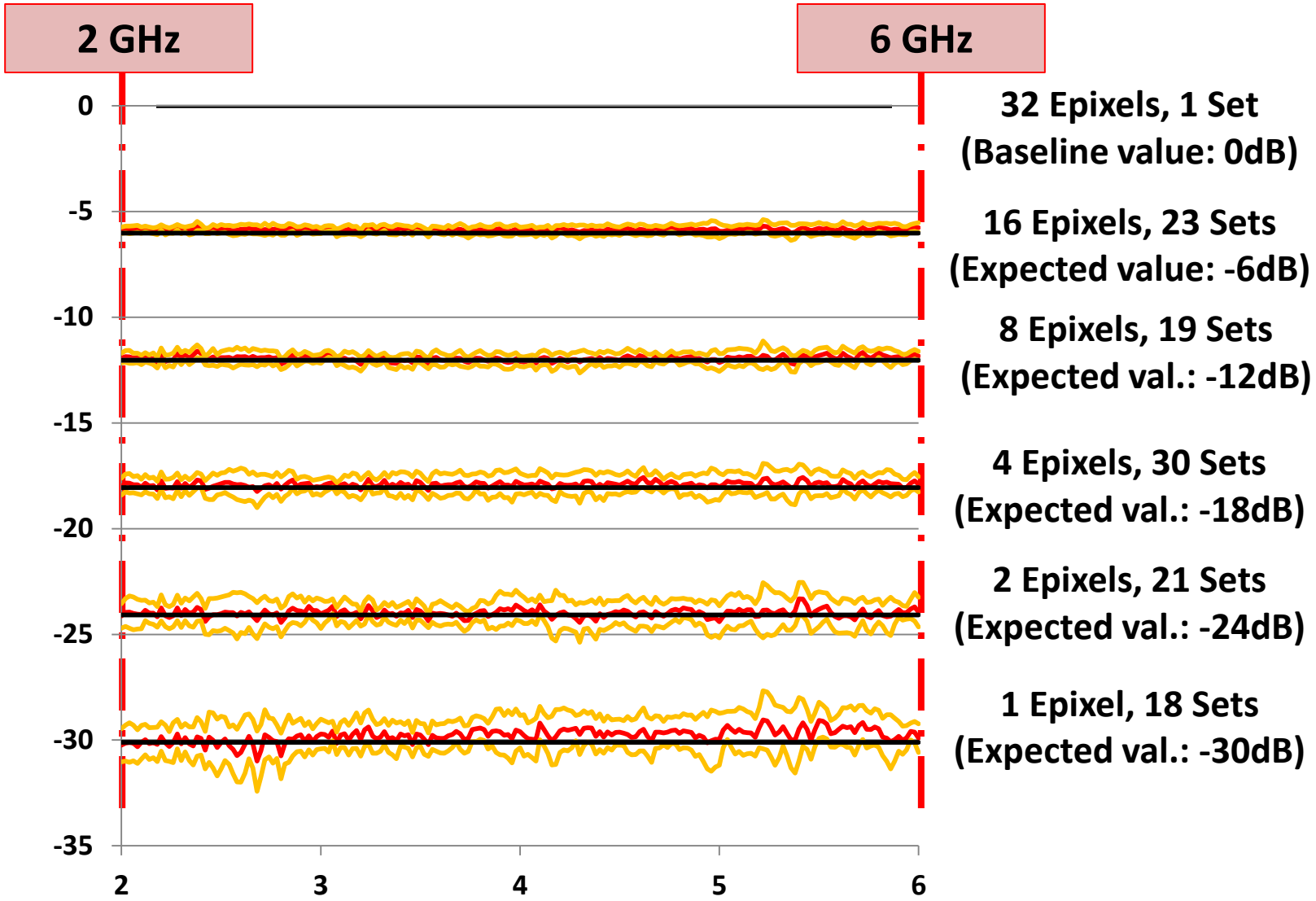
Spatially Combined Far Field EIRP for a Wideband Partitioned Air Interface Transmitter



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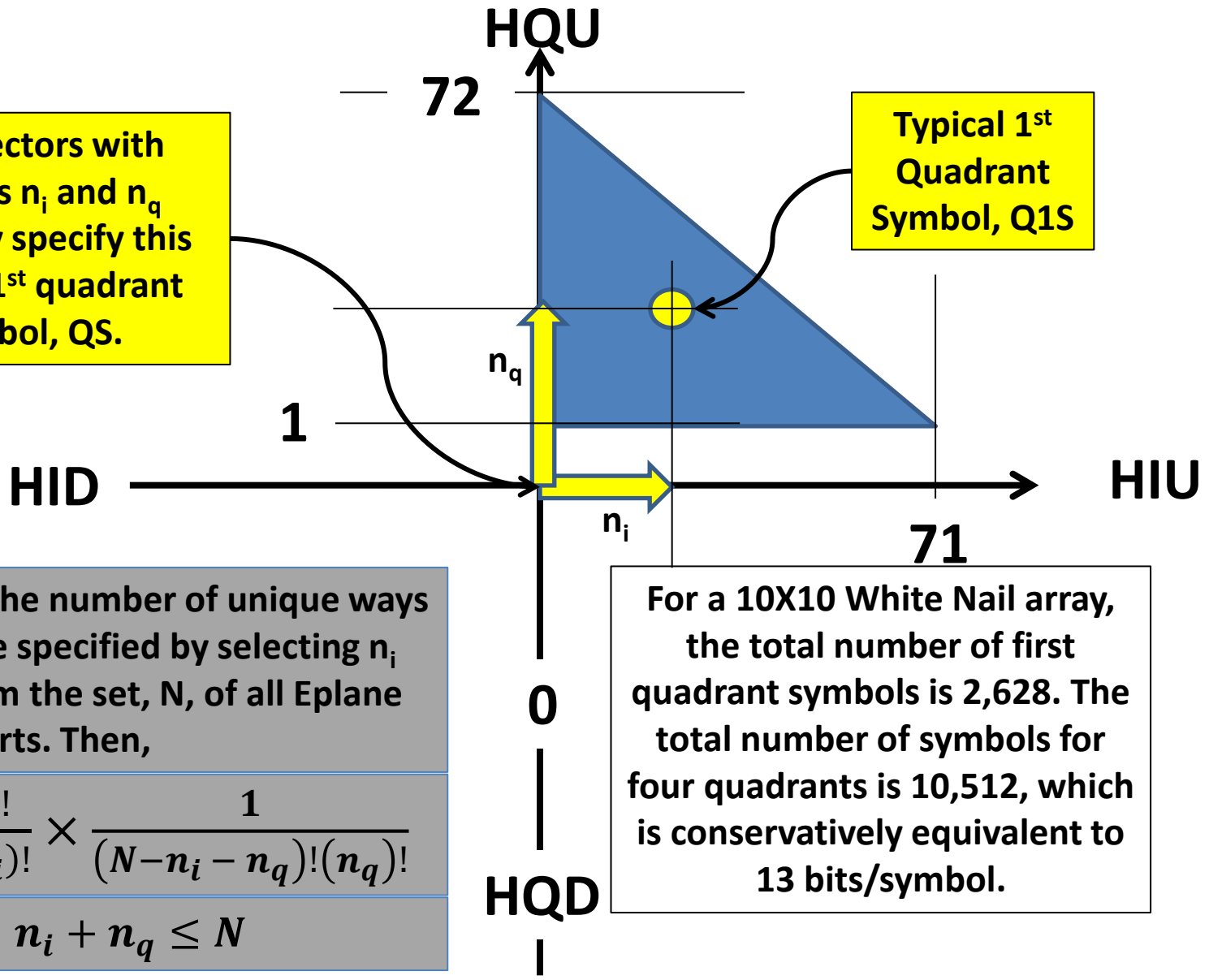
10 X 10 Array Modulation Symbol Space



Let 'p' be the number of unique ways Q1S can be specified by selecting n_i and n_q from the set, N, of all Eplane vertical ports. Then,

$$p = \frac{N!}{(n_i)!} \times \frac{1}{(N-n_i-n_q)!(n_q)!}$$

$$n_i + n_q \leq N$$

For a 10X10 White Nail array, the total number of first quadrant symbols is 2,628. The total number of symbols for four quadrants is 10,512, which is conservatively equivalent to 13 bits/symbol.

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The partitioned Epixel array is symmetrical in Vertical and Horizontal Polarization.

For the 10 X 10 Array,

- **The Number of Vertically Polarized Symbols is 10,512, and**
- **The Number of Horizontally Polarized Symbols is 10,512.**
- **If a complex symbol is defined as the Simultaneous Transmission of One Vertically Polarized Symbol and One Horizontally Polarized Symbol, then the total number of possible complex symbols is**

$$10{,}512^2 = 110{,}502{,}144$$

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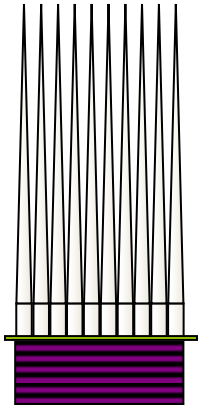
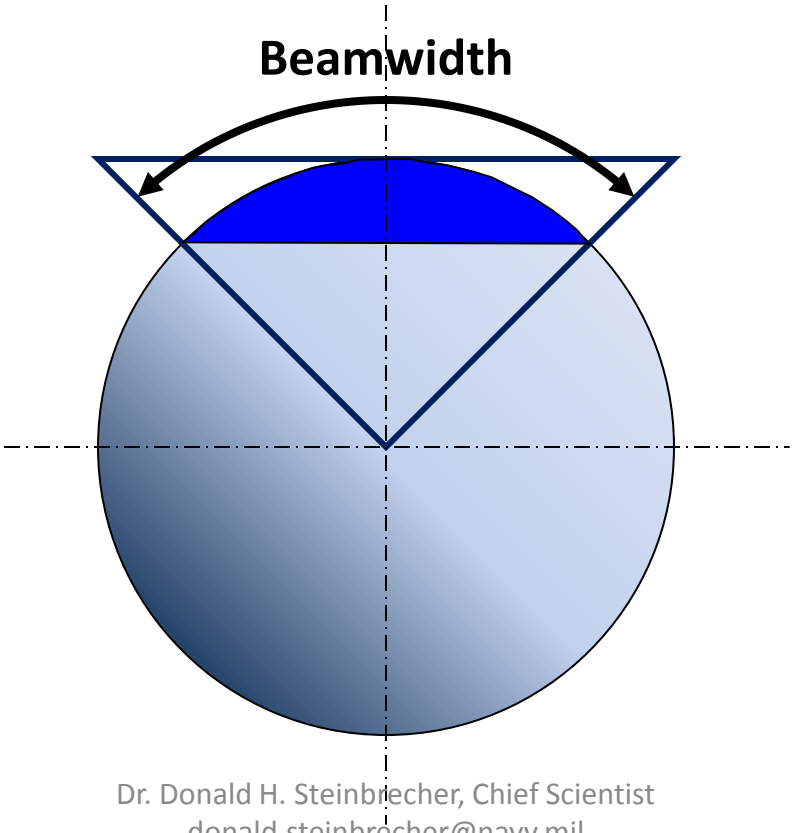
Theoretical Beamwidth for an Ideal Antenna



$$\text{Beamwidth} = 2\text{Cos}^{-1}\left(1 - \frac{\lambda^2}{2\pi A_{\text{Effective}}}\right)$$



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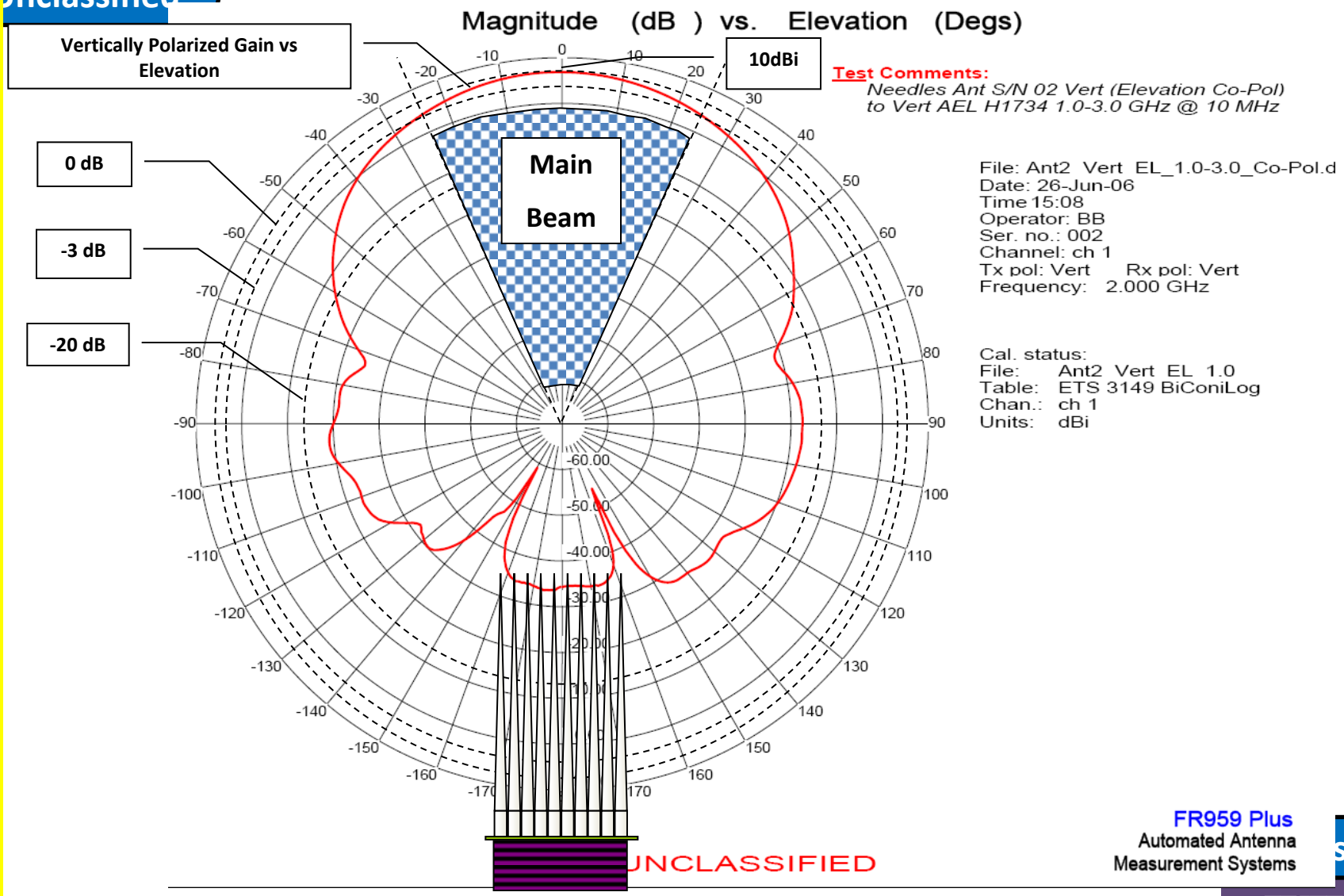
Air Interface Eplane Functionality at 2-GHz



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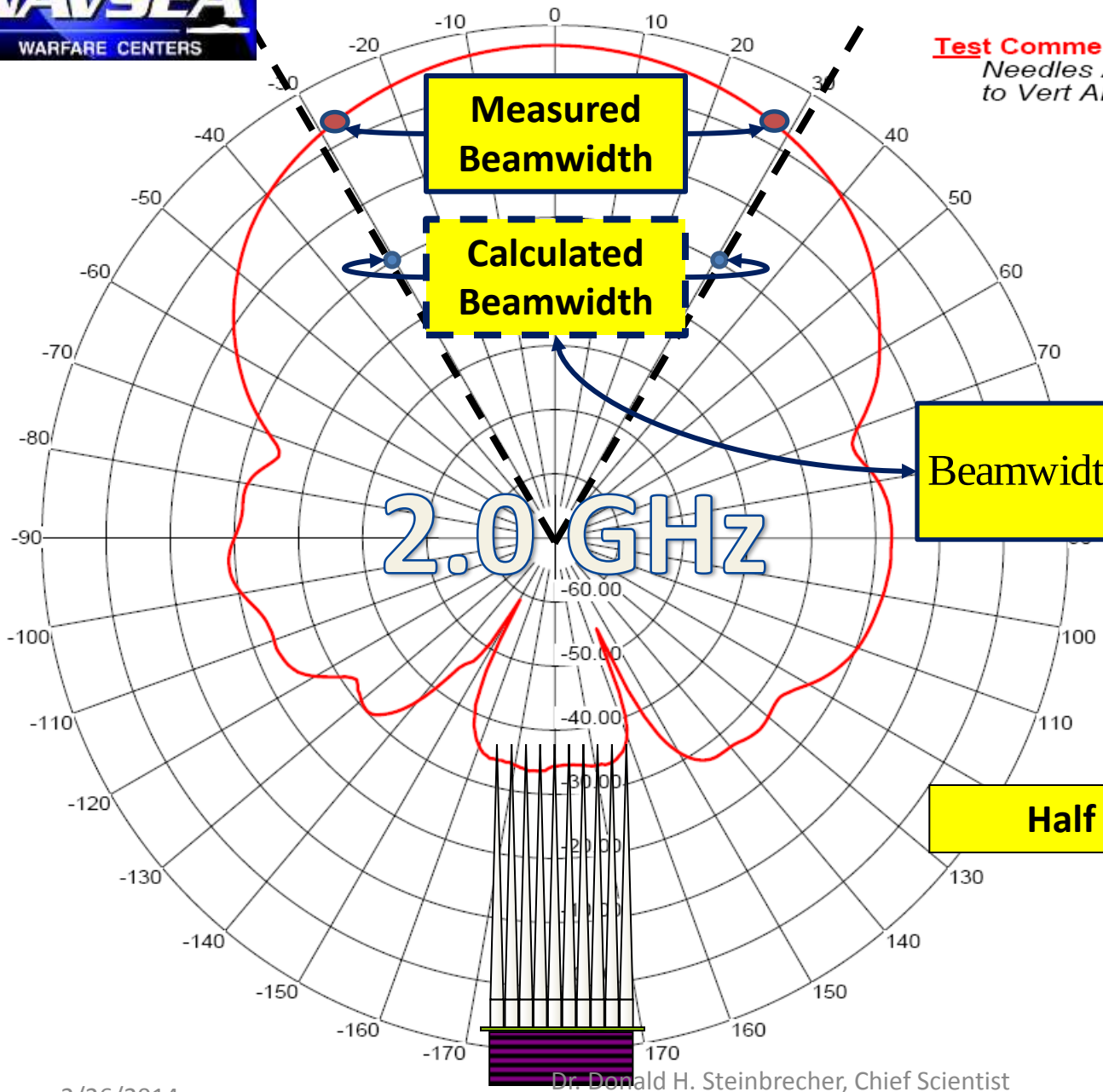

Test Comments:
Needles Ant S/N 02 Vert (Elevation Co-Pol) to Vert AEL H1734 1.0-3.0 GHz @ 10 MHz

File: Ant2 Vert EL_1.0-3.0_Co-
Date: 26-Jun-06
Time:15:08
Operator: BB
Ser. no.: 002
Channel: ch 1
Tx pol: Vert Rx pol: Vert
Frequency: 2.000 GHz

$$\text{Beamwidth} = 2\text{Cos}^{-1}\left(1 - \frac{\lambda^2}{2\pi A_{\text{Effective}}}\right)$$

LOOP

Half Beam=30.87 Degrees

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FR959 Plus

Summary:

- **We have investigated how a partitioned air interface can be used to generate modulation symbols using a simple logic-driven architecture and enable agile EM spectrum emission and interception capability,**

- **We have presented experimental results for the White Nail partitioned air interface that are consistent with theory and demonstrate one practical solution, and**

- **We have shown that a partitioned air interface can help to redefine the battlespace role of the EM Spectrum.**

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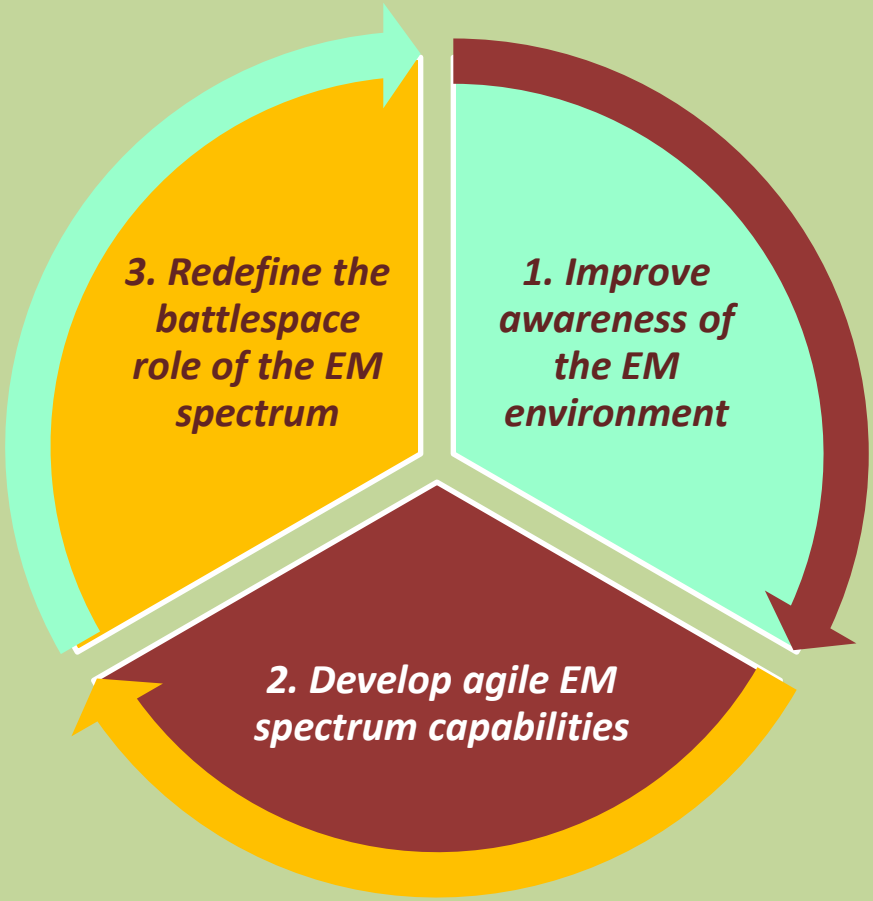
The REAL challenge is now up to you. Given an opportunity to manage virtually all EM functionality in SOFTWARE, your task is to enable our success in future wireless cyberspace conflicts.



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