NAVSEA
WARFARE CENTERS
NEWPORT

Software Defined Wireless Systems

Enabling technology for

Deploying Wireless Systems in a Highly Contested Electromagnetic Environment

SDRF15 March 26, 2015

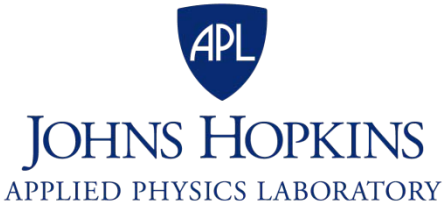
Dr. Donald H. Steinbrecher, Chief Scientist, NUWCDIVNPT

"An argument for partitioned apertures in software defined wireless systems"

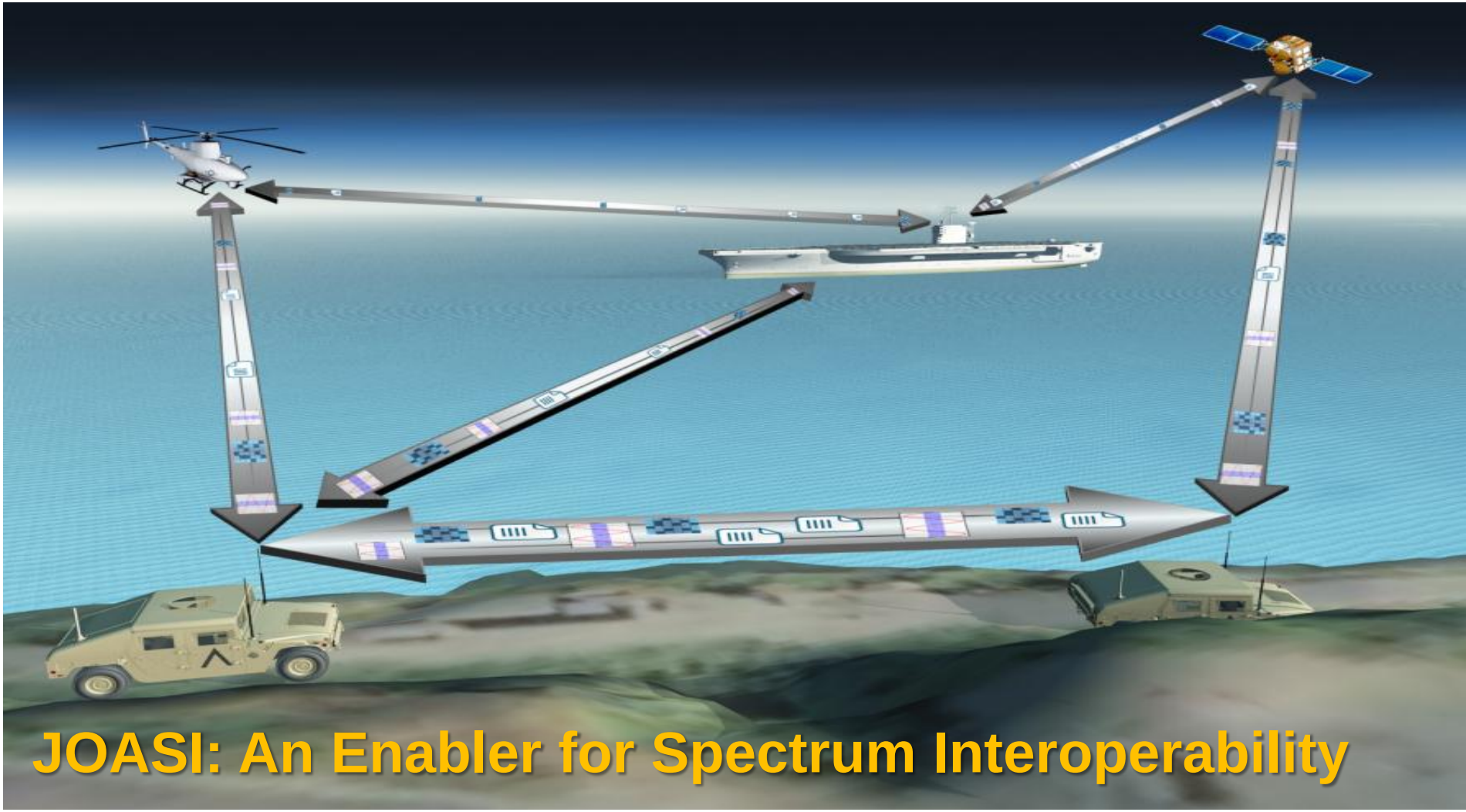
Joint Open Architecture Spectrum Infrastructure Ontology for Software Defined Radios

Introductory slides provided by Robert Normoyle, JHU/APL
and Program Manager Debra Hurt, JHU/APL

This work, which is being conducted at Johns Hopkins Applied Physics Laboratory, is funded by The Office of Naval Research Code 312



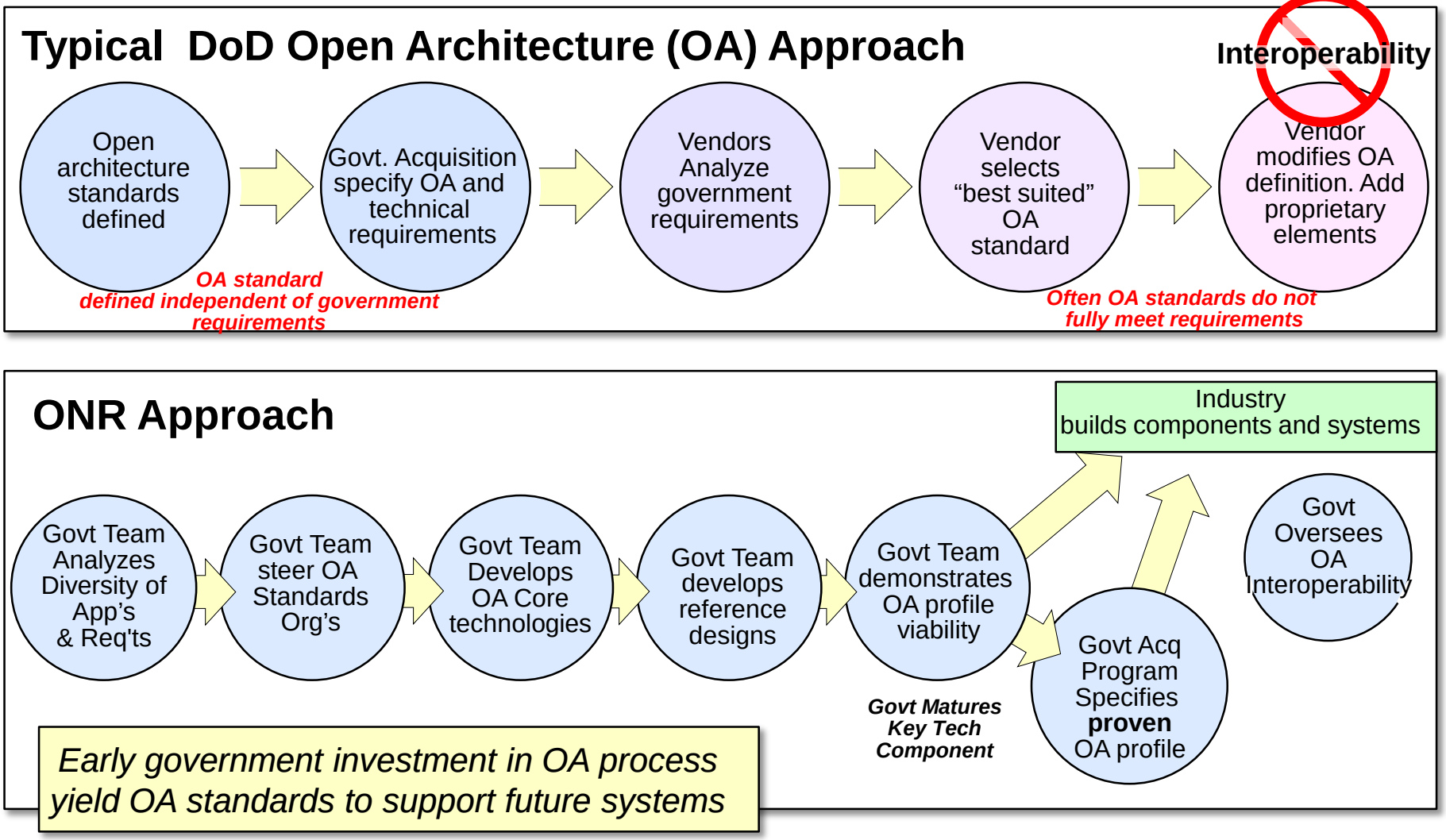
What is JOASI?



Joint Open Architecture Spectrum Infrastructure (JOASI) Ontology for Spectrum Interoperability

Enhancing the Open Architecture Process

Enhancing DoD Open Architecture Approach



What is an Architecture, Framework Infrastructure?

Architecture

- Use specific HW & SW components
    - Software Defined Radios

Framework

Standards that provide a wide diversity of capability

- Applicable to many applications
- Applicable to many architectures
- Building blocks to specify architectures
- Examples: VITA 49, IEEE 1900, Pub 8

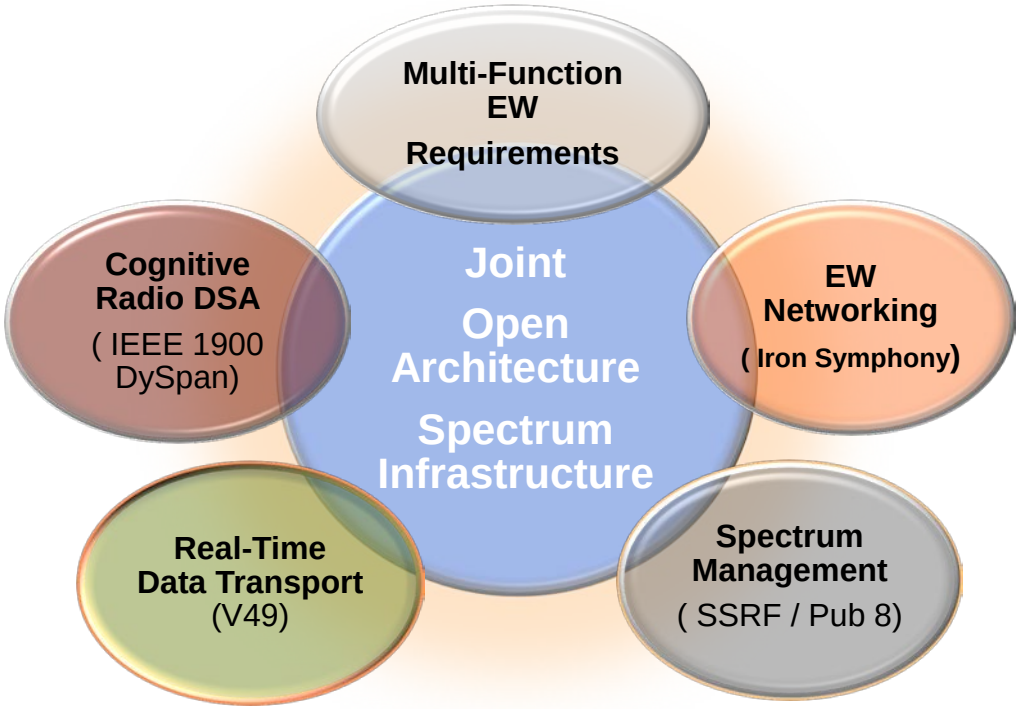
Infrastructure

A collection of orthogonal “Frameworks” integrated together to provide greater functionality than each standard by itself

Class

A sub-set of a standard(s) attribute used for a specific implementation/application - Narrowband radios may have different attributes than ultra wide band radios

Spectrum Infrastructure



Joint Open Architecture Spectrum Infrastructure (JOASI)

- *An enabling technology for future radio architectures and spectrum applications:*
  - *Spectrum de-confliction*
  - *Improved situational awareness*
  - *Improved jamming effectiveness and capability*
  - *Dynamic Spectrum Access*
  - *Alternative Position Navigation and Timing*
  - *Framework for multi-function RF applications*

NAVSEA
WARFARE CENTERS
NEWPORT

Software Defined Wireless Systems

Enabling technology for

Deploying Wireless Systems in a Highly Contested Electromagnetic Environment

SDRF15 March 26, 2015

Dr. Donald H. Steinbrecher, Chief Scientist, NUWCDIVNPT

"An argument for partitioned apertures in software defined wireless systems"

Properties of an Ideal Digital Signals Acquisition System

Comprising a minimum of five parts:

1. **An Air Interface device for capturing the EM signal energy,**
2. **A signal amplifier with gain, G, that establishes the system noise figure,**
3. **An anti-aliasing filter, AAF, that establishes the system bandwidth,**
4. **An Analog to Digital Converter, ADC, and**
5. **A digital signal processing sub-system where signal acquisition takes place.**

Properties of an Ideal Digital Signals Acquisition System

Comprising a minimum of five parts:

1. **An Air Interface device for capturing the EM signal energy,**
2. **A signal amplifier with gain, G, that establishes the system noise figure,**
3. **An anti-aliasing filter, AAF, that establishes the system bandwidth,**
4. **An Analog to Digital Converter, ADC, and**
5. **A digital signal processing sub-system where signal acquisition takes place.**

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Properties of an Ideal Digital Signals Acquisition System

Comprising a minimum of five parts:

1. An Air Interface device for capturing the EM signal energy,
2. **A signal amplifier with gain, G, that establishes the system noise figure,**
3. An anti-aliasing filter, AAF, that establishes the system bandwidth,
4. An Analog to Digital Converter, ADC, and
5. A digital signal processing sub-system where signal acquisition takes place.

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Properties of an Ideal Digital Signals Acquisition System

Comprising a minimum of five parts:

1. An Air Interface device for capturing the EM signal energy,
2. A signal amplifier with gain, G, that establishes the system noise figure,
3. **An anti-aliasing filter, AAF, that establishes the system bandwidth,**
4. An Analog to Digital Converter, ADC, and
5. A digital signal processing sub-system where signal acquisition takes place.

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Properties of an Ideal Digital Signals Acquisition System

Comprising a minimum of five parts:

1. An Air Interface device for capturing the EM signal energy,
2. A signal amplifier with gain, G, that establishes the system noise figure,
3. An anti-aliasing filter, AAF, that establishes the system bandwidth,
4. **An Analog to Digital Converter, ADC, and**
5. A digital signal processing sub-system where signal acquisition takes place.

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

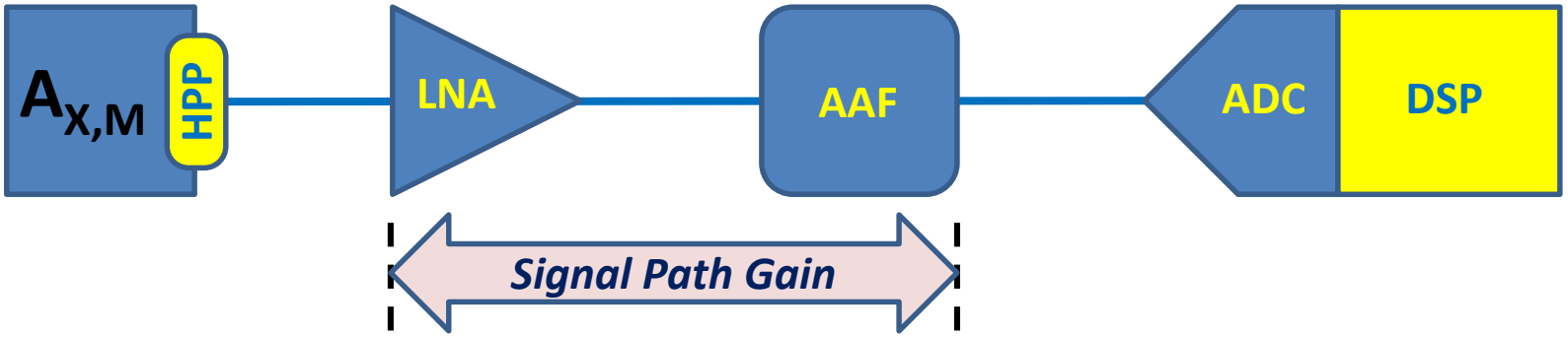
Properties of an Ideal Digital Signals Acquisition System

Comprising a minimum of five parts:

1. An Air Interface device for capturing the EM signal energy,
2. A signal amplifier with gain, G, that establishes the system noise figure,
3. An anti-aliasing filter, AAF, that establishes the system bandwidth,
4. An Analog to Digital Converter, ADC, and
5. **A digital signal processing sub-system where signal acquisition takes place.**

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

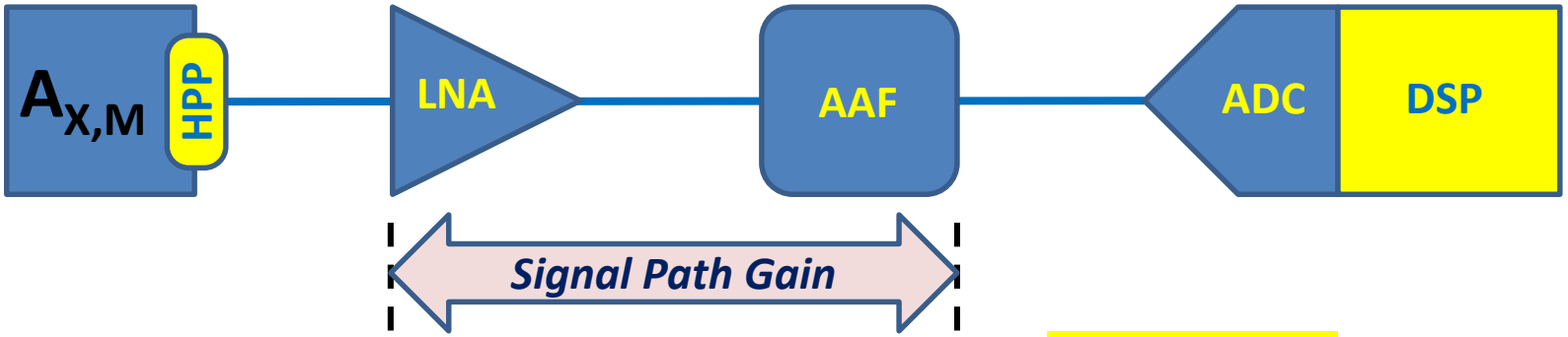
Signal Path GAIN Fundamental Limit



$$Gain \geq \left[\frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N}\right] \frac{1}{F_{SYS} - 1}$$

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Signal Path GAIN Fundamental Limit



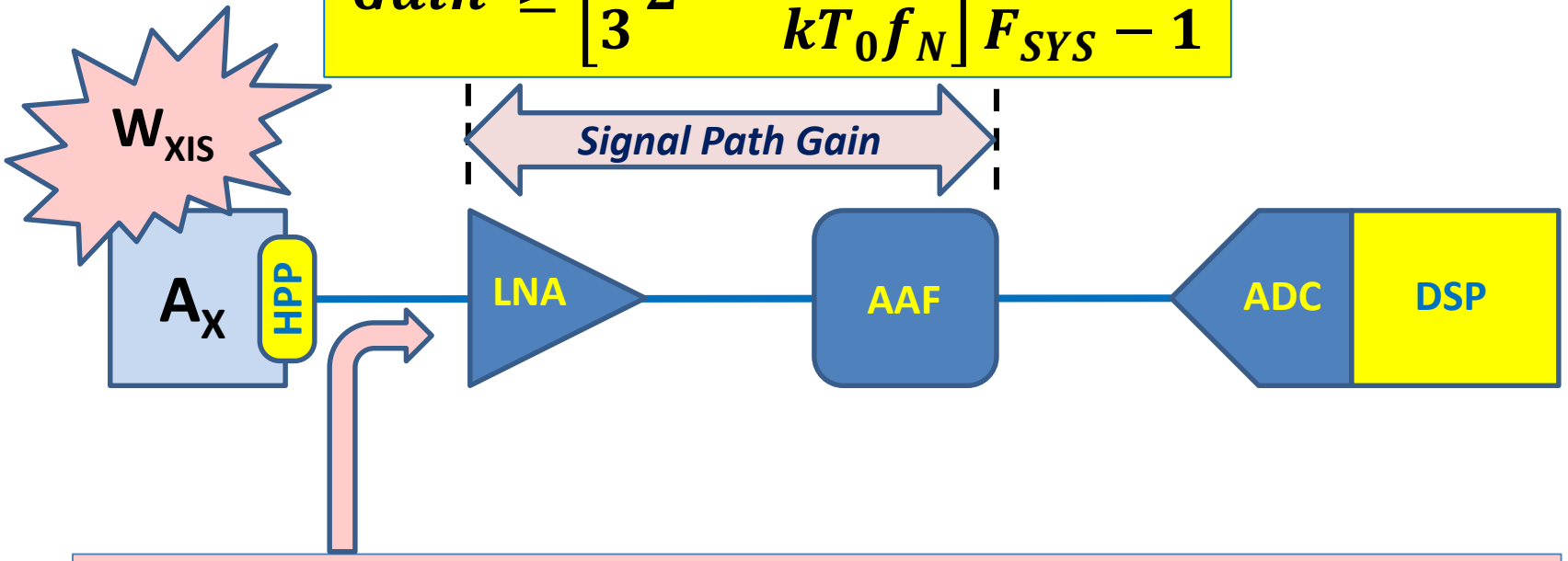
$F_{ADC} - 1$

$$Gain \geq \left[\frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N}\right] \frac{1}{F_{SYS} - 1}$$

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Signal Path GAIN Fundamental Limit

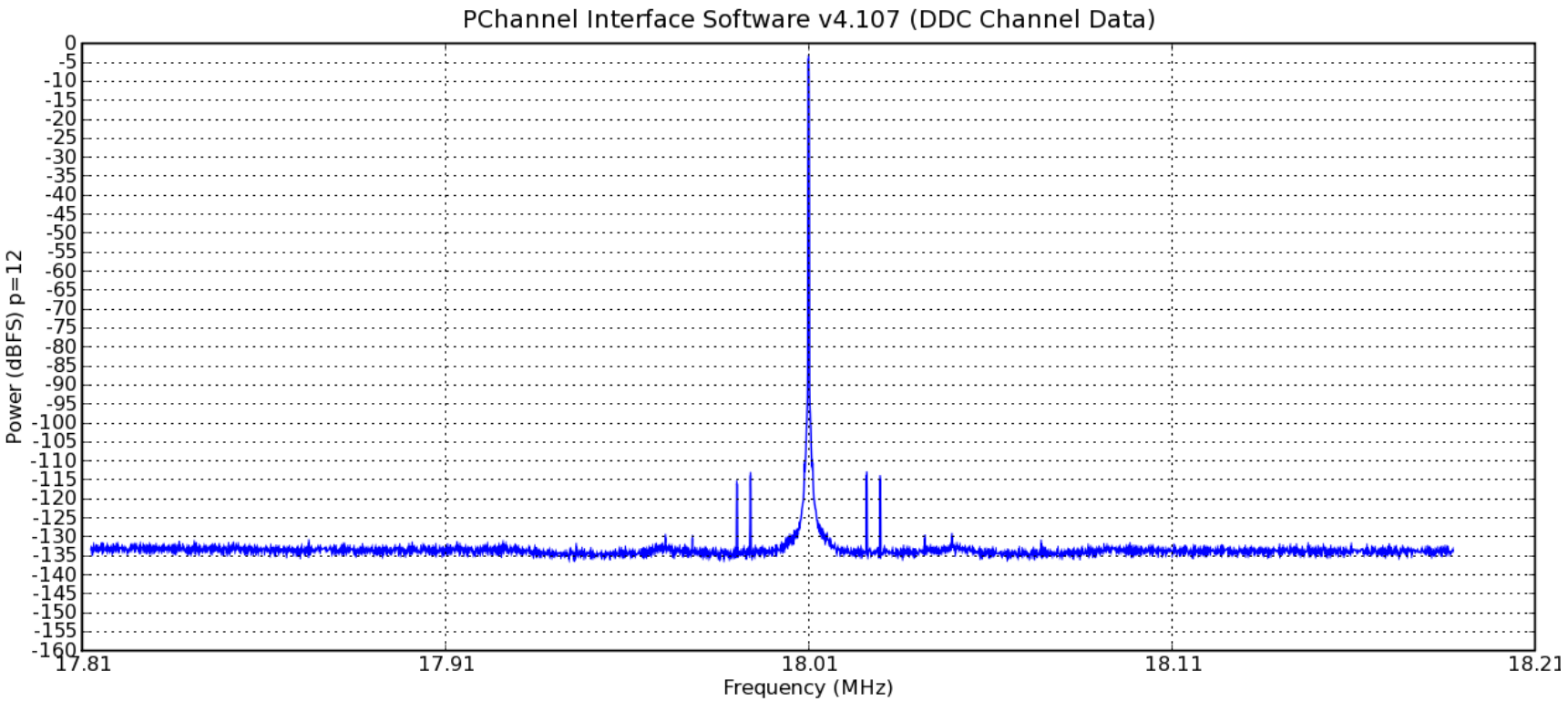
$$Gain \geq \left[\frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N}\right] \frac{1}{F_{SYS} - 1}$$



$$P_{MAX} = \frac{P_{FSAO}}{Gain} = \left[\frac{3}{2} 2^{2N} kT_0 f_N\right](F_{SYS} - 1) = W_{XIS} A_x$$

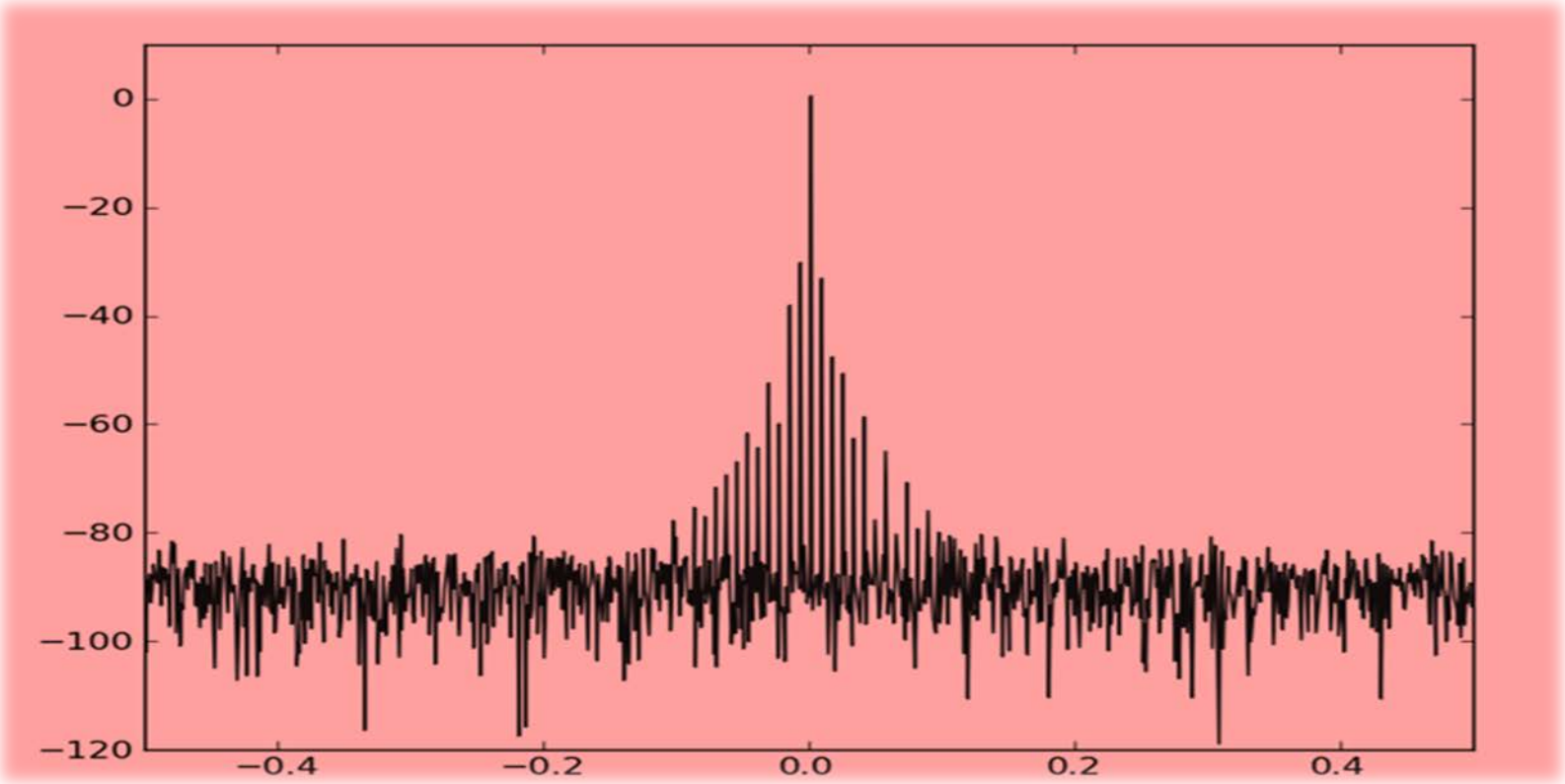
Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

$P < P_{MAX}$



Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

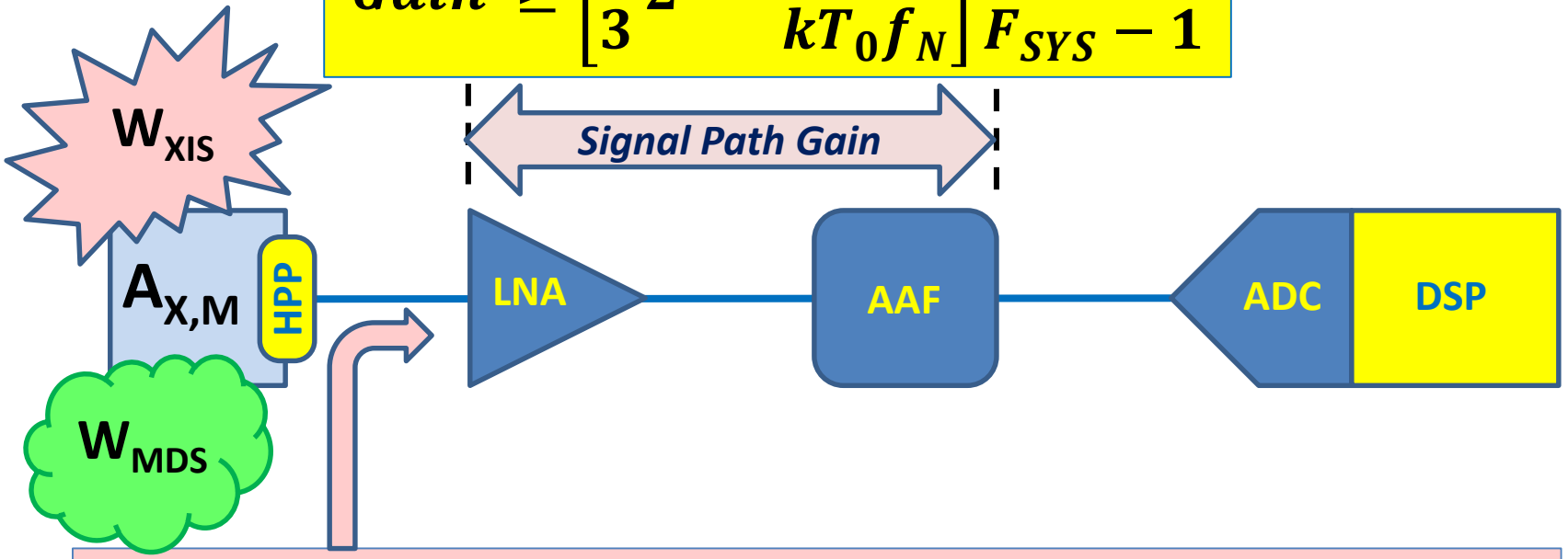
$P > P_{MAX}$



Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Signal Path GAIN Fundamental Limit

$$Gain \geq \left[\frac{2}{3}2^{-2N}\frac{P_{FSAO}}{kT_0 f_N}\right]\frac{1}{F_{SYS}-1}$$



$$P_{MAX} = \frac{P_{FSAO}}{Gain} = \left[\frac{3}{2}2^{2N}kT_0 f_N\right](F_{SYS}-1) = W_{XIS}A_X$$

$$P_{MDS} = kT_0 F_{SYS} B_{MDS} = W_{MDS}\,A_M$$

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

FUNDAMENTAL LIMITS

$$P_{MAX} = \frac{P_{FSAO}}{Gain} = \left[\frac{3}{2} 2^{2N} kT_0 f_N\right](F_{SYS} - 1) = W_{XIS} A_X$$

$$P_{MDS} = kT_0 F_{SYS} B_{MDS} = W_{MDS}\, A_M$$

$$SDR = \frac{3}{2} 2^{2N} \frac{f_N}{B_{MDS}} \frac{F_{SYS}-1}{F_{SYS}}$$

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

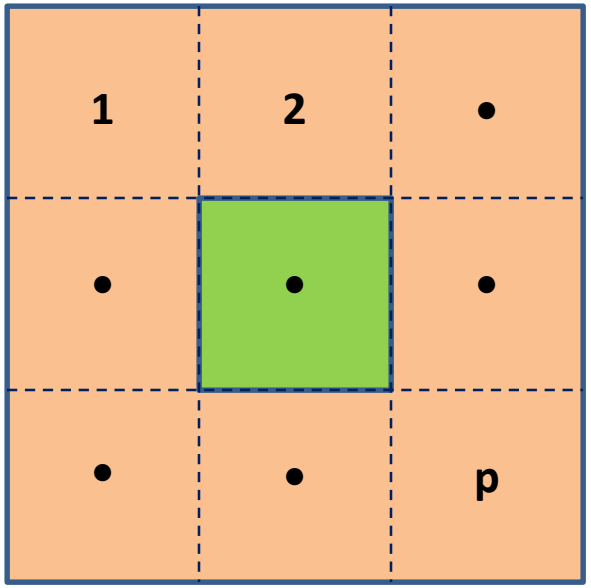
Definitions for an Ideal Partitioned Air Interface (Antenna)

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.



FUNDAMENTAL LIMITS

$$P_{MAX} = \frac{P_{FSAO}}{Gain} = \left[\frac{3}{2} 2^{2N} kT_0 f_N\right](F_{SYS} - 1) = W_{XIS} A_X$$

$$P_{MDS} = kT_0 F_{SYS} B_{MDS} = W_{MDS}\, A_M$$

Let 'p' represent the number of aperture partitions, then

$$SDR(p) = p\,\frac{3}{2}\,2^{2N}\,\frac{f_N}{B_{MDS}}\,\frac{F_{SYS}-1}{F_{SYS}}$$

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Battelle
The Business of Innovation

HF pCHANNEL RECEIVER

Nonexclusive Patent License Agreement No. 12-02 Between Battelle Memorial Institute and the U.S. Department of Navy

Patents:

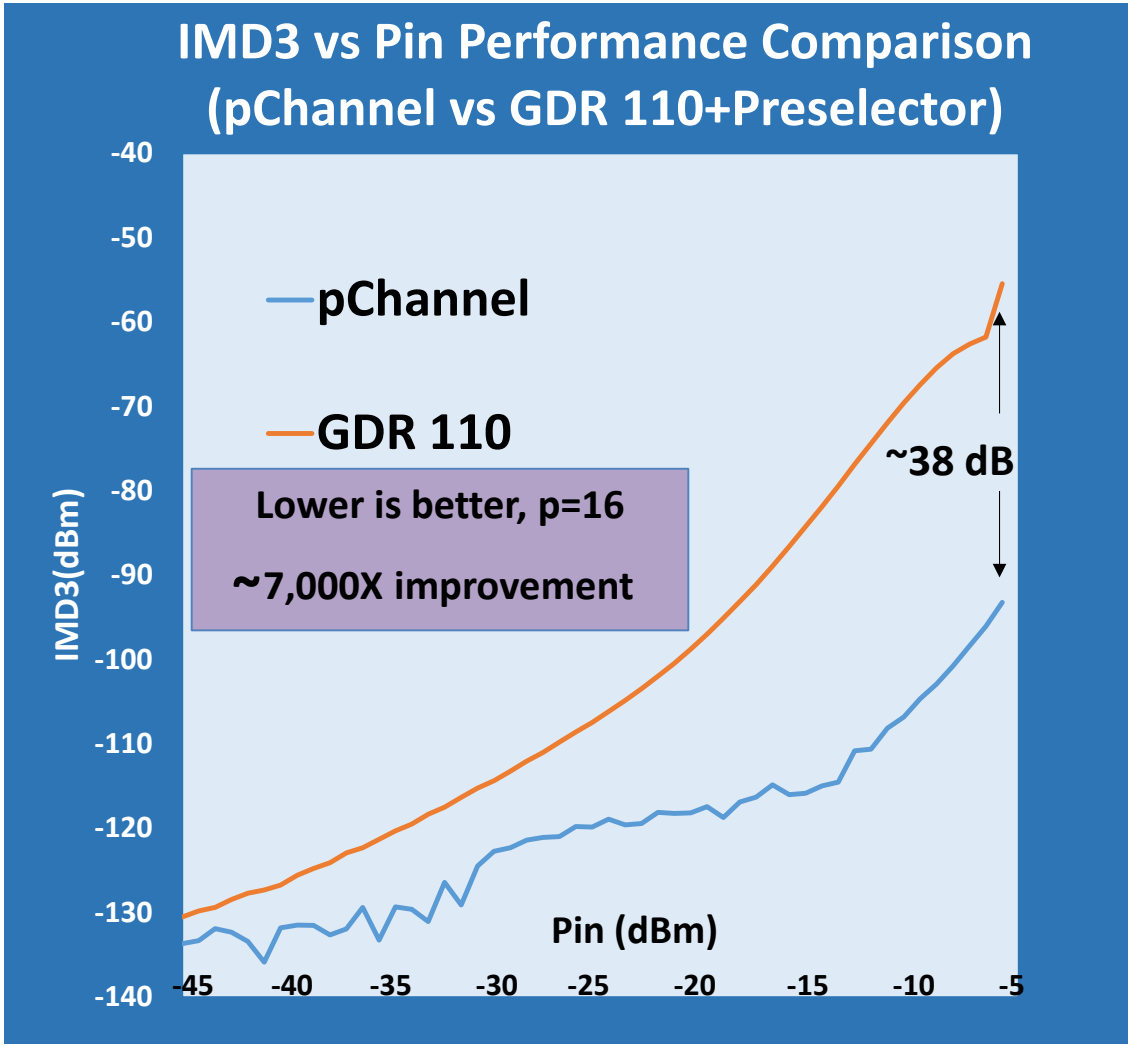
- ***8,401,134*** ***19 March 2013***
- ***7,250,920**** ***31 July 2007***
- ***6,466,167**** ***15 October 2002***

*** These patents cover aspects of both pChannel and White Nail**

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Standard pChannel
p = 64

Ruggedized (p=16) pChannel

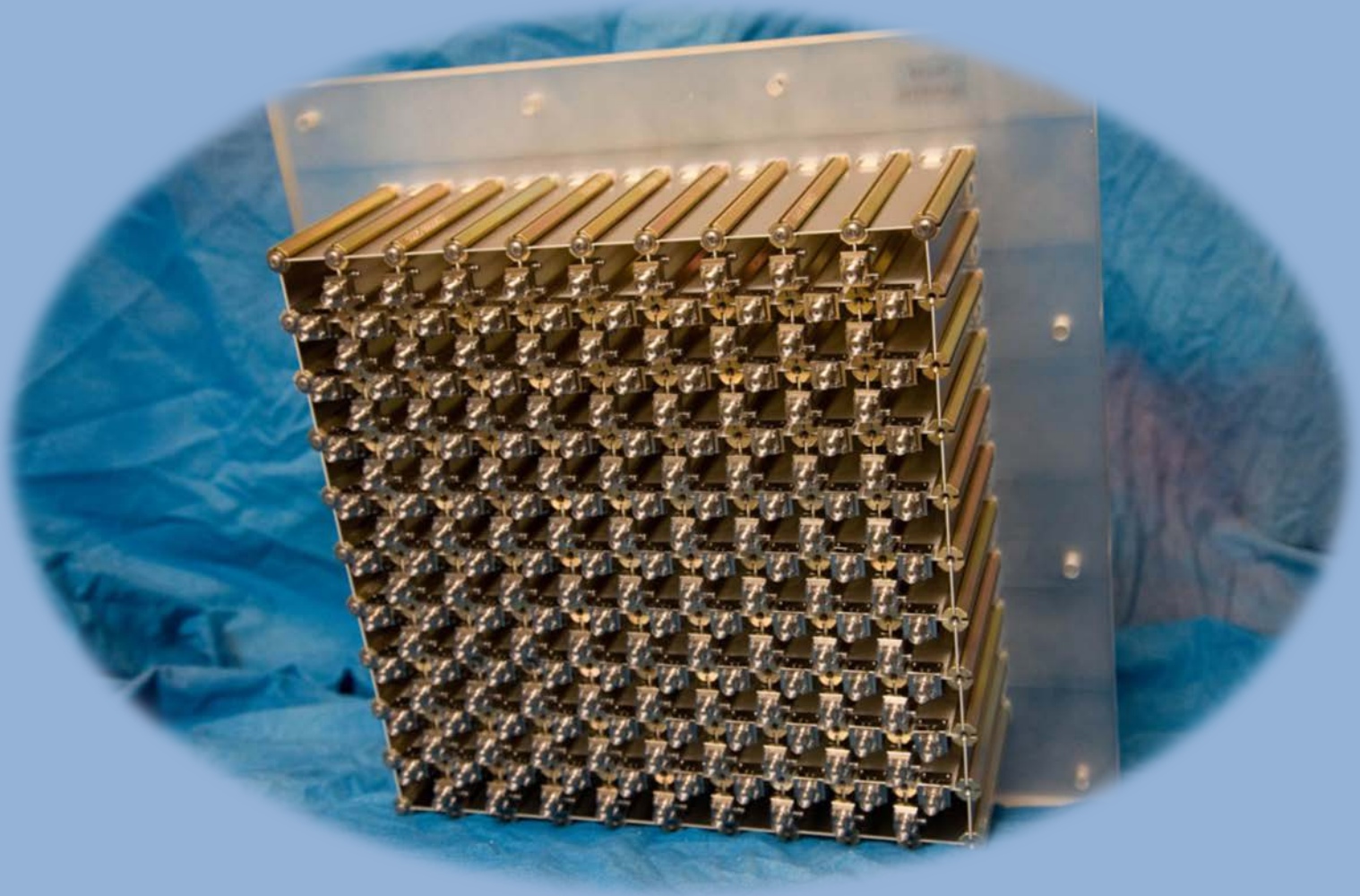


The White Nail Innovation Project

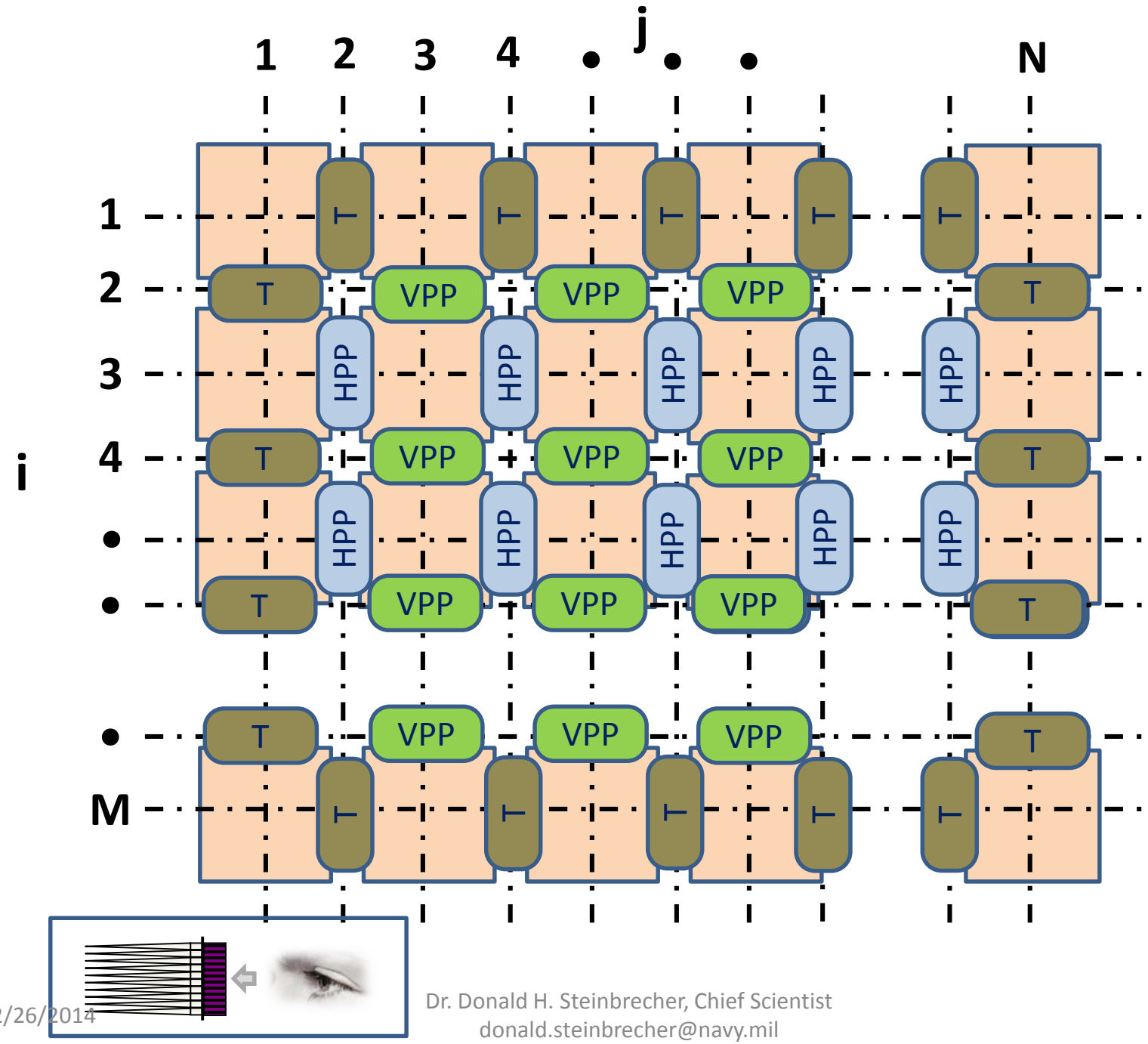
Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

NAVSEA
WARFARE CENTERS

DISTRIBUTION STATEMENT A: APPROVED FOR PUBLIC RELEASE DISTRIBUTION IS UNLIMITED

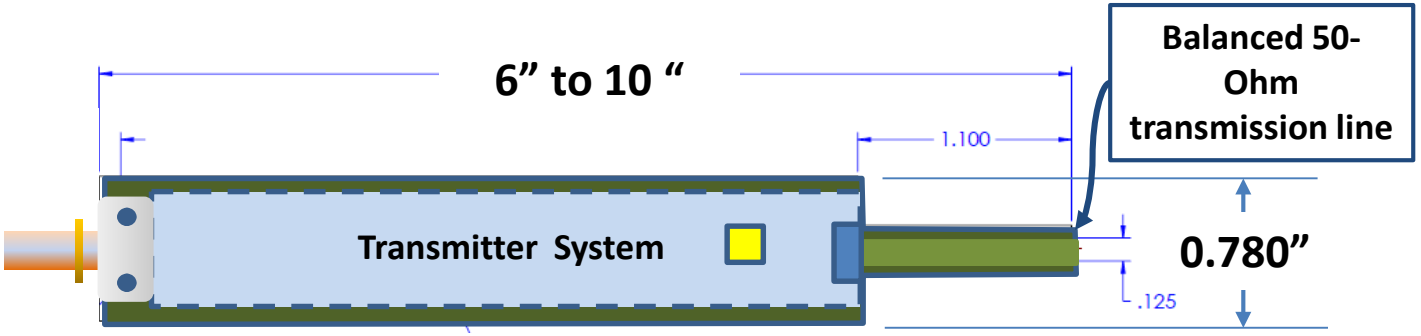


Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil



Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

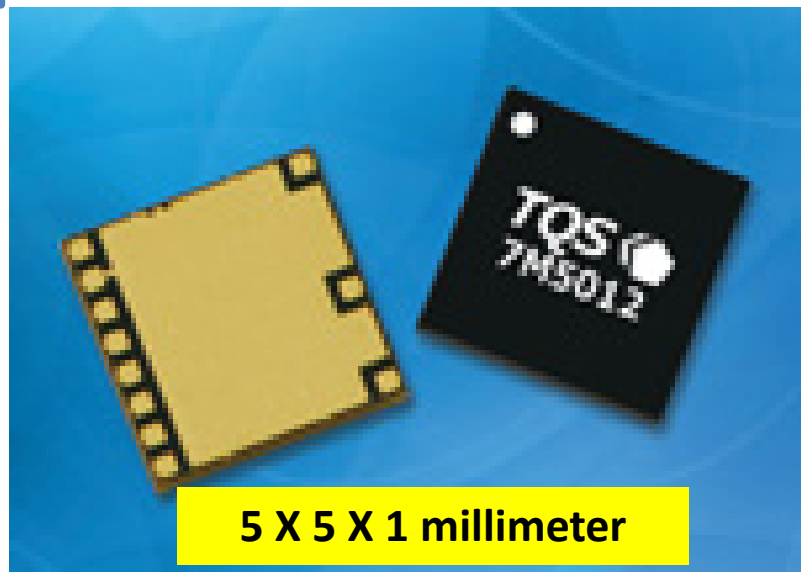
White Nail Vision



800 – 2100 MHz

Electrical Specifications

Parameter	850 Band	900 Band	DCS Band	PCS Band	Units
	Typ	Typ	Typ	Typ	
GSM Pout	35	34.7	33	32.7	dBm
Efficiency	53	55	48	50	%
Pin	6	6	6	6	dBm
EDGE Pout	29	29	28	28	dBm
Efficiency	25	25	25	26	%
Pin	6	6	6	6	dBm



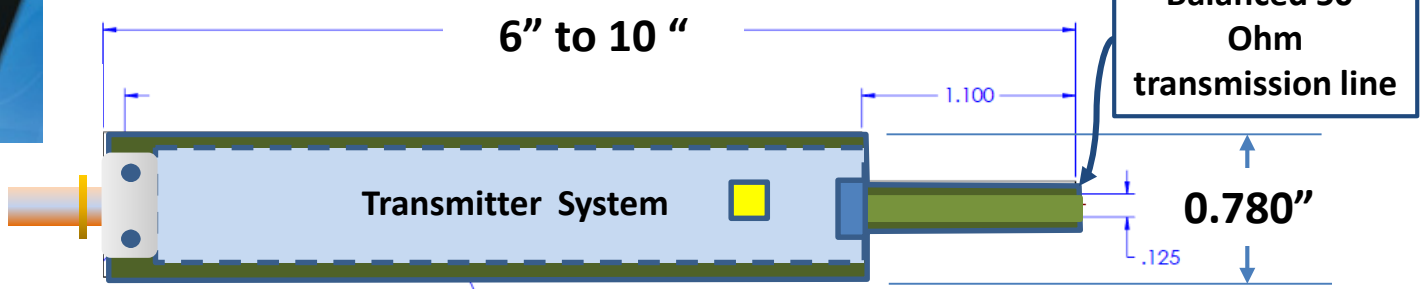
5 X 5 X 1 millimeter

http://www.triquint.com/products/p/TQM7M5012H

Dr. Donald H. Steinbrecher
Donald.steinbrecher@navy.mil

White Nail Vision

Fiber Optic Connector



White Nail CW Transmitter Performance				
Partitions (p)	ratio	32	64	128
System Gain	dB	25	31	37
Amp. Output	dBW	6	6	6
EIRP	dBW	31	37	43
Aperture Efficiency	%	94	94	94
Amplifier Efficiency	%	55	55	55
Tx Efficiency	%	52	52	52
Unit Amplifier cost	$	16	16	16
Total Amplifier cost	$	512	1,024	2,048

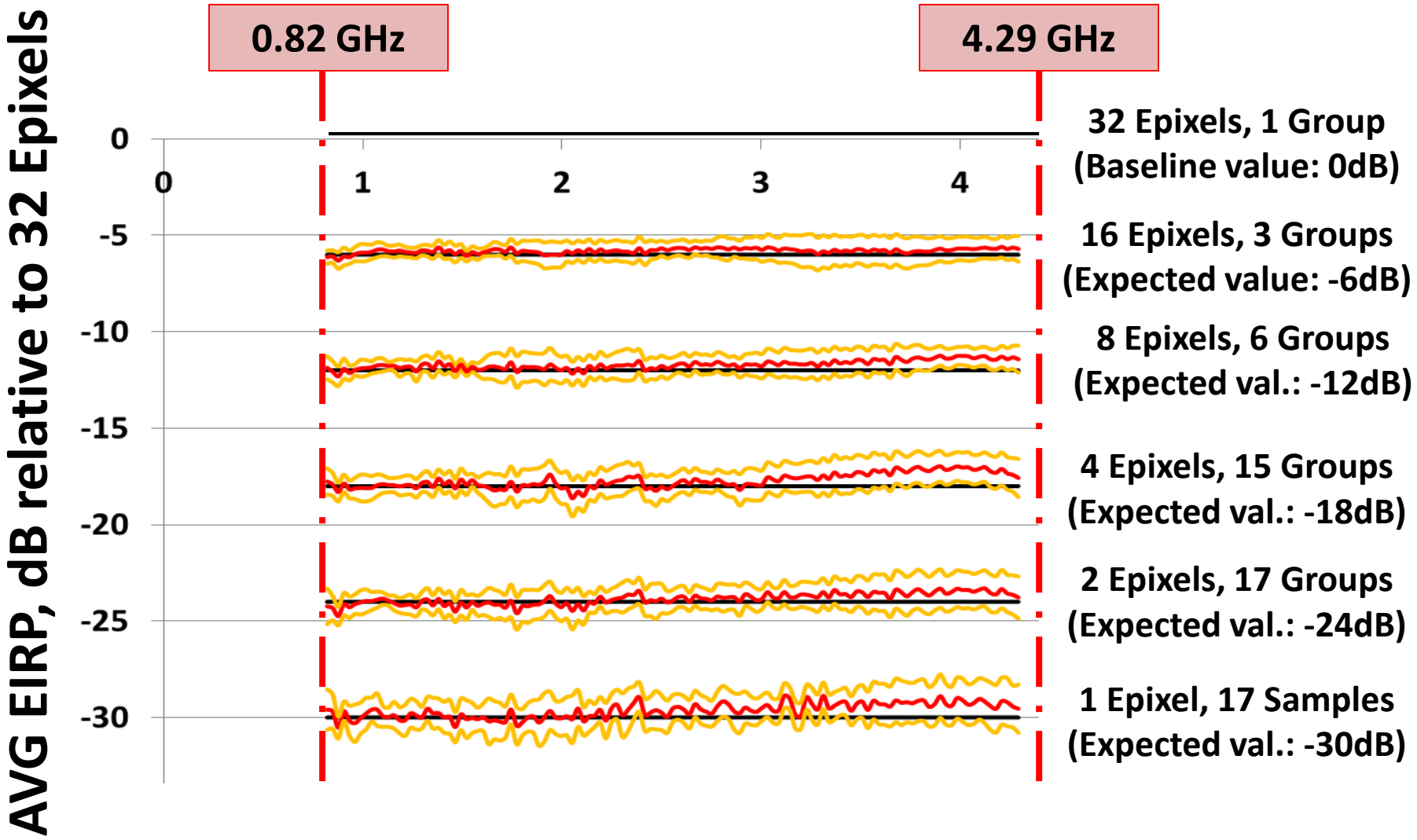
Dr. Donald H. Steinbrecher
Donald.steinbrecher@navy.mil

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

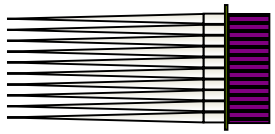
Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

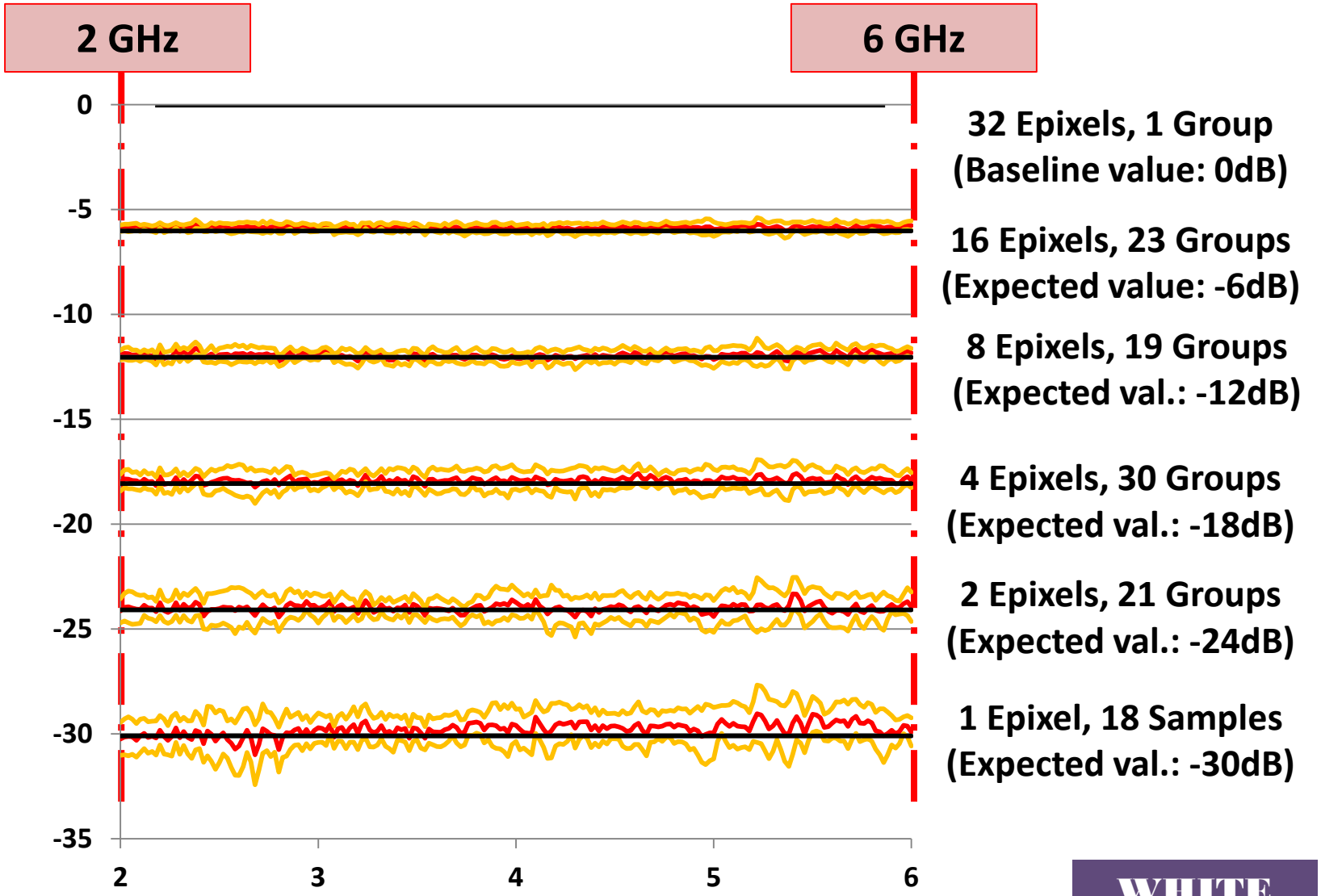
Mean ± One Standard Deviation
vs Frequency for each Epixel Grouping



Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Mean ± One Standard Deviation vs Frequency for each Epixel Grouping

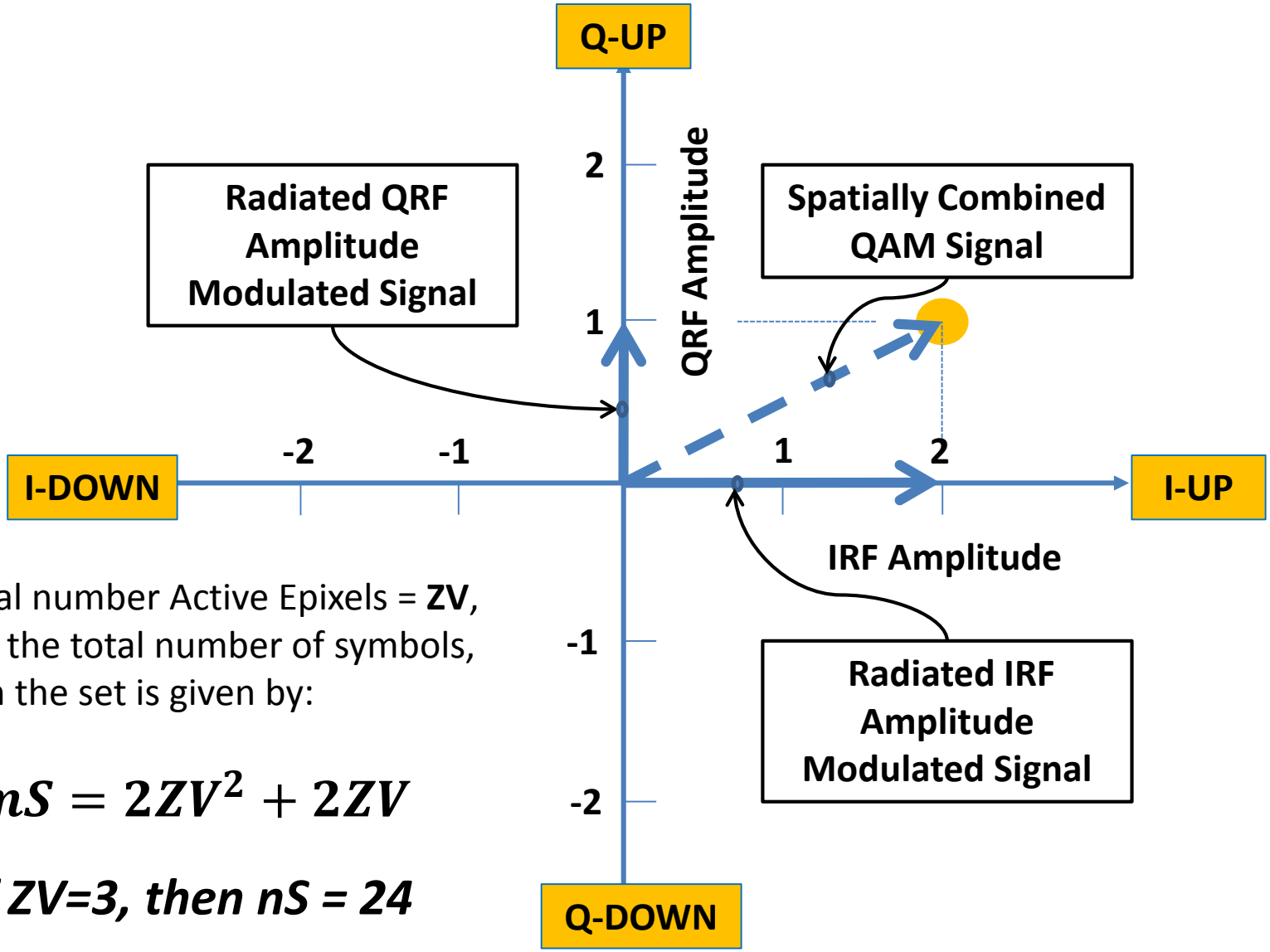




Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

WHITE NAIL

Quadrature Amplitude Modulation



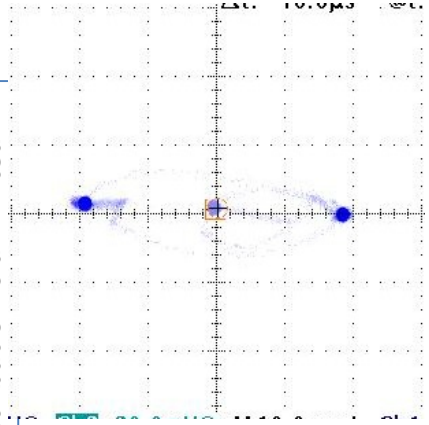
If total number Active Epixels = **ZV**, Then the total number of symbols, **nS**, in the set is given by:

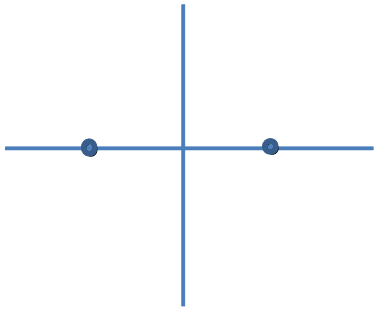
$$nS = 2ZV^2 + 2ZV$$

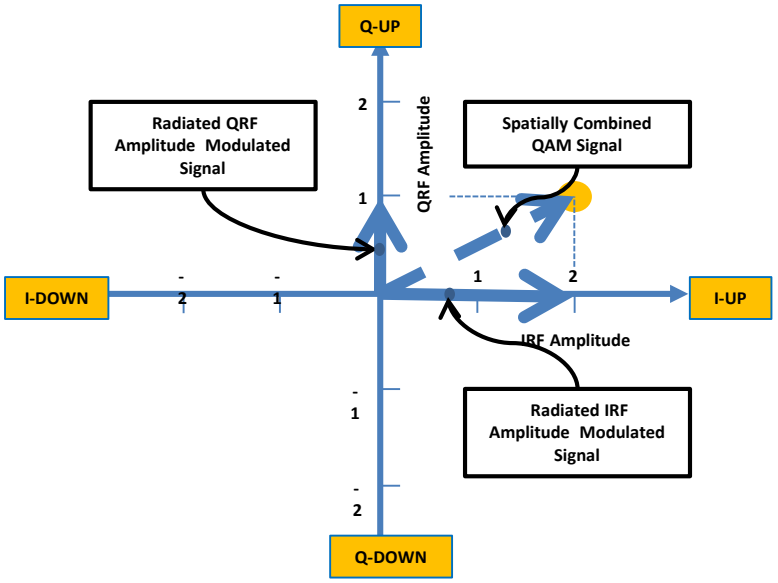
If ZV=3, then nS = 24

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

IBPSK

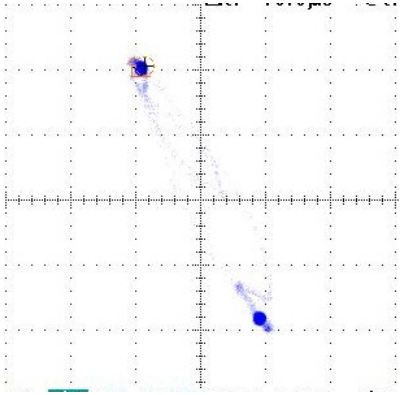


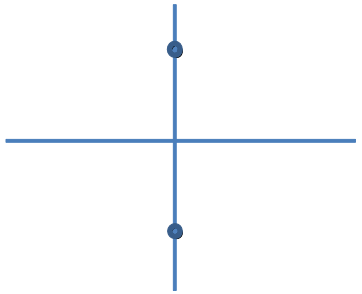




Measured Expected

Note that the quadrature components are mis-aligned, which results in a distortion in the symbol sets

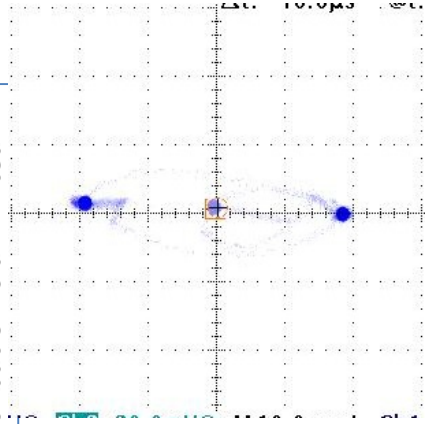


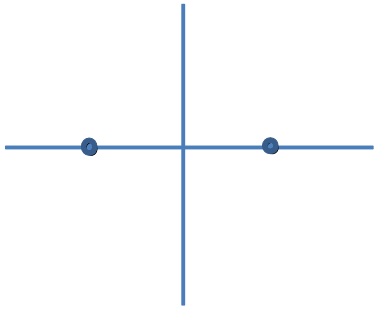


Measured **QBPSK** Expected

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

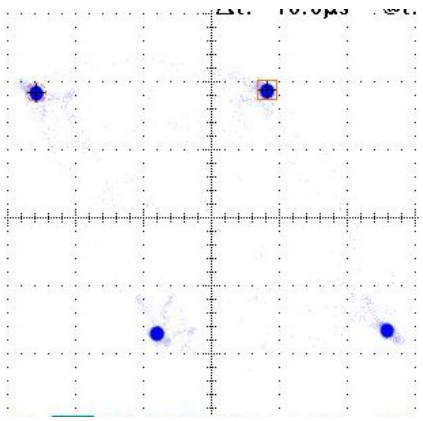
BPSK

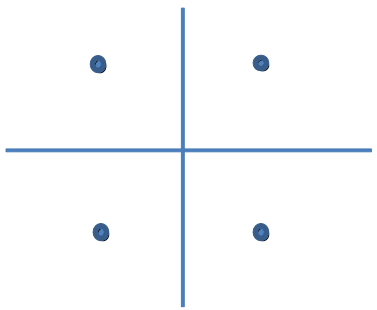




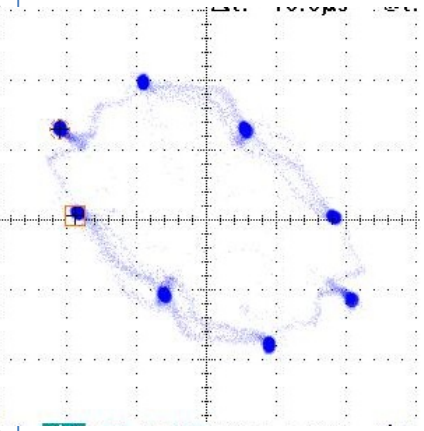
Measured Expected

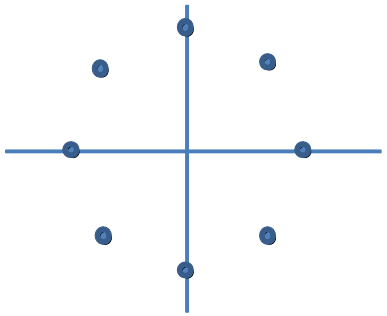
QPSK



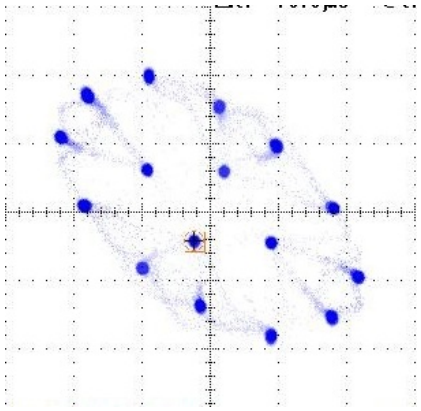


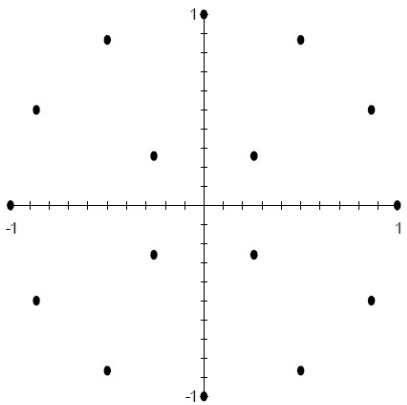
Measured Expected





Measured **8QAM** Expected

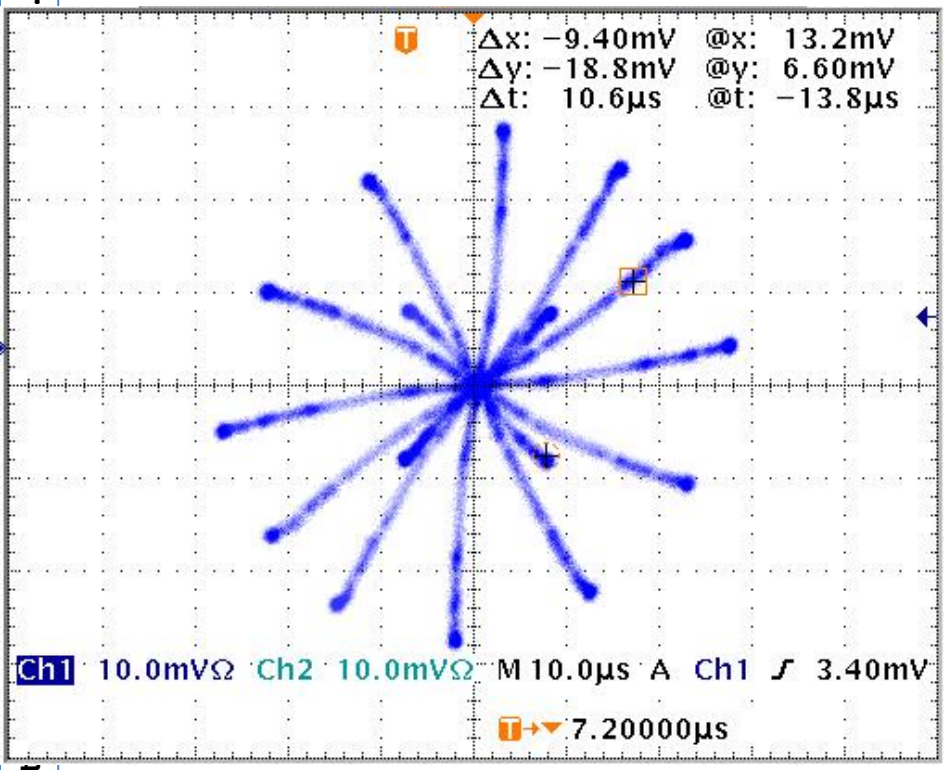


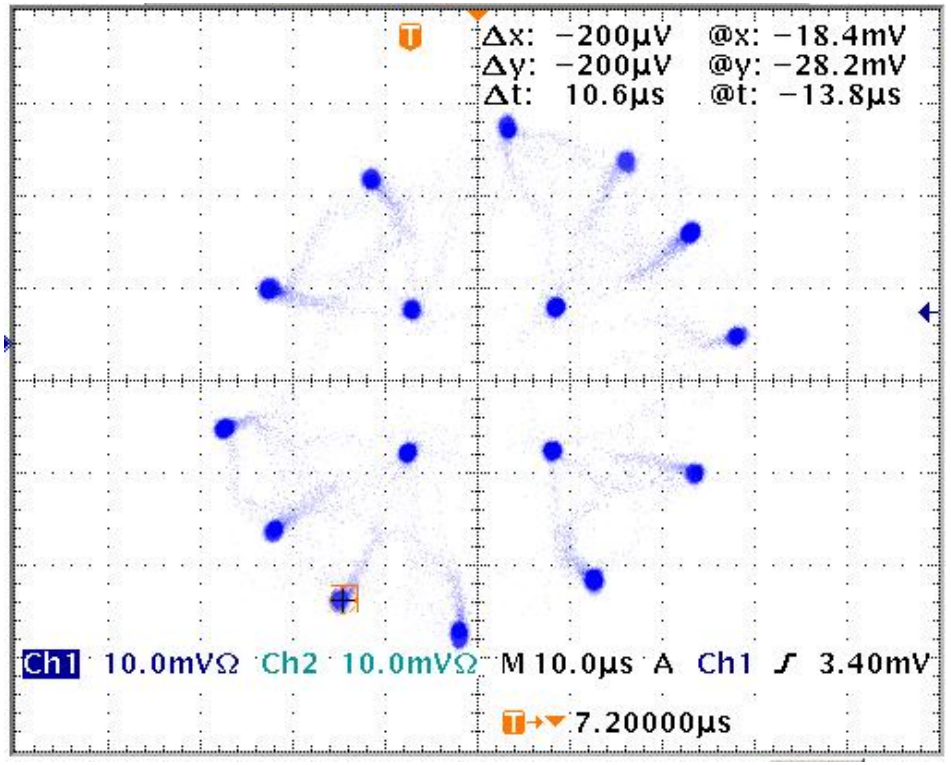


Measured **16QAM** Expected

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

White Nail 16-QAM Symbol Map



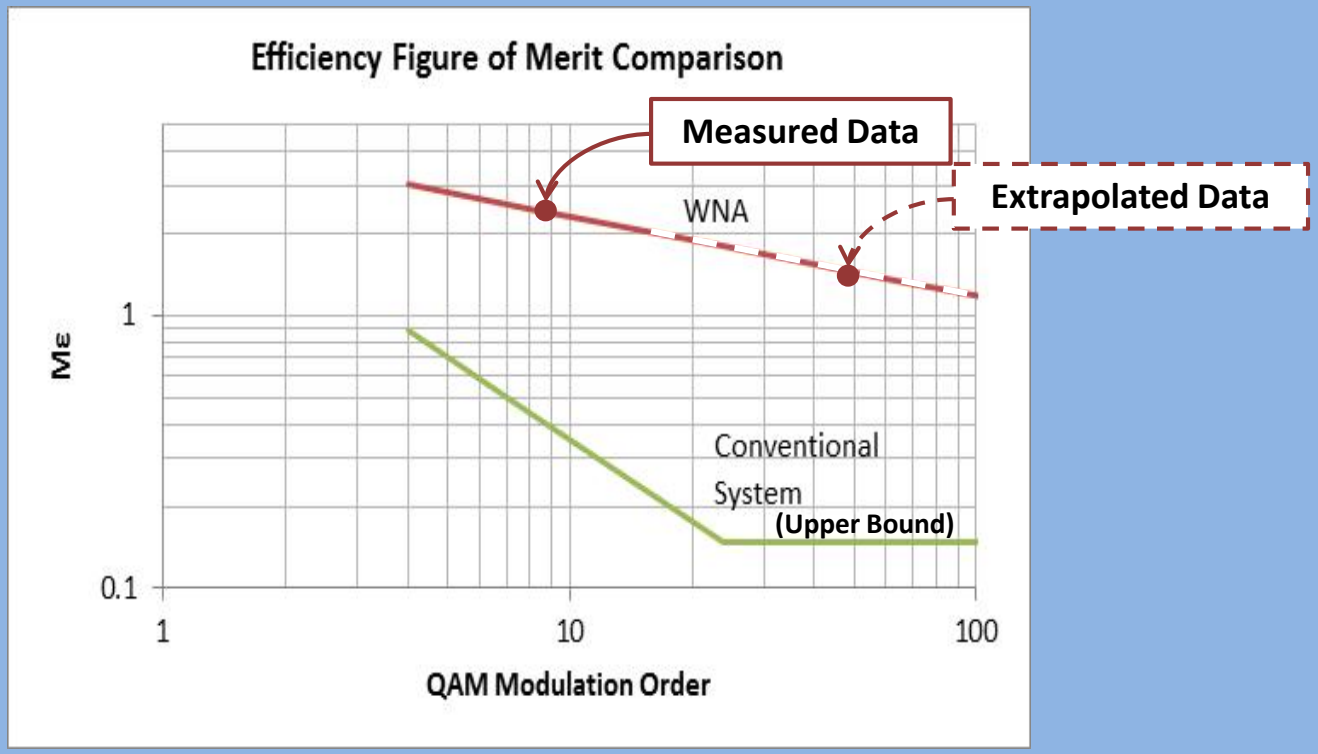


Ramp ON

Ramp OFF

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

Figure of Merit for White Nail QAM Transmitter vs Conventional QAM Transmitter of the same QAM order.

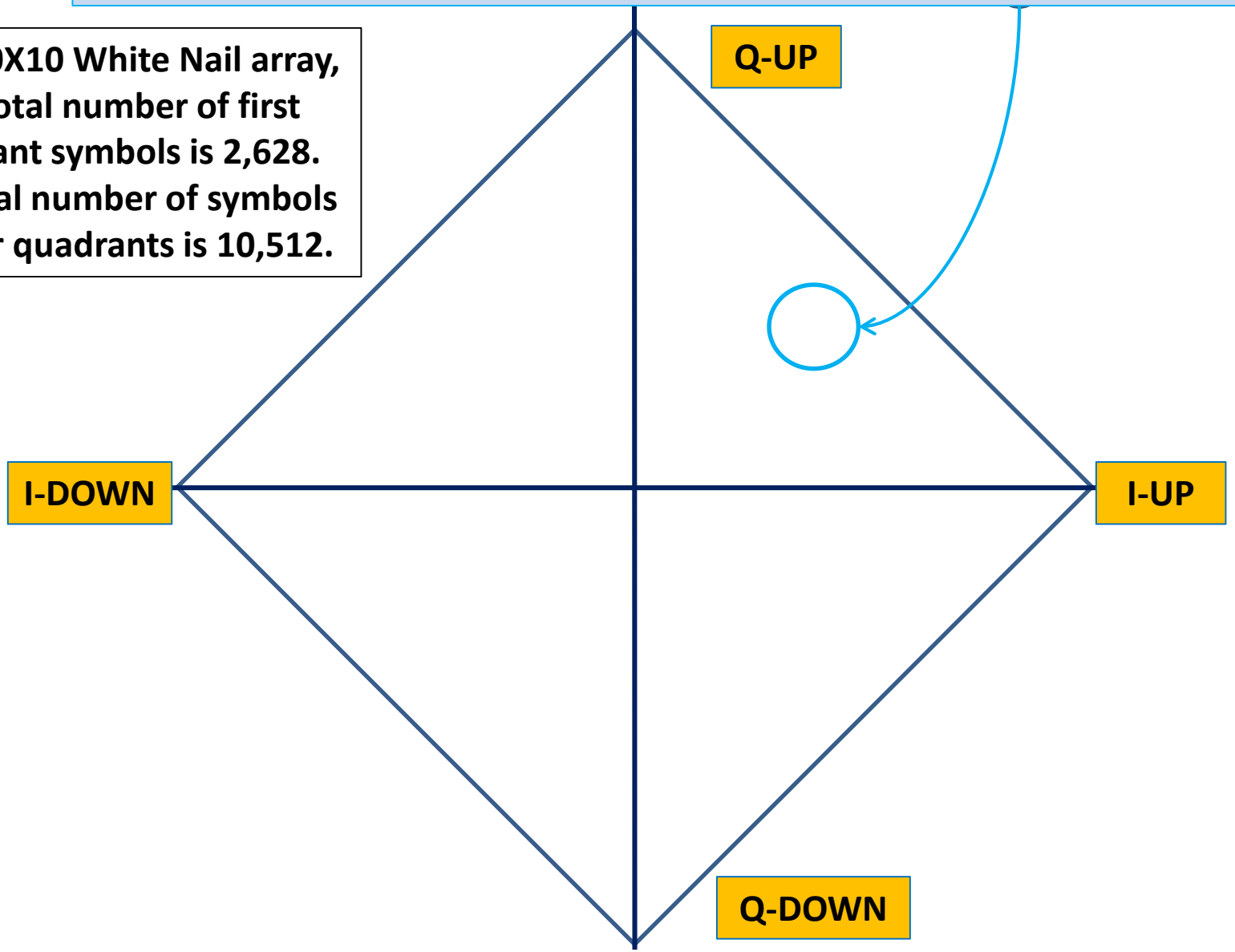


$$M_\epsilon = \frac{EIRP}{P_{DC}} = \frac{P_{TX}G_{TX}}{P_{DC}} = \frac{4\pi A_{phys}\epsilon_{amp}\epsilon_{ant}}{\lambda^2}$$

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

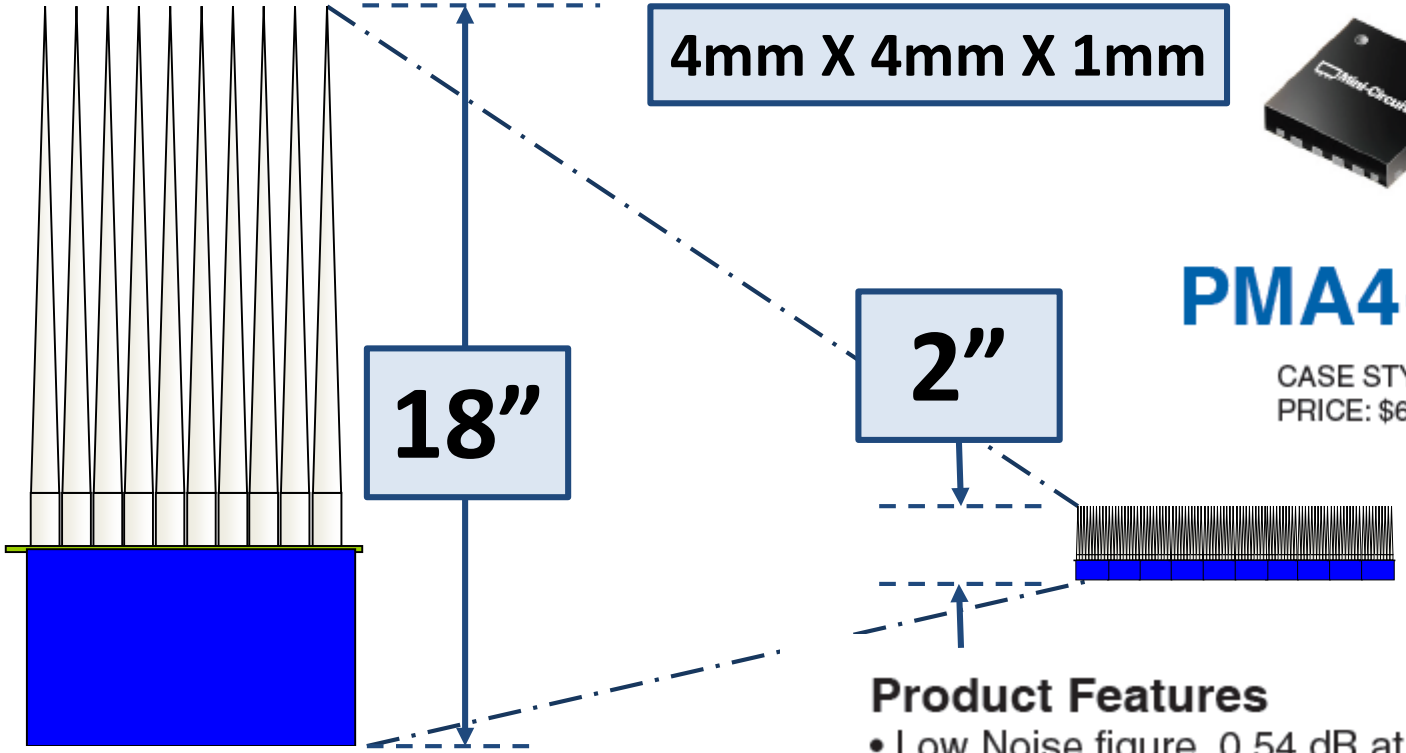
Approximate Modulation Symbol Density for a 10 X 10 White Nail Array

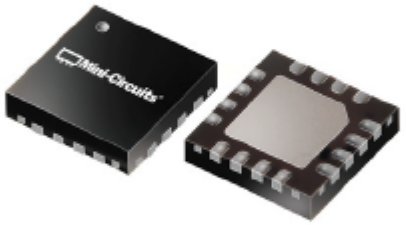
For a 10X10 White Nail array, the total number of first quadrant symbols is 2,628. The total number of symbols for four quadrants is 10,512.



Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

0.7-3.0 GHz



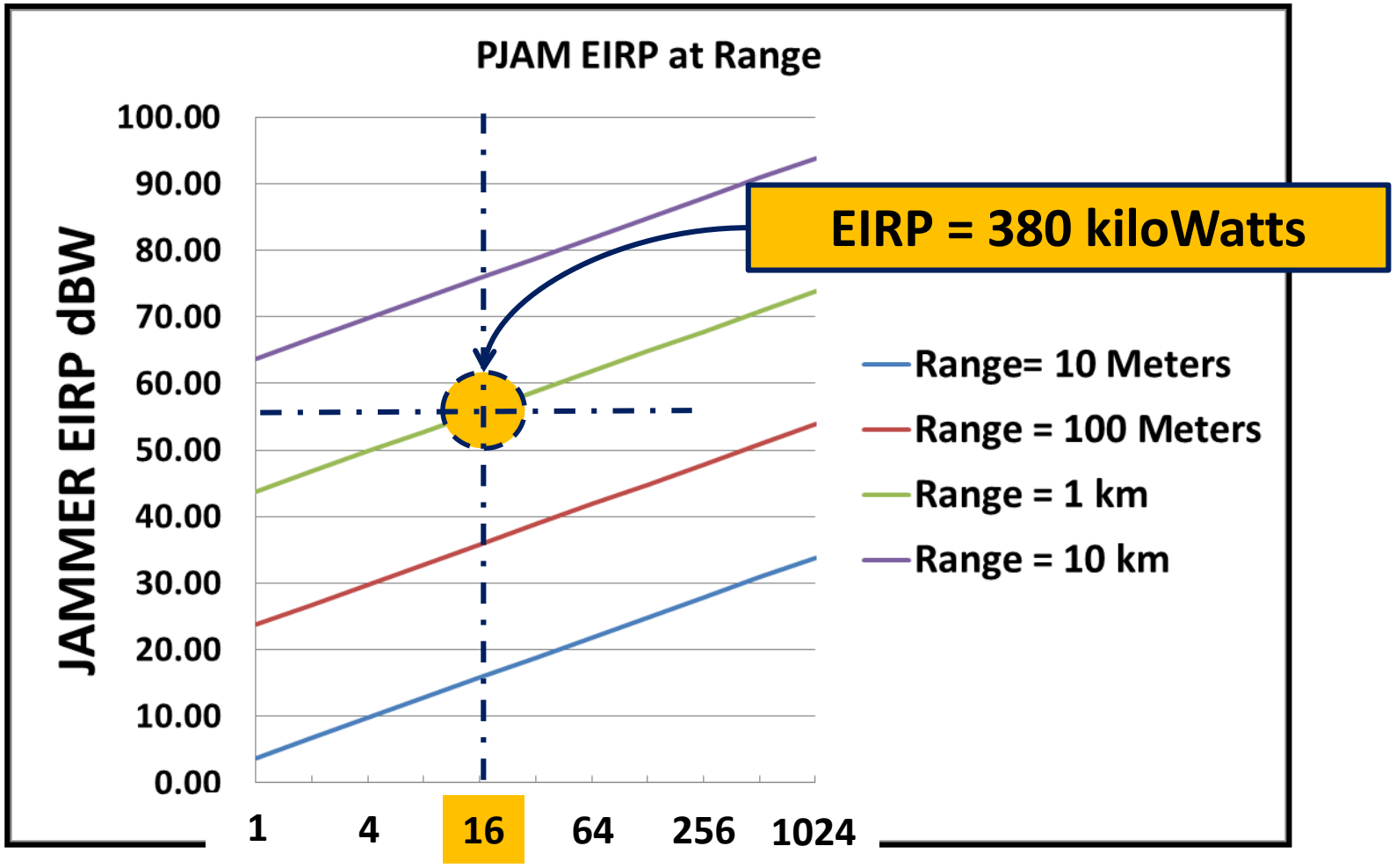


PMA4-33GLN+

CASE STYLE: DG1886
PRICE: $6.95 ea. QTY. (20)

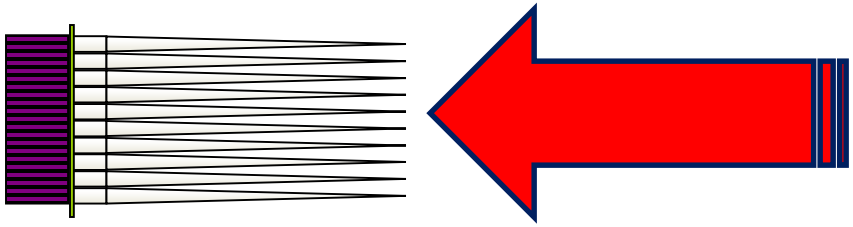
Product Features

- Low Noise figure, 0.54 dB at 900 MHz
- High IP3, 40 dBm typ. at 900 MHz
- High Pout, P1dB 22.6 dBm typ. at 900 MHz
- High Gain, 39 dB at 900 MHz



Partition factor, p, for a fixed aperture of 16 (in)^2

p = 256



ADC Full-Scale Input:
W_{XIS} = -3.16 dBW/meter^2

JAMMER at 10 km

$EIRP_{(Jammer\ at\ 10km)}$ = -3.16 dBW + 80 dB +11dB = 87.84 dBW

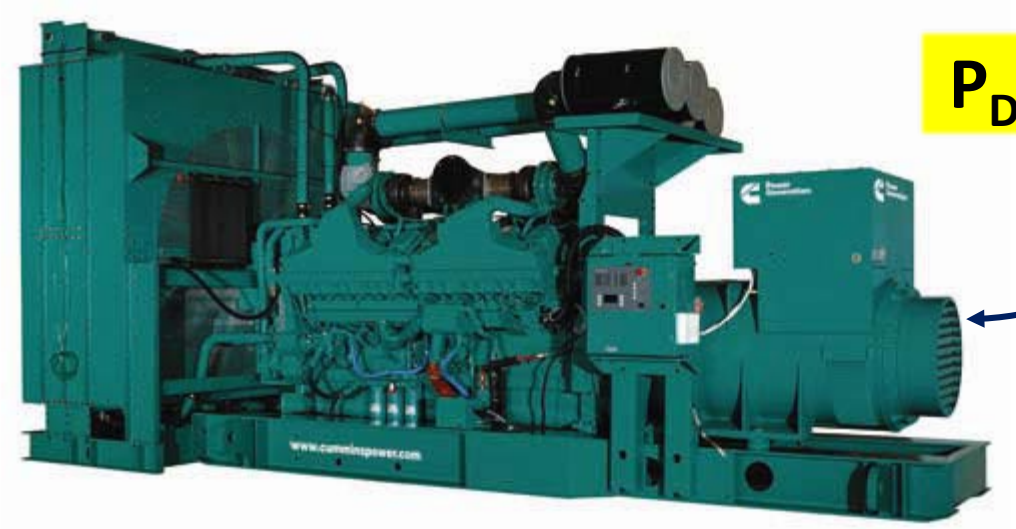
Assume JAMMER Antenna Gain = 24.84 dB

Then, the required JAMMER Output Power = 63 dBW or 2,000,000 Watts (2 Mega-Watts)

Dr. Donald H. Steinbrecher
Donald.steinbrecher@navy.mil

Cummins 2,000 kW ready to go! Call for current pricing.

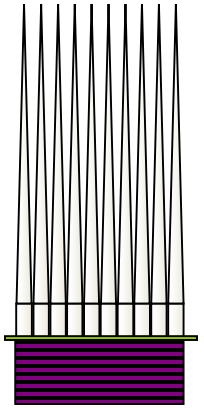
Also check out Detroit MTU generators

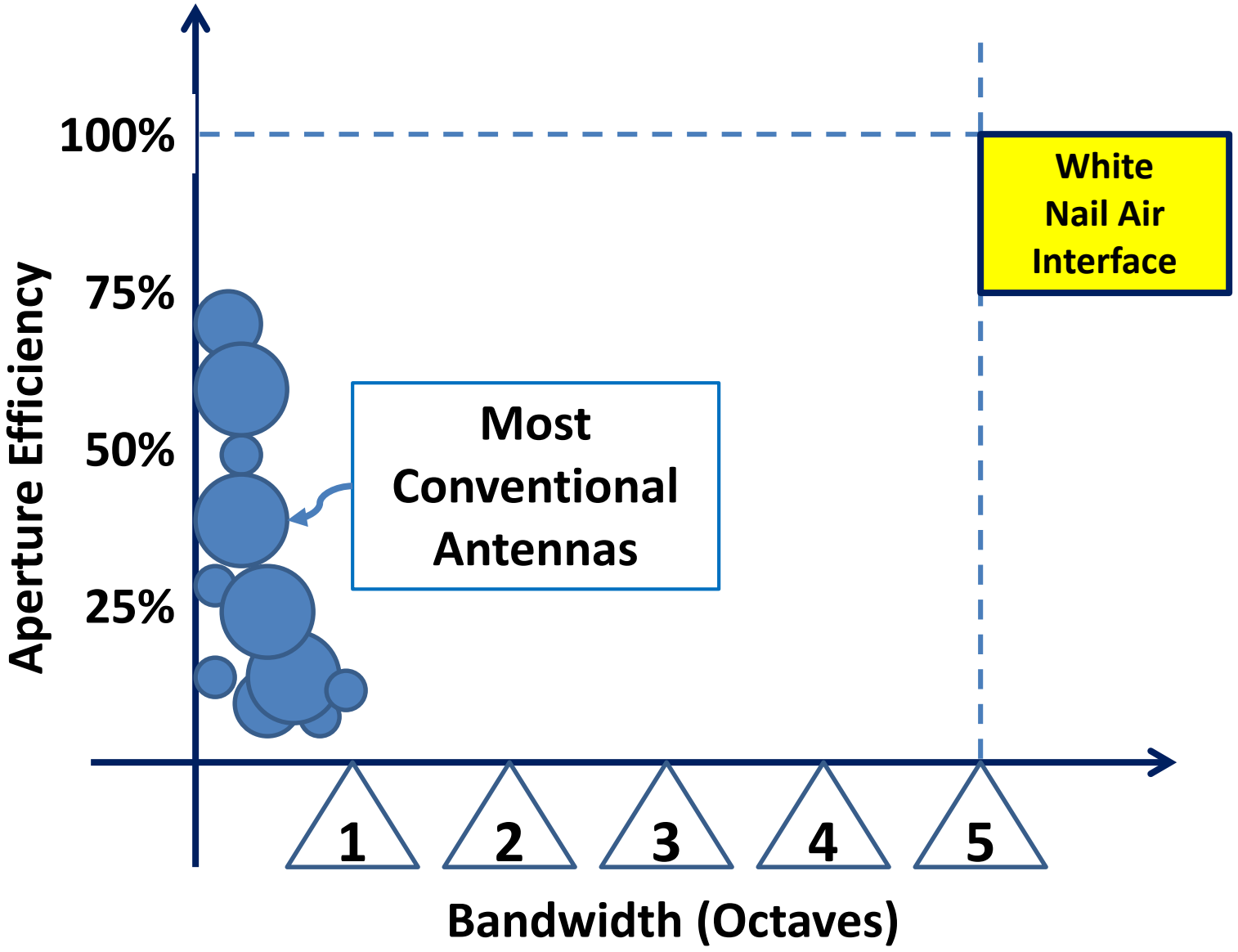


$P_{DieselGen}$ = 63 dBW

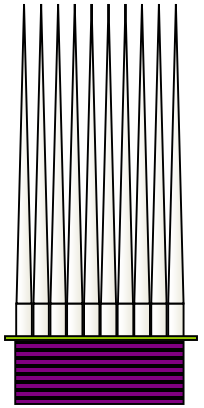
Brand new with manufacturer's warranty. On the ground ready for immediate delivery. Call for shipping Quote. Professional installation available anywhere in the world.

http://www.hardydiesel.com/diesel-generators/cummins-2-mw.html

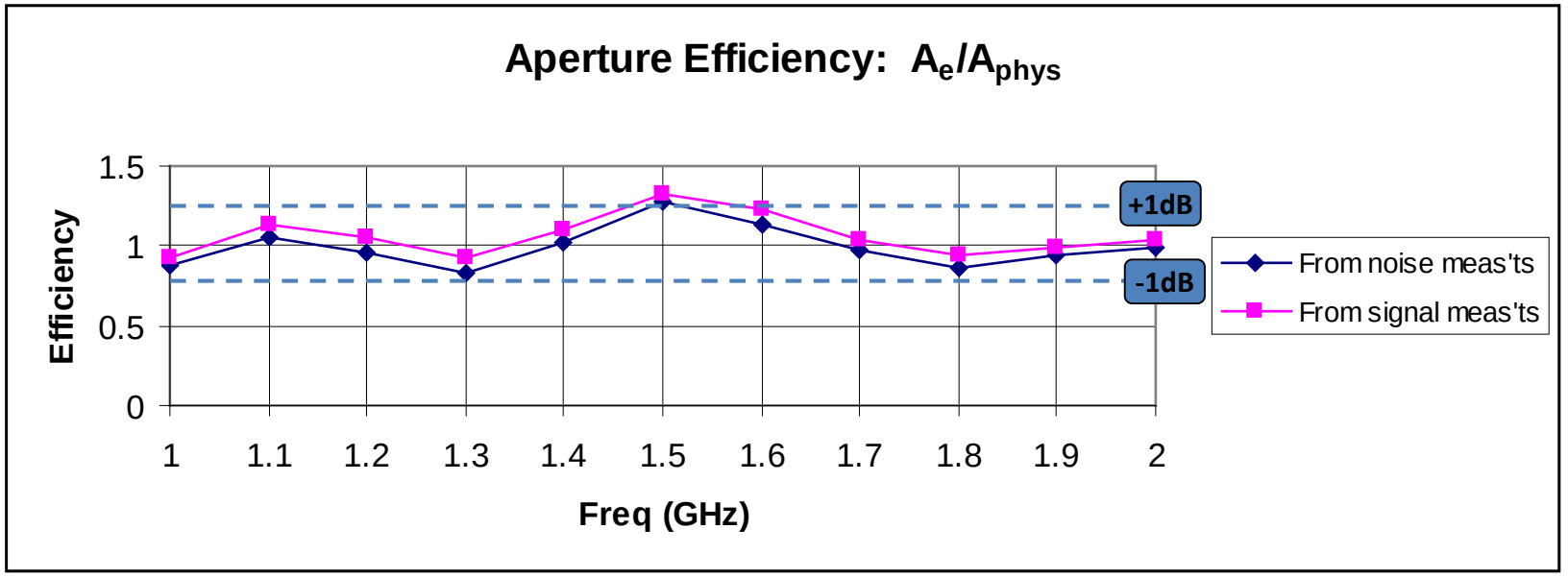




Aperture Efficiency Attributes

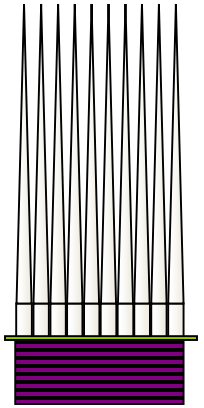


- Approaches 100%
- Virtually Frequency Independent
- Effective Aperture can be made as large as desired

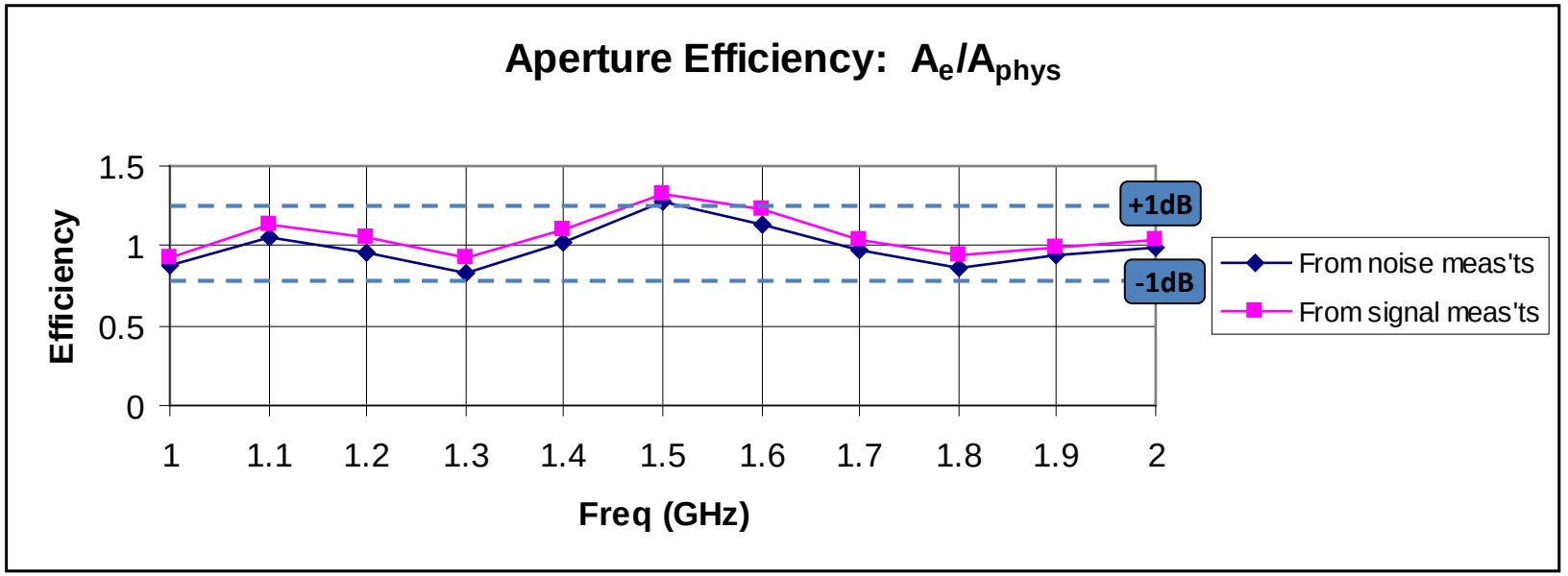


Dr. Donald H. Steinbrecher
Donald.steinbrecher@navy.mil

Aperture Efficiency Attributes

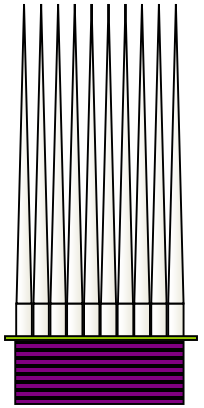


- Approaches 100%
- Virtually Frequency Independent
- **White Nail Effective Aperture can be made as large as desired**

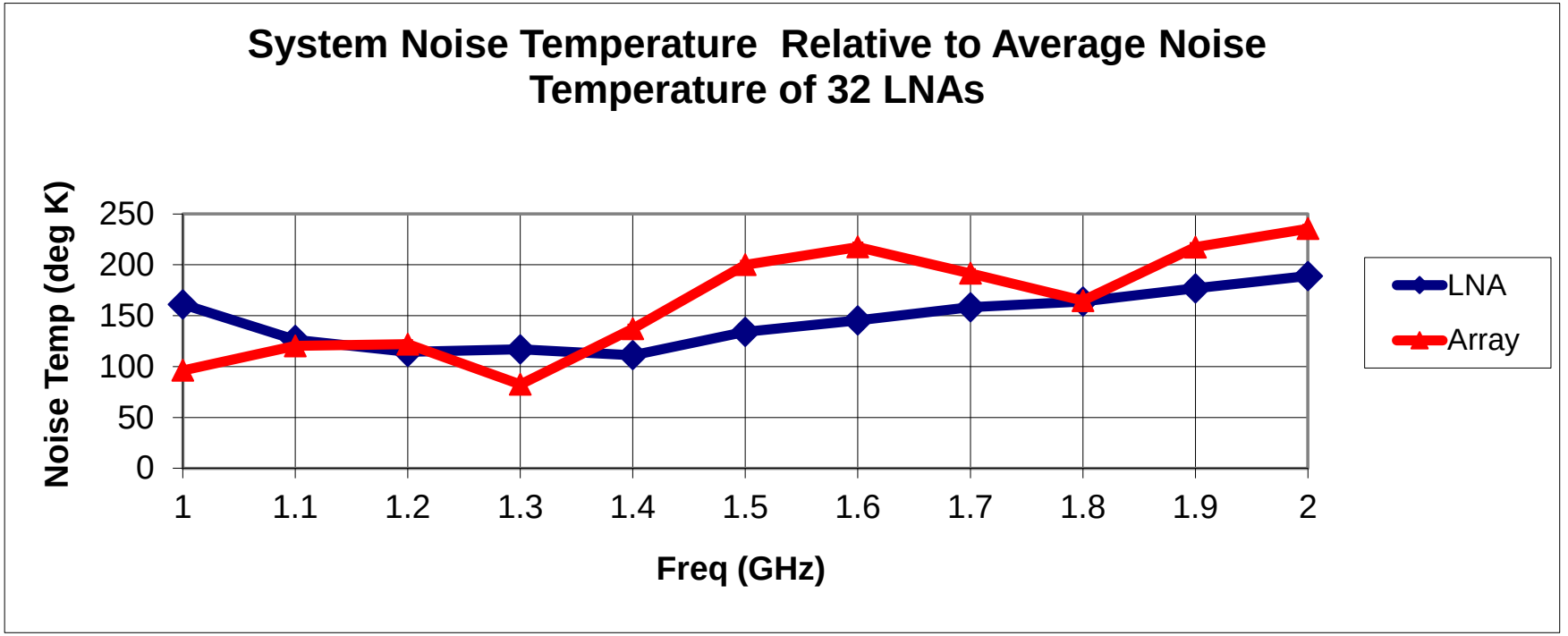


Dr. Donald H. Steinbrecher
Donald.steinbrecher@navy.mil

System Noise Temperature Attributes

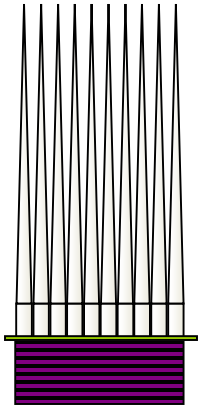


- Partitioned aperture preserves noise temperature of LNA
- Small additional temperature contribution from aperture losses
- Essentially frequency independent system noise temperature

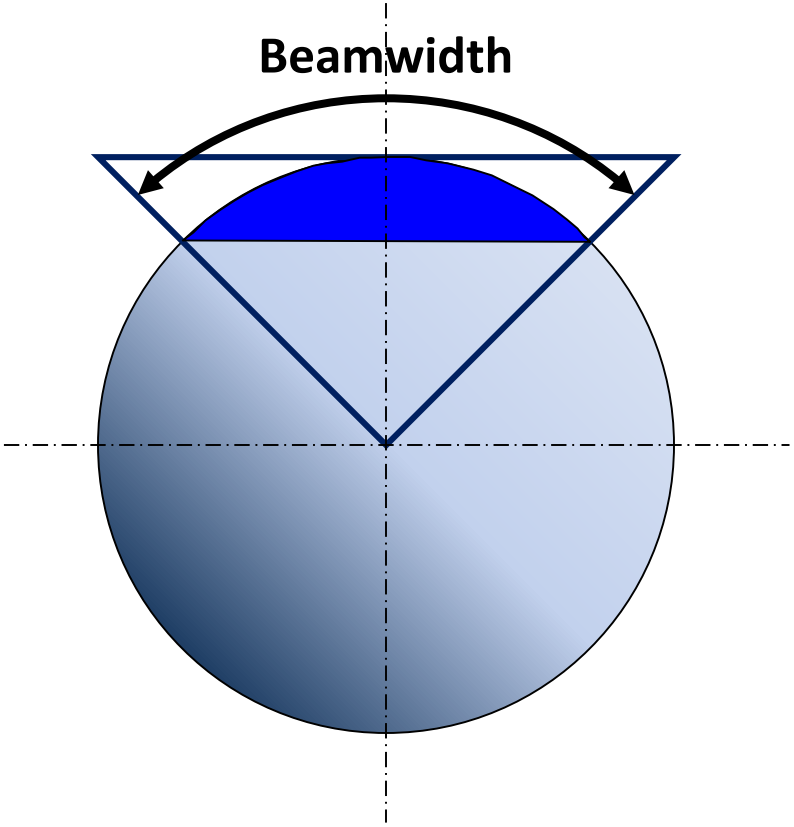


Dr. Donald H. Steinbrecher
Donald.steinbrecher@navy.mil

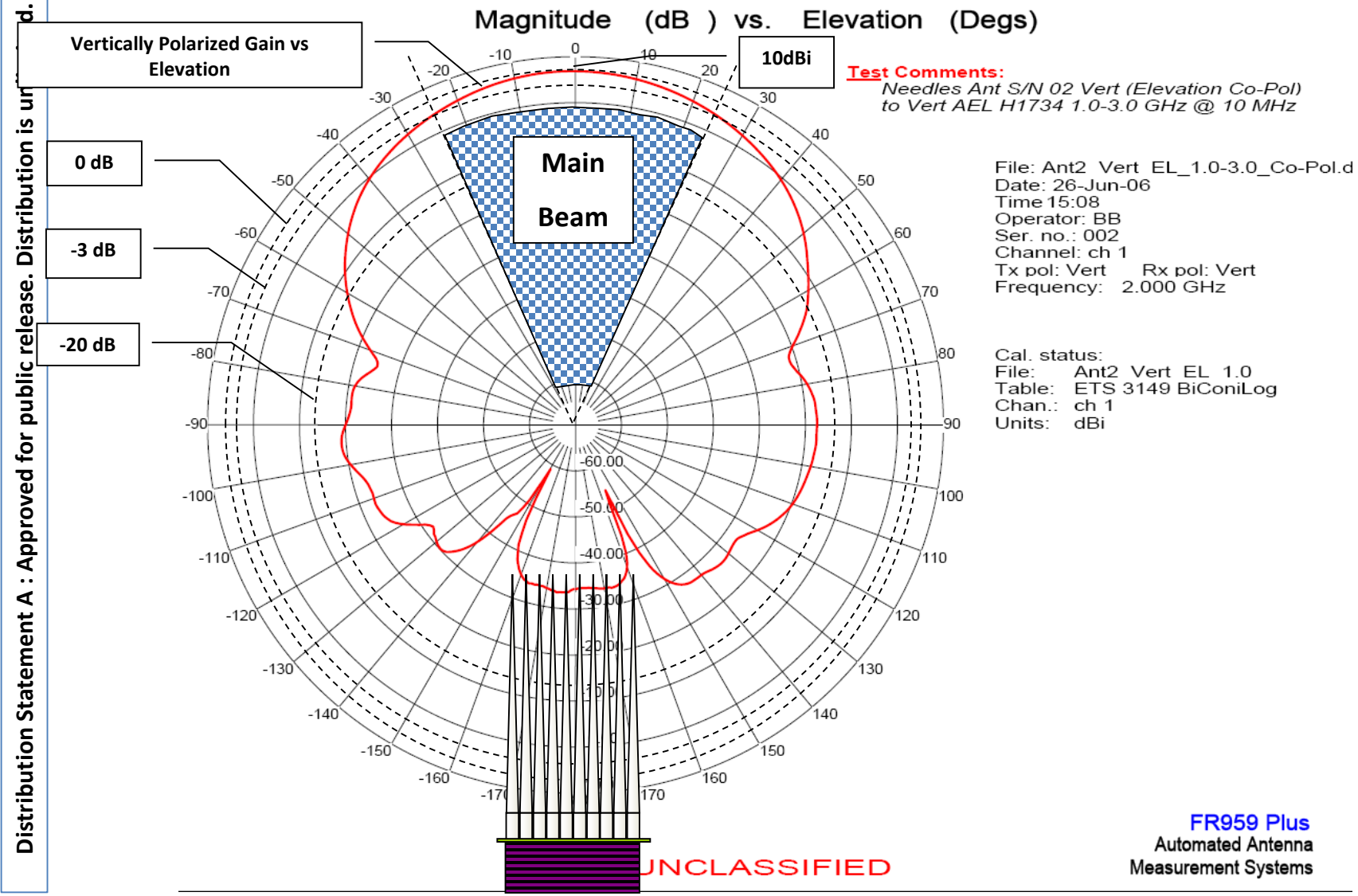
Theoretical Beamwidth for an Ideal Antenna



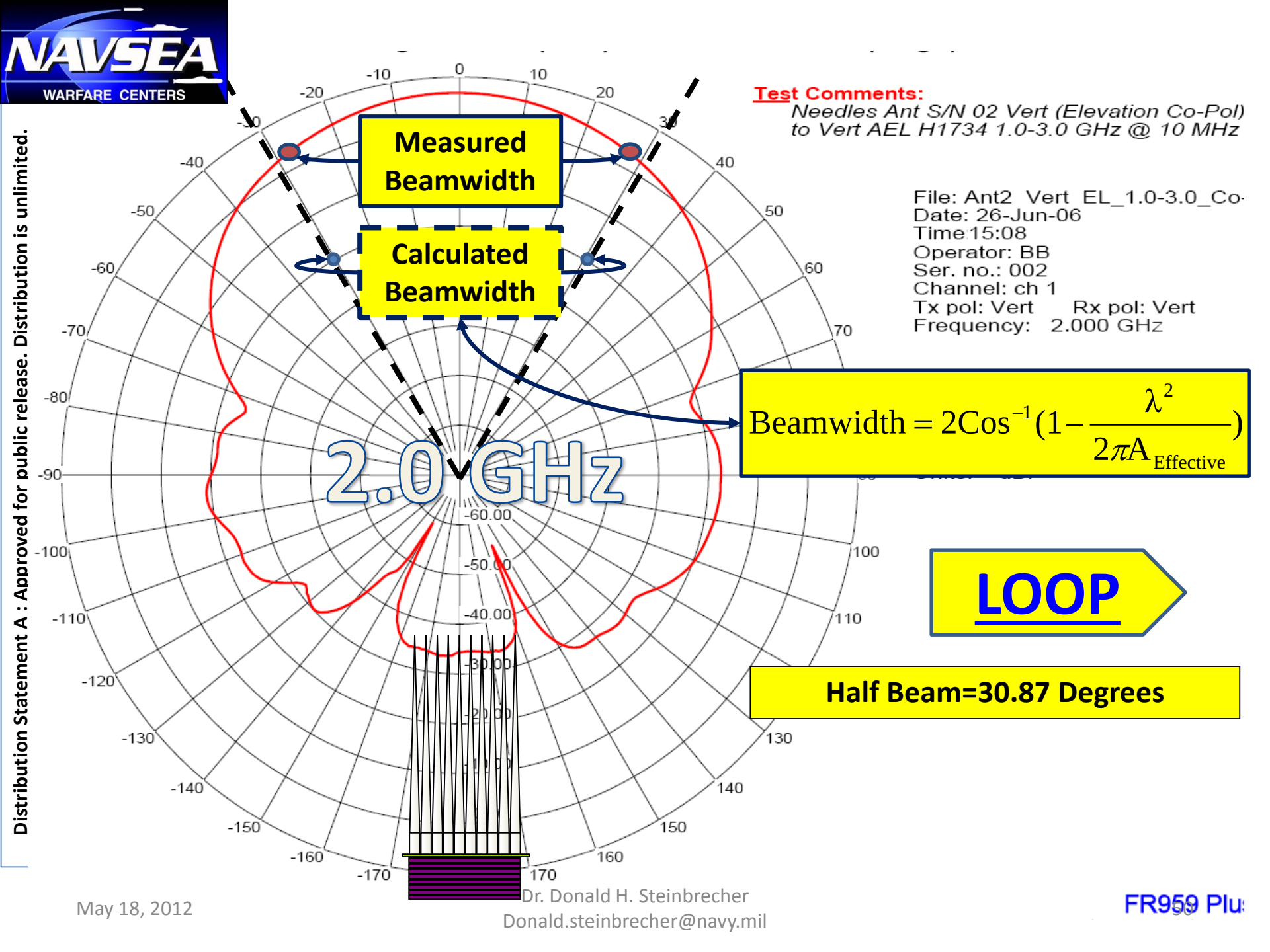
$$\text{Beamwidth} = 2\text{Cos}^{-1}\left(1 - \frac{\lambda^2}{2\pi A_{\text{Effective}}}\right)$$



Air Interface Eplane Functionality at 2-GHz



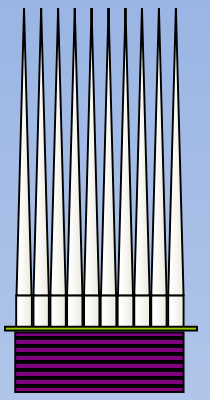
Dr. Donald H. Steinbrecher
Donald.steinbrecher@navy.mil



Dr. Donald H. Steinbrecher
Donald.steinbrecher@navy.mil

The White Nail Innovation Project

OVERVIEW 28 APRIL 2014

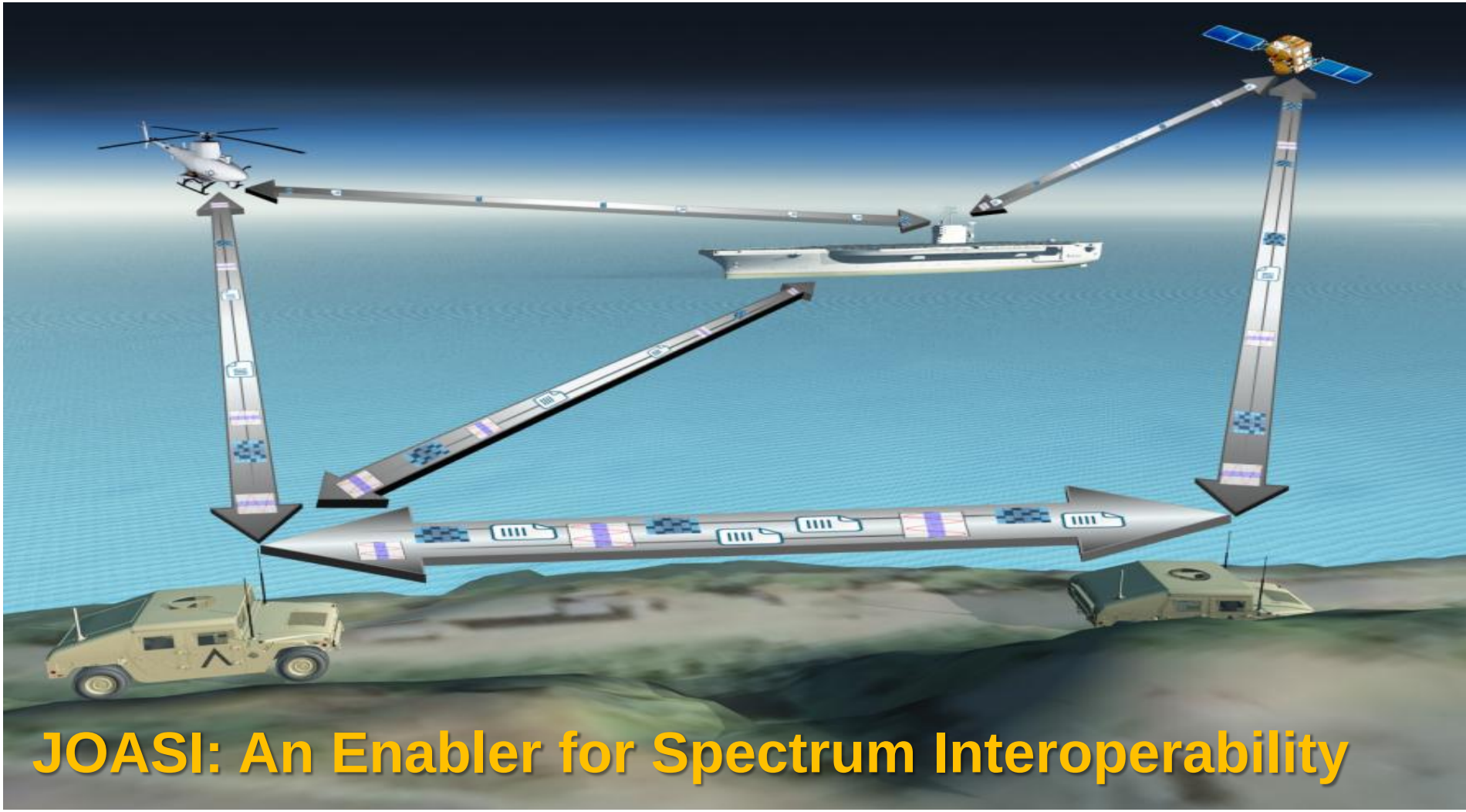


SOMEDAY…

…partitioned apertures, like White Nail, will be commonplace in digitally enabled wireless EM systems.

Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil

And Maybe Wireless Data Exchange Will Evolve to Support Future EM Maneuver Warfare Themes?



Dr. Donald H. Steinbrecher, Chief Scientist
donald.steinbrecher@navy.mil