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"

"Future conflicts will be won in a new arena—that of the electromagnetic spectrum and cyberspace. We must merge, then master those realms."

…Admiral Jonathan Greenert, Chief of Naval Operations

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Israeli Air Force F-15I Ra’am
Eight Aircraft Participated

Israel>>>>Syria
Operation Orchard
Just after (local) midnight on September 6, 2007

The Wireless CYBER Battlespace

It is widely believed that this action was successful because the Israelis triggered a secret kill-switch installed in the Syrian air defense system.

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2,500 Ordered

Cost: $300 Billion

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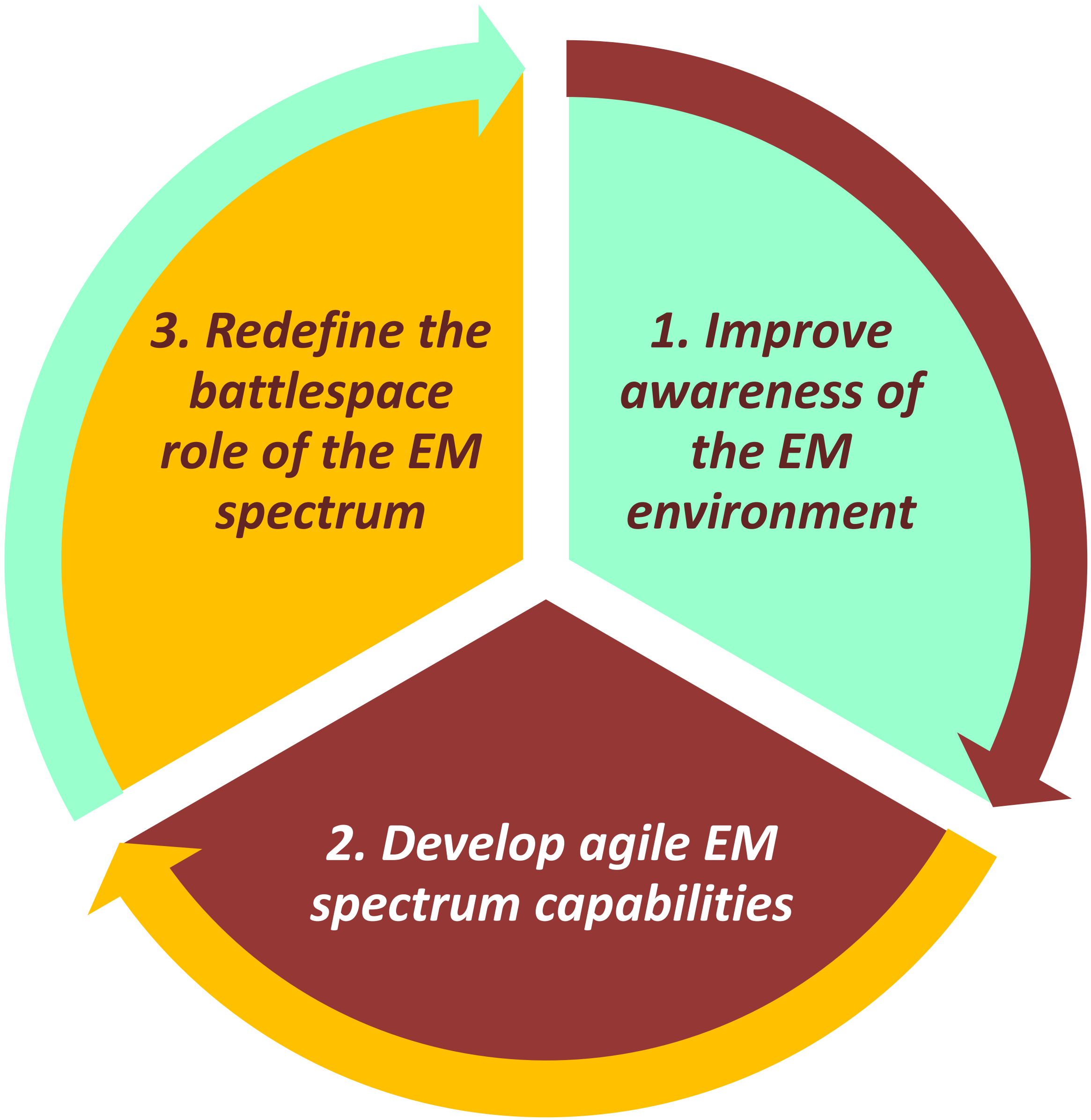

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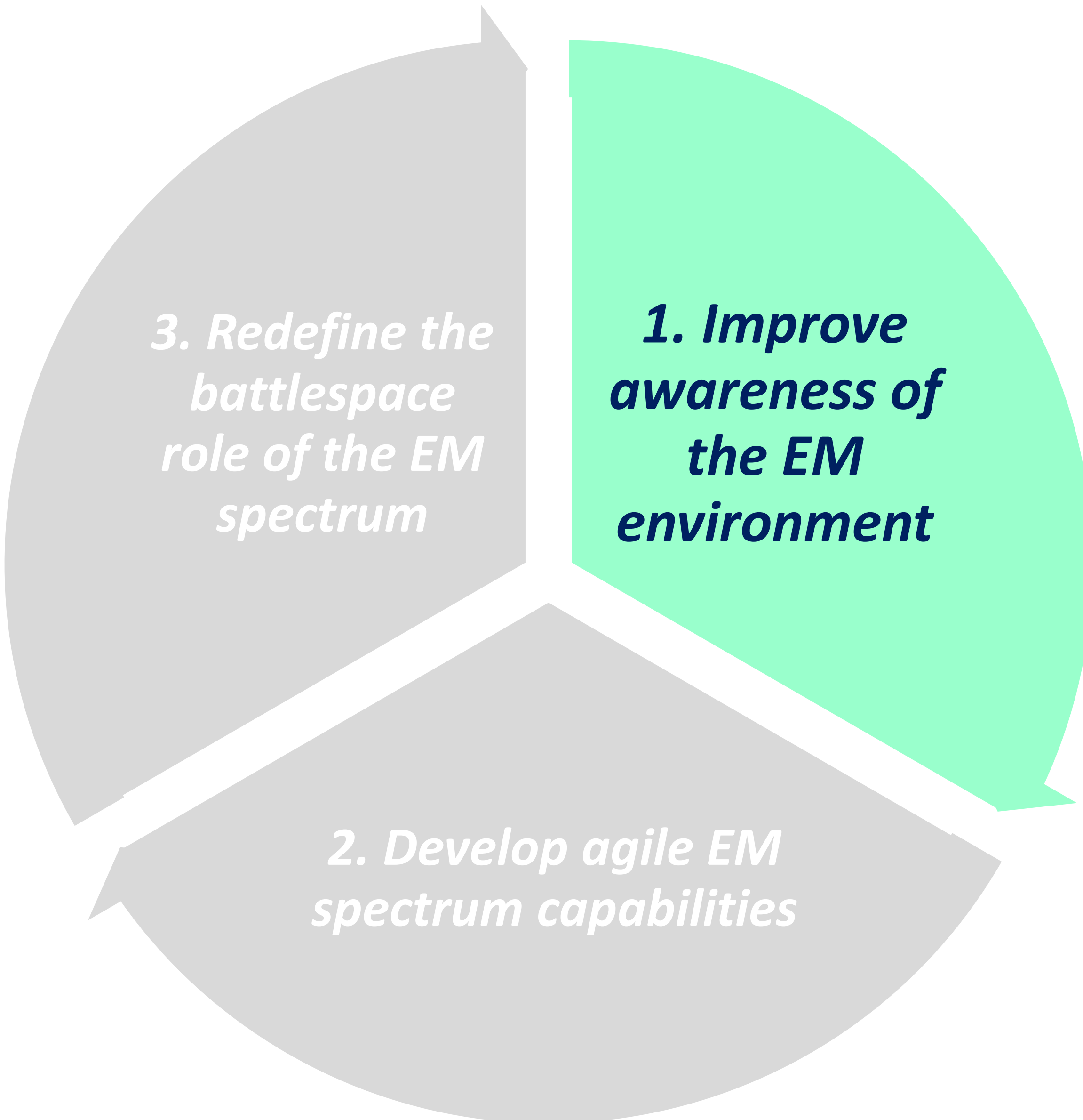
1. Improve awareness of the EM environment
2. Develop agile EM spectrum capabilities
3. Redefine the battlespace role of the EM spectrum

Digital Signals Intercept Systems with

→ **Wide Signals Intercept band,**

→ **High Dynamic-Range,**

→ **High Jammer Immunity, and**

→ **Able to Tolerate EMP Assaults.**

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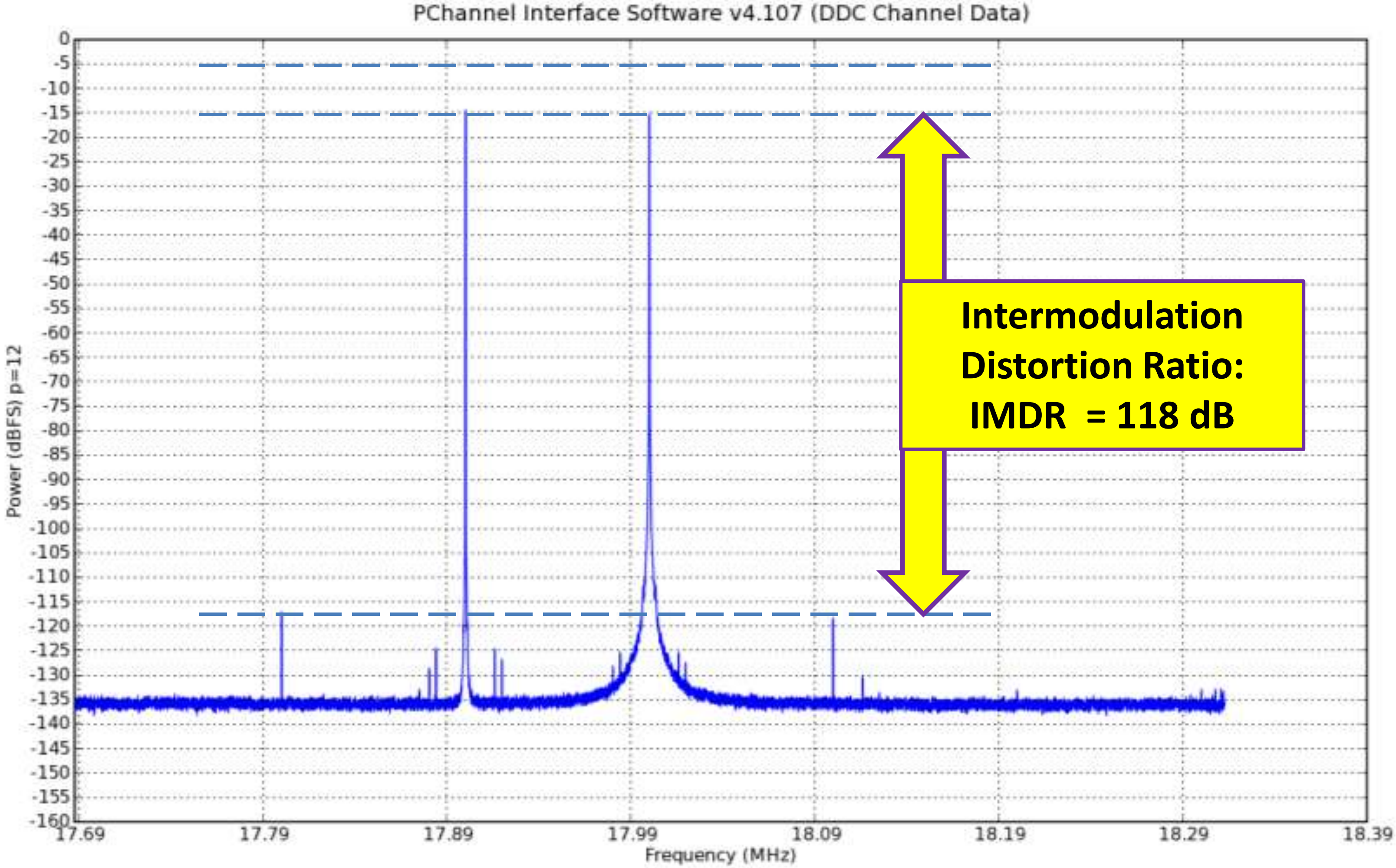
pChannel Signal Input Level = -5 dBm/tone
Input Third-Order Intercept: TOI = +54 dBm



Two-tone response of a pChannel digital signals acquisition system with p = 12

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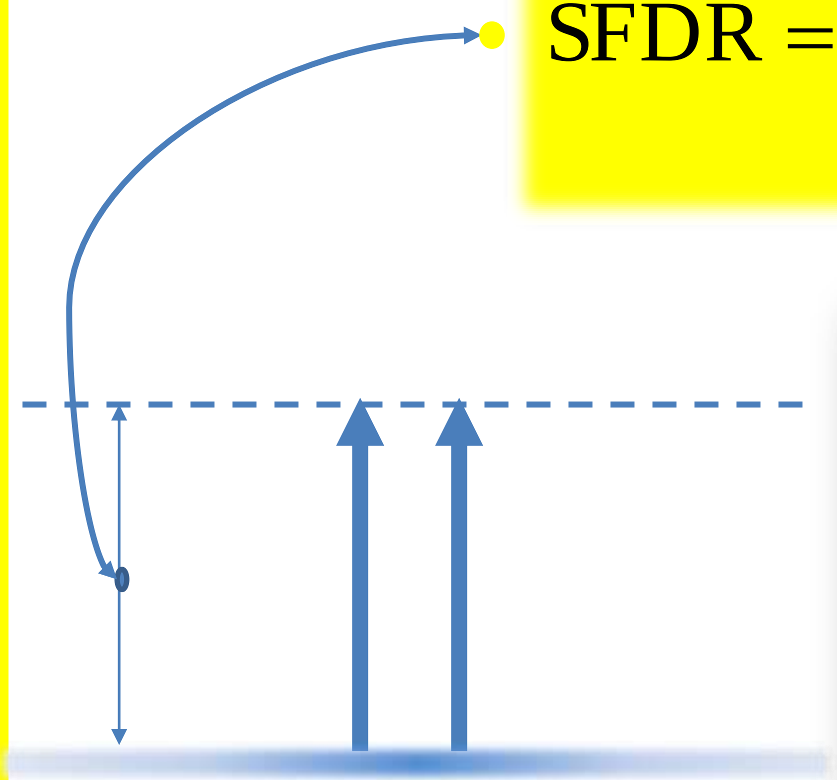
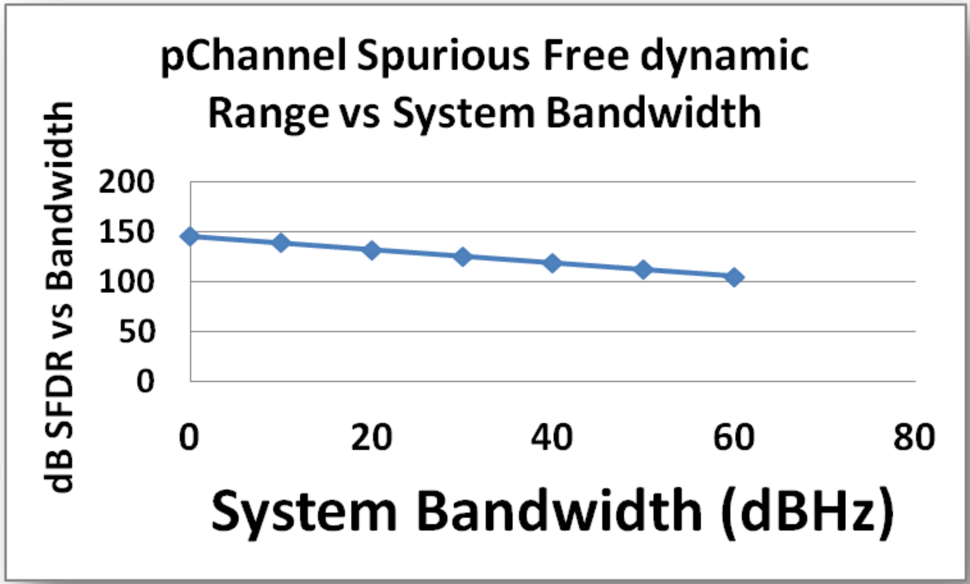
$$\mathrm{SFDR} = \left[\frac{\mathrm{I}^{3}}{kT_0FB}\right]^{\left(\frac{2}{3}\right)}$$





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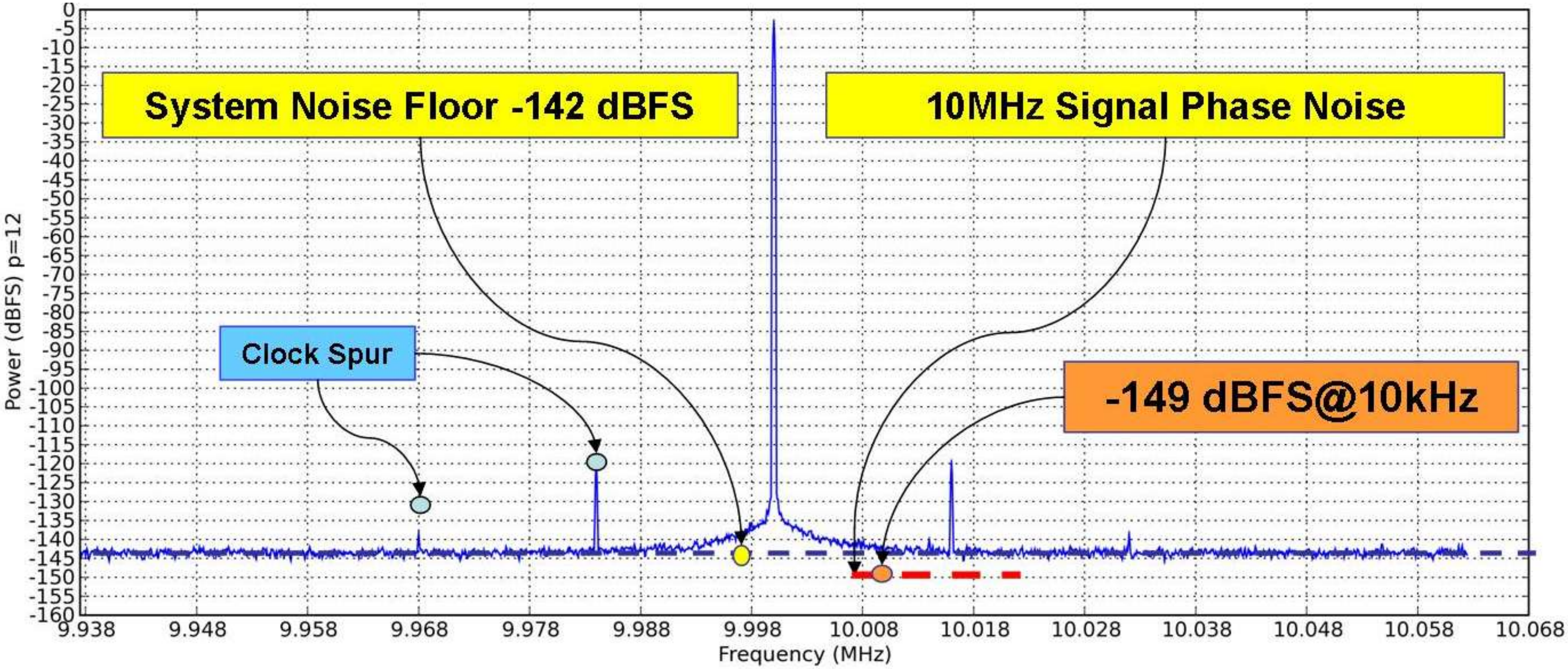
p =12 Spectrum Resolution Attributes

- Very low phase noise reduces reciprocal mixing
- Very high spurious-free dynamic range
- Instantaneous bandwidth limited by ADC Nyquist bandwidth



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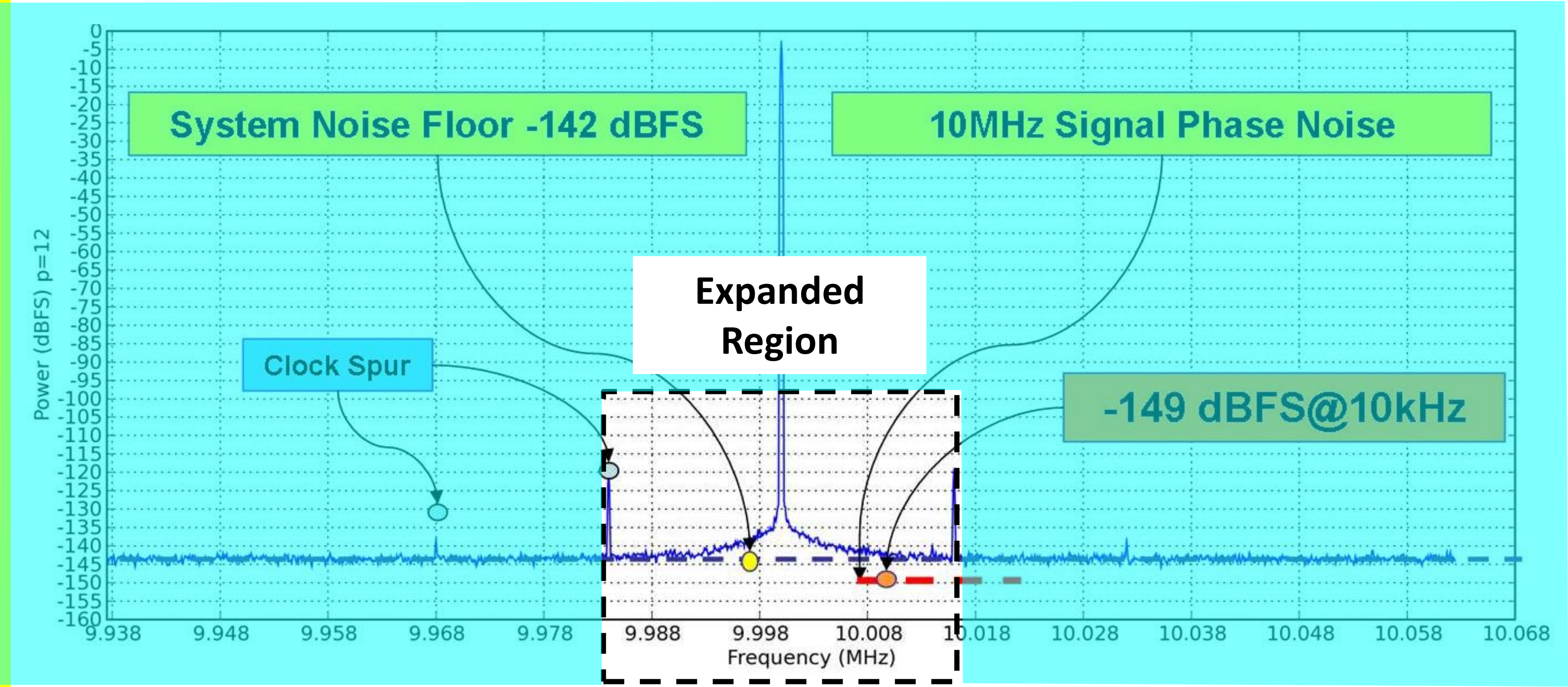

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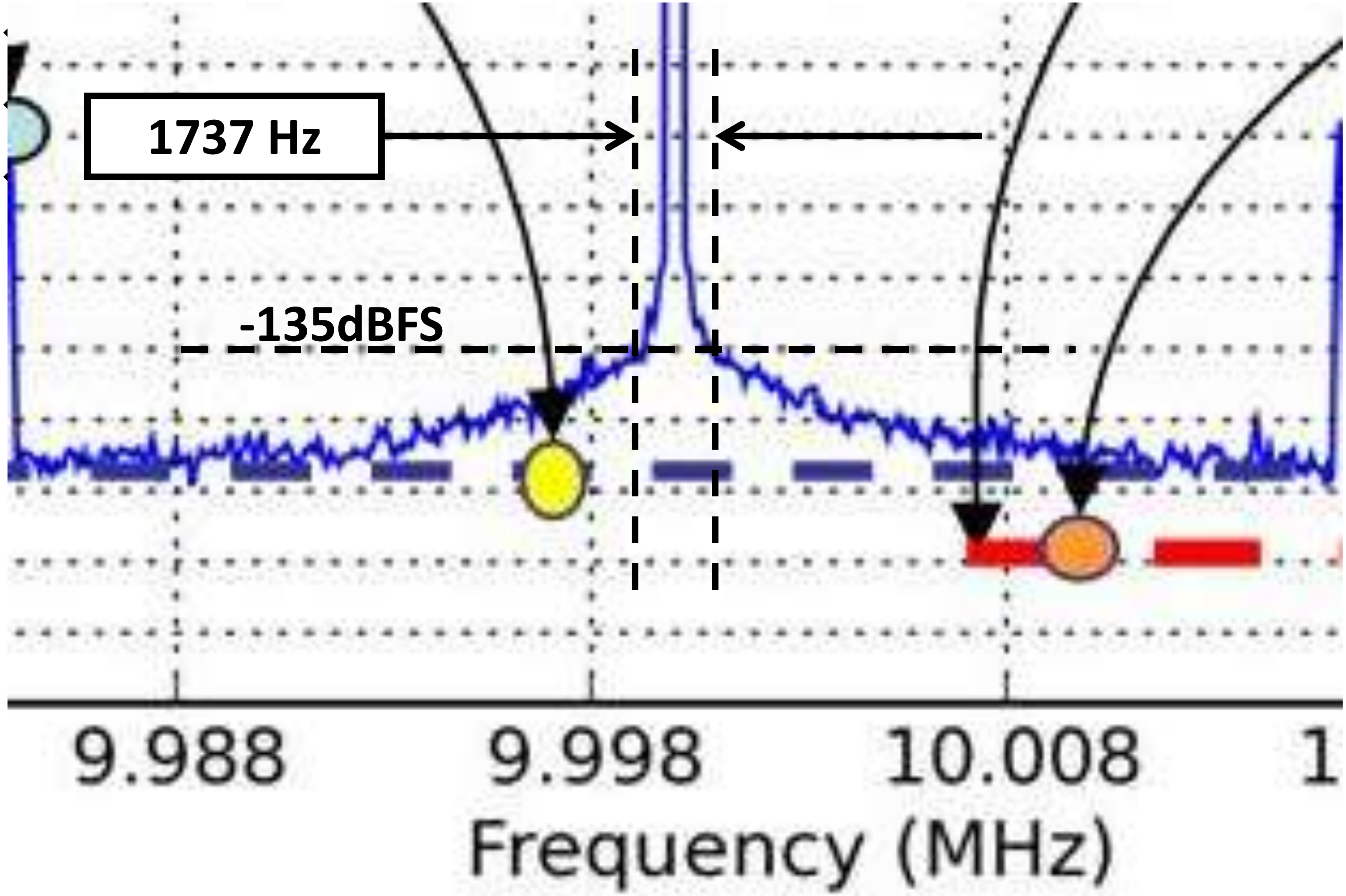

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Properties of an Ideal Digital Signals Acquisition System

Before a SMART digital algorithm can be effectively applied, <u>ALL</u> of the EM signals within the system frequency aperture must be digitally captured and transferred into the digital domain.

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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.**

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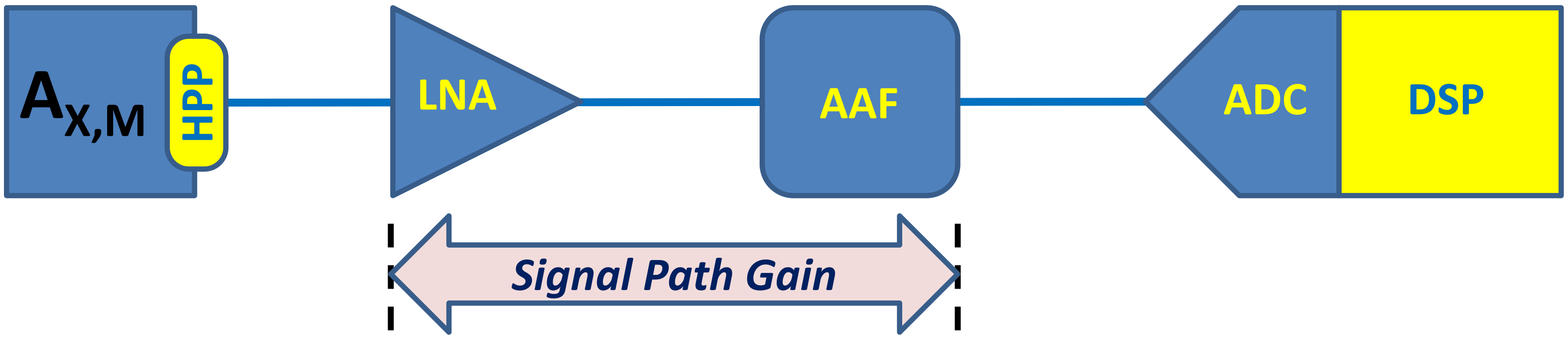
Signal Path GAIN Fundamental Limit



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

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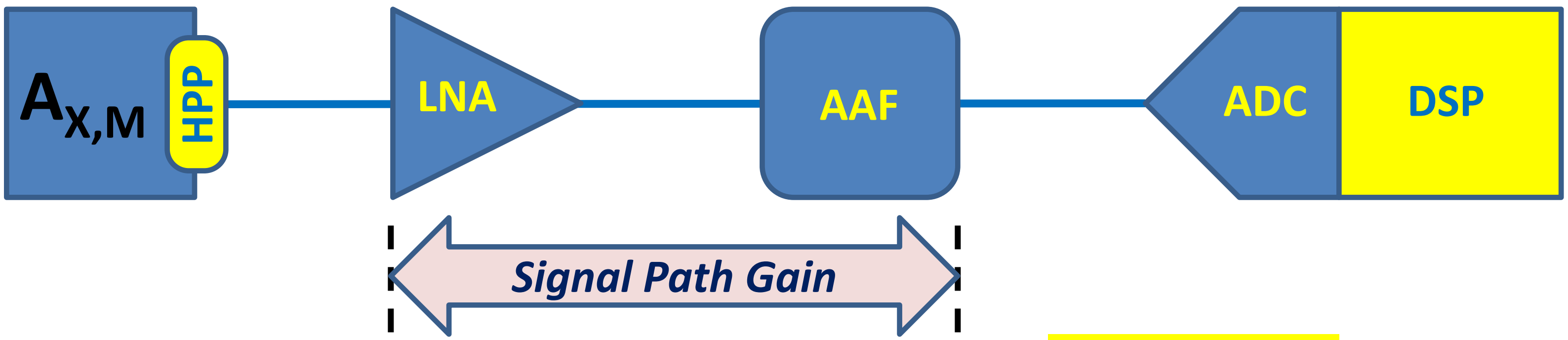
Signal Path GAIN Fundamental Limit



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

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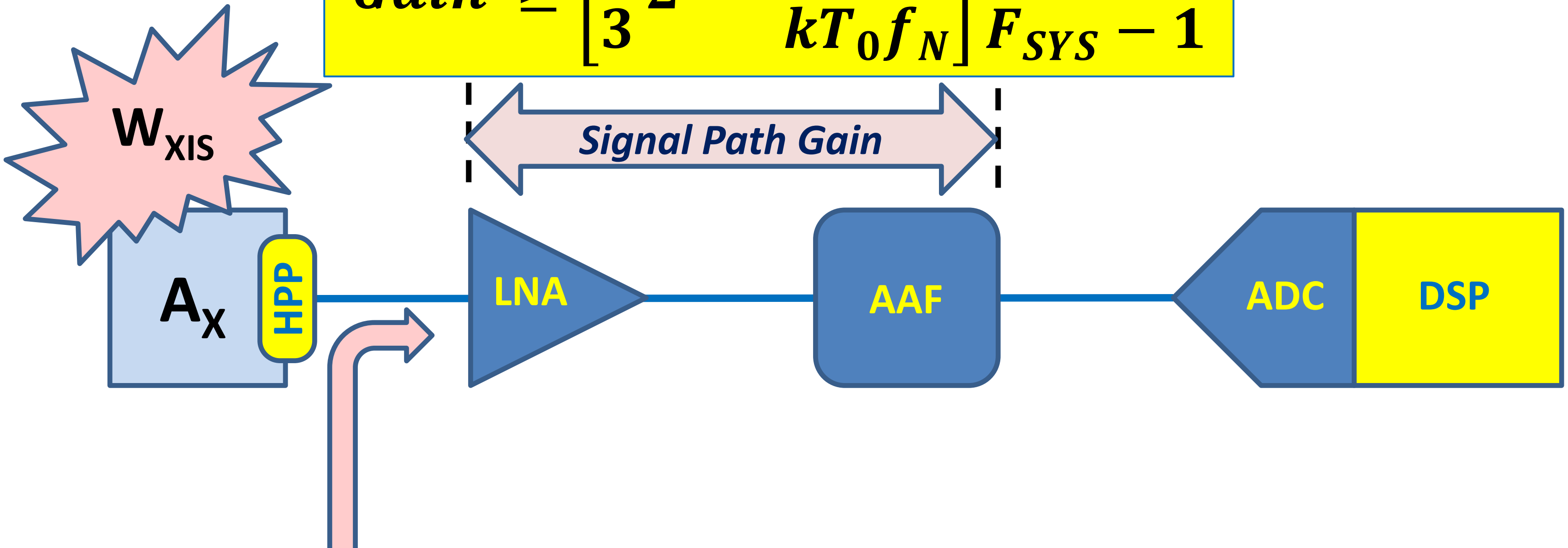

$$P_{MAX} = \frac{P_{FSAO}}{Gain} = \left[\frac{3}{2} 2^{2N} kT_0 f_N\right](F_{SYS} - 1) = W_{XIS} A_x$$

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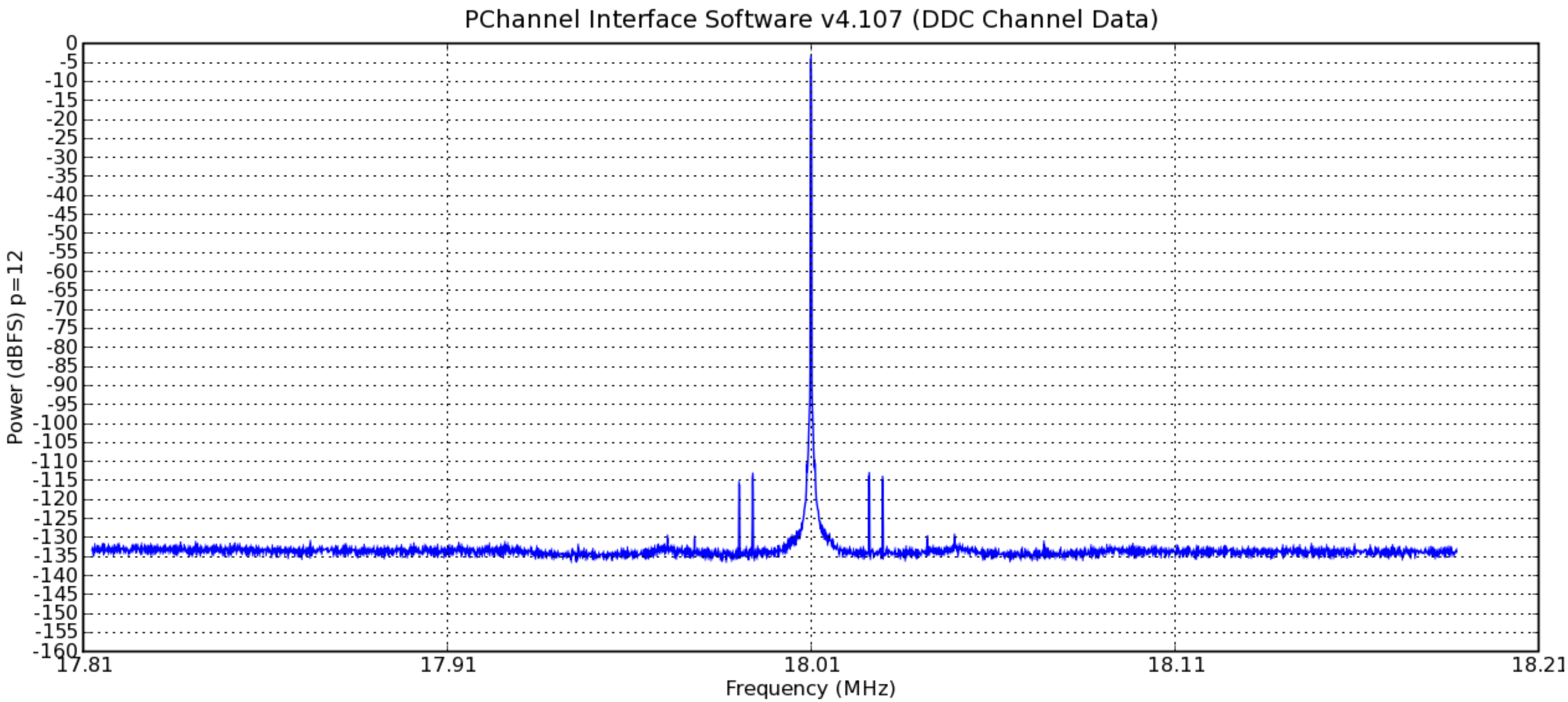
$P < P_{MAX}$



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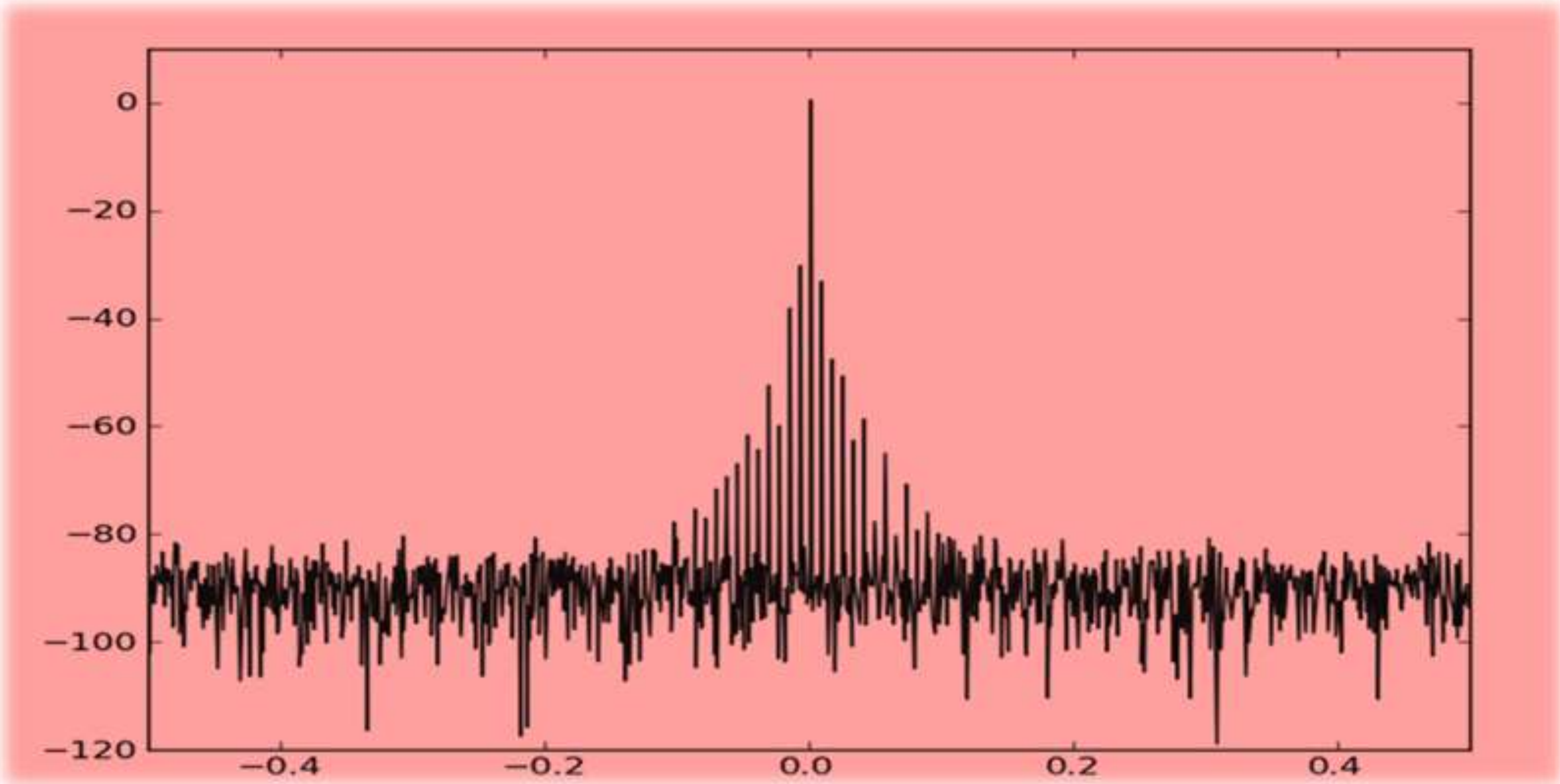
$P > P_{MAX}$



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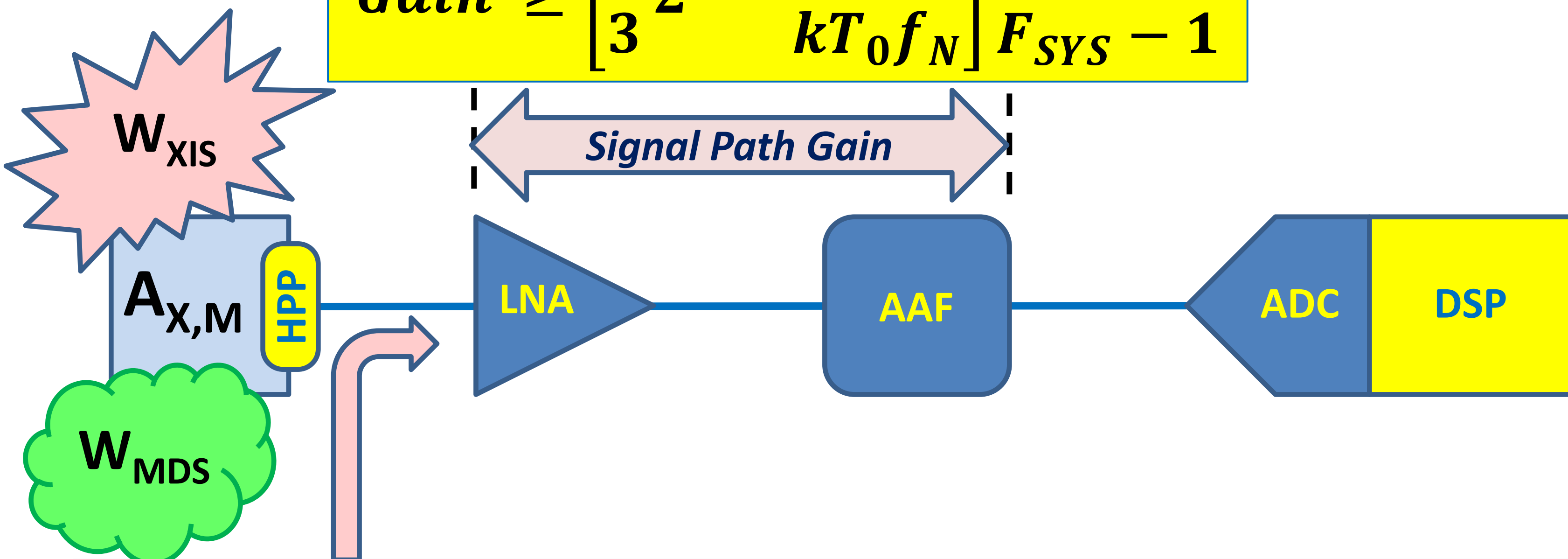
Signal Path GAIN Fundamental Limit

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



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

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

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FUNDAMENTAL LIMITS

$$P_{MAX} = \frac{P_{FSAO}}{Gain} = \left[\frac{3}{2} 2^{2N} k T_0 f_N\right](F_{SYS} - 1) = W_{XIS} A_X$$

$$P_{MDS} = k T_0 F_{SYS} B_{MDS} = W_{MDS} A_M$$

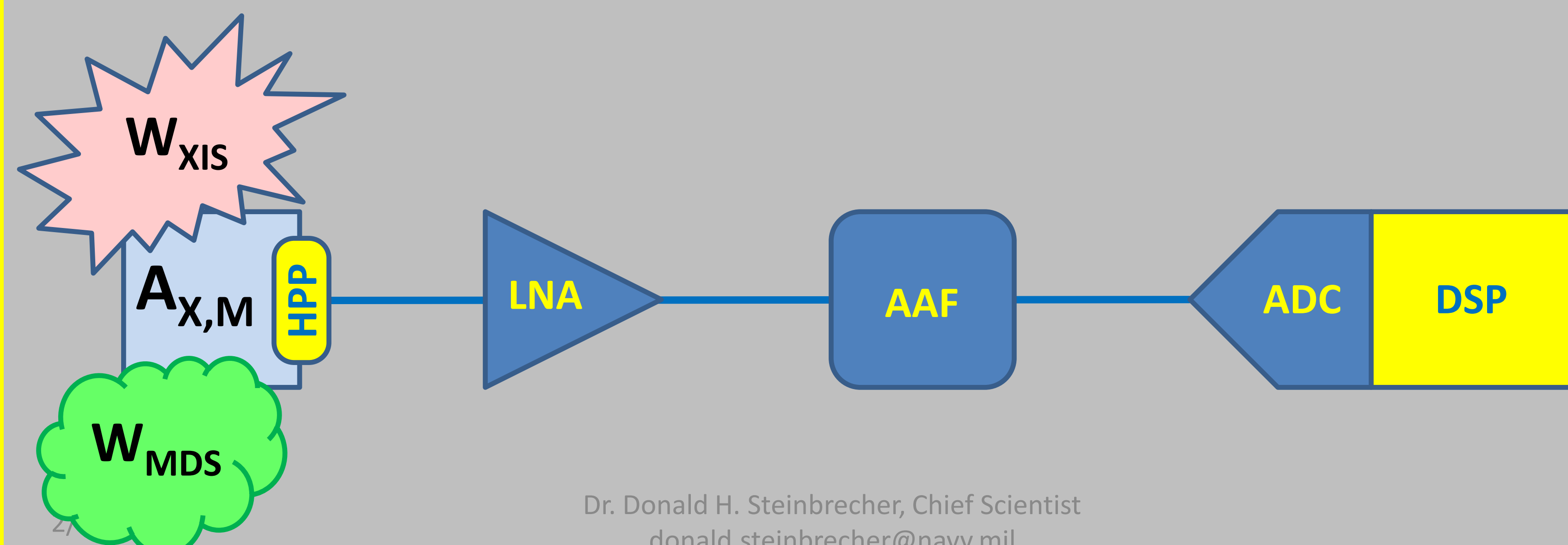
$$SDR = \frac{3}{2} 2^{2N} \frac{f_N}{B_{MDS}} \frac{F_{SYS}}{F_{SYS} - 1}$$

FUNDAMENTAL LIMITS

$$P_{MAX} = \frac{P_{FSAO}}{Gain} = \left[\frac{3}{2} 2^{2N} k T_0 f_N\right](F_{SYS} - 1) = W_{XIS} A_X$$

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

$$p = \frac{A_M}{A_X} = \left[\frac{2}{3} 2^{-2N}\right] \left[\frac{B_{MDS}}{f_N}\right] \left[\frac{F_{SYS}}{F_{SYS} - 1}\right] \left[\frac{W_{XIS}}{W_{MDS}}\right]$$



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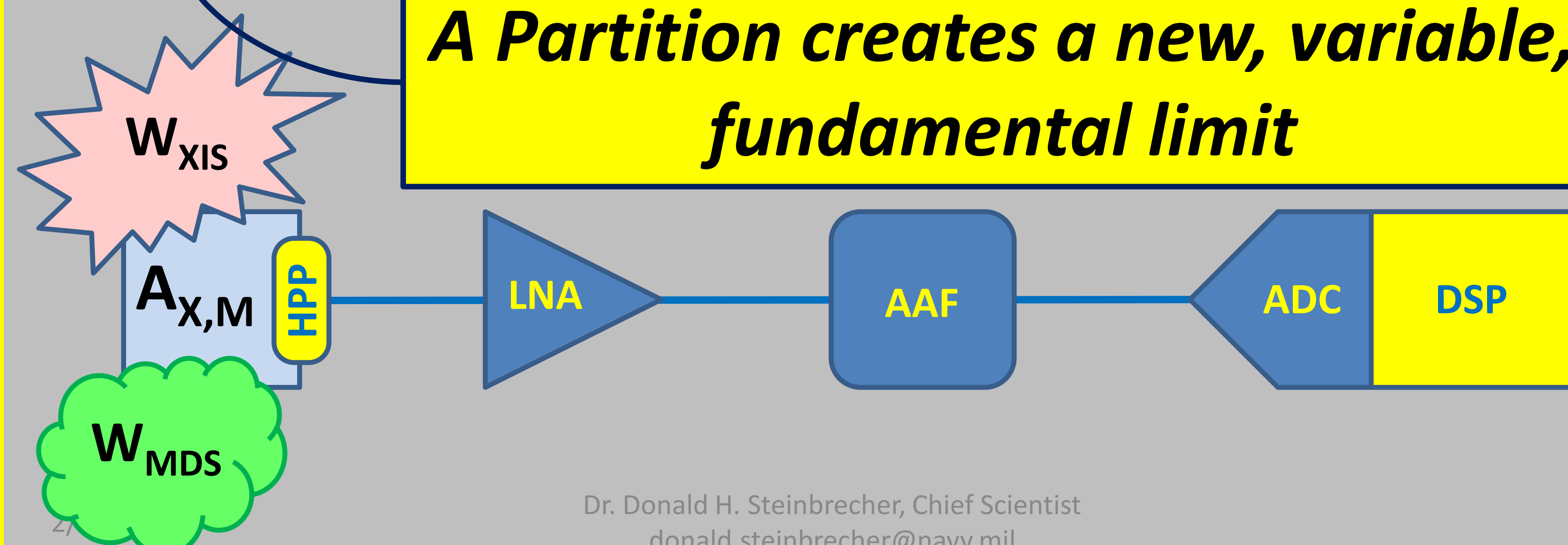
$$P_{MDS} = kT_0F_{SYS}B_{MDS} = W_{MDS}\,A_M$$

$$\mathbf{p} = \frac{A_M}{A_X} = \left[\frac{2}{3}2^{-2N}\right]\left[\frac{B_{MDS}}{f_N}\right]\left[\frac{F_{SYS}}{F_{SYS}-1}\right]\left[\frac{W_{XIS}}{W_{MDS}}\right]$$

A Partition creates a new, variable, fundamental limit



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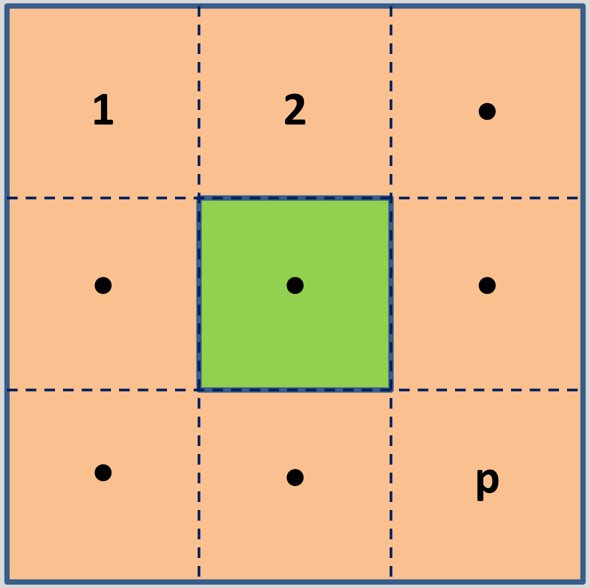
Definitions for an Ideal Partitioned Air Interface (Antenna)

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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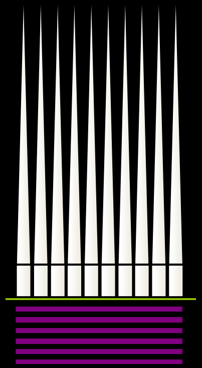
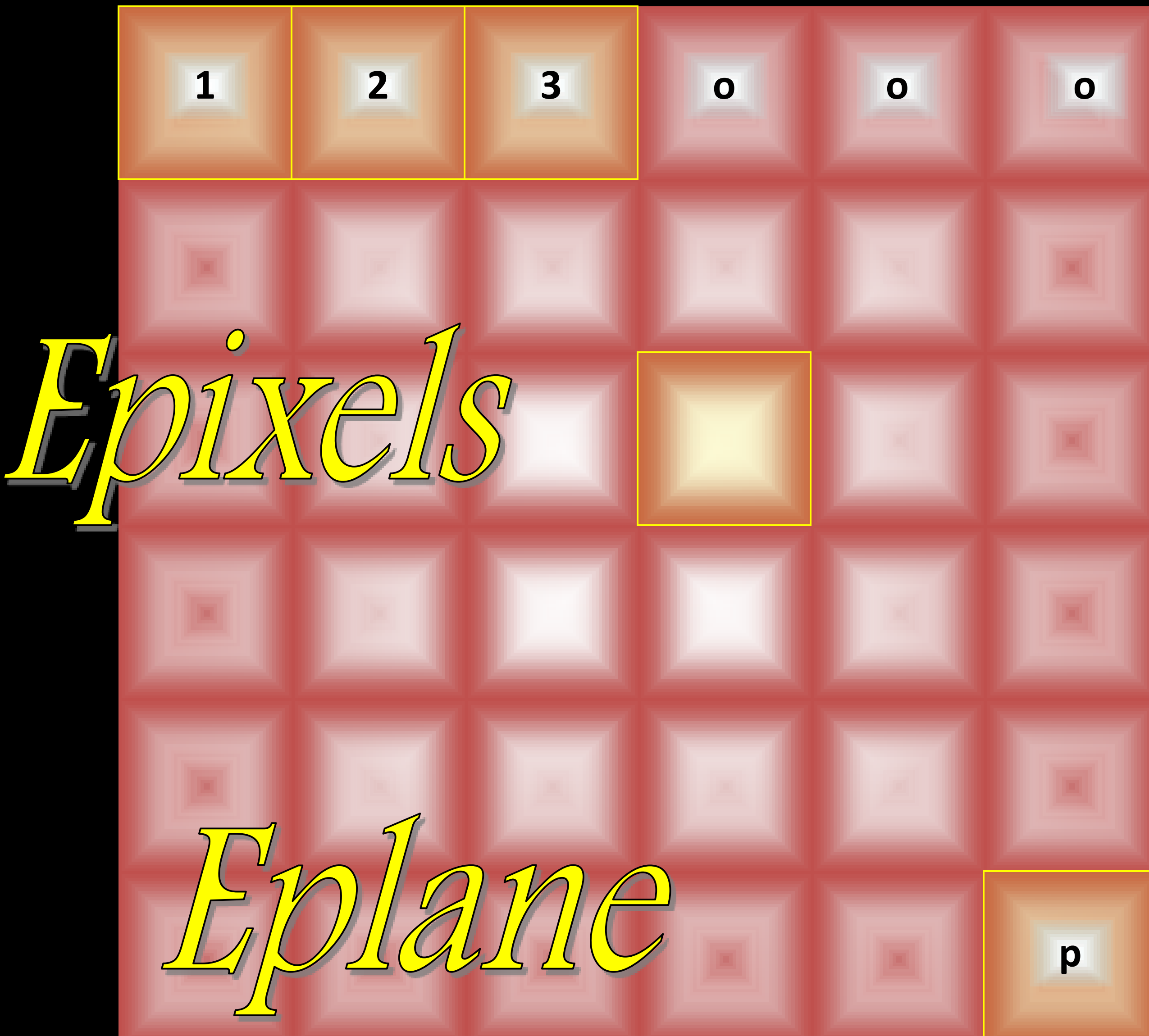
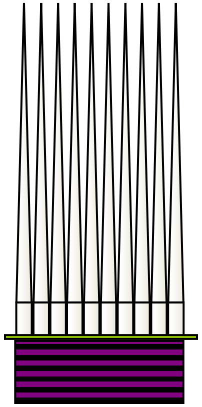
NAVSEA WARFARE CENTERS NEWPORT





$$p_{FundamentalLimit} \geq \left(\frac{2}{3}\right) 2^{-2N} \frac{B_{Detection}}{f_{Nyquist}} \frac{F_{System}}{\left(F_{System} - 1\right)} \frac{W_{MaximumInterferer}}{W_{MinDetSignal}}$$



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Energy Density of Maximum Interfering Signal (W/m²)

$$p_{FundamentalLimit} \geq \left(\frac{2}{3}\right) 2^{-2N} \frac{B_{Detection}}{f_{Nyquist}} \frac{F_{System}}{\left(F_{System} - 1\right)} \frac{W_{MaximumInterferer}}{W_{MinDetSignal}}$$

Energy Density of Minimum Detectable Signal (W/m²)

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Minimum Detection Bandwidth

System Noise Figure

$$p_{FundamentalLimit} \geq \left(\frac{2}{3}\right) 2^{-2N} \frac{B_{Detection}}{f_{Nyquist}} \frac{F_{System}}{\left(F_{System} - 1\right)} \frac{W_{MaximumInterferer}}{W_{MinDetSignal}}$$

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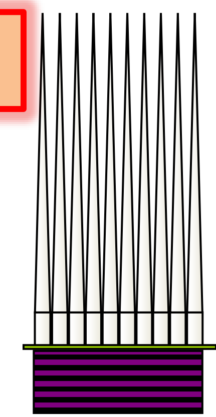
½ ADC Sample Rate

ADC Signal/Noise Ratio = (6.02N + 1.76) dB



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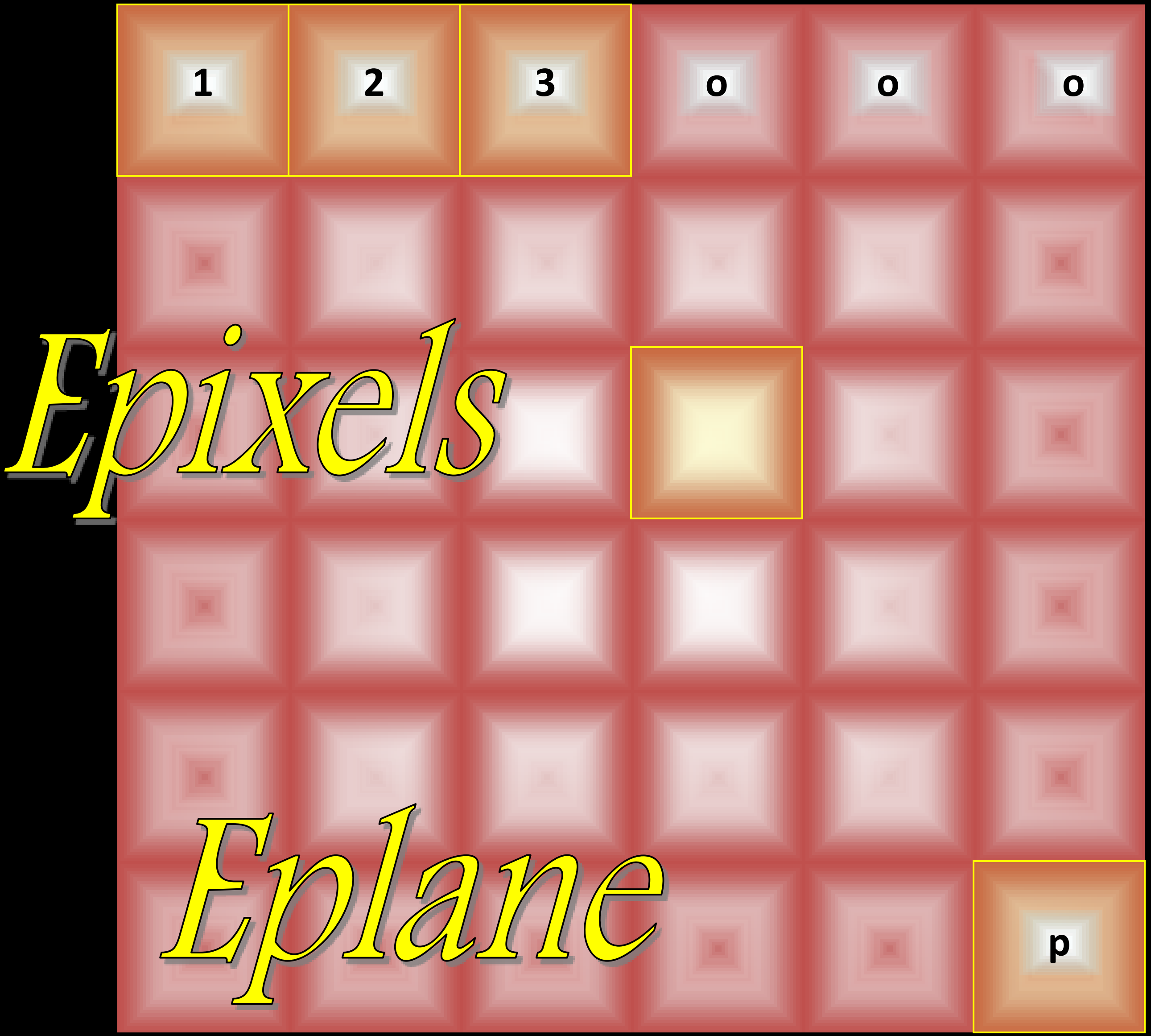
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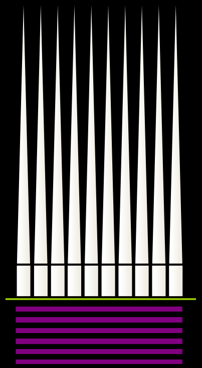

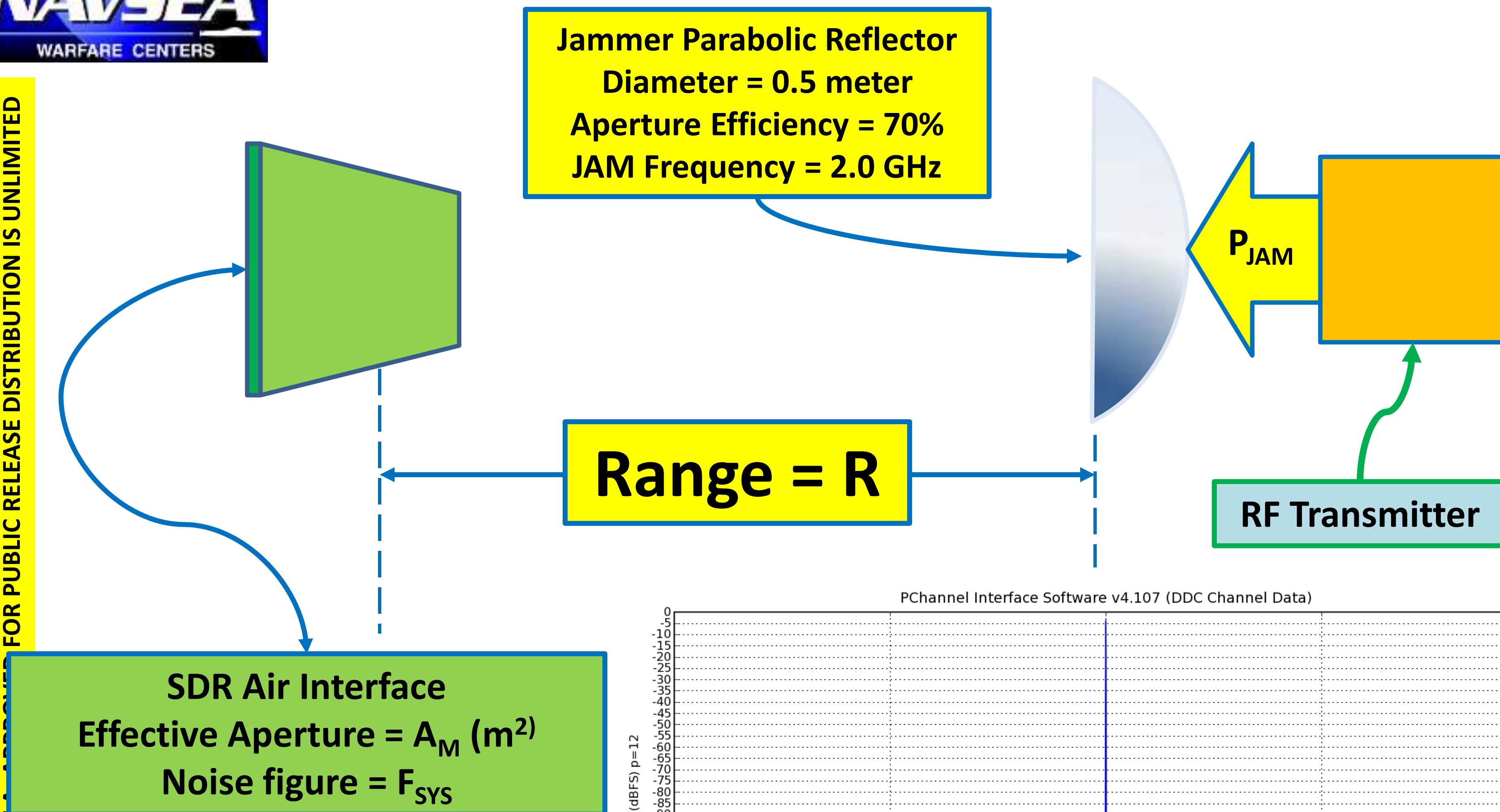

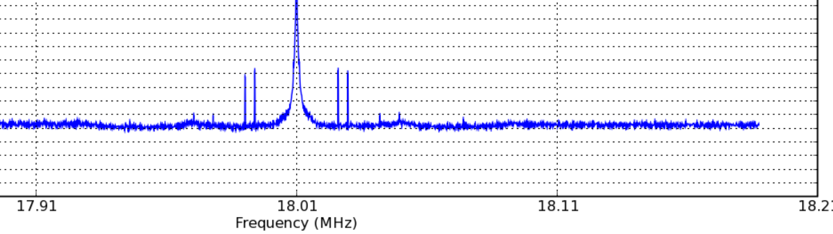

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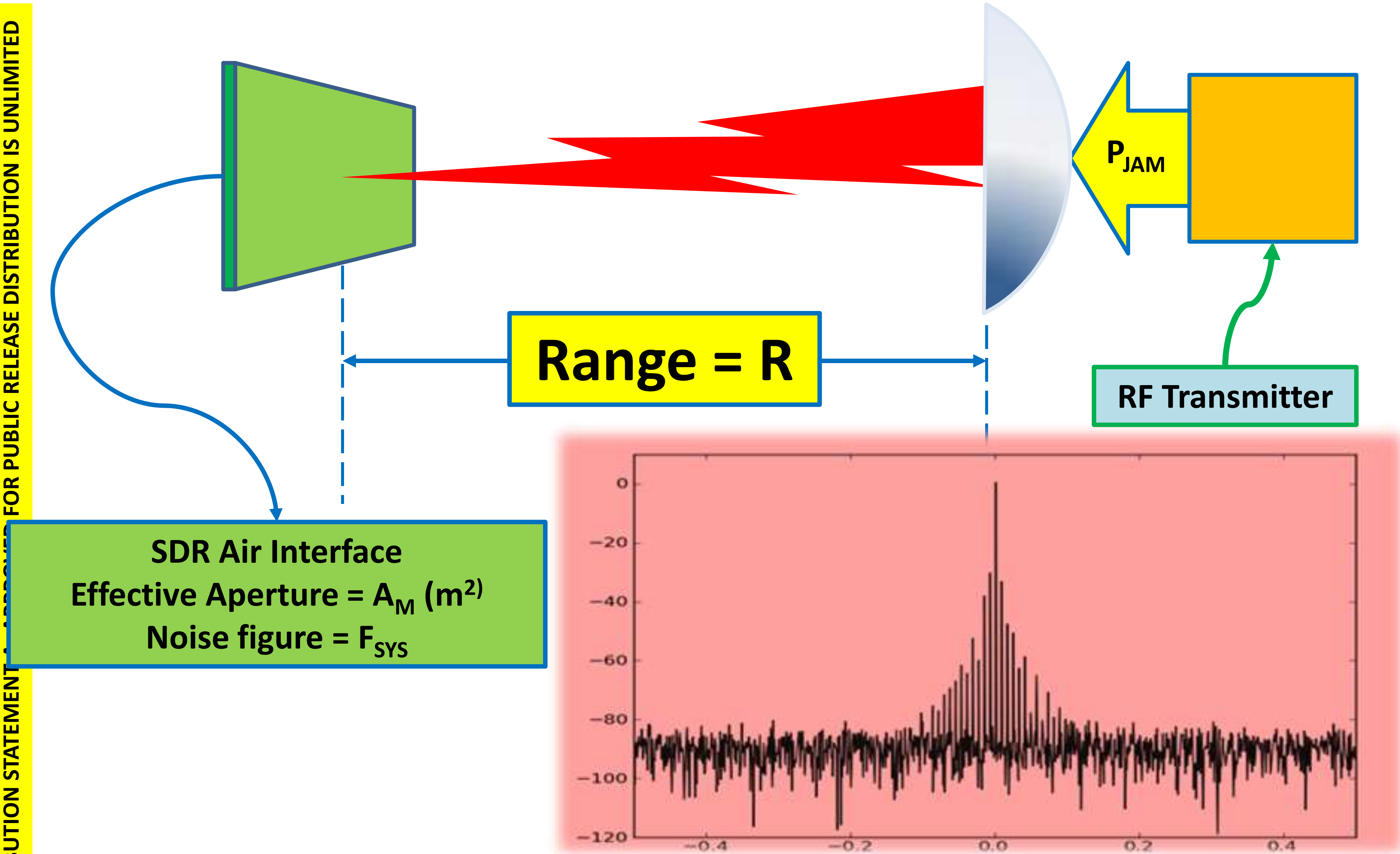
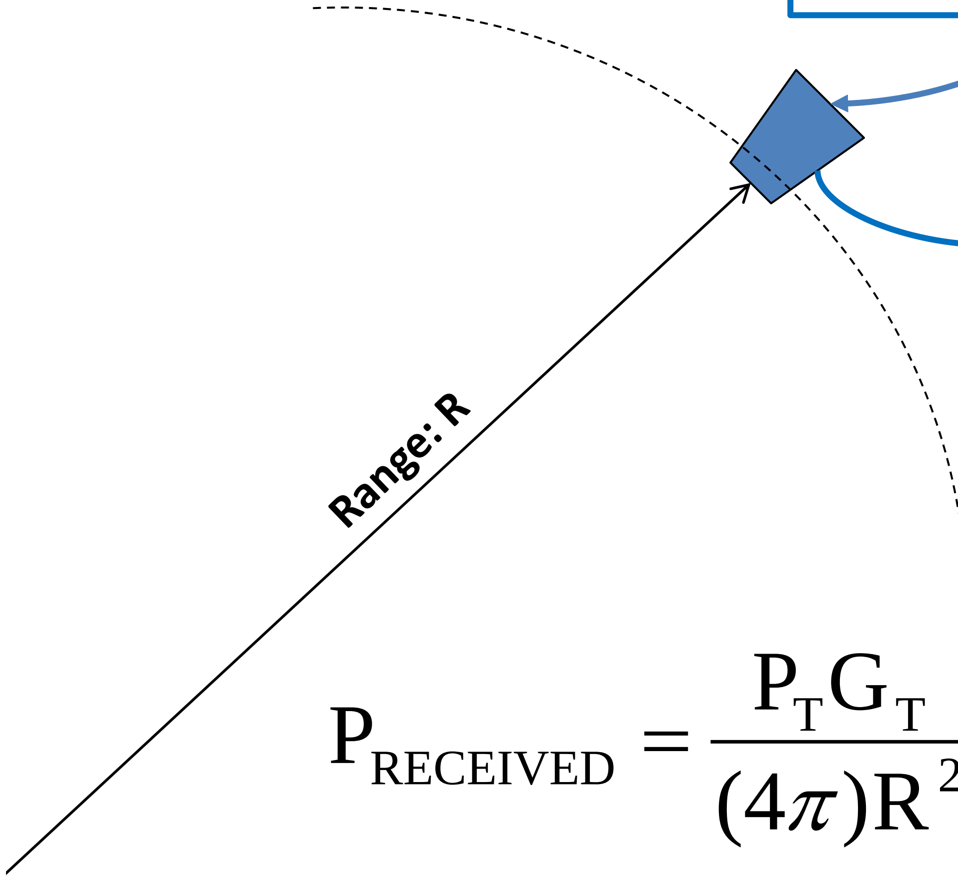


Effective Aperture Area = A_M meters^2



Received Power, $P_R = A_M\, W_{SIGNAL}$

Xmtr Power, P_T

$$P_{RECEIVED} = \frac{P_T G_T}{(4\pi)R^2} A_M \text{ Watts}$$

$$\text{EIRP} = (\text{Effective Isotropic Radiated Power})$$

$$\text{EIRP} = P_T G_T$$

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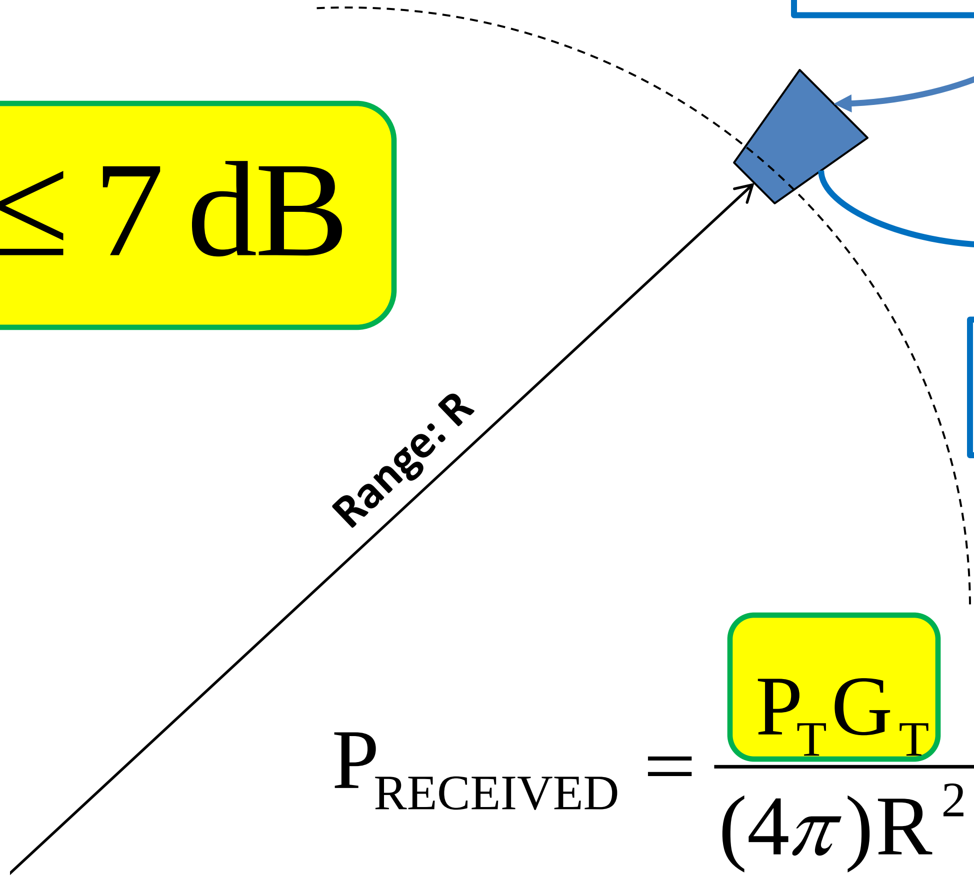
$$G_T \le 7\ \mathrm{dB}$$

Effective Aperture Area = A_M meters^2



Received Power, $P_R = A_R\, W_{SIGNAL}$

Transmitted Power, P_T

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$$\text{EIRP} = P_T G_T$$

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Effective Aperture Area = A_M meters^2

$$G_T \le 7\,\mathrm{dB}$$

Received Power, $P_R = A_M W_{SIGNAL}$

Range: R

Transmitted Power, P_T

$$P_{RECEIVED} = \frac{P_T G_T}{(4\pi)R^2} A_M \text{ Watts}$$

$$\mathrm{EIRP} = (\text{Effective Isotropic Radiated Power})$$

$$\mathrm{EIRP} = P_T G_T$$

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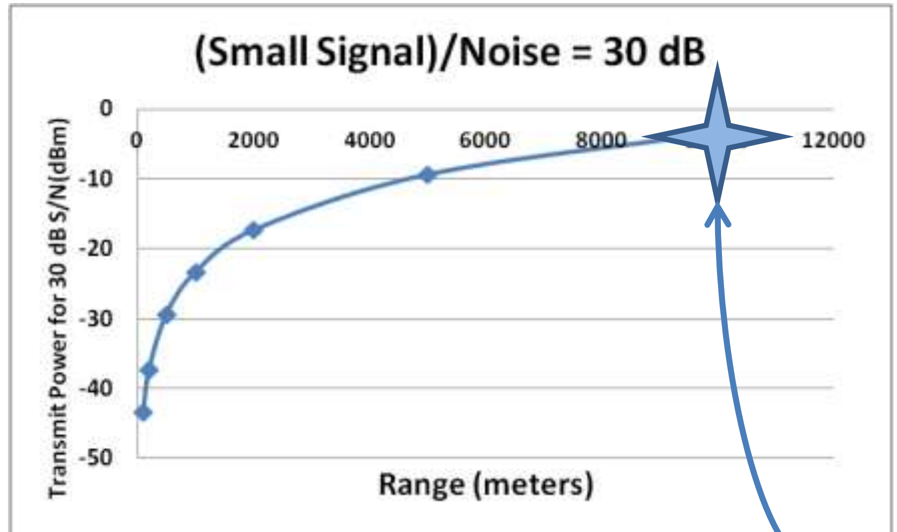
Small Signal Calculation		
Noise Figure:	dB	10
Signal Bandwidth:	dBHz	35
kT0:	dBW	-204
Min. Det. Signal:	dBW	-159



Xmtr EIRP Required		
Range	dBmeter	40
4*PI	dB	11
Eplane Aperture	dBmtr^2	-11.9
Min. Det. Signal:	dBW	-159
Xmtr EIRP:	dBW	-56

Xmtr Power for 30 dB S/N		
EIRP 0dB S/N	dBW	-56
Xmtr Ant. Gain	dB	7
Desired S/N	dB	30
Xmtr Power Out	dBW	-33

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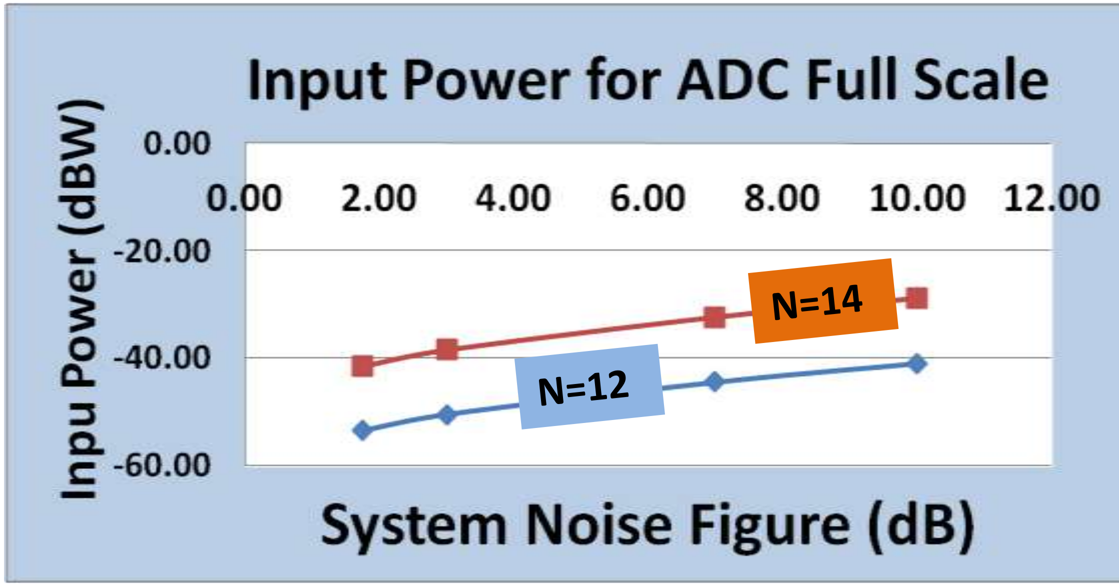

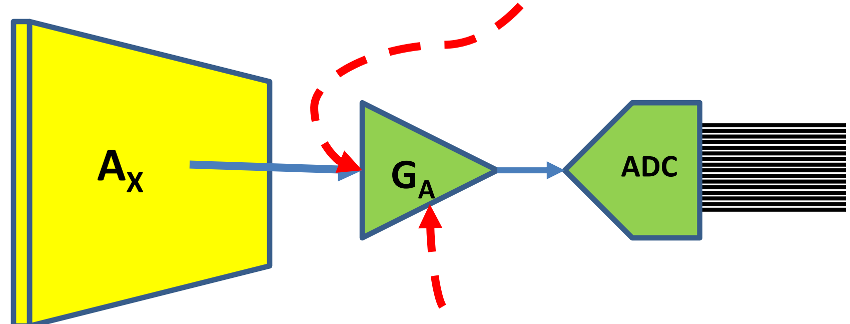

Minimum Gain ADC Factor			
Full Scale Power	dBW	-20	-20
Nyquist frequency	MHz	90	90
Nyquist frequency	dBHz	79.54	79.54
Quantization(N)	ratio	12	14
Quantization(N)	dB	10.79	11.46
kT0	dBW	-204	-204
ADC N/S	dB	-74.01	-86.05
ADC Noise Factor	dB	30.45	18.41

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

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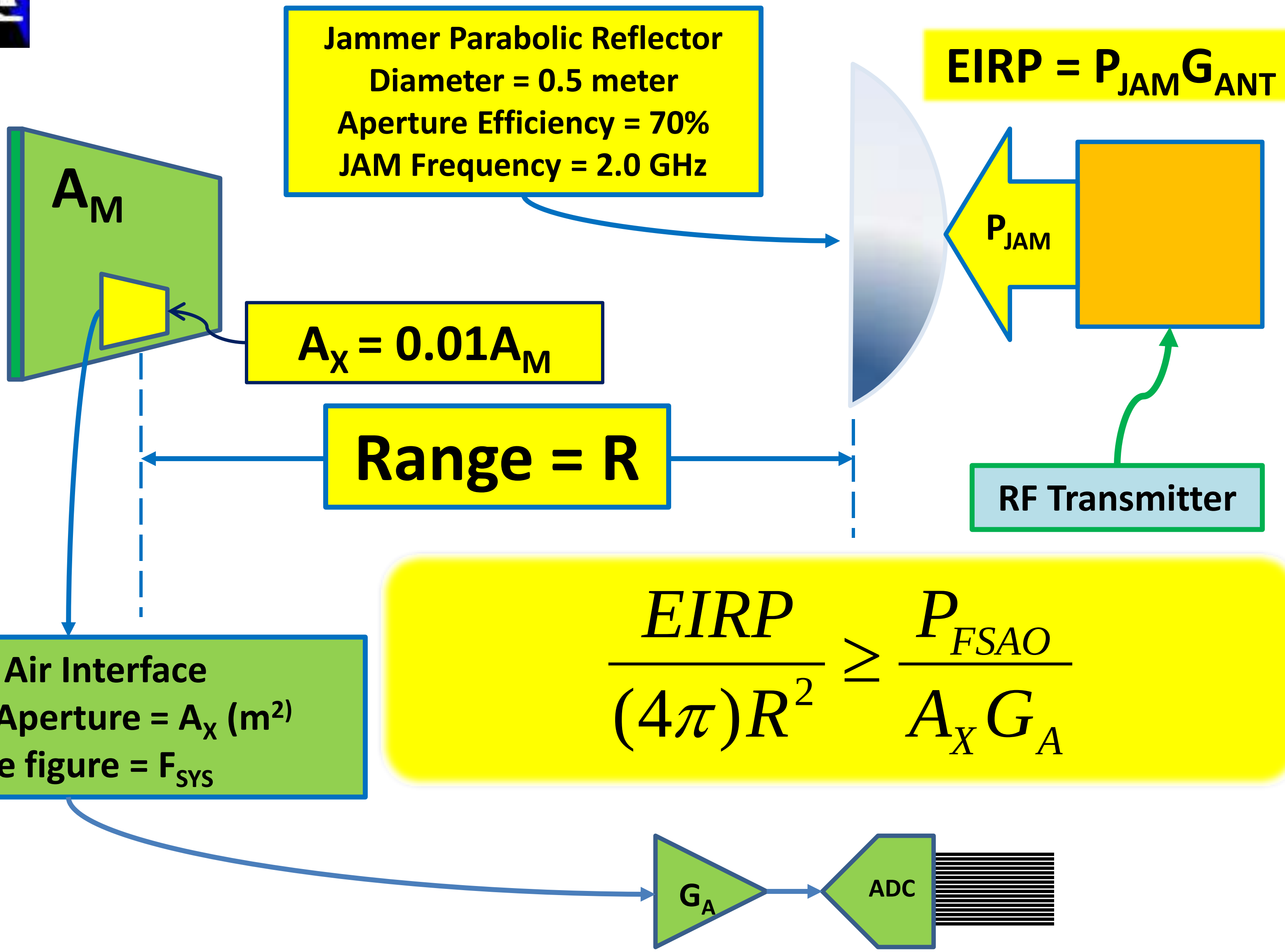

$$\frac{EIRP}{(4\pi)R^2} \geq \frac{P_{FSAO}}{A_X G_A}$$

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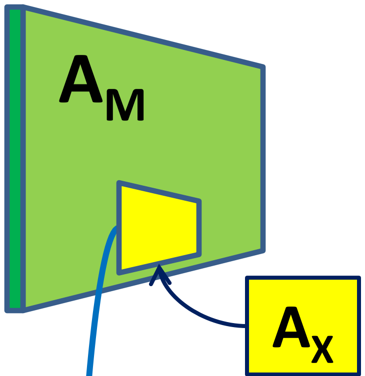
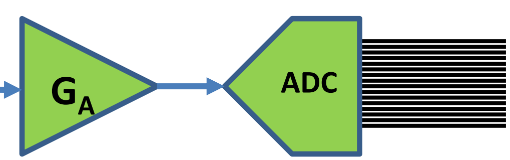


Receiver Jamming Threshold		
Rec. Eff. Aperture (one Epixel = A_X)	dBm^2	-31.9
Rec. Preamp Gain	dB	22.32
PFSAO	dBW	-20
Rec Jam Threshold	dBW/m^2	-10.42

$$\frac{EIRP}{(4\pi)R^2} \geq \boxed{\frac{P_{FSAO}}{A_X G_A}}$$

SDR Air Interface
Effective Aperture = A_X (m^2)
Noise figure = F_{SYS}



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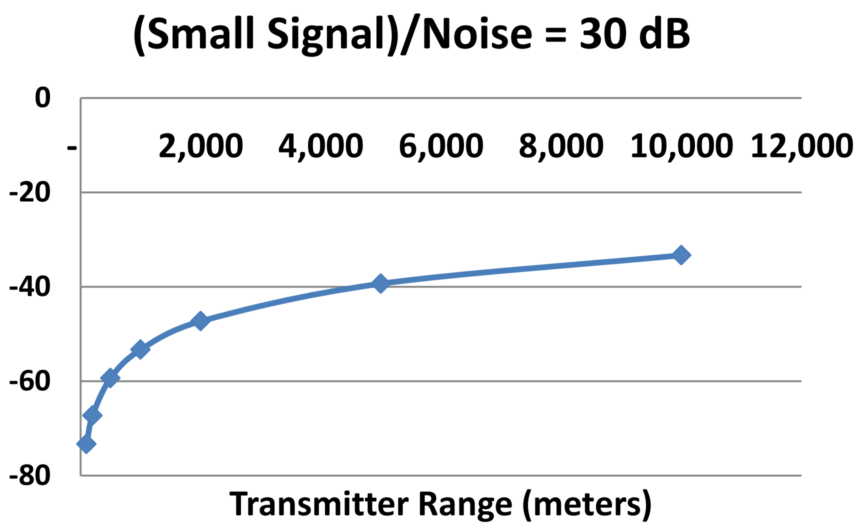

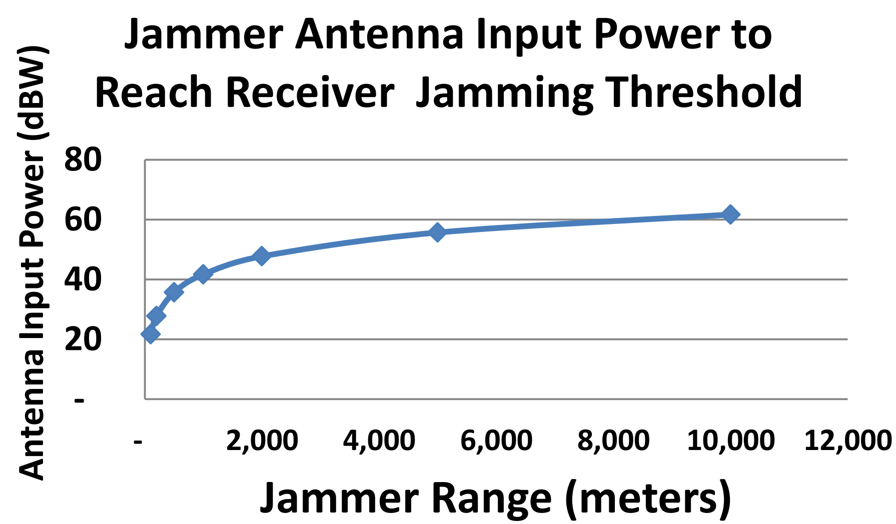

Xmtr Power for 30 dB S/N			Receiver Jamming Threshold		
EIRP 0dB S/N	dBW	-56	Rec. Eff. Aperture	dBm^2	-31.9
Xmtr Ant. Gain	dB	7	Rec. Preamp Gain	dB	22.32
Desired S/N	dB	30	PFSAO	dBW	-20
Xmtr Power Out	dBW	-33	Rec Jam Threshold	dBW/m^2	-10.42

Transmit Signal dynamic Range: 123 dB

Partitioned Receive Aperture (p=100)

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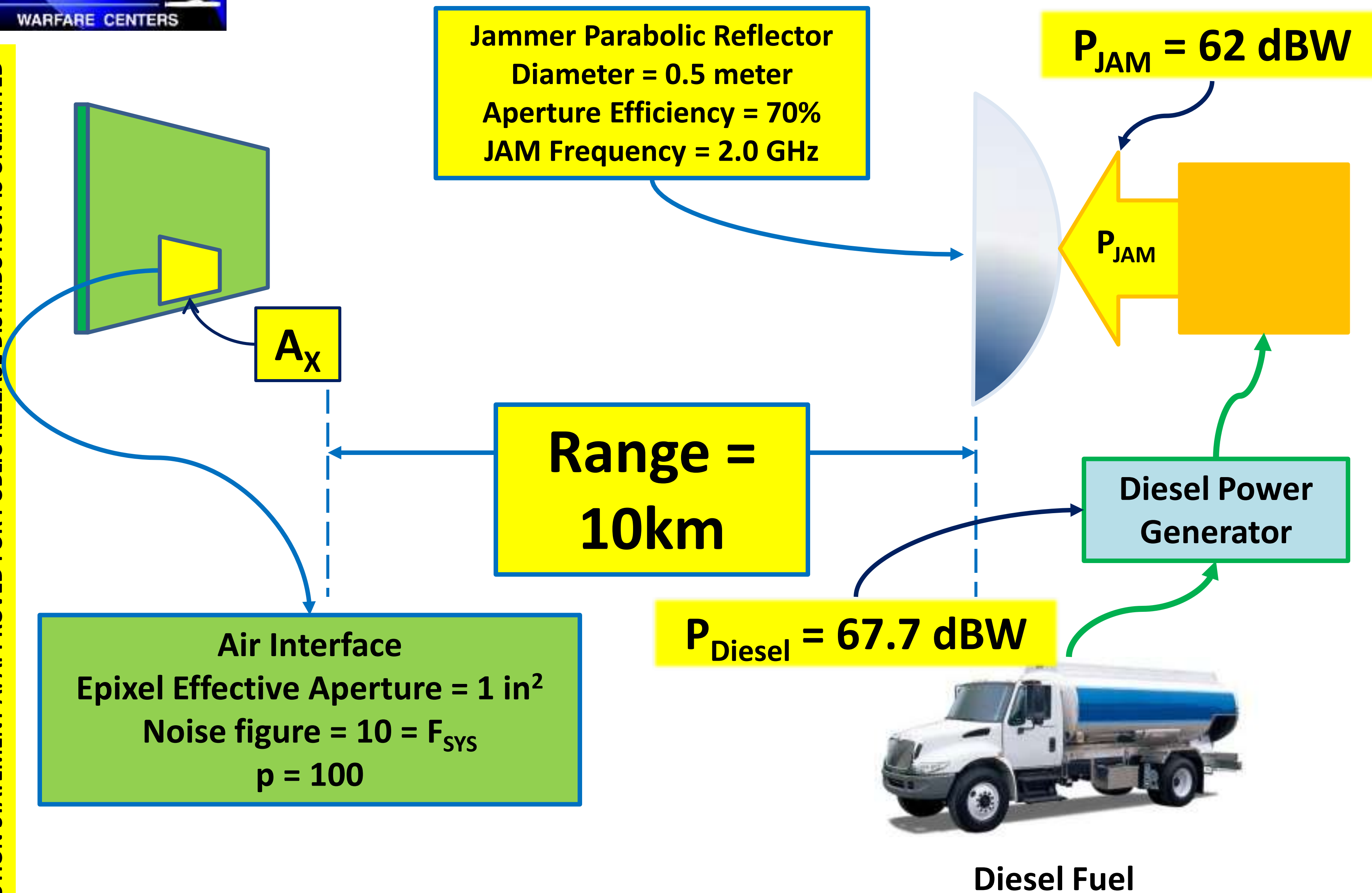

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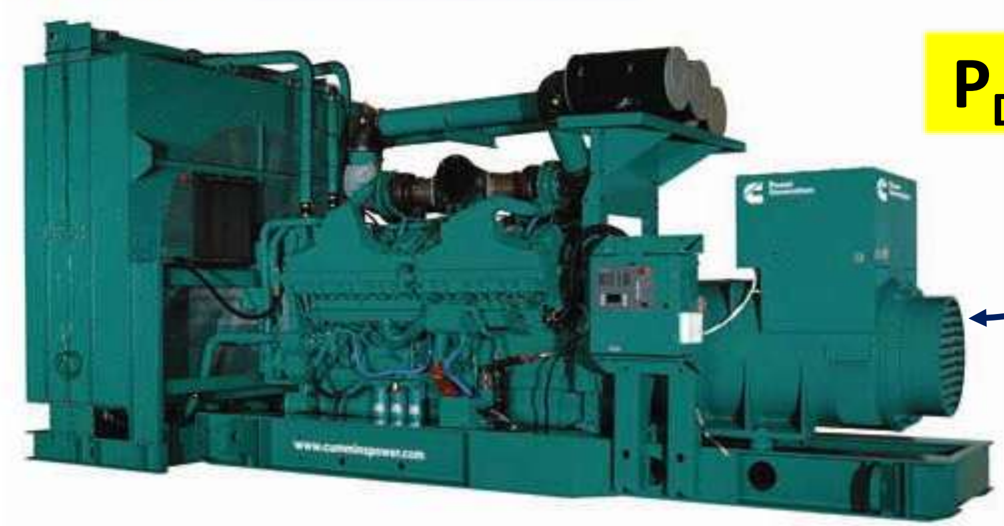
Cummins 2,000 kW ready to go! Call for current pricing.

Also check out Detroit MTU generators



$P_{DieselGen}$ = 63 dBW

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

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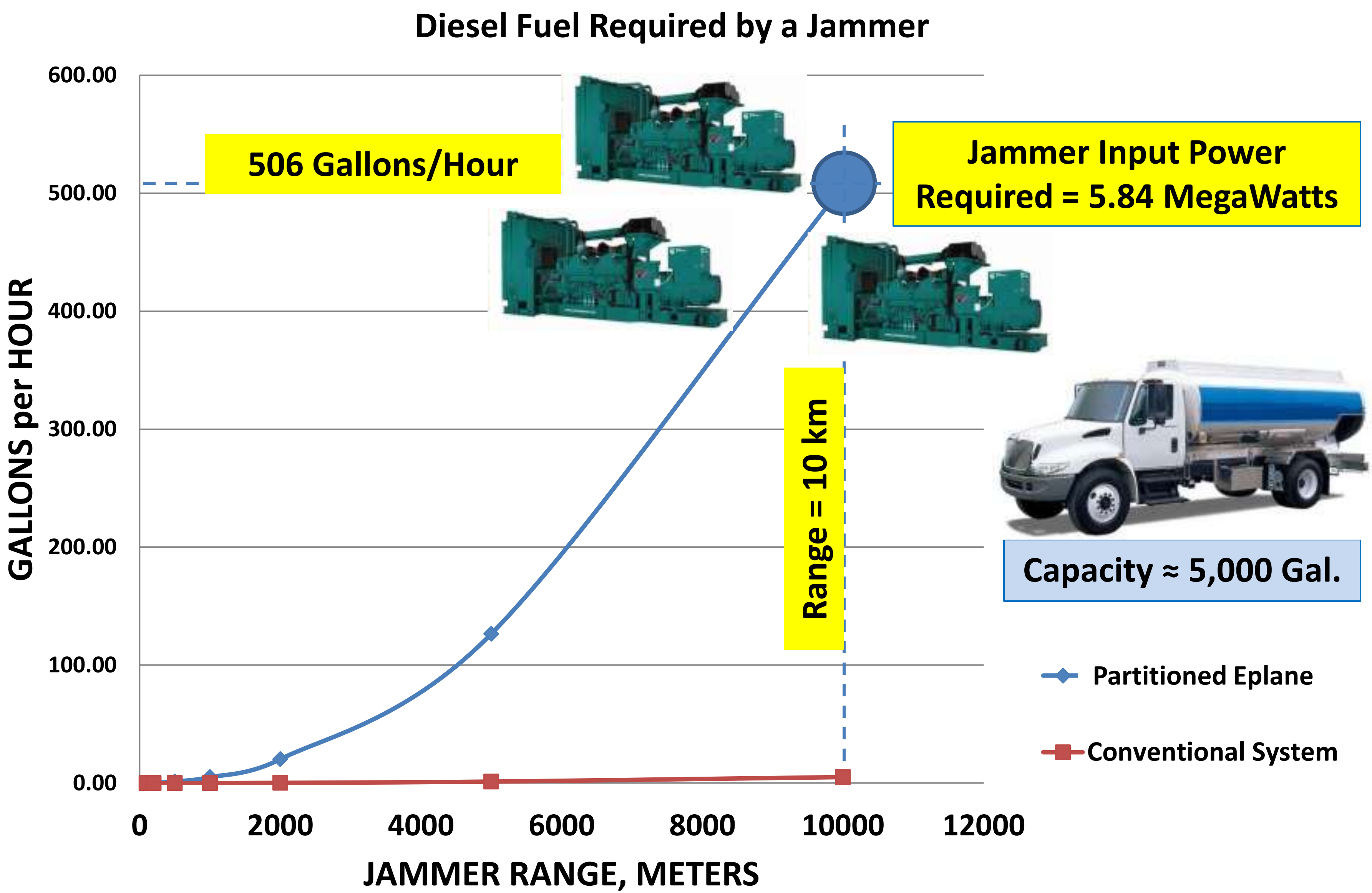

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Guglielmo Marconi sent and received his first wireless communications in Italy in 1895.

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First Portable Telephone Call Made 78 Years Later

Martin Cooper changed the world when he made the first cell phone call on April 3, 1973. The former Motorola vice president and division manager made the call on the company's DynaTAC phone while standing in front of the New York Hilton on Sixth Avenue. His first call: to the head of research at Bell Labs, also attempting to build the first cell phone.

Force XXI Battle Command Brigade and Below—Blue Force Tracking

More than 95,000 FBCB2-BFT systems have been deployed worldwide since 1998.

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Summary:

- **We have investigated the fundamental limits for a digital wireless-signals intercept system and described an ideal partitioned air interface,**
- **We have demonstrated that an ideal partitioned air interface enables virtually jam-proof operation of digital signals intercept systems deployed in in hostile EM environments, and**
- **We have introduced the topic of cyber warfare in the wireless domain.**

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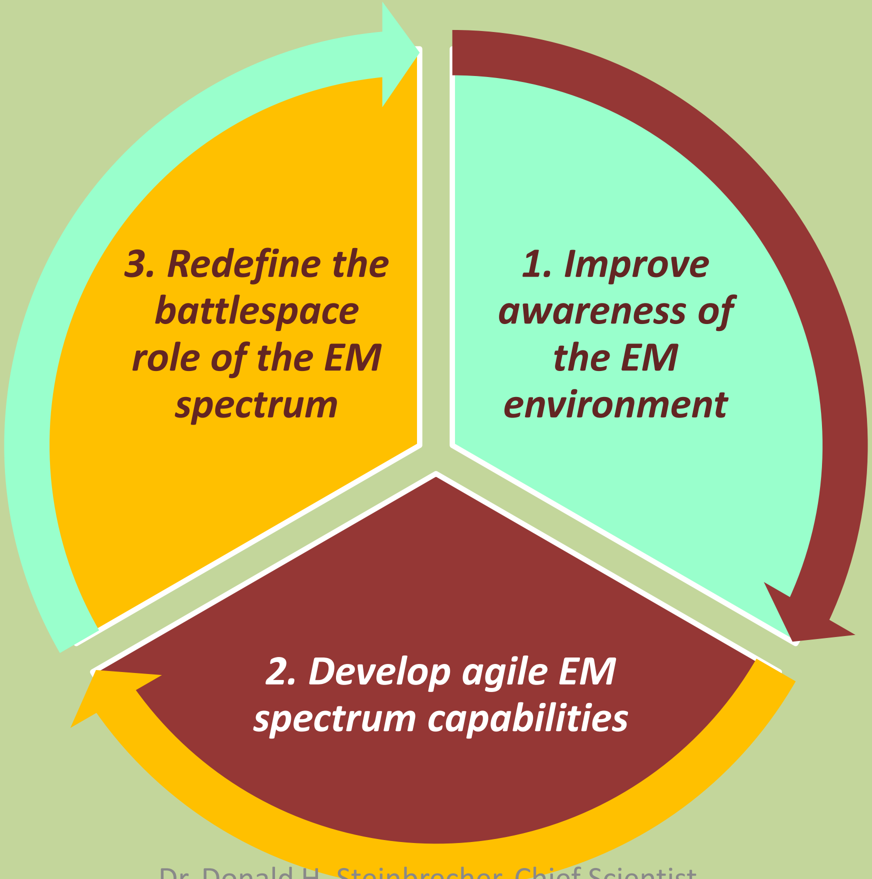
After a Break,

- **we will investigate the properties of a software defined transmitter system that is based on a partitioned air interface,**
- **We will address Items 2 and 3, and**
- **We will look at actual results for one example of a partitioned air interface.**



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