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Session D “Improvements in T&E Instrumentation”
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Validating The Calibration of a Hardware-In-The-Loop Test Facility Using Dynamic and Monte Carlo Techniques

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Classification

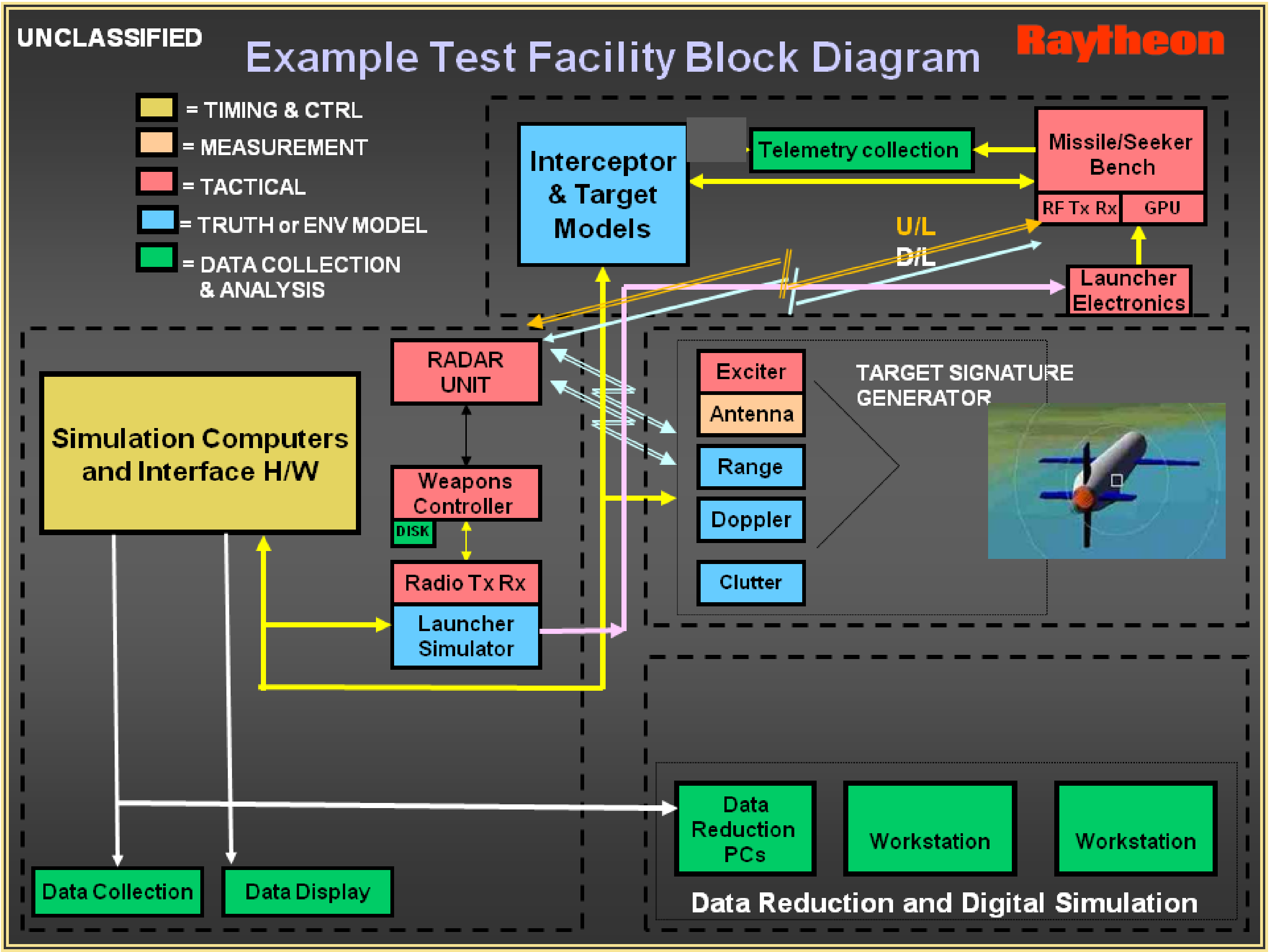
U	UNCLASSIFIED
	THIS PRESENTATION HAS BEEN REVIEWED AND APPROVED FOR GENERAL AUDIENCES **TPCR IDS-2790**

The system described herein is for educational purposes and was developed solely to illustrate the principals described.

All system constants used for the calculations were arbitrary multiples of π.

Any similarity to any existing system whether fielded or planned is unintentional and purely coincidental.

Applying the Method to Facility Power Validation



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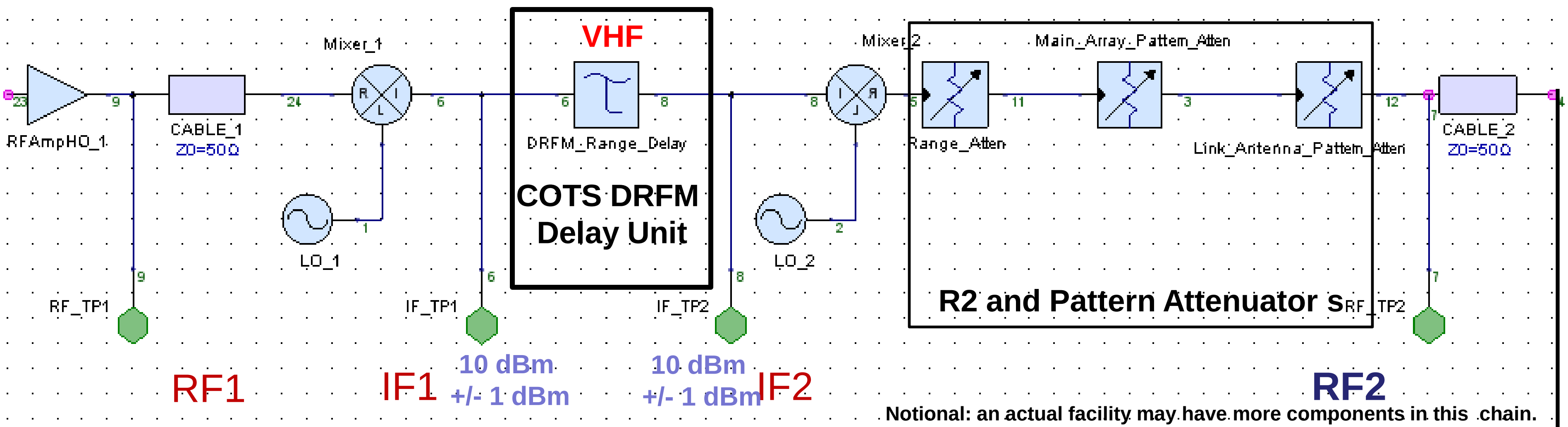
Example HWIL Facility Downlink Path

Tactical HW D/L

D/L at Tactical Freq with Doppler, Delay, Range and Pattern Attenuation

True Sys Freq *(S,C,X, etc.)*

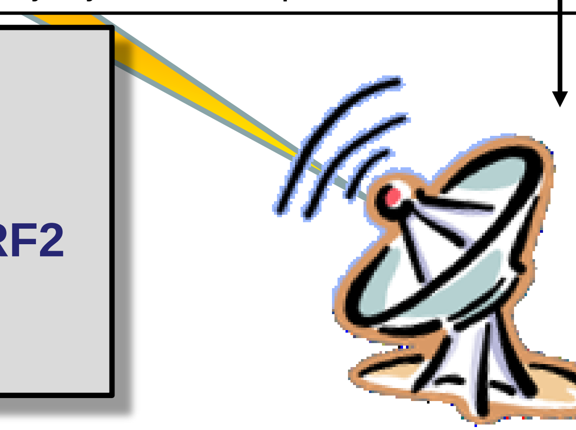
True Sys Freq *(S,C,X, etc.)*



Notional: an actual facility may have more components in this chain.

☞ **Verification of Calibration Requirements Is Done at Test Points RF1, IF1, IF2**

☞ **Validation of D/L Performance Can Only Be Done at RF2**
$P_{D/L\ RF2}$ must equal "Truth" plus cable loss
+/- tolerance in dB_m



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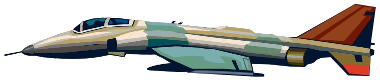
General Method



1)Establish the Performance Measure Equation

2)Compute Performance Sensitivity to a Change in the Parameter of Interest

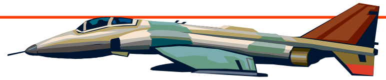
3) Design a Tactical Scenario Which Minimizes the Rate-of-Change Using the Sensitivity Equation

4) Make the Measurements

5) Validate the System or Sub-System Performance Using the Measurements Made Under Tactical Scenarios

System Performance & System Sensitivity

Reference: Glisson T.H. , *Introduction to Systems Analysis,* McGraw Hill Book Company, New York, 1985, pages 33-35



1) Define System Performance Measure

$$\psi_0 = \psi(\, p_1,\ p_2,\ p_3,\ \ldots\ p_n)$$

2) Approximate Sensitivity

$$\Delta\psi \approx \sum_{n=1}^{N} (\partial\psi/\partial p_n)*\Delta p_n \qquad \text{let } \Delta p_n = 0 \ \ i \neq n$$

$$\text{then } \Delta\psi \approx (\partial\psi/\partial p_n)*\Delta p_n$$

$$\text{or} \quad \boxed{\frac{\Delta\psi}{\psi_0} \approx \frac{\partial\psi}{\partial p_n}\frac{\Delta p_n}{\psi_0}}$$

Received Power Levels in dB_m

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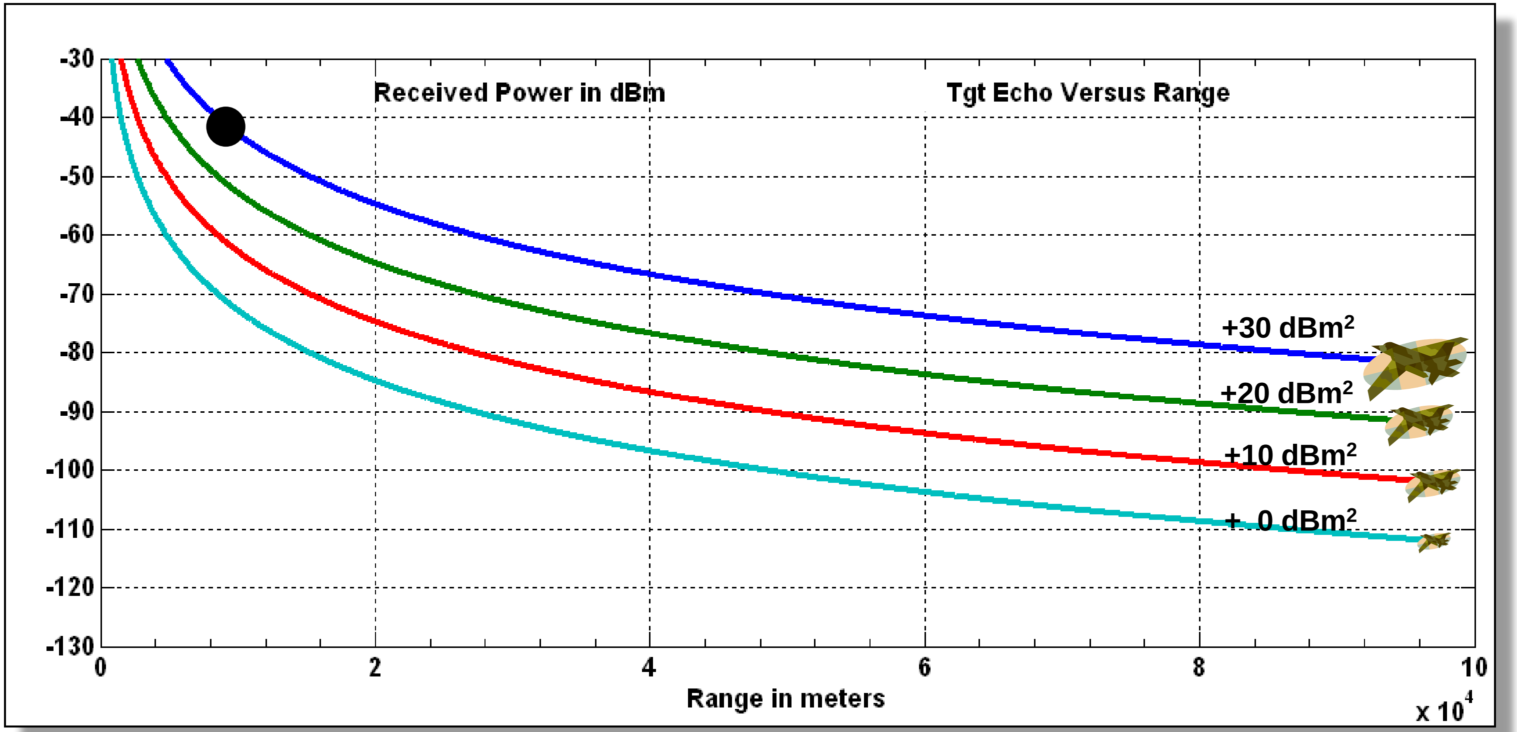
$$P_{rcv\ tgt} = \frac{P_t\ G_t\ \sigma\ G_r\ \lambda^2}{(4\pi)^2\ R^4}$$



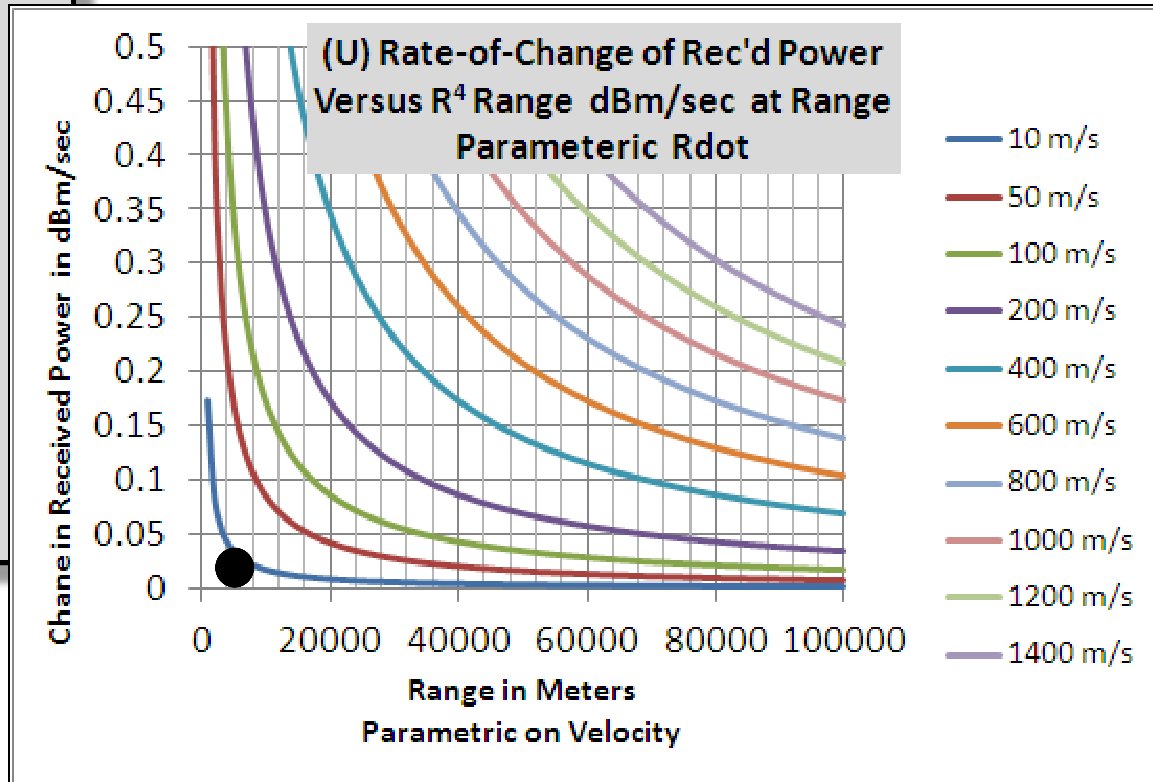
$\partial P_{rcv}/\partial t$ versus Range

Skin Target

$$\partial P_{rcv}/\partial t = -40/\ln(10)*\dot{R}/R$$

using

$$\frac{d}{dx}\log_b(x) = \frac{1}{x\ln(b)}.$$



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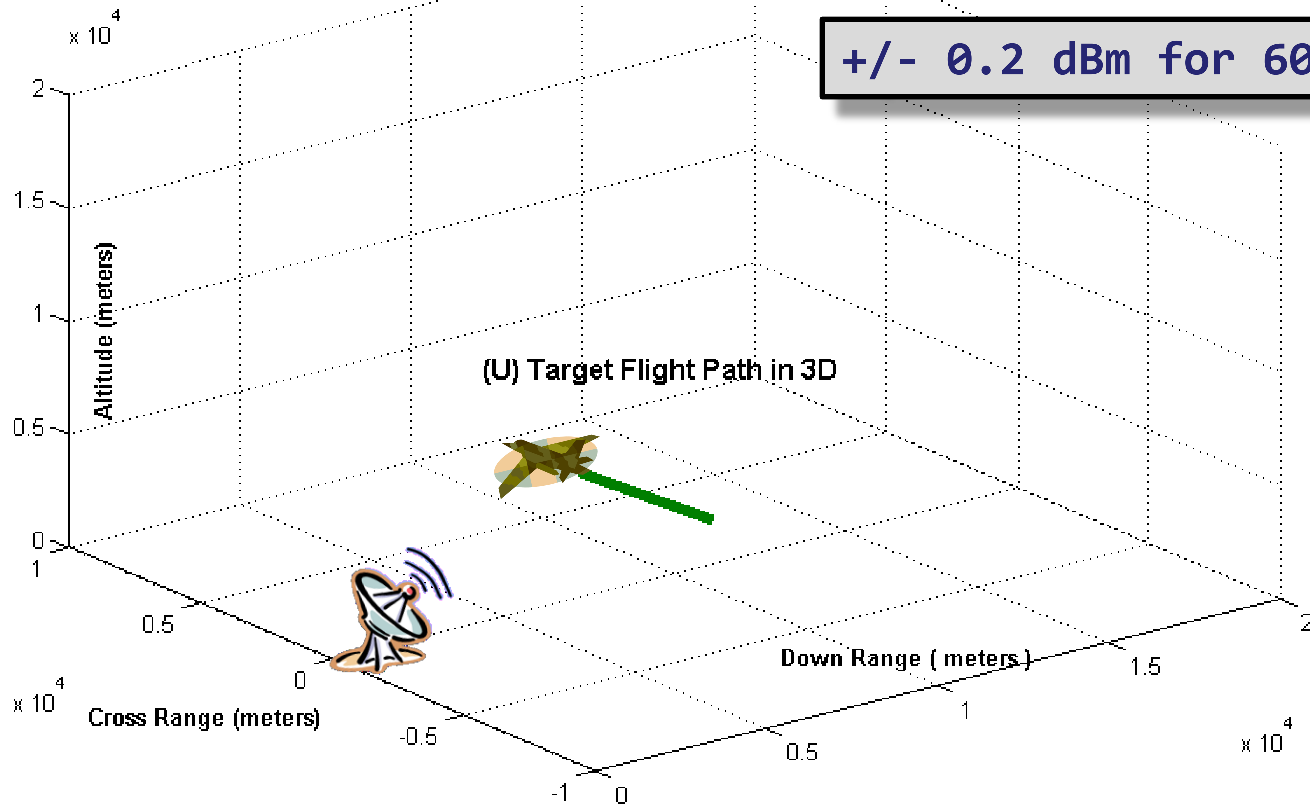
Scenario for Large, Slow Crossing Object

+30 dBm² 50 m/sec Crossing Target at Range of 10400 meters
Rdot ~ 0 since it is a crossing target

+/- 0.2 dBm for 60 seconds



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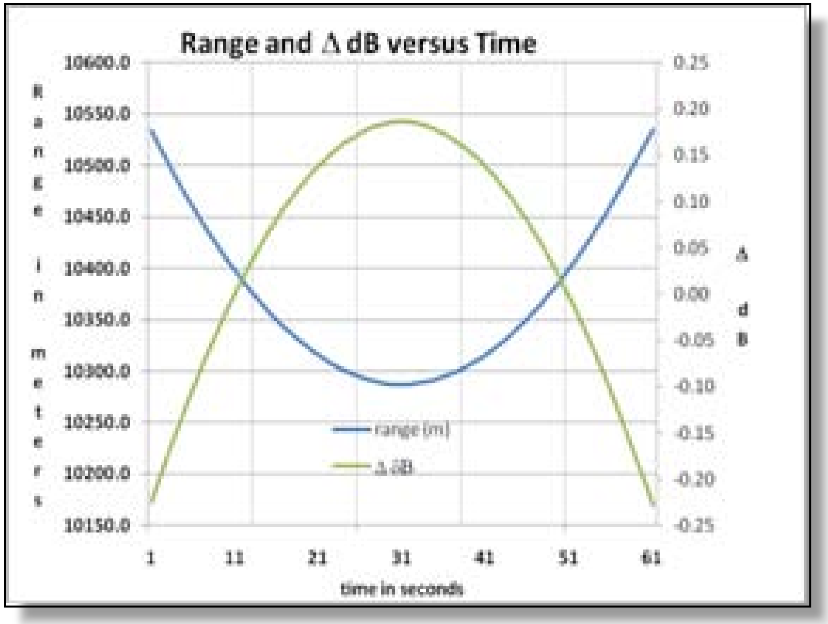
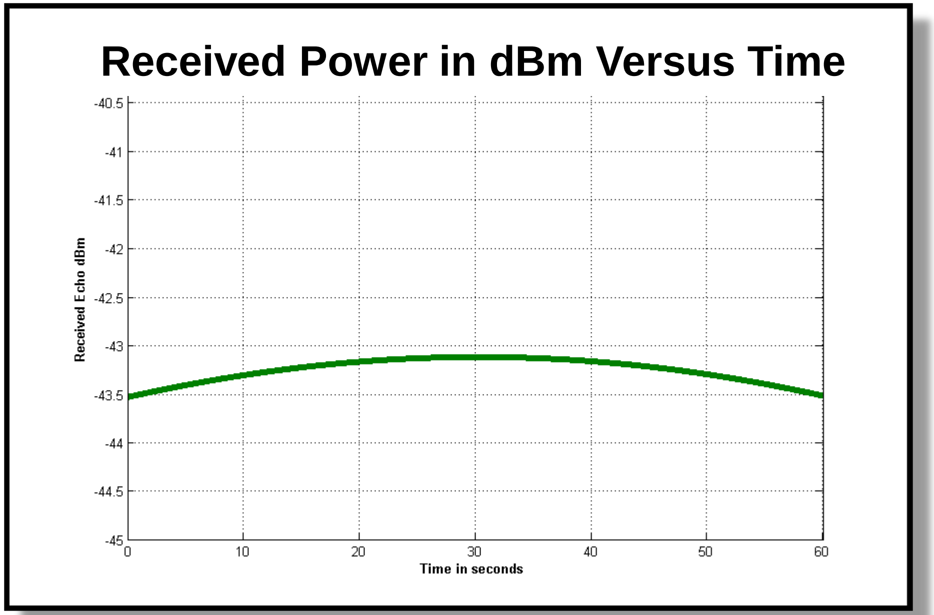
∂P$_{rcv}$/∂t & P$_{rec'd}$ For a Slow Crossing Object

+30 dBm^2 50 m/sec Crossing Target at Range of 10400 meters
Rdot ~ 0 since it is a crossing target





+/- 0.2 dBm for 60 seconds

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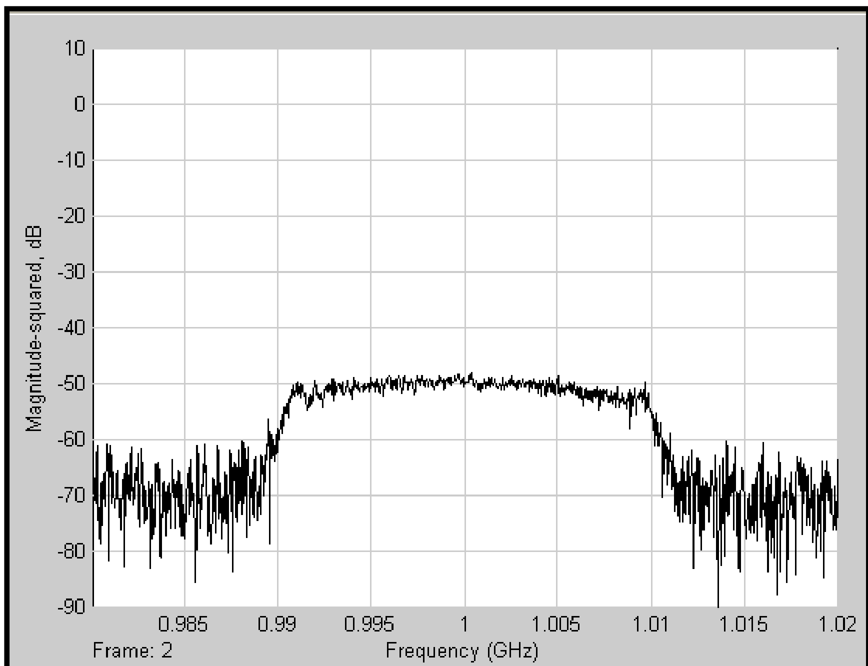
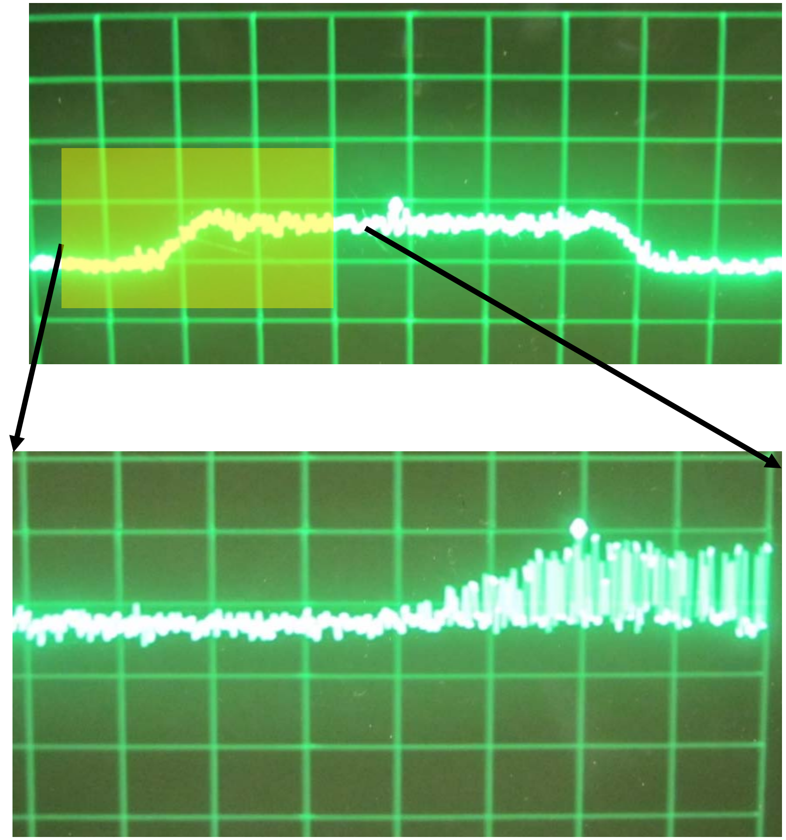
Simulated* and Measured Power for the Scenario

+30 dBm² 50 m/sec Crossing Target at Range of 10400 meters
Rdot ~ 0 since it is a crossing target





15 usec 5 MHz Up Chirp*

*** Powel level and waveform parameters are based on an 'education system' only and are not known to be related to system whether fielded or planned.**

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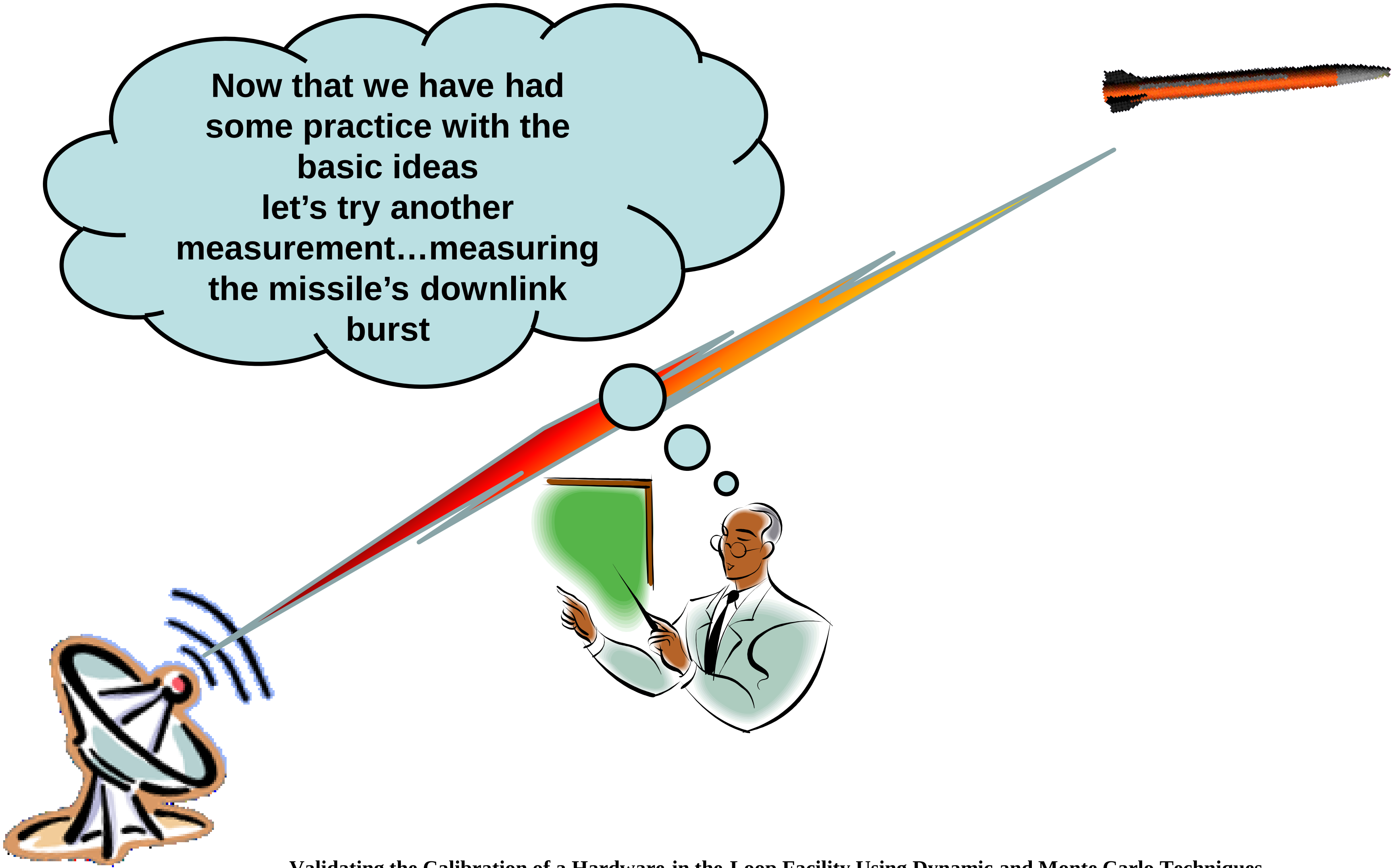
Measuring a Missile Downlink



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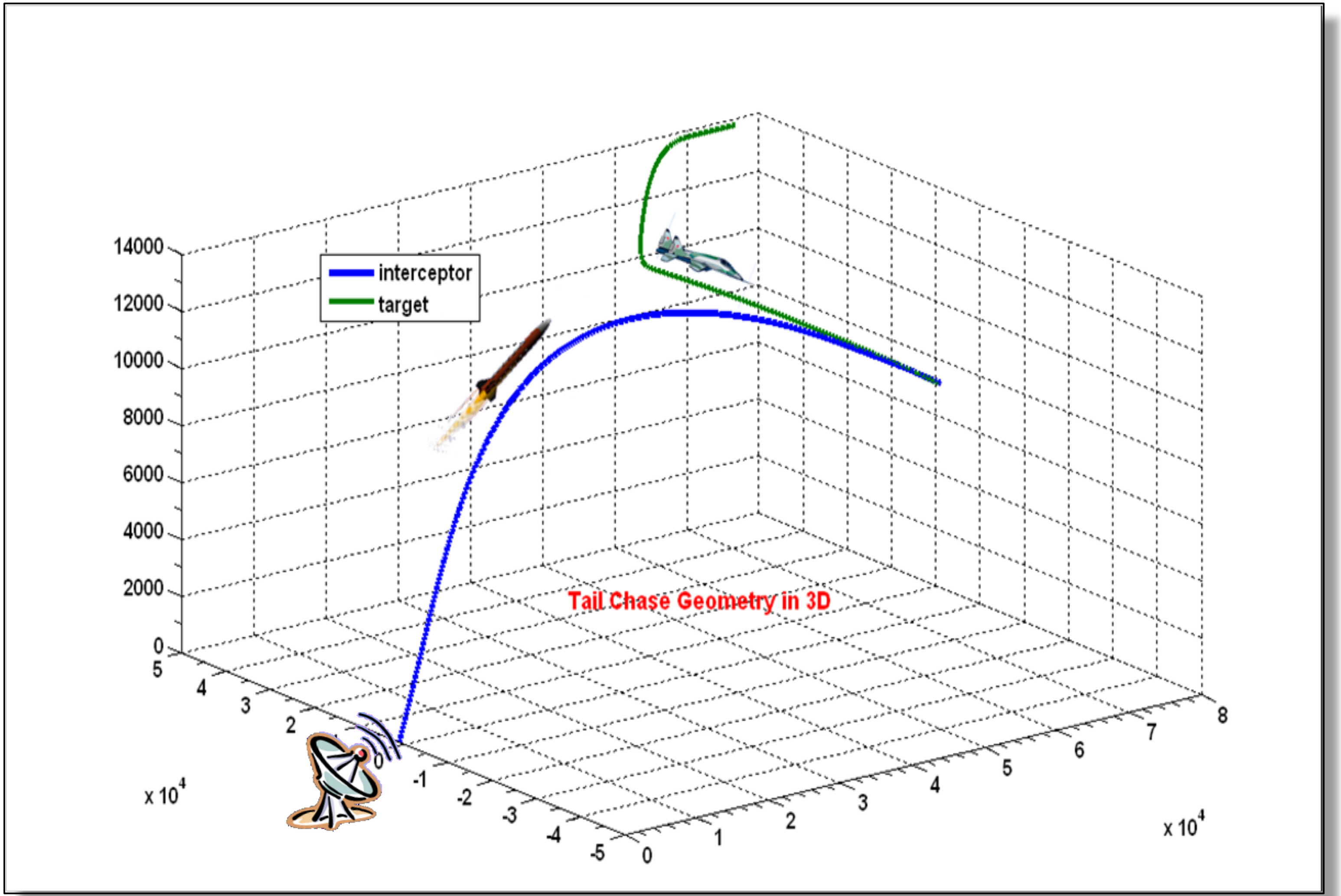
Geometry for Measuring Missile Downlink



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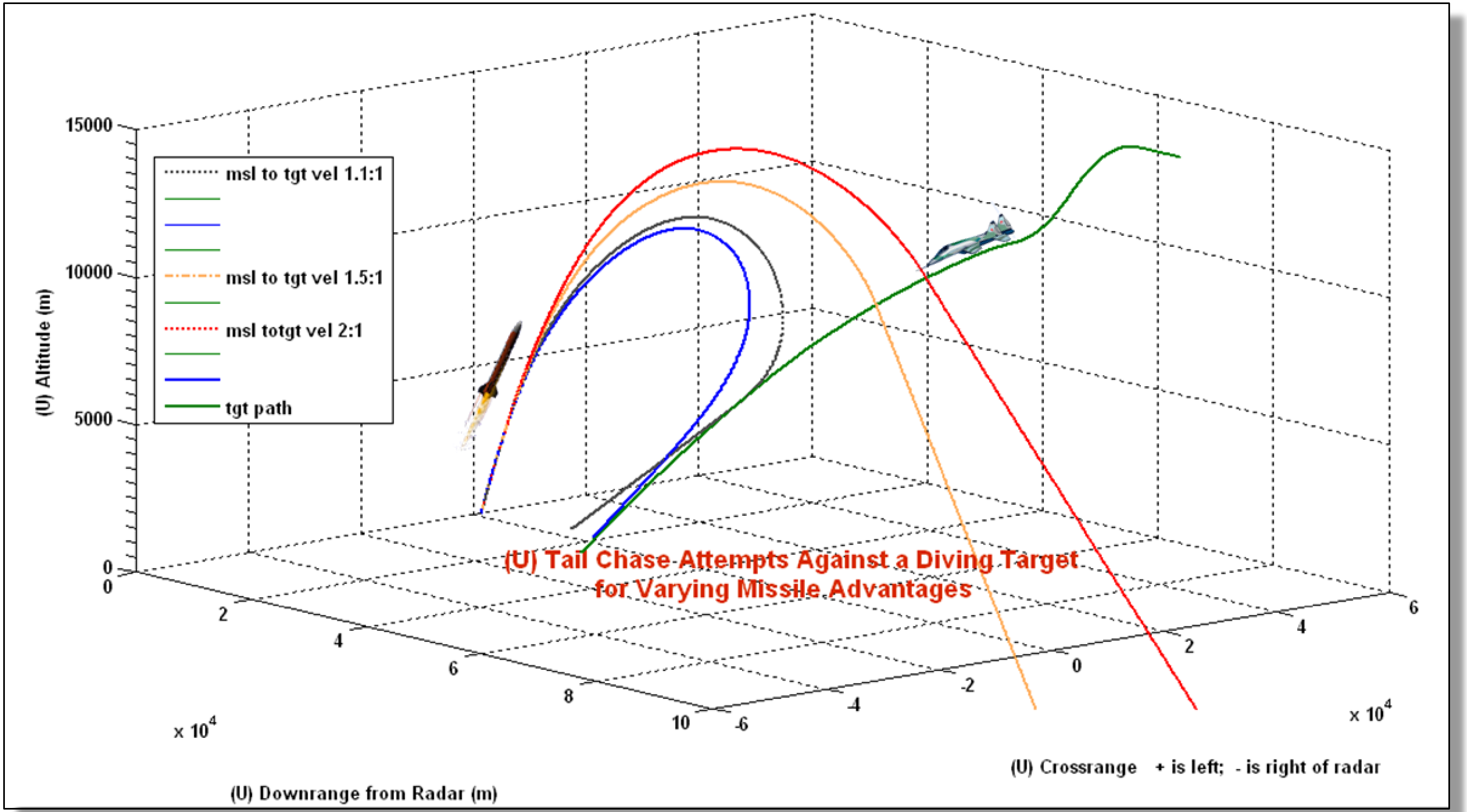
Missile Tail-Chase Flyout Parametric Study



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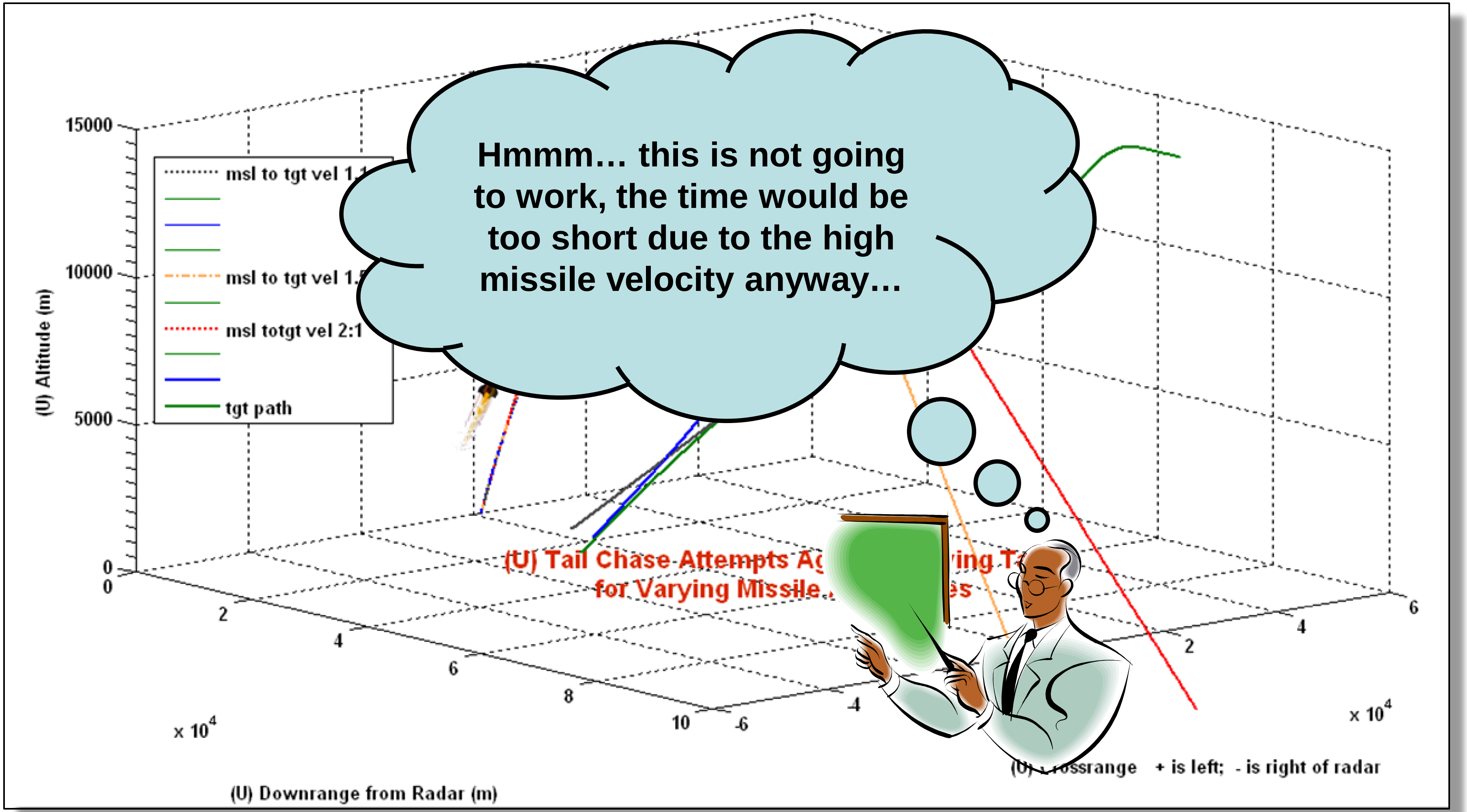
Missile Tail-Chase Flyout Parametric Study



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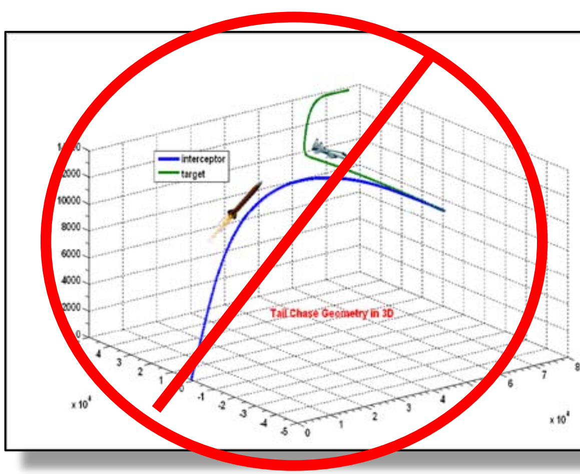
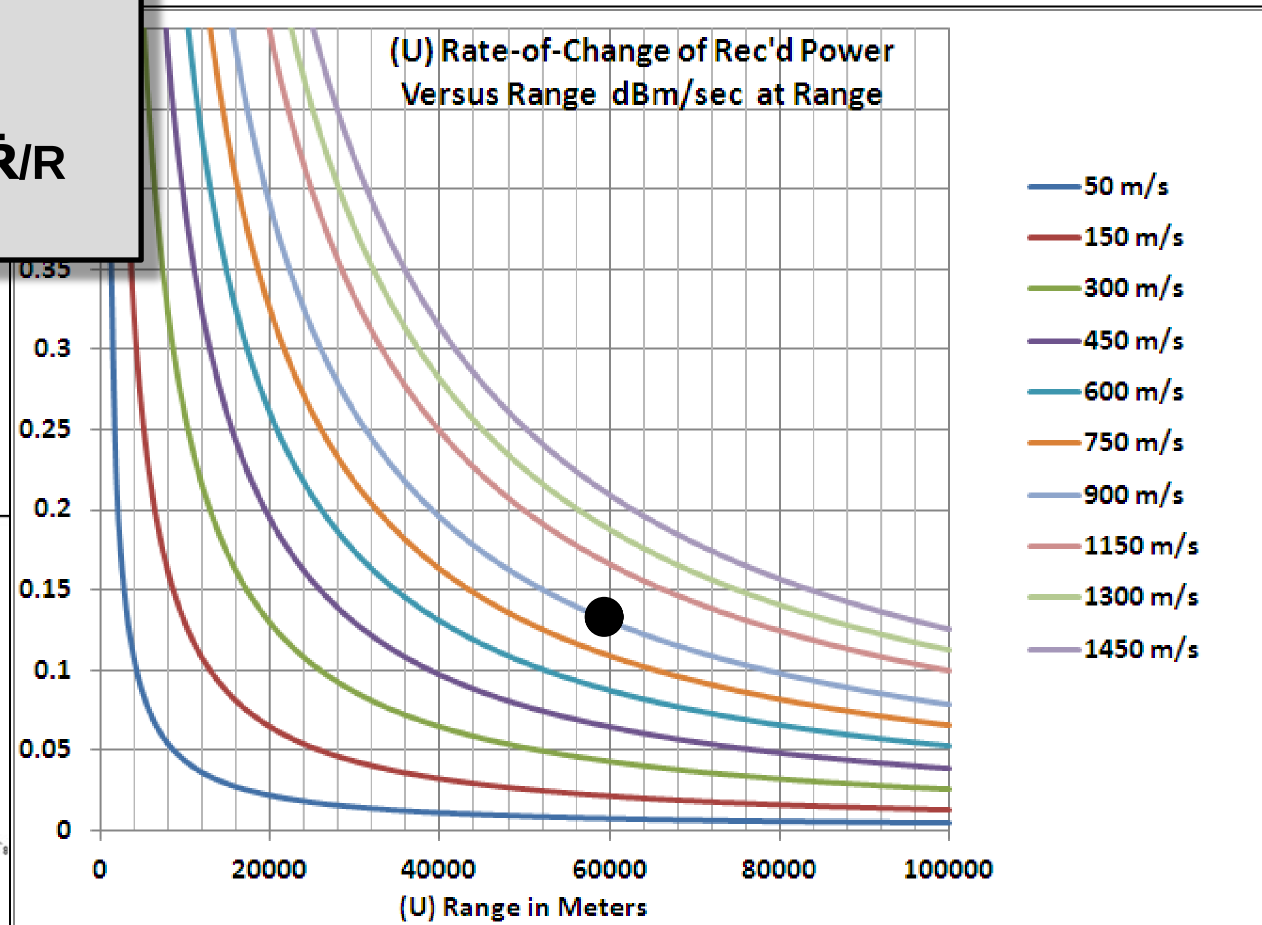
Tail-Chase Won't Work: Exploit the Range Term

Beacon Signal

$$\partial P_{rcv}/\partial t = -20/\ln(10)*\dot{R}/R$$





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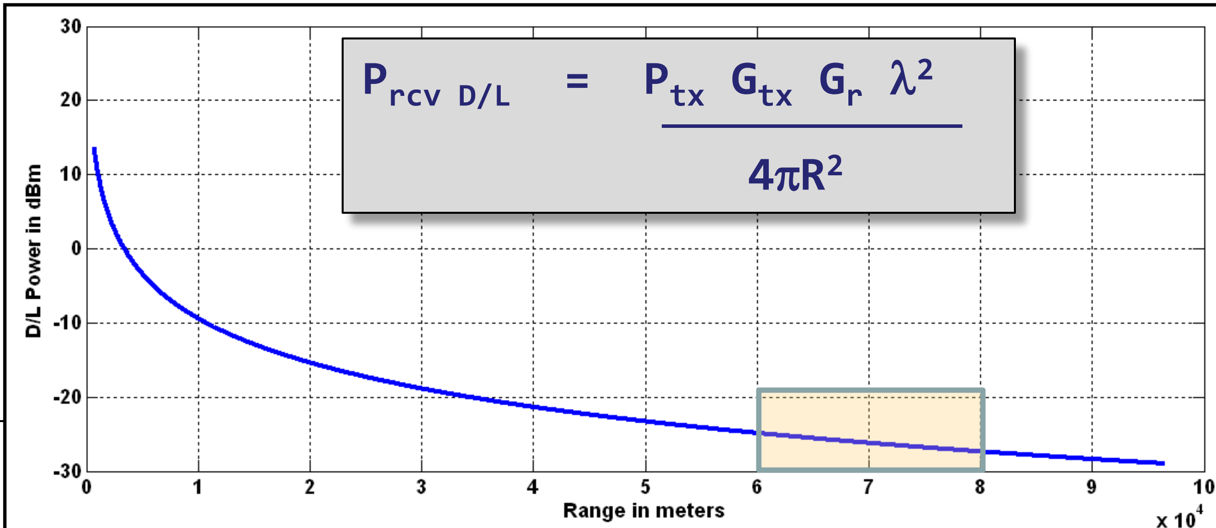
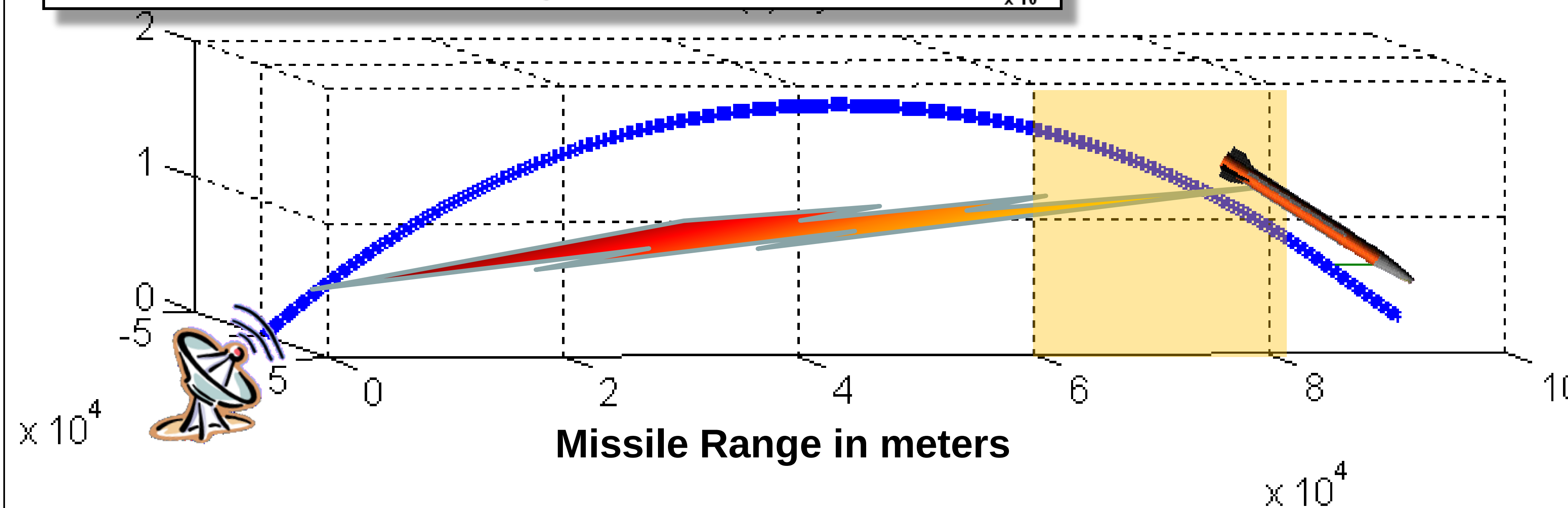
Missile Flyout for Downlink Measurement

$$P_{rcv\ D/L} = \frac{P_{tx}\ G_{tx}\ G_r\ \lambda^2}{4\pi R^2}$$



Ranges Selected for this Measurement
R = 60 to 80 kilometers DR



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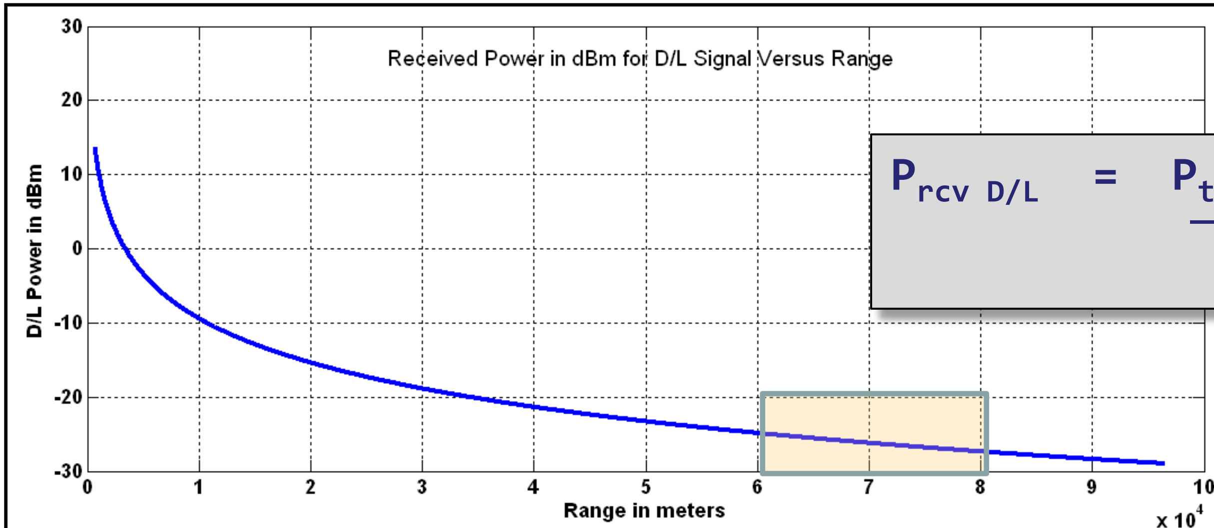
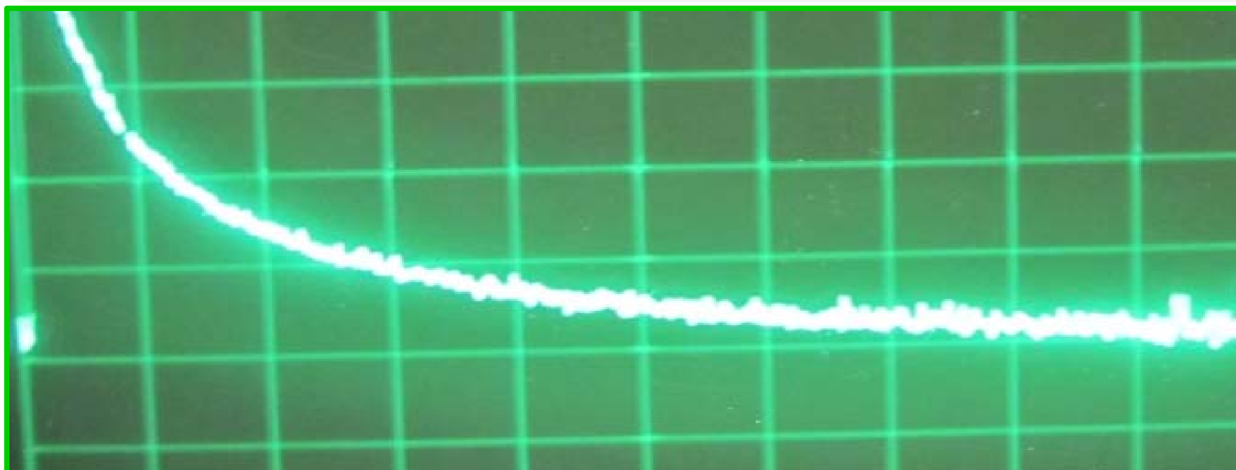
Received Power for Missile Downlink



$$P_{rcv\ D/L} = \frac{P_{tx}\ G_{tx}\ G_r\ \lambda^2}{4\pi R^2}$$



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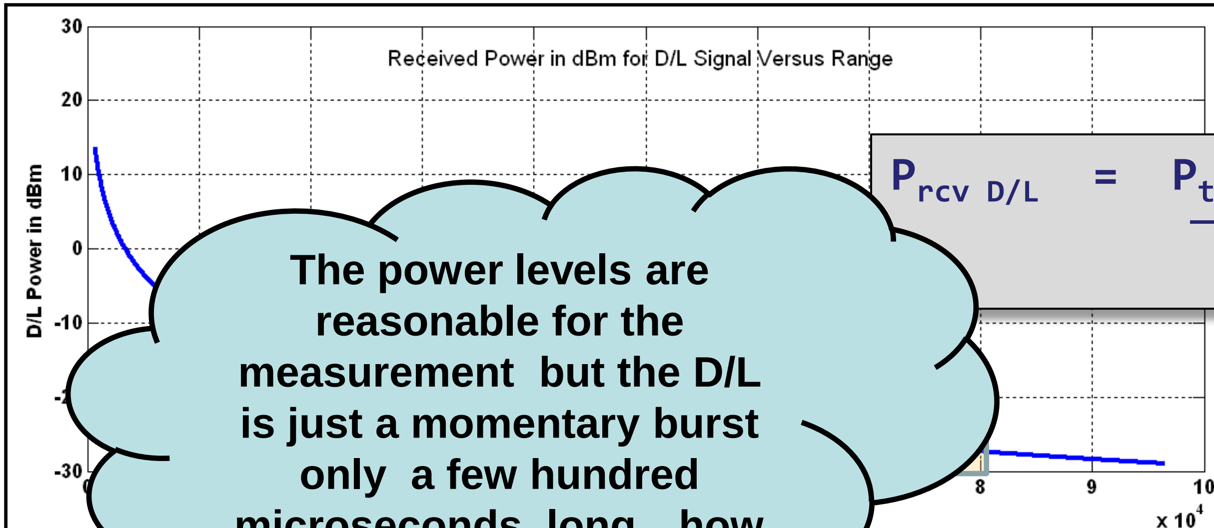
Received Power for Missile Downlink



$$P_{rcv\ D/L} = \frac{P_{tx}\ G_{tx}\ G_r\ \lambda^2}{4\pi R^2}$$

The power levels are reasonable for the measurement but the D/L is just a momentary burst only a few hundred microseconds long…how can I find it?

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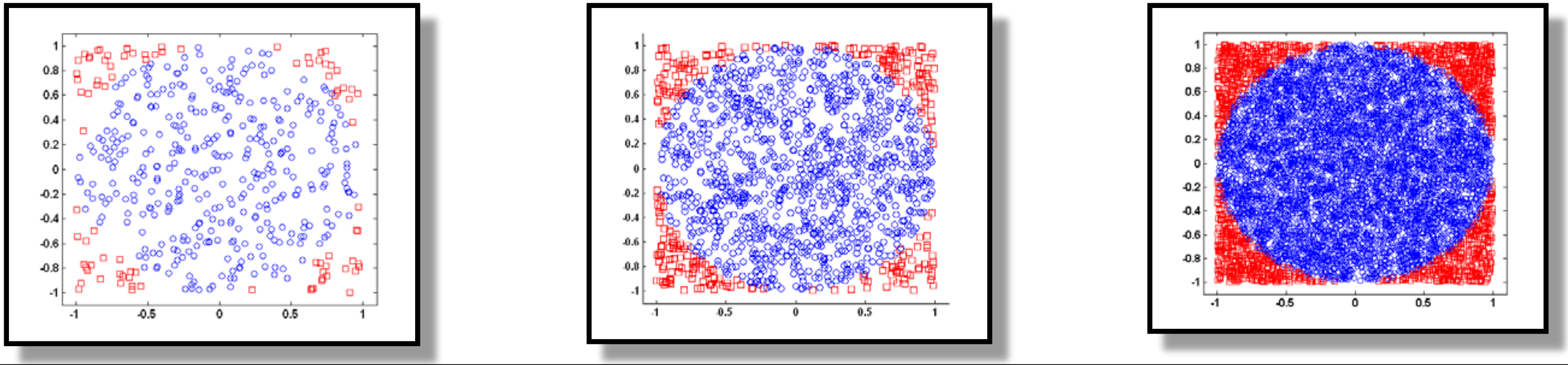
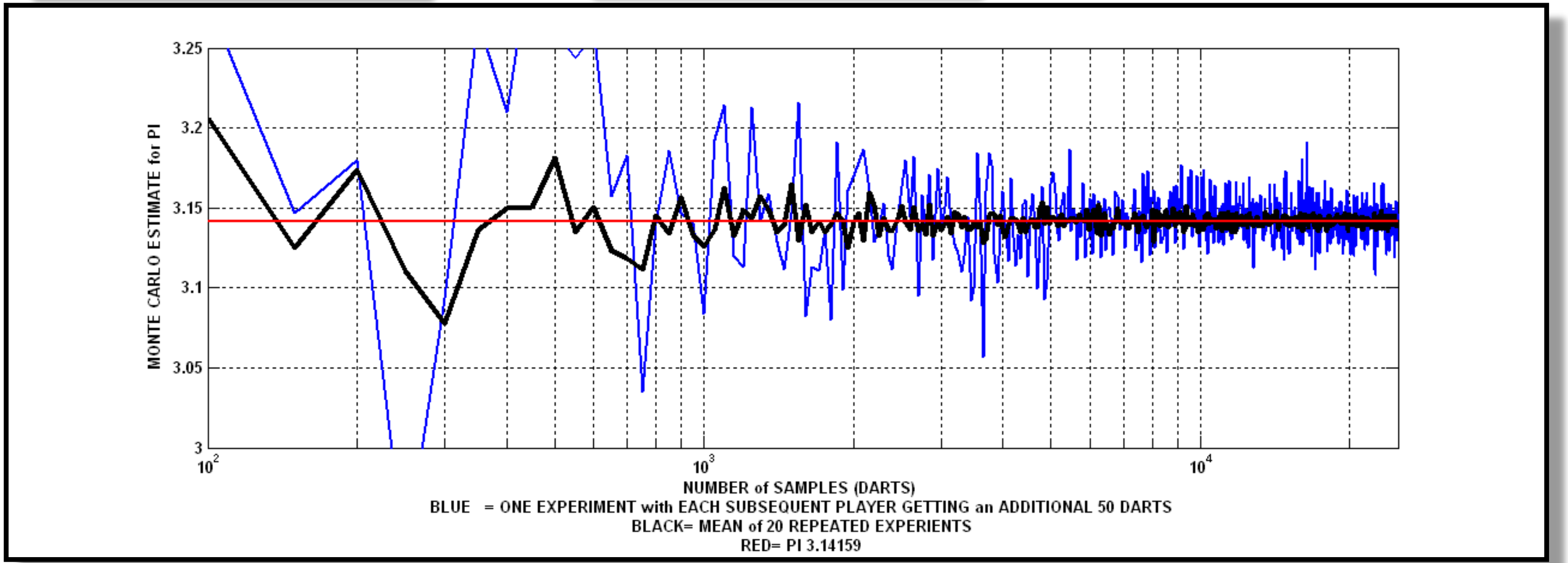
Monte Carlo Estimation of π





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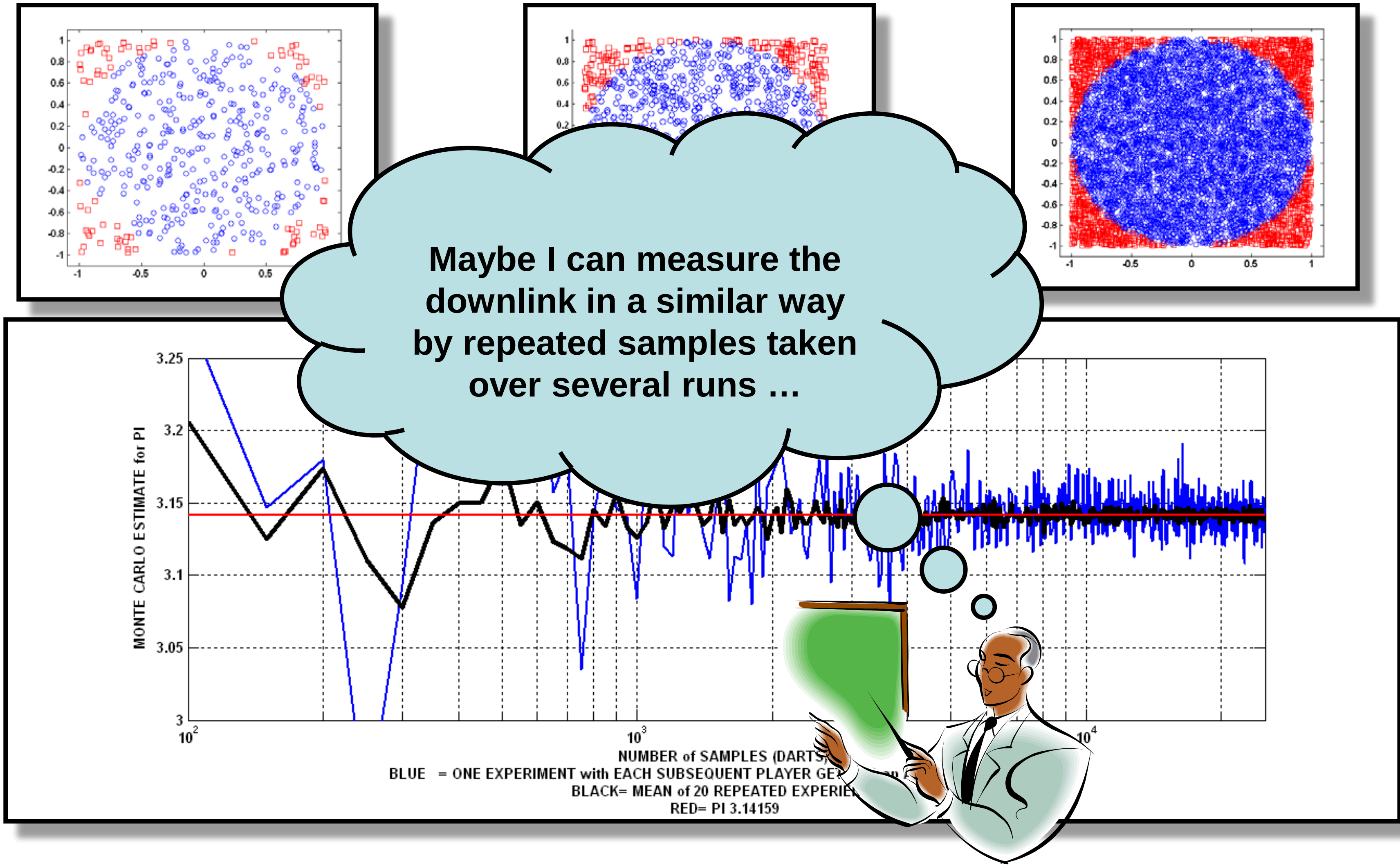
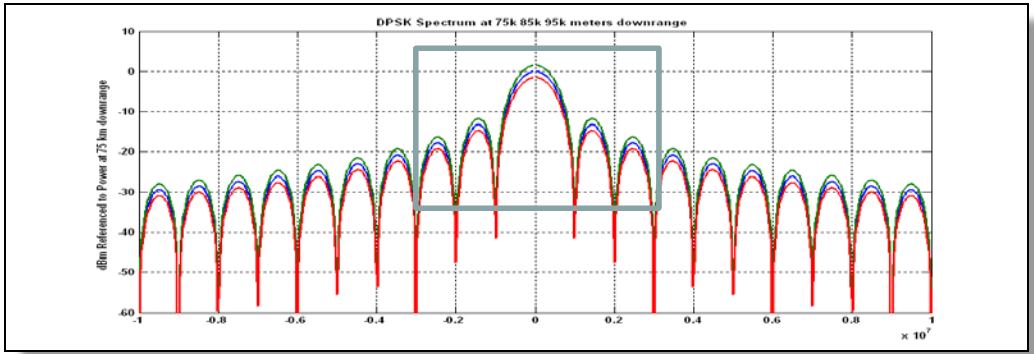
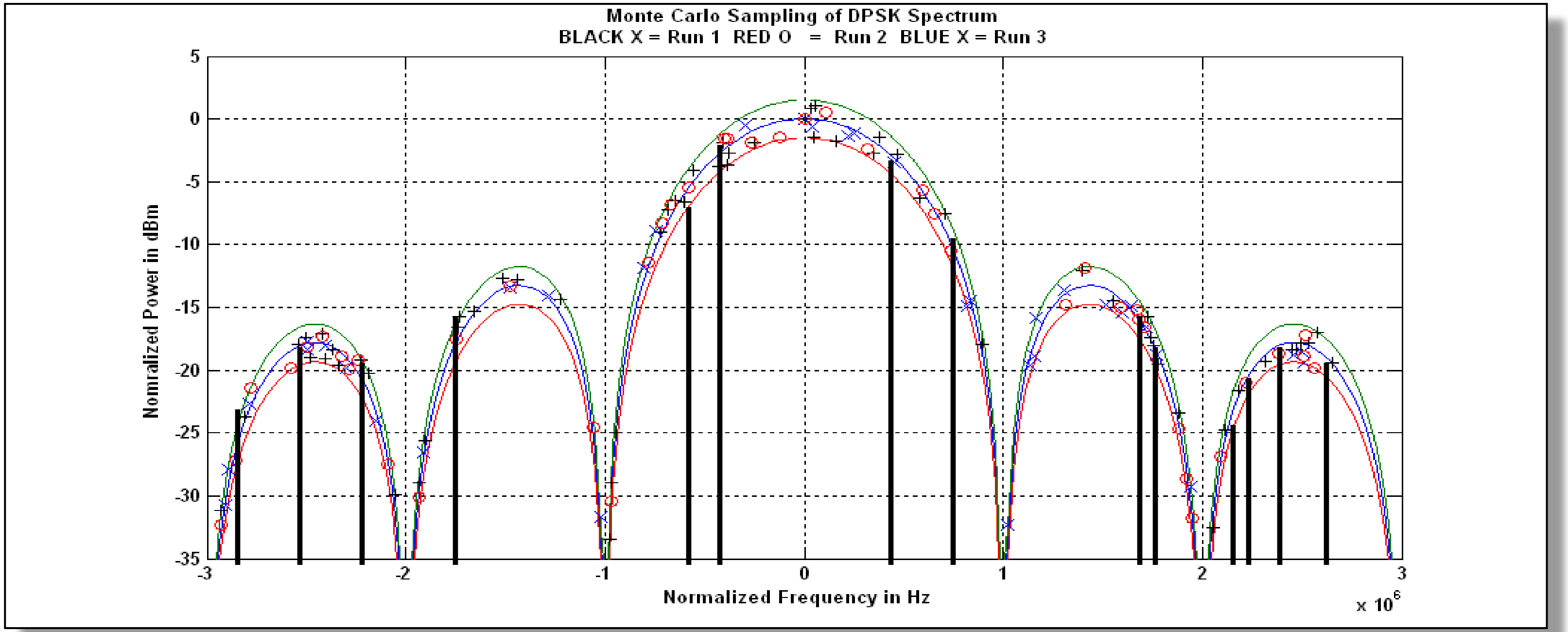
Monte Carlo Estimation of π



Monte Carlo Estimation of Downlink Spectrum



$$\frac{S(f)}{A^2 T_b} = \frac{1}{T_b}(1-2p)^2 \delta(f) + 4p(1-p)\frac{[\sin^2(\pi f T_b)]}{(\pi f T_b)^2}$$



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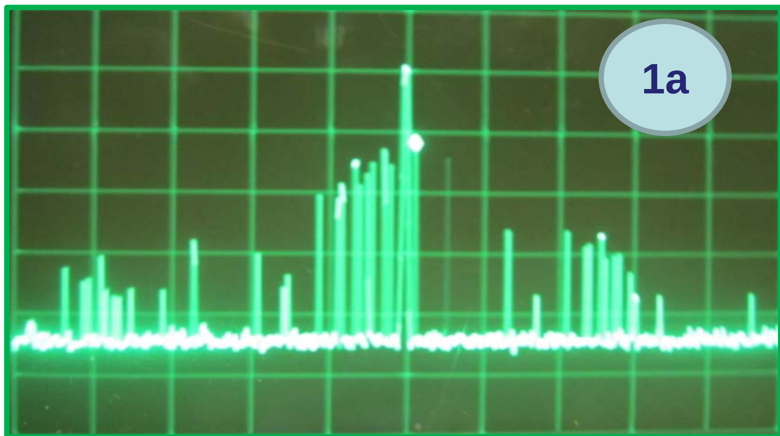
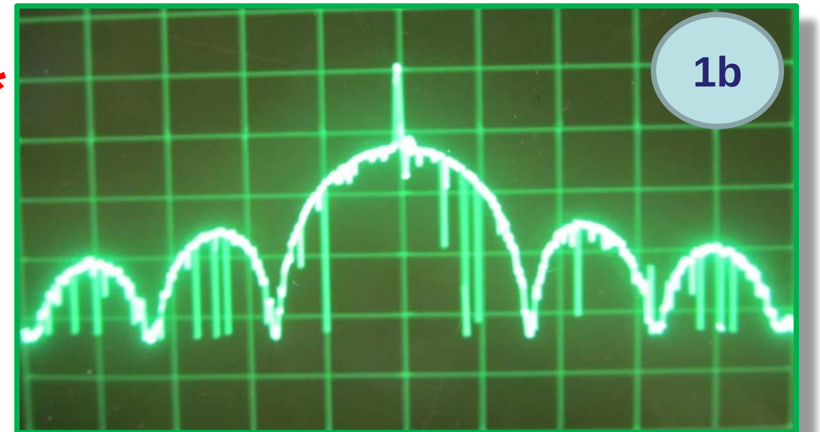
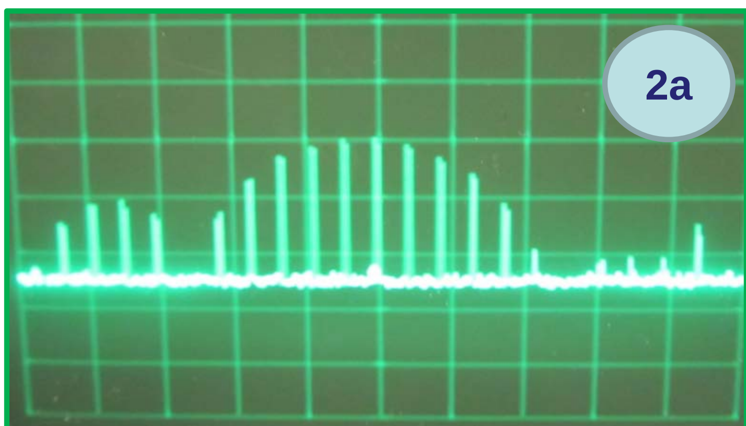
Burst by Burst Build Up of Spectrum

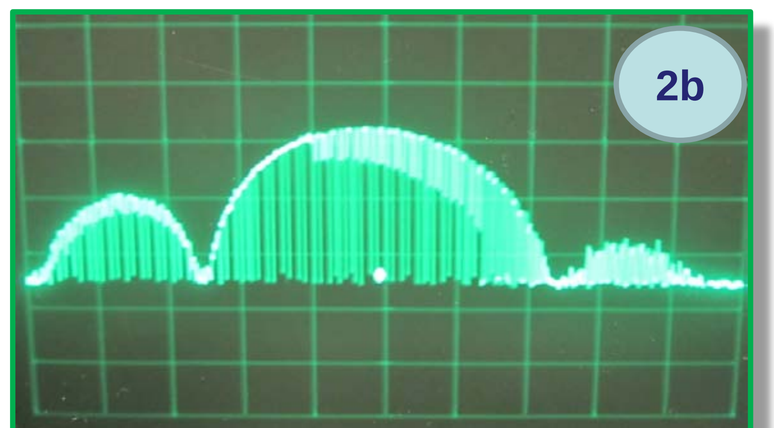


Multiple Sweeps* per Run





Single Sweep* per Run



*See additional materials section at the end of the presentation

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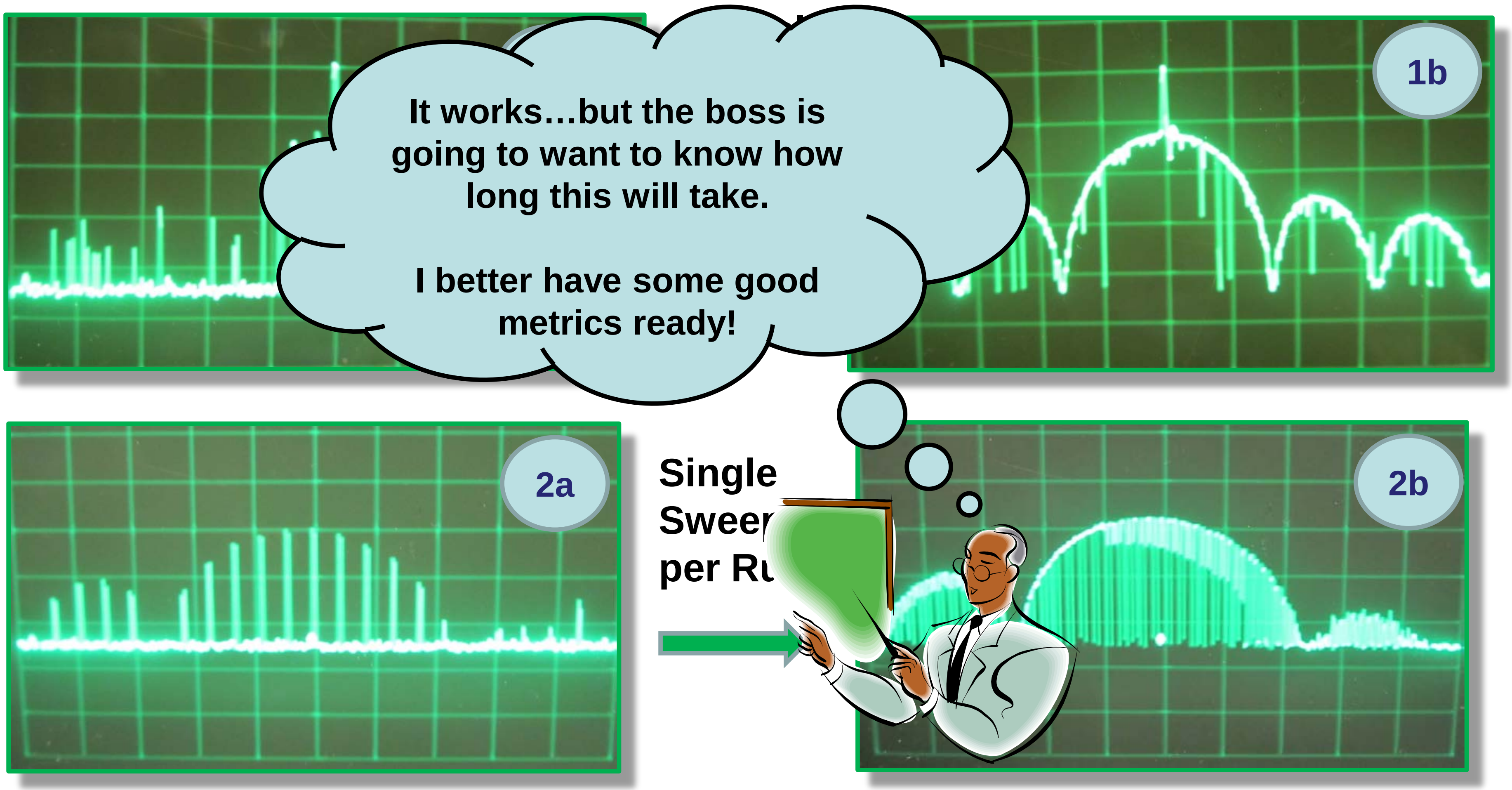
Burst by Burst Build Up of Spectrum



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Metrics, Statistics & Probability Section

1) Sweep Times Which Allow for Equally Probable Hits in One Run

$$F_{sweep} = F_{\frac{D}{L}} \left\{ p + \left[\frac{1}{\left(T_{meas} F_{\frac{D}{L}} \right)} \right] \right\}$$

2) Sensitivity to Deviations From The Ideal Sweep Time

$$\Delta N = pF^3_{D/L} T_{meas} - pF^2_{D/L} \Delta T_{sweep}$$

3) Binomial Distribution / Bernoulli Trials Simulation of the D/L Process

$$\binom{n}{k} p^k q^{n-k} \text{ where } \binom{n}{k} = \frac{n!}{[k!\,(n-k)!]}$$

$$P_r = \left[\frac{\frac{(n-1)!}{(k-1)!\,(n-k)!}}{\frac{(n)!}{(k)!\,(n-k)!}} = \frac{k}{n} \right]$$

Probability of Hitting Peak vs Normalized Span to RBW Ratio*

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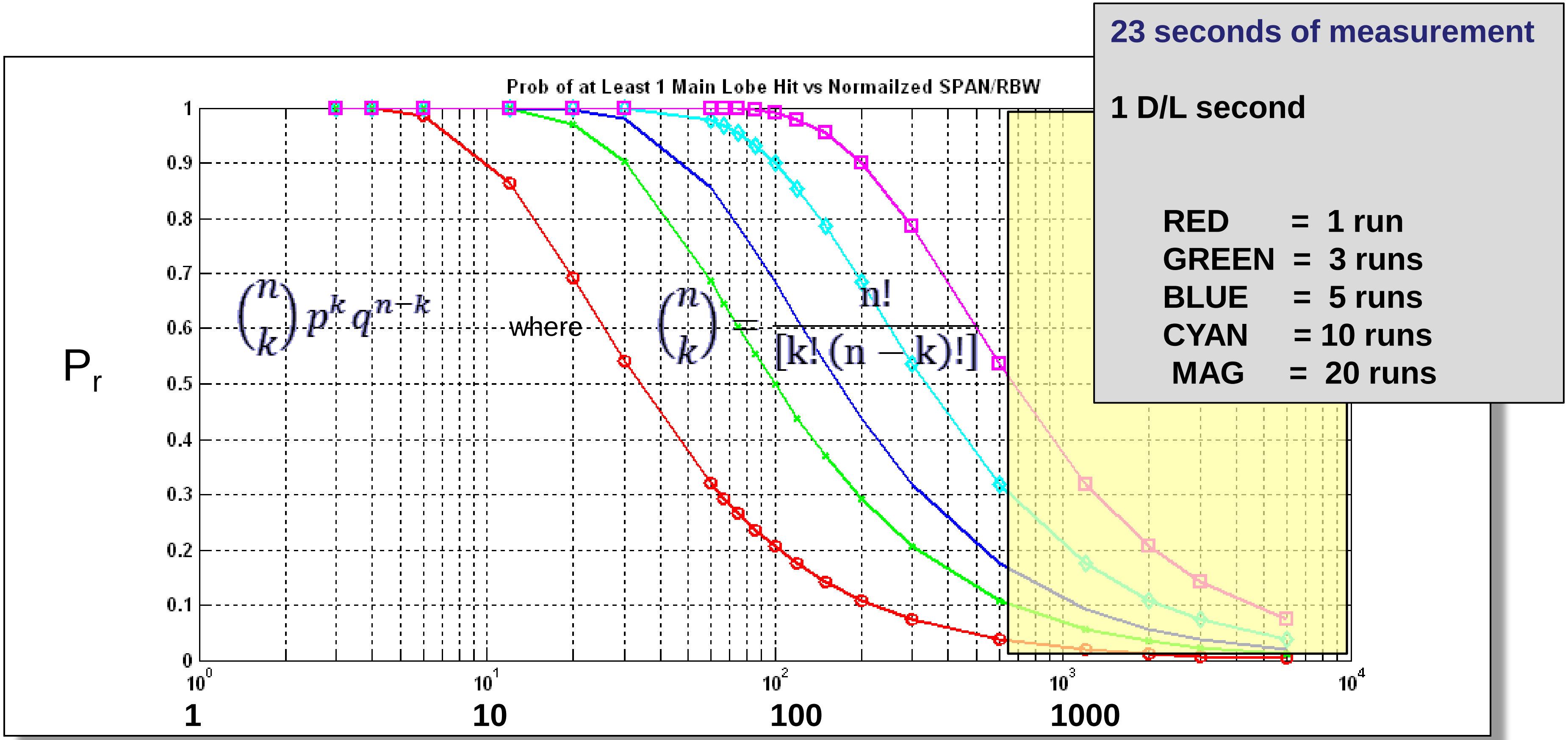

SPAN/RBW Ratio (in Decades) on Semi Log

* Computed Using Binomial Rule (see the 'Additional Material' section of this presentation)

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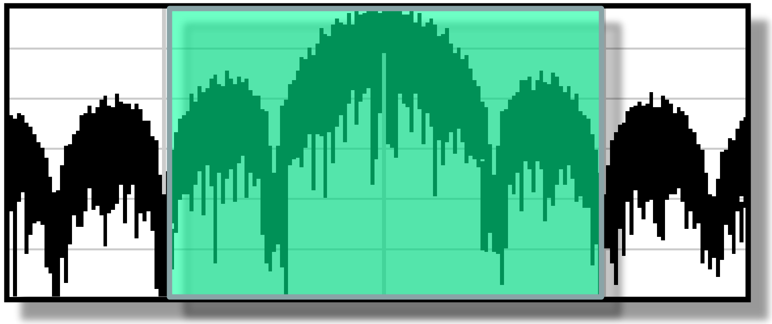
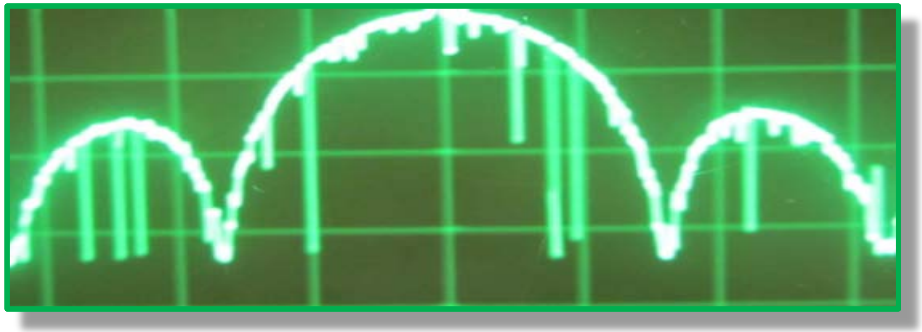
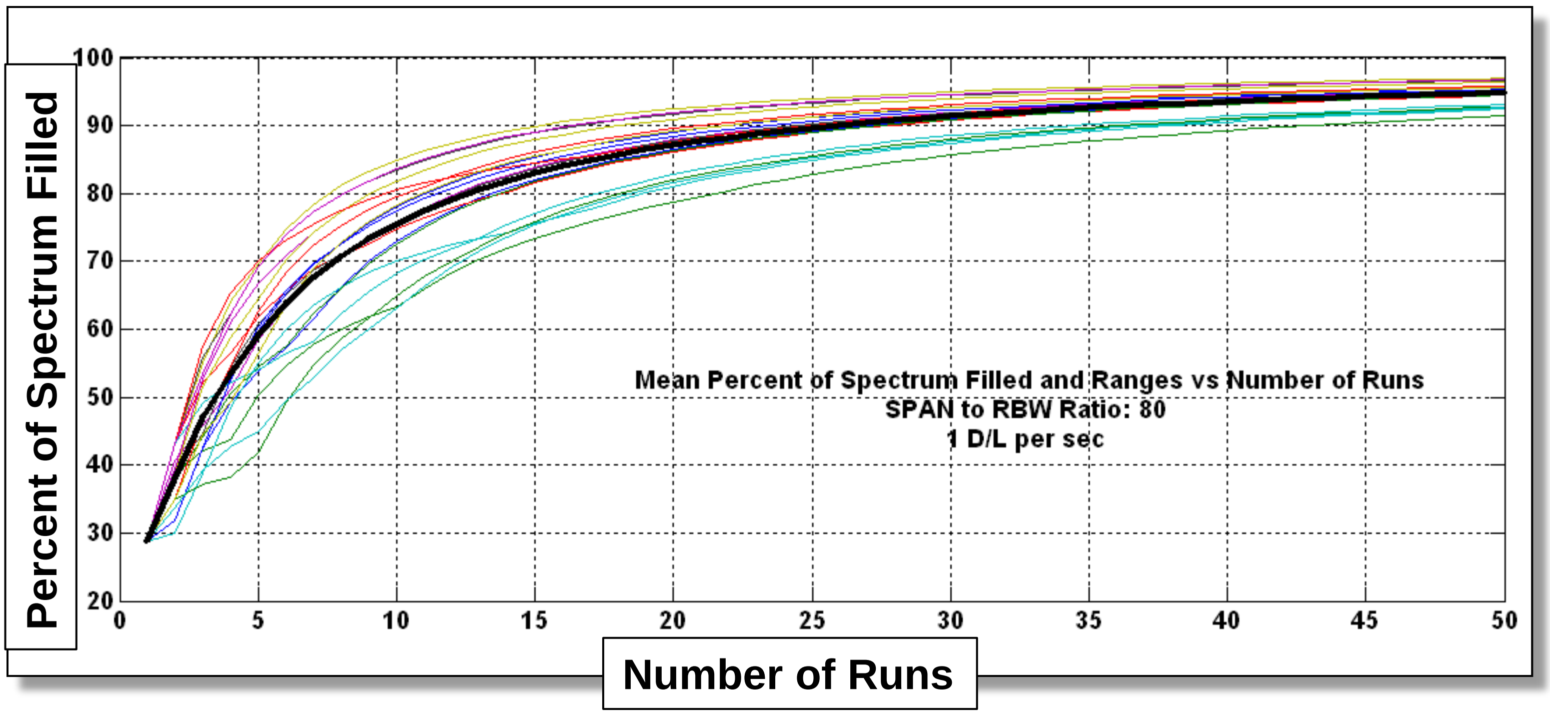
Simulated and Measured Build Up of Spectrum





Bit Rate = 2Mb/sec
Span = 8 MHz
RBW = 100 kHz
T meas = 23 s



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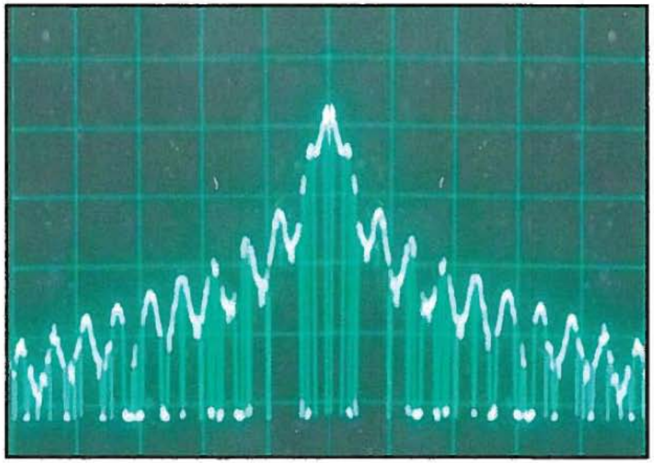
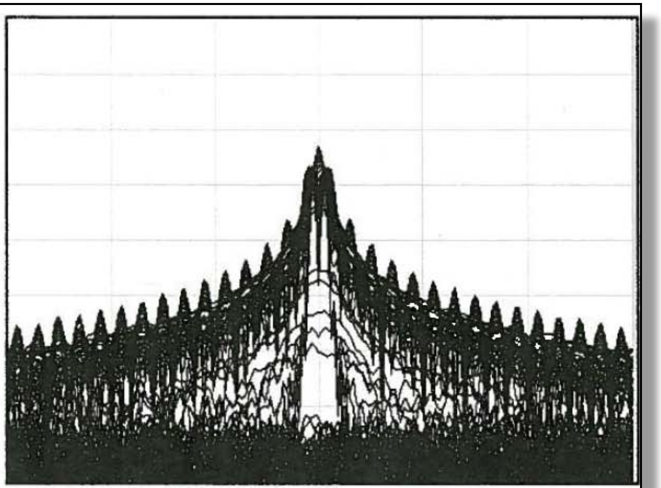
Summary


(U) Measured


(U) *Monte Carlo Simulation*

A Method For Measuring the Spectrum for Small Duration Signals Using Repeated Samples Taken Over Several Runs Has Been Discussed

The Technique Has Proven Useful for Validating the Power Levels of a HWIL Facility Using Its Dynamic Scenarios and Tactical SW

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References

Adamy D.L., *EW102*,
Artech House, Boston MA., 2004, page 130

Glisson T.H. , *Introduction to Systems Analysis,*
McGraw Hill Book Company, New York, 1985, pages 33-35

Lindsey W. C. and Simon M. K., *Telecommunications Systems Engineering*,
Dover Publications, Inc., New York, NY, pages 17-21

Papoulis A. , *Probability ,Random Variables and Stochastic Processes ,*
2nd Ed, McGraw Hill Book Company, New York, 1984, page 75-76

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Additional Materials

The materials which follow provide additional information related to the topic which would make the topic too long for the 25 minute time allotted in the NDIA conference but will aid those who may want to investigate this topic further or try it in their own lab.

Addition Material Includes:

1) Sweep Times Which Allow for Equally Probable Hits in One Run
2) Sensitivity to Deviations From The Ideal Sweep Time
3) Approaches for Handling Frequency Diversity
4) Binomial Distribution / Bernoulli Trials
5) Simulation of The Sweep and Downlinks

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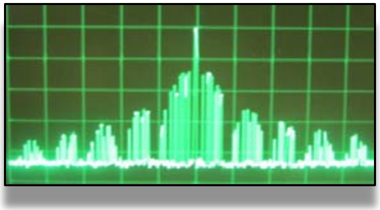
Theoretical Scope Sweep Time Options

Which Prevent Repeated Hits in any RBW

$$F_{sweep} = F_{\frac{D}{L}} \left\{ p + \left[\frac{1}{\left(T_{meas} F_{\frac{D}{L}} \right)} \right] \right\}$$



$p \in [\ \{ m: m = 0,1,2,\ldots\}\ ]$

D/L per sec	0	1	2	3	4	5	6	7	8	9	10
1	23	0.958333	0.489362	0.328571	0.247312	0.198276	0.165468	0.141975	0.124324	0.110577	0.099567
2	23	0.489362	0.247312	0.165468	0.124324	0.099567	0.083032	0.071207	0.062331	0.055422	0
4	23	0.247312	0.124324	0.083032	0.062331	0	0	0	0	0	0
6	23	0.165468	0.083032	0.055422	0	0	0	0	0	0	0
8	23	0.124324	0.062331	0	0	0	0	0	0	0	0
10	23	0.099567	0	0	0	0	0	0	0	0	0
12	23	0.083032	0	0	0	0	0	0	0	0	0
14	23	0.071207	0	0	0	0	0	0	0	0	0
16	23	0.062331	0	0	0	0	0	0	0	0	0
18	23	0.055422	0	0	0	0	0	0	0	0	0

Sweep Time Options in sec *For Varying Downlink Rates Which Ensure No Double Hits During the Experiment Time*

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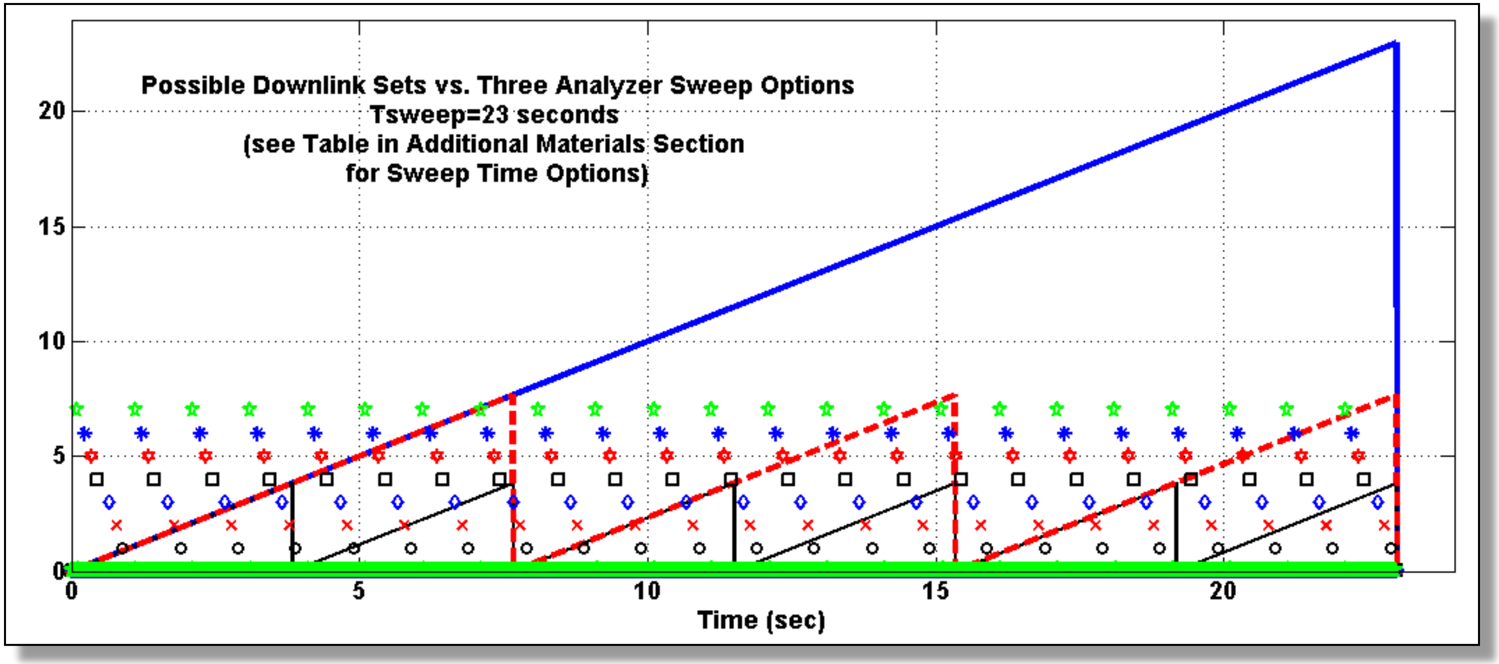
Theoretical Scope Sweep Time Options

Which Prevent Repeated Hits in any RBW

$$F_{sweep} = F_{\frac{D}{L}} \left\{ p + \left[\frac{1}{\left(T_{meas} F_{\frac{D}{L}} \right)} \right] \right\}$$



Sweep Time Options in sec *For Varying Downlink Rates Which Ensure No Double Hits During the Experiment Time*

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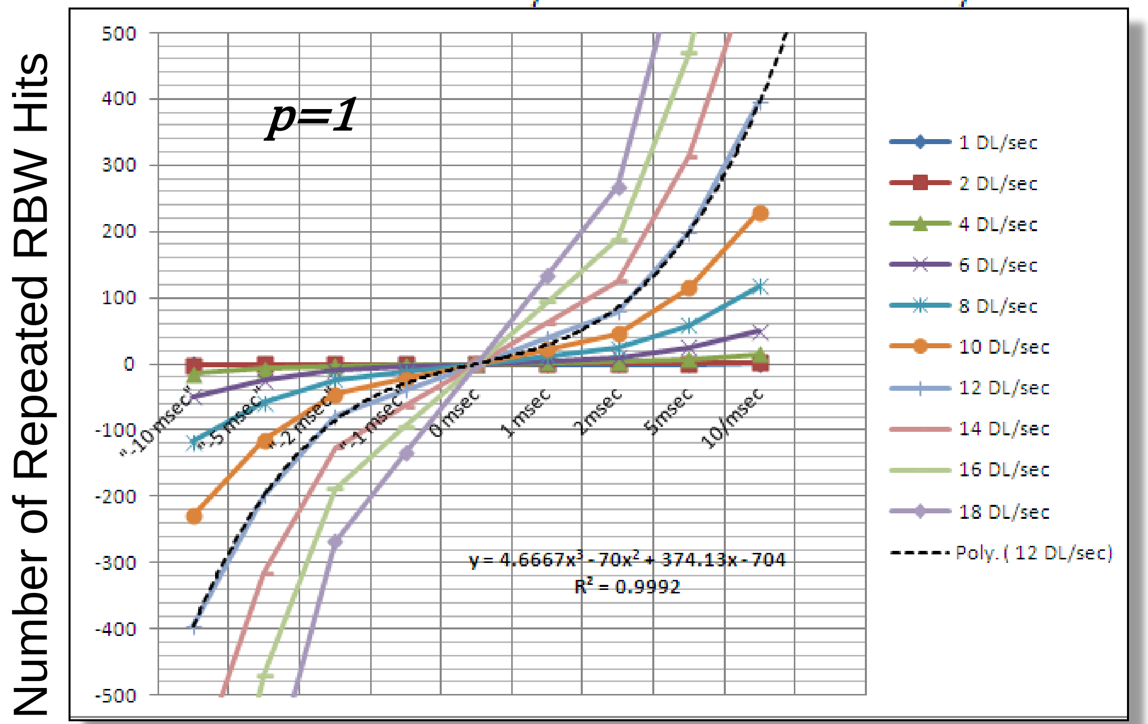
Sensitivity to Deviations in Sweep Time From the Theoretical

$$\Delta N = pF_{D/L}^{3}\,T_{meas} - pF_{D/L}^{2}\,\Delta T_{sweep}$$



Deviation From Ideal Sweep Time (msec)

Negative ΔN implies the repeat is from undershoot rather than overshoot.

This is similar in concept to the the way the spokes of a wheel will stay still, rotate clockwise or rotate counterclockwise based on the ratio between the wheel's angular rate and the 'sampling rate' or 'frame rate' in a movie.

Number of Expected Repeats When Actual Sweep Time Varies From the Theoretically 'Ideal' Sweep Time

Probability of Sampling Any One RBW in One Experiment *

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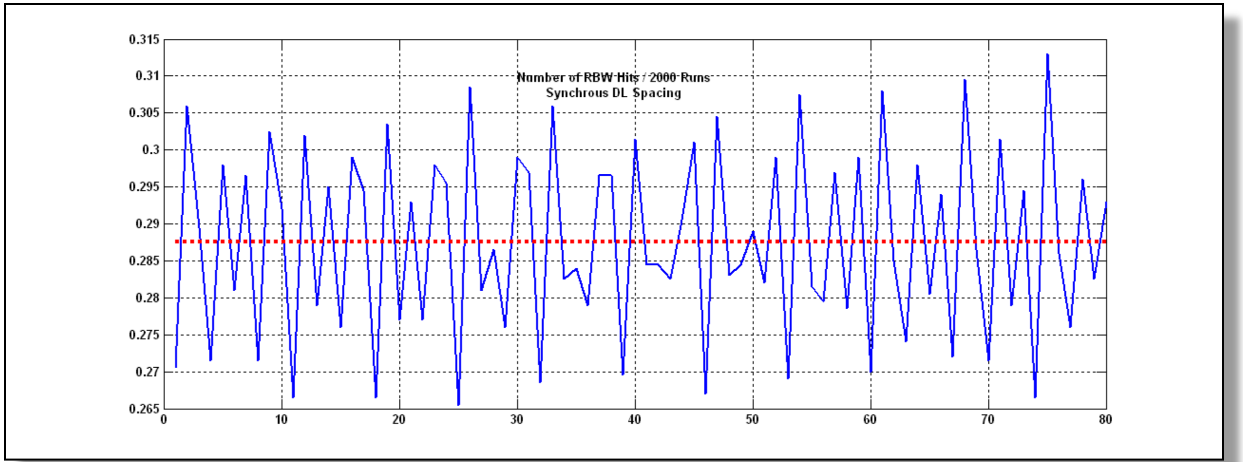

Probability of the Main Lobe Peak Getting Hit in One Experiment of 'k' Downlinks *

$$P_r = \left[\frac{\dfrac{(n-1)!}{(k-1)!\,(n-k)!}}{\dfrac{(n)!}{(k)!\,(n-k)!}} = \frac{k}{n} \right]$$

* T_{sweep} chosen so there are no double hits (see the 'Additional Material' section of this presentation)

Probability of Hitting Peak vs Normalized Span to RBW Ratio*

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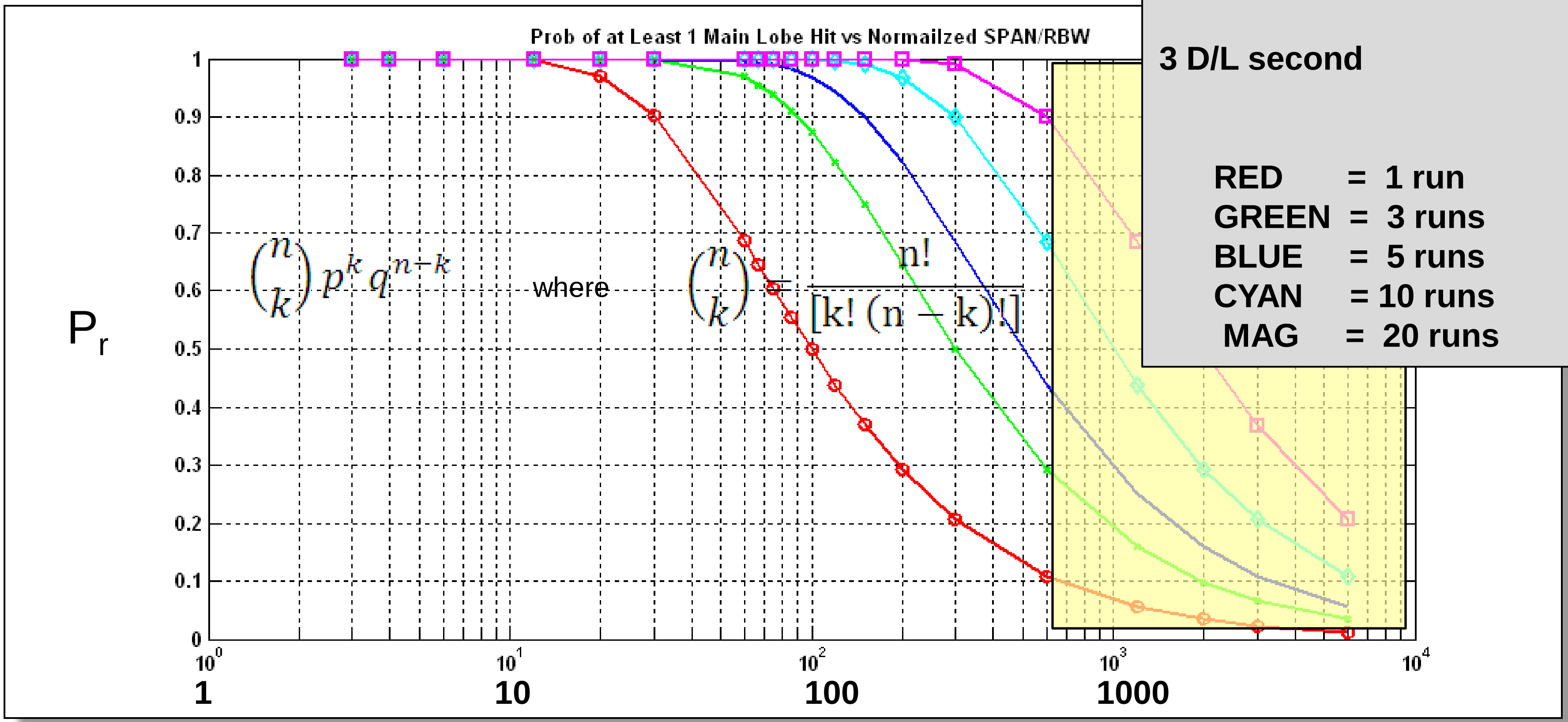

23 seconds of measurement

3 D/L second

RED = 1 run
GREEN = 3 runs
BLUE = 5 runs
CYAN = 10 runs
MAG = 20 runs

SPAN/RBW Ratio (in Decades) on Semi Log

* Computed Using Binomial Rule (see justification in the 'Additional Material' section of this presentation)

Probability of Hitting Peak vs Normalized Span to RBW Ratio*

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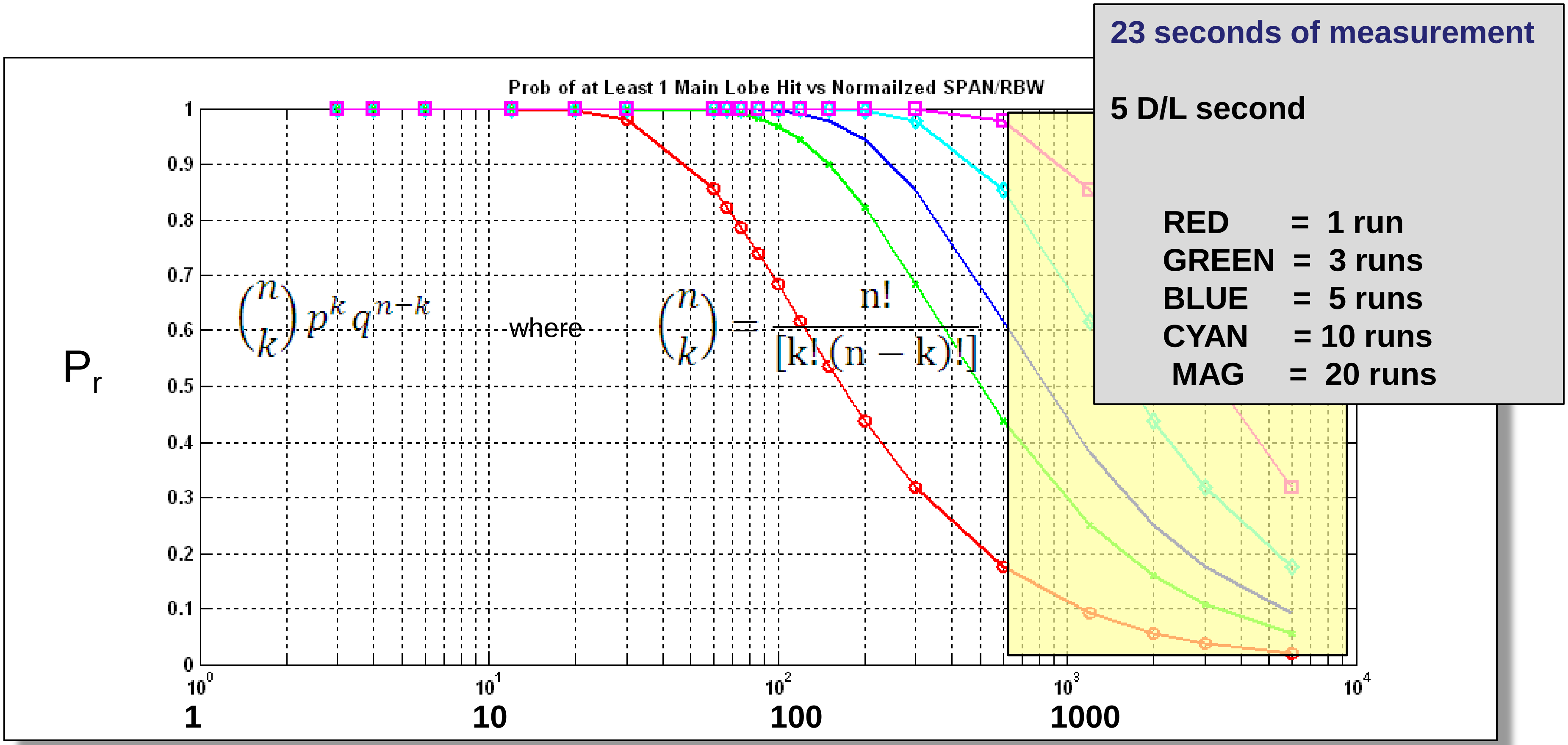

SPAN/RBW Ratio (in Decades) on Semi Log

* Computed Using Binomial Rule (see justification in the 'Additional Material' section of this presentation)

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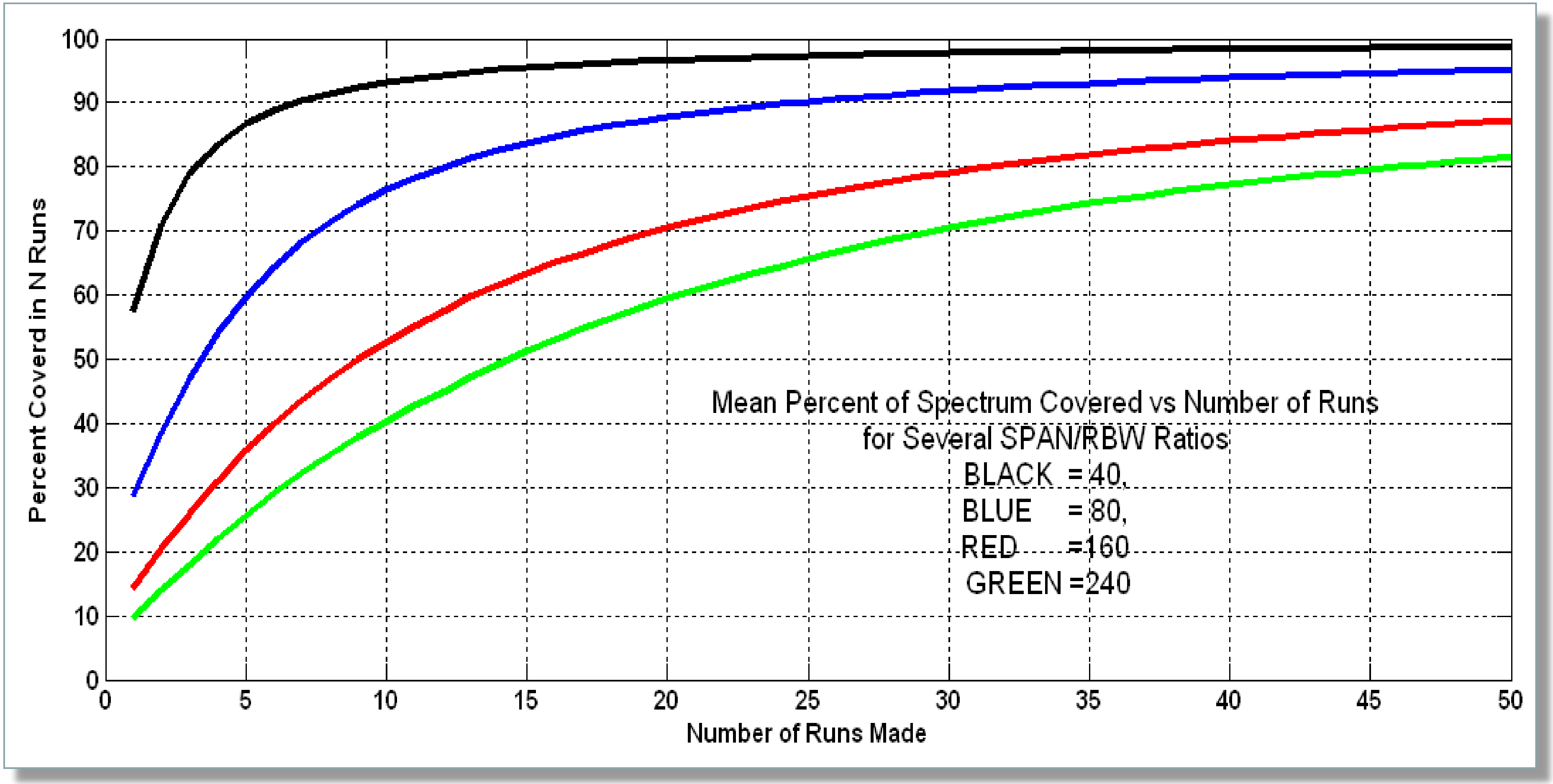
Simulated and Measured Build Up of Spectrum



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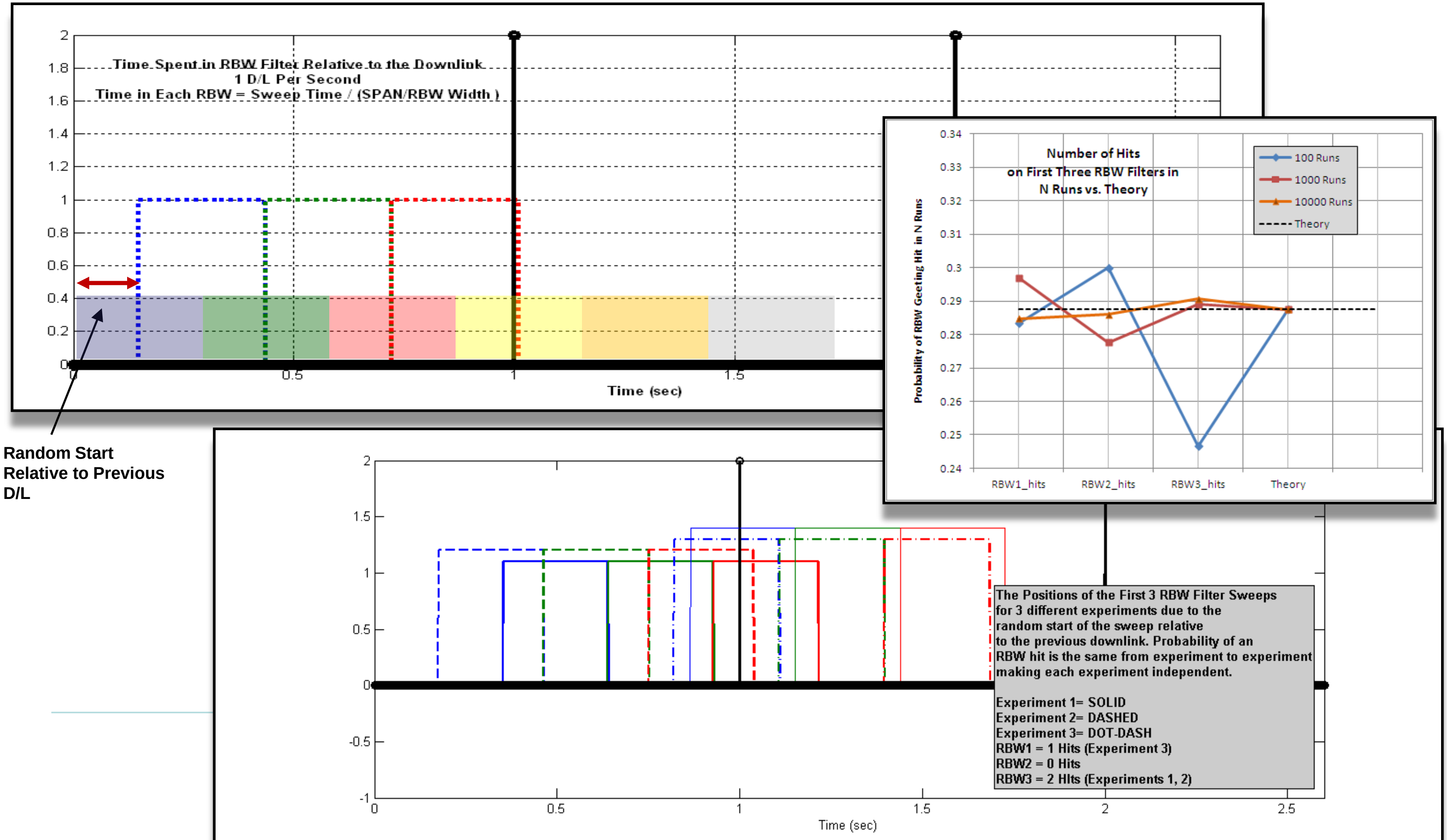
Which RBWs Can Be Hit ?



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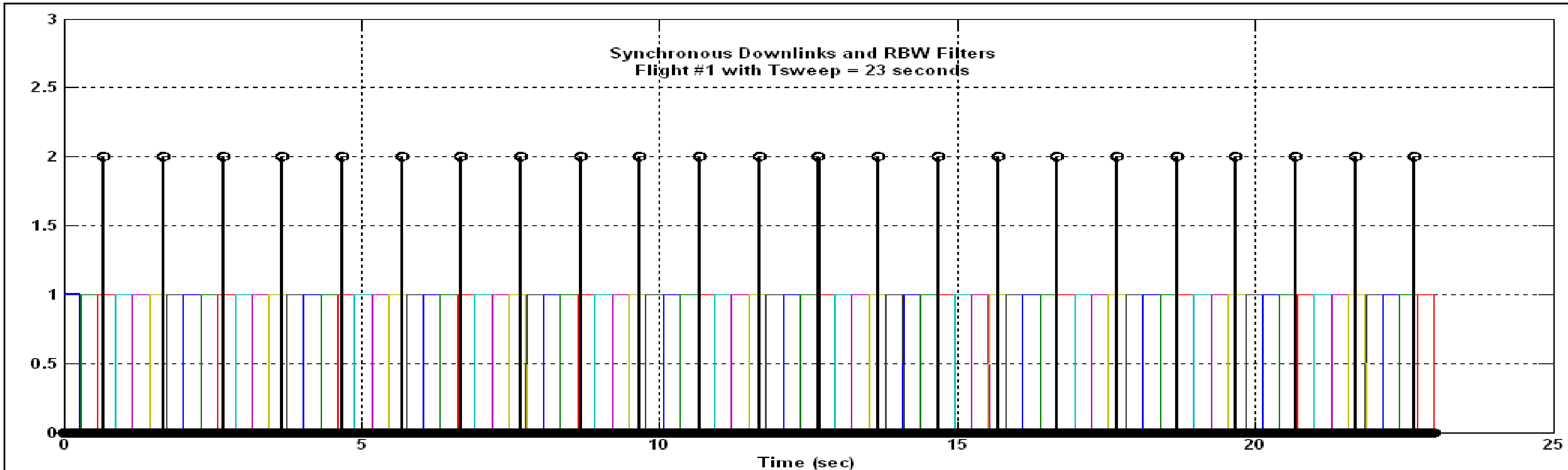
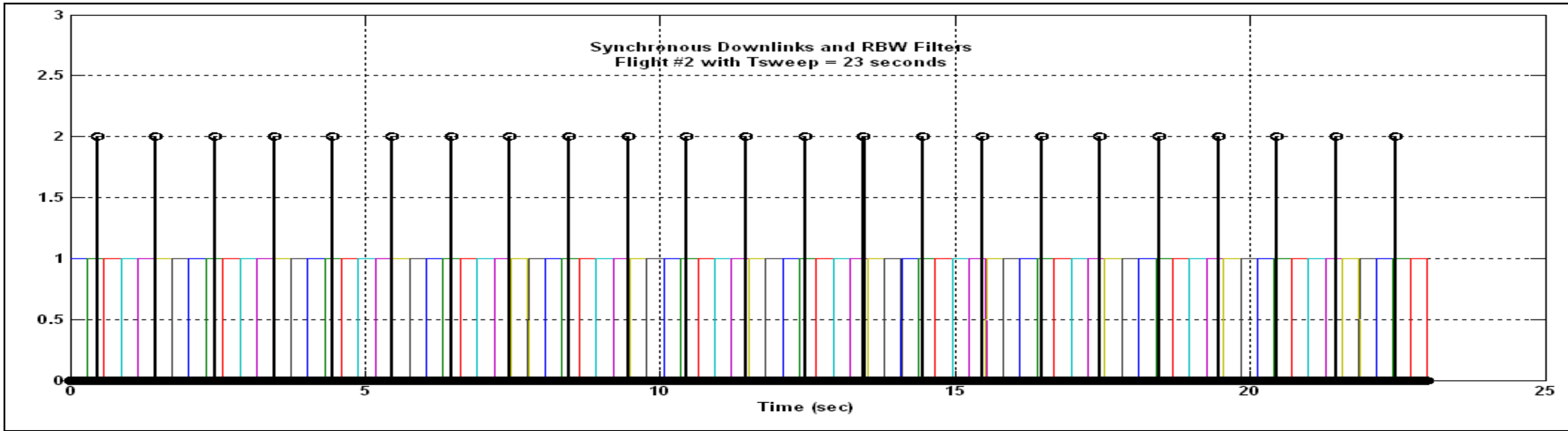
Synchronous Filling of RBW Filters in a Single Sweep (2 Runs)





Monte Carlo Variation On Which RBW Are Hits

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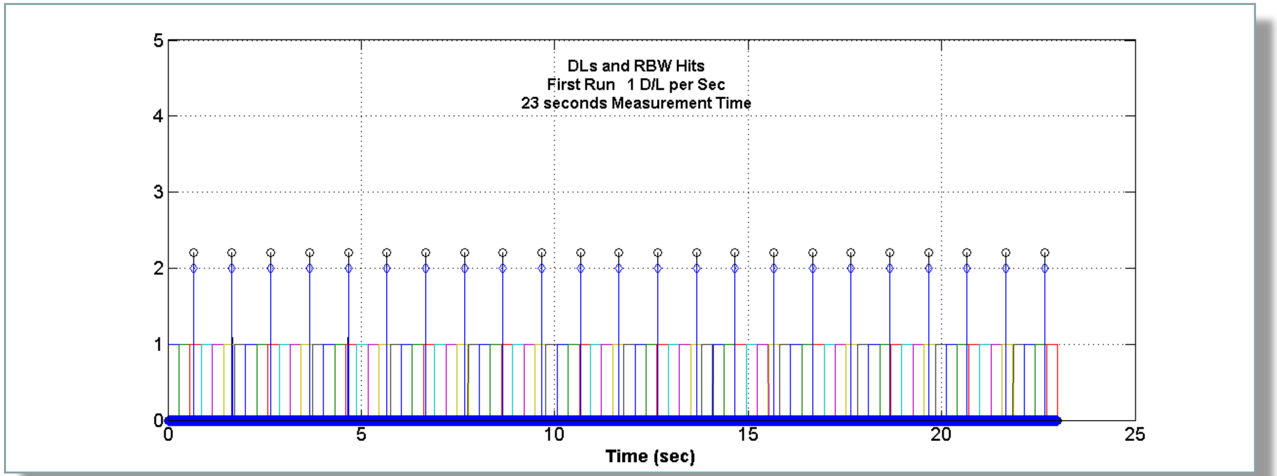

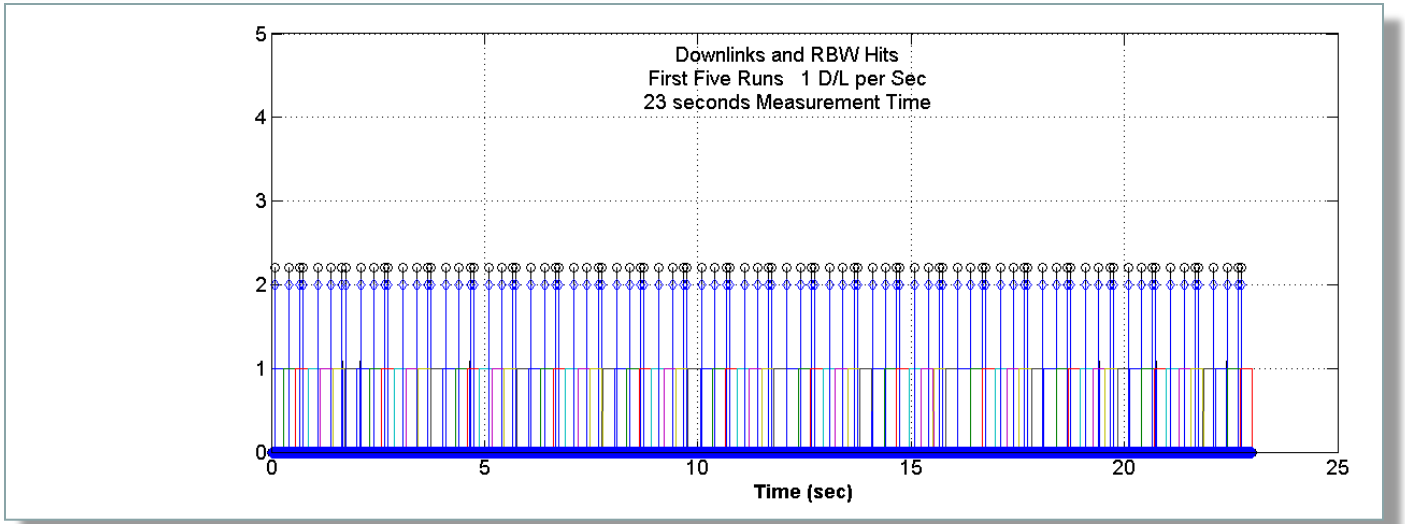

Asynchronous Filling of RBW Filters in a Single Sweep (2 Runs)

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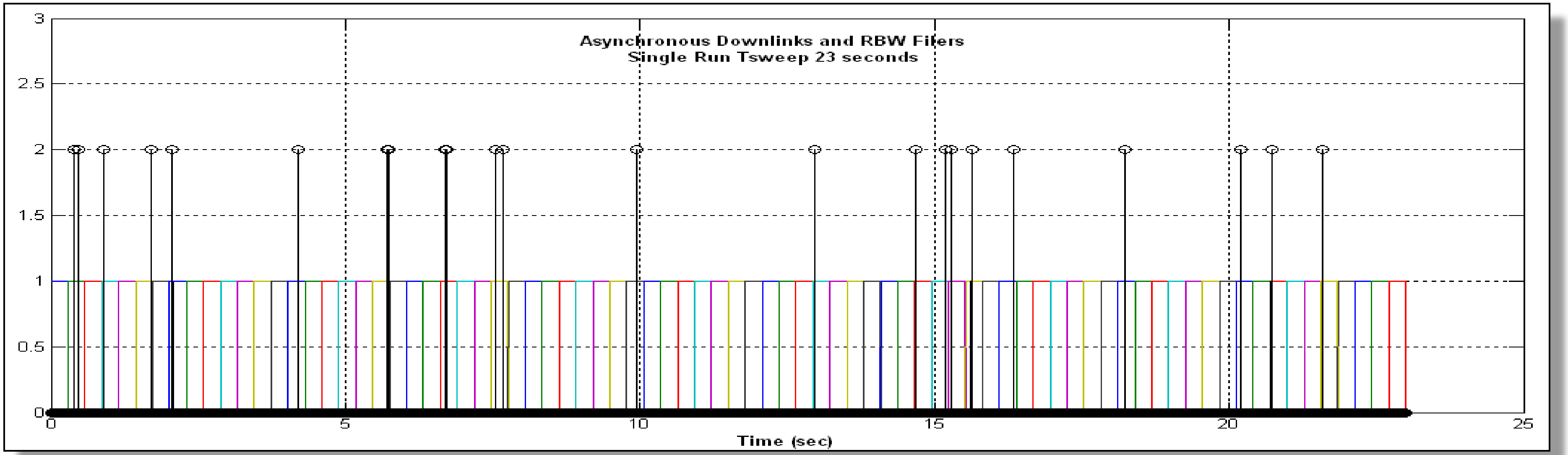

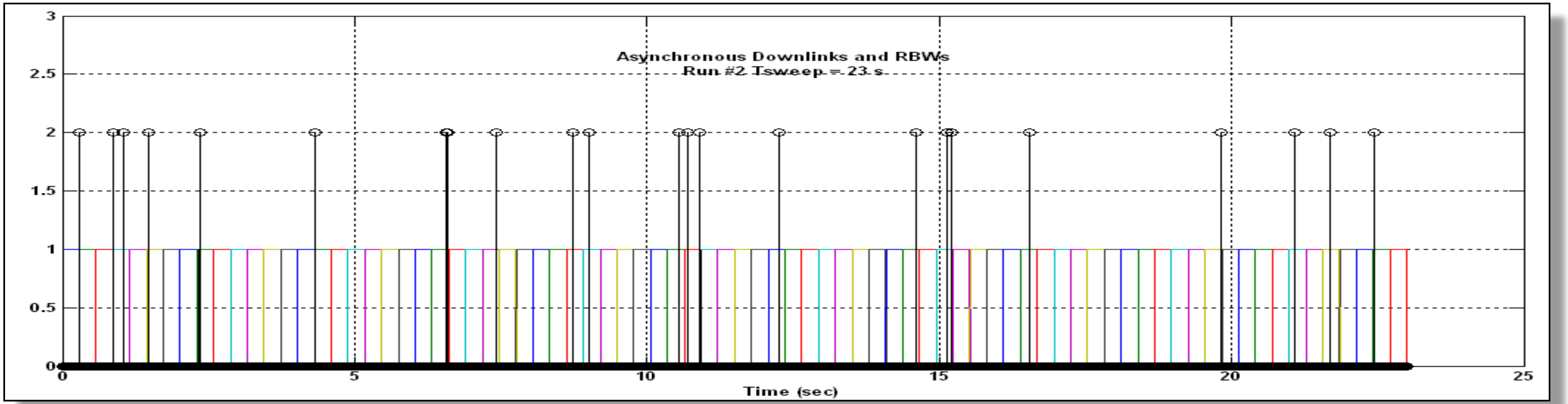

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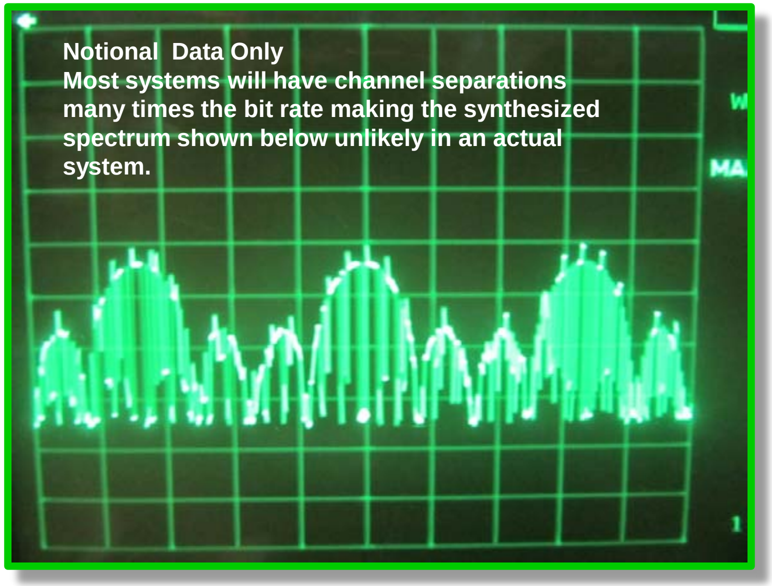
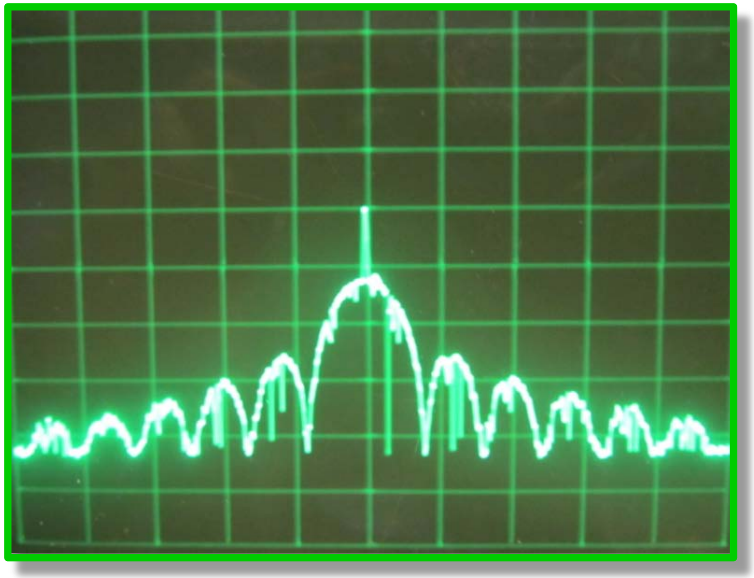
Approaches for Handling Frequency Diversity





Frequency Changes With One Run
-- System Tables
-- Wider Span
-- Live with More Runs & Measurements

Run-to-Run Diversity
-- Adjust Analyzer Center Frequency Between Runs

Spectrum for NRZ Signals

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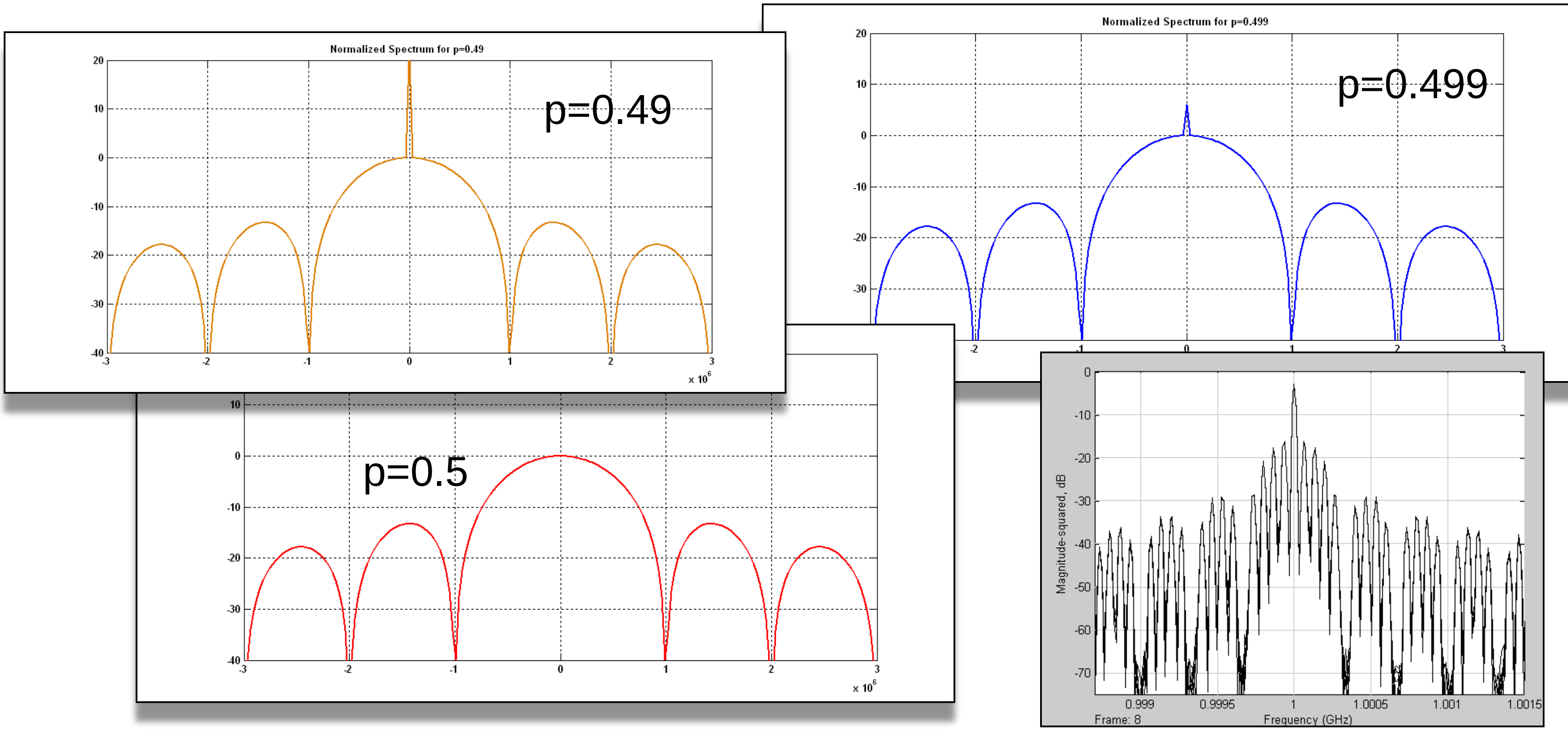
$$\frac{S(f)}{A^2 T_b} = \frac{1}{T_b}(1-2p)^2 \delta(f) + 4p(1-p) \frac{[\sin^2(\pi f T_b)]}{(\pi f T_b)^2} \quad [1]$$



[1] Lindsey W. C. and Simon M. K., *Telecommunications Systems Engineering*, Dover Publications, Inc., New York, NY, pages 17-21

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Additional Considerations For Using the Technique

For Small Signals Focus on the Peak or Center Area to Reduce the Span to RBW Ratio

Remember to Factor in Doppler and the Change in Doppler and over Measurement

Understanding the Spectrum Analyzer Output versus the 'True' power

-- This is a topic to be studied in and of itself

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Biography

Author Biography

Mr. Boncek is a Senior Principal Engineer who has worked in the area of computer modeling simulation and Hardware-in-the-Loop testing at Raytheon for 22 years. He earned his MSEE from Georgia Tech as part of Raytheon's Advanced Graduate Study program. Mr. Boncek has pioneered several innovative techniques in Modeling & Simulation at Raytheon. He is also active in the community working with High School and Middle school students in the area of STEM education. In one effort he collaborated with the educational branch of the New England Patriots to host an engineering design challenge he designed where students design, build and test parabolic microphones. He was awarded the quarterly Citizenship Award in May 2011 for his work with students in the area of STEM by the president of Raytheon's IDS business.