NAVAL SURFACE WARFARE CENTER
DAHLGREN DIVISION

ELECTROMAGNETIC & SENSOR SYSTEMS DEPARTMENT

Random Walk Technique: Measuring EME in Below-Deck Complex Cavities

22 August 2008

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E^3 Assessment & Evaluation Branch (Q52)

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Outline

- **Background – Evolution of Below-Deck Test**
  - > 60 spaces: Sacagawea, Battan, Iwo Jima
  - Refinement of measurement techniques
- **New “Walk-Around” Measurement Method**
  - Comparison with other methods
  - Validation
  - Data analysis

Technology Is Changing

- **Improved Command, Control & Communications**
  - Automation Provides…..
    - Better Process Control
    - Real Time Situational Awareness
    - Reduced Manning Capabilities
- **Wireless Interfaces Enhance Automation…..**
  - Reduces Installation Costs
  - Provides Greater Flexibility
  - Allows Remote Monitoring & Control

E^3 Issues

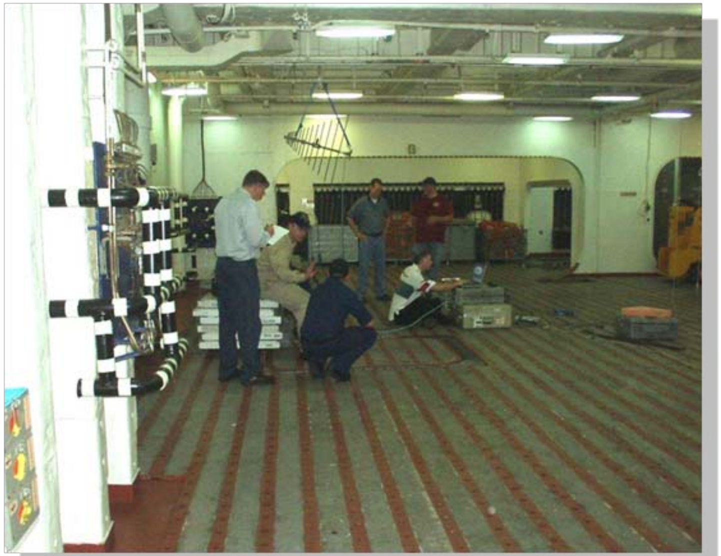
- **RF Emissions Can Be Problematic**
  - Potential Issues With
    - HERO, EMI, EMC & Spectrum Usage
    - RF Emissions in Confined Spaces are Additive
- **Such Spaces Become Low-Power Microwave Ovens**
  - Reverberation Chamber / Complex Cavity Characterization Bounds The Problem
    - Gain Qualitative Understanding Spectrum Usage
    - Allows Prediction Of Potential EMI To Legacy Systems
    - Provides A Means To Assess Deployment Scenarios
    - Assures That Ordnance Safety Protocols Are Maintained

Below-Deck Spaces

T-AKE, LHD, CVN

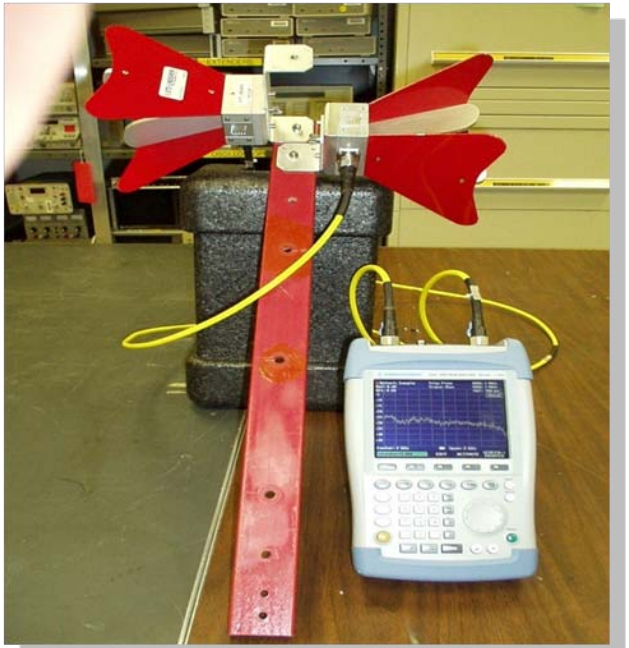
- Ordnance Magazine
- Pyrotechnics Storage
- Operations Center
- Electronics
- Decks

Designated DoD HERO lead for AIT equipment



Measurement Techniques

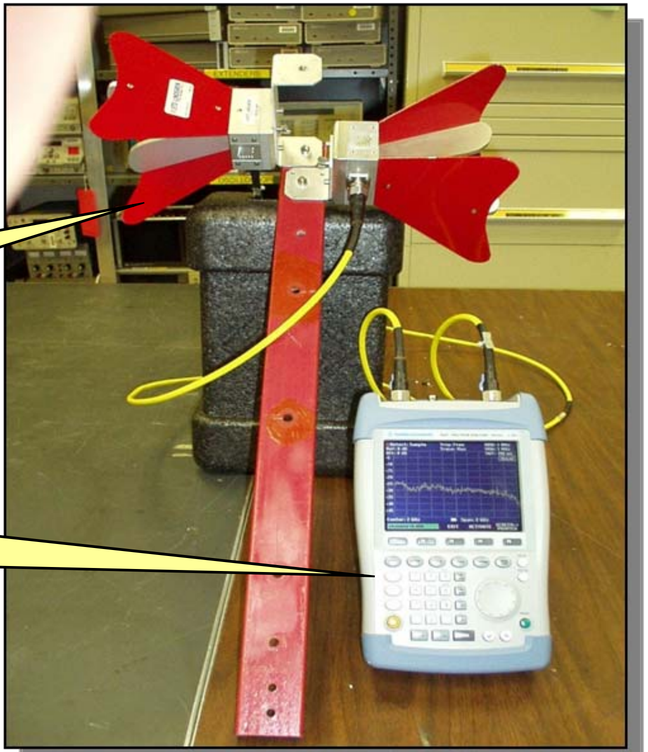
- **Mode Stir: Mechanical**
- **Volume Sample: Multiple Antenna Positions**
- **Frequency Stir**
- **Random Walk**



Continuous Technique

- **Continuous Location Field Mapping**
  - Sweep RF Across Test Spectrum
  - Transmit, Measure and Hold Maximum Value
  - Walking Through Space
  - Repeat 6 Times

"Random Walk" Origin

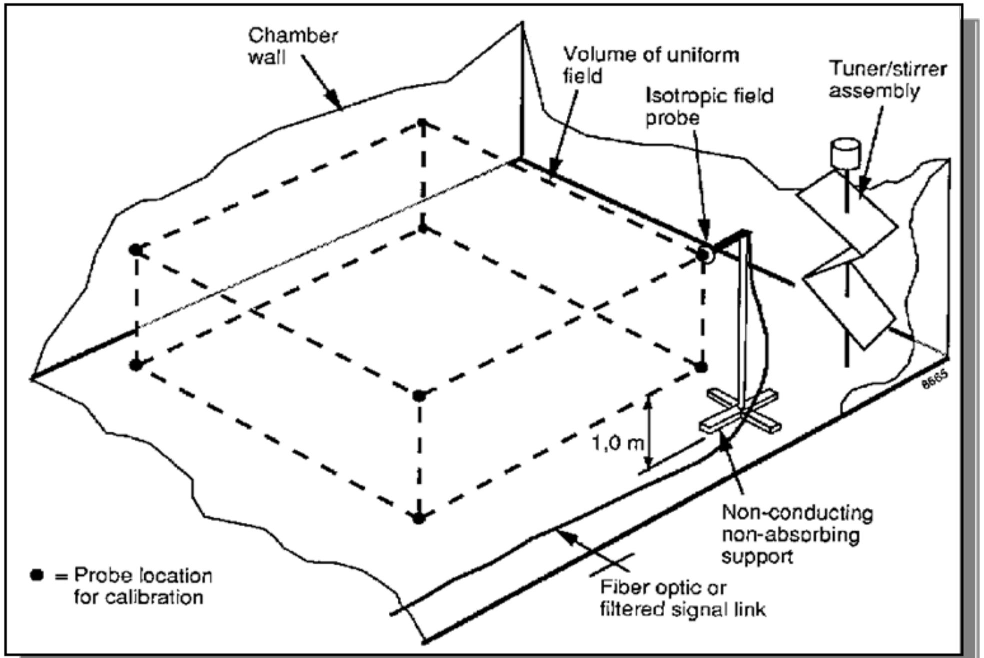


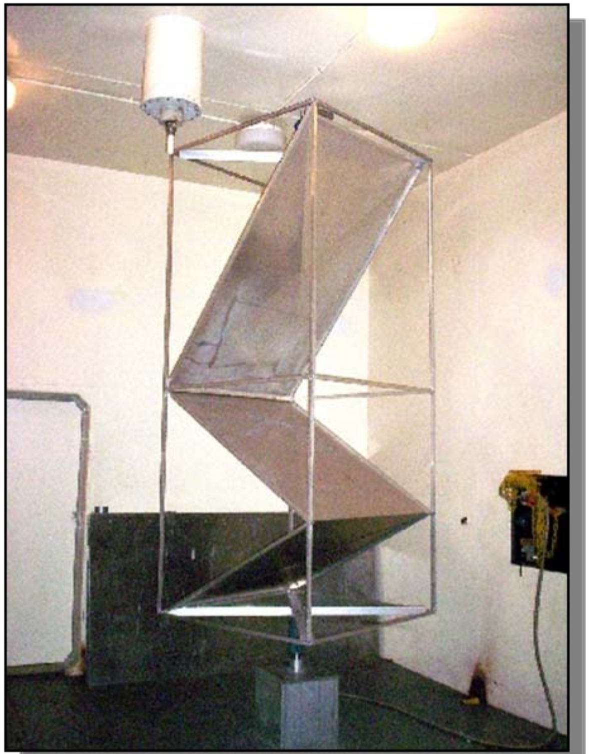
Transmit and Receive Antennas

Handheld Spectrum Analyzer w/TG

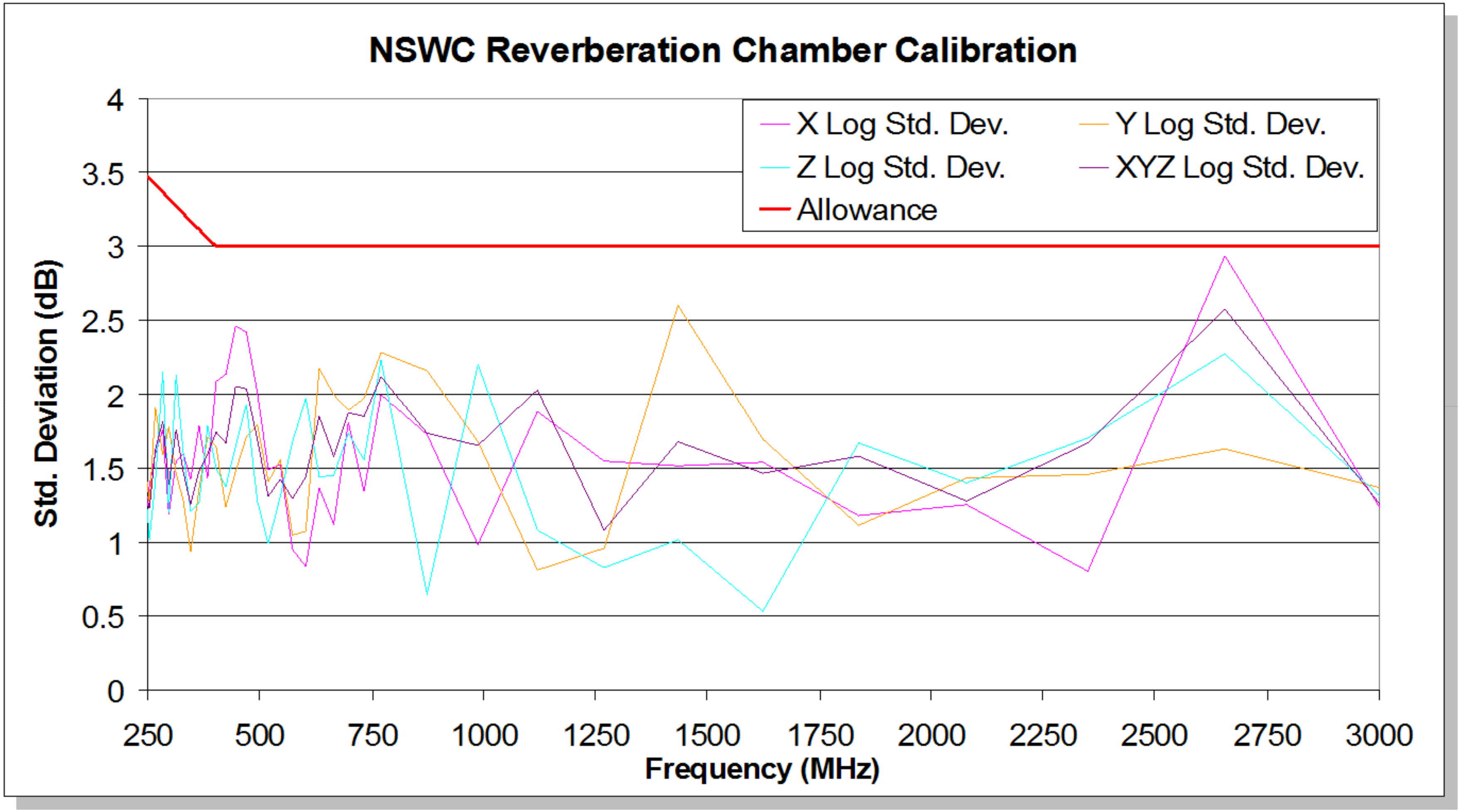
Standards Based Practices

- **Reverberation Chamber Calibrations**
  - Provide Data On….
    - Resultant E-Field per Root Watt Input
    - Volumetric Uniformity

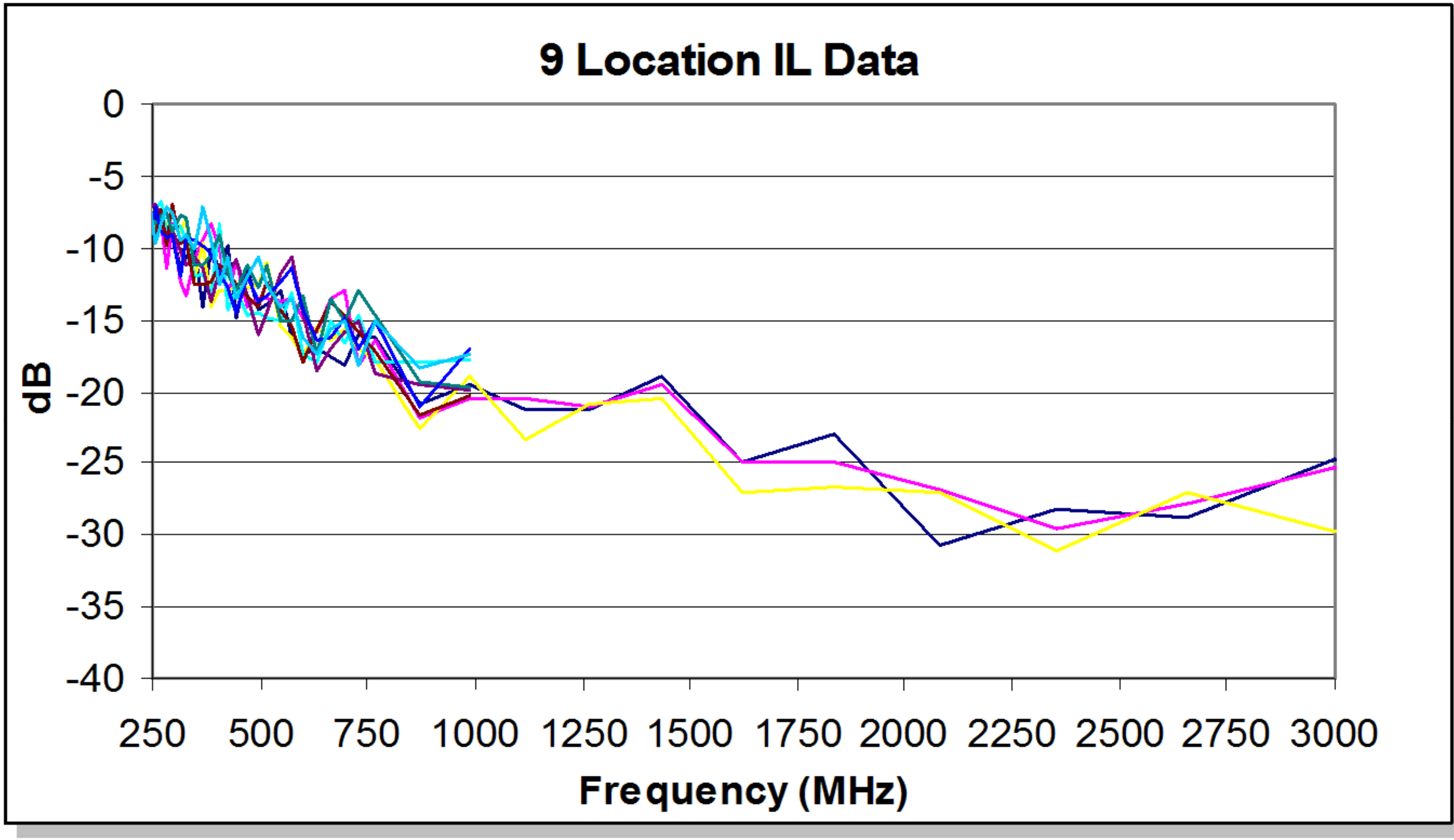




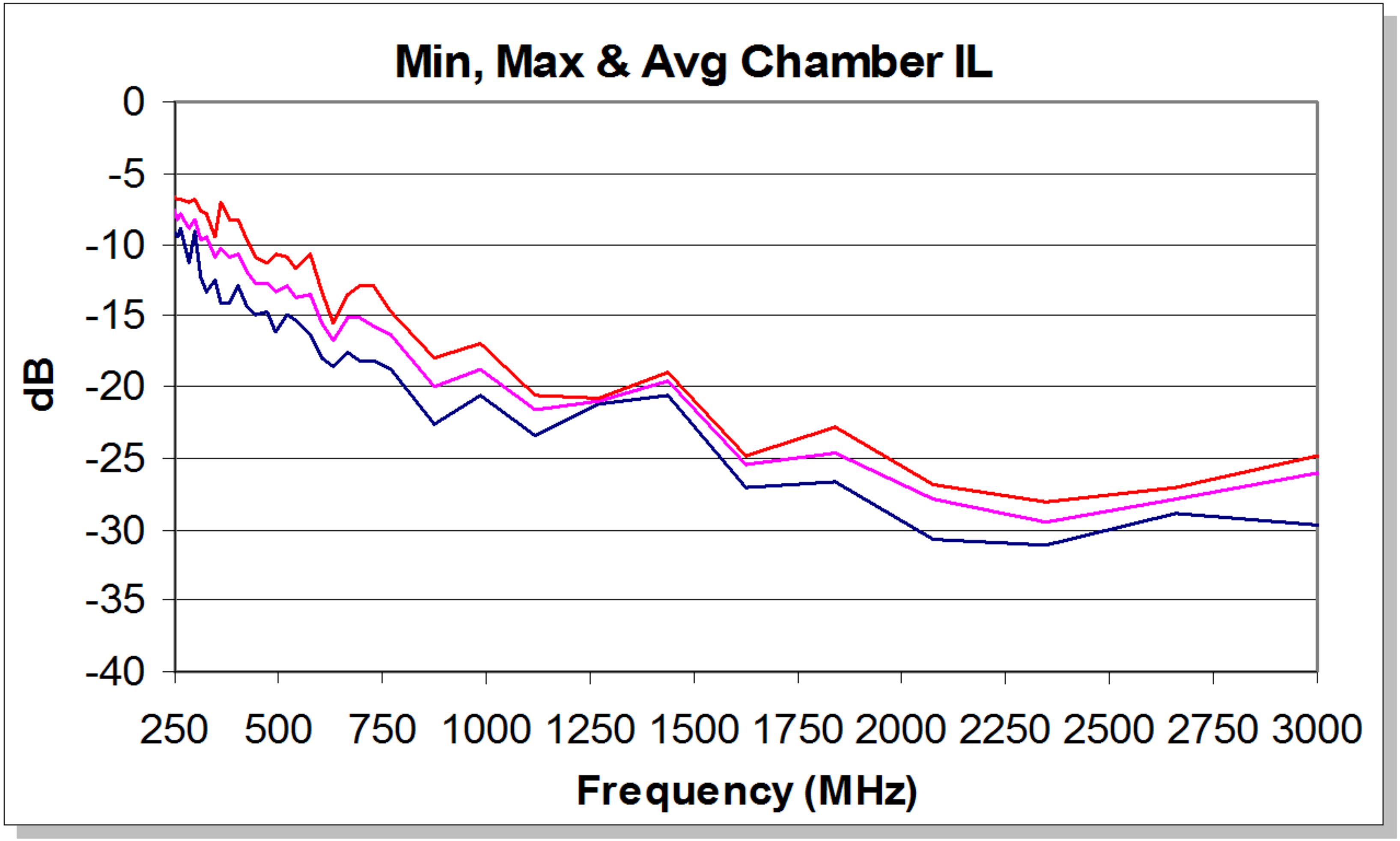
Standards Based Practices (Cont'd)



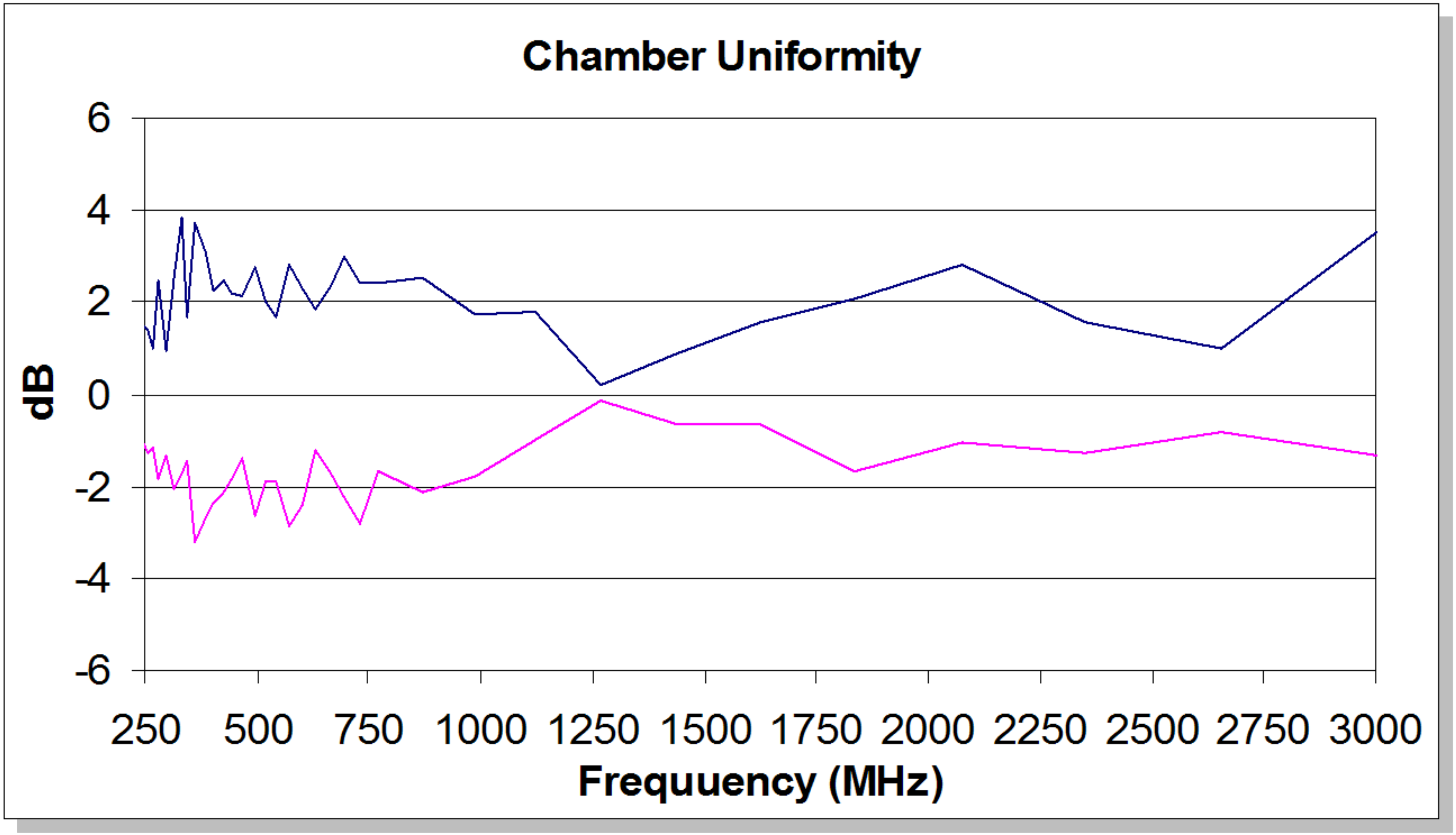
Standards Based Practices (Cont'd)



Standards Based Practices (Cont'd)



Standards Based Practices (Cont'd)



Technique Comparison

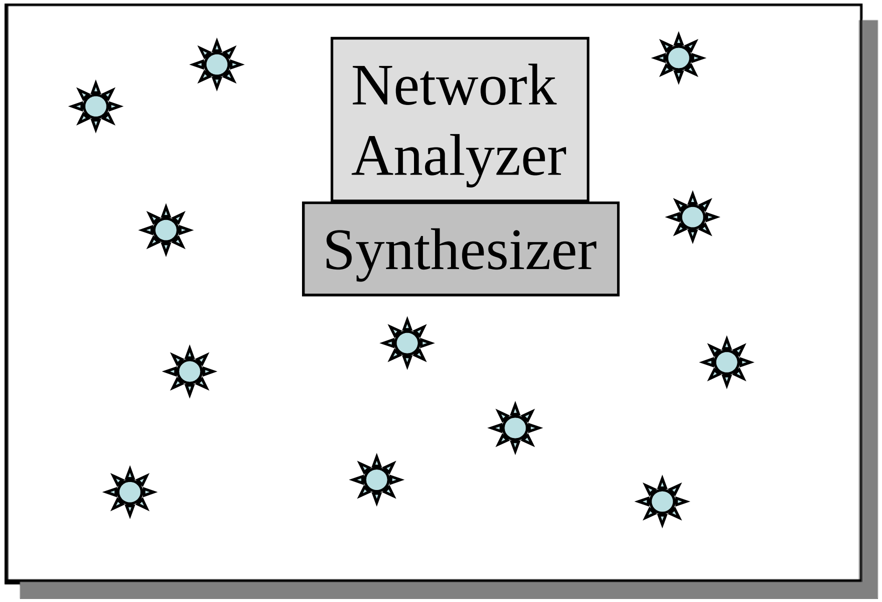
Standards Based Calibrations

- Pros
  - Gold Standard to Assess Other Techniques
- Cons
  - Interferes With Normal Operations
  - Requires ~1 Watt of Tx Power
  - Significant Equipment Requirement
    - Requires AC Line Power
    - Tuners, Power Meter, E-Field Probe, Spectrum Analyzer
    - Takes Approx. 40 Hours per Space

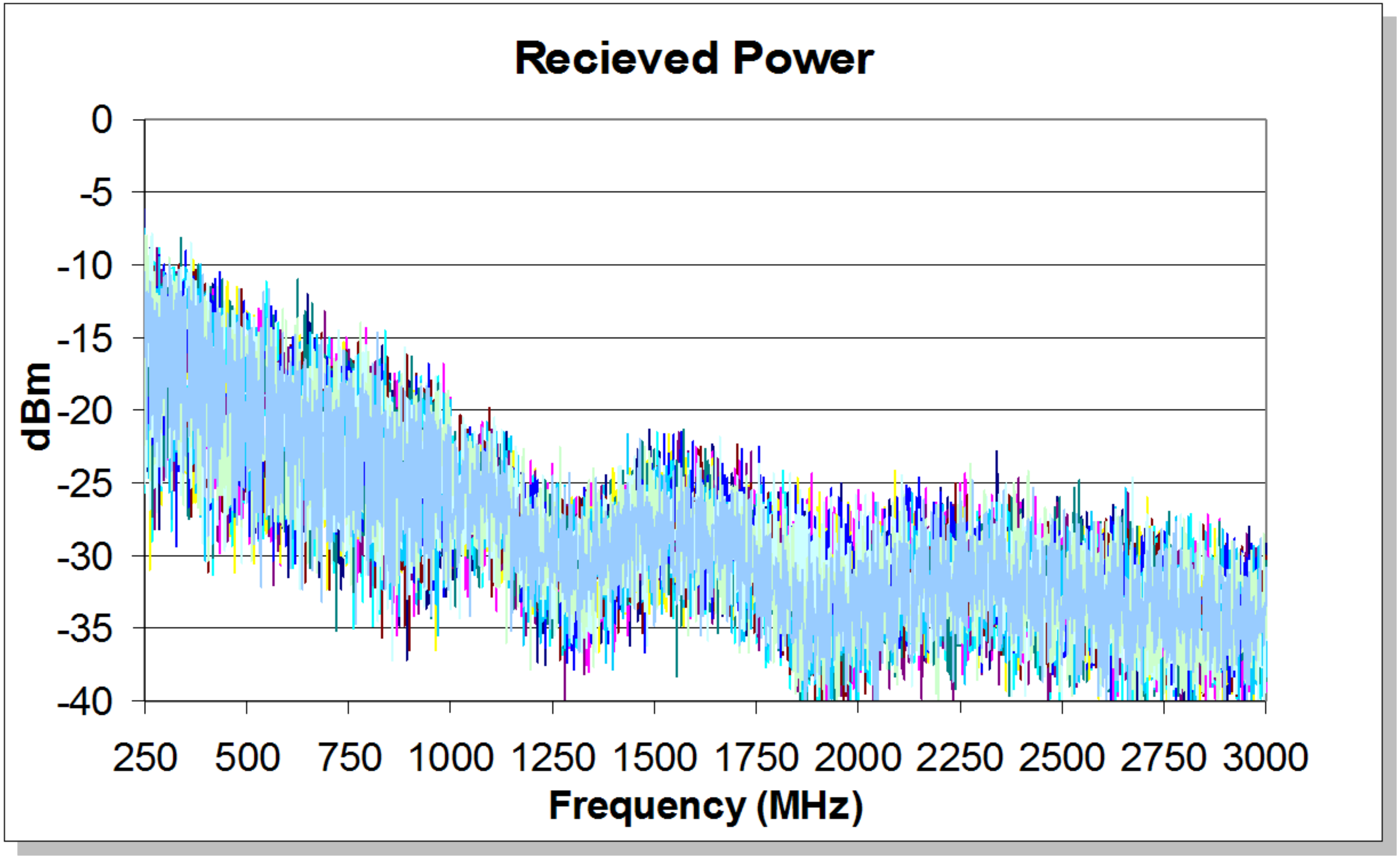
Fixed Location Technique

EMAC
ELECTROMAGNETIC MISSION ASSURANCE CENTER

- **Multiple "Fixed" Location Field Mapping**
  - Sweep RF Across Test Spectrum
  - Reposition Antennas (Tx & Rx)
  - Repeat 12 Times



Fixed Location Technique (Cont'd)



Fixed Location Technique (Cont'd)

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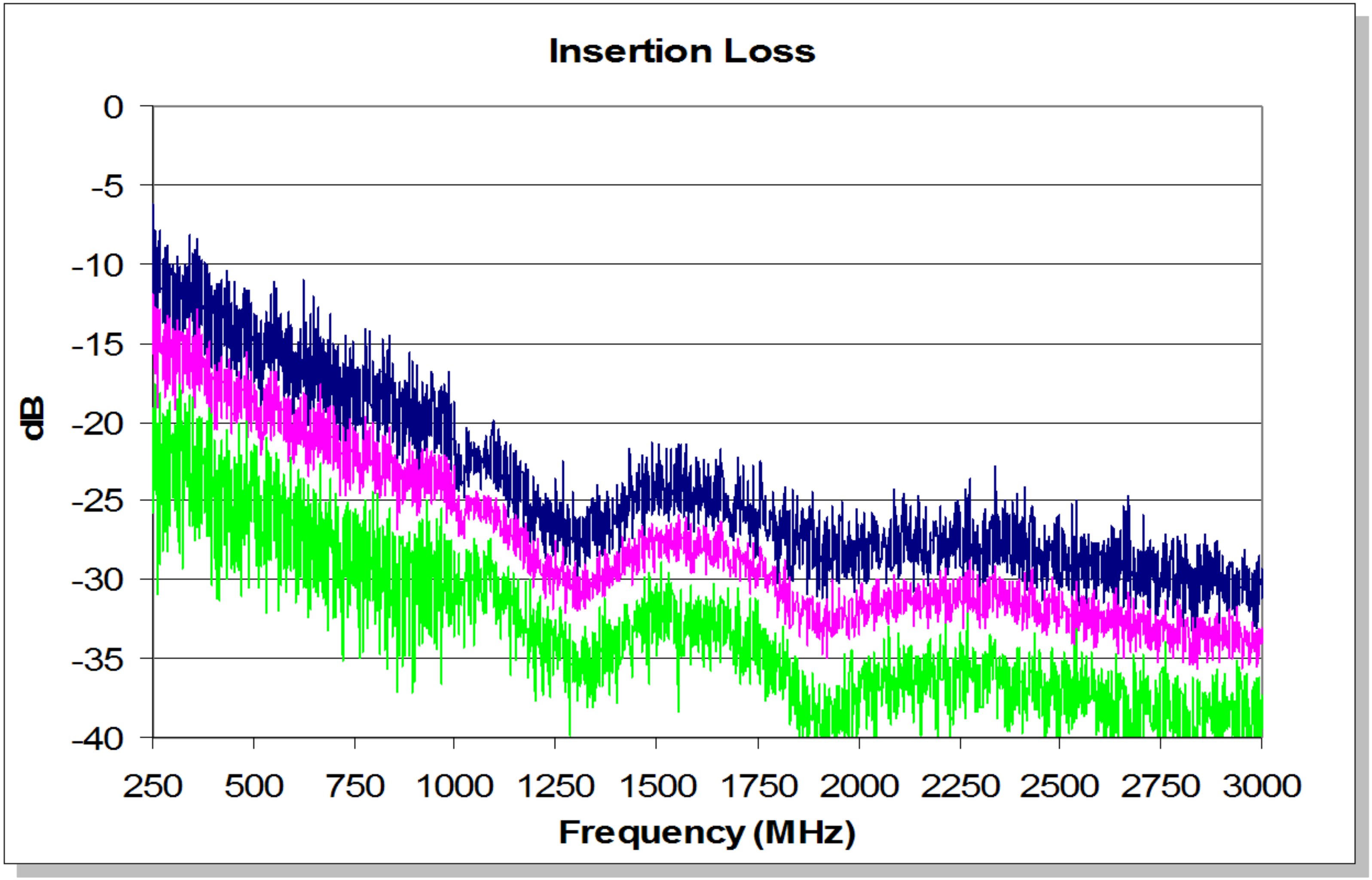
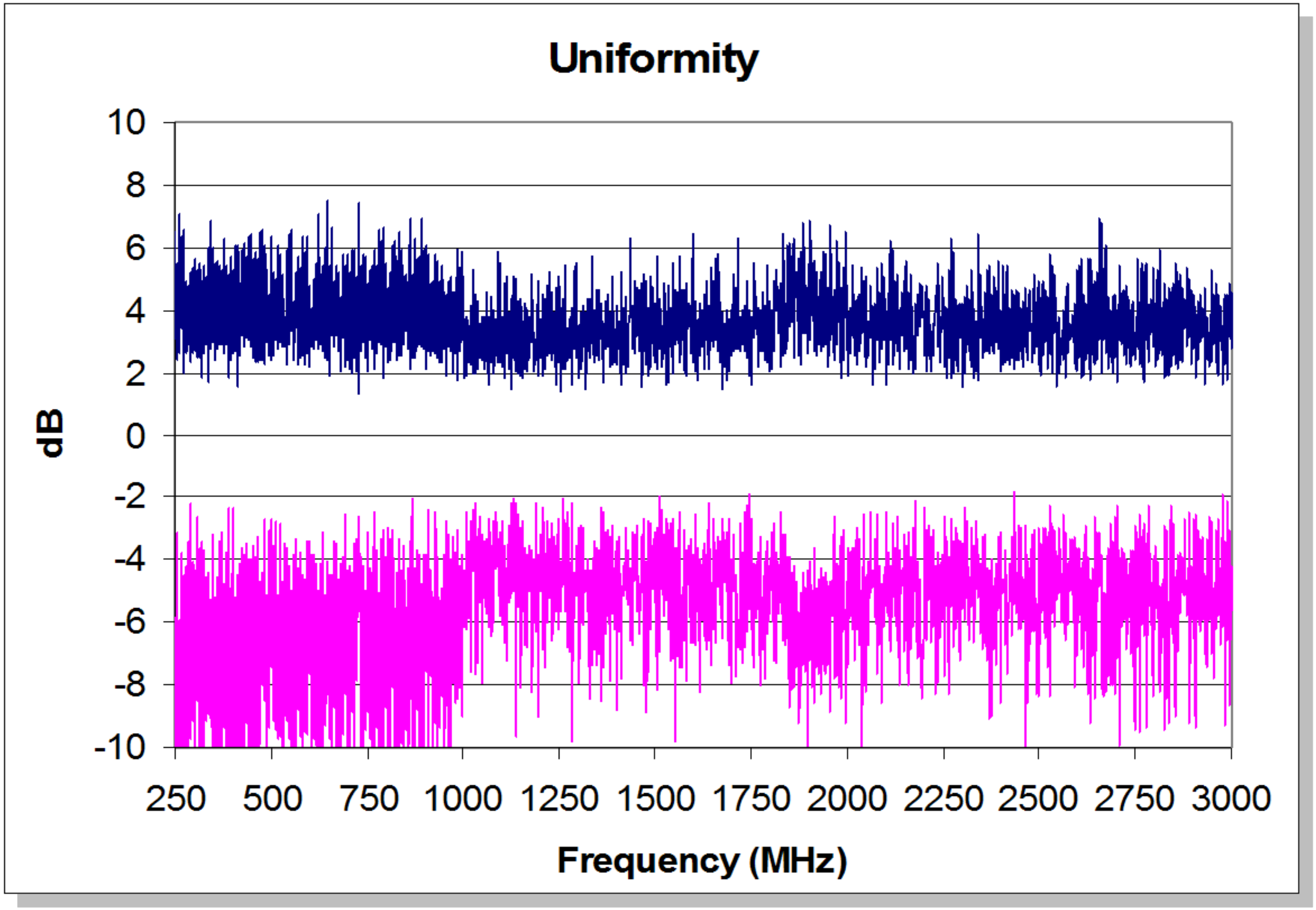


Fixed Location Technique (Cont'd)



Technique Comparison

Fixed Location Calibrations

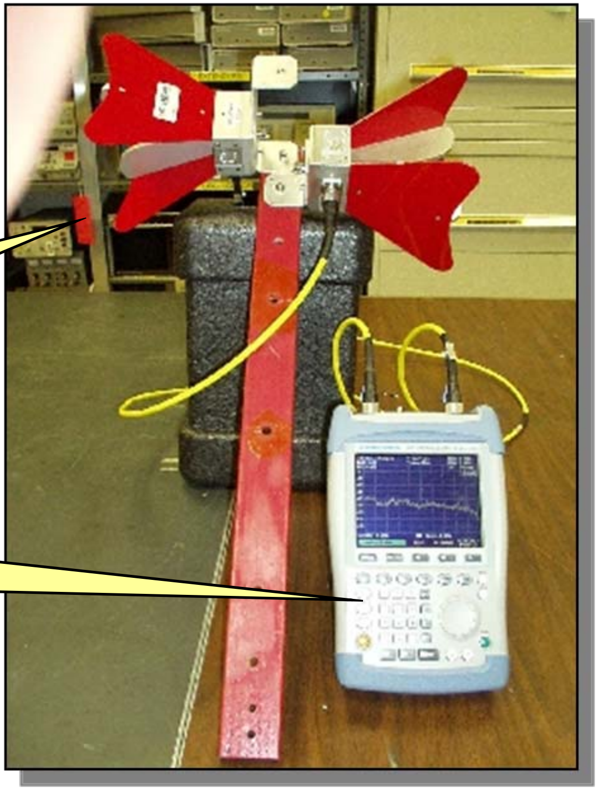
- Pros
  - Reduces Complexity of Test
    - Network Analyzer & Synthesizer
  - Reduces the Time Required
    - ~ Two Hours per Space
- Cons
  - Interferes With Normal Operations
  - Requires AC Line Power
  - More Sampling Would Improve Result

Continuous Technique

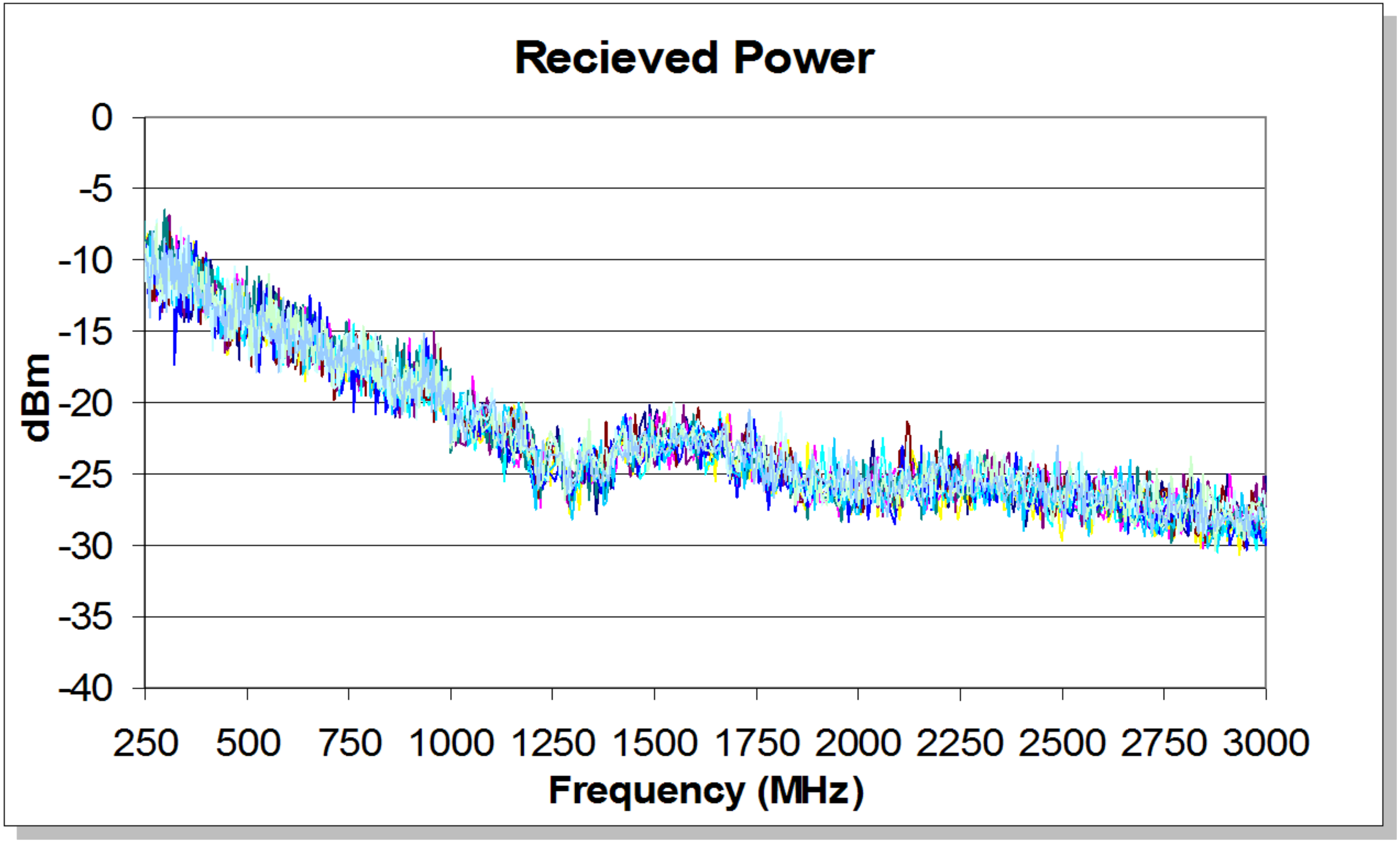
- **Continuous Location Field Mapping**
  - Sweep RF Across Test Spectrum
  - Transmit, Measure and Hold Maximum Value
  - Walking Through Space
  - Repeat 12 Times

Transmit and Receive Antennas >1000 MHz

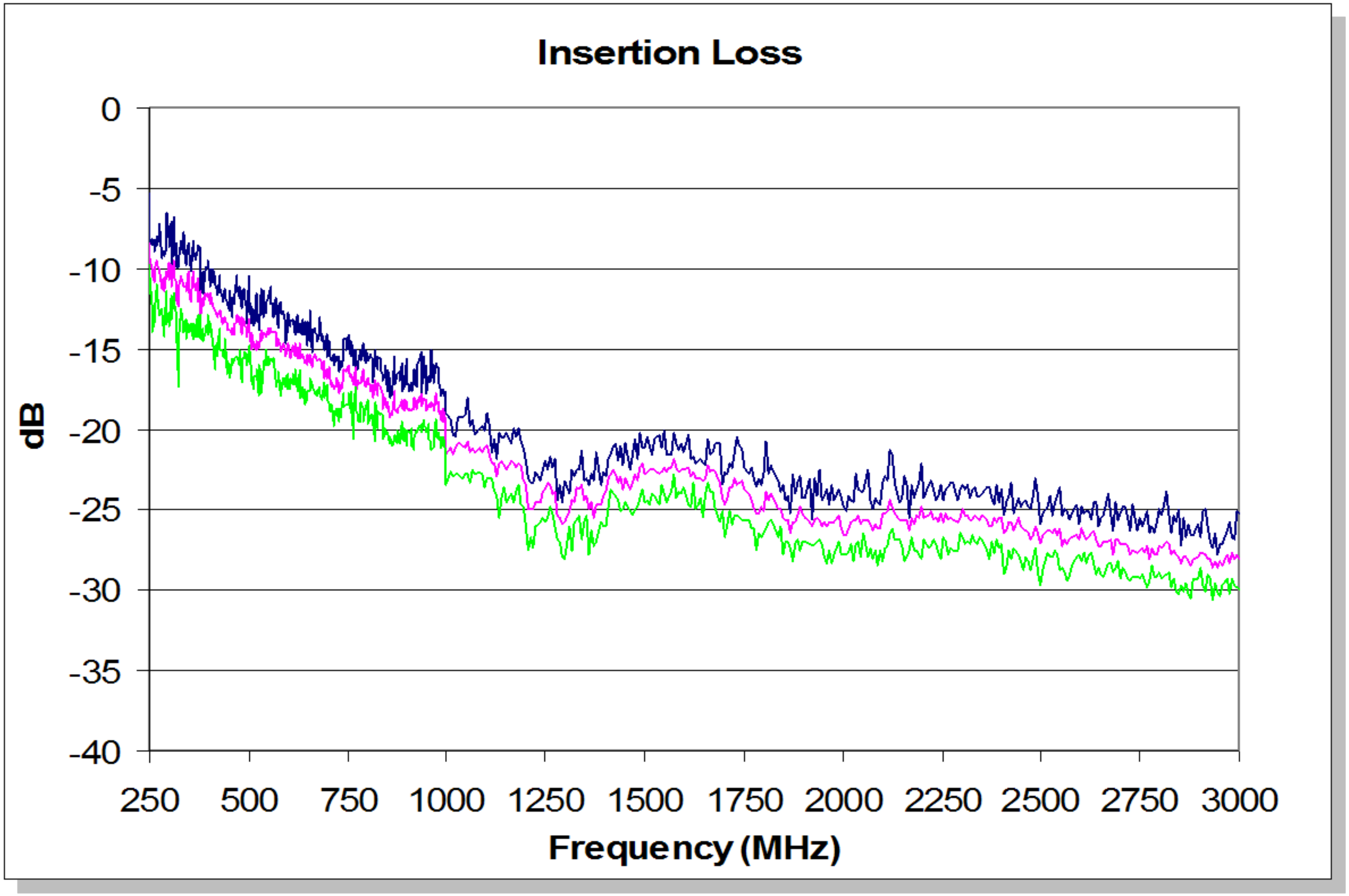
Handheld Spectrum Analyzer w/TG



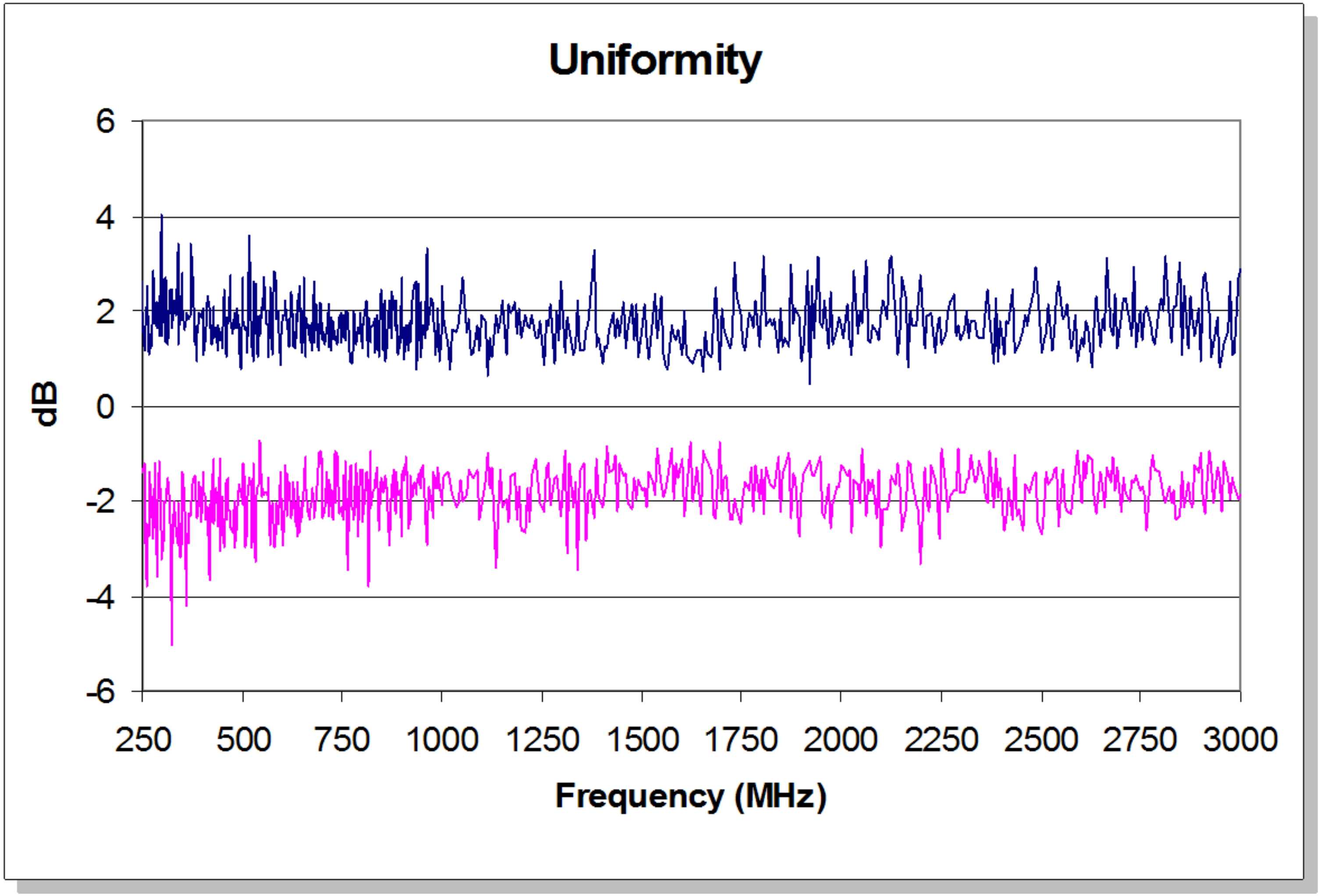
Continuous Technique (Cont’d)



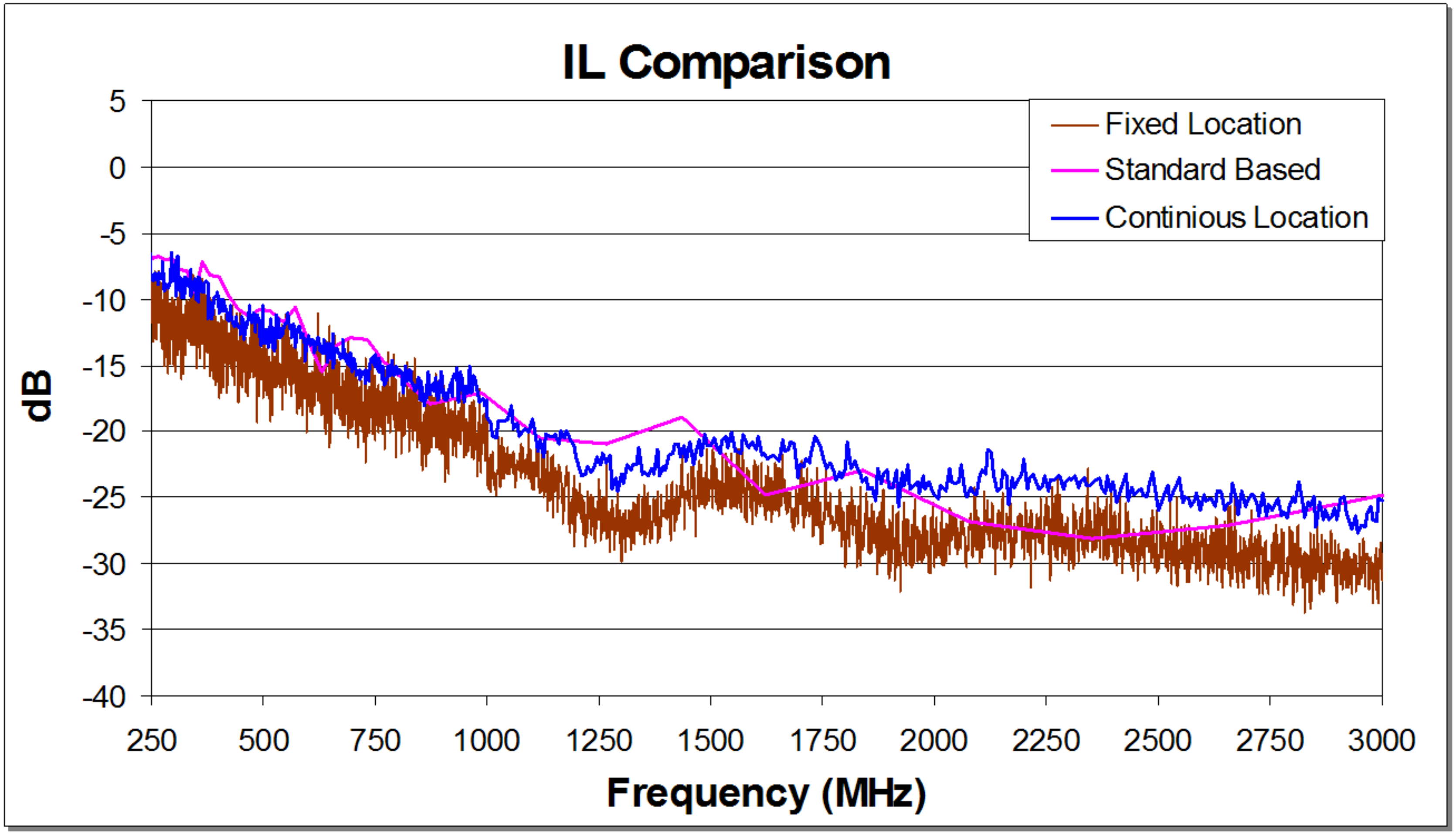
Continuous Technique (Cont'd)



Continuous Technique (Cont'd)



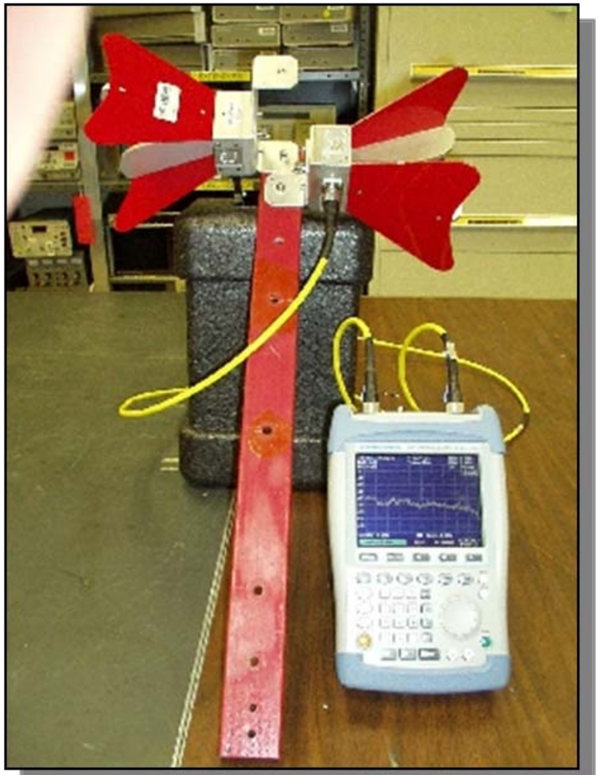
Technique Comparison



Technique Comparison (Cont'd)

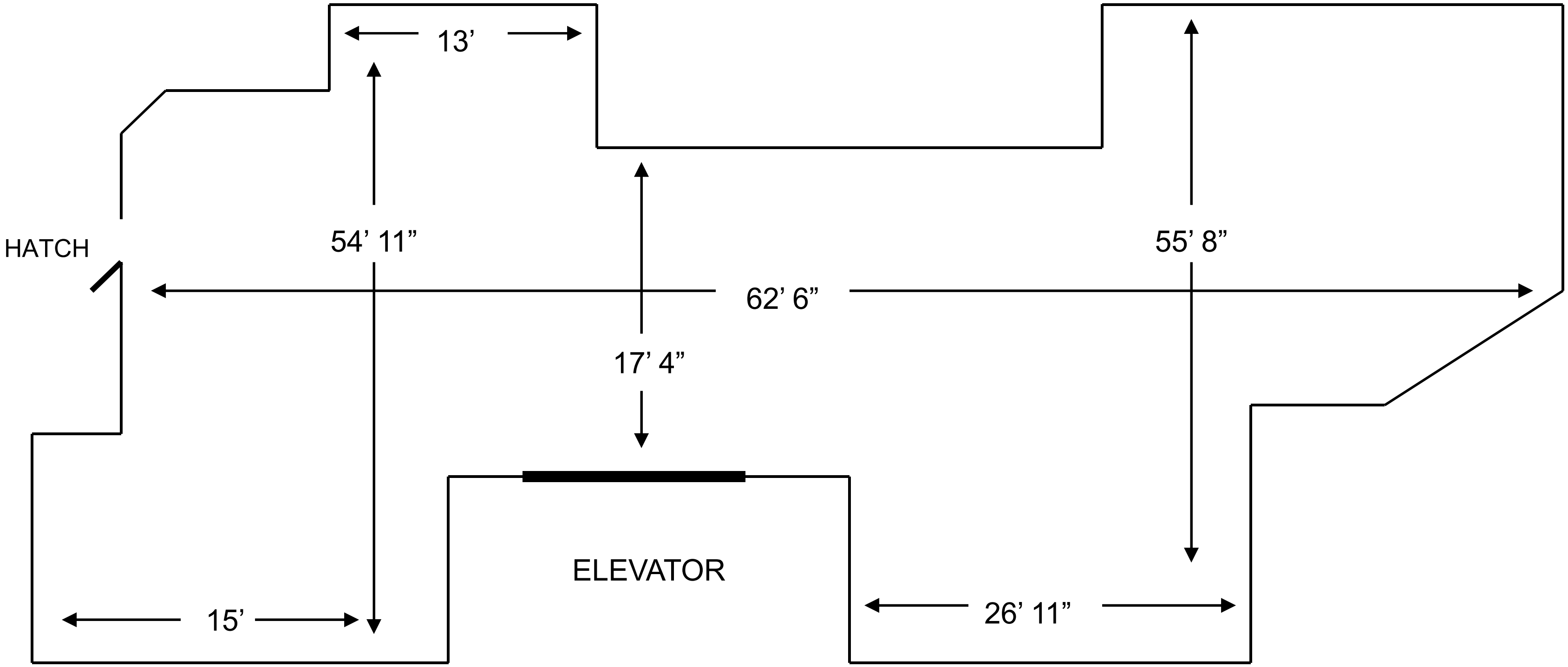
Continuous Location Calibrations

- Pros
  - Data Agrees Well With Standards Based Technique
  - Battery Powered
  - Eliminates Shipping Costs
  - Reduces Complexity of Test
    - One Unit Source & Receiver
  - Reduces the Time Required
    - ~ ½ Hour per Space
- Cons
  - Limited Frequency Range

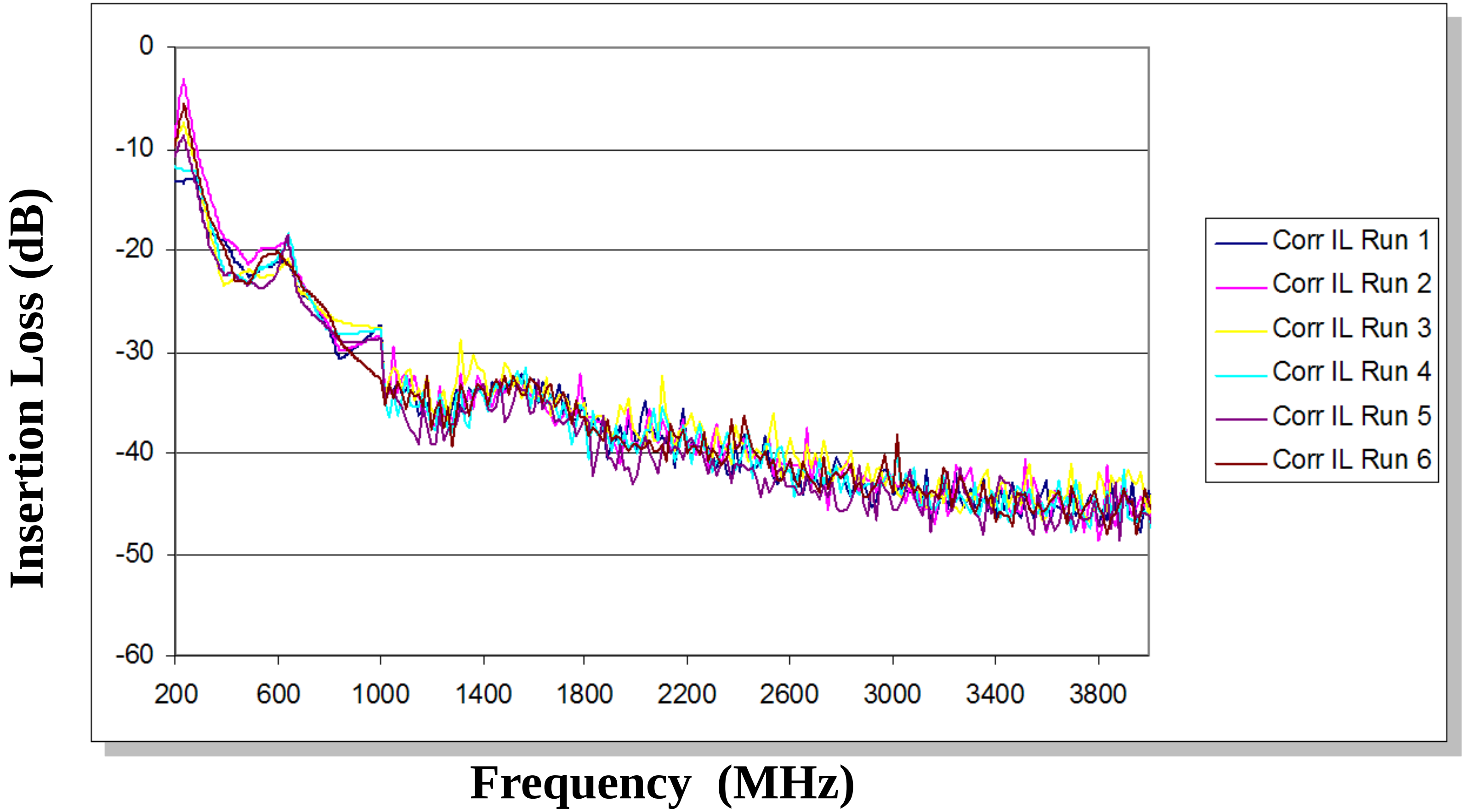


Characterization Results

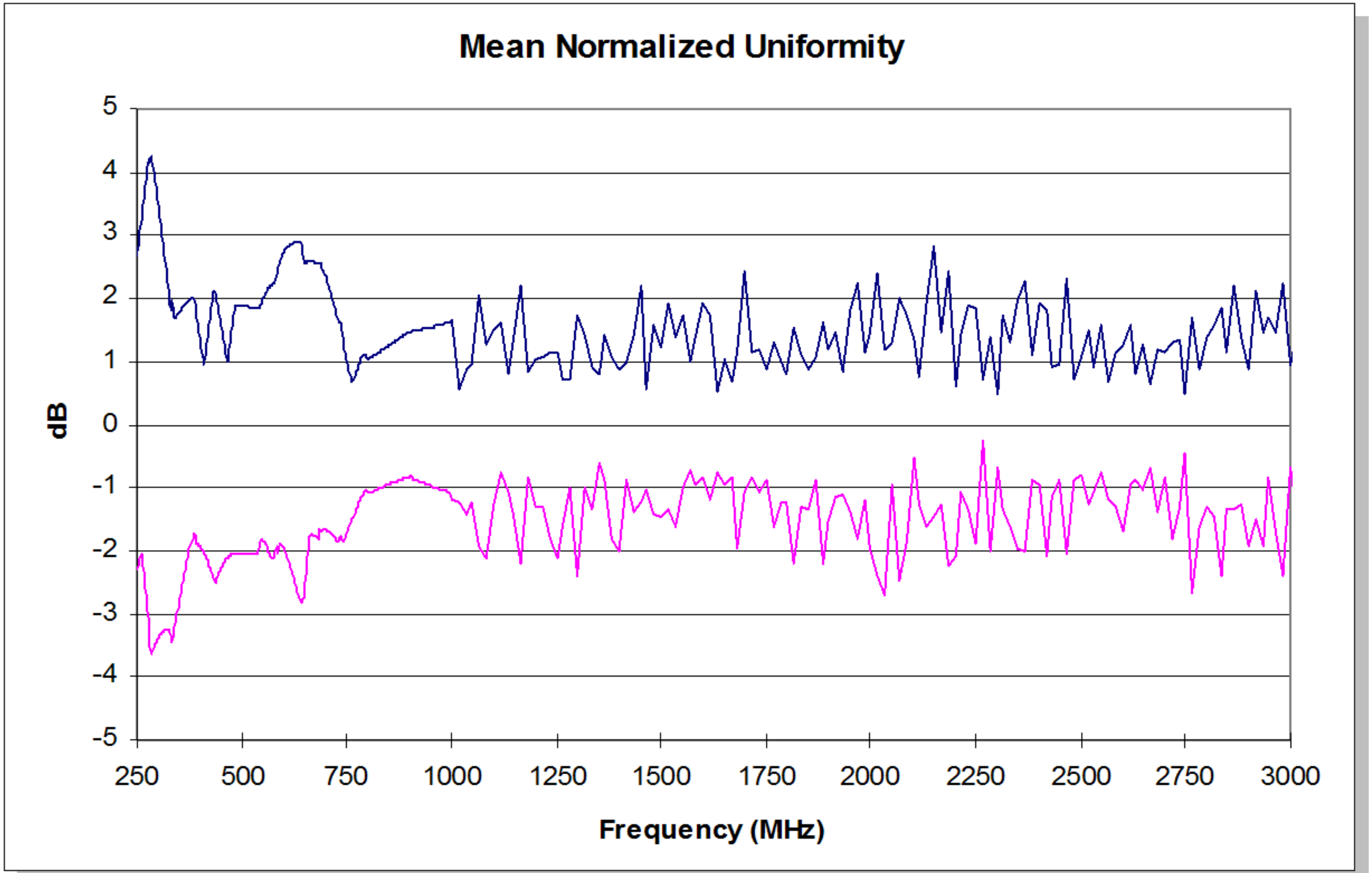
LHD 5, Bataan, Magazine 4



BATAAN, LHD 5, Magazine 4



BATAAN, LHD 5, Magazine 4



Random Walk Evolution

- **Spectrum Analyzer / Tracking Gen**

  Calibrated for Max. Dynamic Range

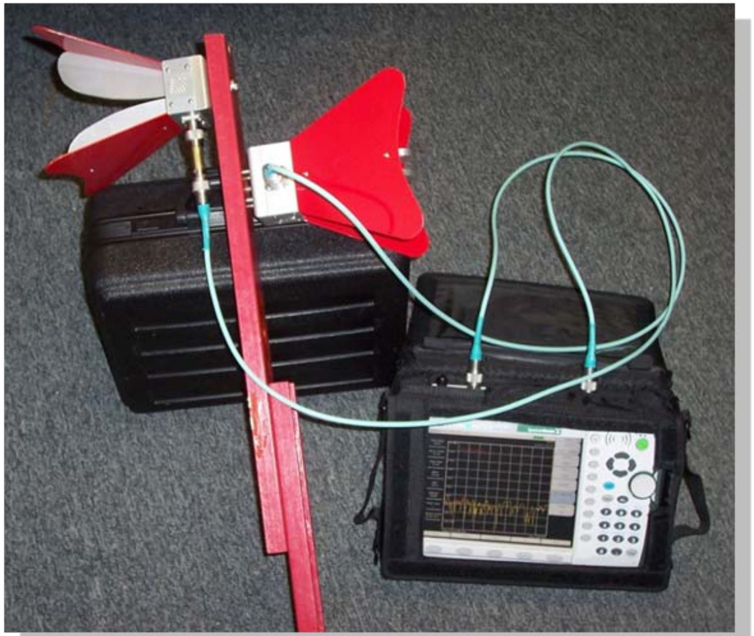
  400 MHz ≤ f ≤ 4 GHz

- **Dual-Ridge Horn Antennas**

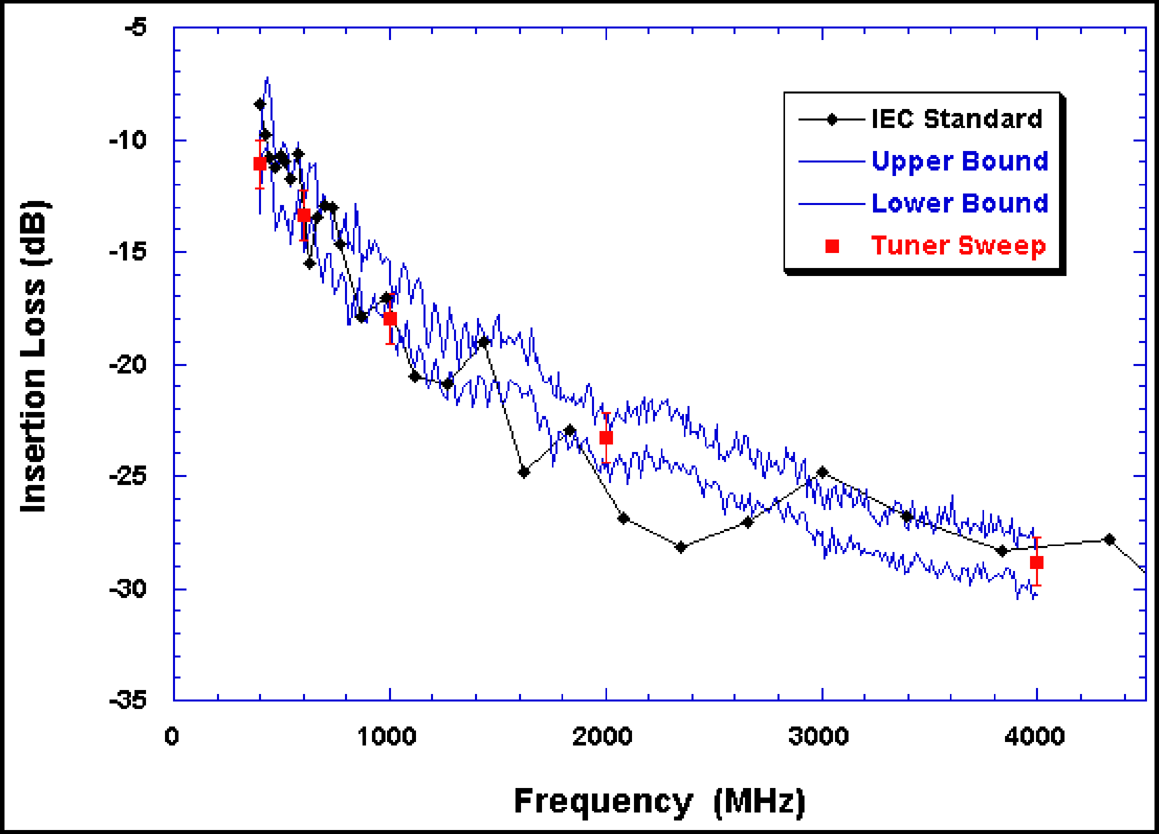
  Efficiency and AF Corrected in Post-Processing

- **12 Runs, Max Hold I.L.**

  Add'l Sampling with Frequency Sweep



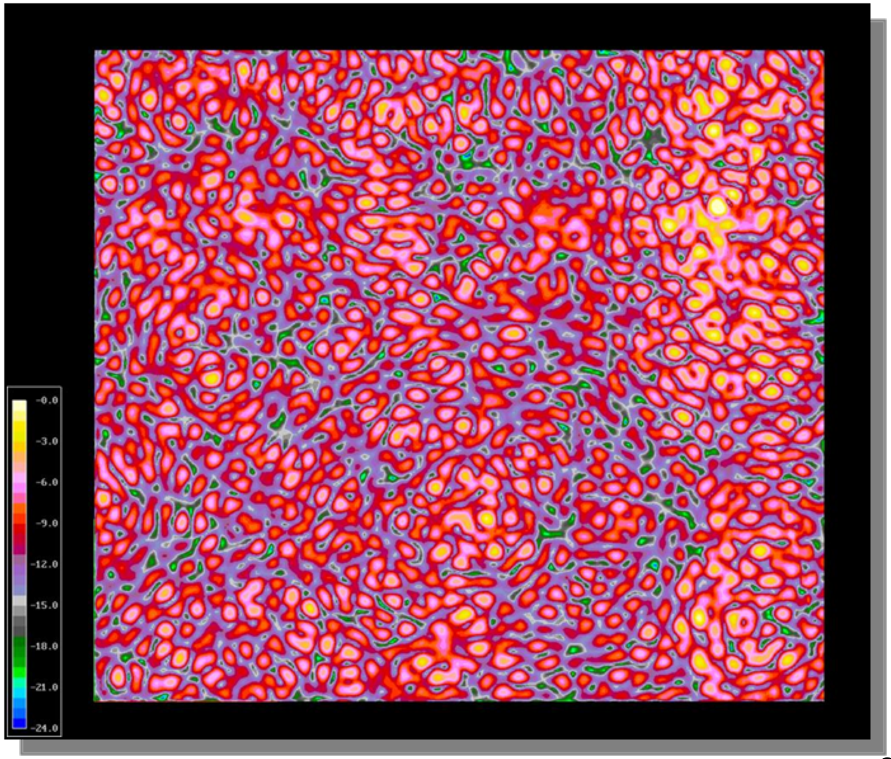
Walk-Around Validation II



Analysis: Complex Cavity

- **Large D > λ :** Overmoded
- **Reflective:** Chaotic or Diffuse Field
- **Deterministic Solution:** Neither practical nor useful
- **Statistical Analysis:**

  Predict Avg & Max Field Within Specified Uncertainty



E. Coffey, ARA

Data Analysis: Insertion Loss

Insertion Loss:

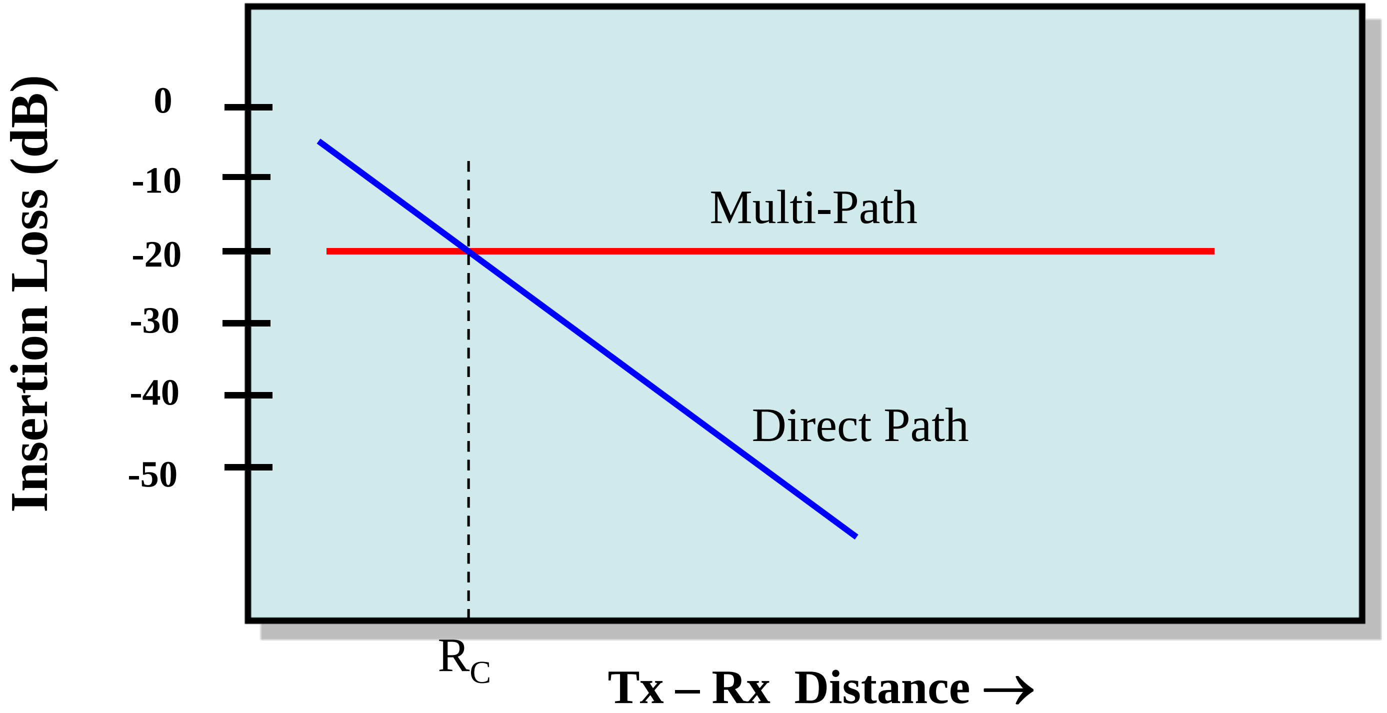
$$I.L. \equiv \frac{< P_{Max,rec} >_{ant.loc.}}{P_{input}} = \frac{1}{16\pi^2} \frac{c^3}{f^3} \eta_{tx} \eta_{rx} \frac{1}{Vol} \xi_{\max/mean} Q$$

Unloaded Quality Factor:

$$Q = \omega\tau \cong 3 \frac{Vol}{Surface\,Area} \sqrt{\frac{\sigma}{\mu_r}} \sqrt{f\,(MHz)}$$

$$I.L. = const. \frac{\sqrt{\frac{\sigma}{\mu_r}}}{Surface\ Area} \frac{\xi_{\max/mean}(f)}{f^{5/2}}$$

Multi-Path vs. Direct Path



Critical Distance:

$$R_C = \sqrt{\frac{1}{2\pi} D_{tx} D_{rx} \frac{vol}{c\tau}}$$

Cavity Calibration Factor

$$E_{Max} = \frac{8\pi}{\lambda}\sqrt{\frac{5 \cdot P_{\max, rec}}{\eta_{rx}}}$$

$$CCF \equiv Normalized\ E_{Max} = \frac{E_{Max}}{\sqrt{P_{input}}} = \frac{8\pi}{\lambda}\sqrt{\frac{5 \cdot IL}{\eta_{rx}}}$$

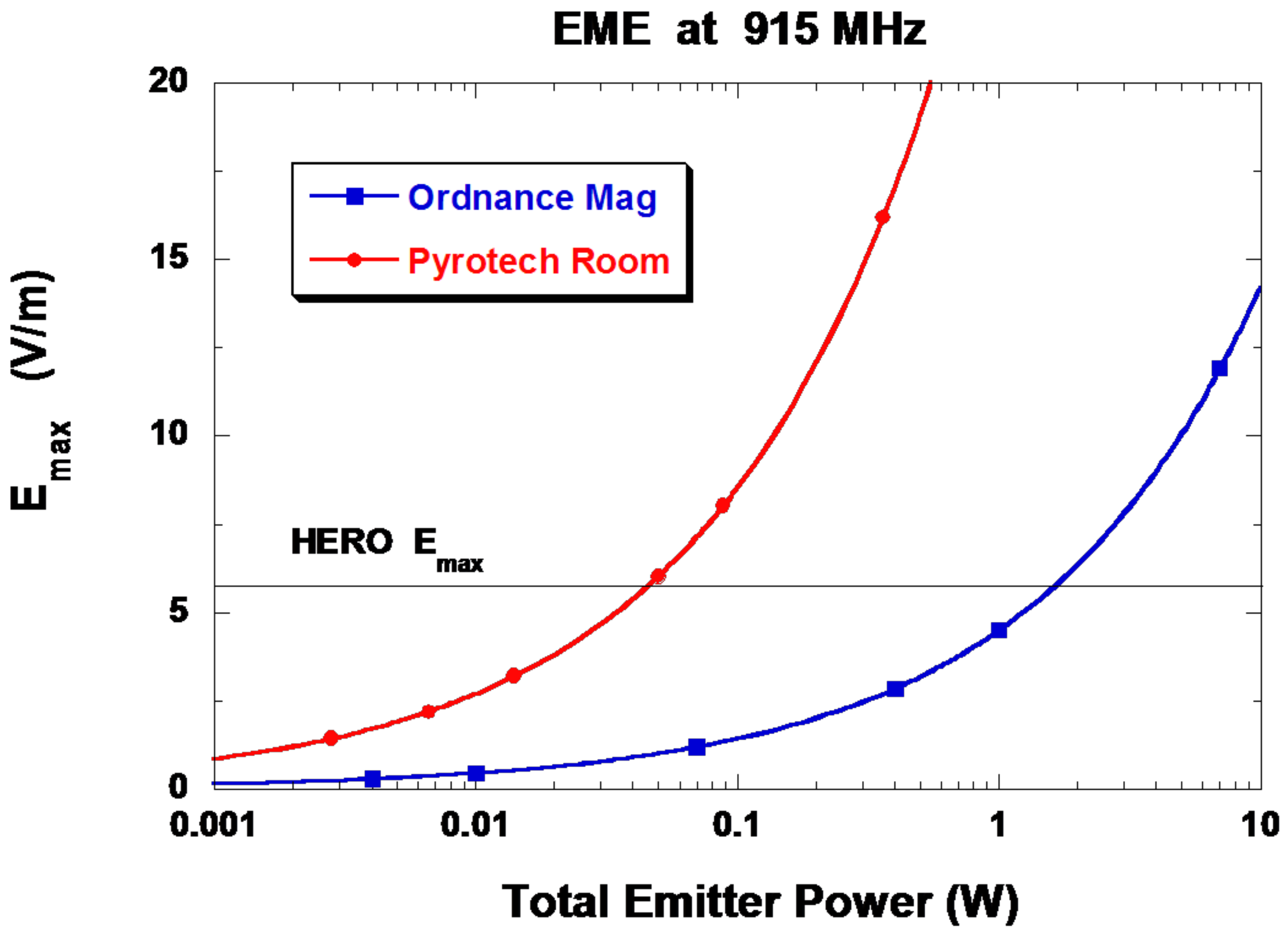
Diffuse-Field Dominant

$$E_{\max} \cong CCF \cdot \sqrt{P_{input}}$$

NAVSEA OP 3565

$$E_{\max}^{HERO} = 0.00625 \cdot f\,(MHz) \qquad (V/m)$$

Electromagnetic Environment



Recap

- **EME in Reverberant Spaces Influenced By:**
  - Frequency
  - Volume and Surface Area
  - Wall Effective Conductivities (σ/μ_r)
  - Space Functionality (Size and Loading)
  - Leakage via Large Apertures
- **Ship, Aircraft, and Bunker Cavities**
  - Maximum Diffuse Electric Fields Can Be Estimated Using a Cavity Calibration Factor
- **Potential Problems**
  - EMI, EMV, HERO

Statistical Analysis

- **Maximum power density data**
- **Walk-Around Volume Sampling → Large Number of Independent Samples N**
- **At 1 Frequency: 12 Max Values**
- **Augment Samples: Frequency BW e.g. 4 adjacent frequencies (12 MHz separation)**
- **60 Max data points: Mean and STD**
- **Work statistics "backwards"**
- **P_{max}, P_{avg}, E_{max}, E_{avg} & associated uncertainties**

Statistical Analysis

Some "details"

$$w = \frac{P_{max}}{<P>}$$ **Max-to-Mean Power Ratio**

$$<w> \equiv \int_0^\infty w\, f_N(w)\, dw = <P_{max}>/<P>$$

$$<w^2> - <w>^2 \equiv \int_0^\infty w^2 f_N(w)\, dw - \left(\int_0^\infty w\, f_N(w)\, dw\right)^2 = S^2_{P\,max}/<P>^2$$

Measured Data

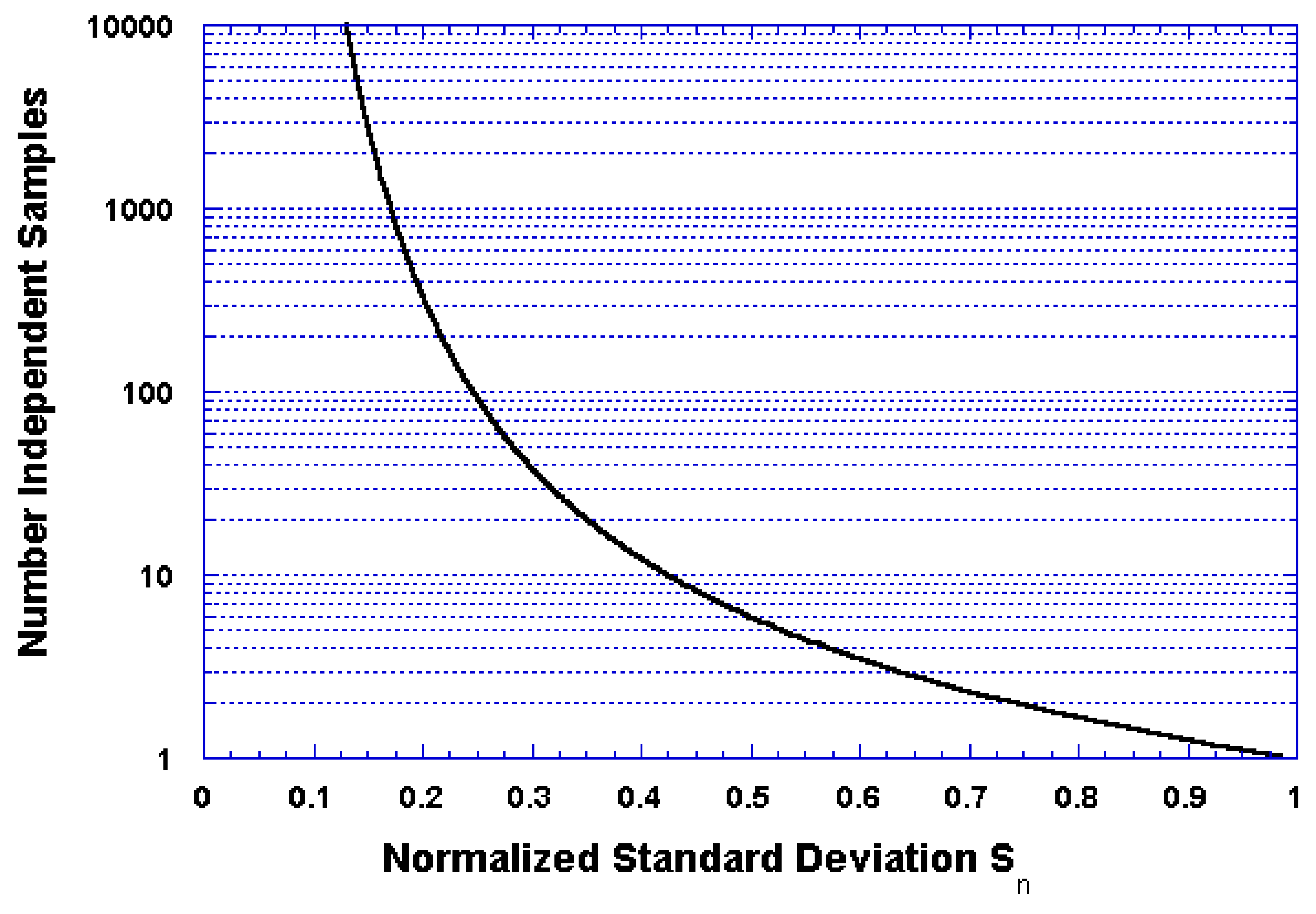
$$I(N) \equiv \frac{\int_0^\infty w^2 f_N(w)\, dw}{\left[\int_0^\infty w\, f_N(w)\, dw\right]^2} = 1 + S_n^2$$

$$S_n = \sqrt{S^2_{P\,max}}\,/<P_{max}>$$

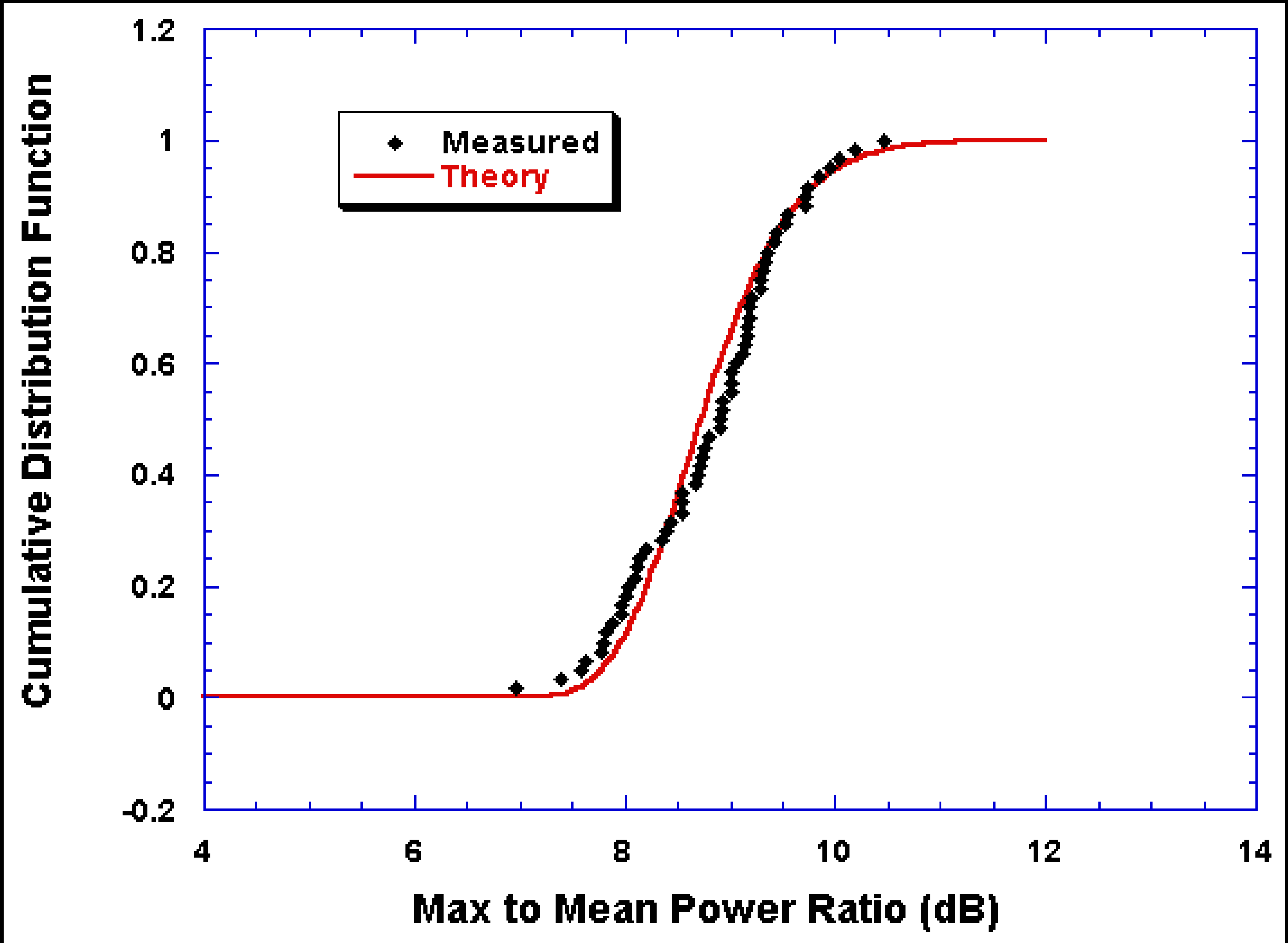
$$f_N(w) = N \exp\{-w\}\left[1 - \exp\{-w\}\right]^{N-1}$$

Equivalent Number of Independent Samples

Statistical Analysis



Statistical Analysis



Statistical Analysis

Comparison of Techniques at 2 GHz in Reverberation Chamber

(power units are dB or dBm as appropriate)

	Measured Data			Statistical Inference					
Tuner Sweep	P_{max} (single value)	$\langle P \rangle$	$P_{max}/\langle P \rangle$	N	$\sigma_{\langle P \rangle}$	$\langle P_{max} \rangle / \langle P \rangle$	$\sigma_{Pmax/\langle P \rangle}$	$\langle P_{max} \rangle$	$\sigma_{\langle Pmax \rangle}$
	-23.3	-31.0	6.9	188	0.4	7.5	1.0	-23.5	1.1
Random Walk	$\langle P_{max} \rangle$	S_{Pmax}	S_n (linear units)	N	$\sigma_{\langle Pmax \rangle}$	$\langle P_{max} \rangle / \langle P \rangle$	$\sigma_{Pmax/\langle P \rangle}$	$\langle P \rangle$	$\sigma_{\langle P \rangle}$
	-23.3	0.7	0.168	1140	0.1	8.8	0.7	-32.1	0.7

Conclusions

- **Walk-Around Technique**
  - Methodology of choice
    - Equal or better accuracy
    - Significant reduction in time/cost
    - Simplifies evaluations
      - Little training required
- **AIT systems can pose E^3 Risks….**
  - Consideration must be given to:
    - HERO & EMI
    - Need to balance deployment with ROI