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

22 August 2008

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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
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
- Mode Stir: Mechanical
- Volume Sample: Multiple Antenna Positions
- Frequency Stir
- Random Walk
Continuous Location Field Mapping "Random Walk" Origin

- Sweep RF Across Test Spectrum
- Transmit, Measure and Hold Maximum Value
- Walking Through Space
- Repeat 6 Times
Reverberation Chamber Calibrations

- Provide Data On…
  - Resultant E-Field per Root Watt Input
  - Volumetric Uniformity
Standards Based Practices (Cont’d)
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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
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)
Fixed Location Technique (Cont’d)
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 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)

Uniformity

Frequency (MHz)

dB

250 500 750 1000 1250 1500 1750 2000 2250 2500 2750 3000
IL Comparison

- Fixed Location
- Standard Based
- Continuous Location
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
LHD 5, Bataan, Magazine 4

HATCH

13’

54’ 11”

17’ 4”

55’ 8”

15’

62’ 6”

ELEVATOR

26’ 11”
Characterization Results

BATAAN, LHD 5, Magazine 4

Insertion Loss (dB) vs Frequency (MHz) for different runs:
- Corr IL Run 1
- Corr IL Run 2
- Corr IL Run 3
- Corr IL Run 4
- Corr IL Run 5
- Corr IL Run 6
Characterization Results

BATAAN, LHD 5, Magazine 4

Mean Normalized Uniformity

dB

Frequency (MHz)
**Random Walk Evolution**

- **Spectrum Analyzer / Tracking Gen**
  - Calibrated for Max. Dynamic Range
  - $400 \text{ MHz} \leq f \leq 4 \text{ GHz}$

- **Dual-Ridge Horn Antennas**
  - Efficiency and AF Corrected in Post-Processing

- **12 Runs, Max Hold I.L.**
  - Add’l Sampling with Frequency Sweep
Large $D > \lambda$: 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: \[ I.L. \equiv \frac{< P_{\text{Max,rec}} >_{\text{ant.loc.}}}{P_{\text{input}}} = \frac{1}{16\pi^2 f^3} \frac{c^3}{\eta_{\text{tx}} \eta_{\text{rx}}} \frac{1}{\text{Vol}} \xi_{\text{max/mean}} Q \]

Unloaded Quality Factor: \[ Q = \omega \tau \approx 3 \frac{\text{Vol}}{\text{Surface Area}} \sqrt{\frac{\sigma}{\mu_r}} \sqrt{f (\text{MHz})} \]

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

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

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

Diffuse-Field Dominant

\[ E_{\text{max}} \approx CCF \cdot \sqrt{P_{\text{input}}} \]

NAVSEA OP 3565

\[ E_{\text{max}}^{\text{HERO}} = 0.00625 \cdot f(MHz) \quad (V/m) \]
Electromagnetic Environment

EME at 915 MHz

- **Ordnance Mag**
- **Pyrotech Room**

![Graph showing E_max vs Total Emitter Power (W)](image)

**Axes:**
- E_max (V/m)
- Total Emitter Power (W)

**Lines:**
- Blue: Ordnance Mag
- Red: Pyrotech Room

**Key Points:**
- The graph illustrates the relationship between E_max and Total Emitter Power.
- The blue line represents Ordnance Mag, and the red line represents Pyrotech Room.

**Note:**
- The graph shows a significant increase in E_max as total emitter power increases.
- The E_max values are higher for Pyrotech Room compared to Ordnance Mag.
Recap

EME in Reverberant Spaces Influenced By:
- Frequency
- Volume and Surface Area
- Wall Effective Conductivities (\(\sigma/\mu_r\))
- 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 $\rightarrow$ 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”

$P_{\text{max}}, P_{\text{avg}}, E_{\text{max}}, E_{\text{avg}}$ & associated uncertainties
Some “details”

\[ w = \frac{P_{\text{max}}}{< P >} \quad \text{Max-to-Mean Power Ratio} \]

\[ < w > \equiv \int_{0}^{\infty} w f_N(w) \, dw = \frac{< P_{\text{max}} >}{< P >} \]

\[ < w^2 > - < w >^2 \equiv \int_{0}^{\infty} w^2 f_N(w) \, dw - \left( \int_{0}^{\infty} w f_N(w) \, dw \right)^2 = \frac{S_{P_{\text{max}}}^2}{< P >^2} \]

\[ I(N) \equiv \frac{\int_{0}^{\infty} w^2 f_N(w) \, dw}{\left[ \int_{0}^{\infty} w f_N(w) \, dw \right]^2} = 1 + S_n^2 \]

\[ S_n = \sqrt{ \frac{S_{P_{\text{max}}}^2}{< P_{\text{max}} >} } \]

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

Equivalent Number of Independent Samples
Comparison of Techniques at 2 GHz in Reverberation Chamber
(power units are dB or dBm as appropriate)

<table>
<thead>
<tr>
<th>Measured Data</th>
<th>Statistical Inference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tuner Sweep</strong></td>
<td></td>
</tr>
<tr>
<td>$P_{\text{max}}$</td>
<td>$&lt;P&gt;$</td>
</tr>
<tr>
<td>-23.3</td>
<td>-31.0</td>
</tr>
<tr>
<td><strong>Random Walk</strong></td>
<td></td>
</tr>
<tr>
<td>$&lt;P_{\text{max}}&gt;$</td>
<td>$S_{P_{\text{max}}}$</td>
</tr>
<tr>
<td>-23.3</td>
<td>0.7</td>
</tr>
</tbody>
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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