

U.S. Air Force T&E Days 2010
2 - 4 February 2010, Nashville, Tennessee

AIAA 2010-1767

Using A Virtual BAF in EW Testing

William C. Chen

772nd Test Squadron, 412 Electronic Warfare Group,
Edwards AFB, CA 93524-8210

Chad Kuffenkam

772nd Test Squadron, 412 Electronic Warfare Group,
Edwards AFB, CA 93524-8210

Benjamin Hua*

772nd Test Squadron, 412 Electronic Warfare Group,
Edwards AFB, CA 93524-8210

James D. Brownlow

772nd Test Squadron, 412 Electronic Warfare Group,
Edwards AFB, CA 93524-8210

*Previously worked with 772TS/EWOI, Edwards AFB
Approved for Public Release: PA# AFFTC-PA-10013

Copyright © 2010 by the American Institute of Aeronautics and Astronautics, Inc.
The U.S. Government has a royalty-free license to exercise all rights under the copyright claimed herein for Governmental purposes. All other rights are reserved by the copyright owner.

Using a Virtual BAF in EW Testing

Abstract:

The Benefield Anechoic Facility (BAF), located at Edwards Air Force Base, is the world's largest anechoic chamber. The BAF provides a test environment that has a number of uses:

- Evaluation of radar warning receiver (RWR) systems. The BAF can generate both free-space and direct-inject signals to test RWR systems, provide real-time environment monitoring, and can record both the simulated signal environment and system under test (SUT) emissions.
- Evaluation of defensive avionics system testing: communication, navigation, and identification friend or foe (IFF) testing (CNI). The BAF can simulate a wide variety of signals in the IFF arena.
- Measure antenna patterns. The BAF can measure antenna patterns of both installed and uninstalled systems.
- Perform electromagnetic interference / electromagnetic compatibility (EMI/EMC) testing.

Test requirements at the BAF are increasing in complexity with the development of sophisticated manned and unmanned systems; as a result, ways to improve existing test methods are important. Test setup and test execution must be done in an efficient and timely manner. A "Virtual BAF" 3D modeling and simulation tool is proposed to be used to assess test set up and produce simulation model results. This Virtual BAF simulation tool is a software model of the anechoic chamber and uses the uniform theory of diffraction to predict the RF field environment in the BAF.

The Virtual BAF 3D computer simulation model uses Remcom's XGtd[®] ray-tracing electromagnetic simulation software to provide a preliminary RF analysis of test setup. Test requirements are used to set up a "virtual test" in software; this will allow test engineers to complete RF link analyses and to identify potential problems with the test early in the process. As a result, this testing methodology will help resolve test ambiguities and ensure that the facility is used in the best possible manner. This paper presents the major components of the "Virtual BAF" simulation model as well as a few examples of its use in preliminary test design and setup. Example applications are given that show how the Virtual BAF simulation may be used in the following areas:

- multipath investigation
- evaluate the test set up before the SUT and BAF facilities are brought into play
- incoming receiver signal magnitude as a function of location

1. Introduction

The US DoD Defense Acquisition Guidebook states, "Modeling and Simulation (M&S) technology is a fundamental part of all product design and development. It is also a fundamental part of Test & Evaluation (T&E)" ^[1]. The U. S. Air Force Flight Test Center (AFFTC) at Edwards Air Force Base has a long history of using modeling and simulation (M&S) in the test and evaluation (T&E) process. "M&S works have been in the continued and expanded way at all area such as flight test, ground test, system design; extensive work is also ongoing in the Avionics and Electronic Warfare (EW) arenas attempting to replicate a real world battlefield environment by combining the radio frequency capabilities of the Benefield Anechoic Chamber (BAF), the avionics simulation abilities of the IFAST and the Digital Integrated Air Defense System (DIADS). The M&S use across the test process is expanding" ^[2]. In this paper, we propose pre-system test simulation using the "Virtual BAF."



Using a Virtual BAF in EW Testing

In short, we propose to model the test process in order to assist in test set up, to provide insight into the conduct of the test and to establish preliminary expected test results.

2. Benfield Anechoic Chamber (BAF)^[3]

The Benfield Anechoic Facility (BAF), located at Edwards Air Force Base, is the world's largest anechoic chamber. Figure (1) is a picture of the BAF at Edwards AFB.



Figure (1) Benfield Anechoic Chamber (BAF) at Edwards AFB

The BAF provides a test environment that has a number of uses:

- Evaluation of radar warning receiver (RWR) systems. The BAF can generate both free-space and direct-inject signals to test RWR systems, provide real-time environment monitoring, and can record both the simulated signal environment and system under test (SUT) emissions.
- Evaluation of defensive avionics system testing: communication, navigation, and identification friend or foe (IFF) testing. The BAF can simulate a wide variety of signals in the IFF arena.
- Measure antenna patterns. The BAF can measure antenna patterns of both installed and uninstalled systems.
- Perform electromagnetic interference / electromagnetic compatibility (EMI/EMC) testing.
- An example of a SUT at the BAF^[3] is shown in Figure (2).



Using a Virtual BAF in EW Testing



Figure (2) MC-130 under test at the BAF, Edwards AFB

3. Virtual BAF

“Virtual BAF” is a 3D modeling and simulation tool which is proposed to be used to assess test set up and produce simulation model results.

The “Virtual BAF” 3D computer simulation model is based on a model of the BAF (**Including detail 3D design drawing, such as shape, door, panel, light etc.**) and SUT and uses Remcom’s XGtd ray-tracing electromagnetic simulation software to provide a preliminary analysis of test setup and results. **The ray tracing software is the calculation engine; the parameter input, such as antenna pattern, test set-up, etc. are custom design.** Test requirements **from customer** are used to set up a “virtual test” in the software; this will allow test engineers to complete RF analyses and to identify potential problems with the test early in the test design process. This of course may offer considerable savings in time and may serve to resolve test ambiguities and ensure that the facility is used in the most efficient manner possible.

The process of using the Virtual BAF involves the following steps:

- a. Work with the Project Lead Engineer (PLE) to determine the SUT and BAF RF test concept.
- b. Set up the BAF (chamber) with the SUT and appropriate RF transmitting equipment based on the test concept in the “Virtual BAF”. Run the XGtd simulation, determine preliminary expected RF results and identify possible difficulties in the RF test
- c. An example of the computer “Virtual BAF” model is shown in Figure (3).



Using a Virtual BAF in EW Testing

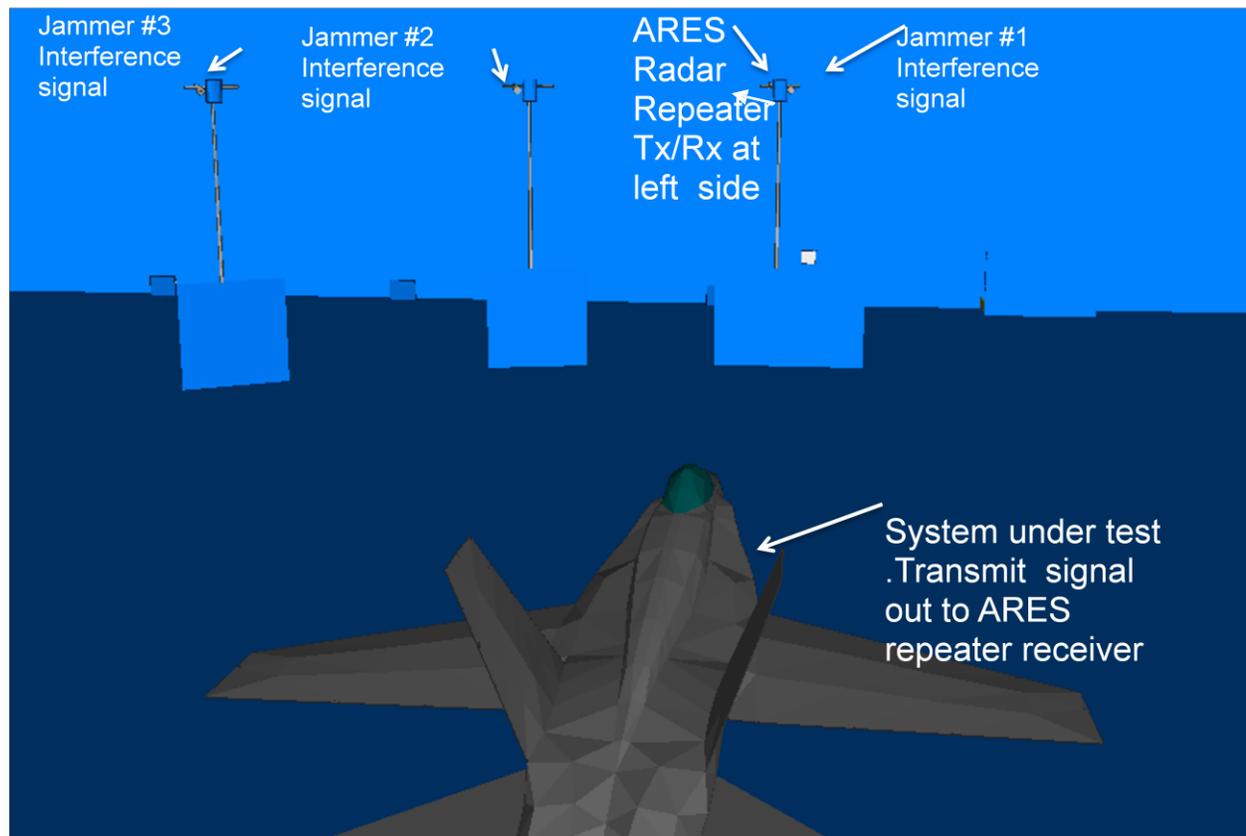


Figure (3) An example of a “Virtual BAF” test setup

Figure (3) shows an application of the “Virtual BAF” model being used to investigate aircraft radar wave reflections expected in a test set up. The System Under Test (SUT) transmits the test signal to Advanced Radar Environment Simulator (ARES) Radar Repeater receive port (Rx), the interference signal from Jammers to the ARES Rx is simulated and examined. The purpose is to simulate antenna isolation in between Jammers and ARES Repeater receiving signals, and set up the optimal system test condition. Ray tracing and geometric theory of diffraction^[4] are used (reflection/diffraction wave tracing) to identify propagation paths and associated reflections and diffractions in the chamber that are expected to occur in an actual test.

Multipath effects that occur during testing in the BAF introduce errors in measurement data (signal strength and direction of arrival for example). To reduce this error, the “Virtual BAF” model can investigate the multipath phenomena, and in turn may help to determine a test set up that will minimize this effect.

Using a Virtual BAF in EW Testing

3A. Basic Ray Tracing Review

Ray tracing is based on geometrical optics theory for a point-to-point ray correspondence between two successive positions of a wavefront. A single ray from the transmitter to the receiver point is constructed. For “Virtual BAF” applications, specular reflection is used^[5] as shown at Figure (4):

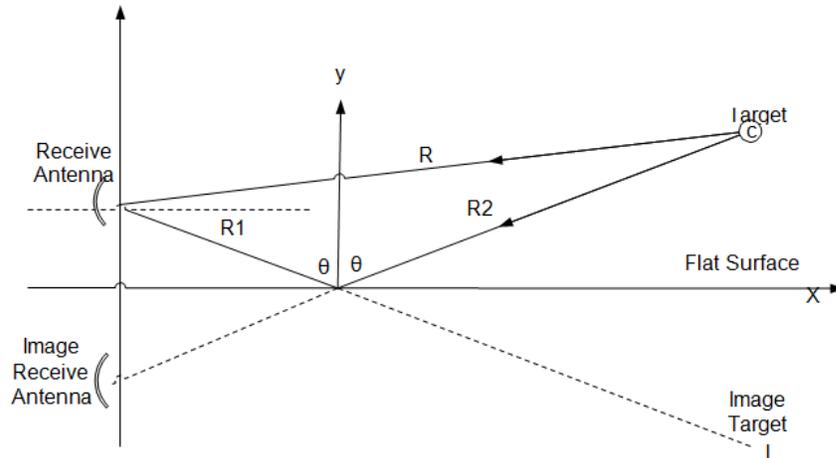


Figure (4) Specular Reflection Model from Surface

Here: R is the direct path return from the target to the receive antenna. R1 and R2 is the indirect, multipath return from target to the receive antenna.

As an example, Figure (5) shows reflection and transmission of a TE plane wave at a dielectric surface field component.

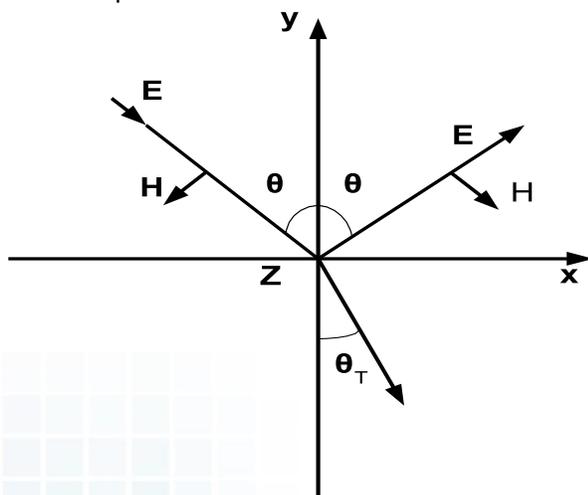


Figure (5) Field component of reflection and transmission TE plane wave



Using a Virtual BAF in EW Testing

- Θ is the incident and reflect angle
- θ_T is the deflection angle to dielectric surface

For a simple example, if we consider the Transverse Electrical (TE) mode propagation of an electromagnetic plane wave in the chamber as shown in Figure (5) the electrical and magnetic fields along the x, y and z (into the direction of paper) can be written as ^[6]

$$E_z(x, y) = (V^R e^{-jky \cos \theta} + V^I e^{+jky \cos \theta}) e^{-jkx \sin \theta} \quad \text{----- (1)}$$

$$H_x(x, y) = \frac{\cos \theta}{\eta} (V^R e^{-jky \cos \theta} - V^I e^{+jky \cos \theta}) e^{-jkx \sin \theta} \quad \text{----- (2)}$$

$$H_y(x, y) = \frac{\sin \theta}{\eta} E_z(x, y) \quad \text{----- (3)}$$

Where:

- V^I : is the incident wave strength of the electrical field
- V^R : is the reflective wave strength of the electrical field
- η : is the wave impedance of the surface medium in ohms
- K : is the wave vector which points to the direction of propagation

From equation (1), (2) and (3) the electrical field strength can be calculated, or programmed via software calculation, at point-to-point or point-to-multipoint field magnitude and phenomena.

3B. Virtual BAF Application

As shown in Figure (3), the application of the “Virtual BAF” model: the Model was used in conjunction with an Advanced Radar Environment Simulator (ARES). ARES is a radar signal repeater. ARES is shown on the left side of figure (6). The “Virtual BAF” was used in the investigation of a pre-system test set-up to evaluate aircraft radar wave reflections expected in this test. Figure (8) shows the pre-system test of the interference transmit and radar repeater receiver port isolation ^[7] that was designed from the simulation result.



Using a Virtual BAF in EW Testing

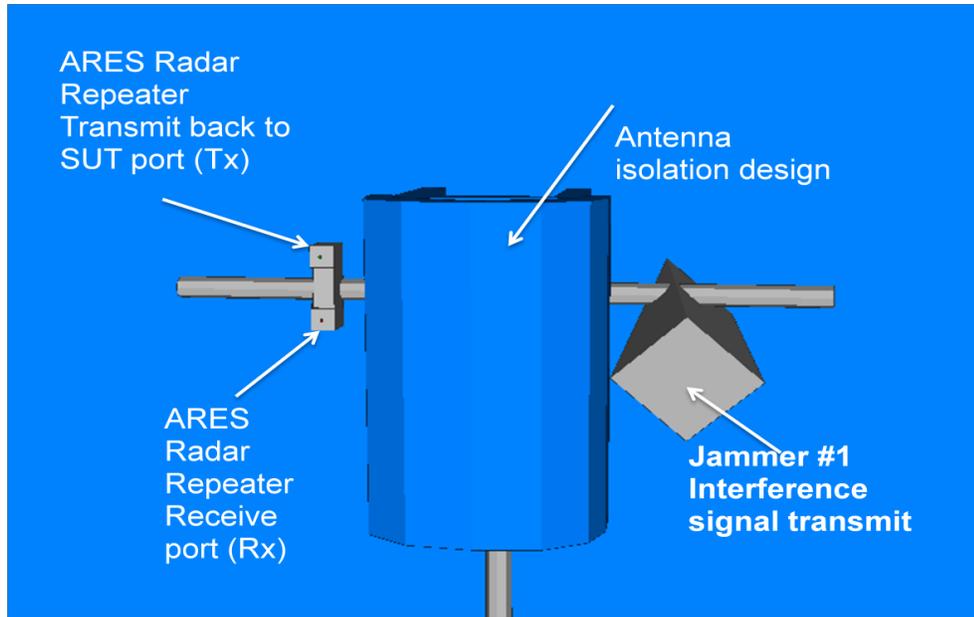


Figure (6) Antenna Isolation Designed from "Virtual BAF" Simulation

Figure (7) shows the ray tracing example of how Jammer #3's interference signal (direct and multipath signals) propagate to the receiver port of the ARES Radar repeater. The time of arrival of the direct and multipath signals to the radar repeater receiver can also be calculated and plotted as shown in Figure (8).

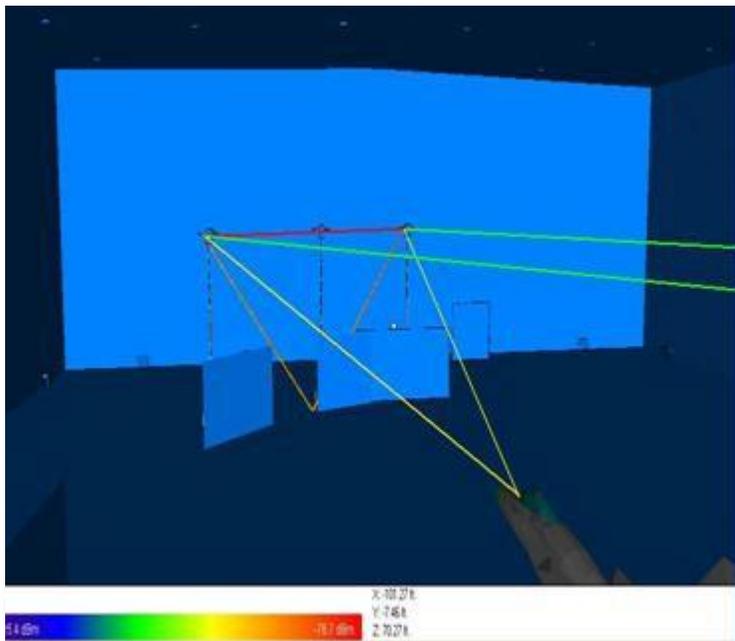
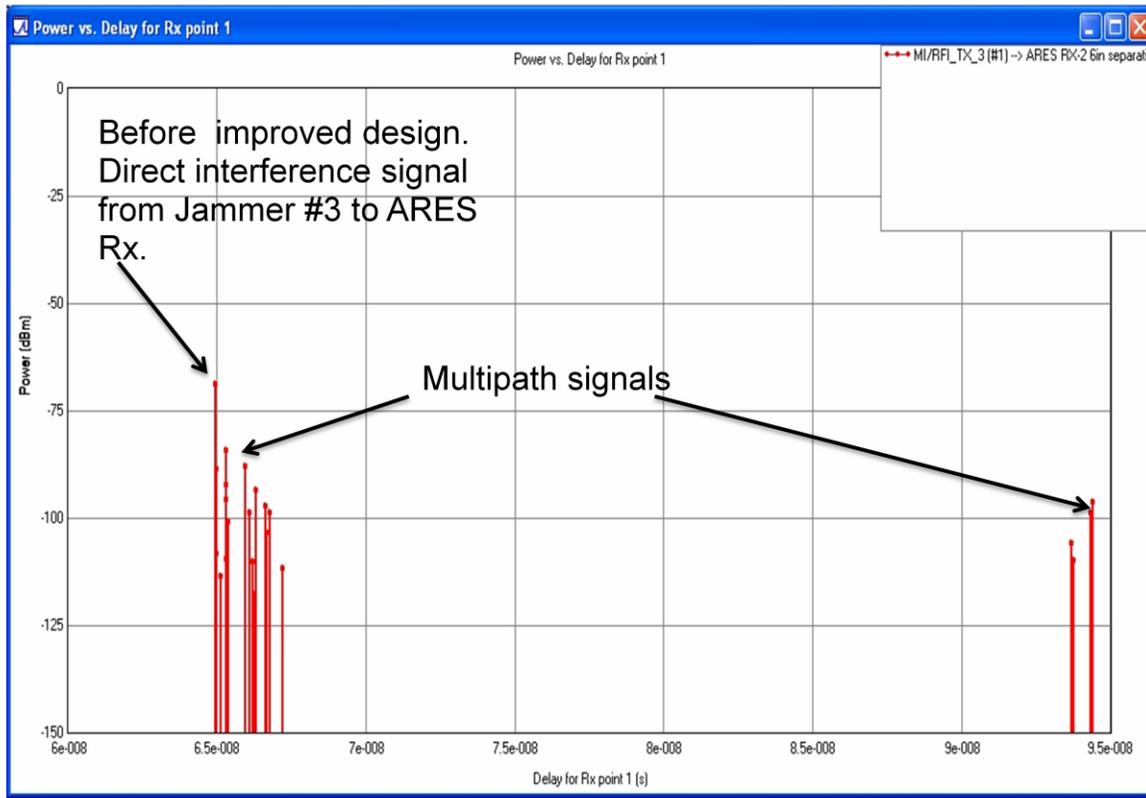


Figure (7) interference signals (direct and multipath signals) from Jammer #3 to the ARES Radar Repeater receiver. Red color is direct interference signal trace. Green is the multipath interference signals from Jammer #3.

Using a Virtual BAF in EW Testing

Interference Signals Time of Arrival



Time of interference signals arrive from Jammer #3 to ARES Repeater Rx

Figure (8) Plotted time of arrival from Emitter #4 to the radar repeater receiver

Figures (9) and (10) also show how the simulation can be used to provide the system test engineer the multipath and interference signal distribution to the radar repeater receiver port. Further, using signal versus time distribution, the model can provide information on how signals arrive at a radar repeater receiver port both directly and indirectly. This information is highly valuable and reduces the need for manually calculating time gating to eliminate the multipath signals. Figure (9) shows the example of Emitter #4's direct signal propagating to the receiver of a radar repeater as well as the incoming multipath signal. Figures (11) and (12) show on the time domain graph the received signal power as a function of time delay.

The shortest incoming power appears as the main beam of a transmit antenna, and unwanted signals appear throughout time thereafter. This information is invaluable for effectively gating out the reflections. The application will be useful in such cases where the BAF tests EW jammer interference.



Using a Virtual BAF in EW Testing

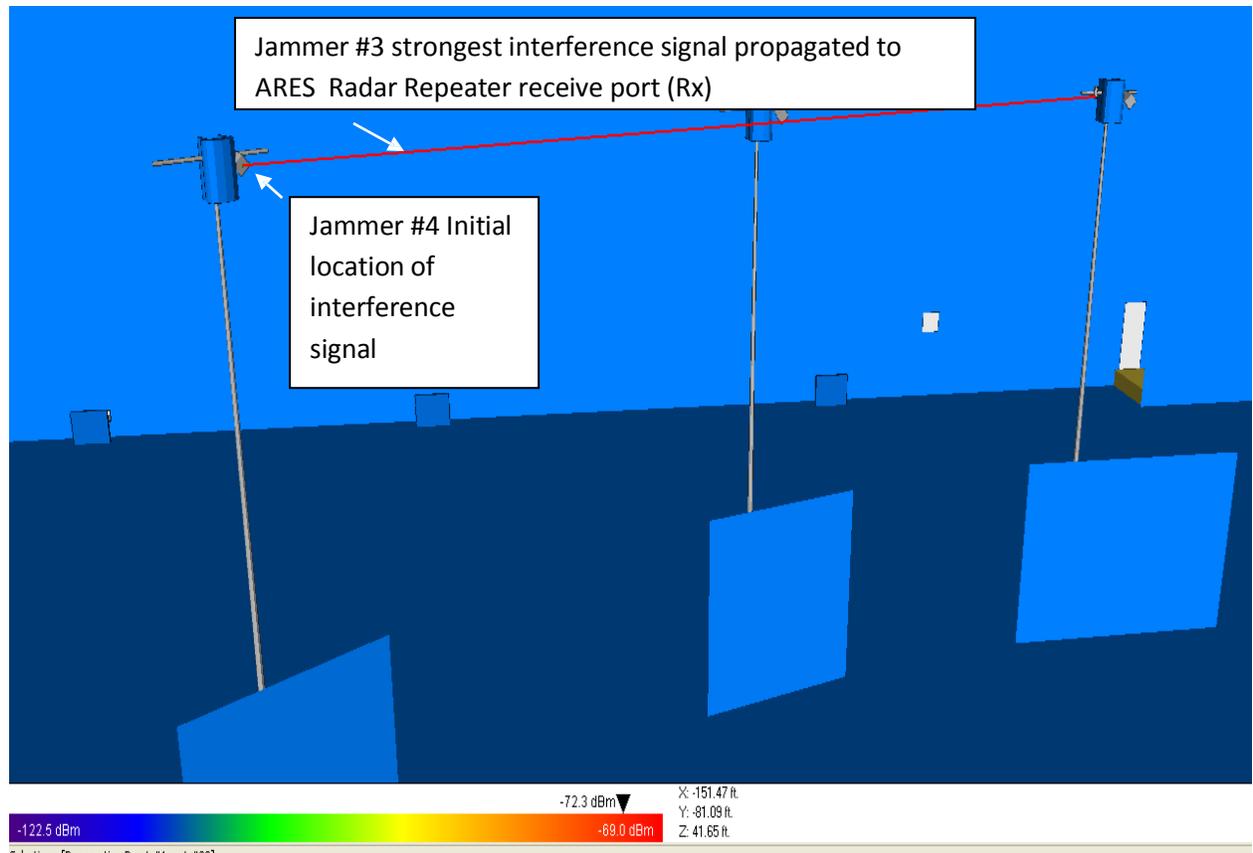


Figure (9) Initial Design of Interference Signal Location in “Virtual BAF” Simulation



Using a Virtual BAF in EW Testing

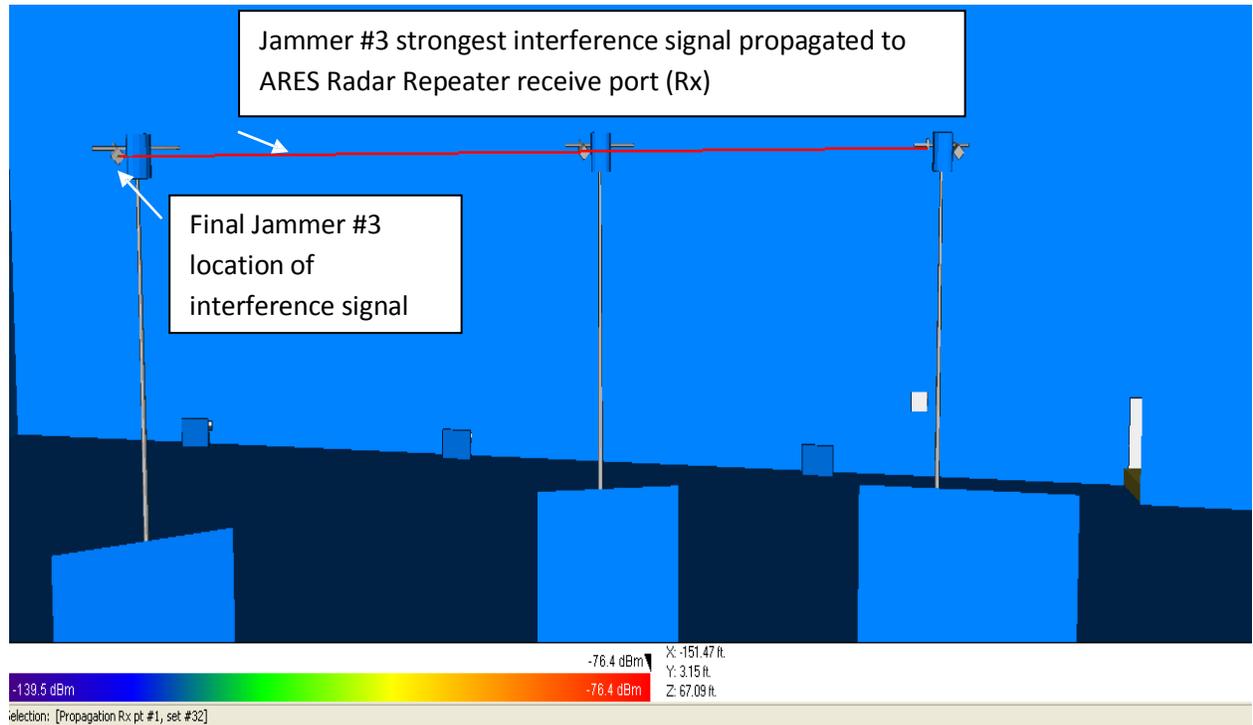


Figure (10) Final Design of Interference Location in “Virtual BAF” Simulation



Using a Virtual BAF in EW Testing

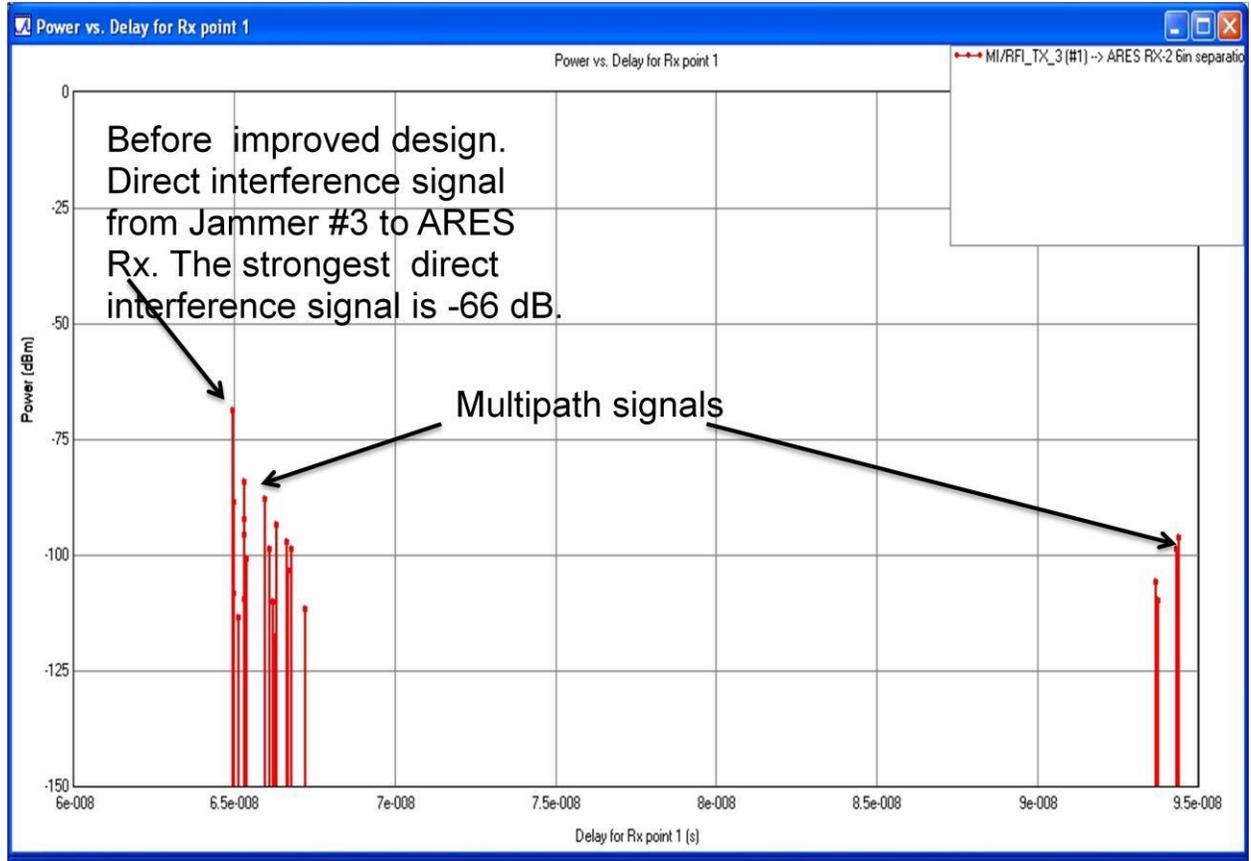


Figure (11) Jammer #4 Interference Signals Delay vs. Power into ARES Radar Repeater Receive Port. Note this output corresponds to Figure (8)'s set up configuration. The strongest interference multipath signal is -66 dB.

Using a Virtual BAF in EW Testing

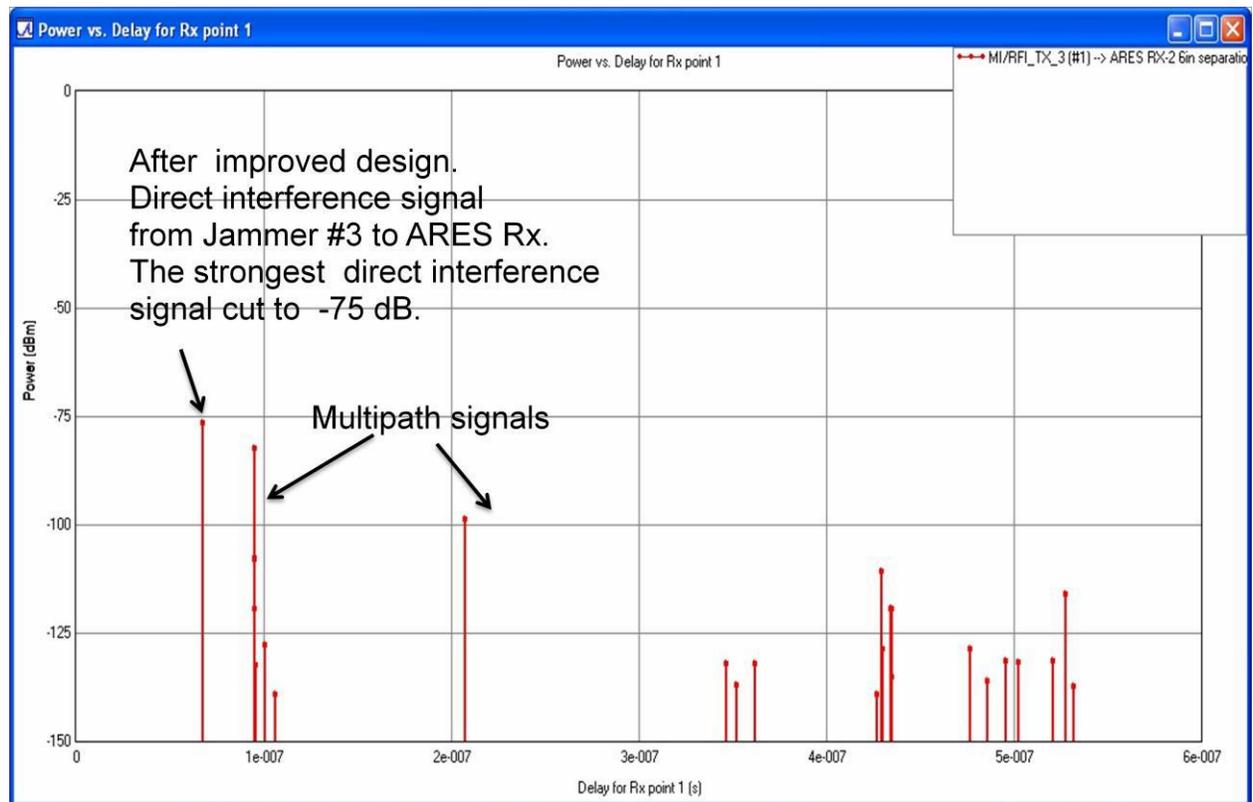


Figure (12) Multipath Interference Signals Delay vs. Power into radar Repeater Received. Note this output corresponds to Figure (9)'s set up configuration, and the strongest interference signal cut down to below -75 dB.

Power distribution can also be investigated with the “Virtual BAF” model. This reveals potential “hot spots” inside the chamber. This information will be useful from a safety perspective in determining safe zones for personnel and for the Radar Absorbing Material (RAM). Figure (13) shows an example power distribution. RAM has a specific tolerance for absorbing energy before it will burn, and this is a major concern with any high-power RF testing. With the “Virtual BAF” model, analysis can be done beforehand to identify and mitigate these issues.



Using a Virtual BAF in EW Testing

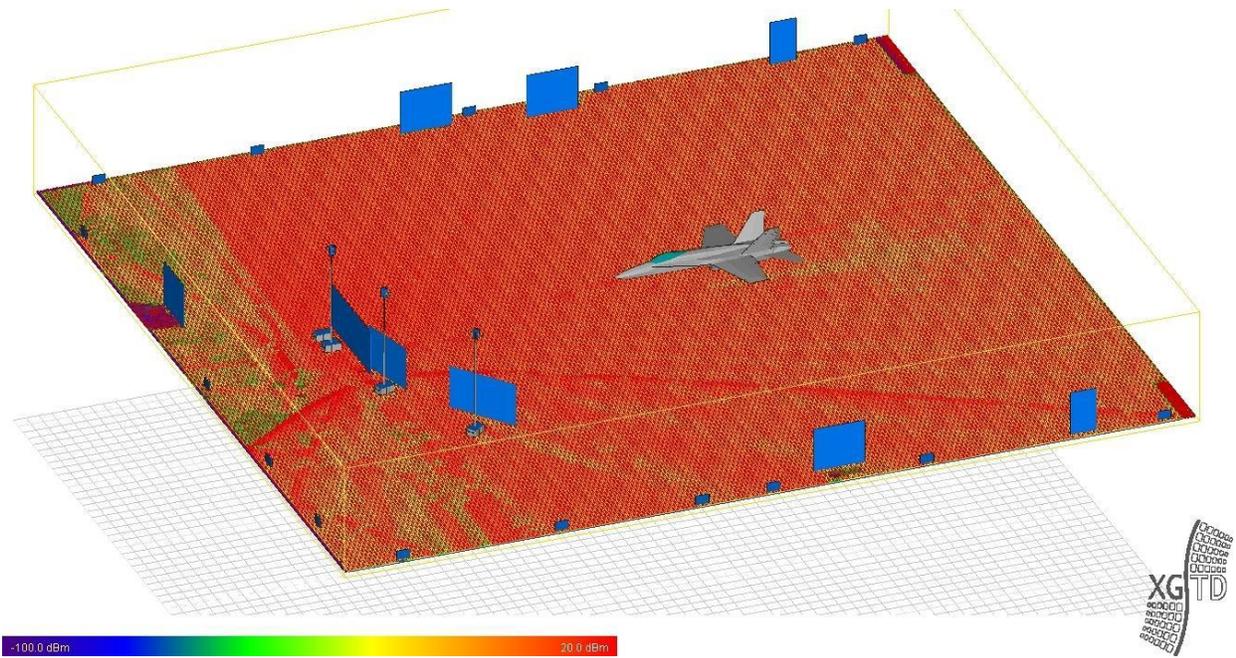


Figure (13) Power distribution of received power at ground level

These are just a few examples of how a simulated “Virtual BAF” model could benefit the BAF testing. Using a basic ray tracing simulation tool like Remcom’s XGtd program, the “Virtual BAF” model will help improve the test design, execution, and increase overall confidence in test results. For all these reasons the “Virtual BAF” model, incorporated with the custom waveform design, antenna pattern, etc., can be a useful tool for modeling and simulation in EW testing at the 772nd Test Squadron and the BAF.

4. Data Analysis – Design of Experiments (DOE)

The “Virtual BAF” simulation system has been in development for a year and a half. The simulation uses XGtd software. Throughout this developmental time period the XGtd software has been corrected and improved upon. To gain further confidence in the simulation software we have applied a data analysis tool – Design of Experiments (DOE) -- to analyze the results of the simulated data.

DOE is one of the mature data analysis tools widely applied in the M&S field here at the AFFTC, Edwards AFB. For example, it was used in a recent test of an AN/ALR 69A(V) Radar Warning Receiver (RWR) installed on a Block 30 F-16C/D ^[8]. The technical report was selected as the “best technical paper of the year” at the AFFTC, Edwards AFB of 2009.



Using a Virtual BAF in EW Testing

One application of DOE with the “Virtual BAF” was to determine what (if any) interference was present in a Radar Warning Receiver (RWR) test. Transmit signals were received by a radar receiver and it was thought that there may be interference (either additive or cancelative) RF energy also feeding into the radar receiver. For this data experiment, the transmit signal going into the receiving port of the radar repeater was designed as follows:

Designated	Emitter Source
Transmit #1 (Tx.1)	System under test
Transmit #2 (Tx.2)	Interference #1
Transmit #3 (Tx.3)	Interference #2
Transmit #4 (Tx.4)	Interference #3

Table (1) Jammer source designated

An error signal was introduced at the system under test emitter (SUT, Tx.1), which assumes the SUT radome is not a perfect EM wave transmission. Full factor statistical data was applied to examine the first set of data. Table (2) lists the Pr value when the emitter was on.



Using a Virtual BAF in EW Testing

Emitter turned on	Pr value (Error ray result)
Tx.1 only	0.002715
Tx.2 only	0.306183
Tx.3 only	0.826737
Tx.4 only	0.450528
Tx.1 & Tx.2	0.448212
Tx.1 & Tx.3	0.82622
Tx.1 & Tx.4	0.450895
Tx.2 & Tx.3	0.370572
Tx.2 & Tx.4	0.362784
Tx.3 & Tx.4	0.533319

Table 2 Interference occurred probabilities

The Pr values are the estimated probabilities that the measured interference from the emitter occurred simply by chance. In the example shown above, the RF energy measured has a probability of occurring by chance of only 0.0027. This occurrence is small enough to conclude that measured RF energy indeed came from TX.1. In a like manner, TX.4 may be an interfering emitter and there may be RF interaction between TX.3 and TX.4 that affect the measured RF energy. **This information can save many hours of testing with the actual equipment to identify sources of RF interference.**

5. Summary

This paper proposes that the ray tracing method used to examine the multipath effect at the BAF be done by the 3D computer model "Virtual BAF" method. The "Virtual BAF" can never replace the "Real Test," but it offers a useful "Pre System Test" prediction and approximation. Modeling and Simulation (M&S) has always been a strength at the AFFTC, Edwards AFB, and we are proposing one more method to be used in EW testing to add value to our test process by modeling the test in the "Virtual BAF" prior to actually conducting a test.

Working with the system test engineer to understand the test requirements is a necessary step for an accurate "Virtual BAF" model. We update the model from time to time to fit different types of test conditions, and the software is updated periodically. Given proper input information, simulations of Identification Friend or Foe (IFF) and Communications, Navigation, IFF (CNI) signals can also be included in virtual testing.



Using a Virtual BAF in EW Testing

This “Virtual BAF” will provide assistance to test planning, execution and data analysis at the BAF. Progressive validation of the modeling and verification of the simulation results by real test data is an ongoing effort to gain confidence in the model. This “Virtual BAF” approach will add value to the T&E here at the BAF Electronic Warfare Group of Edwards Air Force Base.

References:

“Techniques for integrating ground and flight test and modeling and simulation to improve aircraft propulsion system acquisition”, David S. Kidman , Donald J. Malloy and Andrew A. Hughes. 40th International SFTE Symposium, 7-11 September 2009, Linkoping and Stockholm, Sweden.

“Lesson Learned From Modeling & Simulation Use In The Flight Dynamics Test And Evaluation Process. 55 Years Of AFFTC Experience. Fredrick R. Webster, 773 TS. Edwards Air Force Base. 40th Annual SFTE International Symposium, 7-11 September 2009, Linkoping and Stockholm, Sweden.

“EW Survivability Ground Testing”, Lt Col Taylor Selden, 772 TS. Antelope Valley Chapter , The International Test & Evaluation Association , April 8, 2009.

“Introduction to The Uniform Geometrical Theory of Diffraction”. D.A. McNamara, C. W. I. Pistorius, and J. A. G. Malherbe. Artech House, Boston, 1990.

“Modern Radar System Analysis”, David K. Barton, Artech House, pp 512 – 528.

“Radio Propagation for Modern Wireless System”, Henry L. Bertoni, Prentice Hall, pp 62-68.

“Antenna Isolation Determination Test”, Hans Lambrecht, Josh Rozas, John Parra, Saul Correa. Internal Report, 772TS/EWOI. August 18, 2009.

“F-16 ALR-69A Testing at the Benefield Anechoic Facility Using Design Of Experiments”, James D. Brownlow, William Kitto, Mario Dorado and Paul E. Kladitis, all AFFTC, Edwards AFB. AIAA Air Force T&E Days, 5-7 February 2008, Los Angeles, CA.

