“Portable Range Threat Simulators”

Bill Williams

AAI Corporation
P.O. Box 126
Hunt Valley, MD 21030-0126

William McClelland

AAI Corporation
P.O. Box 126
Hunt Valley, MD 21030-0126

ABSTRACT

Pilot training coupled with test and evaluation of the next generation of Radar Warning Receiver and Electronic Countermeasures systems requires extensive flight testing, which is necessary to verify pilot skills and validate ECM countermeasures. Current range testers are generally limited to very large, very expensive systems; or smaller, less expensive, and less capable systems limited in both frequency bandwidth and the ability to output multiple, high fidelity threats. In addition, vertical testability demands a common thread for testing; from flight test through flightline to depot.

The challenge is twofold: to provide a portable range tester that can create a realistic, threat dense environment necessary to properly stress the ECM system, while providing a path for vertical testability.

This paper discusses the design challenges and solutions for a ruggedized, portable range threat simulator (PRTS) system capable of stimulating aircraft with a wide variety of high fidelity threat signals at distances up to 5 nautical miles. Using established synthesizer technology and threat parameter definition software developed for the AN/USM-670 Joint Service Electronic Combat Systems Tester (JSECST) flightline tester, the PRTS offers a low-cost solution to range simulators. Threats defined on the PRTS may be directly ported to the Model 527 Radar Simulator and/or JSECST for flightline testing or the Lab JSECST for depot level test, thereby establishing the key link necessary to maintain vertical testability.

INTRODUCTION

Testing modern electronic warfare systems requires multiple phases of test; from initial design verification, through intermediate and organizational support, to end-of-runway testers providing the vital pre-flight verification that all is OK prior to launch. In all of these test scenarios, the aircraft sits on the tarmac. The all important test of the system in flight - with the associated pilot training in ECM evasive maneuvers – has not yet been achieved.

Flight testing requires a free space (or open air) threat simulator that provides cost-effective threat signatures in a flight range environment. The Range Simulator is the key asset required to perform this critical test function.

RANGE SIMULATORS

Pilot training against “real-world” threats in a simulated environment allows evaluation of both pilot training and EW suite countermeasures effectiveness. This training cannot be readily evaluated in any place but during flight as pilot reaction time and evasion tactics are involved. Current range testers fall between two general categories:

1. **Large, expensive, full-up range testers**. These systems can do it all; however, the unit cost limits its use; not everyone can afford these systems. These systems can support automated tracking, and some can measure and record the aircraft ECM jamming waveforms.
2. **Small man-portable systems**. While less-expensive, these systems generally have limited bandwidth (on the order of 1 GHz), requiring multiple amplifiers (adding to the unit cost) to cover the expected threat coverage. The units are limited to low duty cycle (<5%) threats, and have limited or no ability to simulate scan characteristics. Duty cycle limitations tend to narrow the threats that can be simulated; for example, modern high PRF pulse Doppler systems cannot be readily simulated.

A middle-ground need has been identified; one where complex threat scenarios over a wide frequency range are required, while keeping both cost and complexity down. The Portable Range Threat Simulator (PRTS) has been designed to meet this need.

THE PORTABLE RANGE THREAT SIMULATOR

Evolution of design. As a leader in the field of flight-line EW testers, AAI recognized the need for a portable range tester that could still provide the necessary threat simulations (i.e., the modulations) over extended frequency ranges. However, before beginning any design, we talked to the end users. In these discussions, the following complaint was heard:

> *"Range testers are going away. I have no ability to verify my countermeasures systems during flight test. Can you help me?"*

As part of the initial design, AAI developed a small proof-of-concept unit using the following set of requirements derived from discussions with various end users.

- The system must be easily deployable. For example, it must be small enough to load on the back of a pickup truck or be easily towed by a pickup truck.
- The system must have sufficient radiated power to apply minimum detectable thresholds at distances up to at least 5 km.
- The system must have good threat fidelity. Simple pulse threats are not sufficient. Real-world modulations are required to adequately stress the ECM hardware.
- The system must provide EO/IR test capability. In addition, the EO/IR threats should be able to be synchronized with the corresponding RF threats.
- The system must be extensible, supporting multiple configurations such as frequency bands of interest.
- The system must be relatively inexpensive. Of course, what is "relatively inexpensive" depends on to whom you are talking!

Design trades. The initial study phase focused on the high power amplifiers. Lower cost magnetron-based simulators have a much narrower bandwidth with relatively high peak power levels. The disadvantage is that they do not support continuous wave (CW) or high duty cycle emitters. The alternative is to use traveling wave tube amplifiers (TWTA's) to take advantage of the broadband stimulus capability of the Model 527 or JSECST. To support the simulation bandwidths of the larger more expensive simulators TWTA's were selected. Either pulsed or dual mode CW/pulsed TWTA's could be used. Generally, pulsed tubes allow higher peak powers at the expense of lower duty cycles. This is fine for search/track radars; however, modern pulsed Doppler radars, and CW illuminator threats must also be considered. The trade is the number of pulsed amplifiers coupled with lower power CW amplifiers. In the final PRTS design, both pulsed and dual mode devices are supported. The dual mode traveling wave tube amplifiers support both CW and pulsed operation at their inputs. They also support the ability to be pulsed modulated via the TWTA grid. This is important since it allows the true dynamic range of the TWTA to be seen, opposed to blanking the TWTA input where the dynamic range is set by the quiescent noise of the TWTA which is still on.

How much power is required is the next problem. Amplifier power output (P_T) is determined by the required power on target (P_R, or threat lethality level), system cabling losses (L_{CAB}), antenna gains/losses (L_{ANT}, G_{ANT}), and free space spreading loss (L_S) as given by:

$$P_R = P_T + G_{ANT} - L_{CAB} - L_{ANT} - L_S$$

where $L_S = 32.44 + 20\log_{10}(\text{Freq}_{MHZ}) + 20\log_{10}(\text{Dist}_{KM})$.

Since operating frequency is a key component of the loss equation, selection of operating frequency is key. For proof of concept testing, a frequency range of 6 to 18 GHz was chosen. This provides a fairly wide frequency range supporting multiple threat types.

The required power on target (P_R) is usually specified in one of two ways; 1) indirectly by specifying an effective radiated power (ERP) or 2) as a power on target at a distance; i.e., "ensure a minimum -40dBm[1] on target at 3 nm." Generally, the second type of specification assumes nothing fancy about atmospheric conditions (such as attenuation effects due to rain), and may therefore be used directly.

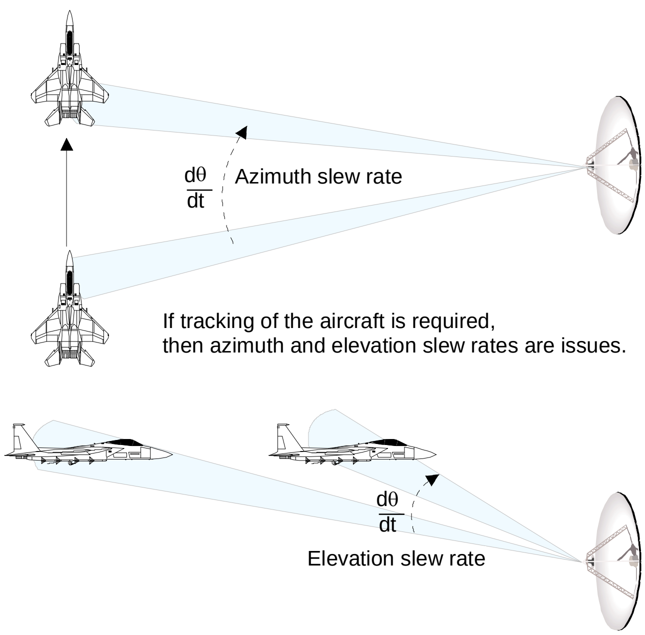
The gain of the antenna (G_{ANT}) is generally a trade between maximizing antenna gain (in turn minimizing beamwidth) over a frequency range while minimizing antenna size.

Antenna losses (L_{ANT}) due to antenna VSWR is defined as $-10\log_{10}\left[1-\left(\frac{VSWR-1}{VSWR+1}\right)^2\right]$ and must be included system loss calculation. Cabling losses (L_{CAB}

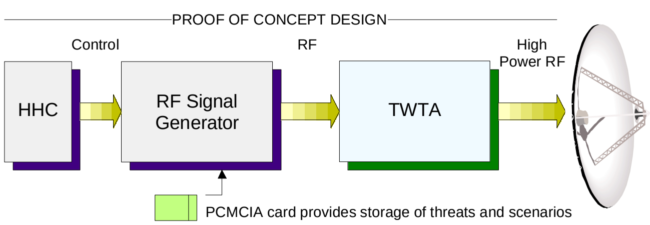
[1] Note that this specification is in dBm. Propagation is generally in terms of $\frac{\text{volts}}{\text{meter}}$; conversion to watts requires knowledge of the effective aperture size of the aircraft antennas. Since this is unknown, we assume an isotropic antenna of 0 dBi gain.

e.g., RF cables, circulators, isolators, etc) all drive the TWTA selection.

One issue is tracking the target during test. To minimize cost, the PRTS does not include automated target tracking, instead using “man in the loop” steering; however, this option will be available in future models. Therefore, another part of the trade is ensuring that the beamwidth is ‘wide enough’ to allow manual tracking of a target given an expected distance to the aircraft and its tangential and/or radial velocity. If an antenna is too large, it cannot be readily slewed when mounted to a tripod. Of course, one option is to have a stationary tripod/antenna setup and have the aircraft ‘fly through’ the beam. This option requires no antenna tracking and allows for unattended operation.



PRTS prototype. A block diagram of the prototype unit is shown in the following figure. A high power pulsed/CW TWTA was chosen for the demonstrator since it could output both CW, high duty cycle, and low duty cycle pulsed RF signals. The antenna was selected for its gain characteristics over the operating frequency range of 6 to 18 GHz. The prototype antenna selected is a 2-foot WRD-650 waveguide fed reflector antenna that supports a 3 dB beamwidth of 6° to 2.6°. To maintain signal fidelity and generate realistic threats, the Model 527 was chosen as the RF signal generator.



As shown in the following photograph, the proof of concept PRTS fit within a small chassis. This unit provides full modulation capabilities over the 6 to 18 GHz range.

Preliminary test results. Laboratory testing has demonstrated very good fidelity on threat reproduction at the TWTA output. Minimum pulse widths of 100 nsec are achievable, with pulse repetition frequencies (PRF’s) up to 100 kHz. Measured amplitude modulations agreed with programmed values.

Given the success of the proof–of-concept unit, the decision was made to develop the specifications for a full up PRTS system including full support of the 2 to 18 GHz frequency range and EO/IR support using ESL Mallina family of systems. The following discussions focus on four main areas of the PRTS concept:

1. **Concept of operations (CONOP)**. The CONOP for a typical PRTS system is presented. The CONOP is key to understanding the requirements for the PRTS as it reflects both AAI’s and the customer’s understanding of how the PRTS is used.
2. **Hardware**. The PRTS architecture is presented, along with a discussion of the tradeoffs involved in the design.
3. **Software**. The PRTS has state-of-the-art capabilities to define and build threats and scenarios. The threat builder, scenario builder, and simulation capability are presented.
4. **Vertical testability**. By using a common RF stimulus system, the PRTS fills the vertical testability ‘gap’ that can exist when different hardware and software are used to verify system operation at differing levels of test.

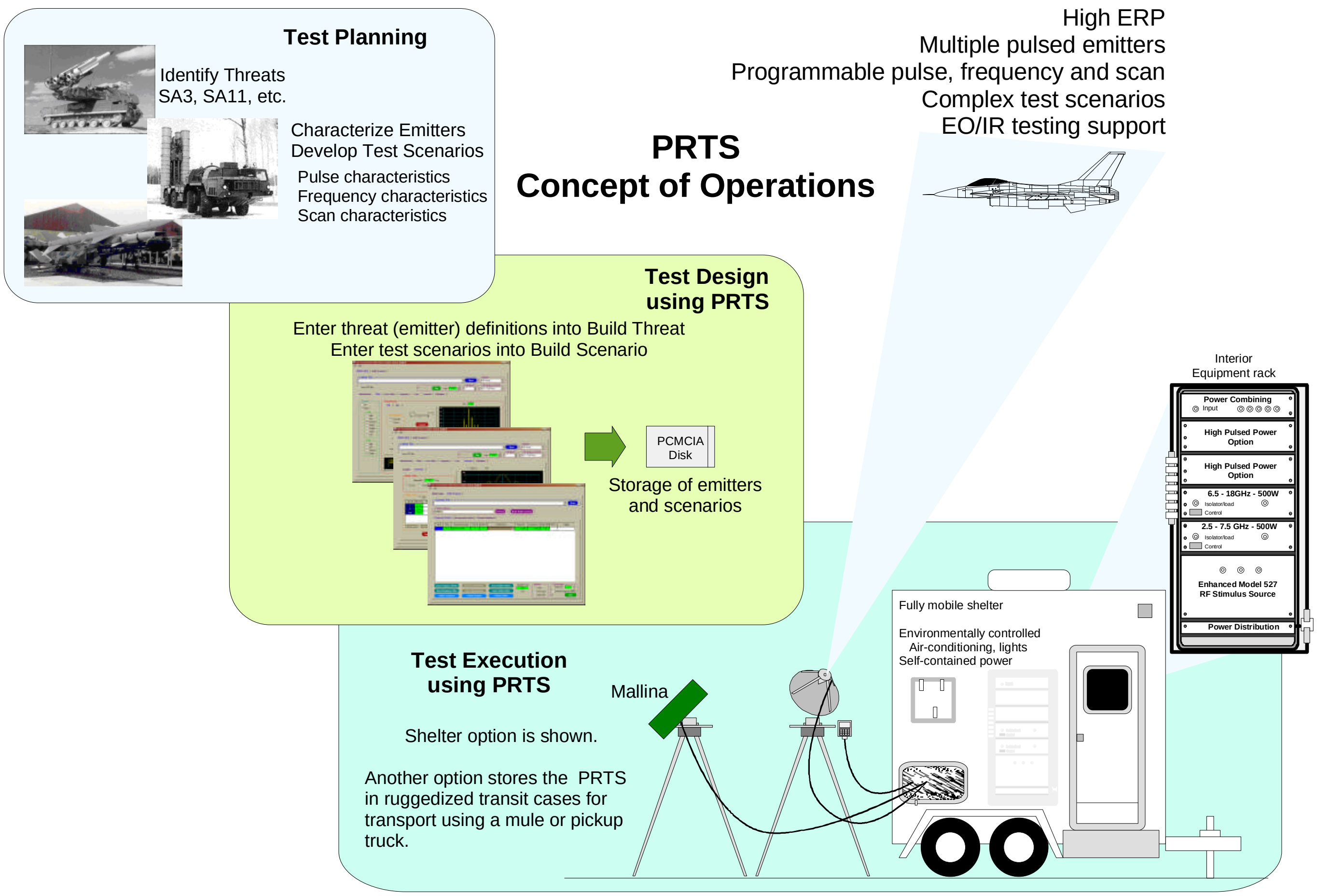
PRTS CONCEPT OF OPERATIONS

THE PRTS concept of operations (CONOP) is shown below.

Use of the PRTS begins with the test planning phase, where the test director determines the threat types that the aircraft will fly against. The threat types will vary depending on the mission scenario. Surface-to-Air missile (SAM) sites are common threat types. SA1 “Guild” through SA20 “Triumf”, etc., are all example SAM sites against which the pilot must be protected.

Once the threats and scenarios are defined and stored, the PCMCIA disk is inserted into the Model 527 RF signal generator.

Located within a portable, environmentally controlled shelter, or within transit cases, the PRTS is transported to the site and set up. The antennas are unpacked and mounted to the tripods. Finally, the antennas are connected to the PRTS using the supplied RF cables. The handheld controller (HHC) is mounted on the tripod to allow easy access to the controls for threat and scenario application.



Once the threats are identified and test execution scenarios are planned, the parameters of the threats are entered into the PRTS Build Threat program. The parameters are pre-validated, and the threat is optionally simulated. Next, the user defines the specific scenarios. These scenarios may range from simple scenarios (e.g., one threat is applied, then another, with some programmed delay) to more complex scenarios such as the simulated search, track, and then missile launch/missile guidance. (These threat parameters are generally classified.) The PRTS stores all threat/scenario parameter information on removable media in a non-proprietary format, ensuring that the PRTS remains unclassified once the media is removed.

Power is applied using the portable generator and the PRTS is powered on. The PRTS performs a system power on built-in test (BIT) to verify basic hardware integrity. Each TWTA is queried and its BIT status is returned and displayed to the operator.

At this point, the PRTS is ready to test. As the aircraft flies through its planned route, the user tracks the aircraft using the sighting scope and applies emitters and scenarios using the HHC. An alternate approach is to set up the antenna and have the aircraft fly through the antenna beam.

Once testing is complete, teardown is quick and easy. The PRTS is powered down. The RF cables are disconnected and stored; the antennas are removed from the tripod assemblies and stored along with the tripods; and the HHC is stored. Once complete, the entire system can be transported back to the maintenance or back shop for storage.

At the back shop, the PCMCIA card is removed from the signal generator and, if classified, is stored using appropriate safeguards. Once the PCMCIA card is removed, the PRTS is no longer classified, ensuring simpler maintenance and lower logistics costs.

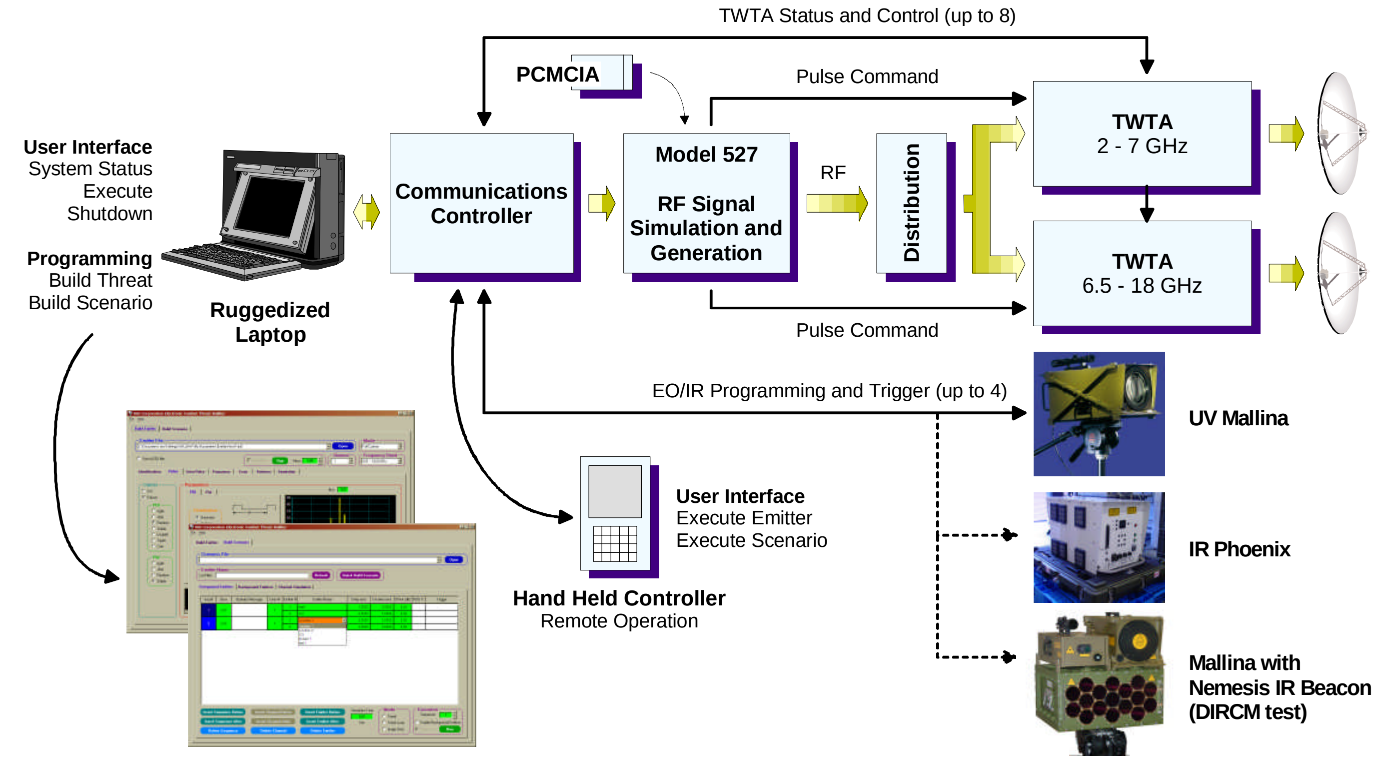
The brief discussion of the CONOP provides an overview of the PRTS. The following discussions provide information on the hardware and software design used to meet the CONOP.

PRTS HARDWARE DESCRIPTION

The PRTS is a more capable portable range threat simulator system, the key advantages being frequency coverage, signal fidelity, and cost relative to capability.

The PRTS serves as the RF/microwave portion of an integrated solution capability including the electro-optics. A functional block diagram of the PRTS system is shown below.

PRTS Functional Block Diagram



The PRTS consists of a ruggedized laptop serving as the software development station and test executive, a programmable RF signal generator (enhanced Model 527), 19-inch rack-mounted TWTA assemblies, high gain antennas, a transportable generator, an environmental shelter, and an ESL Mallina with IR beacon option for directed infrared countermeasures (DIRCM) testing and training. The high gain antenna and the ESL Mallina source are mounted to tripod assemblies for man-in-the-loop steering.

The RF signal simulation and generation is controlled by the enhanced Model 527. As shown in the following table, the PRTS is fully programmable from 500 MHz to 18 GHz. Options exist to extend capabilities from 28 to 40 GHz and down to 20 MHz. Threats can be programmed as CW or pulsed. These programmable capabilities of the Model 527 provide great flexibility in threat definition and modeling. The Model 527 is capable of multiplexing a maximum of eight independently programmed emitters at high speed to simulate simultaneously executing emitters.

PRTS Hardware Capabilities	
RF Stimulus Generator	
Frequency range	0.5 - 18 GHz Optional 28 - 40 GHz
Accuracy	0.001% single emitter 0.002% single emitter 28 - 40 GHz 5 MHz multiple emitters 20 MHz multiple emitters 28 - 40 GHz Resolution < 500 KHz
Switching time	< 200 usec single emitter to 0.001% < 1 usec multiple emitters to 5 MHz
Spurious/Harmonics	-50 dBc / -10 dBc -15 dBc / -10 dBc 28 - 40 GHz
Intrapulse modulation	FM, Bi-phase
Pulse modulation	PRI range 1 usec (min) PW range 50 nsec (min) to CW Rise / fall < 15 nsec / 15 nsec
Amplitude modulations	Range 45 dB Rate 0.005 – 2 kHz
High Power Output	
Frequency range	2.5 GHz - 18.0 GHz (0.5-40 GHz available)
TWTA output power	500W CW and pulsed
Effective radiated power (ERP)	Up to 400 kW
Spurious/Harmonics	-50dBc / -3dBc typical

The high power microwave amplifier assemblies (TWTA's) are mounted in a portable shelter to weather the environment and minimize cost. The design provides for the ability to cover the 2 to 18 GHz frequency range. Both CW and pulsed signatures are implemented. The Model 527 is designed to provide time synchronized pulse triggers to each of the TWTA's – up to a maximum of eight TWTA devices.

The PRTS antennas are specified to optimize gain over the TWTA operating frequency range. The antennas are segmented parabolic reflectors that can be disassembled and stowed in a re-useable case. The base system provides coverage from 2 to 18 GHz utilizing two bands; 2 to 7 GHz and 6.5 to 18 GHz. The 2 to 7 GHz antenna, at 3-foot diameter, has an SC-female connector and supports power levels up to 500W CW. The 6.5 to 18 GHz antenna, at 4-foot diameter, has a WRD-650 flange and also supports power levels up to 500W CW, and is configured with a low pressure waveguide window. The antennas are equipped with a red dot scope, mounted at the edge of the dish for sighting purposes. The antennas are linearly polarized with a specified VSWR of 2.5:1 maximum over the operating frequency range.

Both antennas are mounted on a rugged tripod with a fluid damped pan/tilt head. The tripod is designed to support heavy loads in severe environments and collapses for easy storage.

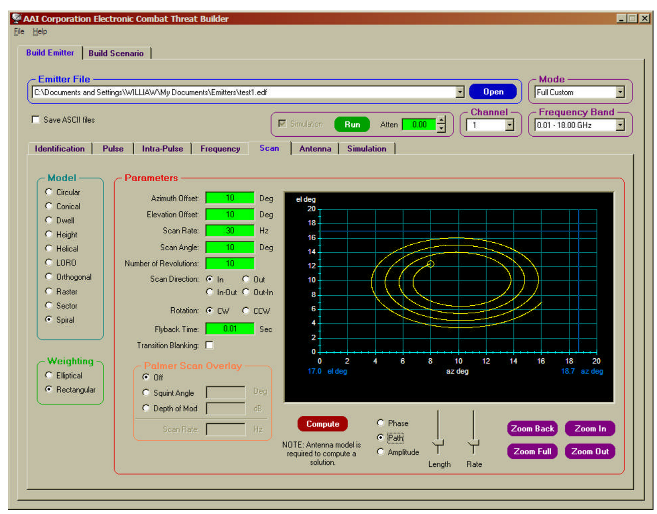
PRTS SOFTWARE DESCRIPTION

The software is key to the operational effectiveness of the PRTS. The software should provide:

- A simple easy-to-use interface for defining and building the threat parameters
- A method to simulate the threats prior to use
- A method to define threat scenarios
- Maintenance software:
  - Full systems status checking
  - Built-in system alignment

Each of these key requirements is addressed in the PRTS software design as discussed in the following sections.

Building threats. The build emitter portion of the PRTS software provides an easy-to-use interface to design and simulate complex emitters. As shown in the following figure, intuitive, easy-to-use graphical representations of each phase of the emitter build (i.e., Identification, Pulse, Intra-Pulse, Frequency, Scan, and Antenna model) are provided. For each phase of the build, the user is provided graphical information in the form of data plots and pulse trains, allowing him to review how the emitter will be simulated and output by the hardware. Error checking is performed as data are entered, thereby providing immediate feedback to the user. Color-coded data entry fields tell the user what data are optional, what data are required, and what data are incorrectly entered. Once defined and validated, the emitter can be saved to a file in a non-proprietary format for later use in building scenarios.

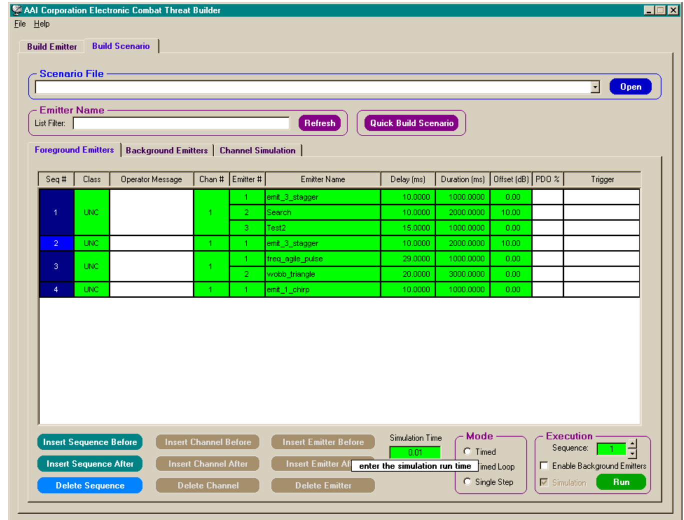


As shown in the table below, full support of threat characteristics is available for programming.

PRTS Software Capabilities	
Parameter	**Programming Model**
Frequency	Agile, Dwell, Jitter, Random, Stable, and Stagger
PRI	Agile, Jitter, Random, Stable, Doublet, Triplet, and User Defined
PW	Stable, Agile, Jitter, and Random
Intra-Pulse	Chirp, Barker, and Bi-Phase
Scan	Circular, Conical, Dwell, Height, Helical, LORO[2], Orthogonal, Raster, Sector, and Spiral
Antenna	Simulate independent Azimuth and Elevation Beam Width (using $\frac{\sin(x)}{x}$ or parabolic distribution), Number of Lobes, and Magnitude[3]
Scenario Support	
Scenario mode	Full support for emitters, sequences of emitters, and scenarios consisting of emitters or sequences.
EO/IR Device Support	
EO/IR devices	Range support: IR and UV Mallina, Phoenix, and Nemesis IR beacon Flightline support: Baringa, Meon
Number of EO/IR devices	Up to four
Programming	Program select Synchronized trigger to emitter/scenario

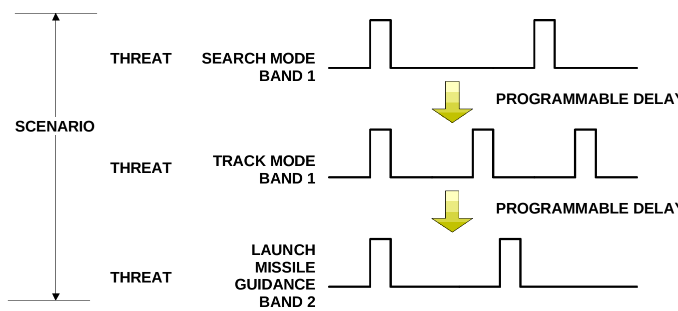
Simulating threats. Once an emitter is defined, the emitter may be simulated over a user-defined period of time. The user may then review the frequency, PRI, and PW characteristics over the simulation interval. The ability to simulate the threat provides a final test of the emitter definition, ensuring that the emitter model is outputting the expected pulse trains.

Building scenarios. While applying a simple emitter can be useful, a true test of an EC system may require multiple emitters, applied in a specific order, and changing in a defined way. The use of multiple emitters is the only true test of EC resource management and correlated threat analysis. To apply these emitters in a specific manner requires a scenario mode. The PRTS software suite supports a scenario development mode as shown in the following figure.

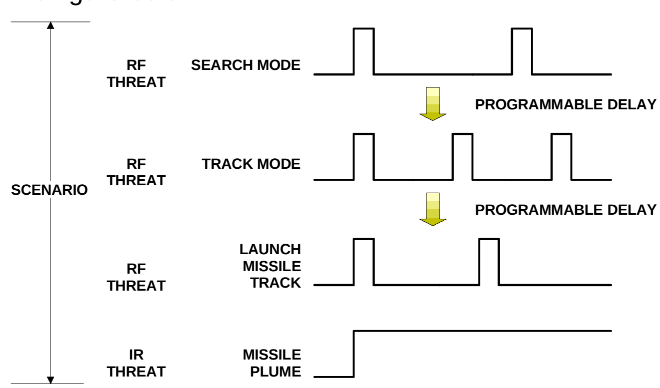


Build scenario is designed to minimize the task of creating complex multiple emitter applications that can simulate a wide variety of threat-dense environments. The user can build an emitter sequence (i.e., a list of emitters that are applied at one time), and then connect a series of sequences to build a scenario.

For example, a complex Search, Track, and then Launch scenario can be applied to an RWR to verify that it recognizes and properly displays all phases of the threat acquisition process as shown below.



Since the PRTS supports EO/IR testing through the Mallina family of systems, correlated RF and IR scenarios may be generated and applied as illustrated in the figure below.



[2] Lobe On Receive Only

[3] This programming is useful when testing on bench (or in a lab), where the system under test (SUT) antennas are bypassed using direct connections.

In this example, the missile launch plume is simulated with the Mallina system. This signal is synchronized with the RF signature, ensuring that a consistent real-world scenario is presented to the system under test. This example illustrates a guided missile scenario; a MANPAD (or shoulder fired missile) would not normally include an RF signature.

Maintenance software. The main user interface executes under Windows XP on a ruggedized laptop. During PRTS operation, all critical system functions are monitored. TWTA operating status is returned and displayed to the user. For remote operation, a hand held controller (HHC) is available that allows the user to remotely apply emitters and scenarios.

The PRTS supports a fully automated alignment procedure where the TWTA output is measured over its frequency range and a compensation table is developed to ensure accurate amplitude modulations.

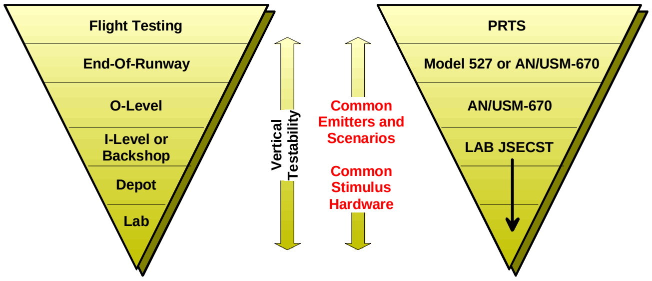
VERTICAL TESTABILITY

Vertical testability demands traceability of the stimulus and measurement parameters and accuracies from one level of test to the next. However, with the range of testers available at each testing phase - all from different manufacturers - vertical testability may be overlooked.

When testing the ECM systems at each level of test, the stimulus may be different. At depot level, the emitters may exactly represent the threat; multiple emitters may be applied to stress the system. At I-level, the emitters may be defined as simple pulse/PRI models using pulse generators. On the flightline, the RF stimulus may be applied using an RF generator with some simple modulations. The end of runway tester may use another RF stimulus source, and may apply multiple emitters. At each level, the applied emitters may be different (e.g., complexity of emitter scenarios, frequency accuracies, spurious/harmonics, and threat fidelities to name but a few parameters). A subtle failure on the flightline may not be duplicated at I-level due to the testing scenario or emitter parameter. A worse case is that a failure on the flightline may be missed because the test approach does not adequately stress the system.

Key to vertical testability then is the commonality of the stimulus across all phases of test. Since the PRTS is a derivative of the Lab JSECST, AN/USM-670 JSECST, and Model 527, a common test capability is maintained. In the back shop or laboratory, the Laboratory JSECST is key to RWR and jammer test and evaluation. Moving up the test chain, the AN/USM-670 is the flightline tester of choice for testing aircraft countermeasures systems. As testing approaches the end of runway, the Model 527 is available to deliver operational level flightline free space verification of aircraft-installed electronic warfare systems.

In each of the testers, the RF stimulus remains essentially unchanged. The models for emitter development, generation, and display are identical. The software development user interface is consistent across all testers. This commonality of design simplifies training and overall logistics costs. However, a greater asset is the emitters and scenarios themselves. Once developed, they run on all testers, ensuring that a common emitter scenario is applied to the aircraft at all phases of test.



AAI's approach to emitter and scenario development is best stated as:

"Build and validate once – run anywhere"

This philosophy is one key to unlocking the vertical testability dilemma; the design of the PRTS is the other.

CONCLUSIONS

As the newest member of AAI's line of flightline test equipment, the PRTS is designed as a low-cost alternative for users requiring a high power, wide band frequency coverage, high signal fidelity, multi-spectral free space range simulator.

The PRTS leverages on AAI's flightline design experience by incorporating the Model 527 as the RF stimulus generator. The use of the Model 527 simplifies the design and provides a common stimulus architecture with already fielded flightline test equipment (e.g., the AN/USM-670 and Model 527).

The PRTS supports fully synchronized RF/EO/IR testing though its hardware support of the Mallina family of systems. Designed to be upgradeable, the PRTS has built-in hardware and software support for up to eight high power amplifiers and up to four EO testers in any configuration. This flexibility allows the user to customize the PRTS configuration to his testing and training needs.

Today's warfighter is facing ever increasing numbers of threats, changing at an ever increasing rate. As the number of threats increase, so does the maintainers' testing and training complexity. As the developers of the Lab JSECST, AN/USM-670 JSECST, and Model 527, AAI has provided maintainers with many tools required to address testing problems. The PRTS is AAI's latest instrument that can be added to the maintainer's toolbox.