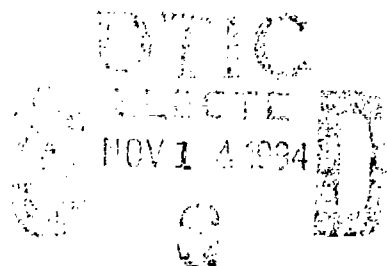


NAVAL POSTGRADUATE SCHOOL
Monterey, California

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THESIS



ELECTRONIC COMBAT HARDWARE-IN-THE-LOOP
TESTING IN AN OPEN AIR ENVIRONMENT

by

Ronald K. Stepp

September 1994

Thesis Advisor:

D. Jenn

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Electronic Combat Hardware-in-the-Loop Testing in an Open Air
Environment

by

Ronald. K. Stepp
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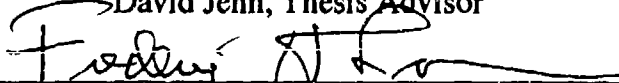


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ABSTRACT

Although the development process for electronic warfare systems includes hardware-in-the-loop testing and open air range flight testing, it does not specify the need to conduct hardware-in-the-loop testing in an open air facility. This thesis evaluates the usefulness of open air hardware-in-the-loop testing. This evaluation is based upon the comparison of two indoor hardware-in-the-loop facilities to an outdoor hardware-in-the-loop facility. In addition to the comparison of the facilities, this thesis presents feedback from three sources who have hardware-in-the-loop test experience at both indoor and outdoor facilities. Based on the research conducted, the conclusion of this thesis is that the established electronic combat test process should be formally modified to include open air hardware-in-the-loop testing.

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I. INTRODUCTION

A. ELECTRONIC COMBAT TEST PROCESS

The development of Electronic Combat (EC) equipment is an extremely complex process. In an effort to standardize how EC equipment is developed and tested, the Air Force has defined [Ref. 1] the following process as the one to be followed in the development of all EC equipment:

1. modeling and simulation
2. integrated laboratory testing
3. Hardware-In-The-Loop (HITL) testing
4. Installed Systems Test Facilities (ISTF) testing
5. Open Air Range (OAR) testing

As the EC system progresses through this process, both the hardware and the software are tested at several different facilities to verify system performance. Typically, the number of tests conducted at each facility is reduced as the testing progresses toward the OAR. Figure 1 illustrates the scheduling and equipment flow between the different types of facilities for a typical test [Ref. 1]. This five stage process has been generally accepted and followed by the Electronic Warfare (EW) community for years. Furthermore, the Joint Commander's Group for Test and Evaluation (T&E) has stated this process is to be adhered to.

The goal in establishing a specific test process to be used by all services, is to make the development of EC equipment more standardized. Therefore, decision makers should have a more accurate understanding of not only the equipment's capabilities but also be able to more accurately compare the capabilities of similar systems.

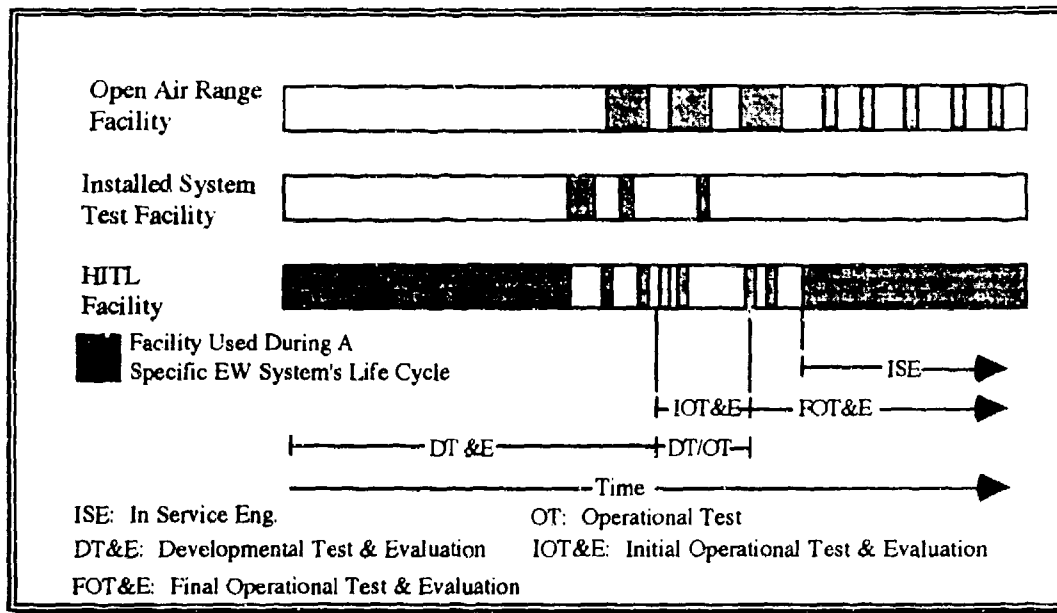


Figure 1: EC System Flow During T&E Process

The flight testing of most EC systems begins with the seemingly unavoidable situation referred to as fly-fix-fly. Meaning, put the equipment in an aircraft, expose it to the defined signal environment, land the aircraft, fix the problem, and fly another mission. Although this approach is effective, it is an expensive way to identify and correct problems. Consequently, identifying and correcting problems during the ground testing (i.e. HITL) of the system is preferable.

When a EC system progresses from an ISTF with a controlled environment to an OAR, many new variables are introduced into the situation. The primary differences between testing in the indoor facilities and testing in an open air environment are the use of actual, full power radar systems and the effects of the atmosphere. Consequently, it is these differences that frequently cause the problems that lead to the fly-fix-fly scenario. Although a systems response to actual high power radar systems and atmospheric effects can only be evaluated

by testing in an open air environment, a test system does not need to be installed in an aircraft to gain useful information from its first exposure to these effects.

One way to significantly reduce the number of new variables a test system is exposed to in a new flight test environment, as well as reduce the number of flight missions lost to equipment failure, is to conduct some HITL testing in an open air environment. If this type of HITL testing is conducted at the same facility used for the subsequent flight testing, then the cost required to develop the system could be significantly reduced. Therefore, this thesis addressed the question: "can an OAR provide a HITL test capability that significantly improves upon the established test process?"

B. HARDWARE-IN-THE-LOOP

The primary purpose of an electronic combat HITL facility is to provide a secure environment for the testing and validating of a system's performance against actual threat systems or threat simulators. Hardware-in-the-loop testing is the first opportunity for the entire EC system to be evaluated as it performs against real Radio Frequency (RF) or multispectral inputs. Consequently, the data provided by HITL facilities is frequently used as the Test and Evaluation (T&E) baseline of the system's effectiveness [Ref. 2].

Most HITL facilities offer a mixture of both "open" and "closed" loop simulators. An open loop simulator provides a one way path from the simulator to the EC system for a representative threat signal to travel. This type of simulator has no capability to receive or process any returned signals. A closed loop simulator is both a transmitter and a receiver processor. This type of simulator provides a realistic operator interface capability that allows for human input into

the track loop. Open loop simulators only provide a signal in space; they do not provide any signal reception capabilities.

Although open loop simulators do not offer any capability to evaluate Electronic Countermeasures (ECM) techniques, they are useful for testing Radar Warning Receivers (RWR) as well as providing the multiple simultaneous inputs (pulse density) required in an ECM test. The key features of open loop simulators are: 1) they only require that the characteristics of the transmitted signal are known, and 2) they are much less expensive than a closed loop simulator.

Closed loop simulators are expensive because they require a threat representative receiver processor. This requirement is not always easy to achieve. While Electronic Intelligence (ELINT) techniques provide detailed characteristics of the transmitted signal, they do not provide any information about how a system processes the returned signal. This information must either be speculated or gained through exploitation of actual hardware. Consequently, the time and money required to provide suitable closed loop simulators is significant.

In a HITL facility the threat inputs, as well as the test system's output, are transmitted through a hardwired RF medium. The inputs are not transmitted or received through an antenna. One advantage of this technique is that the response from an ECM system is not susceptible to unfriendly ELINT. A second advantage of a hardwired RF input and output is that advanced concepts and prototypes can be tested without subjecting them to unnecessary mechanical and atmospheric effects. Additionally, since HITL testing does not require the use of an aircraft, it is cost effective to accomplish as much as possible while the equipment is still on the bench.

C. INSTALLED SYSTEM TEST FACILITY

Hardware-in-the-loop facilities are limited in their ability to evaluate a system's integrated performance with the host aircraft. Most ISTF are anechoic chambers large enough to accommodate a full-scale aircraft. It is possible to avoid the requirement for a large chamber by using "hats" mounted over the aircraft's antennas. The primary purpose of an ISTF is to get an understanding of any Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) problems between the test system and its host platform.

While an ISTF does allow the EC system to receive actual free space signals, typically the ISTF's chamber size requires allowances to be made for near and far-field propagation effects. Since a far-field signal can be transmitted from an antenna hat to the aircraft's antenna, the use of these hats alleviates this propagation problem. However, antenna hats are unable to account for fuselage reflections and masking effects [Ref. 3]. Additionally, due to the aircraft's static condition, its flight dynamics must be simulated in the evaluation as the input signals are moved around the aircraft. Although these limitations exist, testing at an ISTF provides a cost effective method of identifying system performance and compatibility problems [Ref. 3].

D. OPEN AIR RANGE

The final step of the EC test process is OAR testing. Open air ranges consist of actual threat hardware, realistic threat simulators, a Command, Control and Communications (C³) network, and all of the required instrumentation and tracking equipment necessary to conduct a successful evaluation [Ref. 3]. Therefore, the OAR provides the only environment that closely simulates actual

battlefield operational conditions. The OAR can provide the data necessary to determine how the system will function in its intended environment [Ref. 3].

Because of the nature of open air testing, many effects can be evaluated at an OAR that can not be adequately investigated in either a HITL facility or an ISTF. These effects are [Ref. 3]:

1. atmospheric attenuation and ducting
2. meteorological conditions (wind, rain, dust, ect.)
3. aircrew interaction in the test to include time-critical mission decisions
4. system interactions on the host aircraft and other aircraft or resources
5. terrain effects on RF propagation
6. interference with other aircraft in close proximity
7. aircraft structural masking of sensors
8. actual antenna patterns and gains for each antenna or aperture

While an OAR provides the most realistic test environment and has numerous advantages over other methods, some disadvantages do exist. The difficulties of testing at an OAR include [Ref. 3]:

1. threat simulator location and lay down are not representative of an operational environment
2. signal density
3. time required to field a threat system replica or simulator
4. safety constraints
5. cost

Due to the complexity of a suitable OAR facility and the expense of the aircraft flight time, the most limiting aspect of OAR testing is the cost. It is typically much higher than the cost of using HITL or ISTF facilities as shown in Figure 1. The cost listed for the OAR facility is the facility's cost of supporting a flight test. It does not include any associated aircraft costs.

TABLE 1: TYPICAL FACILITY COST

HITL	\$1,500/hr
OAR	\$12,000/hr

The objective of this thesis is to evaluate the usefulness and cost effectiveness of the Electronic Combat Range's (ECR) open air HITL test capability. Since the usefulness and effectiveness of the existing HITL laboratories are understood, this evaluation will be based on a comparison of the process used at the ECR to the process used at the existing facilities.

Chapter II of this thesis describes the operational capabilities and test process of two existing dedicated HITL facilities as well as the HITL capability and test process of an OAR. Chapter III outlines the needs of three customers of HITL facilities and relates these needs to the capabilities of the different facilities. Finally, Chapter IV presents the conclusions of this study and provides specific recommendations to improve the EC test process.

II. FACILITY CAPABILITIES

A. PURPOSE

The purpose of this chapter is to provide a complete operational overview and a top level technical description of three HITL facilities:

1. the Air Force Electronic Warfare Evaluation Simulator (AFEWES)
2. the Electronic Combat Simulation and Evaluation Laboratory (ECSEL)
3. the Slate Range Facility (SRF) at the ECR

The AFEWES and the ECSEL are well established, dedicated indoor HITL laboratories that have supported the testing of EC for many years. The SRF provides the capability to conduct HITL testing in an open air environment. The information in this chapter illustrates that the capabilities and the process used in the open air environment parallels the capabilities and the process used at the dedicated facilities. The primary difference is open air environment.

B. AIR FORCE ELECTRONIC WARFARE EVALUATION SIMULATOR

The AFEWES is managed by the Air Force Developmental Test Center and is considered as a major EC test facility. Its mission is to "Provide technical evaluation of the performance of electronic combat systems and techniques in a simulated IR and RF threat environment." The effectiveness testing of EC equipment in a dense signal environment is accomplished through the integration of both open- and closed-loop simulations [Ref. 1].

Since the simulators are a mixture of hardware and software components, they are considered to be hybrid simulations. These simulations generate real time RF signals that are connected to the system under test by waveguide [Ref. 1].

Although the received signal has not gone through either a transmit or receiving antenna, the antenna pattern is simulated through the use of a Software Programmable Antenna Pattern Generator (SPAG). While this technique is not completely representative of a space propagated signal, it stimulates the test object with a threat representative signal while controlling the number of variables being introduced. This approach allows the tester to evaluate the system's response to a well defined and understood signal.

Although detailed information on the actual equipment used at the AFEWES is not available, Figure 2 illustrates the process for providing a signal to a test item. In this process, the simulated target signal receives Radar Cross Section (RCS) input, one-way range attenuation, and transmitter antenna pattern/gain information at PIN-1. The signal supplied to the test item receives one-way range attenuation, transmitter antenna pattern/gain, and the equipment's antenna gain information at PIN-3. The output signal from the system under test receives transmitter antenna gain inputs at PIN-4. After the simulated target signal is combined with the signal from the EC equipment, it receives receiver antenna pattern/gain, target scintillation, and one-way range attenuation information.

When the EC system under test is a passive radar warning receiver, the response of the system to a dense threat environment can be evaluated using open-loop simulators. However, closed-loop simulators can be used in this type scenario to provide a specific signal and/or pulse density. In this configuration, the AFEWES is able to provide an excellent opportunity for testers to determine and control the receiver response to a given threat scenario which can be repeated as many times as required. This repeatability is essential, and is a consequence of the ability to control all of the input variables.

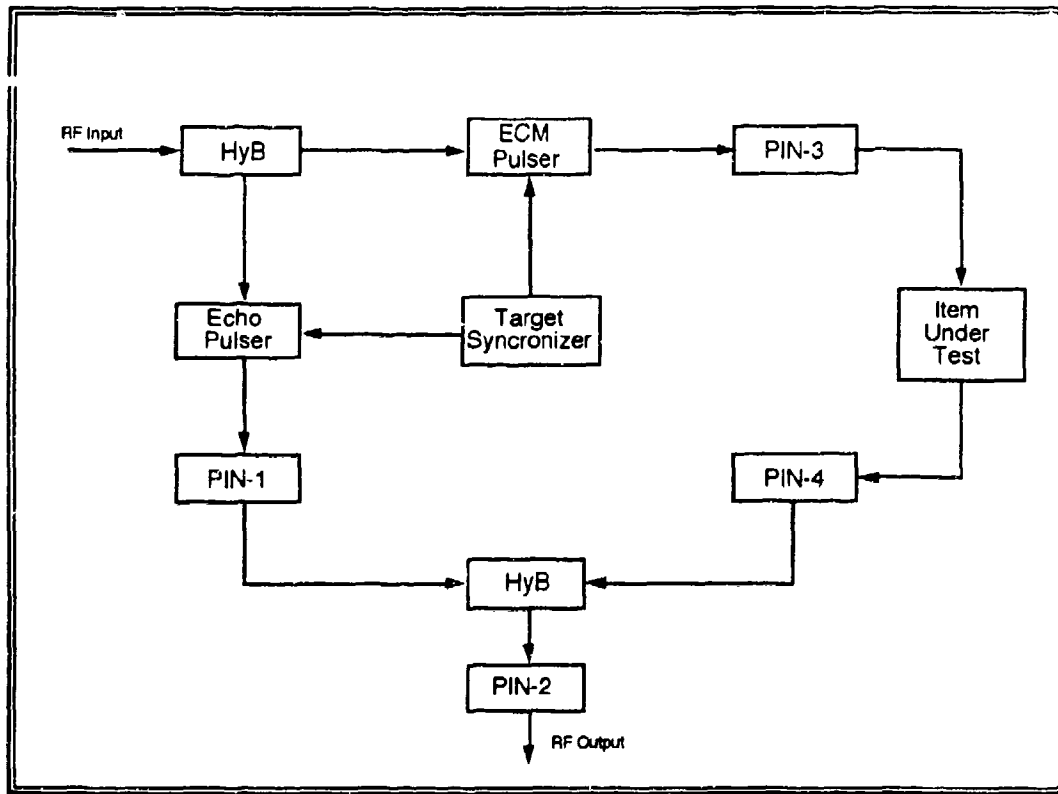


Figure 2: AFEWES' Typical Modulation Package (from [Ref. 4]).

Since open-loop simulators need only provide the correct transmitted waveform, the AFEWES uses a Multiple Emitter Generator (MEG) for the generation of its open-loop signals. This type of signal generator provides a very efficient, cost effective way to supply the required threat environment. The MEG used at the AFEWES can continuously cover from 0.5 to 18.0 GHz as well as provide millimeter wave signals at 30-40 and 90-100 GHz. It can produce an environment of 73 emitters from 64 sites; however by multiplexing the sources, this environment can be increased to 217 emitters for 195 sites [Ref. 1]. A list of sample threat simulations available from the MEG is given in Table 2.

Signal generators such as the MEG do an excellent job of stimulating passive EC equipment. However, the signals from the MEG can only be used to create a dense pulse environment in the testing of ECM equipment. While this dense

TABLE 2: SAMPLE MEG THREAT SIMULATIONS (from [Ref. 1]).

RED SIGNAL SIMULATIONS

Back Net	Muff Cobb
Back Track	Long Track
Ball Gun	Low Blow
Bar Lock	Low Sleeve
Bass Tilt	Odd Pair
Big Bird	Owl Screech
Big Nose	Pat Hand
Clam Shell	Peel Group
Dog Ear	Pop Group
Drum Tilt	Prok Trough
Fan Song B	Rock Cake
Fan Song E	SU AWACS
Fire Dome	Scan Fix
Fire Wheel	Sean Odd
Flap Lid	Side Net
Flap Wheel	Skip Spin
Flash Dance	Slot Back
Flat Jack	Spin Scan
Fox Fire	Spoon Rest
Gin Sling	Square Pair
Gun Dish	Squat Eye
Grill Pan	Straight Flush
Hawk Screech	Sun Visor
Head Light	Tall King
High Fix	Team Work
High Lark	Thin Skin
High Sieve	Tin Shield
Hot Shot	Tube Arm
Jay Bird	Twin Scan
Kite screech	Whiff
Land Roll	Wild Card

GRAY SIGNAL SIMULATIONS

Crotale
Cyrano
Fly Catcher
Fox Hunter
Rapier
Super Fledermaus
Sky Guard

BLUE SIGNAL SIMULATIONS

AN/APG-63 (F-15)
AN/APG-66 (F-16)
AN/APQ-113 (A-7)
AN/APQ-120 (F-4E)
AN/APQ-126 (F-111)
ANAWG-9 (F-14)
I-Hawk

environment is often required, closed-loop simulators are essential in evaluation of a jammer's effectiveness. It is not only important to understand how an ECM signal effects the receiver processor of a system, but it is also important to evaluate how a system's operator might interact with electronic counter counter measure techniques. Table 3 is a list of closed-loop simulations available at the AFEWES.

TABLE 3: AFEWES CLOSED-LOOP SIMULATIONS (from [Ref. 1]).

SA-2	SA-12	Flanker	SA-7A,B
SA-3	Spin Scan	Fulcurm	SA-13
SA-4	Skip Spin	Foxhound	SA-14
SA-6	Twin Scan	AIM-9L	SA-16
SA-6M	Big Nose	AIM-9M	Gun Dish
SA-8	Jay Bird	Red Eye	Flap Wheel
SA-10	Fox Fire	Stinger Basic	Long Track
SA-11	Generic PD	Symptom Ares	Wild Card

In the evaluation of active ECM equipment, the primary data AFEWES provides to the customer is miss distance data [Ref. 1]. This data is not probability of kill; it indicates how close the simulated weapon came to the simulated target. To generate this information, the aircraft's tactics are simulated in the AFEWES software using customer supplied profiles, RCS, and antenna pattern data. This data is provided in a look-up-table of RCS values at different attitudes. Consequently, any flight profile (straight and level or maneuvering) can be simulated [Ref. 1].

In this simulated engagement scenario, the radar operators make tactical decisions based on system capabilities as to when to engage the target. The miss distance data from an ECM run can then be evaluated against the same data from a non-ECM run. This comparison provides the basis to determine the

effectiveness of the EC test system. In addition to miss distance data, the AFEWES can provide radar tracking error information to allow the tester to evaluate how the EC system is effecting the radar component circuits. The AFEWES is also able to provide target acquisition/track denial data as well as missile engagement zone reduction information [Ref. 1].

In addition to being able to evaluate specific ECM equipment, the AFEWES can also evaluate ECM techniques and concepts prior to the development of actual hardware. This capability is provided by the Jammer Technique Simulator (JETS) system. The JETS system is typically used in the development of system requirements or the assessment of potential upgrades to existing systems [Ref. 1]. This system can provide a wide range of ECM techniques. However, since its capabilities are not critical to the proposal of conducting some HITL testing in an open air environment, the JETS system will not be addressed in detail. Nevertheless, in an overview of the AFEWES facility, this system should not be totally ignored.

One difficulty presented in HITL laboratories is the lack of real world phenomena such as ground clutter. The AFEWES facility addresses this difficulty with the Generic Pulsed Surface Radar (GPSR) clutter generator. This system generates site specific clutter maps for the SA-4 and SA-8 simulators. Future plans for the GPSR system call for it to interface with the reconfigurable surface-to-air missile system. This system is not yet operational, but it is planned to provide a generic simulation of any one of three systems: SA-6, SA-11, SA-12 [Ref. 1].

In today's battlefield, the frequency spectrum for electronic combat is no longer limited to the RF region. In fact, while the RF spectrum will always be a

key area in EC, most of the future EC equipment will provide coverage of the Electro-Optical (EO) and Infrared (IR) spectrums as well. The AFEWES accommodates this situation. It is currently able to support testing in the IR region and projects potential capabilities to test laser counter-measures in the future.

The original IR laboratory shown in Figure 2 was created for the evaluation of Infrared Countermeasures (IRCM) equipment and flare effectiveness against IR missiles. The target simulator is used to model both the aircraft's IR profile and the IRCM. These IR emissions are projected through an 8° field-of-view parabolic mirror onto tracking mirrors and then to an actual missile seeker that is mounted on a motion table [Ref. 1]. While this facility does not allow for the testing of actual IRCM equipment, it does provide an ability to evaluate how an actual seeker will respond to different CM techniques.

While the original IR laboratory at AFEWES is able to perform many types of tests, it is unable to evaluate some of the advanced IR technologies. Consequently the enhanced IR laboratory was developed. This enhanced facility shown in Figure 3 can simulate as many as eight dynamic sources in the foreground. Its IR background generator is able to simulate IR, near IR, or visual backgrounds as well as external IR sources and spectral discrimination. By using the flight table's real-time fly out motion for guidance units and avionics packages/pods against this generated IR scenario, the AFEWES provides the ability to evaluate multi-directional flare launches, non-linear flare separation, advanced aerodynamic flares, and multiple flare scenarios.

With the addition of the enhanced IR laboratory, the AFEWES can use its two laboratories simultaneously creating the integrated IR simulation complex

illustrated in Figure 4. This configuration can not only evaluate a warning receiver's ability to detect an IR target, but it can also evaluate an air defense system mounted on the large flight table against a missile seeker mounted on the other motion simulator. This closed loop IR testing provides the essential ability to test and evaluate advanced IR technology.

The AFEWES facility provides an extensive EC HITL test capability. Because of its ability to simulate a wide variety of signal environments over a large part of the frequency spectrum, the AFEWES is able to support the HITL testing of all types EC equipment. As a result of the facility's ability to control and repeat test conditions, it is a very effective and critical step in the EC test process.

C. ELECTRONIC COMBAT SIMULATION AND EVALUATION LAB

The ECSEL is located at the Naval Air Warfare Center Weapons Division (NAWCWPNS), Point Mugu, California. The primary role of this facility "... is to evaluate and optimize ECM techniques against specific threats, evaluate the operational and technical characteristics of new EW systems, reprogram and update threat parameters of reprogrammable EW systems, and determine the effects of changes in the electro-magnetic environment on EW systems and techniques" [Ref. 2].

The primary difference between the ECSEL and the AFEWES facilities is that the ECSEL facility provides signals for sea-based threat systems, and the AFEWES facility provides signals for land-based and air-to-air threat systems. Consequently, the ECSEL facility is also equipped with both open and closed-loop simulators. A list of ECSEL's closed-loop simulators is provided in Table 4.

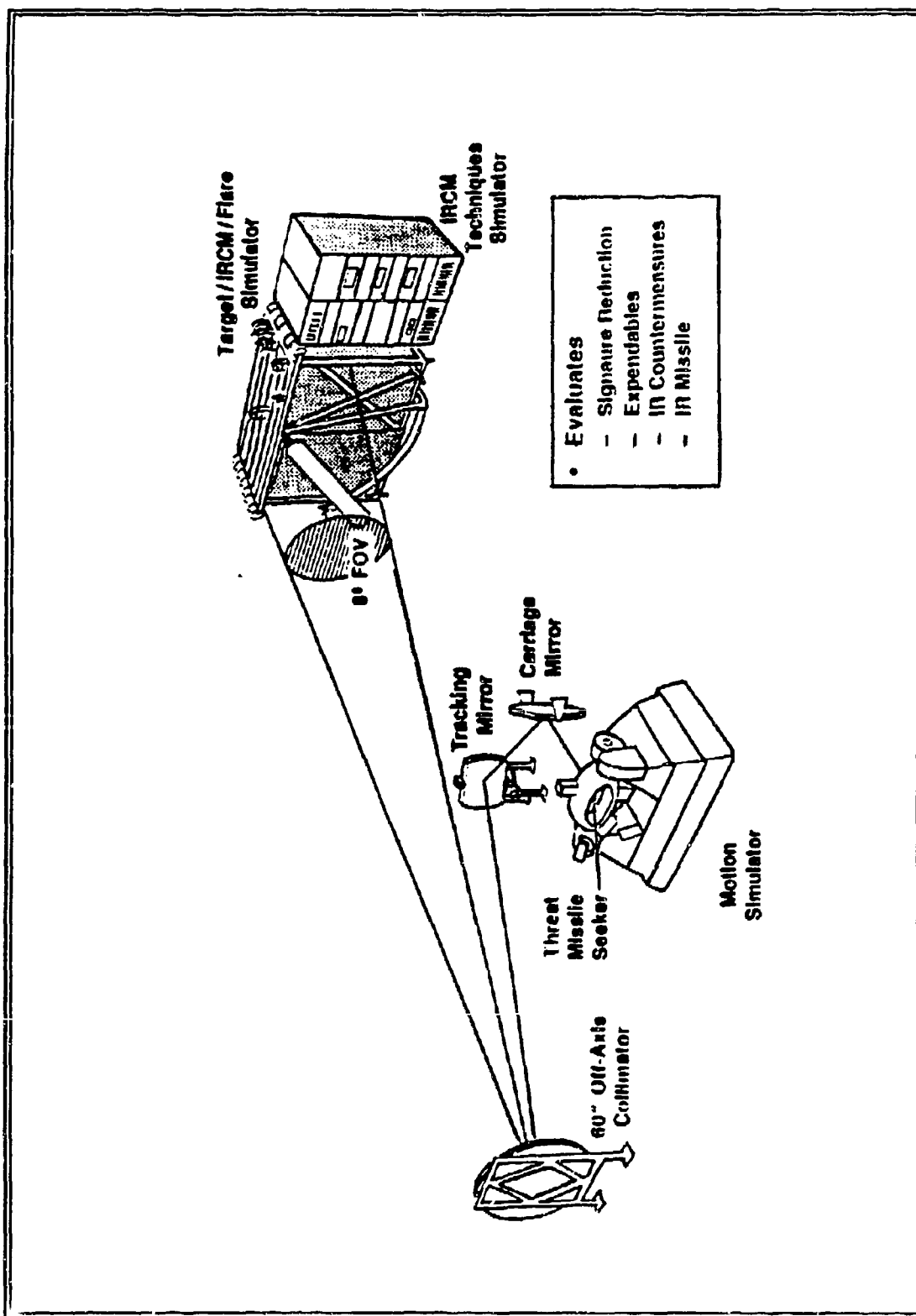


Figure 2: AFEWES' Infrared Laboratory (from [Ref. 1]).

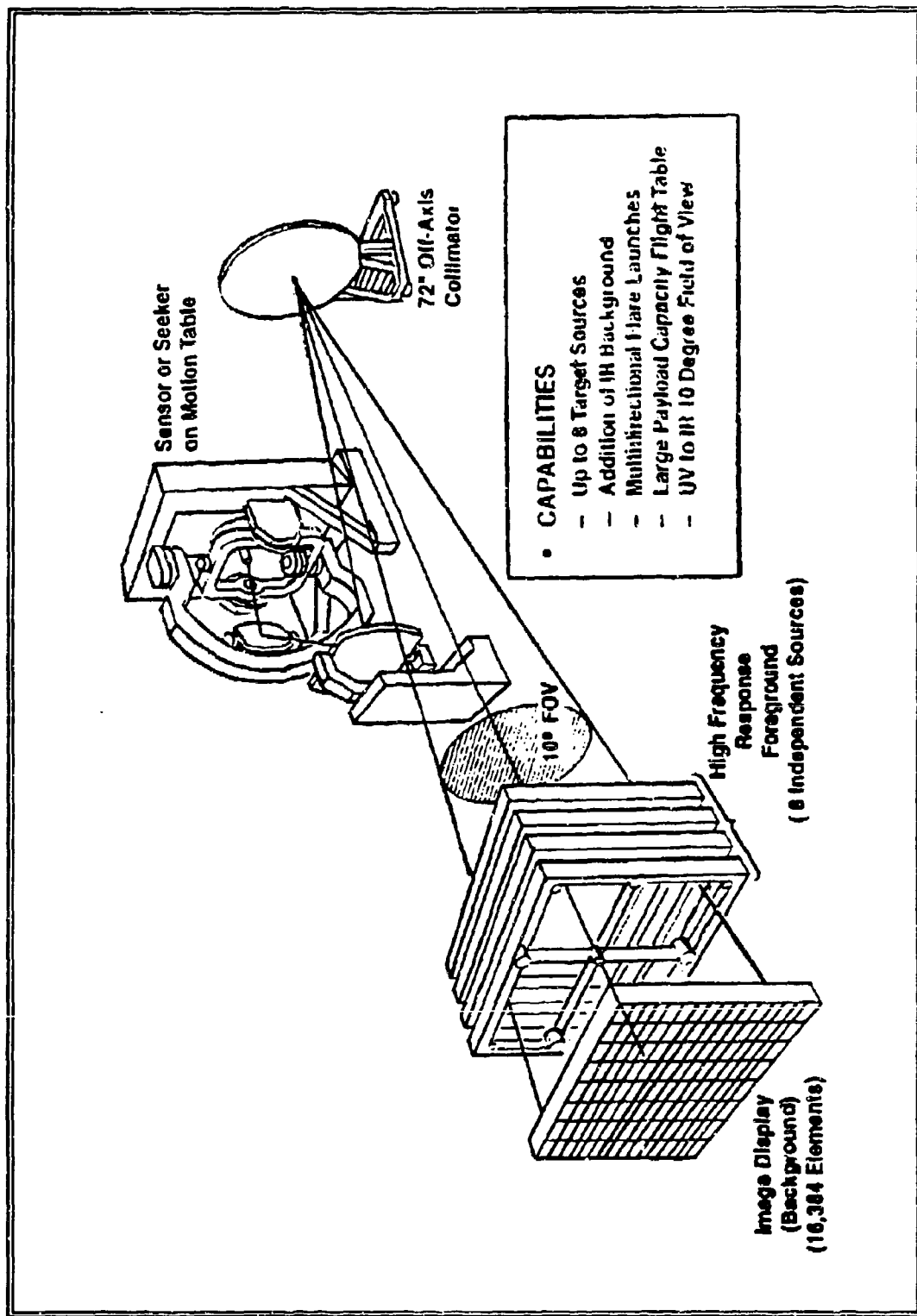


Figure 3: AFEWES' Enhanced Infrared Laboratory (from [Ref. 1]).

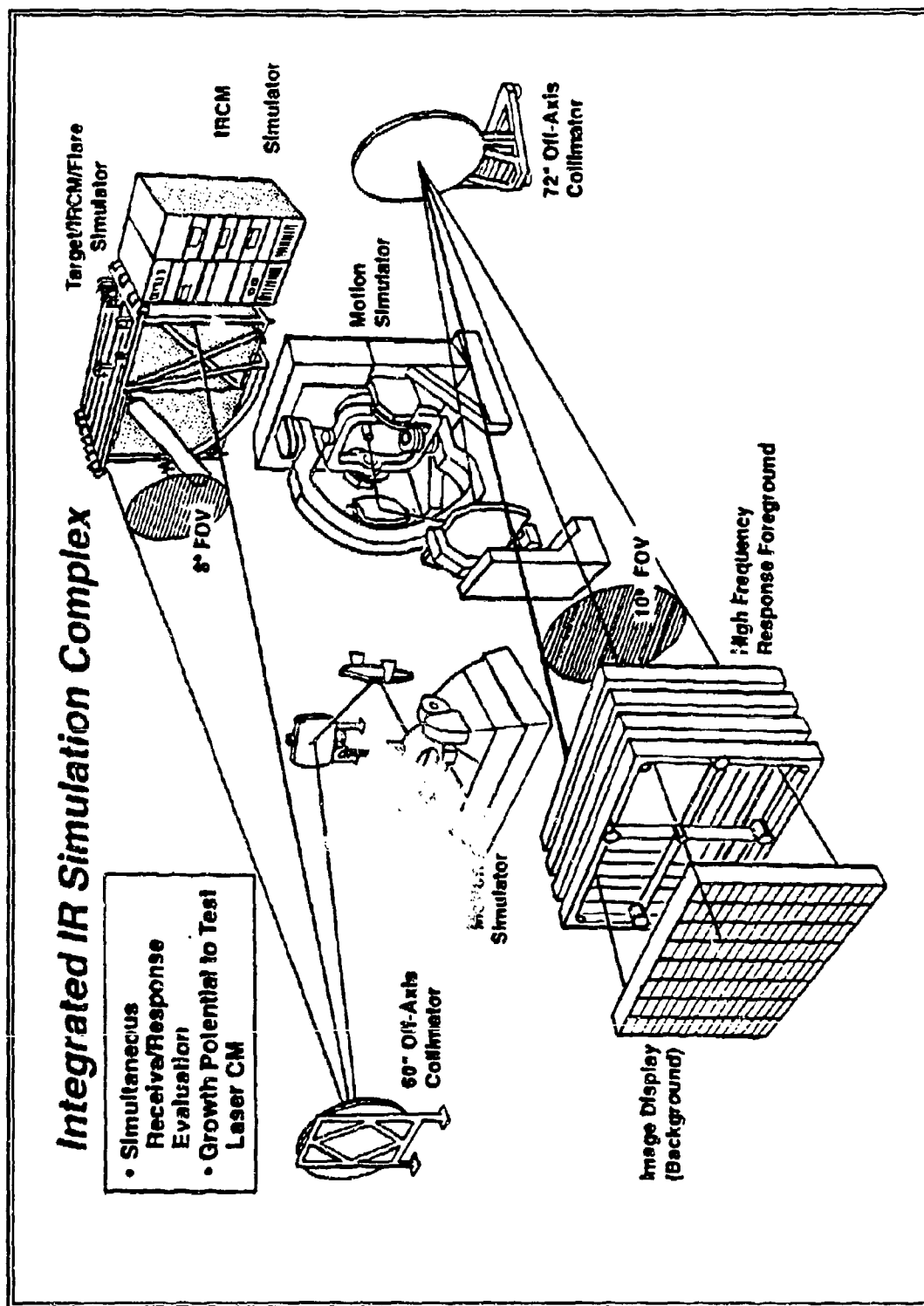


Figure 4: AFEWES' Integrated Infrared Complex (from [Ref. 1]).

TABLE 4: ECSEL's CLOSED-LOOP SIMULATIONS

SAN-1	I-Hawk
SAN-3	Gun Dish
SAN-4	Drum Tilt
SAN-6	Flap Wheel

In addition to the closed-loop simulators, the ECSEL uses five Advanced Multiple Environment Simulators (AMES) systems as open-loop simulators. These systems are similar in function to the MEG systems used at the AFEWES facility. They provide the capability of generating a dense pulse environment for the evaluation of EC equipment. They are also excellent tools for creating specific threat scenarios in the evaluation of passive EC systems. These AMES systems provide signal coverage from .5 GHz to 18 GHz as well as two millimeter wave bands centered at 35 GHz and 95 GHz. As a result of the reprogramability of these systems, they are capable of supporting the in service evaluations of threat libraries used in the currently deployed software based EC systems (i.e. ALR-67 and HARM).

The block diagram in Figure 5 illustrates the general process used in the ECSEL's closed-loop configuration. As in the description of the process used at the AFEWES, detailed technical information on the ECSEL facility was not obtainable. Therefore, Figure 5 only depicts a very top level description of the system. While both Figure 2 and Figure 5 are simplistic illustrations, they are provided to allow for the comparison of the methodology employed at the HITL facilities.

At the ECSEL facility, the input RF signal from the threat simulator has received the applicable one way range attenuation before it reaches the splitter. As depicted in Figure 5, the input RF signal is split to provide both a simulated aircraft target and a signal to the item under test. These signals are first

synchronized, then the delay associated to the aircraft's transmission line is added to the test item's signal. Linear Modulator 1 is used to provide the synthetic target signal with the appropriate transmit pattern. It also provides the target signal with the appropriate RCS and target scintillation characteristics. The signal provided to the equipment being tested receives appropriate transmit pattern at Linear Modulator 2. Additionally, this linear modulator also provides for the gain of the receiving antenna as well as the appropriate line losses.

After the introduction of the antenna gain and line loss characteristics, the signal is then provided as the input for the test item. The test item's output receives line loss and transmit antenna gain characteristics at Linear Modulator 3. The signal from the test item is then mixed with the simulated aircraft signal. The combined signal receives the appropriate range attenuation for the returned signal as well as the threat system's receiving antenna's gain characteristics at Linear Modulator 4.

While the ECSEL facility is significantly smaller than the AFEWES facility, it provides a unique capability in the EC test process. The ECSEL is the only dedicated HITL laboratory capable of providing sea based threat simulators. Except for its is unique in its abilitiy to provide naval threat signals, the operational approach and process employed at the ECSEL facility is essentially similar to those used at the AFEWES facility. The process used at these indoor HITL laboratories has been demonstrated to be effective at achieving the desiredgoals.

D. ELECTRONIC COMBAT RANGE

By using this established HITL test process as the foundation for supporting the development of EC equipment, a capability to conduct similar testing in a free

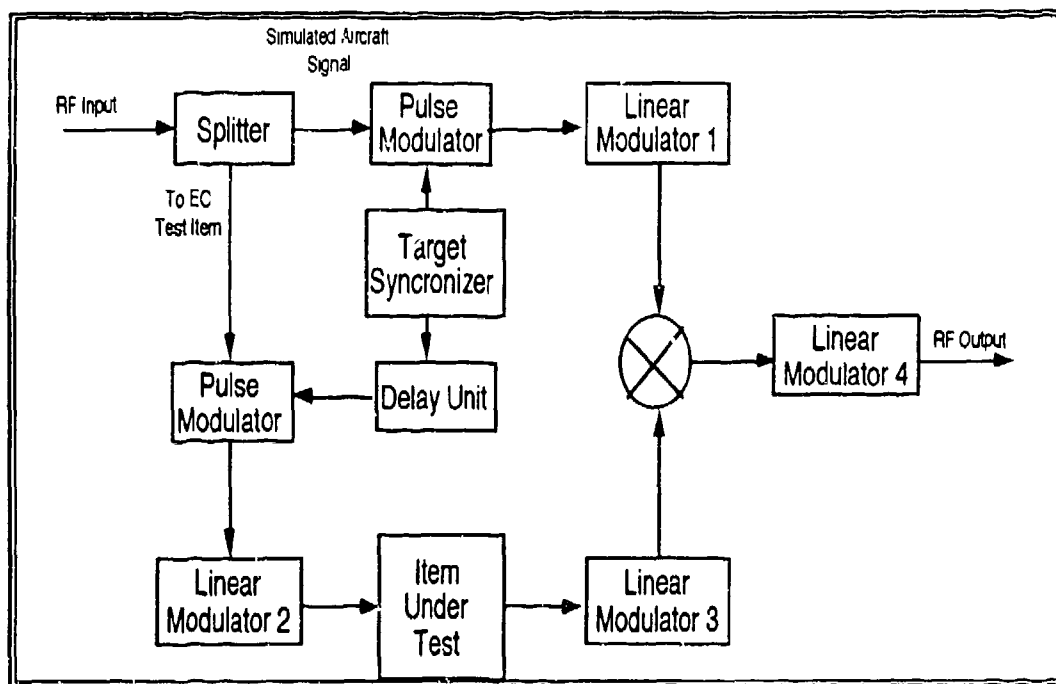


Figure 5: ECSEL's Typical Modulation Package (from [Ref. 5]).

freespace environment has been developed at the ECR. The ECR is part of the NAWCWPNS located in the Mojave Desert at China Lake California. This complex is the Navy's EW open air test range designed to support the Research and Development (R&D) and the operational evaluation of airborne EC equipment. The ECR's remote location and its sizable amount of secure ground space and restricted airspace make it an excellent location to conduct EC flight testing. While this remoteness does not reduce its vulnerability to ELINT efforts, it does provide an environment with a minimum amount of Radio Frequency Interference (RFI). This isolated location also increases the range's ability to obtain approval for operating within restricted portions of the electromagnetic spectrum.

The SRF facility is an EW HITL test facility at the ECR located at the southern end of the Slate mountain range approximately 2500 feet above the

valley below. Its mission is to provide the highest quality and the most versatile open air platform for testing both active and passive EC equipment [Ref. 6]. Figure 5 illustrates the SRF's location within the ECR, and Figure 6 shows an expanded view of the ECR's site distribution [Ref. 6]. These figures illustrate that from Slate Range's elevated position, it has a clear line of sight to all sites shown in Figure 6 including Land Site 2. Consequently, the SRF can process signals generated from all systems located at the ECR.

Although the SRF is remotely located, it has multiple voice communications systems to maximize the tester's ability to fulfill the mission requirements. The SRF has eight telephone lines that have both commercial and Autovon access, and one of these lines is equipped with a STU-III system. In addition to the telephone system, the site is equipped with the range Internal Communications(IC) system to allow for prompt, convenient test communications to the range's established sites. To allow for the communication to vehicles and temporary test sites, personnel also have direct access to Frequency Modulation (FM) radios. The availability to these different systems allows the SRF to meet almost all test related communications requirements.

The equipment at the SRF is cooled by a 15 ton refrigerated air conditioner. If additional cooling needs are required by a customer, an auxiliary three ton air conditioner is also available. Three types of power are available at this facility. The first is 500 kVA of unconditioned, three-phase, 60 Hz power. The second is 100 kW of conditioned, three-phase, 60 Hz power. The third type of power available is 50 kW of conditioned, three-phased, 400 Hz power. The conditioned power for both frequencies is supplied by motor generators.

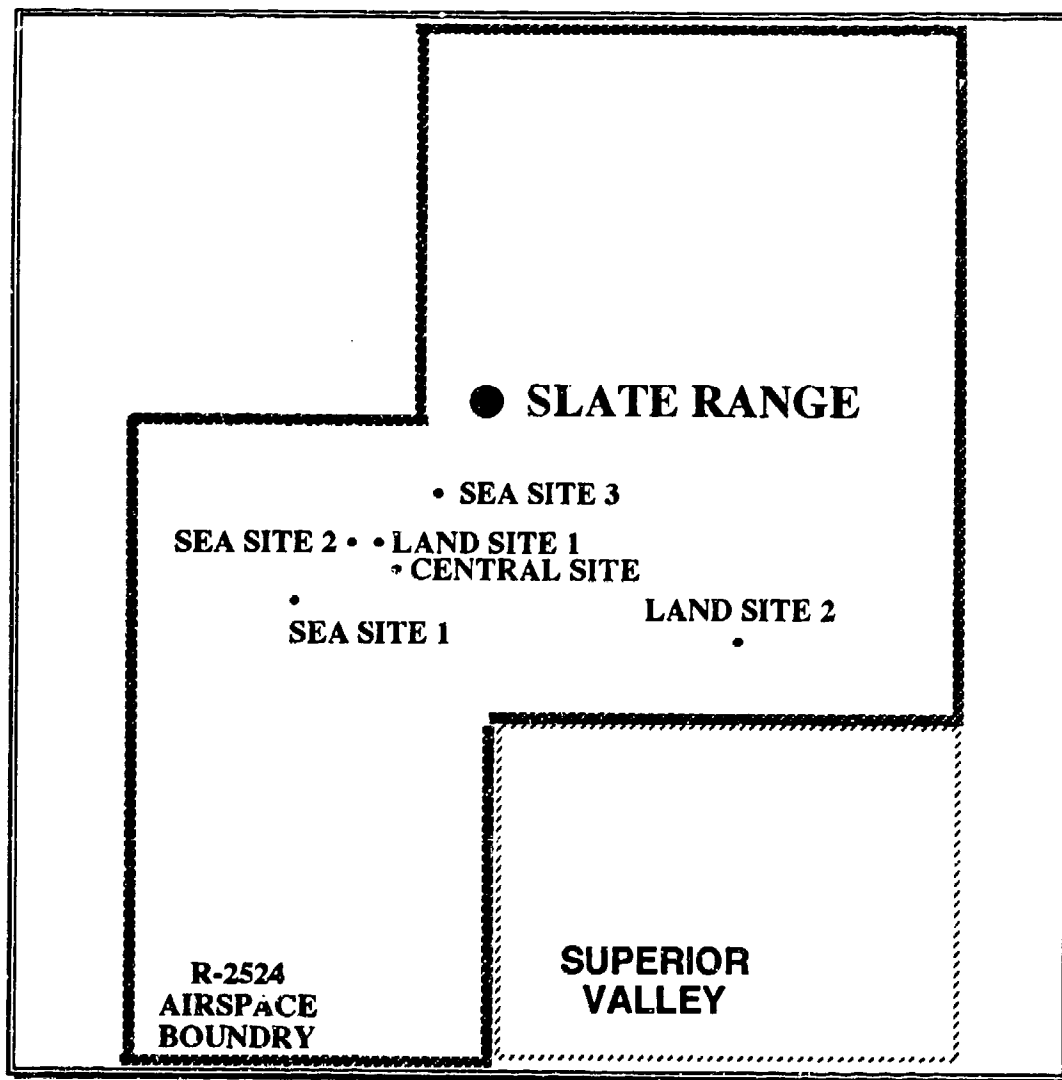


Figure 5: ECR's Airspace (from [Ref. 7]).

While the SRF has excellent frequency monitoring and signal analysis capabilities, its primary customer support function is as an open air HITL laboratory. It has two systems to support this role. The Static Radar Performance Exerciser (STARPEX) and the Moving Target Simulation (MTS). The STARPEX system produces static targets to be tracked by threat radar systems, and the MTS system provides dynamic targets. Since these systems provide targets with known RCS and ranges, they are used to close the simulated track loop for any

instrumented threat or reference system located at the ECR. Being able to close this open air track loop provides a HITL test capability using actual radar signals collected in a free space environment. Consequently, many of the essential elements of airborne equipment testing can be accomplished in a multi-threat open air environment while the equipment is still on a bench.

The operation of the STARPEX system and the MTS is identical except for the delay induced upon the signal. While the STARPEX system utilizes a fixed 30 μ s delay, the MTS injects a variable delay to simulate dynamic targets. The schematic diagram shown in Figure 7 illustrates the technical process used for both the STARPEX and MTS systems. The following discussion of the hardware used to produce the HITL test capability applies to both systems unless specified otherwise.

The operation of the STARPEX system and the MTS is identical except for the delay induced upon the signal. While the STARPEX system utilizes a fixed 30 μ s delay, the MTS injects a variable delay to simulate dynamic targets. The schematic diagram shown in Figure 7 illustrates the technical process used for both the STARPEX and MTS systems. The following discussion of the hardware used to produce the HITL test capability applies to both systems unless specified otherwise.

The input to the system comes from a series of five three foot parabolic antennas. Technical details for the complete SRF antenna system are provided in Appendix A. The receiving antennas are broadband and dual linear fed (vertical and horizontal). Two of the antennas are boresighted directly at Sea Site #1, and two are boresighted directly at Land Site #1. The fifth receiving antenna is on a steerable mount. Since this antenna provides good 290° coverage (330° to 260°

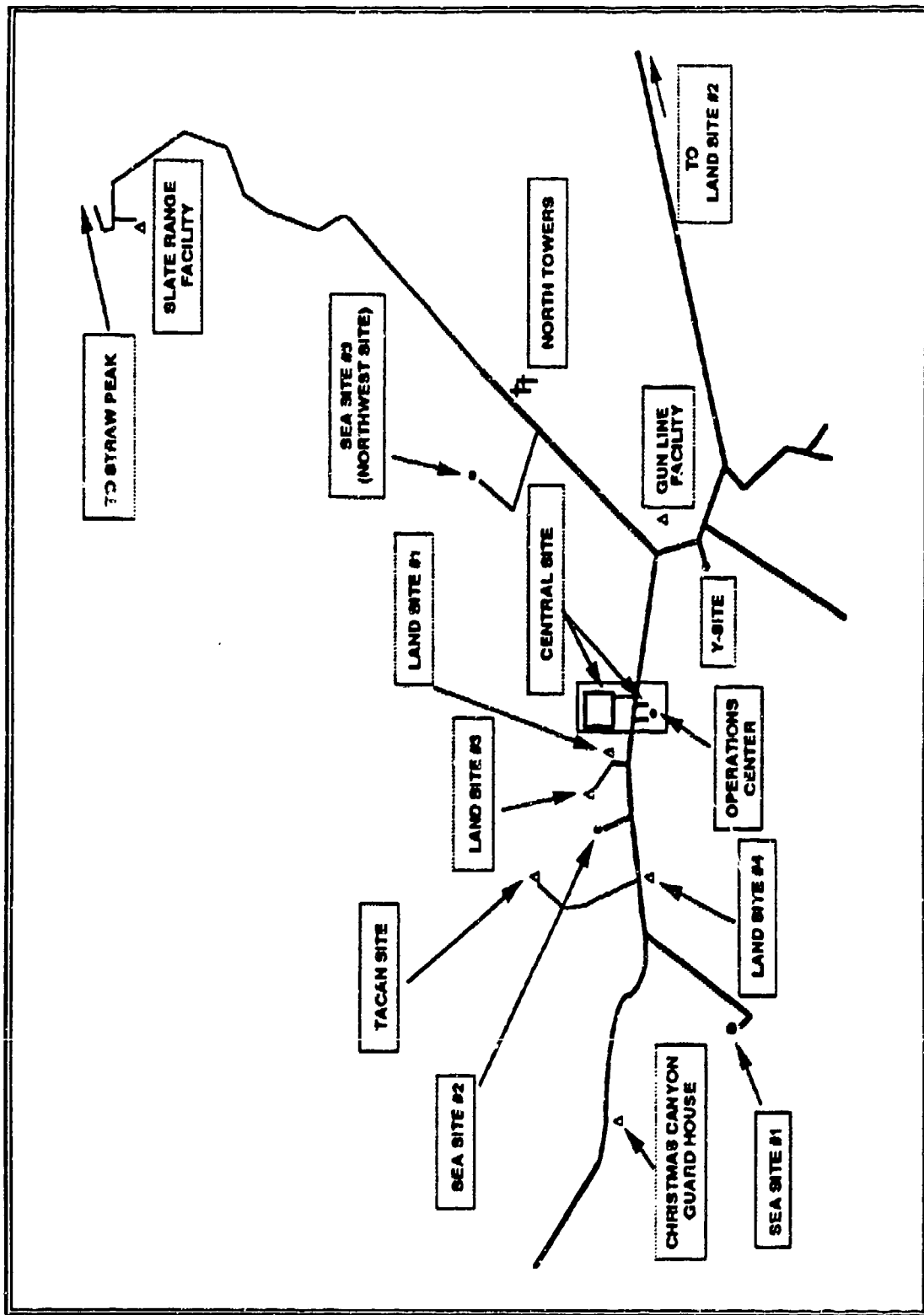


Figure 6: ECR Sites (from [Ref. 6]).

true) in azimuth and 0° to 10° in elevation, it is used for receiving signals that are generated from systems located elsewhere on the range.

At the front end of the system is the receive switch matrix. This matrix is comprised of a series of RF coaxial switches, each containing a set of Omni Spectra power dividers and 50 ohm terminations. It is this matrix that allows the operators to choose the correct signal to be processed. The key element in the system's operation is the signal processors chassis. Technical specifications for all of the equipment discussed in this section can be found in Appendix B.

In order to control the input and output signal levels, the processors contain two Hewlett Packard variable attenuators. Additionally, the processors also contain three Watkins-Johnson balanced mixers. The first mixer is operated in a superhetrodyne configuration to translate the received RF into the intermediate frequency. The second mixer provides amplitude modulation to the same local oscillator with the delayed IF signal. The third mixer in the system superimposes the aircraft scintillation on the processed RF signal. The Watkins-Johnson mixers have a dynamic range of over 45 dB and provide excellent RF to IF port isolation.

To provide the required delay to the IF, the SPCs contain a Teledyne Microwave Bulk Acoustic Wave (BAW) delay line as well as a Coherent Variable Delay Unit (CVDU). The CVDU is a high-speed digital RF memory device. Since the STARPEX system always uses a static 30 μ s delay, the BAW delay line is used in conjunction with this system. However, when the MTS system is being used, the generated target is dynamic. To create this dynamic target, the signal goes through the CVDU to vary the time delay added to the signal.

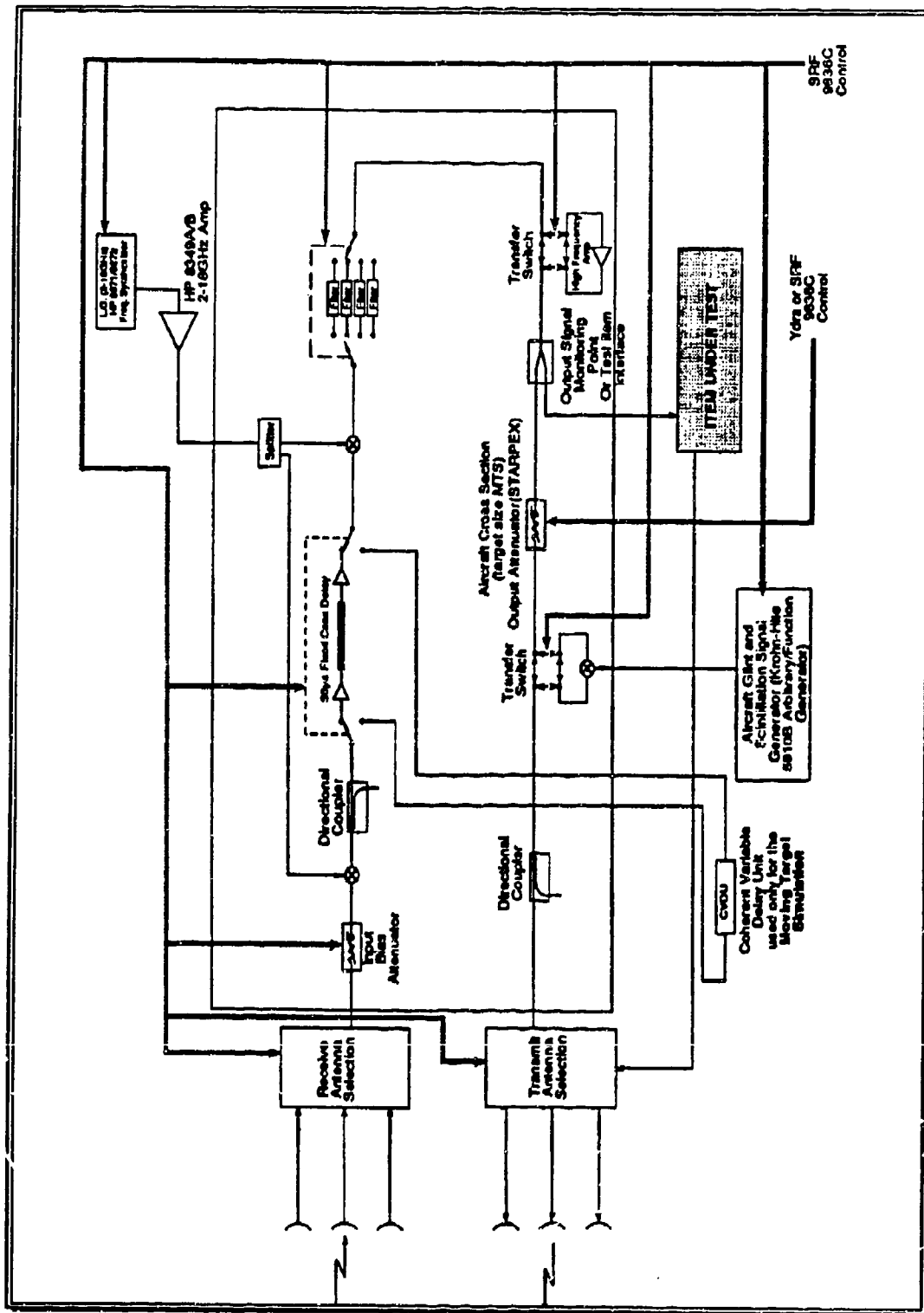


Figure 7: HITL System Schematic (from [Ref. 6]).

After the signal is properly delayed, it is then converted back to the original RF frequency. The unwanted sideband signals resulting from the frequency conversion process are rejected through the use of Daden filters. The losses incurred due to the delay process are overcome by the use of two Avantek IF amplifiers. At this point in the process, the delayed RF signal is divided. The signal from one port of this divider goes to the system being tested, and the signal from the other port of the divider receives aircraft return characteristics.

The ECM signal received from the test system receives one-way range attenuation (R^{-2}). However, the simulated target signal receives two-way range attenuation (R^{-4}). In addition to being properly attenuated, the target signal also receives RCS value to correspond to the simulated aircraft type, attitude and range. This RCS value is obtained from a look-up table, and it can vary between 1 m^2 to 1000 m^2 . Therefore, if the customer desires to use a specific table to maintain comparability to previous testing, the system can accommodate this requirement.

After receiving the required RCS information, the target signal then receives aircraft glint and scintillation characteristics. These characteristics are provided by a Krohn-Hite Arbitrary Function Generator. Included in the aircraft characteristics added to the signal is Jet Engine Modulation (JEM) lines, and the pulse-to-pulse amplitude change rate is $.3 \text{ } \mu\text{s}$. With the introduction of these dynamic signal variation, the final signal has the same characteristics as one returned from an actual aircraft and therefore appears as realistic to a system operator.

After the simulated target signal and the test system's output are superimposed, the combined signal passes through a directional coupler. This

coupler is provided to monitor the Jamming-to-Signal (J/S) ratio before the signal reaches the transmit antennas.

When measuring J/S, the personnel at the SRF use spectrum analyzers to systematically monitor both the target return and the output from the system under test. In order for the measurements to be accurate, knowledge of the jamming technique and duty cycle are extremely important. To avoid any distortion of the test system's output the SRF uses only passive processing techniques on the signal. This test system's output cannot be amplified. Therefore, if the signal is to be divided for transmission to multiple radars, the jamming signal may not be strong enough to achieve the desired J/S ratio.

The HITL test capability at the ECR has two major limitations. First, a radar system must maintain one frequency throughout the entire "run." A run is defined as the time period of continuous recording of a computer event. Therefore, since the length of a "run" is primarily determined by the customer, multiple runs are achieved in every test period. Consequently, many frequencies can still be used in a given test period.

The second major limitation is that due to clutter the minimum range of the target is the physical range between the radar and the SRF plus 5,000 yards [Ref. 6]. This situation makes it impossible to use short range missile and gun simulations in the evaluation of a system's performance.

Although these limitations exist, the HITL test capability available at the ECR is significant. By reviewing the processes and capabilities described in this chapter, it can be determined that the HITL test capability at the ECR is functionally the same as the well understood and accepted process used at the traditional HITL test facilities. The significant difference is the ability to evaluate

a system's performance against actual free space radar signals when the test system is still on the bench.

E. INDOOR VS. OPEN AIR TESTING

As discussed at the end of the introduction, the primary differences between testing at indoor facilities compared to testing at open air facilities are atmospheric effects and the use of full power radar systems. In the following discussion of these differences, the basic form of the radar range equation given is used to illustrate which variables change as a system enters the free space environment. The basic form of the equation is [Ref. 8]

$$S/N = \frac{P_t G_t G_r \sigma \lambda^2 G_p}{(4\pi)^3 R^4 L_s k T_o B_r F} \quad (1)$$

where

- P_t = transmitter power
- G_t = transmitting antenna gain
- G_r = receiving antenna gain
- σ = RCS
- λ = wavelength
- G_p = processing gain
- R = range to target
- L_s = system losses
- k = Boltzmann's constant (1.38×10^{-23} J/deg)
- T_o = standard temperature (290° K)
- B_r = receiver bandwidth
- F = noise figure

In a simulation, one or more of these parameters is modified or adjusted to simulate a change that would occur in the real operational environment. The particular parameters that are simulated depend on the test facility configuration.

The variables in Equation 1 simulated at the indoor facilities are P_t , G_t , G_r , σ , R , and T_o .

One of the primary advantages of using an indoor HITL facility is the repeatability that comes from the ability to control the variables that influence the results. While this repeatability is essential in the initial testing of EC equipment, it does not come without a price. It comes by simulating many aspects of the threat signal.

In addition to simulating variables in the radar equation, the indoor HITL laboratories do not generate high power microwave radar signals. The RF inputs at the AFEWES and the ECSEL are generated by low power RF signal generators. Since the signal travels only a short distance in a low loss RF medium (i.e. waveguide or coaxial cable), high power signals are not necessary to meet the test requirement at indoor facilities. It does not make sense to generate a signal with megawatts of power only to attenuate it down to milliwatts before it enters the receiver.

Another key area of simulation at the indoor facilities results from not using antennas. Since the threat systems are hardwired to the test items, antennas are not required. The RF input can easily be amplified to simulate the antenna gains, G_t and G_r , in the range equation. The absence of the transmit and receive antennas requires for more than just their gains to be simulated. The appropriate scan patterns must also be introduced into the signal to create a reasonably accurate model.

In the final stage of the EC test process, that is, actual flight testing, the effects from all of the variables in Equation 1 are real, not simulated. It is only at this level of test that a complete, accurate understanding of a system's

performance can be obtained. However, most of the realism of open air testing is maintained in the open air HITL test process.

Without the presence of an actual aircraft for the threat system to track, the RCS data used in the HITL process is provided from a look-up table. The RCS values applied in the simulation are correlated to the simulated aircraft type and aspect angle. The only other parameter in Equation 1 that is simulated in the open air HITL test process is range attenuation. In the case of the SRF, since the threat radar system is physically separated from the target by a fixed distance, the attenuation for the corresponding free space transmission is real. However, the range attenuation associated with any additional range delay introduced by the HITL facility is simulated.

Since the significant realism lost in open air HITL testing is the target's dynamics (RCS) and a portion of the range attenuation, most of the variables introduced in flight testing can be initially observed with the test system still on the bench. In most cases, the primary difficulty in progressing to open air testing is in the threat's transmitted waveform. As discussed earlier in this section, the indoor facilities use low power signal generators. While these signal generators are cost effective to use and meet the P_t requirement in the range equation, they do not produce completely threat realistic pulses.

These RF generators are capable of producing signals at the desired frequency, pulse width, and pulse repetition interval. They are also able to give the generated pulse the correct rise time and fall time specified by threat intelligence sources. The characteristics lost by using signal generators are those that result from the use of high power microwave devices such as magnetron RF generators and klystron amplifiers.

The pulses generated by full scale threat systems vary significantly depending on the condition of the RF devices being used at the time. A signal generated from a magnetron with 100 hours of operation will be significantly different than a signal generated from a new magnetron. While this type of situation alone may not cause a great deal a difficulty, it is important to understand that many full scale radar systems have some idiocencricies.

In many cases, these situations result from the system's scan pattern. While the indoor facilities model the antenna patterns for specific threat systems, it is extremely difficult to understand and model the idiocencricies. Therefore, during their first few exposures to actual radar signals, EC systems frequently have difficulty correctly identifying and/or responding to the signals. Not every aspect of the threat waveform can be understood well enough to produce a perfect model.

III. OPEN-AIR HITL CUSTOMER FEEDBACK

A. PURPOSE

This chapter discusses the usefulness of conducting open air HITL testing at the SRF. This discussion, presents feedback from the Air Force's Tactical Electronic Warfare System (TEWS) project office as well as the Navy's Advance Special Receiver (ASR) project office. Additionally, this chapter includes feedback received from Advanced Tactical Protection System office, PMA-272.

B. TACTICAL ELECTRONIC WARFARE SYSTEM

The TEWS is the EW suite in the F-15 (Eagle). In 1992 the Air Force incorporated the HITL test capability at the ECR into the EC testing of the TEWS. During this test phase of the TEWS, the MTS was used to create the dynamic flight test simulation. Consequently, the data available to the project office (real time and the post flight) from this ground testing was identical to the data available during the latter flight test phase of the equipment's performance evaluation.

While the availability of the real time and post flight information provided for a useful system evaluation prior to beginning the flight test phase of the system, the primary payoff of doing the additional HITL testing was in the areas of signal identification and technique optimization [Ref. 9]. During the system's first exposure to the free space threat signals, "...it experienced some unexpected operational difficulties" [Ref. 9]. The waveform characteristics of these signals

were not exactly the same as the characteristics of the waveforms at the AFEWES facility.

The information contained in [Ref. 9] was in no way critical of the AFEWES facility or its simulations. The primary point made was that being able to recognize, evaluate, and correct the unexpected operational difficulties in a laboratory environment is "significantly beneficial" to the program. The TEWS program office was unable to approximate the financial savings recognized through the use of the MTS. However for every hour of effective open air HITL testing conducted, simple arithmetic indicates a savings of about \$10,000 (difference between flight test and HITL cost at the OAR) plus aircraft costs. Thus, even a conservative estimate of reducing the amount of required flight testing by just one hour for only five key threat systems results in significant savings.

C. ADVANCE SPECIAL RECEIVER

The ASR system is currently undergoing developmental testing at both the ECSEL and SRF facilities. Due to the high degree of coordination between these two facilities, the ability to conduct coordinated testing at both an indoor and an open air HITL facility is beneficial to the program [Ref. 10].

As with its predecessor, the ALR-67 system, the ASR employs the use of a software based threat library for signal identification purposes. This approach to signal classification and identification allows for the key operational parameters of the threat systems specific to the current operational environment to be loaded into the warning systems of the aircraft involved. The usefulness of this software based threat library was well demonstrated during the war in Iraq. Having the ability to modify the threat library of a receiver system requires the system's

software to be periodically evaluated. Consequently, these types of systems spend a lot of time in HITL facilities.

The ECSEL facility has a pre-programmed threat scenario that is highly representative of the threat environment at the ECR. The advantage of using this "canned" ECR scenario at the ECSEL facility is that the signal's parametric characteristics can be easily modified within the AMES signal generator. Configuration control and hardware constraints make parametric modifications difficult in actual radar systems. Consequently, the flexibility available in an indoor facility is very useful.

While the use of the open-loop signal generator at the ECSEL facility allows for the ASR system to evaluate the effects of possible waveform fluctuations, the signals are not actual threat signals. Therefore, at some point the EC system must be evaluated using these actual signals. Traditionally, this evaluation has been done in flight testing. The advantage of getting to do HITL testing at the SRF is in the area of emitter identification [Ref. 10]. Being able to receive and process real world radar signals while having complete access to the system's hardware and software has been an essential part of the ASR's development process [Ref. 10]. Without this open air HITL test capability, the amount of flight testing required in the development of the ASR would significantly increase. Therefore, the cost and time for development would also increase [Ref. 10].

D. PMA-272

The office of PMA-272 is responsible for overseeing the development of all advanced tactical aircraft protection systems within the Navy with the exception of the EA-6B. This office is currently held by Mr. A. C. McMullin. Mr. McMullin was the first developer to ground test an airborne ECM system at the ECR back

in 1977. His background in the field of EC equipment development ranges from Project Manager of the ALQ-126A and ALQ-126B systems to overseeing the development and testing of the ALQ-165 (ASPJ). Consequently, as a result of his current position as PMA-272 and his extensive experience in the development and testing of EC equipment, Mr. McMullin's opinions concerning the open air HITL test capability at the ECR are well founded and highly regarded.

The development of advanced digital technology has greatly improved the capabilities of today's modern EC systems. It is the use of digital table look-up systems that allow for the programmable threat libraries used in receiver systems. In addition to providing for more capable systems, digital technology has created a demand for much better intelligence information [Ref. 11]. However, the indoor laboratories will never know everything they need to know about specific radar systems [Ref. 11].

This lack of complete knowledge does not indicate the indoor facilities are ineffective. It only means that their effectiveness is limited. An example of this limitation occurred during the initial open air HITL testing conducted at the SRF in the mid 1970's. While it was known that a threat system's PRI and antenna scan rate were the same, the indoor simulation did account for the fact that the synchronization of the PRI and scan pattern in the actual threat system appeared as a phase shift to the equipment in the open air environment [Ref. 11].

These types of unique, unpredictable situations are the primary difficulty that systems must overcome as the progress in to open air testing. Without the ability to conduct HITL testing in the open air environment, all of these unpredictable situations must be identified in flight testing. This situation demands that an R&D

aircraft asset be tied up and the associated expense be realized. It also does not allow access to the EC test system during the test. Having to overcome the initial signal identification and ECM technique optimization in a flight test results in a significant increase in the equipment's development costs and time line [Ref. 11].

In the development of EC equipment, the amount of time spent at each stage of the process should decrease as the equipment progresses through each stage. The use of the ECR's HITL test capability in conjunction with an indoor HITL facility allows for problems to be characterized in the open air environment. The problems can then be corrected at an indoor facility and verified at the open air facility [Ref. 11].

While each stage of the established EC test process presented in the Introduction is necessary, the efficient testing of any EC system needs to include open air HITL testing. Because of its high degree of sophistication and ability to expose an EC system to multiple real world radar systems, the SRF at the ECR is an essential part of the EC development process [Ref. 11].

IV. CONCLUSION

A. SUMMARY

The development of modern EC systems is a complicated process. In order to provide some standardization throughout the Department of Defense (DoD) the Joint Commander's Group for Test and Evaluation directed that a five step test process be followed.

While this process is well founded, it fails to address the usefulness of open air HITL testing. Consequently, this thesis outlined the process used to provide a HITL test capability at the DoD's established indoor HITL facilities as well as the process used at an open air EW range. This outline indicates that the process followed at the open air range highly parallels the well established process used at the indoor facilities. Therefore, the open air HITL test capability is very similar to the capability provided by the indoor facilities. The difference is that in an open air environment the RF signals used to stimulate the EC equipment are actual radar signals. They are not threat representative signals generated by a low power RF signal generator.

In addition to outlining the processes used at the different HITL facilities, this thesis discusses the usefulness of open air HITL testing from a customer's perspective. Feedback from the Air Force's TEWS program, the Navy's ASR program, and the Advanced Tactical Protection System office was obtained to provide for a well rounded perspective of the capability's usefulness. The information provided by all three sources clearly indicated that conducting HITL

testing in an open air environment prior to the flight test phase of an EC system was both highly productive and cost effective.

B. RECOMMENDATION

The advanced technology of the EW threat has enhanced the requirement to fully understand the performance characteristics and capabilities of EC equipment designed to counter the threat. Given this requirement in today's environment of continuously declining DoD funding mandates that a more efficient means of effectively developing EC equipment employed.

To ensure that the most efficient, effective process is used in the development of all EC systems, open air HITL testing should be formally added to the defined five step test process.

APPENDIX A. SRF ANTENNAS SPECIFICATIONS

1.5 - Foot Antennas: Quantity: (1) Primary Purpose: Signal Reception

Manufacturer:	Hughes
Model Number:	45811H-2118
Type:	Parabolic Cassegrain
Size:	1.5-Foot Diameter
Bandwidth:	26.5 - 40 GHz
3 dB Beam Width:	0.55° - 1.0°
Gain:	20 dB
Polarization:	Circular

3-Foot Antennas: Quantity: (10) Primary Purpose: Signal Reception

Manufacturer:	Tecom
Model Number:	202359
Type:	Parabolic Reflector
Size:	3-Foot Diameter
Bandwidth:	1-18 GHz
3 dB Beam Width:	24° - 1.3°
Gain:	14 - 39 dB
Polarization:	Horizontal and Vertical Linear

8-Foot Antennas: Quantity: (2) Primary Purpose: Signal Transmission

Manufacturer:	Nike
Model Number:	***
Type:	Parabolic Reflector
Size:	8-Foot Diameter
Bandwidth:	12.4 -18 GHz
3 dB Beam Width:	***
Gain:	***
Polarization:	45° Slant

12-Foot Antennas: Quantity: (4) Primary Purpose: Signal Transmission

I - Band Quantity: (2)

Manufacturer:	Mark Antenna
Model Number:	MPH-78A144DL
Type:	Parabolic Reflector
Size:	12-Foot Diameter
Bandwidth:	7 - 10 GHz
3 dB Beam Width:	0.74°
Gain:	46 - 47.5 dB
Polarization:	Horizontal and Vertical Feeds

G - Band Quantity: (1)

Manufacturer:	Andrew
Model Number:	HPX12-44D
Type:	Parabolic Reflector
Size:	12-Foot Diameter
Bandwidth:	4.4 - 5 GHz
3 dB Beam Width:	1.2°
Gain:	41.9 - 43 dB
Polarization:	Horizontal and Vertical Feeds

G - Band Quantity: (1)

Manufacturer:	Technical Systems Associates
Model Number:	11177
Type:	Parabolic Reflector
Size:	12-Foot Diameter
Bandwidth:	4.9 - 6.7 GHz
3 dB Beam Width:	1° - 1.49°
Gain:	41.2 - 44.3 dB
Polarization:	Horizontal and Vertical Feeds

APPENDIX B. SRF EQUIPMENT SPECIFICATION

RF Amplifier: **Quantity: (10)**

Manufacturer:	Hewlett Packard
Model Number:	8349 A/B
Bandwidth:	2 -18 GHz
Gain:	15 dB (minimum)
Noise Figure:	15 dB (maximum)

Coherent Variable Delay Units (CVDU): **Quantity: (4)**

The CVDU is the range delay device used in the moving target simulation. It delays a radar pulse by an amount of time specified by the simulation. The CVDU uses high-speed digital RF memory for data storage. The pulses are stored for reconstruction a short time later at the Intermediate Frequency (IF).

Manufacturer:	Datacom/Telemus
IF:	600 MHz
Pulse Width:	100 - 10,000 ns
Delay Time Range:	0.3 - 600 μ s
Delay Time Accuracy:	$\pm$ 5 ns
Delay Step Size:	10 ns
Output Matches Input:	by $\pm$ 1 dB
Internal Delay:	< 300 ns

Function Generator: **Quantity: (4)**

These devices are used to create aircraft scintillation characteristics.

Manufacturer:	Krohn-Hite
Model Number:	5910 B
Frequency Range:	.0001 Hz - 5 MHz
Frequency Accuracy:	$\pm$ 0.05 %
Output Power:	15 Volts Peak - Peak (50 Ω)
Rise Times/ Fall Times:	< 60 ns
Sine Wave Distortion:	3 % (-30 dB) at 5 MHz

Function Generator: Quantity: (5)

These devices are used to create aircraft scintillation characteristics.

Manufacturer:	Hewlett Packard
Model Number:	8116 A
Frequency Range:	.0001 Hz - 50 MHz
Frequency Accuracy:	$\pm 0.05 \%$
Output Power:	15 Volts Peak - Peak (50 Ω)
Rise Times/ Fall Times:	< 60 ns
Sine Wave Distortion:	3 % (-30 dB) at 5 MHz

Pulse Analyzer: Quantity: (1)

Manufacturer:	SciComm
Model Number:	2160
Input Frequency:	160 MHz
Pulse Width Accuracy:	20 ns
Dynamic Range:	- 65 to + 5 dBm
Pulse Repetition Interval:	20 μ s to 99.9 ms (± 20 ns)

Pulse Modulator: Quantity: (6)

Manufacturer:	Hewlett Packard
Model Number:	11720 A
Frequency Range:	2 - 18 GHz
Rise Times/ Fall Times:	10 ns
Maximum Repetition Frequency:	5 MHz
Minimum Pulse Width:	50 ns

RF Synthesizer: Quantity: (10)

This device is the local oscillator used to convert the RF signal to the 600 MHz IF signal.

Manufacturer:	Hewlett Packard
Model Number:	8671/8672
Frequency Range:	2 - 18 GHz
Frequency Resolution:	< 3 kHz
Output Power (Maximum):	+ 8 dBm

LIST OF REFERENCES

1. Humphries, John E. Lt. Col. USAF, *Air Force Electronic Warfare Simulator*, July 1993.
2. Electronic Warfare Test and Evaluation Reliance working group, "EW T&E Reliance Hardware In The Loop Test Capability Master Plan", 31 July 1992.
3. Wright, Frederick L., Major, USAF, *Operational Test and Evaluation of Electronic Combat Systems*, August 1993.
4. B. Ross, Air Force Electronic Warfare Simulator, private communication, August 1994.
5. P. Kobashikawa, Electronic Combat Simulation and Evaluation Laboratory, private communication, June 1994.
6. Naval Air Warfare Center Weapons Division, *Slate Range Facility User's Guide*, September 1992.
7. Naval Air Warfare Center Weapons Division, Electronic Combat Range Departments Briefing Notes, August 1994.
8. Skolnik, M. I., *Introduction to Radar Systems*, McGraw Hill Inc., 1980.
9. S. Ordonia, Captain, USAF, Tactical Electronic Warfare System Program Office, private communication, November 1993.
10. R. Brenner, CTA, Advanced Special Receiver Program Office, private communication, July 1994.
11. A. C. McMullin, Advanced Tactical Protection System Office, private communication, September 1994.

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