Use of AN/SLQ-32A(V) Electronic Support Data for ASCM Engagement and Situational Awareness

Richard C. Kochanski and Bruce A. Bredland

The AN/SLQ-32A(V) Electronic Warfare System was designed to warn U.S. Navy ships of Anti-Ship Cruise Missile (ASCM) attack by the early detection of missile seeker radio-frequency emission. The AN/SLQ-32A(V) reports the characteristics of the radiation, i.e., frequency and power, probable identification, etc., and these data can complement the radar track picture. The Ship Self-Defense System (SSDS) installed on the LSD 41 class concurrently processes the data reported by AN/SLQ-32A(V), including probable identification, and the data reported from other sensors (radar) to increase ship survivability by supplying Rolling Airframe Missile (RAM) the input it needs to perform optimally. RAM is a Navy resource for ship self-defense against ASCM attack. Algorithms developed at APL that effectively integrate AN/SLQ-32A(V) data into the SSDS weapons control function have been successfully demonstrated in live testing aboard the Self-Defense Test Ship and members of the LSD 41 class.

INTRODUCTION

The combat system for LSD 41 class ships, the Ship Self-Defense System (SSDS) Mk 1, contains advanced electronic support (ES)-to-radar track association algorithms developed at APL. These algorithms support the capabilities of the recently introduced Rolling Airframe Missile (RAM) Block 1 weapon system and also increase the operator's situational awareness.

LSD 41 class ships must defend against Anti-Ship Cruise Missile (ASCM) attack in a littoral environment densely populated by aircraft and surface vessels. LSD 41 sensors used to detect and track these objects (airplanes, ships, boats, missiles, etc.) include the AN/SPS-49 long-range surveillance radar, Phalanx Close-In Weapons System, AN/SPS-67 surface search radar, and AN/SLQ-32A(V) Electronic Warfare System. Based on sensor input, the SSDS Mk 1 automatically determines which tracks represent threatening objects, i.e., ASCMs, and schedules weapons to engage those threats. The primary self-defense weapon used for threat engagement aboard the LSD 41 class is the RAM Guided Missile Weapon System.

The main purpose of integrating AN/SLQ-32A(V) into the SSDS and associating ES tracks to radar tracks is to support the execution of RAM Block 1 engagements, including RAM launch timing and selection of RAM guidance mode. ES tracks represent RF signals detected by the AN/SLQ-32A(V), and SSDS maintains a track file of ES tracks, i.e., detected azimuth, power, frequency, etc. Ship survivability against ASCM attack depends on many factors, one being RAM initialization, which depends on the ES data on the threat axis. As the integration effort proceeded at APL, it became apparent that the same algorithms used to support RAM would also improve operator situational awareness and the assessment of self-defense engagement effectiveness.

The APL-developed ES-to-radar track association algorithms have proved to be successful in supporting RAM Block 1 engagements during laboratory simulation and in live testing environments. The most notable testing occurred aboard the Self-Defense Test Ship during the RAM Block 1 operational evaluation in which common ASCM targets (e.g., Exocet and Harpoon) and surrogate targets (the supersonic Vandal Extended, Extended Range) were successfully engaged.

ELECTRONIC SUPPORT ASSOCIATION

The goal of the ES-to-radar track association and resolution process is to determine those ES and radar tracks that could potentially represent the same object. ES-to-radar track association is the process of finding candidate track pairs based on track bearing (azimuth). Resolution is the process of refining the list of association candidates down to one pairing, which is the ultimate decision that the two tracks truly represent the same object. An ES-to-radar track association is said to be "resolved" if it is believed that the target represented by the radar track is emitting RF represented by the AN/SLQ-32A(V) ES track (Fig. 1). Knowing whether an object is emitting is important in the SSDS selection of RAM Block 1 mode and also influences RAM Block 0 initialization.

The AN/SLQ-32A(V) provides the SSDS with the ES tracks that represent emitters on objects in the tactical environment. ES track data include azimuth angle, RF frequency, received power amplitude, scan, scan type, pulse repetition interval (PRI), PRI type, identity (hostile, friend, unknown), and identification amplification, which includes the missile, missile launch platform, search radar, etc. To determine identity and identity amplification, the AN/SLQ-32A(V) uses measured frequency, PRI, PRI type, scan, and scan type to access an emitter database.

The accuracy of the AN/SLQ-32A(V)-measured angle of arrival is poor compared with azimuth measurements made by radars and modern ES sensors (e.g., AN/SLY-2(V), which is currently under development). Associating inaccurate ES track azimuth measurements with accurate radar data is difficult and prone to errors in a normal shipboard tactical environment where many radar track association candidates exist within the measurement uncertainty regions of an ES track. This is problematic because the SSDS needs to know if the object detected by the ship's radar sensors, presumably an ASCM, is truly the target carrying an RF emitter detected by the AN/SLQ-32A(V). There is a good possibility of falsely associating ES and radar tracks using azimuth only, even if the measurement accuracy of the ES sensor is very good.

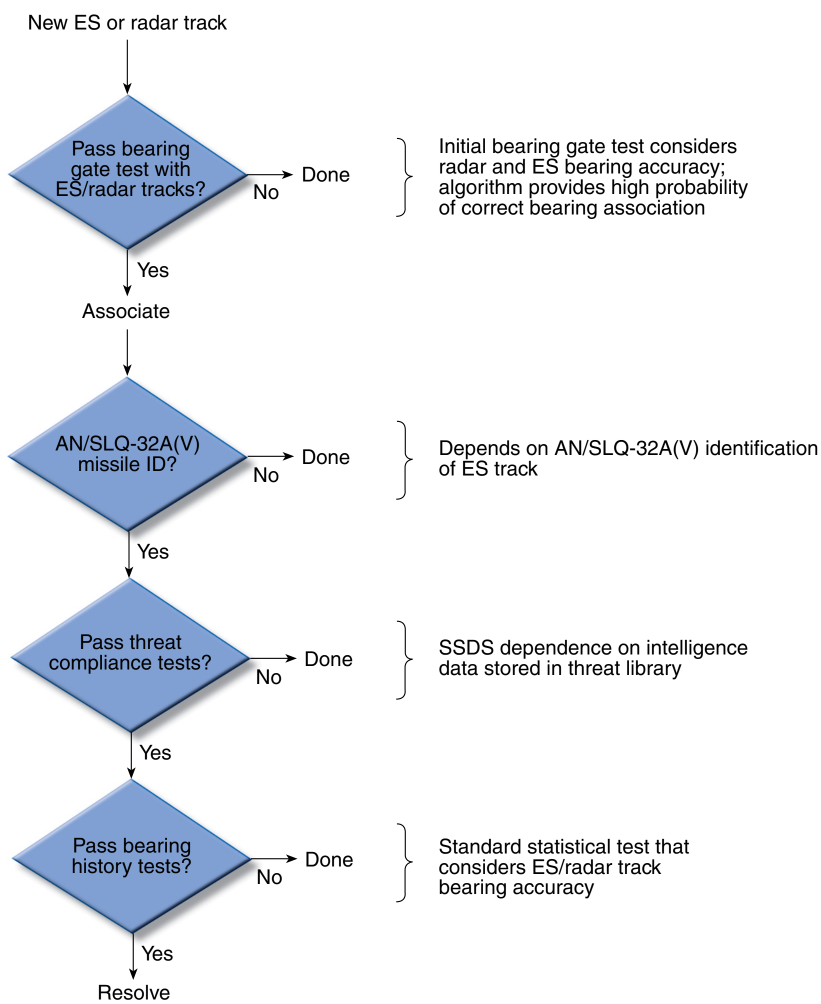

Figure 1. Simplified SSDS ES track/radar track association resolution thread. If more than one ES/radar track passes the test, an ambiguous marking will occur.

Therefore the SSDS treats ES-to-radar track pairings based on bearing association as candidates for resolution (a unique pairing), and the relatively large uncertainty in ES track bearing, more often than not, results in a radar track having several ES tracks associated with it.

RAM BLOCK 1 INTEGRATION

To ensure that RAM Block 1 engagements are properly executed, the SSDS must select the proper RAM guidance mode. On LSD 41 class ships, this is done with specialized ES-to-radar track association algorithms. These algorithms were designed to provide the best weapon response given the azimuth accuracy and identification capabilities of the AN/SLQ-32A(V). The RAM Block 1 system has the RF guidance capability (known as dual mode), but also can guide and intercept on infrared (IR) energy alone. This new mode is known as the autonomous IR (AIR) mode.

One advantage of the AIR mode is the restoration of maximum engagement range against non-RF-emitting targets. With the RAM Block 0 system, targets to be engaged that have insufficient RF signal strength or have no RF signal detected are given more time to approach the ship. For those targets with no RF signal detected, this allows some additional time for the ASCM seeker to turn on, which will result in proper RAM initialization but still provide sufficient time for multiple firings prior to minimum engagement range. For targets with low-power RF seekers, the additional time allows for a shorter engagement distance and therefore increased signal strength at the RAM during flyout. For both of these cases the close-in firing range is predetermined; however, if the RF signal power level becomes sufficient, RAM may be launched prior to this range. Instead of allowing the target to approach the ship because the AN/SLQ-32A(V) has detected a weak signal or has not detected an RF signal, the RAM Block 1 AIR mode will be selected for target engagement at maximum range. This is because RAM Block 1 AIR mode does not require the target to be actively radiating an RF signal. Subsequent detection of the ASCM RF seeker may allow for reengagement with dual-mode guidance.

Whereas the RAM Block 1 AIR mode is effective against both RF-emitting and non-RF-emitting threat types, dual mode is only effective against targets with active RF seekers and is not effective against passive targets. It is therefore beneficial for the combat system (and the ship) to select the correct RAM guidance mode. RAM Block 1 also has a "dual-mode enable" capability that allows the missile to switch from AIR mode to dual mode in flight upon RF detection. The SSDS will also select this mode depending on the ES-to-radar track association status and the ES environment surrounding the target.

The selection of RAM Block 1 guidance mode depends on the combat system's decision as to whether the target is RF-emitting. For the SSDS, this depends on the ability to resolve ES-to-radar track associations. A feature that allows the SSDS to resolve these associations with a low false resolution rate is the use of an ASCM database (threat library). The AN/SLQ-32A(V) operating with Rev. 17.02 software will report emitter identification candidates to the SSDS for each ES track reported. These are the candidates found in its emitter database search. The search may find more than one emitter candidate for the ES track, all of which will be reported to the SSDS. This additional information about the ES track is the enabling data for the SSDS Mk 1 resolution algorithm. All of the ASCM entries that are stored in the AN/SLQ-32A(V) emitter library are researched, and the pertinent intelligence data for those threats are stored in the SSDS threat library. The threat library includes ASCM speed, maximum launch range, seeker turn-on range, and general flight profile information such as sea-skimmer or diver.

Upon RF detection, the AN/SLQ-32A(V) forms a track, searches its database for possible emitter candidates, and reports the candidates to the SSDS. The SSDS retrieves the kinematics profile for any missiles that are reported as being candidates for a particular ES track. The profiles are compared to all of the trajectories of the associated real-time radar tracks. ES-to-radar track pairings that pass these comparison tests are treated by the SSDS as having higher confidence than those association pairs that do not pass. The SSDS labels these associations as "threat-compliant," i.e., the radar track and the ES track both represent objects threatening to the ship, and the information known about the ES missile track does not conflict with radar observations.

For example, the AN/SLQ-32A(V) may detect a radar that has a frequency and PRI close to those of an Exocet ASCM seeker and will therefore report an Exocet to the SSDS as an emitter candidate for the ES track. During this time the SSDS may be tracking an aircraft traveling toward the ship at 250 kt on the identical bearing as the reported ES track, and these tracks will therefore be associated. This association will not be threat-compliant and will remain at a lower confidence level, i.e., not resolved, since the radar track speed is slower than the Exocet speed stored in the SSDS threat library. However, if it truly were an Exocet, it would have been traveling faster and—if all other criteria were met (e.g., range, altitude, seeker turn-on time, etc.)—the association would then be classified as threat-compliant and resolved. (Closeness in bearing with consideration to track radar and ES track bearing accuracy is also a factor in determining resolved status.)

The design of the SSDS Mk 1 association algorithm was geared specifically to increase ship survivability with the use of RAM Block 1 as a self-defense weapon. Analysis was performed on the AN/SLQ-32A(V)'s reporting nature and the performance difference between the

RAM Block 1 modes with respect to the SSDS association algorithms. To find the best ES-to-radar track resolution bearing gate size, a study was conducted to determine the effects of RAM mode (dual or AIR), the nature of the threat (active or passive), and the false ES resolution rate on probability of kill. (Resolution bearing gate size determines how close in bearing the two tracks must be to be resolved.) Values for probability of kill against a threat using RAM Block 1 in dual mode, P_k(dual), and AIR mode, P_k(AIR), can only be assumed for the population of threats and their characteristics (RF-emitting, maneuvering, IR signatures, etc.) without extensive simulation. A parametric analysis was therefore performed to gain insight into the performance behavior based on ES-to-radar track resolution bearing gate size. The objective of this analysis was twofold: (1) to find a relationship between the resolution bearing gate size and the expected performance of the system, and (2) to compare performance sensitivity to assumptions. Based on these studies, a relationship between RAM engagement performance and the ES-to-radar track association gate size was developed and used to select the most appropriate association resolution threshold.

An illustration of the parametric analysis technique used to characterize the system performance is shown in Fig. 2. As can be seen, if there were no performance difference between the RAM Block 1 dual mode and AIR mode against RF-emitting targets, then the best gate size would be zero, eliminating the chance of firing dual mode against a passive target. As the performance of dual mode against RF-emitting targets increases relative to AIR mode, a non-zero bearing gate is needed to increase overall system performance. The peak overall performance and choice of optimum bearing gate depend on the exact performance difference between RAM Block 1 modes. This is illustrated by the optimum bearing gate contour shown in Fig. 2. However, the exact performance difference can only be known on a threat-by-threat basis. Fortunately, the variation in optimum gate size was relatively insensitive to small changes in the assumptions about the expected threat type (RF-emitting or not) and the expected false resolution rate due to ES track misidentification.

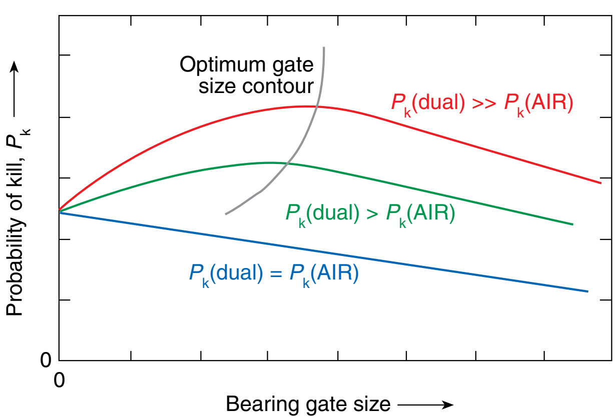

Figure 2. The optimum gate size depends on the exact difference between RAM modes. An appropriate bearing gate size was selected for the SSDS Mk 1 on LSD 41 class ships given the characteristics of the near-term threat, the reporting characteristics of the AN/SLQ-32A(V), and the performance difference between RAM modes.

SITUATIONAL AWARENESS

As noted earlier, the association algorithms developed by the Laboratory can greatly enhance the ability of the operator to assess the tactical situation. All ES tracks are displayed on a Plan Position Indicator (PPI) window as varying lengths of a red bearing line. In the SSDS Demonstration System the bearing lines originated near the center of the PPI display (ownship) and extended to the perimeter, indicating the azimuth of the detected RF emissions. In the SSDS Mk 1, the length of the ES track bearing line will change as a function of its threat level—the more threatening the target, the longer the line. ES tracks that are identified as missile targets by the AN/SLQ-32A(V) will have a full-length bearing line at track initiation. However, if the ES track maintains its missile identification for a time in excess of the expected or reasonable time based on data stored in the threat library, the track will be marked as “old” by the SSDS and drawn with a short bearing line on the PPI. In addition, the high-confidence association pairs will be highlighted on the PPI in a manner immediately recognizable to the operator. For radar tracks with a resolved ES track, a red bearing line is drawn from the radar track symbol to the perimeter of the PPI. This manner of displaying ES data informs the operator, at a single glance and without the need for manual action, of any current missile threats detected by the AN/SLQ-32A(V), those that are detected and are associated with increased confidence to radar tracks, and those that are identified as missiles but have persisted beyond the expected observation time. These changes were successfully adopted and tested, and are currently deployed on LSD 41 class ships.

Figure 3 shows the SSDS Sensor Supervisor PPI display window. Here, three ES tracks (red bearing lines) and two radar tracks (unknown air symbols with green heading indicators) can be seen. With this display, a trained operator knows immediately that the AN/SLQ-32A(V) has identified two ES tracks as missiles and one nonthreatening ES track. Furthermore, the operator knows that SSDS processing flagged one of the ES-to-radar track pairs as having high confidence, since the radar track symbol and the ES line are connected. This tells the operator that there is an increased evidence-supporting hypothesis of ASCM attack. The other ES track identified as a missile is not flagged as having a high-confidence association with any radar track, and this should alert the operator to watch for newly forming radar tracks or evaluate existing radar tracks on that bearing.

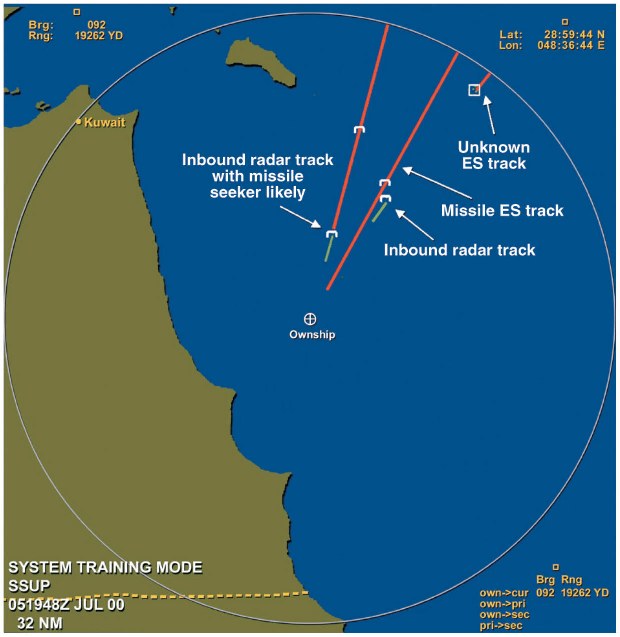

Figure 3. This SSDS Sensor Supervisor PPI display shows two inbound radar tracks and three ES tracks. One ES track is unknown, one is identified as a missile but is not associated with high confidence to any radar track, and the third is identified as a missile seeker and is automatically associated with high confidence to the target to which it belongs.

FUTURE ES INTEGRATION

In preparation for the integration of SSDS Mk 2 and the AN/SLY-2 Advanced Integrated Electronic Warfare System (AIEWS), which will replace the AN/SLQ-32A(V), APL has been generating requirements that will enable a ship's combat system to take full advantage of all available data to improve situational awareness as well as the defense of the ship and force. AN/SLY-2 will be a modern ES receiver and will provide full ES capabilities. Besides providing ES azimuth and elevation measurement accuracies comparable with radars, the AN/SLY-2 will also provide improved ES classification capabilities, thus enabling the SSDS to improve the identification of combat system tracks. ES-to-radar track integration will be drastically improved: they will be correlated with a high probability of correct resolution, and ES measurements will be able to kinematically update these correlated tracks. Because the AN/SLY-2 will be able to update these emitting objects at a variable update rate (rotating radars are limited to a fixed update rate), AN/SLY-2 updates will enable the SSDS to maintain the track of maneuvering objects with high confidence.

THE AUTHORS

RICHARD C. KOCHANSKI is a member of the APL Senior Professional Staff. He works in the Combat System Analysis Section of ADSD's Combatant Integration Group. Mr. Kochanski received a B.S.E.E. from Loyola College in 1992 and an M.S. in electrical engineering from The Johns Hopkins University in 1996. He has contributed to the development of software requirements and software design for the electronic warfare capabilities of the Ship Self-Defense System (SSDS) Mk 1. Recently, he has led system analysis efforts concerning the integration of the Rolling Airframe Missile (RAM) Block 1 Autonomous Infrared Mode and RAM Helicopter-Aircraft-Surface (H.A.S.) with SSDS. His e-mail address is richard.kochanski@jhuapl.edu.

BRUCE A. BREDLAND received a B.S. degree in electrical engineering from the University of Maryland in 1978, an M.S. degree in electrical engineering from The Johns Hopkins University in 1980, and an M.S. degree in numerical science from The Johns Hopkins University in 1985. He is a member of the Senior Professional Staff and the Electronic Warfare Systems Program Manager. Mr. Bredland joined APL in 1978 and works in the Air Defense Systems Engineering Group of ADSD. His e-mail address is bruce.bredland@jhuapl.edu.