Free Gyro Imaging IR Sensor In Rolling Airframe Missile Application

October 1999

R. F. Walter
Raytheon Missile Systems
Tucson, AZ 85734
E-mail: rfwalter@west.raytheon.com
TEL: (520) 794-8623

ABSTRACT

The Rolling Airframe Missile (RAM) provides the US and German Navies with a quick reaction, high firepower defense against Anti-Ship Missiles (ASM) such as the Exocet and SSN-22. RAM incorporates passive RF and IR sensors allowing track and guidance against both radiating and non- radiating threats. The "fire and forget" feature coupled with RAMs quick reaction protects ships against dense raids of ASMs. RAM has achieved exceptional accuracy and reliability during firings against simulated and real ASMs in both single and multiple threat scenarios. RAM incorporates several unique design features. RAM incorporates a statically controlled rolling airframe during flight with full maneuverability obtained by a single plane of control surfaces and a closed loop autopilot. A body fixed RF interferometer incorporates only two forward facing antennas, obtaining two planes of target information over the roll cycle. The IR sensor is mounted to a free gyro seeker, which also serves as the inertial reference for body decoupling. The IR sensor incorporates 80-element linear array which uses the free gyro spin and missile roll to provide an accurate inertially referenced IR image. This allows real time acquisition and discrimination of targets in a variety of maritime backgrounds. The IR sensor and signal processing will be the focus of this paper.

1.0 RAM SYSTEM DESCRIPTION

The RAM MK 31 Guided Missile Weapon System is a high-speed, high-firepower, lightweight self-defense weapon system for defense against anti-ship missiles (ASMs). It is designed to interface with existing shipboard sensors and digital fire control systems. It is designed to receive launcher power, target designations for train and elevation, and missile initialization data from these ship systems. The Block 1, Rolling Airframe Missile (RIM 116B) has a dual mode (RF/IR) and an autonomous IR (AIR) mode capability. It utilizes an image scanning Infrared (IR) seeker to provide an autonomous IR search and acquisition capability. Its dual mode RF/IR operation uses Radio Frequency (RF) midcourse with terminal IR guidance. RAM missiles are launched from the MK 49 Guided Missile Launching System, which carries 21 missiles. Specific self-defense capabilities include fast reaction time, multiple-threat engagement (more than 4 threats), high maneuverability and high lethality.

RAM missiles and launcher systems have been produced for the navies of both the United States and Germany. To date, approximately 2,000 missiles and 99 launcher systems have been delivered. The US Navy has installed RAM on 22 ships, with plans on installing a total of 150 RAM systems on 83 ships. The German Navy has installed 40 RAM systems on 25 ships (additional systems on 3 more ships are currently planned) to date.

Form SF298 Citation Data

Report Date ("DD MON YYYY") 00101999	Report Type N/A	Dates Covered (from... to) ("DD MON YYYY")

Title and Subtitle Free Gyro Imaging IR Sensor In Rolling Airframe Missile Application	**Contract or Grant Number**
	Program Element Number
Authors	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Raytheon Missile Systems Tucson, AZ 85734	**Performing Organization Number(s)**
Sponsoring/Monitoring Agency Name(s) and Address(es)	**Monitoring Agency Acronym**
	Monitoring Agency Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes	
Abstract	
Subject Terms	
Document Classification unclassified	**Classification of SF298** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** unlimited
Number of Pages 15	

RAM Block 0 missiles have been fired over 120 times for a variety of evaluation purposes. The performance has been excellent with a greater than 95% success rate. The RAM Block 1 Weapon System recently completed DT/OT evaluation with a series of firings from the unmanned Self-Defense Test Ship, which incorporates a complete sensor suite and Ship-Self Defense System (SSDS) Combat System. The success rate was 100% against a variety of stressing real world threat scenarios. These scenarios included a sea-skimming Exocet, diving high speed target, maneuvering high speed target, a stream raid of two high speed targets and a low IR signature target embedded in a sunglint corridor.

2.0 MAJOR COMPONENTS

The major components of the RAM MK 31 Guided Missile Weapon System are identified in Figure 1. The RAM MK 31 is comprised of two major subsystems, the MK 49 Guided Missile Launching System and the MK 44 Guided Missile Round Pack (GMRP).

Figure 1. RAM MK 31 Guided Missile Weapon System

2.1 MK 49 GUIDED MISSILE LAUNCHING SYSTEM (GMLS)

The launching system for RAM provides for storage and environmental protection of twenty-one GMRPs. It receives target designation data from the defense system controller, points the missile towards an intercept trajectory, and controls the missile firing sequence.

2.2 MK 44 MOD 2 GUIDED MISSILE ROUND PACK (GMRP)

The RAM Missile (RIM 116B) is delivered in a sealed container. Together these are designated the MK 44 Mod 2 Guided Missile Round Pack (GMRP). This GMRP has a ten-year storage life with no testing or maintenance required. There is provision for a digital data interface (MIL-STD-1553B) with the missile while in the GMRP. This allows updating the missile operating software with no disassembly required.

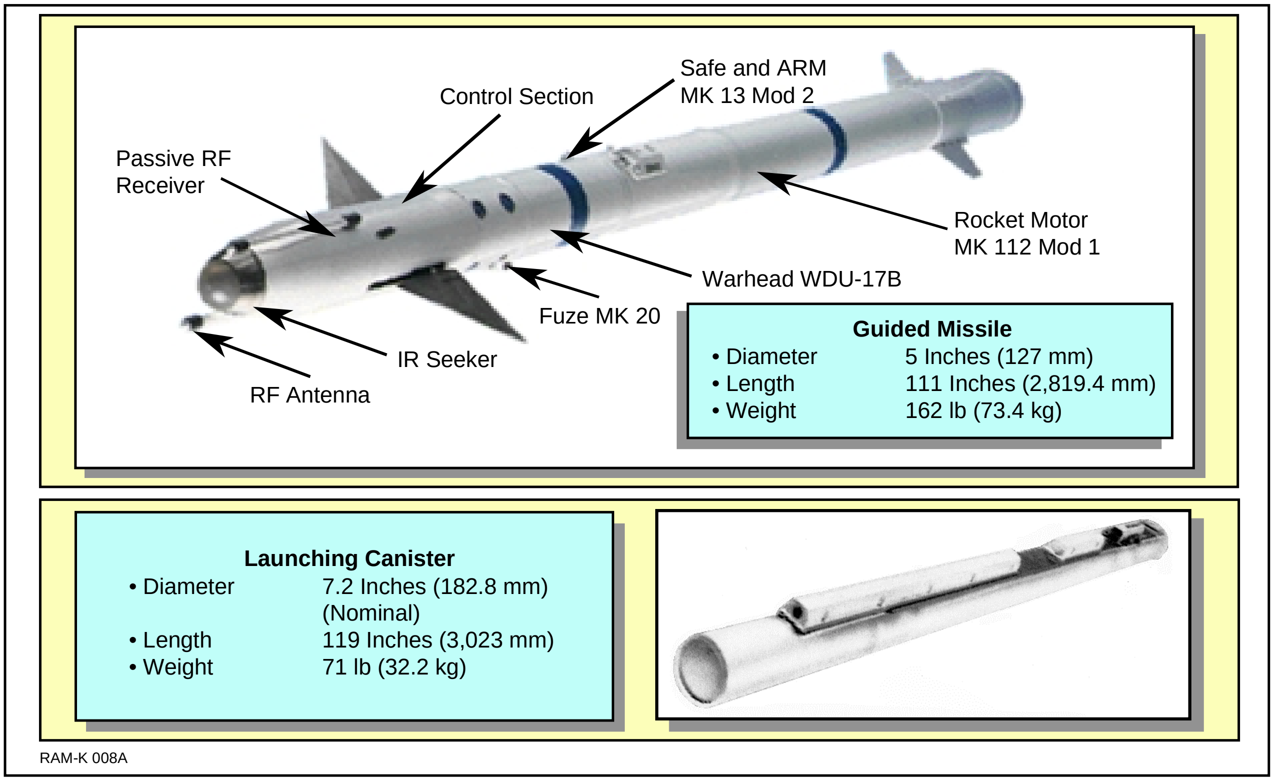


FIGURE 2. MK 44 MOD 2 GUIDED MISSILE ROUND PACK

2.3 RIM-116B GUIDED MISSILE

The supersonic 5-inch Rolling Airframe Missile was originally developed using existing AIM-9 Sidewinder components. The RAM Missile utilizes the Sidewinder fuze (upgraded for RAM), warhead, and solid propellant rocket motor. Two variable incidence canards in conjunction with the rolling airframe and a closed loop autopilot provide high maneuver capability.

The RAM Missile employs a dual-mode capability against RF radiating targets. A passive radio frequency seeker provides midcourse guidance and the passive IR seeker provides terminal guidance. The RAM missile utilizes an image scan IR seeker to provide an autonomous IR acquisition and track mode against non-RF radiating threats. The use of passive IR and RF seekers eliminates the need for a shipboard illuminator and provides a fire-and-forget missile operational capability.

The control section steers and stabilizes the missile by providing a closed loop autopilot with aerodynamic feedback. The control section processes the acceleration guidance command from the guidance section into a steering command, which actuates the variable incidence canards to steer the missile to target intercept.

An active optical proximity fuze initiates warhead detonation. A contact fuze located in the control section provides an alternate method of fuzing by detonating the warhead upon target impact. The MK 20 Mod 2 AOTD is a narrow-beam, active optical proximity fuze system which has been adapted from the AIM-9 Sidewinder program to improve performance against anti-ship cruise missiles at extremely low altitudes over water. The warhead is an annular blast fragmentation device, which uses a conventional high explosive. The warhead is identical to the one used on AIM-9 Sidewinder.

The RAM MK 1 Mod 0 propulsion section consists of MK 112 Mod 1 reduced smoke rocket motor which is also derived from AIM-9 Sidewinder. A folding tail assembly is attached to the rocket motor near the aft end of the motor tube. The four tails are folded when the missile is installed in the canister and automatically erect at launch when the missile leaves the canister. The tails are canted slightly from the missile longitudinal axis to sustain missile roll during flight. The inner surface of the canister has four raised spiral rails which bear against the forward surfaces of the missile tail assembly to develop the initial missile roll during launch.

3.0 GUIDANCE SECTION

The guidance section, as shown in Figure 3, consists of a passive RF receiver and an IR processor. The guidance section has two RF antenna assemblies mounted on the forward surface of the section to detect RF energy radiated by the target. Two RF antennas mounted on the rear are used for rejecting RF emitters from launching ships. IR energy from the target is transmitted through the seeker dome for subsequent processing. The guidance section shell provides a low-drag aerodynamic contour. The guidance section is about 12 inches long, with a 5-inch primary diameter (excluding the antenna contour).

The guidance section receives initialization data (RF target frequency, target speed and guidance mode of operation) from the launching system. Once launched the guidance section processes the RF/IR energy from the target to calculate tracking error signals. The guidance processor provides acceleration commands to the control section to steer the missile to target intercept.

The guidance section performs the following functions: mode control; RF detection and tracking; IR search, detection, and tracking; gyro control; detector cooling; end game detection; serial communication with the launching system; and reprogramming flight software

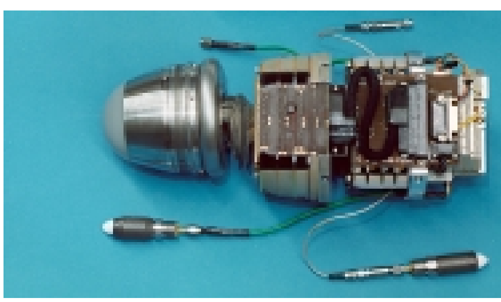


Figure 3a. Guidance Section Components

Figure 3b. Guidance Section Shell and Antennas

3.1 MISSILE RF SEEKER

The RAM RF seeker is designed to autonomously acquire and track the signals from radar guided ASMs. When such missiles are to be engaged by RAM, the combat system sends a message to RAM designating the target and identifying it as an RF radiator and also identifying the RF frequency of the threat. The RAM system automatically sets the missile mode to RF/IR, which will cause it to acquire and track the RF emitter.

The target RF energy, angle and amplitude information is captured using a single plane RF interferometer (two forward facing antennas). The roll motion allows this angle information to be obtained in the entire forward sector. The unique signal processing from the RF seeker allows this angle information to be obtained unambiguously even when exact knowledge of the threat RF frequency is lacking. The two rear facing antennas as well as the two interferometer antennas process “pulse to pulse”, allowing discrimination of the RF energy from the RAM launching platform.

The IR seeker free gyro is also an integral part of the RF seeker. The body referenced angle information from the free gyro is used to precisely body decouple the target angle information from the rolling interferometer. This permits accurate RF Line-of-sight rate signals to be processed for RF proportional navigation of the missile. This IR seeker is accurately pointed at the target until the target’s IR energy is acquired and a solid track is confirmed. At that point the IR seeker will take over missile guidance. In the event that the IR seeker does not acquire the target, the RF seeker is capable of guiding the missile to intercept. The terminal accuracy is improved with terminal IR guidance.

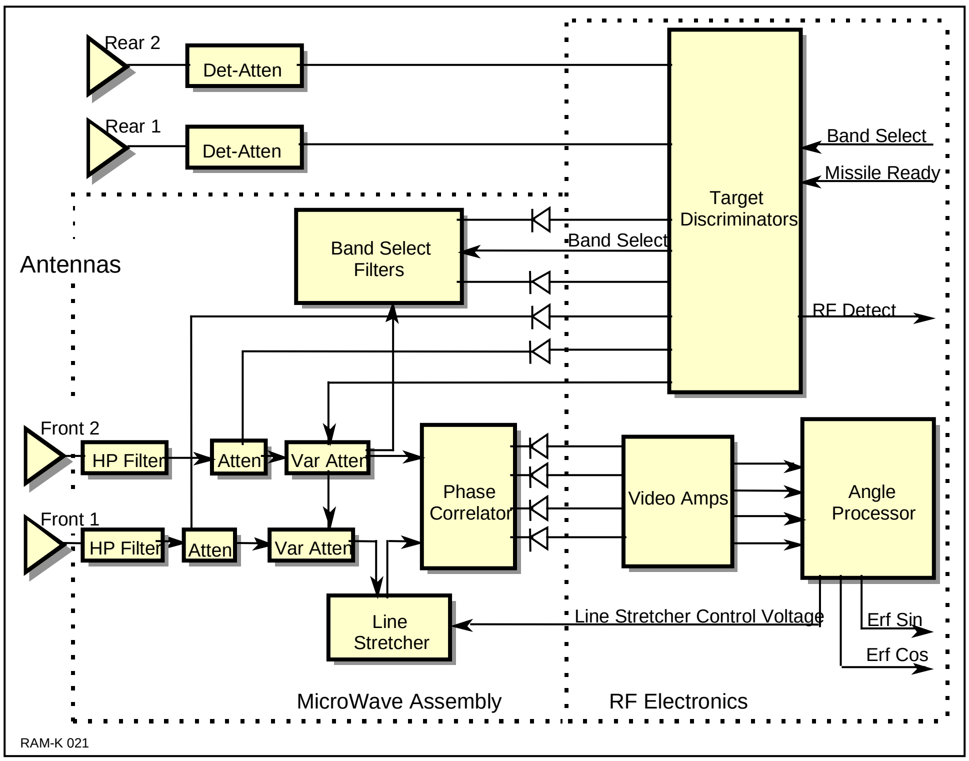
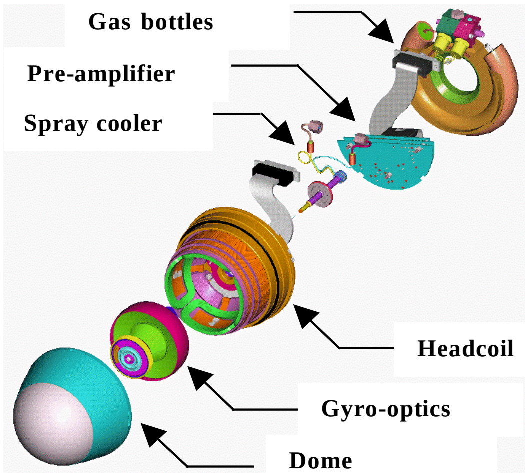


Figure 4. R. F. Receiver Block Diagram

The RF seeker utilizes four antennas, two pointing forward to receive emissions from the target and two pointing to the rear. The rear antennas are used to reject signals coming from the rear so that these signals will not interfere with acquisition or track of the intended target.

3.2 RAM Block 1 IR SENSOR

The RAM IR sensor (IR Processor Assembly) autonomously searches for and acquires IR targets permitting engagement of non-RF radiating targets. This is accomplished using a space stable gyro with a gimbal-mounted, 80-element linear detector array which is conical scanned to form a two dimensional image. Image processing algorithms discriminate between the desired IR target and background features and reject potential countermeasures. This autonomous acquisition and track provides a lock-on-after launch capability with no further ship inputs required after missile launch. The IR sensor is reprogrammable to provide future growth options to counter evolving threats.



IR Seeker

IR Electronics

Figure 5. RAM Block 1 IR Sensor

The IR sensor is composed of an IR Seeker, which operates in the midwave IR spectral band, and a digital signal processing based IR electronics. Figure 5 shows a cutaway IR Seeker view and IR Electronics photo.

The IR seeker gyro optics consists of a Neodymium rotor with a cassegrainian optical system. The seeker has a single asphere optical design which has been optimized to provide superior performance in rejecting background clutter. The use of a rare earth Neodymium magnet for the gyro rotor provides a rapid gyro spin-up time to enhance reaction time. The IR detectors are cryogenically cooled with a two-stage Joule Thompson spray cooler. The high cooling capacity of the cooler combined with extremely low thermal mass and thermal isolation of the IR detector yield a very fast cooldown time, which also reduces reaction time.

The optical system includes a narrow band IR spectral filter that is mounted on the 80-element detector array. This filter has been optimized for IR target signatures and attenuates background features to improve IR clutter discrimination.

The conical scan motion of the gyroscope creates the detector scan pattern to provide the seeker Total Field of View (TFOV). The IR seeker combined with the high precession currents from the IR electronics provides a scenario programmable search pattern, which covers a large area very quickly. The roll motion of the missile combined with the conical spin motion of the gyro provides very effective search coverage. The resulting scan patterns are shown in Figure 6. The large search coverage area combined with a small Instantaneous Field of View (IFOV) provides the RAM with the ability to search large regions while providing excellent clutter rejection.

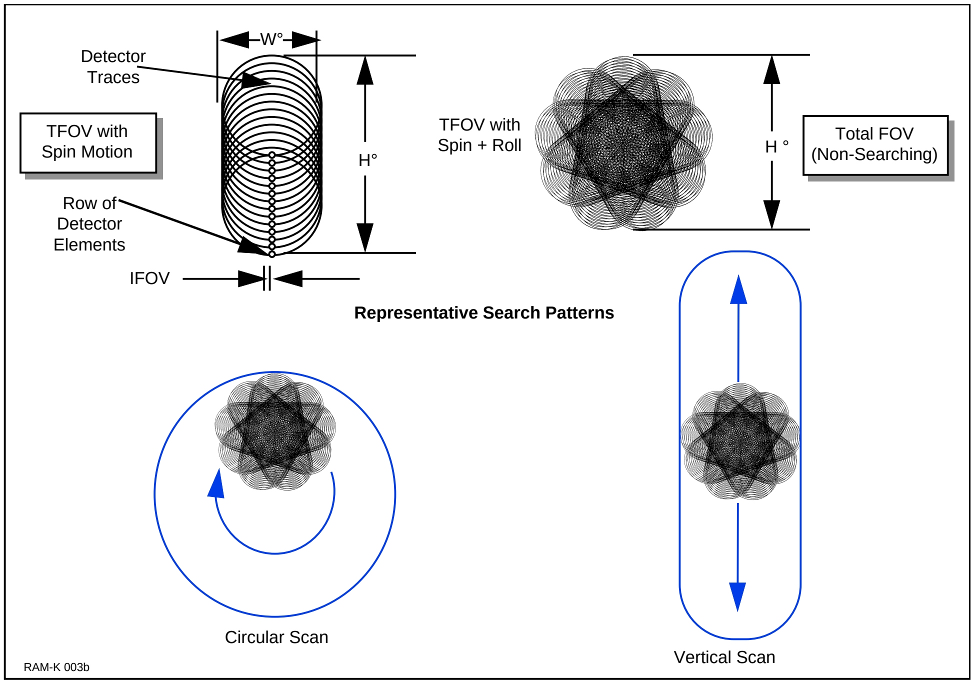


Figure 6. IR Seeker Fields of View

The IR Electronics assembly consists of four Circuit Card Assemblies (CCAs) with surface mounted electrical components attached to each side. The entire assembly is about 2.5 inches long with a 5-inch major diameter. The 80 detector element outputs are pre-amplified and digitized in the Seeker Assembly and the data is serially fed to specialized Systolic Array Processors (SAP) on CCA2. The SAPs perform real-time filtering of the detector data and threshold detection. The IR Electronics uses a TMS320C50 controller and two TMS320C42 Multi-chip Modules, each containing two C40 Digital Signal Processors (DSPs). Two DSPs are used for IR Signal Processing, one for Guidance Processing and one for Telemeter Processing. The DSPs reside on CCA3 and CCA4 with the software primarily written in the Ada language. CCA4 also contains the circuitry for the serial 1553 Mil Bus that communicates to the GMLS pre-launch, and the serial connections to the AOTD and Telemeter. CCA1 contains electronics for gyro precession and spin control as well as interface control. A Xilinx Field Programmable Gate Array (FPGA) on CCA1 provides for DSP interrupt generation, processing of the seeker look angle sensors and reference digital phase lock loop circuitry.

The signal processing provides the ability to discriminate against previously launched RAM missiles thereby providing fratricide prevention and reducing the reaction time. The signal processing also provides a retargeting capability. If the primary target has been destroyed by a lead RAM missile, the signal processing autonomously searches for a secondary target.

The signal processing algorithms provide the RAM missile with an autonomous IR acquisition and track capability. No additional inputs are required from the ship after launch. This provides the RAM with a multiple target capability and improved performance against multiple target stream and wave attacks

4.1 DUAL MODE TARGET SEARCH AND TRACKING

The pre-launch events for a Dual Mode engagement (selected when the designated target has an active RF emitter) begin when the ships combat direction system designates a target, round power is applied and the round is initialized with target engagement data. A typical Dual Mode operational sequence for engaging one RF-emitting target is shown in Figure 7.

The processor receives target specific initialization data including range, speed, RF operating frequency if applicable, bearing, and elevation. It also receives bearing, elevation, and range on leading RAM missiles for fratricide prevention. Additionally, the launching system issues a command for the missile to operate in either Dual Mode or AIR Mode. During this pre-launch phase, the missile is in continuous communication with the launching system and target engagement data is periodically updated. The IR sensor utilizes the target data and mode settings to calculate an expected intercept time, establish mid-course guidance times and to initialize the IR signal processing algorithms.

When the designated target is at the specified engagement range, the launching system initiates the launch sequence with a series of non-reversible Intent-To-Launch commands (ITLs). Upon receipt of the first ITL, the cryogenic gas supply in the IR seeker is activated and IR detector cooling is initiated. The two-stage cooler provides for detector cooling to be completed within seconds after activation. The second ITL activates the roll reference sensor in the control section and the AOTD thermal battery. The third and final ITL activates the thermal batteries in the control section and completes the pre-launch phase.

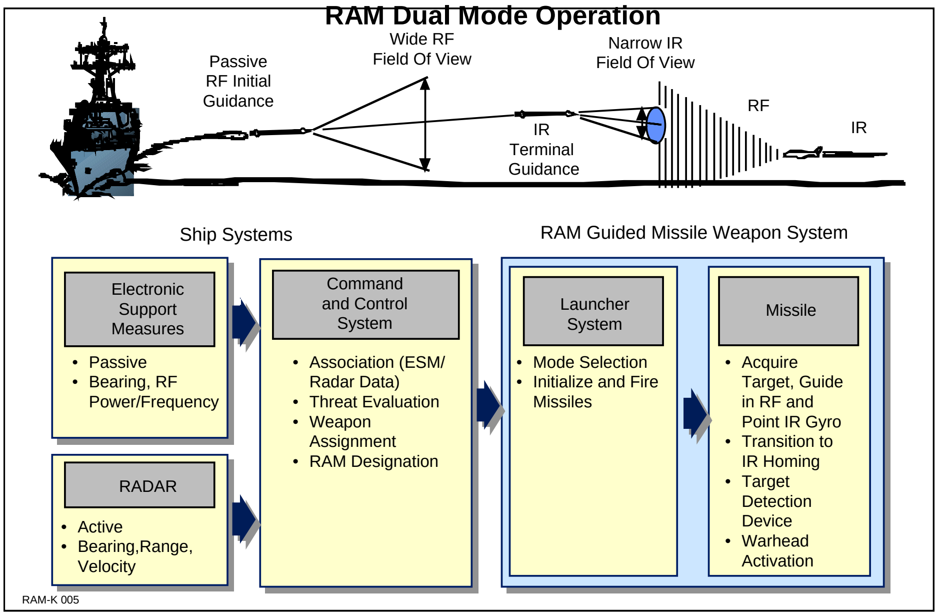


Figure 7. RAM Dual Mode Operational Sequence

Immediately prior to launch, the launching system issues a “Last Message” command. At this point, no further target updates are received. The launch sequence is completed with the issuance of a rocket motor fire command at which time the missile exits the launch tube and initial roll is imparted to the missile via raised rails inside the canister. Once the missile leaves the canister, it operates autonomously to search and acquire the designated target. No further communication or support from the ship is required and the launching system is available to engage other targets.

In Dual Mode (RF/IR), missile guidance begins with RF pursuit guidance. RF acquisition occurs when the target meets RF power level, RF frequency, and front/rear logic criteria. Once RF acquisition is achieved, the RF sensor outputs are used to point the IR gyro at the RF target. Once the IR gyro is pointed at the RF target, compound (i.e. combination of RF pursuit guidance plus RF proportional guidance) guidance is used to steer the missile. At a predetermined time, compound guidance is transitioned to purely RF proportional navigation to complete the mid-course guidance phase of flight.

Once the RF seeker has pointed the IR gyro at the IR target, RF pull-in is established. At this time, the IR signature of the target is within the field of view of the IR sensor. When the IR target satisfies the IR acquisition criteria of the IR signal processing algorithms (intensity, size, angular rate, temporal growth) the missile indicates an IR detection and initiates a IR handover sequence to begin IR tracking and subsequent terminal IR guidance. (A more detailed description of the IR signal processing and acquisition logic is provided below in the discussion of AIR mode.) In terminal IR guidance, the missile uses a high gain IR proportional navigation to steer toward target intercept with a very high accuracy.

Based upon the launcher supplied target engagement data, an estimated time of target intercept is calculated. Using this discriminant and an end-game indicator from the IR image processing, an enable signal is sent to the AOTD proximity fuze to arm the warhead. When the AOTD detects the target in one of its range gates, it transmits a fire pulse to the warhead for lethal detonation. In the event of a head on engagement, the Contact Fuze Device located in the control section provides a fire pulse for warhead detonation upon impact.

4.2 Autonomous IR (AIR) Mode Target Search and Tracking

A typical autonomous IR operational sequence is illustrated in Figure 8. After the command and control system has sent a target designation to the RAM GMWS and external power has been applied to the GMRP, the IR sensor operation begins. The GMWS selects a missile search pattern (Circular, or Vertical) depending upon the accuracy of the ship's designation source. A circular pattern is used when an accurate 3-dimensional designation is available. A vertical scan pattern can be selected if only a 2-dimensional target designation is available.

The AIR mode sequence of operations differs from the dual (RF/IR) mode operation by precession of the IR sensor gyro to a look angle calculated from the target geometry. This ensures the IR seeker will be pointed at the estimated target position to improve acquisition performance. This gyro preposition capability also enhances the GMWS ability to shoot around the ship's superstructure when Command and Control System designations are in a restricted engagement zone.

In AIR mode, the post launch phase is followed by a midcourse guidance with a period of Fly-Behind-The-Head (FBTH) guidance, which shapes missile trajectory to optimize the probability of keeping the target within the RAM missile IR search field of view. FBTH guidance is a low-gain pursuit guidance phase during which the missile steers using gyro look angle information. The duration of the FBTH guidance time is target scenario dependent and based upon the initialization data received from the launching system. Longer intercept ranges allow for longer FBTH times, short-range intercepts would have shorter or possibly no FBTH guidance duration.

At the end of the FBTH midcourse guidance phase, the IR sensor begins an autonomous IR search. The search pattern size and shape is determined by the launch system search pattern selection. The high precession capability allows for a large search coverage area to be scanned in a very short time.

The IR signal processing filters and sorts the IR detector outputs to form a two-dimension image. This image is classified into objects with specific criteria assigned to each object. Based upon features of the object (e.g. size, intensity, line of sight rate, and growth rate) the signal processing algorithms reject background objects and select an object most likely to be the IR target. Once a potential object satisfies the criteria for being a true target, the missile processing state transitions from IR search to IR track. At this point, the missile has transitioned from acquisition to track. Once a valid IR track has been established, the guidance mode of the missile is also transitioned from low-gain pursuit guidance to a high-gain proportional navigation for terminal IR guidance. IR proportional navigation provides an accurate high gain steering capability.

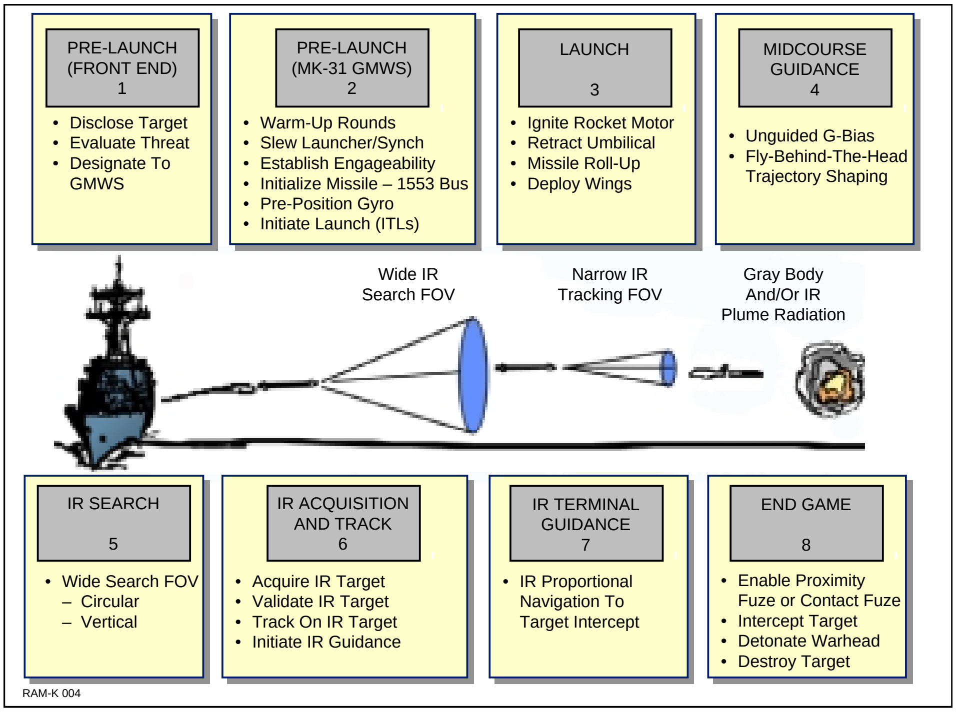


Figure 8. Autonomous IR Acquisition Operational Sequence

The endgame is identical to dual mode operation. The IR signal processing detects the end game condition and arms the AOTD. The AOTD proximity fuze detects the presence of the target and detonates the warhead. In the event of a head on geometry, the Contact Fuze Device provides a fire pulse to the warhead upon target impact.

5.0 Signal Processing Description

The Signal Processor employs maximum flexibility and adaptability to optimize target detection in a variety of background and target scenarios. The signal processing recognizes and adapts its detection algorithms to maximize detection performance in benign blue sky; structured backgrounds, such as clouds and littoral background; unstructured backgrounds, such as sun glint; multiple target and countermeasure engagements. The IR Signal processing is broken down into four major blocks as highlighted in Figure 9.

Matched Filtering and Threshold Detection. This block performs real-time filtering of the detector data and threshold detection of possible targets. The outputs of this block are known as “events”, which are mapped into body-fixed space.

Front End Processing. The Front End Processor receives the events and performs coordinate transforms to map the events into inertial space. Correlated events are grouped into “objects”. The objects represent structures in inertial space that may represent targets, background, countermeasures or leading RAM missiles.

Back End Processing. The Back End Processor places the object information that it receives from the Front End Processor into track files. Each track file is tested for temporal persistence, intensity, and rate of change of intensity and trajectory to classify the tracks as targets, background features, false alarms, countermeasures or leading RAM missiles. The set of all targets is rated to determine the maximum likelihood target and a target designation is made. At this point, target inertial position information is generated and passed on to the Guidance Processor.

Guidance Processing. The Guidance Processor provides all control of the seekerhead gyroscope motor and precession. It receives the target position information from the Back End, generates gyro control signals to close the track loop, estimates the target line-of-sight rate and generates guidance commands to the control section autopilot.

5.1 MATCHED FILTERING AND DETECTION

The main function of the Matched Filtering and Detection processing is to maximize receiver signal-to-noise ratio and designate areas of interest for the subsequent signal processing to investigate further.

This processing is performed in four custom Very Large-Scale Integrated (VLSI) circuits known as the Systolic Array Processors (SAP). The SAP is programmable hardware for which a custom High-Order Language and compiler have been developed. It has been optimized for very high throughput and multiple channel, simultaneous processing.

The SAP employs a combination of matched linear and non-linear filtering to maximize target signal-to-noise ratio, broadband noise estimation, background clutter estimation and threshold detection.

Each of the 80 detector outputs is passed through a linear Finite Impulse Response (FIR) filter that is matched to the signal and noise characteristics. Each channel has an independent detection threshold that is determined by estimating the noise and background clutter in each channel and adapting the threshold in real-time. Those signals that exceed the detection threshold are termed "events" and are passed, along with body-fixed reference information based on scanned position, to the target classification processing.

This filtering methodology takes advantage of the inherent strengths in the scanning process of the seekerhead in that every channel is independently spatially filtered. This approach has several advantages over two-dimensional filter operators often employed in scanned systems:

- Blue-sky sensitivity is maximized. Signal-to-noise ratio improvement approaching the theoretical limit of 2 is achieved, compared with an improvement of 1 possible with two-dimensional operators.
- Since each detector channel independently sets its detection threshold, the detection process is insensitive to detector array non-uniformity. Non-uniformity across the array does not contribute an additional noise term to the detection process.
- The data rate to the subsequent target classification processing is reduced because information only on areas of interest is transmitted.

To increase performance in clutter backgrounds, the SAP implements non-linear filters to estimate the magnitude of the background clutter in unstructured backgrounds, such as sun glint. If a high clutter background is detected, the SAP processing automatically adapts from the normal mode described above, that has been optimized for blue sky performance, to a processing algorithm that is optimized for detection of targets against high clutter backgrounds. Further non-linear filtering and logical algorithms are performed to detect, classify and reject structured clutter such as clouds and littoral backgrounds.

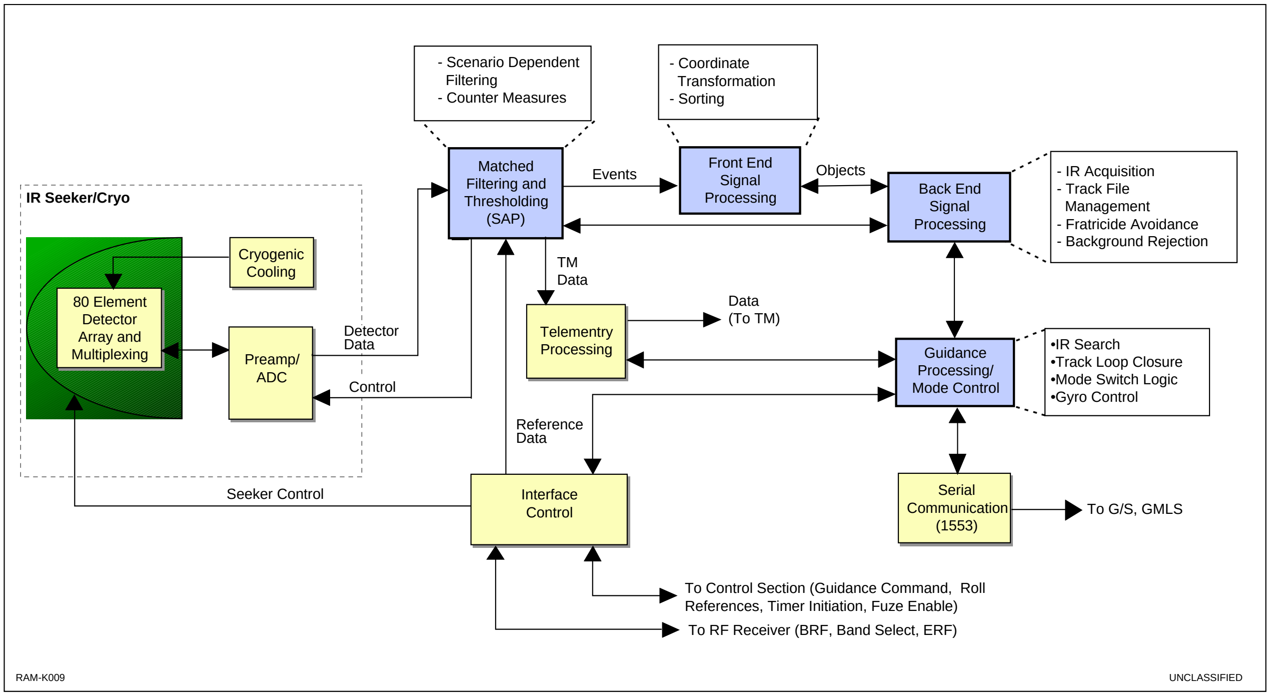


Figure 9. Top Level IR Processor Architecture

After initial detection, the matched filtering is continually adapted to the target characteristics. As the target range decreases, the target's apparent spatial extent increases from that of a point source to an extended source. The FIR filter tap weights are adjusted to respond to the target growth to preserve overall sensitivity and to decrease miss distance.

5.2 FRONT END PROCESSING

Because the scanning method employed by the seekerhead gyro and detector array does not provide a true inertial image, the events generated in the Matched Filter Processing must be mapped into inertial space for subsequent processing. The Front End Processor performs this task.

The events that are generated in the SAP and passed to the Front End Processor are tagged with intensity and scan position information, which is referenced to the missile body. The Front End Processor takes the scan position information and performs coordinate transformations based upon the missile roll orientation, seeker gyroscope spin position and gyroscope gimbal angle estimates to map the events into true inertial space.

Events that correlate in inertial position within a predefined limit are grouped together and cast as "objects". These objects represent regions of interest in inertial space upon which further processing will be performed to determine whether or not they are valid targets, background or other features. Each object, along with its inertial position and intensity information is passed to the Back End Processor.

5.3 BACK END PROCESSING

The filtering and correlation processes performed prior to the Back End Processing, reduces the very large amount of data that is received from the seekerhead detector array. This permits the Back End Processing to perform highly sophisticated processing algorithms to classify objects, designate targets, perform countermeasure rejection and track other RAM missiles and targets. The ability to perform such advanced algorithms is key to RAM's performance against multiple target, multiple countermeasure and severe background environments. This results in a system that autonomously acquires, tracks and guides, providing high-firepower and fire-and-forget operation.

The Back End Processor receives objects from the Front End Processor. For each new object, a track file is created. If the object is correlated in inertial space with an existing track file, it is associated with that track file, which is updated. Its target probability rating criteria is reevaluated. The Back End Processor has the capability of maintaining and processing a large number of track files.

For each track file that is opened, the Back End Processor performs a temporal persistence test. This test is similar to a post-detection integration scheme. Track files must be updated and persist for a statistically significant percentage of processing frames (defined by the frame rate of the scanner) to be considered a valid track file. This processing step reduces the False Alarm Rate (FAR) by excluding detections caused by uncorrelated random noise from the track file set. Track files that do not persist in time are eventually dropped from the possible target set. This processing has the same effect in reducing FAR and increasing detection sensitivity as Time Delayed Integration (TDI). The post-detection integration time is varied depending on the richness of the target environment.

At this point, the Back End Processor evaluates all the track files for the objects in its field-of-view to classify them as target, background, countermeasure or leading RAM missile.

At the time of launch, the Back End Processor receives information from the launch system on the target bearing and bearing rate for each target in its field of view, as well as information on RAM missiles that have been launched previously. The Guidance Processor calculates leading RAM trajectories and passes this information to the Back End Processor. The Back End Processor correlates these leading missiles to the most statistically likely target in the field of view, continues to observe them until impact and then drops them from the potential target set. The result is rapid engagement and high firepower.

In addition to this discrimination, the Back End Processor uses other attributes of the objects in the track file to classify targets, background and countermeasures. Based upon characteristics such as intensity, growth rate of intensity, line-of-sight rate and others, the Back End Processor calculates a "target rating" to provide to each track file. The target rating is based on a combination of probabilities and provides a statistical confidence that a track file represents a target, background or countermeasure. Track files are sorted based on their target rating and the maximum likelihood target is designated. The target designation algorithms in conjunction with the seekerhead's small Instantaneous-Field-of-View and large Total and Search Fields-of-View provide excellent background and countermeasure rejection.

At target designation, inertial position information is passed to the Guidance Processor to close the track loop.

5.4 IR IMAGERY

The IR Detector array is mounted to the gimbal of the spinning free gyro IR Sensor. This sensor rolls with the RAM airframe. The IR signal processing inertially processes this information to form IR imagery of exceptional fidelity. The following is a sequence of images from a recent test firing. Two RAM missiles were fired at a high-speed (Mach 2.5) Vandal diving target. The first missile performed an IR Search, acquiring the target and guiding to a physical intercept. The second RAM missile in the sequence also acquired the first target before observing the impact of the Vandal by the lead RAM missile.

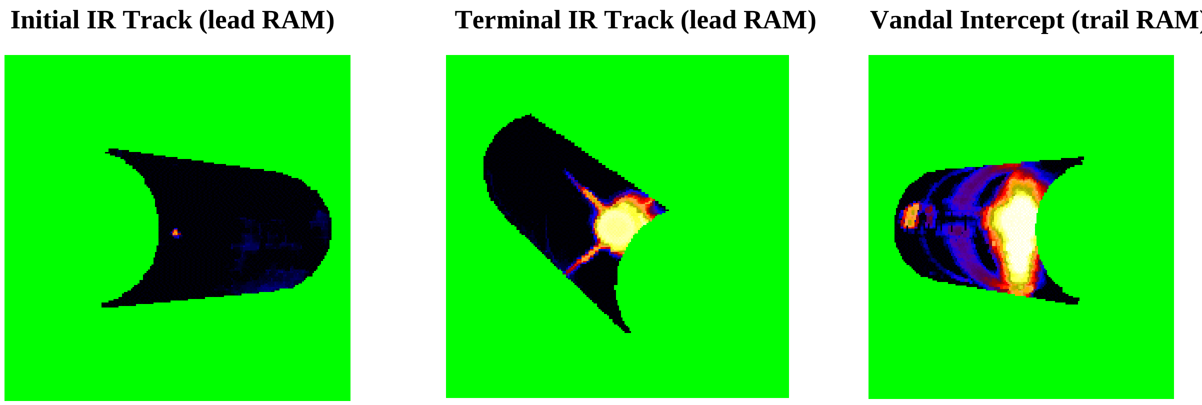


Figure 10. IR images from RAM missiles during flight-testing.

5.5 GUIDANCE PROCESSING

The Guidance Processor performs all tracking and guidance functions. It receives target designation information from the Back End Processor, closes the IR track loop and generates guidance commands to the Autopilot.

The IR track loop is implemented in the Guidance Processor. From the target inertial position provided by the Back End Processor, the Guidance Processor calculates the seeker gyroscope pointing error. The pointing error is input to a proportional-integral track loop filter. The output of the loop filter drives the gyro precession circuitry until the pointing error is zeroed, closing the loop. The implemented track loop is a Type II control loop for zero steady state pointing error under a constant target line-of-sight (LOS) rate. The proportional gain is high enough to accommodate accelerations due to target maneuver for all of RAM's target set, keeping the pointing error within the acceptable limits under extreme target acceleration.

For guidance, the target line-of-sight angle and rate are estimated using a steady state Kalman Filter. The state estimates are calculated directly from inertial information provided by the Back End Processor independently of the track loop, to minimize the effects of track loop jitter and track loop transient response upon the guidance signals. This implementation enables guidance to be initiated upon target designation, prior to closing of the track loop. The result of this is enhanced short-range engagement capability, increasing the missile's performance in degraded weather conditions where visibility in the infrared spectrum is reduced.

6.0 CONCLUSIONS

The RAM Block 1 missile IR sensor autonomously acquires a wide variety of ASMs in a very difficult maritime environment. The IR sensor rejects sunglint, clouds, lead RAMs, and warhead bursts in order to acquire the designated threat. The IR sensor a uses a linear array mounted to a spinning free gyro optical platform. Volume IR search is obtained from the gyro spin, gyro precession and missile roll. Missile signal processing generates a continuous, inertially stable view of the IR scene, where the threat is acquired in the complicated maritime environment. The recent flight test success of the RAM Block 1 missile against real world ASMs have proven the effectiveness of this approach.

7.0 ACKNOWLEDGEMENTS

RAM is a joint development of the Governments of the United States of America and the Federal Republic of Germany. The program recently celebrated the 20th anniversary of the Memorandum of Understanding between the governments which initiated full-scale engineering development of the RAM Weapon System. The program continues to be a model of a cooperative international development and manufacturing effort.

The Block 1 missile EMD development started in August 1994 and completed in May 1998. Special thanks to the RAM Program Office (PMS 472) for leading the international team. The engineering staff at Raytheon Missile Systems (formerly Hughes Missile Systems) and the German companies RAMSYS, BGT and DASA with support from the Applied Physics Lab, NAWC/China Lake, NSWC/Dahlgren and NRL completed the design and engineering proofing activity within the cost and schedule requirements of the program.

I am especially thankful to Konrad Jones and Sam Sirimarco of Raytheon Missile Systems for their authoring and editing support for this paper.