BGT
Bodenseewerk

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ADVANCED TECHNOLOGY DEMONSTRATOR

FOR

IR IMAGING MISSILE WARNING SYSTEM

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1 Introduction

Within the context of the German MOD's research & technology activities, Bodenseewerk Gerätetechnik GmbH (BGT) received an order for the development and manufacture of an advanced technology demonstrator (ATD) for a passive IR missile warner (PIMAWS). Basis for this contract were the long lasting activities of BGT in the field of ground based hemispherical sensor systems, mainly the so called ABF (Aufklärung und Bekämpfung von nicht ballistischen Flugkörpern). See Figure 1. Within the ABF-study, BGT was able to develop a broad know-how in real-time image- and signal-processing of this kind of sensor systems.

Figure 1: ABF

With the extensive know-how in IR-technology – gained from the IR-seeker work – the following two demanding objectives have to be fulfilled within the PIMAWS contract:

- On the one hand, with a new type of scanning concept a detection range sufficient for countermeasures and a sensitivity sufficient for post-burnout tracking has to be achieved.

- On the other hand, a low false-alarm rate of 1 per 2 hours is to be achieved through application of a small instantaneous field of view (IFoV) and subsequent image and signal-processing.

The study started in 1997. The first phase was funded by the German MoD and BGT, the subsequent phases are all MoD funded. In phase 1, the optronic system was designed and manufactured. In Phase 2, the integration and test of the optronic system were carried out. Extensive trials – including flight trials – were conducted and led to a huge amount of background and target data. In Phase 3 (ending 2003) the development of algorithms is the main goal. See Figure 2 for the PIMAWS ATD.

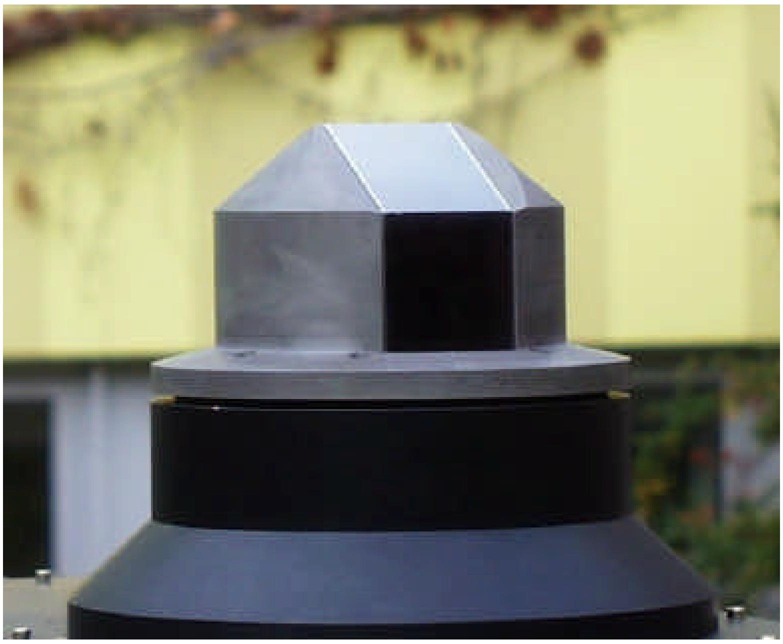

Figure 2: PIMAWS ATD

1.1 Basis for PIMAWS development

In open literature, between 60 % and 80 % of all losses of military aircraft in combat missions since the 1960s are attributed to short-range surface-to-air missiles. This type of surface-to-air missiles and also air-to-air missiles cover considerable distances between missile motor burnout and maximum range. This means that a next-generation missile warner requires the ability to track burnt-out missiles, so-called post-burnout tracking. Remark: UV-missile warning systems are not able to even detect this part of a incoming (engaging) missile.
The initial basis for the PIMAWS development was a Draft NATO Staff Requirement for passive missile warners, stating the following basic requirements:

- Detection range of up to 10,000 m in front aspect ahead of the flying carrier
- Maximum false alarm rate of 1 per 2 hours
- Detection probability of more than 95%

The requirement for post-burnout tracking was added by the German MoD.

2 Technical Concept

Contrary requirements have to be taken into account in the development of a missile warner. On the one hand, a long detection range is demanded – to be achieved by means of large apertures or long integration times. Large apertures have to be ruled out for aircraft – thus, the requirement can only be met through long integration times.

This, however, in contrast to the requirement for an as high as possible overall scan rate. Staring systems offer the possibility of a high overall scan rate, but they need a large number of sensor heads for a spherical coverage.

A possible way out of these contrary requirements is the optical step-and-stare design chosen for PIMAWS where the optical line of sight of the system is stabilized (stare) by appropriate measures during the (long) integration time. Then the optical line of sight is moved rapidly forward to the next image-taking point (step).

If this step-and-stare design were directly realized mechanically, the system lifetime would be considerably reduced. This is why an opto-mechanical principle has been selected for PIMAWS implementing the step-and-stare process exclusively by mechanically continuous movements without accelerations.

The PIMAWS concept is characterized by the following major aspects:

- Monospectral zenith scanner in the medium IR wave band (3…5µm)
- Optical step-and-stare system for realizing long integration times and thus long detection ranges
- Total scan rate of 6Hz with large field of view of 360° x 105° per unit
- Real-time image processing algorithms
- Low false alarm rate

2.1 Optical Concept

When comparing possible concepts of optical layouts for such a scanning system it turns out that zenith scanning is the most favourable solution in terms of both cost/performance ratio and period of realization. The following Figure 3 shows the hemisphere observed by a system in the form of a hemispherical shell. An elevation and azimuth scan is realized through a prism - so called double-Dove prism – in the centre of the shell rotating in elevation and azimuth. Due to the low azimuth turn rate of 3 Hz, image blurring in azimuth can be avoided during the integration time of the detector. The blurring in elevation caused by the high turn rate can be compensated by the optical step-and-stare principle. The hemisphere is scanned in tiles of approx. 30° x 30° for possible targets. These surface areas are transferred through the double-Dove prism and a subsequent lens to a Pechan prism. The image rotation caused by the azimuth rotation is compensated by this Pechan prism. Thus, a de-rotated image is obtained on the detector.

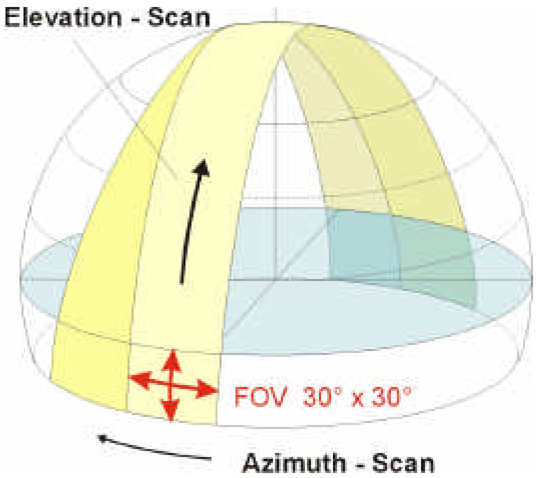

Figure 3: Step-and-stare principle

Subsequently, the beam path is conducted via a path-folding mirror and the detector lens to the detector. Through an appropriate optical element in the beam path, the image blurring caused by the elevation scan is compensated by a movement in the opposite direction during the integration time of the detector.

In order to achieve the sensitivity required for post-burnout tracking, no multispectral optical design (two colours) has been implemented.

The optical system optimised for the spectral range from 3 to 5 µm thus achieves maximum sensitivity. As detector, a 256^2 CMT of the German company AIM is used.

2.2 Signal Processing

The chosen scanning scheme with focal plane array and the high total scan rate of 6 Hz of the hemisphere necessarily leads to very high data rates. These data rates are processed and reduced by the Systolic Array Prozessor (SAP). This processor has been specially designed for real-time image processing and has been specifically developed by BGT for that purpose. It is used in all military image-processing products of BGT. Remark: With this processor, BGT is the single source for the US Navy in the Rolling Airframe Missile (RAM) IR-Mode Upgrade project (in production).

In front-end-near signal processing, about 100 events are detected per frame. Considering the PIMAWS scan rates, somewhat less than 30,000 events are detected per second. Events are in this case either intensity maximal – i.e. point source targets – or contour lines – i.e. edges of background objects. The SAP isolates these events, provides them with a feature vector and transfers the events to the higher level signal processing. The latter is implemented by conventional Digital Signal Processors (DSP).

Through the evaluation of several subsequent frames, tracks are established in the classical way in higher-level signal processing. Subsequently, the clutter in the image is eliminated above all through a motion filter – detecting the clutter by its continuous movement through the images. These algorithms even work with a non moving background, e.g. from a hovering helicopter. Thus, the use of PIMAWS is not limited to fixed wing aircraft.

What remains are tracks with a different dynamic behaviour than the background. Through further filters, the track which represents the missile approaching the carrier is finally prioritised. Further signal processing and a threat yes/no classification leads to a "standard alarm" in a few scan steps time.

Based on a very high signal-to-noise ratio, a faster detection algorithm detects short-range engagements within a 2 detections time frame.

The system is designed for 2 units per carrier for 360° spherical coverage. A comparison is made in the overlapping area of the scan range of the two units to exclude any double alarms for just one target (in the overlapping field of view). The scan pattern between the two units is coordinated in such a manner, that a shift of 180° is achieved. That means, that the two units are always looking in the opposite direction. This doubles the repetition rate in the overlapping area.

In the case of loss of target lock – for instance, due to missile motor burnout – the system switches to memory tracking. The flight path is projected into the future and an expectation window is generated for re-acquisition of the missile. If the missile is detected again, a total of 2 detections are sufficient for re-establishing the track and for alarm generation.

3 Modes of Operation

PIMAWS as an IR device with high sensitivity and high signal processing capacity is able to provide the pilot with additional information about thermal signatures in its field of view and thus perform – at least partially – the functionality of an IRST. Information about horizon lines and mountain crests – also those below the horizon line – can be valuable for flight control.

PIMAWS can be operated in the following modes of operation and is therefore a real dual use equipment:

- Hemispherical missile approach warning system
- Ringmode missile approach warning system or surveillance device
- Imaging pointable forward looking infrared camera

One out of these three modes of operation can be chosen at a time.

3.1 Hemispherical Missile Approach Warning System

PIMAWS in its basic functionality acts as a passive IR missile approach warning system. Its field of regard is more than hemispherical, see Figure 4.

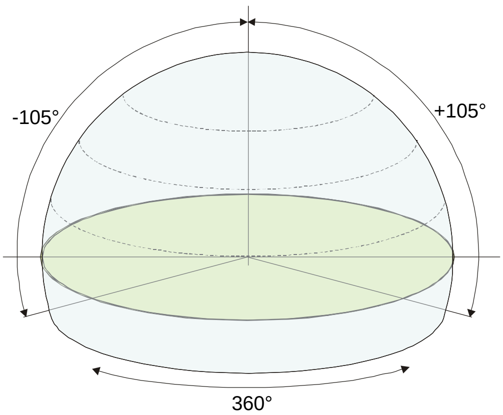

Figure 4: Hemispherical field of regard

During this hemispherical MAW-mode, any frame or set of frames might be chosen for display purposes. These frames or set of frames might be related to the unit itself (means the aircraft) or it might be related a specific direction. With this feature in mind, a pilot could be given a image of a landing strip or an operator can be given images from a surveillance area. See Figure 5 for an example of a hemispherical view from PIMAWS.

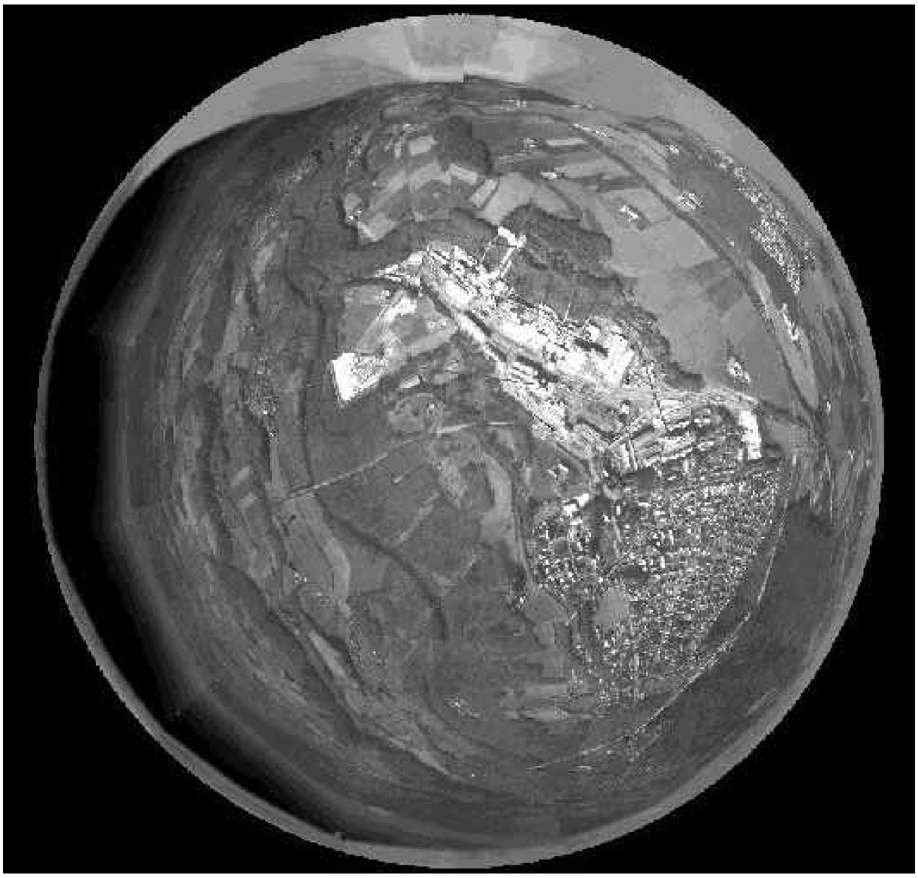

Figure 5: Hemispherical PIMAWS view

3.2 Ringmode Missile Approach Warning System / surveillance device

The scanning of the hemisphere is conducted by independent azimuth and elevation scans. These continuous turning movements can be switched off or given control via the PIMAWS electronics to the MMI of the DASS system.

If the turning of the elevation scan is switched off, the line of sight of the PIMAWS can be directed to a fixed elevation angle. The scan pattern of the PIMAWS then has the shape of a ring with a field of regard of 360° by 30°. Figure 6.

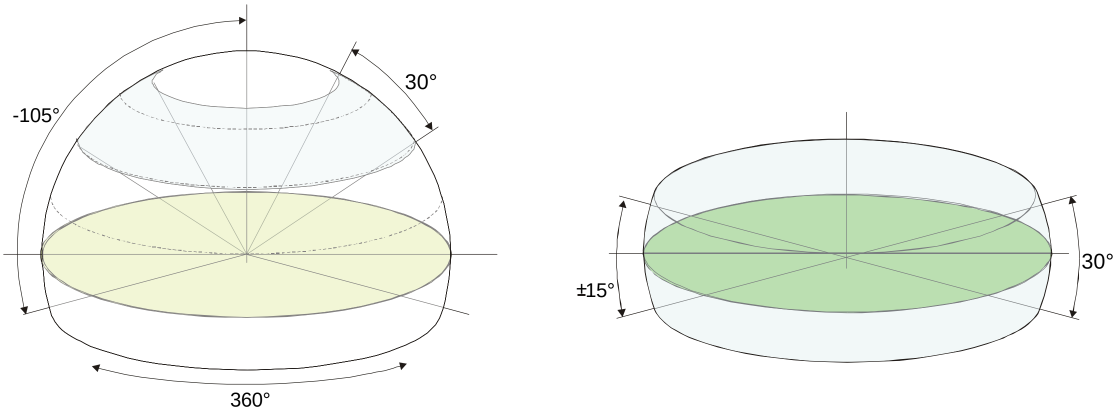

Figure 6: PIMAWS in ringmode operation

The elevation angle (centre of image) can be set in any direction between 0° and 90° as an PIMAWS fixed angle. In this case, the field of regard would cover a stable ring-shaped area with respect to the sensor axis. In definite i.e. limited elevation angle positions movements of the aircraft can be balanced by slewing the elevation axis to the inertial measurement unit. The ringmode operation gives a repetition rate of the field of regard of more than 15 Hz.
As PIMAWS is an imaging device, the images can be presented to an operator for surveillance and/or search and rescue purposes.

3.3 Imaging Pointable Forward Looking Infrared Camera

If the turning of the elevation scan and the turning of the azimuth scan is switched off, the line of sight of the PIMAWS can be directed to a PIMAWS fixed angle in elevation and in azimuth. The PIMAWS then performs as a forward looking IR camera, which is pointable within the whole hemisphere of 360° by +- 90° (centre of image), so off course it is also capable of looking aft of the aircraft. See Figure 7. The image can be transferred to the cockpit crew for display purposes (heads-up-display).

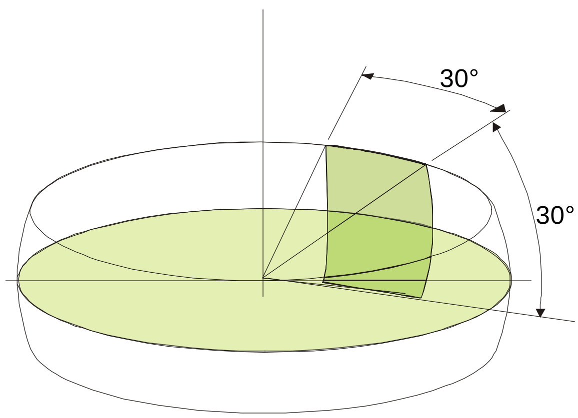

Figure 7: PIMAWS in forward looking infrared camera operation

3.4 PIMAWS interfaces

PIMAWS communicates with the DASS-System via a Mil-Std 1553 or another bus system, transmitting the following data:

- Status and BIT information like detector temperature, cool downtime, etc.
- Alarm list with
  - Alarm number and target number
  - Initial detection time
  - Last detection time
  - Tracking quality
  - Target motion vector
  - Remaining flight time
  - Target classification, as appropriate.

Furthermore, the system of course provides the commands for triggering the on-board equipment to initiate countermeasures via the bus interface and directly (flares and DIRCM).

The aircraft has to submit the electrical power and an adjusted mounting plate for installation. From the DASS, PIMAWS expects the following data and commands:

- Status of the countermeasure units
- IMU and GPS data of the carrier
- Altitude and flight velocity above ground
- Information about the carrier and its subsystems as well as
- Information about the threat to be expected.

Information about the carrier and its subsystems are reasonable for preventive reduction of the false alarm rate, taking especially into account the firing of own missiles and flare ejection. It is also reasonable to know when and in which direction a DIRCM system is used.

In addition, information from other sensors can be processed to reduce the false-alarm rate. After introduction of multi-purpose DIRCM systems, one could imagine a close cooperation between the two system types. For this purpose, a Laser – DIRCM system would have to fire a target following a verification request from the MAW and report its measured characteristics (range, velocity) to the DASS and the MAW.

4 Post-Burnout-Tracking capability

When looking at the values of maximum possible flight paths of current surface-to-air missiles, the necessity of post-burnout tracking becomes abvious. The missiles listed below as examples have in part considerable flight paths to complete after motor burnout (see following Table 1):

System	Spectral Range	Boost	Sustain	Flight path after Burnout	Range	V_{max}	<V>
Type West 1	IR/UV	2s	4s	>3km	>6km	2.3M	1.5M
Type West 2	IR	2.2s	-	5.5km	6.5km	2.6M	1.3M
SA-7	IR	2.2s	6.1s	0.5km	4km	1.5M	1.2M
SA-8	RF	total	14s	5km	12km	2M	1.8M
SA-13	IR	total	4.5s	7km	10km	2.4M	1.5M
SA-16	IR	total	8s	1.5km	5km	1.7M	1.2M

Table 1: Typical SAM-data

At the beginning of a flight, the signature of a surface-to-air missile is relatively intensive in the boost and sustain phases. Then the signature, of course, breaks down – for both IR and UV. Due to the aerodynamic heating, however, the missile's IR signature will get more intensive again as the missile continues its flight and approaches its target.
Owing to its system design, PIMAWS can re-detect post-burnout targets at a distance to the flying carrier sufficient for triggering countermeasures and alarm in due time.

5 Dual Colour

PIMAWS is designed to collect as much as photons as possible to gain the largest detection ranges. Therefore, the MWIR is not split into two or even more bands. Instead of a physical false alarm reduction by comparing several bands PIMAWS gets an excellent false alarm rate by the intelligent real-time image processing with only one colour. As long as the gain of performance of a multi-colour system and the economical availability of multiband detectors is not given, PIMAWS will stay with one colour.

6 Collision Avoidance

The collision avoidance capability of PIMAWS is a fully software based feature. But a few pre-requisites have to be fulfilled:

- The device has to have a spectral range, in which the objects can be seen. Objects are now no longer missiles only, but also mountains, towers, other flying platform and e.g. paratroopers/paragliders. Some of these objects have no plume, this excludes UV-devices for this purpose. Some of these objects are rather cold - compared to missiles – this requires a high IR sensitivity.
- For the "cold" objects – the thermal infrared would have been the choice. But with the past improvements in detector technology, the mid wave IR is also capable in fulfilling this task with an excellent sensitivity. See Figure 8 and Figure 9 for two examples in mid wave IR objects.

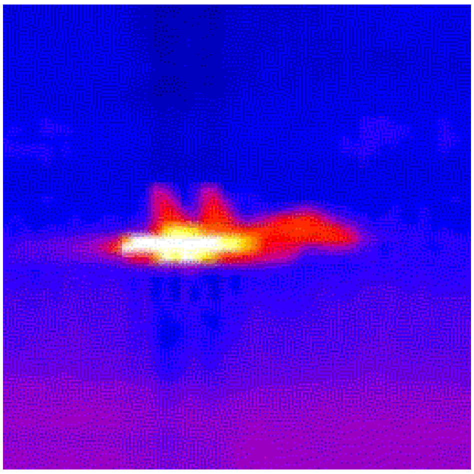

Figure 8: Mig 29

Figure 9:Paraglider

- The device also has to have the ability to recognize these a.m. objects, so it has to be an imaging device with intelligent image processing software. Detecting engageing missiles means the detection of point-like targets. In this case, the objects to be detected always have a width and include several pixels.

All this prerequisites are fulfilled by PIMAWS.

The collision avoidance algorithm basic function is as follows:

- The line of the horizon is determined.
- Objects in course are isolated and tracked
- The increase in size of these objects in time and the to the device known flown flight path (length) shows whether these objects are on a collision course or not.
- Due to the known flight path and the own manoeuvering capability the algorithm is able to cleary state a latest time to begin a out-of-the-way manoeuvre and avoid the collision.

  See Figure 10 and Figure 11 for illustration.

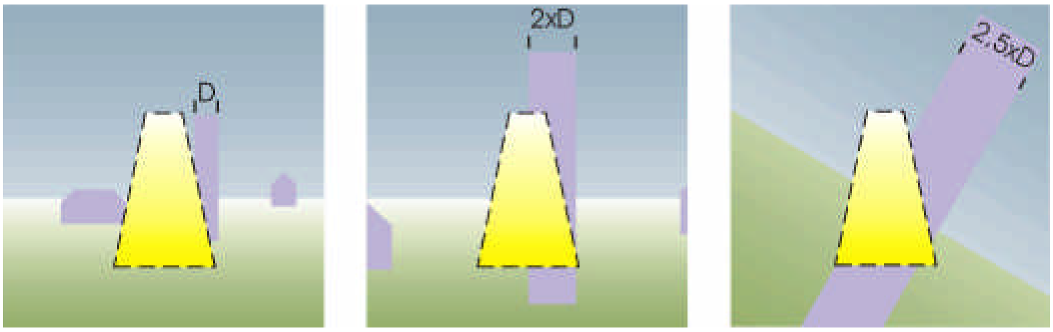

Figure 10: Envisaged flight path

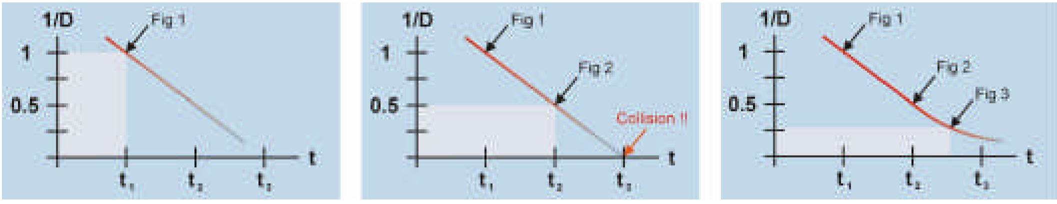

Figure 11: Width of object versus flight time

7 PIMAWS Main Characteristics

Spectral range	MWIR 3…….5 µm
Field of regard (per unit)	360° x 105°
Scan rate (per unit)	6 to 36 Hz
Scan rate (per shipset)	11Hz
Detector	256^2 CMT
Sensor head dimensions	105 x 65 mm
Weight (1 LRU, per unit)	40 kg

8 Cost Issues

As written above, UV-MAW are not able to detect post-burnout missiles. This feature is to IR-MAW only. The actual trend in IR-missile warning goes into staring system - one or more colours. For a spherical coverage at least 6 to 8 staring sensor heads are required. PIMAWS only needs two for a real spherical coverage. Taking similar optical resolutions into account, the staring sensors have to have detectors with 500 to 1,000 pixels square. This kind of detectors is extremely expensive, already as a one-colour device. Therefore, the purchase of two PIMAWS-units is cheaper than the purchase of 6 to 8 staring systems with high complexity. Staring systems, which use similar detectors like PIMAWS do not have the similar optronic performance as PIMAWS due to the larger IFoV (Instantaneous Field of View). Taking integration and LCC into account, the PIMAWS advantage even grows. It is cheaper to integrate and maintain 2 units instead of 6 to 8, even if PIMAWS has a higher complexity than a staring sensor.

Overall, PIMAWS is the cheaper and more powerful solution, based on today's technology.

9 Summary

The technical highlights of the PIMAWS can be summarized as follows:

The PIMAWS achieves its long detection range in the MWIR with a 256^2 CMT-FPA through the implemented step-and-stare system. A sufficient false-alarm rate is achieved when utilizing only one colour. The post-burnout-tracking capability is realized by bridging the time from signature breakdown to subsequent re-acquisition in memory mode. Prerequisite is the ability, to have the very high sensitivity to detect post-burnout missiles.

The high system accuracy will allow direct control of future DIRCM systems and of flares. The standard interfaces Mil-Std 1553 Bus and RS 422 enable the retrofit for a variety of carriers. The high scan rate of about 11Hz per shipset with a field of view of 360° x 105° allows full spherical coverage with only two units per carrier, this keeping installation and overall costs low.

With PIMAWS, the next generation of IR-MAW with post-burnout-tracking capability for direct control of countermeasures for jets and transporters is on the advance.