

TEST AND SIMULATION OF A 5TH GENERATION, HIGH PERFORMANCE, AIR-TO-AIR MISSILE OPTICAL SYSTEM AND PLATFORM USING HARDWARE IN THE LOOP SIMULATION

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Abstract. *An air-to-air 5th generation missile is always submitted to extreme maneuvers conditions and high accelerations during its flight after launch. It is not difficult for the platform and optical system to lose the target, because the flight dynamics are executed in extreme velocity during the tracking. The main objective of this paper is to test a type of platform and optical system design in laboratory before flight. To accomplish these tests, hardware in the loop simulation will be used to send control signals to the missile selecting determined tracking modes. Once the missile tracking mode is defined, the target will be moved to simulate real flight. To achieve this task in the laboratory, two robot arms will be used. One robot arm, holding an infrared collimator source will be used as target, and another robot arm, carrying the missile optical system and platform, will simulate the unit under test. Both robots arms will be moved relatively to each other and the optical and platform results will be computed and analyzed, with the objective to verify the missile front section performance.*

Keywords: *Robots; Hardware in the loop; Missile Platform; Optical System*

1. INTRODUCTION

A 5th generation air-to-air missile is designed to achieve high levels of performance under the most extreme flight conditions. Once the platform and optical designs are ready and integrated, certain performance parameters must be verified in order to check the missile ability to track and pursuit a target. An adequate platform response allied to a good optical quality seeker system will be responsible for the feedback guidance and tracking signals.

The execution of real tests using a missile integrated to an aircraft is not feasible during the missile development phase. Many certification tests must be achieved before flight and the process of missile integration to the aircraft takes a long time and is very expensive. Consequently, it is mandatory to test the missile using a different setup to verify its performance requirements. The idea of this paper is to provide an example of test setup that became extremely useful for the platform and tracking system development.

The concept illustrated in this paper is base on the Hardware in the Loop Simulation (HILS). This concept is extremely useful when feedback from many subsystems is necessary. That is why this missile will be tested under this concept to determine major performance parameters.

The tests that must be performed using this setup include: tracking point, which is the missile ability to follow a determined target; execution of scan patterns that will lock and track targets; platform response to a tracking command and simpler tests of optical performance, including capability to track far and close targets.

2. SCAN PATTERNS FOR IR SEEKERS

Scan patterns are geometric shapes, or patterns as well, that shall be followed or described by a missile seeker, during a target acquisition phase. They must be implemented and employed to enable the detection of potential targets, within a regular area, that around a radar or pilot-defined designation vector.

The type of scan pattern shall (basically) depend on:

a) The magnitude of the half apex angle: for very small angles, no pattern shall be required to cover the respective area, since the instantaneous FOV shall do it. As the half-apex angles increase, and so the designated area, it becomes mandatory having suitable patterns for different situations/missions;
b) The IR sensor characteristics, that may be:
    a. Scanning arrays: are constructed from linear arrays of pixel, which are raster across the desired field of view using an oscillating mirror to construct a 2-D image, integrating over time, according to Figure 1.

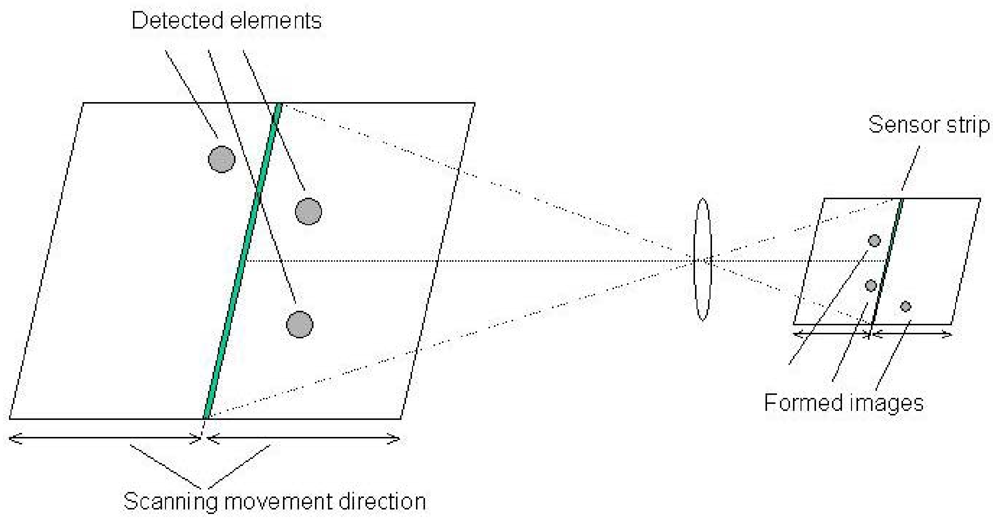


Figure 1 – Schematics for scanning arrays' image formation

    b. Focal plane array (FPA): it directly captures a 2-D image projected by the lens at the image plane. A scanning array is analogous to piecing together a 2D image with photos taken through a narrow slit;

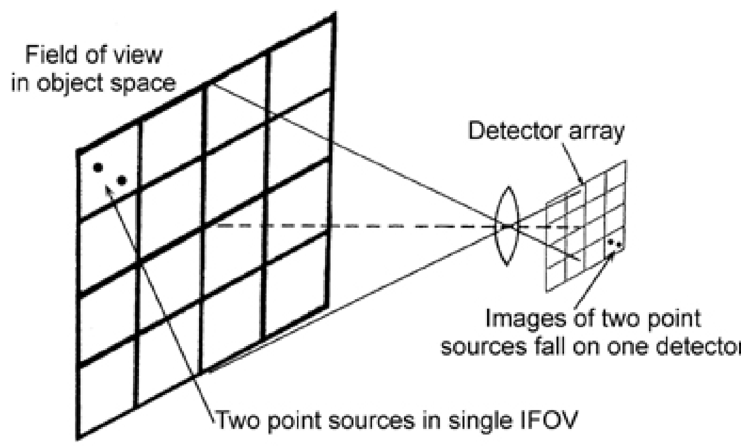


Figure 2 – Schematics for FPA image formation

    c. Seeker's platform maneuvering capabilities: this is related to how many degrees of freedom the seeker is given (commonly 2 or 3-dof are applicable), and the range of excursion for each independent axis;

    d. Additional operational, user-defined requirements: these could be listed like:
        e. Maximize the probability of target detection, in the shortest possible time;
        f. Have as little redundancy as possible;
        g. Allow maximum speed for scanning over the scan pattern;
        h. Cause the least amount of generated heat in the torquers;

2.1. THE CHOICE OF SCAN PATTERNS

As stated above, from one side, the choice of a scan pattern should be mission driven, i.e., it shall be related to the optimal compliance of target searching and acquisition, under strict operational, user-defined conditions.

In accordance with the stated above, it is possible to define types of scan patterns:

i) No scan;
ii) Small scan;
iii) Large scan.

Whatever the pattern is, an optimal choice should occur only after detailed experimentation with the related parameters, as well as the behavior related with the seeker's control system, and the hardware itself.

As constraints for a scan pattern to be proposed, there could be pointed out:

i) Designed curves shall have a limited tightness;
ii) Least generated heat by the torquers (servomotors);
iii) Least amount of acceleration signal changes;
iv) Symmetric shape.

Figure 3 below carries the types of scan patterns, as well as common shapes investigated for implementation and use. It is clear, by the shapes themselves, that a minimum of 2-dof are required for the patterns to be performed.

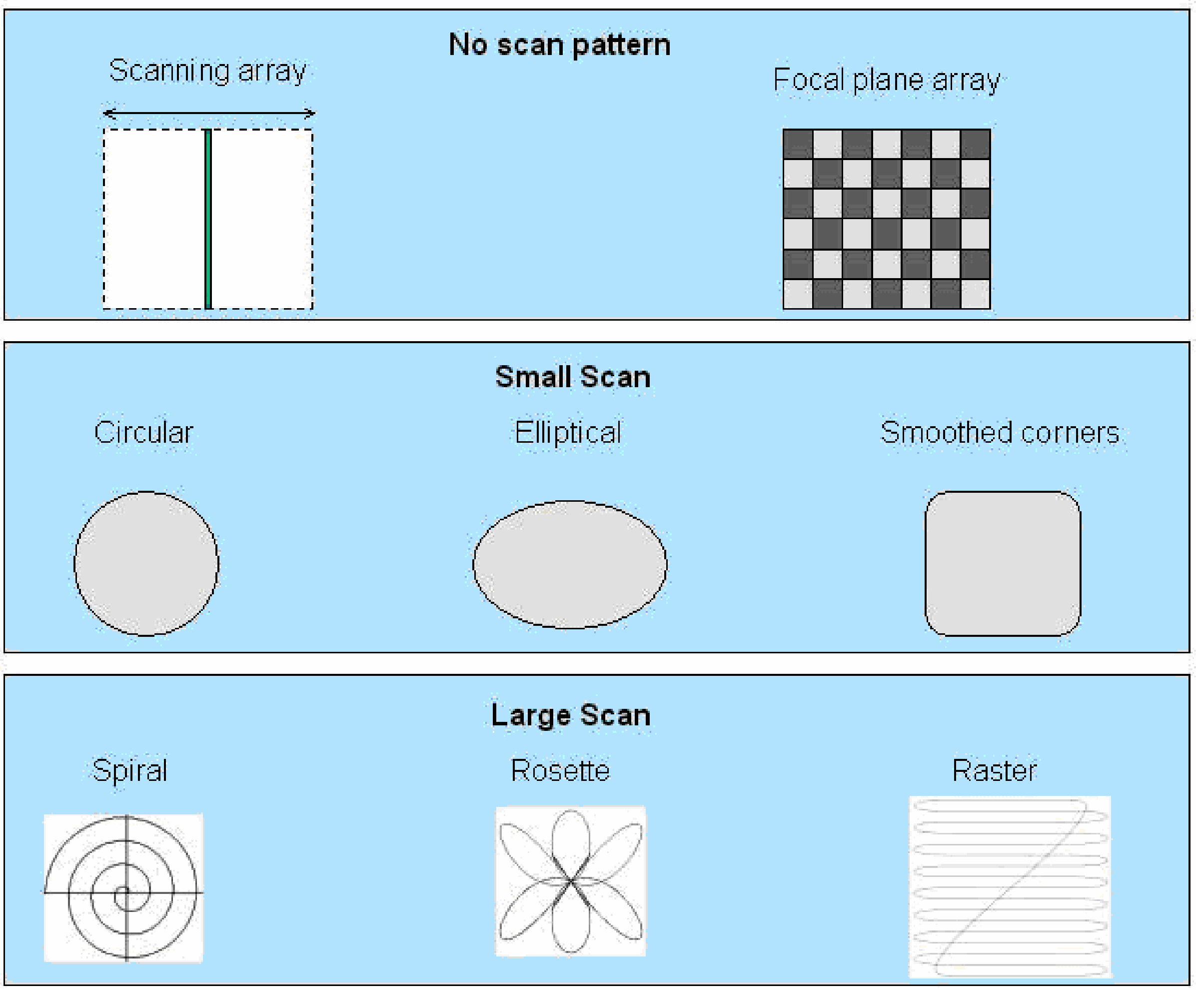


Figure 3 – Common scan patterns collected

2.2. AN IMPLEMENTATION EXAMPLE UNDER STUDY

In this section, an example of a pattern under investigation is shown: the approximation to a raster by coupling harmonic and linear movements, in independent axes.

The advantages sought rely on the possibility of easily choosing the pattern’s frequency, which shall directly affect the desired (and defined) level of overlapping within the search, and the simplicity of the equationing itself.

As shown by Figure 4, the missile gimbaled assembly is shown, with the respective axes along:

Y – axis: PITCH GIMBAL;
X – Axis: YAW GIMBAL;

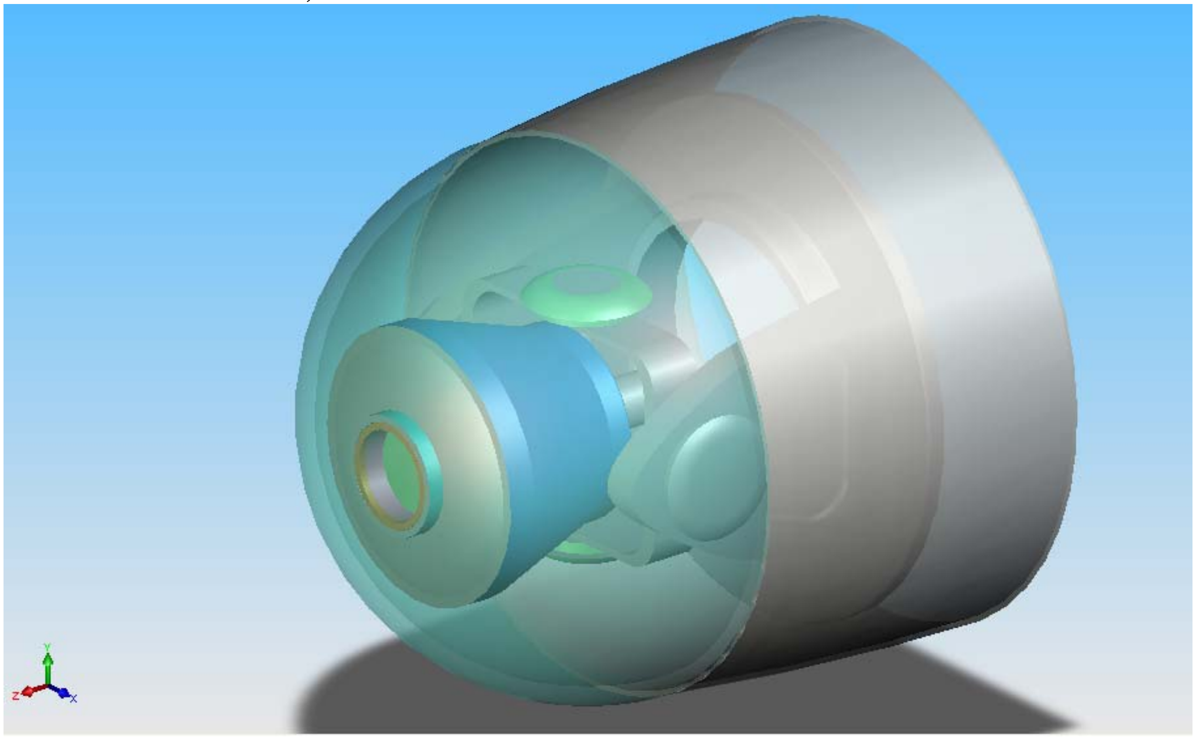


Figure 4 – Schematics for the considered gimbaled assembly

For the PITCH axis, the SHM (Simple Harmonic Movement) is applied, and for YAW the linear constant movement. The equationing is, therefore:

$$pitch(t) = A * \sin(\omega * t) \tag{1}$$

$$yaw(t) = \bar{v}_{yaw} * t \tag{2}$$

Where

$A = half\_apex$ [rad];

$\omega = 2 * \pi * f_{torquer}$ [rad/s]

From (1) and (2) the first temporal derivatives give the speeds for the axes:

$$\frac{\partial}{\partial t}\left[pitch(t)\right] = \omega * A * \cos(\omega * t) \tag{3}$$

$$\frac{\partial}{\partial t}\left[yaw(t)\right] = \bar{v}_{yaw} \tag{4}$$

From (3), one can understand that the speed in PITCH is time dependent, and constant in YAW.

Finally, the second derivative shall, likewise, give the respective accelerations:

$$\frac{\partial^2}{\partial t^2}\left[pitch(t)\right] = -\omega^2 * A * \sin(\omega * t) \tag{5}$$

$$\frac{\partial^2}{\partial t^2}\left[yaw(t)\right] = 0 \tag{6}$$

Therefore, it is shown that the acceleration for PITCH is also time dependent. Both the speed and acceleration for the PITCH axis shall be limited, under design constraints, so they shall not peak undesirably.

3. THE HILS IMPLEMENTATION

To accomplish the tracking modes in hardware for an air-to-air 5th generation missile tests are necessary. For these tests hardware in the loop simulation will be used to send control signals to the missile selecting determined tracking modes. Once the missile tracking mode is defined, the target (infra read source - IRS) will be moved to simulate real flight. To achieve this task in a laboratory, two robot arms will be used. One robot arm, holding an infrared collimator source will be used as target, and another robot arm, carrying the missile optical system and platform (Missile Front Section – MFS); will simulate the unit under test. Both robots arms will be moved relatively to each other and the optical and platform results will be computed and analyzed, with the objective to verify the missile front section performance.

With a robots laboratory is possible to achieve many tests over the system that saves a lot of time comparing to a fly test for example. Making the relative movement between the IRS and the MFS is possible to observe the behavior of the MFS in many different simulated situations. Two different situations, however, are tested and is the distance in kilometers and the velocity between both IRS and MFS.

The velocity between the IRS and MFS is achieved with a math strategy. The first skill is related to the robot arm that can move itself with 5000 mm/s. Changing this velocity over the time is one way for the simulation, but it is possible to simulate it using the apparent velocity.

It is possible to realize that a target with a high velocity, but very far, seems in fact to be at low speed. This characteristic is the beginning for the velocity simulation between target and MFS using the robots arms.

To makes the simulation the target linear velocity is used as horizontal component of the tangential velocity of a circular movement with constant angular velocity and the center point placed in the MFS position. With this strategy is necessary to know the needed linear velocity (tangential) to the robot arm (target) to simulate, in a laboratory and with constant angular velocity, a target that would be very far form the MFS and a high speed. The answer is according to the following math relations and the Figure 5.

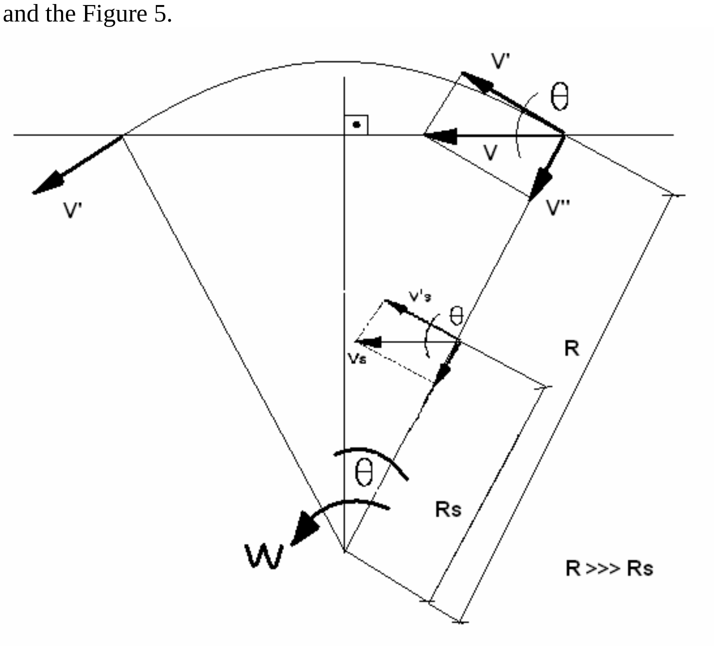


Figure 5 - Circular movement and its elements

The equations that makes the relation between velocities and distances is

$$Vs = (Rs\ V) / R \tag{7}$$

where:

Vs is the simulated velocity
Rs is the simulated radius (distance between MFS and IRS)
V target real velocity
R real distance between MFS and target

The equations source is as the following

$$V' = R\ w \tag{8}$$

$$V' = V \cos \theta \tag{9}$$

$$w = (V \cos \theta) / R \tag{10}$$

$$Vs' = Vs \cos \theta \tag{11}$$

$$Vs' = Rs\ w \tag{12}$$

$$Vs = (Rs\ w) / \cos \theta \tag{13}$$

$$Vs = (Rs\ V) / R \tag{14}$$

V' is the tangential velocity
w is the angular velocity
Vs' is the simulated tangential velocity
Vs is the simulated linear velocity (is the IRS robot arm velocity)
Rs is the simulated target distance.
θ is the angle for the velocities components

The angle became useless in the end, than the simulations have relation only with the distances and velocities. It is possible to have an overview of the system described above at the following. The used robotic arms came from ABB (http://www.abb.com/) and are normally used at the industry for welding and painting.

The system is according to the following description. "Hardware in loop simulation (HILS) controller will be used to send control signals to the missile which will put it in the various modes e.g. Scan, track, lock-on, etc... While the missile is in one of the modes, the target will be moved to simulate the flight pattern of the acquired target. At the same time the missile body movements will be moved to simulate the missile maneuvers taken to track the target. A script file with all the commands will be generated a loaded into the HILS computer which will send the commands at a constant rate to the robot controllers and the seeker-head controller. The HILS computer will also log the data for analysis after the test was done. The main idea can be visualized at the Figure 6.

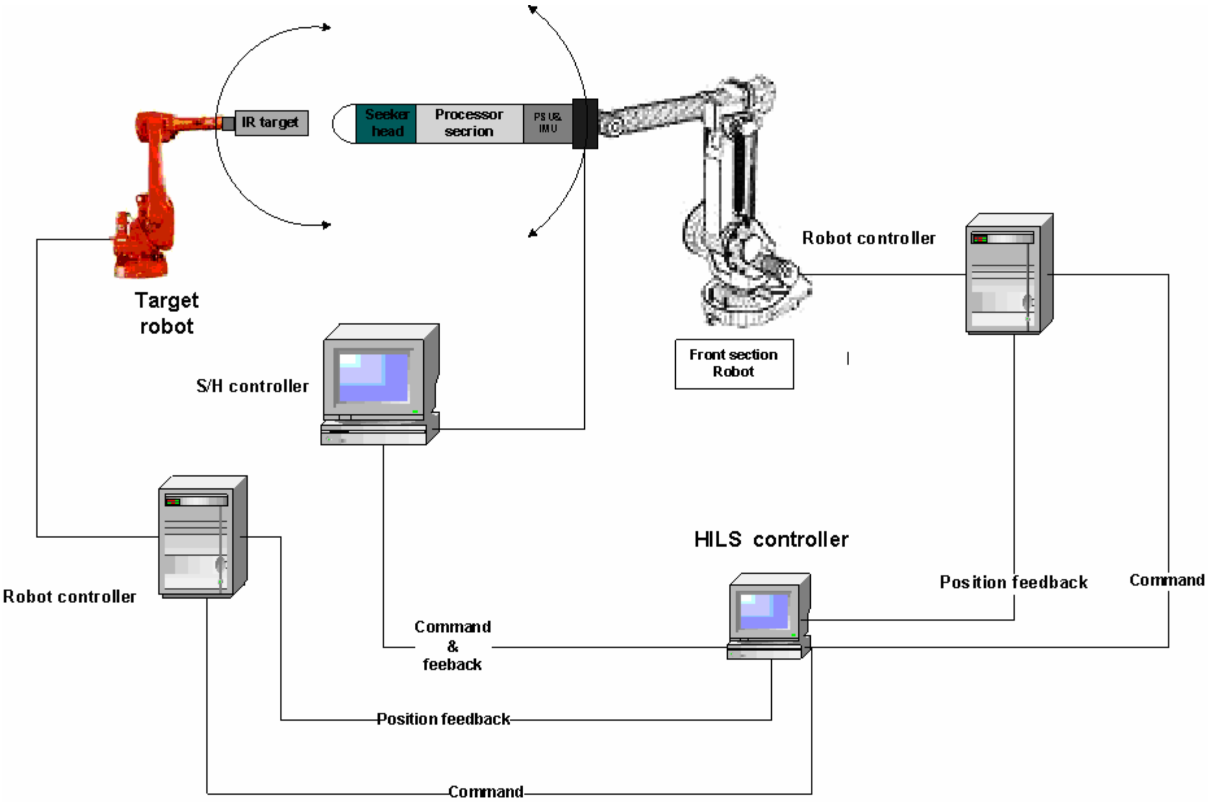


Figure 6 – Schematics for the HILS

3.1. OPTICAL SYSTEM AND INFRARED TARGET

As can be seen in Figure 6, there are an IR target and a seeker head. To simulate the IR target, a collimator will be designed for the medium infrared channel. The collimator will be based on four lenses and will have an aperture of 80mm. The focal length is also 80mm what will provide a very fast optical system with f/1. Figure 7 illustrates this collimator and also the ray trace trough the optical system under test.

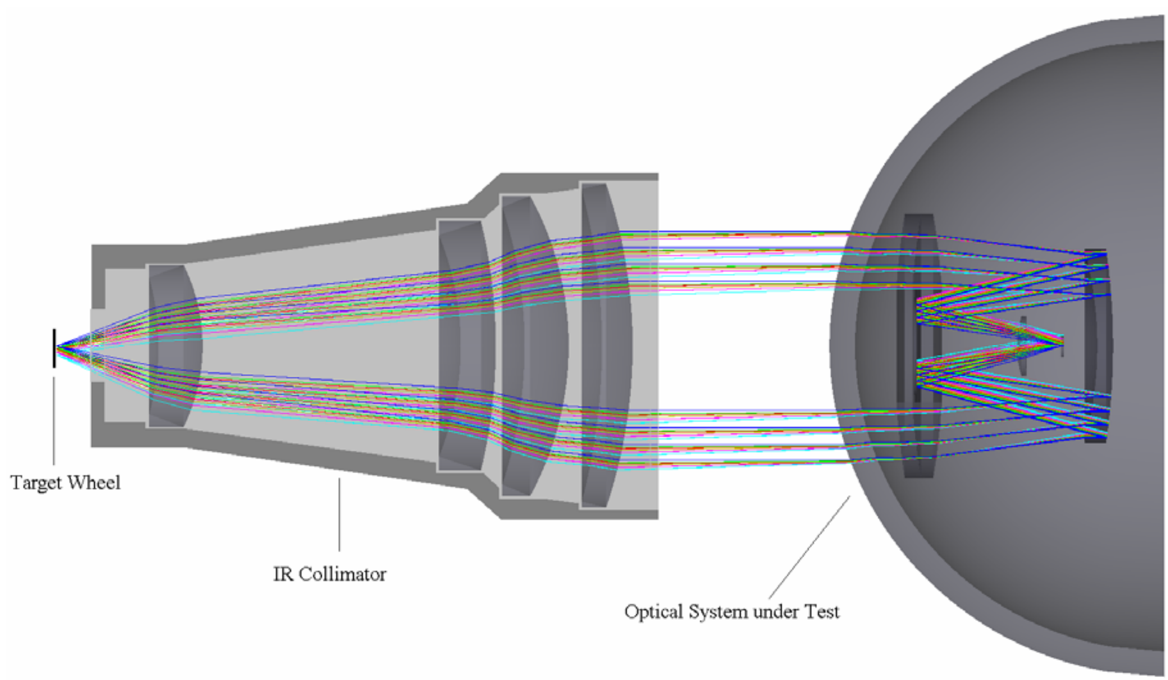
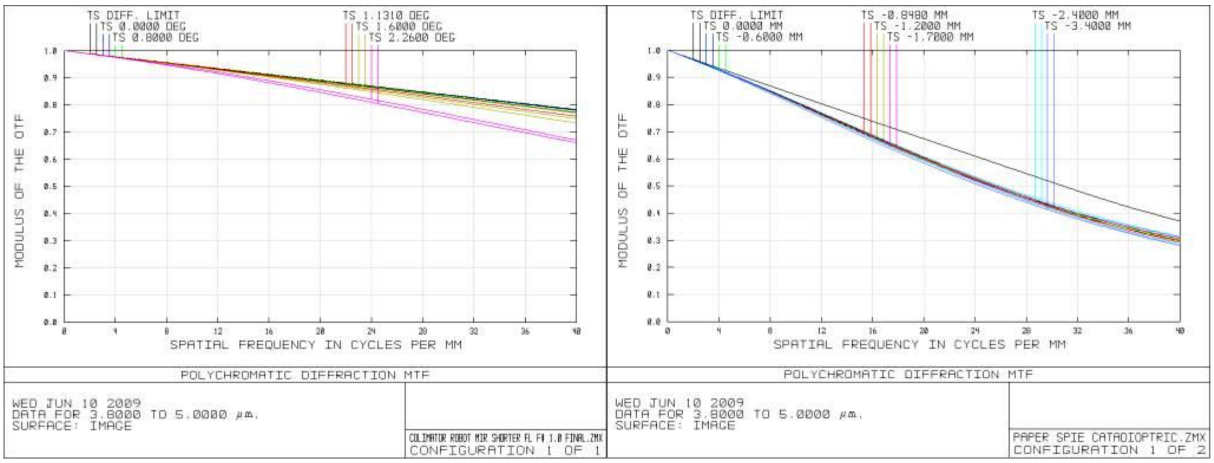


Figure 7 – IR collimator and system under test for the HILS

To simulate far and close targets, a pinhole located at the back of the IR collimator is adjusted. To simulate the radiation emission, an initial approach is to use a soldering iron with temperature on the focal plane of the collimator. If the pinhole size is increased, so is the image size and it simulated a closer target. For a pinhole of about 10mm, full field is available and a very close target can be simulated.

In terms of performance, the collimator designed here is very close to diffraction limit for all fields. Compared to the MTF of the optical system, it is still better in terms of performance. However, the collimator designed here cannot be used for optical evaluation purposes due to its short focal length. The main task is to use it as a tracking target. Both MTF plots can be seen at Figure 8.



MTF IR Collimator **MTF Missile Optical System**

Figure 8 – MTF for the HILS collimator and for the missile optical system

As can be seen at Figure 8, there is a difference in terms of performance when both systems are compared. The IR collimator exhibits a better performance due to its bigger aperture and the absence of an obscuration. The obscuration is necessary for the missile optical system to make it shorter compared to a dioptric system with the same focal length. However, the loss of performance is unavoidable.

4. PRELIMINARY RESULTS

As shown in Figure 9, using an angular frequency of 10 Hz, and acceleration limits between 360 and 540 rad/s^2, which correspond to the torquers' acceleration limits for pitch and yaw axes, respectively. Then, the desired motion could be properly obtained for the gimbaled assembly.

The first two plottings show, respectively, the pitch and the yaw axes movement (position, speed, and acceleration, in this order). For the pitch axis, the flat regions are due to the limitations imposed (in the equationing) not to exceed values imposed by other design restrictions.

As follows, the other two plottings show (1) the scan pattern, as composed by the two axes (having an ideal representation of the area scanned by the sensor), and (2) the same pattern, now having included the scanned area coverage. The coverage's non-symmetric shape is basically due the fact that delays due to discretization/quantization, and the processing actions themselves are inherent to the system, as well as the gimbal's movement shall distort the image then generated.

It is just an initial approach, since other problems must be addressed, like the fly-back to the origin, and the pattern's effectiveness, when seen from the torquers' generated heat point of view. This is not desirable, since the cooler's performance shall be limited, then jeopardizing the sensor's performance.

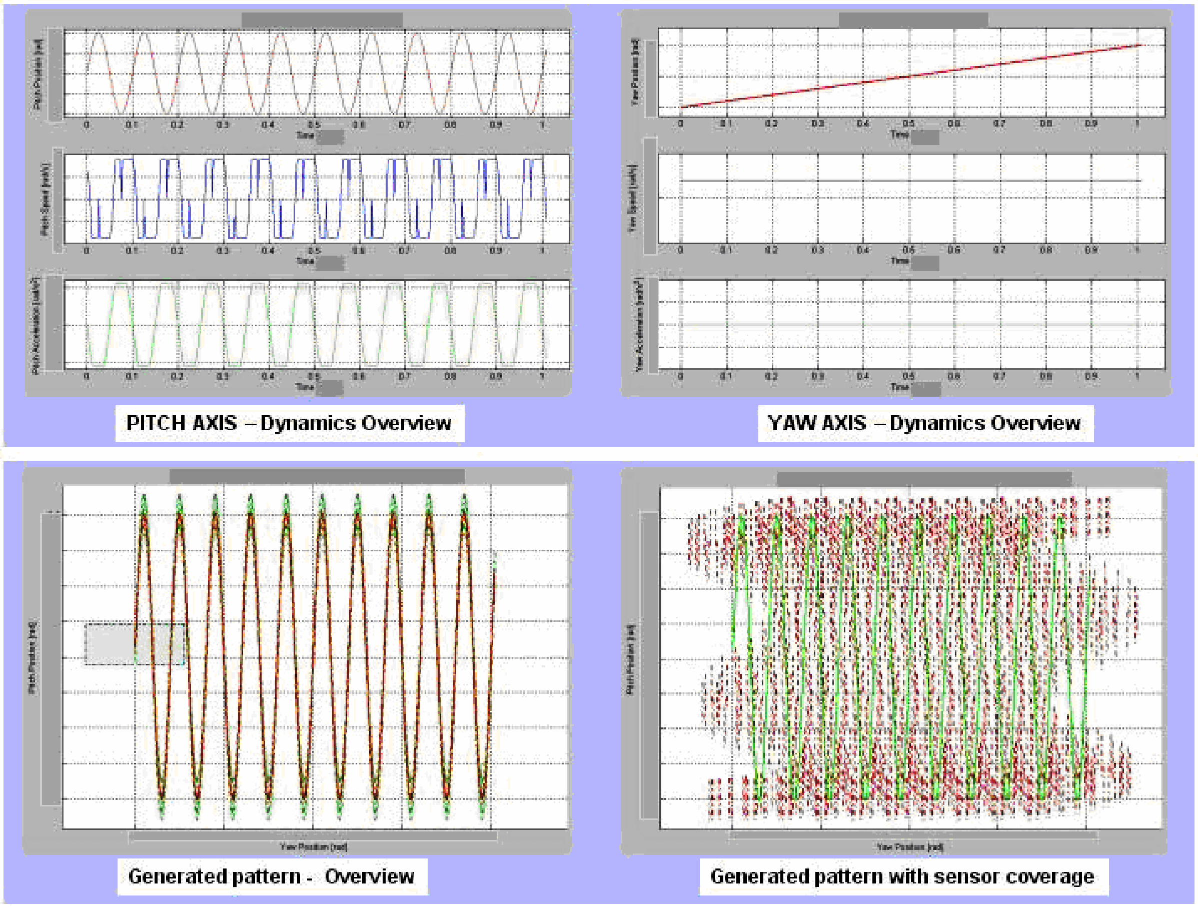


Figure 9 – Schematics for the considered gimbaled assembly

4. CONCLUSION

In this paper an example of the implementation of the hardware in the loop simulation was presented including some preliminary results. The main concept of this work is to show that HILS can be used in the development phase of this air-to-air missile with very good results. HILS is not only a developing tool, but a concept for system developing.

The implementation of a system like this one is not simple and it is necessary a multi-disciplinary interaction among areas like control systems, mechanics, optics and programming. A more detailed overview and description about this system will be given in the next version of this work.

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