Aselsan Infrared Seeker Development Studies

Infrared seekers are missile subsystems that use the infrared (IR) light emission from a target and its background to detect and track it until the target is destroyed. Since the operational requirements (target/background, mission scenarios, etc.), environmental conditions (aerothermal effects, natural background radiation, in-flight vibration values, etc.), and design limitations (weight, power, activation time, etc.) of seekers are extremely challenging compared to other thermal imaging systems, system and subsystem level design processes must be carried out according to the specific missile applications.

Infrared Seeker Technologies

Since the infrared seekers are located at the nose of the missile, they are highly exposed to the harsh conditions of the missile. Some of the factors that make infrared seeker design generally challenging are [1]:

- Very high acceleration and vibration levels due to high speeds and maneuvers,
- High-speed movements of the targets,
- Very short activation/arming time,
- Missile dome heating due to high speeds and maneuvers,

These challenging conditions and specifications require the use of very special techniques and technologies in infrared seeker design.

Stabilization

During the flight, aerodynamic forces create angular vibration effects on the seeker. To eliminate the effects of these vibrations on the image, the seeker is stabilized using a gimballed structure with a gyroscope that measures inertial speeds.

In addition to the high angular vibrations on the seeker, other factors such as:

- High gimbal speed requirements due to the high speed of the missile and the target,
- Wide field-of-view (FoV) requirements,
- Volumetric limits of the missile,

also require a specialized gimbal design.

Image Frequency and Image Blurring

Since both the missile and the target are extremely fast, the image acquisition frequency must be very high, and the rendering time must be very low. In order to acquire a clear image and prevent motion blur, the missiles should be equipped with thermal cameras with a higher image frequency rate than the infrared cameras used in land vehicles.

Since motion blur makes it almost impossible to detect and track targets, it significantly reduces lock-on range. High image frequency requires a high-performance infrared sensor, high processing power, and parallel processing capabilities.

Short Seeker Activation Time

When the threat is detected, the missile should be ready to fire in a very short time. In addition to activating the missile's electronic equipment, one of the most crucial processes that take time before firing is the infrared sensor's ability to provide an image that meets the mission's performance requirements. The time required for this process differs according to the sensor specifications, as well as the use of cooled or uncooled infrared sensors. Sensor temperatures must be lowered to cryogenic levels for the cooled infrared sensors to detect a target. Accordingly, either Joule Thomson (JT) type or Stirling type cooling technologies are used in infrared seekers.

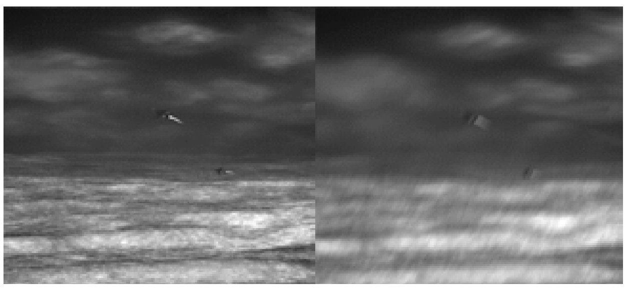

Figure-1 Difference between stabilized (left) and blurred (right) image.

Dome Heating (Heat Flux) and Thermal Shock

The high speed of especially the air defense missiles can cause the missile dome to reach extreme temperatures in a very short time during the flight. The missile's high speed not only heats the seeker dome but also creates a hot air wall in front of the missile by compressing the air in front of it. The hot and compressed air also acts as an optical lens. This can be summarized as trying to see a target that is miles away from behind a very hot wall with a heat-sensitive sensor. These aerothermal conditions cause very high disruptive effects on the seeker, such as:

- Extreme noise and infrared radiation (IR) on the sensor,
- Loss of image clarity as a result of the change in the refractive indices of the dome and lenses,
- Rapid heating of the missile seeker components.

Aselsan carries out dome heating, radiation, and optical analysis studies during the development process of its infrared seekers as well as designs high-performance electro-optical parts using special components, methods, and technologies.

Figure-2 The effects of dome heating on the image.

Especially in air defense applications, dome heating (heat flux) requires the development of a special sensor that can withstand thermal shock and optical lens design that is not affected by temperature change.

Seeker Algorithms

Depending on the mission requirements, the image processing capabilities of the infrared seeker can include target detection, target tracking, and countermeasure detection.

After the target is detected, the tracking algorithm is activated. The tracking algorithm follows the target by fusing both image and inertial data. Since tracking is accomplished using multiple target windows and motion models of these windows, it is both reliable and adaptable to different flight stages. A countermeasure detection algorithm is also run simultaneously to prevent deception during the tracking phase.

Within the scope of infrared seeker development, previously developed Software-in-the-Loop (SIL) and Hardware-in-the-Loop (HIL) systems are used within Aselsan MGEO for the development, parameter optimization, and testing of image processing algorithms. These systems are used to model the target, background, atmosphere, and hardware units. Thanks to the software-in-the-loop infrastructure, all algorithms can be developed in parallel without waiting for the hardware design to be finalized; also, the maturity level and performance of the software can be increased before the highly expensive real tests.

Infrared Detector

One of the most critical sub-components that determine the infrared seeker performance is the capabilities of the infrared sensor used. Infrared sensors are used in various systems such as Forward-Looking Infrared (FLIR) cameras, PODs, Missile Seekers, and Tank Fire Control Systems to detect threats and increase mobility in adverse conditions such as night, fog, dust, and smoke where visibility is poor.

In missile applications where response time and sensitivity are highly vital, the infrared sensor's quality directly influences the missile seeker's performance.

The type of sensor to be used in the seeker is determined by the wavelength range at which the target will be detected, the response time needed, and the sensitivity of detection. Critical sensor parameters affecting seeker success are:

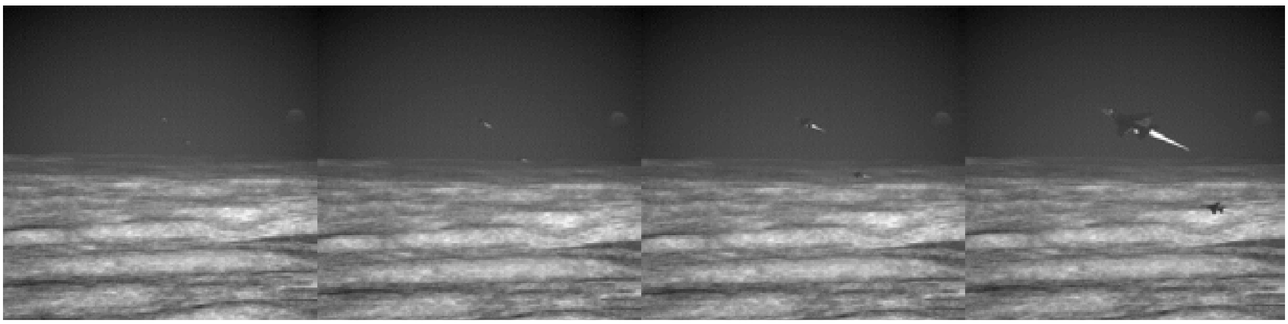

Figure-3 Infrared seeker image of an air defense missile approaching the target.

Detection Wavelength: When selecting the detection wavelength, it is necessary to prioritize the requirements, such as the signatures of the targets and the operating temperature of the sensor.

Sensor Array Format: The sensor array format is a parameter that directly affects the seeker detection range. Increasing the sensor array format, just like the pixel pitch and field-of-view, improves the detection range. On the other hand, the expanded sensor array format also increases the sensor area, increasing the optomechanical carrier volume to be placed inside the sensor and, consequently, its thermal mass. Optimum sensor array formats should be used according to the mission requirements to meet the system's activation time and range needs.

Sensor Pixel Pitch: As the sensor pixel pitch grows, the Signal/Noise ratio of the pixel also increases. Between two systems with the same resolution and field of view, the system with the larger sensor pixel pitch can detect targets at greater distances. However, since increasing the pixel pitch also increases the sensor area, this will also increase the volume and thermal mass of the optomechanical carrier. Therefore, it is necessary to use sensor arrays with optimum pixel pitch that will meet both the time and volume needs determined by the main system requirements and the maximum detection distance.

Sensor Performance: Infrared sensors to be used in missile seekers must have appropriate wavelength detection, resolution, and pixel pitch features and should also be able to meet very high-performance criteria. Important performance criteria for infrared detectors are:

Quantum Efficiency: Quantum Efficiency can be defined as the possibility of photons collected by the sensor to be converted into electrons. High quantum efficiency allows the sensor to be used at both high speeds and low background radiation.

NETD (Noise Equivalent Temperature Difference): NETD can be defined as the smallest temperature difference that the infrared sensor can detect. As the NETD value decreases, the performance of the sensor increases at the same rate.

Reading Circuit: The reading circuit, which will be integrated into the infrared sensor, should have features that can meet the main system reirements. The most important of these features are:

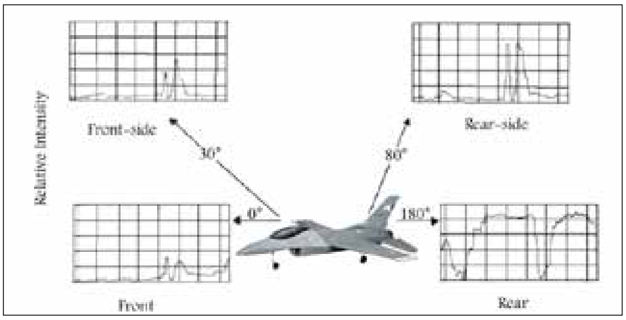

Figure 4: Infrared signature spectrum of a fighter plane [2]

Image Speed: The reading circuit and the sensor array to be integrated into the reading circuit should be able to support and operate at higher frame rates due to the high missile and target speeds.

Reading Circuit Load Capacity: The heating of the dome (heat flux) indicates that the infrared sensor is entirely exposed to emissions that do not contain any target information. If the reading circuit does not have enough load capacity to hide the radiation from the dome and reaches saturation, the emissions from the target will not be detected, and as a result, target detection and tracking will be impossible. Therefore, the reading circuit must have a very high load capacity, and non-standard techniques should be used in the entire circuit design to achieve this goal.

Conclusion

Started with the production of the infrared seekers of the Stinger missiles and continued with the domestic and national development of infrared seekers of antitank weapons and air defense missiles, Aselsan acquired the skills, experience, and infrastructures in the field of seeker technologies that only a few countries have in the world.

The outputs of cutting-edge seeker development activities of Aselsan are also used in technologies and products developed in other fields such as electro-optics, microelectronics, and avionics