Infrared and Electro-Optical Considerations in Electronic Warfare

The object of electronic warfare is to deny an enemy the benefits of the electromagnetic spectrum while preserving those benefits for our own forces. It is easy to fall into the trap of considering only the radio frequency part of the electromagnetic spectrum, but there is a significant amount of EW effort in the IR, visible light, and ultraviolet parts of the electromagnetic spectrum. In this chapter, we will deal with the general nature of these parts of the spectrum, the systems that operate in this range, and the nature of the countermeasures against those systems.

4.1 The Electromagnetic Spectrum

Figure 4.1 shows the portion of the electromagnetic spectrum that is of most interest to the electronic warfare field. Although we typically use frequency to define the RF portions of the spectrum, it is more common to use wavelength at the higher frequencies. Note that wavelength and frequency are related by the speed of light in the formula:

\[ c = f \lambda \]

where

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\( c = \) the speed of light \((3 \times 10^8 \text{ m/s})\);
\( f = \) frequency (in hertz);
\( \lambda = \) wavelength (in meters).

Frequencies below 300 GHz (i.e., wavelengths longer than 0.1 cm) are in the radio frequency range. Above that frequency, we’ll only talk about the wavelengths. The common unit of wavelength is the micron \((10^{-6} \text{ meter})\) which is abbreviated \(\mu\). At very short wavelengths, angstroms are used \((10^{-10} \text{ meter}, \text{ abbreviated } \AA)\).

- From about 30\(\mu\) to about 0.75\(\mu\) is the infrared region;
- From about 0.75\(\mu\) to about 0.4\(\mu\) is the visible light region;
- From about 0.4\(\mu\) to about 0.01\(\mu\) is the ultraviolet region;
- Shorter waves than these are X-rays and gamma rays (these regions overlap).

### 4.1.1 Infrared Spectrum

The infrared region is generally divided into four more definitive ranges:

- The near infrared wavelength range starts at the upper edge of the visible light region (about 0.75\(\mu\)) and ends at 3\(\mu\).
- The middle infrared range is from 3\(\mu\) to 6\(\mu\).
- The far infrared range is from 6\(\mu\) to 15\(\mu\).
- The extreme infrared range has wavelengths greater than 15\(\mu\).
In general, hot targets emit most of their IR energy in the near-IR region. This includes the rear aspect view of a jet engine (looking up into the engine). Most of the Sun’s IR energy is also in the near-IR range. Slightly cooler targets (such as hot metal parts on the exterior of a jet engine and the jet engine’s plume) emit most of their IR energy in the mid-IR region. Objects in the normal range of temperatures (i.e., the skin of aircraft and other vehicles, clouds, and the Earth) emit in the far-IR region.

4.1.2 Blackbody Radiation

A blackbody is a theoretical ideal IR radiator very useful in the study of IR systems and countermeasures. While there are no true “blackbodies,” everything that emits IR energy does so in a pattern similar to that of the blackbody model. IR radiation is stated in watts per cm$^2$ $\mu$m$^{-1}$. The IR emissivity of real-world materials is defined in terms of a percentage of blackbody radiation at a given temperature. Generally, the emissivity values vary from 2% to 98%. Typical examples of emissivity are: polished aluminum 5% at 100°C, average color paint 94% at 100°C, snow 85% at –10°C, and human skin 98% at 32°C.

The blackbody radiation versus wavelength is a function of the temperature of the emitter. As shown in Figure 4.2, there is considerably more energy under the curves for higher temperatures. The total energy varies as the fourth power of temperature. Also, the peaks of the curves move to lower wavelengths as the temperature increases. Figure 4.3 shows a logarithmic curve of radiation.

![Figure 4.2](image)

**Figure 4.2** Radiation from a blackbody has a distinct radiation-versus-wavelength distribution based on its temperature.
versus wavelength for lower temperatures. Note that the curves in the two blackbody figures are for temperatures in degrees kelvin, so 300° is about room temperature. An interesting point is that the surface of the Sun is about 5,900K, which causes its radiation to peak in the visible light spectrum (convenient for those of us with eyes that operate in that range).

4.1.3 IR Transmission

Figure 4.4 shows the relative IR transmission through the atmosphere as a function of wavelength. Note that there are absorption lines from various atmospheric gasses, but there are major transmission widows in the near-, mid- and far-infrared ranges.

In IR transmission, the spreading loss versus range is calculated by projecting the receiving aperture from its range onto a unit sphere around the transmitter as shown in Figure 4.5. The spreading loss is then the ratio of the amount of the surface of the unit sphere covered by the image of the receiving aperture to the whole surface area of the sphere. This is actually the same way we calculate spreading loss for RF signals. However by assuming isotropic antennas we get range and frequency terms in the RF equation.

4.1.4 EW Applications in the IR Range

EW systems and threats receive IR energy to detect, identify, locate, and guide missiles to radiating objects. Examples of these systems and threats are: IR line scanners, forward looking infrared (FLIR), and IR-guided missiles.
There are, of course, countermeasures to all of these systems. Sensors can be blinded (temporarily or permanently) and IR-guided missiles can be defeated by flares or IR jammers.
4.1.5 Electro-Optical Devices

We are making a somewhat arbitrary distinction between IR and electro-optical (EO) devices to isolate devices receiving radiated IR energy from the rest of the field of interest. Some of these EO devices operate in the infrared spectral range. EO systems and applications (and their countermeasures) discussed in this chapter include:

- Laser communication;
- LADARs;
- Laser range finders;
- Laser designators for missile attack;
- Imagery-guided missiles;
- High-power laser weapons;
- Low-light television;
- Daylight television.

4.2 IR Guided Missiles

IR-guided missiles have been among the most deadly threats in all recent conflict. They are primarily air-to-air missiles and surface-to-air missiles, and include small, shoulder-fired weapons. An IR missile detects the IR signature of an aircraft (against a cold sky) and homes on energy in one of the three IR bands. Early IR missiles required high-temperature targets, so they needed to see the hot internal parts of jet engines to achieve good performance. Therefore, they were usually restricted to attacks from the rear aspect of jet aircraft. More recent missiles can operate effectively against cooler targets (the plume, the tailpipe, heated leading edges of wings, or the IR image of the aircraft itself). This allows them to attack all types of aircraft from all aspect angles.

4.2.1 IR Sensors

Original missiles used uncooled lead sulfide (PbS) detectors that required targets in the 2 to 2.5 micron range (near IR band). This type of missile suffered from considerable solar interference and severely restricted air-to-air tactics.

More modern seekers use sensors of lead selenium (PbSe), mercury cadmium teluride (HgCdTe), and similar materials that operate in the mid- and far-IR bands. While these seekers allow all aspect attack, they require that the sensors be cooled to about 77K with expanding nitrogen.
4.2.2 IR Missiles

Figure 4.6 is a diagram of an IR-guided missile. The nose of the missile is an IR dome. This is a spherical protective covering for the seeker optics, made from a material that has good transmission of IR energy. A seeker senses the angular location of the IR source and hands-off error signals to the guidance control group, which steers the missile toward the target by control commands to the rollerons.

Figure 4.7 is a diagram showing the functions of a simple IR seeker (in a cross section). There are two mirrors (a primary and a secondary reflector) that are symmetrical around the optical axis. They focus energy through a reticle onto an IR sensing cell. Not shown in the diagram is the filter that limits the spectrum of signals passed through the reticle—and the sensor cooling if required.

A simple, spinning reticle pattern is shown in Figure 4.8. Often called the “rising sun” pattern, it rotates around the optical axis of the seeker. The top half of this reticle is divided between very low and very high transmission segments. An IR target is shown in one of the high transmission segments. The other half of the reticle has 50% transmission. This reduces the dynamic range required of the IR sensor. As the reticle rotates, the IR energy from the target onto the IR sensor will vary in the partial square wave pattern shown in Figure 4.9. The square wave portion of the waveform starts as the upper half of the reticle starts to pass the target. Since the sensor knows the angular position of the reticle, it can sense the direction to the target from the timing of the square wave portion.

Figure 4.6 A heat-seeking missile is guided by input from an IR sensor.

Figure 4.7 The IR seeker focuses received IR radiation on a sensing cell through a reticule.
of the waveform. This allows the guidance group to make corrections to steer the missile toward the target.

Figure 4.10 shows the amount of maximum signal power as a function of the angular offset of the target from the optical axis of the sensor. When the target is near the center, the high-transmission segment does not admit the whole

Figure 4.8 The reticule modulates energy from a target heat source as a function of its position relative to the seeker.

Figure 4.9 The rotating reticule creates a pattern that allows determination of the correction direction toward the heat source.

Figure 4.10 The error signal from the reticule in Figure 4.8 flattens as soon as the high-transmission segment is wide enough to pass the whole target.
target. As it moves farther from the center, more of the target is passed. Once the whole target is passed, the peak energy level to the IR sensor does not increase more. This means that the sensor only provides proportional correction inputs when the target is quite near the center of the reticle. It also means that the seeker has no way to discriminate against a high-energy false target near the outer edge of the reticle.

Figure 4.11 shows a nonrotating reticle with a “wagon-wheel” pattern. To generate steering information, the energy entering the seeker is nutated to move it around the optical axis. If the target is on the optical axis, it will cause a constant amplitude square wave of energy to reach the sensor. However, if the target is off center, its image will move in the offset circle shown in the figure. This causes the irregular square wave form shown at the bottom of the figure. The control group can then determine that the missile must steer in the direction away from the narrow pulses.

Figures 4.12 and 4.13 show two of the many types of more complex reticles. Figure 4.12 shows a multiple frequency spinning reticle. Since there are different numbers of segments in each of several rings, the number of pulses seen by the sensor changes as a function of the angular distance from the optical axis to the target. This supports proportional steering. Figure 4.13 shows a spinning reticle with curved spokes to discriminate against straight-line objects (like the horizon) and has a different numbers of spokes at different offset angles for proportional steering.

To avoid extremely high g forces on a missile as it reaches its target, missiles use proportional navigation as shown in Figure 4.14. If the aircraft and the

Figure 4.11 The “wagon-wheel” reticule remains fixed, while the image of a fixed target is nutated, causing an irregular pulse pattern when the target is away from the optical axis.
Figure 4.12 The multiple-frequency reticle has different numbers of segments at different distances from the center of rotation.

Figure 4.13 The curved spokes discriminate against straight-line objects.

Figure 4.14 Proportional navigation allows the missile to intercept the target with minimum g forces.
missile are both at constant velocity, a constant offset angle ($\theta$) between the missile’s velocity vector and the optical axis of its seeker will cause an optimum intercept. If either is accelerating (e.g., the target is taking evasive action) corrections must be made to return the missile to the proper offset angle.

### 4.3 IR Line Scanners

The infrared line scanner (IRLS) is one of several IR devices that are useful in various types of reconnaissance applications. The IRLS provides an IR map of a covered area. It is mounted on a manned aircraft or unmanned aerial vehicle (UAV) which flies a fairly low-level path over an area of interest. The IRLS makes a two-dimensional image by scanning an IR detector over an angular increment across the ground track of the vehicle while the second dimension is provided by the movement of the platform along its ground track.

#### 4.3.1 Mine Detection Application

There are a number of military and civil IRLS applications, but the nature and limitations of the IRLS can be well understood from its use in the detection and location of buried mines. This approach to mine detection is practical because buried mines will gain or lose heat at a different rate than the surrounding soil (or sand). Thus, the mines will be at a different temperature during times of temperature change, for example, right after sunset. However, the resolution of the IR sensor must be adequate to differentiate the temperature of the mine from that of the soil, and it must have adequate angular resolution to differentiate mines from other buried objects, for example, rocks.

##### 4.3.1.1 An Example

Let’s assume that a buried mine is about 6 inches in diameter, but that the sensor must have a resolution capability of 3 inches to identify mines with adequate accuracy. Furthermore, let’s assume that the aircraft or UAV is flying at 100 nautical miles per hour (knots), and that the IRST scans a 60° segment across the ground trace as shown in Figure 4.15. Finally, let’s assume that the IR sensor has a 0.25-mrad aperture and that the IR energy level is digitized with 8 bits. This high resolution will be required because the soil can have a relatively wide temperature range and post mission analysis will probably be required to find the relatively narrow temperature difference between the mine and the soil anywhere in this range.

First, let’s determine how high the aircraft can fly and still get the necessary 3-inch resolution from its sensor. The altitude required is:
Ground resolution distance versus $\sin(\text{sensor aperture angle})$

At a 0.25-mrad aperture angle, we achieve a 3-inch resolution at 1,000 feet. Figure 4.16 shows the ground resolution versus altitude for a quarter-milliradian sensor instantaneous field of view.

The vehicle can fly at any speed, but the sweep rate must be fast enough to make one cross-track sweep every 3 inches along the flight path. At our chosen speed, 100 knots, the vehicle travels over the ground at 169 feet per second:

$$100 \times \left( \frac{6,076 \text{ ft/hr}}{3,600 \text{ sec/hr}} \right) = 169 \text{ ft/sec}$$

Figure 4.15 A manned aircraft or UAV is here searching a swath along its ground trace with an IR sensor to detect mines as small as 6 inches. It is traveling at 100 knots, 1,000 feet above the ground.

Figure 4.16 The ground resolution provided by a 0.25-milliradian sensor is shown as a function of altitude above the searched terrain.
One sweep per 3 inches requires 4 sweeps per foot or 676 sweeps per second at 100 knots.

The sampling of the IR sensor must also be performed for every 3 inches of movement of the sensor over the ground in the crosstrack sweep. The width of the cross-track ground coverage (the swath width) is:

\[ 2 \times \sin \left( \frac{1}{2} \times \text{scan angle} \right) \times \text{altitude} = 2\sin(30^\circ) \times 1,000 \text{ ft} = 1,000 \text{ ft} \]

A sample each 3 inches requires 4,000 samples per scan. The sample rate is then \( 676 \times 4,000 = 2.7 \text{ million samples per second} \). At 8 bits per sample, this produces a data rate of 21.6 Mbps. With a typical 16% data overhead, this becomes 25 Mbps.

The ratio of velocity to altitude (V/H) is an operational parameter that effects the required data rate. It is stated in radians per second. To understand this choice of units, consider observing the aircraft from a fixed point below it on the ground. Remember that a radian is the angle observed from the center of a circle for one radius along the circumference of a circle. Thus the subtended angle-per-unit time, converted to radians, would be equal to the velocity divided by the radius (i.e., the altitude over the ground). Figure 4.17 shows the altitude to velocity relationship for a V/H of 0.174 rad/sec (which holds the ground resolution distance at 3 inches and minimizes the altitude at the specified data rate for a particular mine resolution payload).

Figure 4.18 shows the data rate required to recover mine resolution data over a 60° swath width as a function of altitude and vehicle speed. As you can see from this typical example, the detection of buried mines requires an airborne platform that flies low and slow, and the collection and analysis of a great deal of data. Detection of larger objects (for example, tanks in underground bunkers) would require less angular resolution. This will allow operation at higher
altitudes and speeds and/or large swath widths. However, a high-data rate should always be expected for IRLS applications because of the fine temperature resolution and large temperature range required. If the vehicle is unmanned, or for any other reason the data is linked to a ground station, a wide data link will be required.

4.4 Infrared Imagery

Imagery involves the capture and display of a two-dimensional picture. This can be in the visible light wavelength range (television) or it can be in a nonvisible wavelength range. Our concern here is imagery at infrared wavelengths. For all electronically implemented imagery, the displayed picture is divided into pixels. A pixel is a spot on the screen; there must be enough pixels to create the picture to the required quality. The system captures and stores the brightness or the brightness and color to be displayed in each pixel—then displays the appropriate values at each pixel location on the screen. The screen display can be generated with a raster scan as shown in Figure 4.19, or by an array as shown in Figure 4.20.

If an imagery system is mapping the ground, the relationship between the pixels and the resolvable distance on the ground would be as shown in Figure 4.21. If the system is looking level or up, the same relationship applies, but the resolvable distance is a function of the range to the individual objects being observed.

4.4.1 The FLIR

A forward-looking infrared (FLIR) system captures and displays a two-dimensional temperature field. It operates in the far-infrared region, where
Figure 4.19 A raster scan covers a two-dimensional field. The spacing of pixels on each line is approximately the same as the line spacing.

Figure 4.20 A picture can be formed from a group of display points, for example liquid-crystal-display segments. Each element provides 1 pixel.

Figure 4.21 Each pixel in an imagery display (or raster) represents one resolvable distance at the range of the object being observed.
everything emits infrared energy. By differentiating the temperatures of objects and backgrounds, the FLIR allows an operator to detect and identify most common objects. The display is monochromatic, with the brightness level of each pixel indicating the temperature at that position in the observed field. FLIRs have some advantages over visible-light TV systems in that they can operate day or night. Also, because they differentiate between objects by temperature or IR emissivity, they can often see objects of military significance that are hidden from visible-light TV by foliage or camouflage.

FLIRs can use serial or parallel processing, or two-dimensional IR arrays as shown in Figure 4.22. With serial processing, the FLIR uses mirrors to scan the orientation of a single IR sensor across a two-dimensional field of view in a raster scan. The whole scene is presented on a CRT. Pixels are defined by the number of samples in a scanned line and the spacing between parallel lines. With parallel processing, a row of detectors is scanned through an angular segment to provide two-dimensional area coverage. Each element of the sensor array takes a series of measurements, so the pixels are defined by the number of elements and the number of samples in a scanned line (by each sensor). A two-dimensional array

Figure 4.22 (a) A serial-processing FLIR scans a scene with two mirrors to sequentially focus a raster pattern onto a single IR sensor. (b) A FLIR using parallel processing scans a linear array across a scene with a rotating mirror to generate a series of pixels in each sensor. (c) A FLIR using a two-dimensional array of IR sensors instantaneously captures the whole scene being viewed.
captures all of the covered area at once, with each pixel being captured by an array element.

The data rate produced by a FLIR is the product of the number of pixels in a frame (the two-dimensional angular area covered), the number of frames per second, and the number of bits of resolution per sample. Note that one sample is made per pixel.

### 4.4.2 IR Imagery Tracking

Some modern surface-to-air missiles use imagery guidance. In this approach, the area near the target is observed by a two-dimensional IR array operating in the far-IR region. You will recall that objects at moderate temperatures emit in this region, so the array can observe the contrast between the warmer aircraft and the colder sky. A processor will observe the shape of a number of pixels from the array that show the proper contrast (see Figure 4.23). It will then determine that this pixel distribution qualifies as the target and steer the missile in the corresponding direction. Only a few pixels are required to determine the general size and shape of a target and to differentiate it from a much smaller decoy (as opposed to the large number of pixels required to give a high-quality picture).

### 4.4.3 Infrared Search and Track

Infrared search and track (IRST) devices are used on aircraft and ships to detect hostile aircraft. An IRST does not use imagery, but rather looks for a warmer spot target against a cold background. It sweeps a large angular area with an IR sensor array as shown in Figure 4.24. It detects IR targets while rapidly covering its angular range. Then, it develops the necessary data to hand off target tracking information to sensors.

![Figure 4.23](image)

Figure 4.23 An imaging guidance system differentiates the target it is tracking based on a few pixels.
4.5 Night-Vision Devices

Operation Desert Storm started on the night of January 15, 1991. The reasoning behind the decision to start the operation on that particular date no doubt included complex political and military considerations. However, when you consider that the dark of the Moon occurred on this date, it is obvious that one important factor was the ability of the coalition forces to operate in total darkness while the Iraqis could only bring their full military capability to bear during daylight.

The coalition forces had significant numbers of night-vision devices deployed through their forces and had adequately trained them in their tactical application. These night-vision devices were the product of three generations of development and were completely passive, amplifying very low levels of available light—even on moonless nights with cloud cover.

4.5.1 Types of Devices

Night-vision devices include low-light-level television (L³TV), viewers for drivers of trucks and tanks, weapon sights, and night-vision goggles for aircrew and ground forces. These devices are different from FLIR devices in that FLIRs receive infrared energy emitted by objects—while night-vision devices amplify available light reflected from objects. The FLIR can operate in total darkness, while night-vision devices require some (though very little) available light.

Light amplification devices have the advantage of being less expensive than FLIRs, and thus available for much wider distribution. Also, since they operate in the optical region, they present the clues necessary for maneuvering of aircraft and ground vehicles and for the movement of troops over terrain. However,
since night-vision devices provide no peripheral vision, they require significant training for effective tactical use.

4.5.2 Classical Night Operations

Night operations have always been a part of military action, but they have depended on stealth and the extension of the senses of personnel. For example, consider one of every infantry basic trainee’s least favorite training exercises—the infantry platoon in the night attack. The procedure was to maneuver as close to the enemy as possible through the dark. Troops moved single file, each soldier following the luminous strips stapled to the back of the hat of the individual ahead of him in line. The night vision of the troops was carefully guarded by using only red lights to read maps. Troops were trained to keep their eyes moving and to use their peripheral vision (which is more sensitive to light). If you stared directly at an object in the dark (as required to fire a rifle), it would fade out of your vision. Ideally, the troops could sneak close enough to the enemy to move into a final assault line (troops abreast facing the enemy) before being detected. Then artillery-fired flares would light up the battlefield allowing daylight tactics to be used (and completely destroying the night vision of everyone involved).

With modern night-vision devices, troops can move fast and fire with complete accuracy in complete darkness.

4.5.3 History of Development

Before the development of light amplification devices, there were so-called “sniper scopes” which used IR spotlights and IR sensing scopes to fire weapons in “total darkness” (meaning that there was no light that could be sensed by the naked eye). Troops were warned to turn the scope on before the spotlight so they could see any spot lights that were on—and shoot the unlucky enemy who had his light on. You can see a major disadvantage to those devices—which were also used on tactical vehicles.

During the Vietnam War, first generation light amplification devices (called starlight scopes) were used. These could provide a few hundred yards visibility, but emitted an audible “whine” and would “bloom” blanking the entire image when a bright light source was present.

Second generation technology (in the 1980s) included helmet-mounted goggles for helicopter pilots along with sights for rifles and crew-served weapons. These devices provided increased range and rapid recovery from light saturation. However they had short tube life and were subject to saturation by cockpit
lighting. Blue/green instrument lighting and a corresponding filter in the goggles were required to prevent this saturation.

Third generation technology provides increased sensitivity, reduced size, improved tube life, reduced blooming, and visibility extension into the near-infrared region. The IR capability allows night vision goggles to see 1.06-micron laser designators.

### 4.5.4 Spectral Response

Figure 4.25 shows the relative response (versus wavelength) of the human eye as compared to the response of second and third generation light amplification devices.

### 4.5.5 Implementation

Figure 4.26 shows the operating principle of first generation light amplification devices. Light falling on specially coated electrode screens (dynodes) causes

![Figure 4.25](image)

**Figure 4.25** Third generation night vision devices operate in both the visible and the IR ranges.

![Figure 4.26](image)

**Figure 4.26** First generation light amplification devices amplify in dynodes.
electron emissions which are accelerated in a vacuum by high voltage and kept focused by magnetic fields. These accelerated electrons are converted back to optical images by impact on a phosphor screen. Three stages were required to achieve the required amplification.

Figure 4.27 shows the operating principle of second generation devices. They use a combination of vacuum devices and microchannel plates to achieve the necessary gain.

Microchannel plates are pieces of glass with the order of $10^6$ lead-lined holes. Electrons impact the walls of the tubes and dislodge secondary electrons. The secondary emission causes approximately $3 \times 10^4$ exit electrons for each primary electron. These secondary electrons are accelerated and focused on a phosphor screen for viewing.

Third generation devices achieve all amplification in microchannel plates as shown in Figure 4.28. The tubes are angled to assure impact of the primary electrons with the lead lining of the tubes.
4.6 Laser Target Designation

Laser designators and range finders have long been used against fixed and mobile ground targets, and now are also significant threats to helicopters and fixed-wing aircraft.

4.6.1 Laser Designator Operation

When a laser illuminates a target, there is significant energy in the scintillation of laser energy from the surface of the target. A missile with a laser receiver can home on this scintillation, allowing extremely accurate target engagement. Normally, the laser illuminator (called a designator) is coded, improving the ability of the receiver in the missile to discriminate against sun glint and other interfering sources of energy.

The missile must have some sort of guidance scheme (multiple sensors, moving reticule, and so forth) to provide angular error signals for guidance to the target. Its receiver is designed to accept only laser energy at the wavelength of the designator. Its processing circuitry qualifies on the proper coding and converts the angular error signals into guidance commands.

As shown in Figure 4.29, the designator need not be located on the attacking platform. In this case, one aircraft or UAV places the designator on the target and tracks the target if it is moving. A second aircraft fires a missile which homes on the scintillation of the designator from the target. The missiles are fire-and-forget weapons, allowing the attacking aircraft to engage multiple targets and leave the area as soon as the missiles are launched. The designating aircraft must remain within line of sight of the target to keep the designator on the target until missile impact.

Figure 4.30 shows a ground-to-ground engagement with laser designation. The attacking platform places a laser designator on the target and fires its own laser homing missile. Line of sight must be maintained during the whole

Figure 4.29 A laser designator placed on a target by one aerial platform allows a missile from a second platform to home on the scintillation from the target.
engagement to keep the designator on the target. However, in some systems, there is a laser on the missile itself. This allows the attack to continue even if the target maneuvers to avoid line of sight to the attacking platform. Note that a laser range finder on the attacking platform can determine an extremely accurate range to the target, providing a very tight firing solution—which complicates the task of any countermeasures approach.

4.6.2 Laser Warning

The first step in defending against laser-designated weapons is to determine that a laser designator has been placed on the targeted asset. This involves the use of laser detection systems as shown in Figure 4.31, which are used on ground mobile and airborne platforms. These systems typically have four or six sensors distributed around the platform. Since each sensor covers 90° from boresight, four sensors will provide 360° azimuth coverage and about ±45° in elevation. This is normally adequate for ground vehicles. Aircraft typically have six sensors, providing roughly spherical (4 steradian) coverage.

Each sensor has a lens which focuses incoming laser signals on a two-dimensional array which locates the direction to the laser to a single pixel (1-pixel-per-array element). Greater location accuracy can be accomplished if multiple sensor outputs are used as elements of an interferometer.

Figure 4.30 A ground mobile weapon can laser designate and fire a homing missile.

Figure 4.31 A laser warning receiver detects the presence of a laser designator, the type of laser, and the direction of the emitter.
The laser-warning receiver processor determines the type of laser received and the direction of arrival. It either passes this information to a radar-warning receiver (which provides an integrated threat display) or drives its own unique threat display. The laser-warning receiver can also support countermeasures against the laser designator or the associated weapons.

If a low-power laser is scanned through the angular space containing the missile (as in Figure 4.32), the laser will pass through the missile receiver’s lens, reflect from the detection array in the missile, and be further enhanced as the reflection passes back through the missile lens to a receiver on the defended asset. By receiving and performing direction of arrival analysis on the reflected signal, the countermeasures system determines the angular location of the missile.

A plume detector is another way that the countermeasure system can locate the missile.

**4.6.3 Countermeasures Against Laser-Homing Missiles**

There are both active and passive countermeasures against laser-homing missiles.

Active countermeasures (see Figure 4.33) include counterfiring against either the missile or the designator. Since the missile location can be determined by either detecting its plume or detection of laser reflection from its homing receiver, a firing solution for a countermissile missile can be generated. The designator must remain within line of sight of the target, so an accurate laser-warning receiver will give a firing solution for a missile to attack the designating platform (ground or air).

The missile can also be attacked electronically by use of a high-power laser which can either dazzle the missile receiver (saturating its sensor) or actually damaging the sensor.

If a lower power laser has a deceptive jamming signal which causes the missile receiver to pass incorrect error signals to the missile guidance, the missile can be caused to miss its target.

![Figure 4.32](image-url) The reflection of a laser from the detector in a hostile receiver is enhanced by passing through the hostile receiver’s lens twice.
Passive countermeasures obscure the target, making it difficult for the targeting platform to track the target and keep the laser properly aimed. Obscuration also reduces the power of the scintillation from the laser if it is on the target. Finally, obscuration reduces the propagation of the laser signal to the receiver in the missile, denying it the necessary error signals for guidance.

Smoke formulated to obscure IR, visible light, or ultraviolet signals is an important countermeasure. Water-dispensing systems on ground targets can also generate dense fog around the protected platform—which effectively obscures a wide range of signal frequencies.

### 4.7 Infrared Countermeasures

Countermeasures to infrared-guided missiles include flares, jammers, decoys, and IR chaff.

#### 4.7.1 Flares

The principal countermeasure against an IR-guided missile has been a high-temperature flare ejected from an aircraft to break the lock of current types of missiles. The flare breaks the lock of the missile onto the aircraft and causes the missile to home on the flare. Although the flare is much smaller than the aircraft it is protecting, it is significantly hotter. Therefore it radiates significantly more IR energy. As shown in Figure 4.34, the missile tracker tracks the centroid of all of the IR energy within its field of view. Since the flare has more energy, the energy centroid is closer to the flare. As the flare separates from the
protected aircraft, the centroid is pulled away. Once the aircraft leaves the tracking field of view of the missile, the missile homes on just the flare.

Newer weapons use so-called “two color” trackers to overcome the energy advantage of hot flares. The black body curves in Figure 4.2 show that there is a unique energy versus wavelength curve for each target temperature. As shown in Figure 4.35, the spectral radiance of the flare (at 2,000K) versus wavelength can have a significantly different shape than that of the tracked aircraft, which has a

![Figure 4.34](image1.png)

**Figure 4.34** A flare has more IR energy than the target, and the missile steers toward the centroid of IR energy in its tracker. Thus, the missile is lured away from the target.

![Figure 4.35](image2.png)

**Figure 4.35** A two-color sensor can determine the temperature of its target by comparing the energy at two frequencies.
much lower temperature. By measuring and comparing energy at two wave-
lengths (i.e., colors) a sensor can in effect determine the temperature of the tar-
get it is tracking. Two-color tracking allows it to discriminate against the hotter
flare and continue tracking the target. This creates a significant increase in the
complexity required of countermeasures. To fool a two-color tracker, it is neces-
sary to either use a large expendable object at the correct temperature or to fool
the missile sensor in some other way to cause it to receive the proper energy ratio
at the two measured wavelengths.

Flares have the disadvantage that they are expendable, therefore limited in
number. Also, since they are very hot, they represent a significant safety hazard
which prevents their use on civilian aircraft.

4.7.2 IR Jammers

IR jammers generate IR signals which attack the guidance signals passed to the
sensors in IR-guided weapons. They provide IR signals similar to those pro-
duced by the IR energy of a target passing through a reticule as described in
Section 4.2. When both the jamming signal and the modulated target energy
signal are received by the missile’s IR sensor, they cause the tracker to produce
incorrect guidance commands.

Optimum use of an IR jammer requires information about the spin-and-
chop frequencies of the missile seeker that is being jammed. This can be meas-
ured by scanning the missile tracker with a laser. The IR detector surface is
reflective, and the lens gives the laser a double advantage (amplifying both on
the way in and on the way back out). As the reticule moves over the sensor (see
Section 4.2), the level of reflected signal will change. This allows a processor to
reconstruct the waveform and phase of the energy pattern reaching the weapon’s
IR sensor.

Once the missile tracking signal is determined, the IR jammer can create
an erroneous pulse pattern as in Figure 4.36 that will cause the missile tracking
signals to produce incorrect steering commands in a manner similar to the effect
of a deceptive RF jammer. Without direct information about the tracking in the
specific attacking missile, generic false tracking signals can also be generated and
transmitted.

The IR jamming signal comprises pulses of IR energy which can be gener-
ated in several ways. One way is to flash a Xenon lamp or an arc lamp. Another
way, as shown in Figure 4.37, is the time-controlled exposure of a mass of hot
material (called a “hot brick”). Mechanical shutters expose the hot brick to gen-
erate the required jamming signal. Both of these techniques produce jamming
signals over a wide angular area for wide aspect protection.
A third way to generate the jamming signal is by use of an IR laser. The laser is easy to modulate and can produce very high level jamming signals, but is intrinsically narrow in beamwidth. Therefore, it must be accurately pointed at the tracker it is jamming. This requires beam steering controlled by an IR sensor with high angular resolution. The sensor typically detects the IR signature of the platform carrying the tracker (e.g., the missile). Because of its high signal levels at the receiver, the IR laser jammer can protect large platforms.

Note that if a jammer located on the protected target fails to deceive the missile tracker, it may act as a beacon to improve the missile tracking accuracy.

### 4.7.3 IR Decoys

IR decoys can be used to draw IR missiles away from protected platforms of any kind. Decoys can be fixed or can maneuver in ways to optimize deception of
weapon trackers. Under some circumstances, they can be larger than flares to provide more energy at lower temperatures.

Decoys radiating the same order of magnitude of IR energy as a fixed or mobile ground asset can saturate enemy targeting capabilities.

### 4.7.4 IR Chaff

If material with a significant IR signature is deployed from an aircraft or from a rocket launched by a ship, it will have much the same protective capability against IR-controlled weapons as radar chaff provides against radar-controlled weapons. IR chaff can burn or smolder to create the proper IR signature or can oxidize rapidly to raise its temperature to the proper level. Since a chaff cloud occupies a large geometric area, it may be more effective against some kinds of tracking. Like RF chaff, the IR chaff can be used either to break a missile lock or to increase the background temperature to make target acquisition more difficult.