IR For Dummies: a brief non-technical introduction to what you can't see

Infrared (IR) Radiation

In everyday life we encounter electromagnetic radiation in many different forms. Visible light, ultraviolet light, radio waves, and X-rays are all examples of electromagnetic radiation, differing only in wavelength. Infrared radiation occupies that region of the electromagnetic spectrum between visible light and microwaves. The figure below shows the major divisions of the electromagnetic spectrum, along with some specific features within the spectrum.

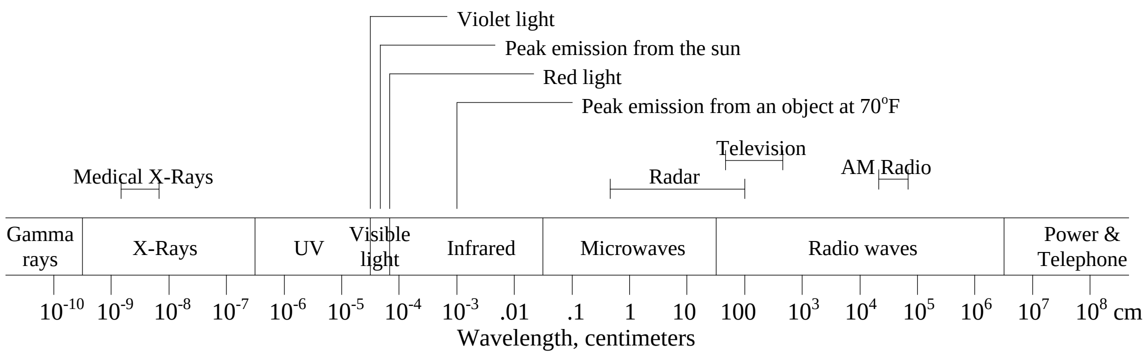

Figure 1. The Electromagnetic Spectrum

All objects constantly emit IR radiation as a function of their temperature. As an object gets hotter, it gives off more intense infrared radiation, and it radiates at shorter wavelengths. At moderate temperatures (above 200°F), the intensity of the radiation gets high enough so that the human body can detect that radiation as heat. At high enough temperatures (above 1200°F), the intensity gets high enough and the wavelength gets short enough so that the radiation crosses over the threshold to the red end of the visible light spectrum. This is why hot steel glows red. As an object gets even hotter (for example, the tungsten filament of a light bulb at 5000°F), the intensity gets even higher (that is, it glows brighter) and the wavelength gets even shorter (more white). But even at low temperatures, below the threshold of visible light emission, everything glows with this longer wavelength infrared light, and objects at different temperatures glow with different wavelengths and intensities. The radiation from these objects creates an infrared scene, similar in nature to a visible light scene.

IR Imaging Systems

The human eye cannot detect infrared light. But infrared energy can be detected electronically. Sophisticated electronic instruments exist which can scan a scene and convert the infrared light to an electrical signal which can be displayed on a video monitor, analyzed by a computer, or recorded on film. Electrically, the output of these instruments is very similar to the output of a conventional video camera.

Unlike the human eye or a conventional video camera, which rely on reflected visible light to illuminate the objects in a scene, these infrared cameras are detecting IR energy which is being *emitted* by the objects in the scene. So an infrared camera works as well in total darkness as it does in normal daylight.

IR imaging systems are designed to satisfy different performance parameters, depending on their intended use. Military applications, such as missile guidance, require the highest level of accuracy and reliability. Many commercial applications require low cost, ease of use, and ease of maintenance.

IR imaging applications are virtually limitless. They allow you to see at night or through haze and smoke. They allow you to measure the temperature profiles of objects at great distances with high accuracy. Military applications include target acquisition, missile and weapon guidance, navigation, reconnaissance, surveillance, and terrain analysis. Commercial applications exist in many fields: industrial (plant maintenance, quality control, non-destructive testing), environmental and scientific (earth and solar sciences, pollution control, energy conservation, resource development), medical (mammography, detection of arterial constriction, evaluation of soft tissue injury), and civil (law enforcement, fire fighting, surveillance, border patrol), to name just a few.

Figure 2 shows the breadth of applications for infrared technology. This table was compiled by Richard Hudson in his 1969 text, Infrared System Engineering, a universally respected infrared handbook. In the time since this publication first appeared, the majority of activity has been in military applications; the high cost of infrared imaging systems has limited its use in commercial applications. However, the last few years have yielded significant breakthroughs in detector technology and associated support electronics, resulting in major reductions in the cost of imaging infrared systems. The price of these new systems now makes practical the whole array of applications listed in Hudson, opening up vast new markets for IR equipment.

Testing and Evaluation of IR Imaging Systems

Due to their complexity, IR imaging systems are expensive, sensitive, high-maintenance devices. To assure proper operation of these systems and to achieve their full performance requires frequent test and calibration. Engineers, who design IR imaging systems, test them during the design and development stage to evaluate performance parameters and to refine designs to optimize performance. Manufacturers of IR imaging systems need to compare actual performance to specifications, and need to calibrate the systems prior to delivery. End users must test their systems regularly to verify proper operation, and must recalibrate them periodically while they are in the working environment.

	Military	Industrial	Medical	Scientific
Search, track, and range	Intrusion detection Bomber defense Missile guidance Navigation and flight control Proximity fuses Ship, aircraft, ICBM, and mine detection Fire control Aircraft collision warning	Forest fire detection Guidance for fire-fighting missiles Fuel ignition monitor Locating hidden law violators Monitoring parking meters Detect fires in aircraft fuel tanks	Obstacle detection for the blind	Satellite detection Space vehicle navigation and flight control Horizon sensors Sun followers for instrument orientation Studies of the optical structure of the horizon
Radiometry	Target signatures	Detection of hot boxes on railroad cars Noncontact dimensional determination Process control Measurement of the temp-eratures of brake linings, power lines, cutting tools, welding and soldering operations, and ingots	Measurement of skin temperature Early detection of cancer Monitor healing of wounds and onset of infection, without removing bandages Remote biosensors Studies of skin heating and temperature sensation	Measurement of lunar, planetary and stellar temperatures Remote sensing of weather conditions Study of heat transfer in plants Measurements of the earth's heat balance
Spectro-radiometry	Terrain analysis Poison gas detection Target and background signatures Fuel vapor detection Detection of contaminants in liquid oxygen piping	Detection of clear-air turbulence Analysis of organic chemicals Gas analysis Determination of alcohol in the breath Discovery of leaks in pipelines Detection of oil in water Control of oxygen content in germanium and silicon	Detection and monitoring of air pollution Determination of carbon dioxide in the blood and in expelled air	Determination of the constituents of earth and planetary atmospheres Detection of vegetation or life on other planets Terrain analysis Monitor spacecraft atmospheres Zero-G liquid level gauge Measurement of magnetic fields
Thermal imaging	Reconnaissance and surveillance Thermal mapping Submarine detection Detection of underground missile silos, personnel, vehicles, weapons, cooking fires, and encampments Damage assessment	Nondestructive testing Inspection Locating piping hidden in walls and floors Inspection of infrared optical materials Detect and display microwave field patterns Study efficiency of thermal insulators	Early detection and identification of cancer Determination of the optimum site for an amputation Localization of the placental site Studies of the efficiency of Arctic clothing Early diagnosis of incipient stroke	Earth resources surveys Locate and map the gulf stream Detect forest fires from satellites Study volcanoes Detect and study water pollution Locate crevasses Sea-ice reconnaissance Petroleum exploration
Reflected flux	Night driving Carbine firing Intrusion detection Area surveillance Camouflage detection Station keeping Docking and landing	Industrial surveillance and crime prevention Examination of photographic film during manufacture Detection of diseased trees and crops Traveling matte photography Automatic focusing of projectors	Measurement of pupillary diameter Location of blockage in a vein Monitoring eye movements Study the nocturnal habits of animals Examination of the eye through corneal opacities Monitor healing processes	Detection of forgeries Determine thickness of epitaxial films Determination of the surface constituents of the moon and the planets Gem identification Analysis of water quality Detection of diseased crops
Cooperative source	Terrestrial communications Command guidance for weapons Countermeasures for infrared systems Range finding Drone command link Intrusion detection	Intrusion detection Automobile collision prevention Traffic counting Radiant heating and drying Data link Intervehicle speed sensing Aircraft landing aid Cable bonding	Ranging and obstacle detection for the blind Heat therapy	Space communications Understand the mechanism of animal communication Peripheral input for computers Study the nocturnal habits of animals Terrain illumination for night photography

Figure 2. INFRARED APPLICATIONS MATRIX
(from *Infrared System Engineering*, by Richard D. Hudson Jr., John Wiley & Sons, 1969)

Some of the important performance characteristics of an IR imaging system are spatial resolution (ability to resolve fine detail), thermal resolution (ability to resolve small temperature differences), speed (ability to respond to a rapidly changing scene without blurring), and dynamic range (how large a temperature span it can view without saturating). Standard tests have been developed to quantify these characteristics. In addition, innumerable specialized tests exist to evaluate specific requirements. For more detail on IR testing, see the article "Automated Testing Improves Infrared Imaging Systems", by Peter L. Chua and Stephen W. McHugh of Santa Barbara Infrared, included in the appendix. This article details some of the complex tests necessary to characterize the various subsystems of an imaging system, and discusses the difficulties involved in achieving accurate and consistent results.

IR Test Equipment

Setup, test, and calibration of IR imaging systems requires the use of specialized test equipment. This test equipment is designed to create an infrared scene of precisely known characteristics, to project this scene to the input of the IR imaging system being tested, and to evaluate the quality of the output of the IR imaging system.

The nature of the testing needed depends on the application of the IR imaging system. Obviously, proper function of a camera used for parking lot surveillance is a less critical than proper function of an IR navigation and targeting system used by a supersonic jet fighter in low-altitude night battle. So different test equipment is needed for different IR imaging systems, and for different applications. For some applications, standard off-the-shelf equipment exists that can be used to properly test an imaging system. For other applications, elaborate custom equipment must be developed to meet the testing requirements. Some of the standard IR test instruments are described below. Pictures of these instruments can be seen in the Product Information section of the Appendix.

Blackbodies. A blackbody is a precisely characterized source of infrared radiation. When used to test an IR imaging system, a blackbody is used to generate an accurate temperature difference between two surfaces, which yields a precise radiance contrast for an input to the IR imaging system being tested. A blackbody with suitable performance for testing state-of-the-art imaging systems is a very sophisticated instrument, controlling the temperature of the blackbody surface with resolution and stability on the order of .001°C.

Targets. A typical target used for IR testing consists of a flat copper plate with a test-specific pattern etched or machined through it. The target is placed in front of the blackbody, and the blackbody controls the temperature difference between the target and the blackbody's surface. When an IR imaging system views the blackbody surface through the target features, it sees an infrared image in the shape of the target pattern with a contrast determined by the temperature difference between the blackbody and the target. One common example of a target pattern is a set of rectangular bars etched through the copper plate. It is used in a test similar to the way an eye chart is used by an optometrist: this target, along with a blackbody, would generate patterns used to test the spatial resolution of an IR imaging system.

Target Wheels. To minimize handling of different targets, to automate target selection, and to speed up test time, several targets of different sizes and different features can be mounted into a motorized target wheel.

Collimators. A collimator is a optical assembly which projects the IR image generated by a blackbody and target onto the IR imaging system being tested. Typically, a collimator is used to create the illusion of the IR image existing at a great distance from the unit under test. This is needed, because an IR imaging system is normally used to view objects at distances greater than those achievable in a laboratory.

Target Projectors. A blackbody, targets, target wheel, and collimator, properly integrated together, form a system called a target projector. Frequently, the blackbody and target wheel in a target projector are designed to be controlled by a computer, to allow automation of the testing. Other special features such as range simulation or boresight alignment tooling are sometimes added as accessories to target projectors. These integrated components are sold as turnkey test equipment for IR imaging systems.

A target projector is analogous to a slide projector, with its components (blackbody, target, target wheel, and collimator) analogous to the slide projector's components (bulb, slide, slide carousel, and lens). A significant difference between the two is that a slide projector projects a *visible light* scene, typically onto a white screen; a target projector projects an *infrared light* scene, typically into the input optics of an IR imaging system. Another important difference is that unlike a slide projector's bulb with its constant light output, the target projector's blackbody provides a precisely variable illumination behind the slide (target).

SBIR's Role in IR Testing

Santa Barbara Infrared designs and manufactures both standard and custom test equipment used to measure performance of IR imaging systems. Products are sold as individual components or as integrated turnkey IR test stations. The company has a robust catalog of standard products which can be delivered in multiple configurations. The company's products are used to test IR imaging systems, in the lab or for field use, in a commercial or military environment. The company also manufactures test equipment for other electro-optical systems such as lasers and visible light cameras, to provide complete test solutions for sophisticated multi-sensor military systems.

The company has developed three distinct business areas related to IR test equipment: standard products, design-to-spec engineering, and build-to-print production. Standard products consist of instruments conceived and designed at SBIR and sold as catalog items, sometimes reconfigured to customer requirements. SBIR's design-to-spec engineering and build-to-print production both support the company's involvement in program-specific products (in contrast to standard products). For the design-to-spec engineering, a customer's specification document is the basis for a custom design by SBIR's engineering staff, which the company will then build, test, and deliver to the customer. Build-to-print production utilizes the customer's engineering design, with SBIR supplying purchasing, fabrication, and test services along with engineering support during the project.