Electromagnetic Spectrum

The **electromagnetic spectrum** is the distribution of **electromagnetic radiation** according to energy, frequency, or wavelength. Electromagnetic radiation can be described as a stream of **photons**, which are particles traveling in a wavelike pattern, moving at the speed of light.

Type of Radiation	Frequency Range	Wavelength Range
Gamma rays	$>3 \times 10^{20}$	<1 fm
X rays	3×10^{17}–3×10^{20}	1 fm–1 nm
Ultraviolet	7.5×10^{14}–3×10^{17}	1 nm–400 nm
Visible	4×10^{14}–7.5×10^{14}	0.4 μm–0.75 μm
Near-infrared	10^{14}–7.5×10^{14}	0.75 μm–3.0 μm
Midwave infrared	5×10^{13}–10^{14}	3.0 μm–6 μm
Longwave infrared	2×10^{13}–5×10^{13}	6.0 μm–15 μm
Extreme infrared	3×10^{11}–2×10^{13}	15 μm–1 mm
Micro- and radio waves	$<3 \times 10^{11}$	>1 mm

Frequencies in the visible and infrared spectral bands are measured in the millions of megahertz, commonly referred to as wavelengths rather than frequencies. Wavelength can be measured interferometrically with great accuracy and is related to the optical frequency by the universal equation

$$c = \lambda \nu$$

where λ is the wavelength, ν is the optical frequency, and c is the speed of light in free space (3×10^8 m/sec).

The difference between the categories of electromagnetic radiation is the amount of energy found in their photons. The energy of a photon is inversely proportional to the wavelength and is given by

$$\mathcal{E} = h\nu = \frac{hc}{\lambda}$$

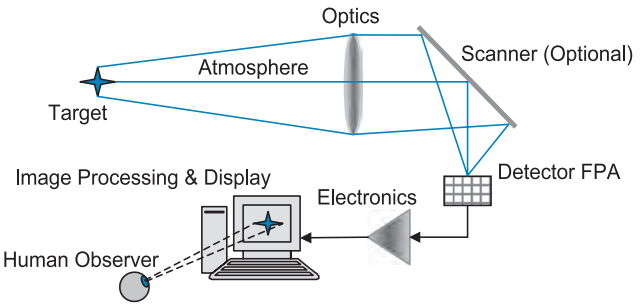
where h is Planck's constant (6.62×10^{-34} J · sec).

Radio waves have photons with very low energies, while gamma rays are the most energetic of all. The electromagnetic spectrum is classified based on the source, detector, and materials technologies employed in each of the spectral regions.

Infrared Concepts

Infrared-imaging systems are often used to form images of targets under nighttime conditions. The target is seen because of **self-radiation** rather than the reflected radiation from the sun. Self-radiation is a physical property of all objects that are at temperatures above absolute zero (i.e., 0 K = −273.15 °C).

In order to make this radiation visible, the infrared system depends on the interaction of several subsystems.



The self-radiation signature is determined by the **temperature** and the surface characteristics of the target. Gases in the atmosphere limit the frequencies at which this radiation is transmitted. The configuration of the optical system defines the **field of view (FOV)**, the **flux collection efficiency**, and the **image quality**. These parameters, along with the detector interface, impact the radiometric accuracy and **resolution** of the resulting image. The detector is a transducer that converts the optical energy into an electrical signal, and electronics amplify this signal to useful levels.

For typical terrestrial and airborne targets, **Planck's equation** dictates that, within the range of temperatures from 300 K to 1000 K, emission of radiation occurs primarily in the infrared spectrum. However, the background is self-luminous as well, causing terrestrial targets to compete with background clusters of similar temperature. Infrared images have much lower **contrast** than corresponding visual images, which have orders of magnitude higher reflectance and emittance differences.

History of Infrared Detectors and Systems

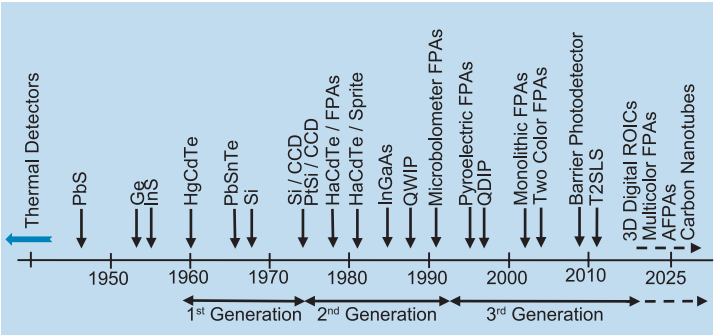
Infrared imaging systems trace their origins to the year 1800 when John Frederik William Herschel's experiments on refraction of invisible rays using a prism and a monochromator discovered infrared radiation, which Herschel called "calorific rays."

The initial infrared **radiation detection systems** were based on thermometers, thermocouples, and bolometers. In 1821, Thomas Johann Seebeck discovered the thermoelectric effect, and soon thereafter, in 1829, Leopoldo Nobili created the first thermocouple. Then in 1835, together with Macedonio Melloni, Nobili constructed a thermopile capable of sensing a person 10 m away. Samuel Pierpont Langley invented the first bolometer/thermistor in 1878. This radiant-heat detector was sensitive to differences in temperature of one hundred-thousandth of a degree Celsius, which enabled the study of the solar irradiance far into the infrared spectrum.

The development of modern **infrared detectors** became possible after John Bardeen and William Shockley invented the transistor in 1947. Thereafter, InSb, HgCdTe, and Si photon detectors were developed. Texas Instruments developed the first forward-looking infrared system in 1963, with production in 1966, and in 1969, the charge-coupled device (CCD) was developed by AT&T Bell Labs. Photon infrared technology combined with molecular beam epitaxy and photolithographic processes revolutionized the semiconductor industry, thus enabling the design and fabrication of complex focal plane arrays.

Three generations of systems may be considered for the foremost military and civilian applications. The first-generation systems were scanning systems limited to single and sparsely populated linear array elements. These devices did not include multiplexing functions in the focal plane. Monolithic and hybrid detector FPA technology with multiplexing read-out circuitry in the focal plane belong to the second-generation systems. Third-generation FPAs are being actively developed and contain several orders of magnitude more pixel elements than the second-generation, as well as many other superior on-chip features.

Detector IRFPA Roadmap



Since 1980, the size of **infrared focal plane arrays (IRFPAs)** has been increasing at an exponential rate following Moore's law, with the number of pixel elements doubling nearly every 1½ years. Essentially, the FPA technology has been increasing at the same rate as random-access memory integrated circuits (RAMICs), but lag in size by approximately 10 years. The pixel density of IRFPAs will keep increasing with time but perhaps below Moore's curve. Most high-volume commercial applications can be utterly satisfied with the current array formats. Market forces that demanded larger FPAs in the past have loosened their grip now that the megapixel barrier has been broken. Military projects will continue to demand larger arrays.