Technology Brief 21
Seeing without Light

When we think of optical technology, we most often think of visible light—the wavelengths we can see, that our eyes are sensitive to. These wavelengths range from about 750 nm (red) to 400 nm (violet), as shown in **Fig. TF21-1**. From $f = c/\lambda$, where $c = 3 \times 10^8$ m/s and λ is the wavelength in meters, the corresponding frequency range extends from 400 THz (1 THz $= 10^{12}$ Hz) for red light to 750 THz for violet light.

Our eyes are insensitive to electromagnetic waves whose frequencies are outside this range, but we can build sensors that are. ***Infrared*** (IR) frequencies (those below the visible spectrum) can be used for thermal imaging (sensing heat) and night vision (seeing in the dark). ***Ultraviolet*** (UV) frequencies (those above the visible spectrum) can be used for dermal (skin) imaging as well as numerous surface treatments (see Technology Brief 5 on LEDs).

Thermal — Infrared (IR) Imaging

Night-vision imaging is used for a wide variety of applications including imaging people for security and rescue (as seen in **Figs. TF21-2** and **TF21-3**). Helicopters can fly over large regions, locating people and animals from their IR signatures. Firefighters can use IR goggles to see through smoke and find victims. Thermal imaging is also used for medical applications (inflammation warms injured body parts) including those involving animals and small children who cannot tell you "where it hurts" and

Figure TF21-2: A night-vision image taken with military-grade goggles.

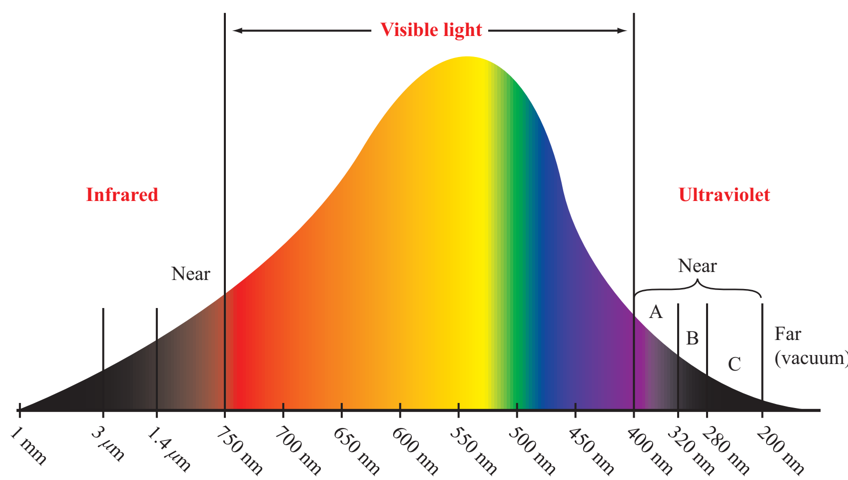

Figure TF21-1: Spectrum of visible light and its two neighbors, the infrared and the ultraviolet.

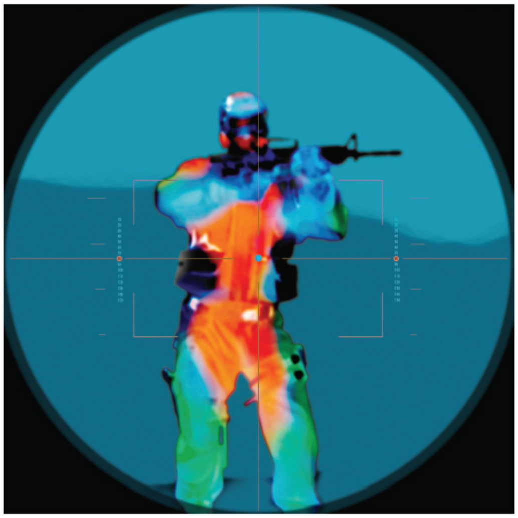

Figure TF21-3: A full-color thermal-infrared image of a soldier.

industrial and mechanical applications (damaged/failing/inefficient parts often heat up). This also is used to locate problems in electrical circuits at the board or chip level (**Fig. TF21-4**). Night vision is important for security, and is highly valued by outdoor enthusiasts as well (IR wildlife cameras can catch pictures of animals when they are most likely to be moving around at night). IR is used for things other than imaging, too, including motion detection and measuring body temperature.

Historically, two approaches have been pursued to "see in the dark": one that relies on measuring self-emitted ***thermal energy*** by the scene and another that focuses on ***intensifying*** the light reflected by the scene when illuminated by very weak sources, such as the moon or the stars. We will explore each of the two approaches briefly.

The visible spectrum extends from the violet (wavelength $\lambda \approx 0.38$ μm) to the red (≈ 0.78 μm). The spectral region next to the visible is the infrared (IR), and it is subdivided into the ***near-IR*** (≈ 0.7 to 1.3 μm), ***mid-IR*** (1.3 to 3 μm), and ***thermal-IR*** (3 to 30 μm). Infrared waves cannot be perceived by humans, because our eyes are not sensitive to EM waves outside of the visible spectrum. In the visible spectrum, we see or image a scene by detecting the light reflected by it, but in the thermal-IR region, we image a scene without an external source of energy, because the scene itself is the source. All material media emit electromagnetic energy all of the time—with hotter objects emitting more than cooler objects. The amount of energy emitted by an object and the shape of its emission spectrum depend on the object's

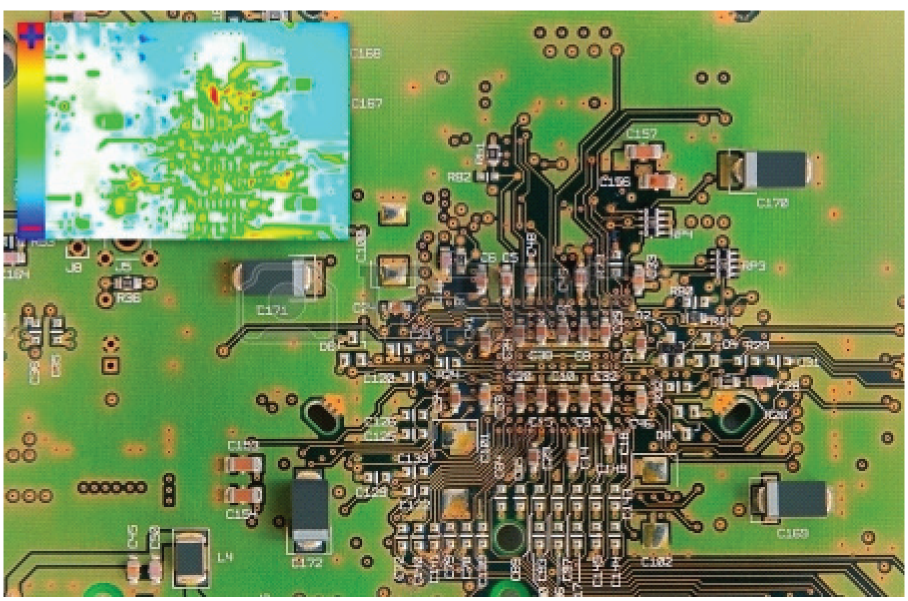

Figure TF21-4: Circuit board with superimposed IR image (inset) identifying (in red) high-temperature components or connections. (Credit: Suljo.)

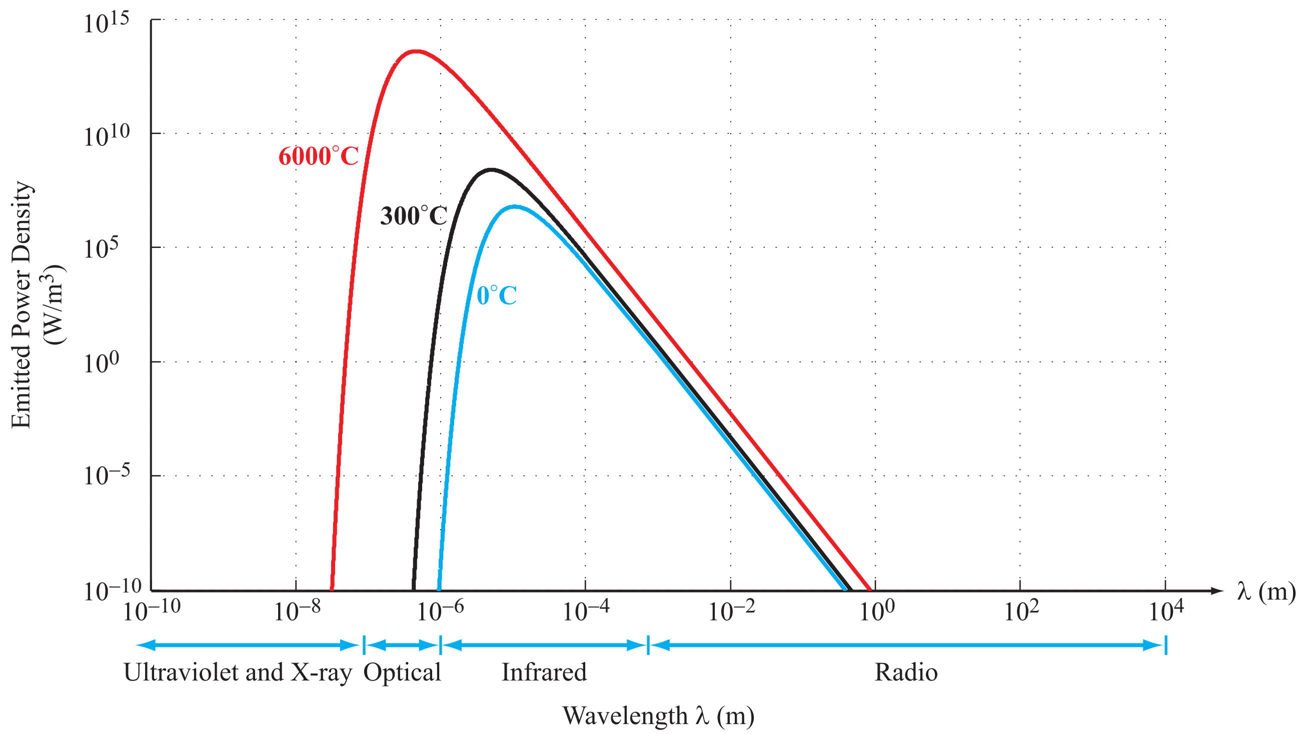

Figure TF21-5: Spectra of power density emitted by ideal blackbodies at 0 °C, 300 °C, and 6000 °C.

temperature and its material properties. Most of the emitted energy occurs over a relatively narrow spectral range, as illustrated in Fig. TF21-5, which is centered around a peak value that is highly temperature dependent. For a high-temperature object like the sun ($\approx$ 6000 °C), the peak value occurs at about 0.5 μm (red-orange color), whereas for a terrestrial object, the peak value occurs in the thermal-IR region.

Through a combination of lenses and a 2-D array of infrared detectors, the energy emitted by a scene can be focused onto the array, thereby generating an image of the scene. The images sometimes are displayed with a rainbow coloring—with hotter objects displayed in red and cooler objects in blue.

In the near- and mid-IR regions, the imaging process is based on reflection—just as in the visible. Interestingly, the sensor chips used in commercial digital cameras are sensitive not only to visible light but to near-IR energy as well. To avoid image blur caused by the IR energy, the camera lens usually is coated with an IR-blocking film that filters out the IR energy but passes visible light with near-perfect transmission. TV remote controls use near-IR signals to communicate with TV sets, so if an inexpensive digital camera with no IR-blocking coating is used to image an activated TV remote control in the dark, the image will show a bright spot at the tip of the remote control. Some cameras are now making use of this effect to offer IR-based night-vision recording. These cameras emit IR energy from LEDs mounted near the lens, so upon reflection by a nighttime scene, the digital camera is able to record an image "in the dark."

Image Intensifier

A second approach to nighttime imaging is to build sensors with much greater detection sensitivity than the human eye. Such sensors are called ***image intensifiers***. Greater sensitivity means that fewer photons are required in order to detect and register an input signal against the random "noise" in the receiver (or the brain in the case of vision). Some animals can see in the dark (but not in total darkness) because their eye receptors and neural networks require fewer numbers of photons than humans to generate an image under darker conditions. Image

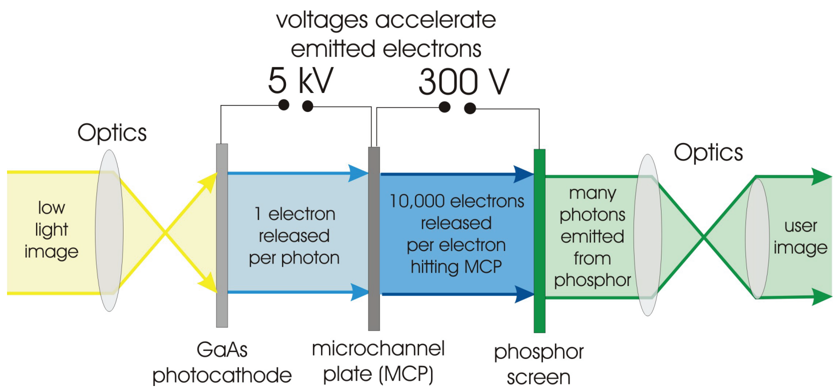

Figure TF21-6: Schematic of image intensifier assembly and operation.

intensifiers work by a simple principle (**Fig. TF21-6**). Incident photons (of which there are relatively few in a dark scene) are focused through lenses and onto a thin plate of ***gallium arsenide*** material. This material emits one electron every time a photon hits it. Importantly, these electrons are emitted at the locations where the photons hit the plate, preserving the shape of the light image. These photoelectrons then are accelerated by a high voltage ($\sim$ 5000 V) onto a ***microchannel plate*** (MCP). The MCP is a plate that emits 10,000 new electrons every time one electron impacts its surface. In essence, it is an amplifier with a current gain of 10,000. These secondary electrons again are accelerated—this time onto phosphors that glow when impacted with electrons. This works on the same principle as the cathode ray tube. The phosphors are arranged in arrays and form pixels on a display, allowing the image to be seen by the naked eye.

Figure TF21-7: Comparison of visible light and UV images. The latter shows skin damage. (Credit: Milford MD Advanced Dermatology Pocono Medical Care, Inc.)

Ultraviolet Imaging

On the other end of the spectrum, UV wavelengths range from 400–200 nm and beyond. UV can also be used to see things that are out of the visible spectrum, particularly skin or soft tissue damage, as shown in the picture of sun-damaged skin in **Fig. TF21-7**. Dark areas of the skin show where UV is absorbed and not reflected. This can be used for treatment planning, and also to show people the value of skin protection from the sun. UV is also used for numerous astrophysical observations, including the solar flare image shown in **Fig. TF21-8**. Much information in the universe is outside of the visible spectrum.

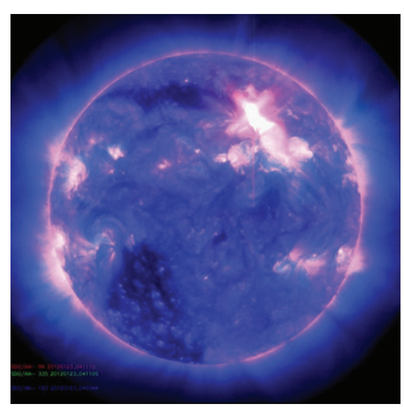

Figure TF21-8: Giant solar flare captured in UV light. (Courtesy NASA/SDO and the AIA, EVE, and HMI science team.)