Chapter 14

Satellite leak location

14.1 BACKGROUND

Radar (Radio Detection and Ranging) is an object-detection system that uses electromagnetic waves in the radio or microwave domain to determine the range, angle, or velocity of objects. Microwaves are a type of electromagnetic (EM) radiation with wavelengths in the spectrum between 0.001 and 1m, shorter than normal radio waves but longer than infrared radiation (Figure 14.1). Radar was developed secretly for military use by several nations in the period before and during World War II.

A radar system consists of a transmitter producing electromagnetic waves in the microwaves domain, a transmitting and receiving antenna (often the same), and a receiver and processor to determine properties of the object. Radio waves (pulsed or continuous) from the transmitter reflect off the object and return to the receiver, providing information about the object. Radar signals are reflected especially well by materials of considerable electrical conductivity, most notably by most metals, seawater and by wet ground. The weak absorption of radio waves by the medium through which it passes is what enables radar sets to detect objects

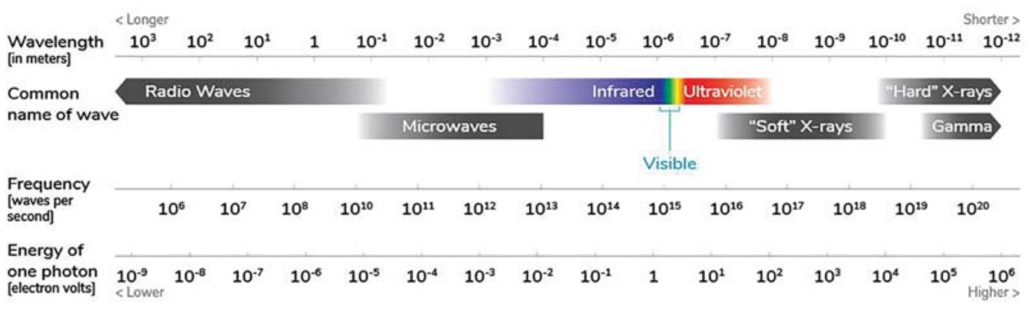

Figure 14.1 The electromagnetic spectrum. (Source: Utilis)

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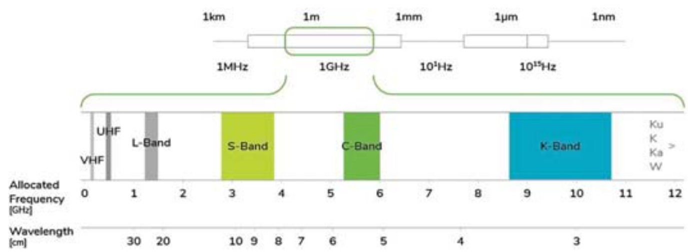

Figure 14.2 Radar frequency bands. (Source: Utilis)

at relatively long ranges, ranges at which other electromagnetic wavelengths, such as visible light, infrared light, and ultraviolet light, are too strongly attenuated.

The traditional radar frequency band names originated as code names during World War II and are still used throughout the world in military and aviation (Figure 14.2). Radar used to track ballistic missiles, or that have over-the-horizon, foliage penetration or ground-penetrating applications include HF (high frequency), UHF (ultra high frequency) and VHF (very high frequency) have bands with frequencies in the 3–1000 MHz range. Radar used in weather applications, air traffic control and missile guidance have frequencies in the range 1–12 GHz and include L (long), S (short), C (compromise) and X (secret in World War II) bands. Radar in the W band (75–100 GHz frequency range) are used in self-driving cars. These land-based applications typically use a pulsed technique whereby an area is illuminated in short bursts and echoes are received in the quiet period in between. Doppler characteristics can determine location, velocity and direction of targets. The performance of radar systems can be gauged by their range, accuracy, ability to filter noise and ability to recognize the intended target. These are greatly impacted by transmitter power and physical size of antenna.

Other systems similar to radar make use of other parts of the electromagnetic spectrum. One example is Lidar, which uses ultraviolet, visible, or near infrared light from lasers rather than radio waves.

Microwave imaging is a science that has evolved from older detecting/locating techniques, such as radar, in order to evaluate hidden or embedded objects in a structure (or media) using electromagnetic (EM) waves in microwave regime. Microwave imaging has been used in a variety of applications such as non-destructive testing and evaluation (NDT&E), medical imaging, concealed weapon detection at security checkpoints, structural health monitoring, and through-the-wall imaging.

14.2 REMOTE EARTH IMAGING

Seasat was the first earth orbiting satellite designed for earth sensing (of the oceans) using synthetic aperture radar (SAR). SAR is a form of radar that is used to create two- or 3-dimensional images of objects such as landscapes. SAR uses the motion of the radar antenna over a target region to provide finer spatial resolution than conventional radars. SAR is typically mounted on a moving platform such as an aircraft or spacecraft. The distance the SAR device travels over a target in the time taken for the radar pulses to return to the antenna creates a large "synthetic" antenna aperture (the "size" of the antenna). The larger the aperture the higher the image resolution will be, regardless of whether the aperture is physical (a large antenna) or 'synthetic' (a moving antenna). This allows SAR to create high-resolution images with comparatively small physical antennas.

To create a SAR image, successive pulses of radio waves are transmitted to "illuminate" a target scene and the echo of each pulse is received and recorded. As the SAR device on board the aircraft or spacecraft

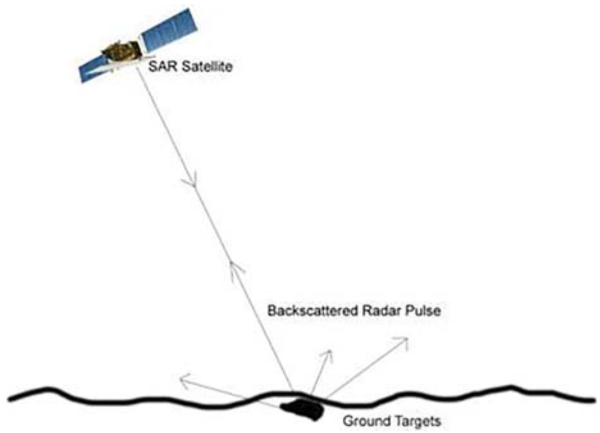

Figure 14.3 SAR schematic. (Source: Utilis)

moves, the antenna location relative to the target changes with time. Signal processing of the successive recorded radar echoes allows the combining of the recordings from these multiple antenna positions to produce a correlated image (Figure 14.3).

The merging of the characteristics of long band radar, including ground penetrating abilities, and, the capabilities of SAR to capture high resolution images from large distances with small physical antennas, has led to an innovation in the water space; namely, identifying leaks from remote platforms using radar from existing orbiting satellites. Time is purchased on a satellite to illuminate a certain area. The satellite is directed and focused at the target based on certain underlying algorithms. which is then analyzed, based on those proprietary algorithms, to determine dielectric constants which denote leaking water pipelines. A map of the likely locations of leaks is the deliverable.

The leak target map deliverable is the first step in managing leaks. Field crews will always be a necessary and critical component of the process by confirming leaks via inspections and making repairs. The map provides specific areas to focus field crew deployment to maximize efficiency. Efficiency can be defined as leaks discovered per kilometer of pipe inspected, or leaks found per crew day.

Radar SAR can be used for remote detection of underground water, for example, drinking water leakage from an urban water system (Figure 14.4). Water sources such as water pipes, lakes or swimming pools reflect electromagnetic (EM) waves, both below and above ground level. Water sources reflect microwaves in long band frequencies when illuminated from the satellite. Every water source has typical reflections and typical EM behavior, therefore the type of the water source may be identified using these typical reflections.

SAR sensors placed on an elevated platform such as a satellite or an aircraft send EM waves at a known frequency towards an area and read the EM waves reflected from that area. The sensor sends a scan that includes all the reflections detected from a particular area to further be processed by a system according to mathematical algorithms. SAR uses the motion of an antenna over a target region to provide finer spatial resolution than is possible with conventional beam-scanning radars. The scan includes all the EM reflections received from the area. These reflections include reflections from water sources and undesired reflections from other bodies in the area, such as buildings, vegetation and other topographical features of the area. In order to identify the water-related reflections, the undesired reflections (e.g., EM noise reflection) is filtered or removed from the scan. In order to reduce, remove or filter the EM noise, two or more scans are taken from the area at different polarizations. For example, two of them are a

Figure 14.4 Map of leak locations from a Radar SAR. (Source: Utilis)

horizontal-vertical (HV) scan and horizontal-horizontal (HH) scan are both taken of the target area of interest. The HH reflections are received from transmitting waves having a horizontal polarization that were received at horizontal modulation. The HV reflections are received from transmitting waves having a horizontal polarization that were received at vertical modulation.

Additional scans having additional polarizations may also be received from the single sensor all with the same resolution. Such additional scans allow for further reduction of the EM noise.

After the filtration of the EM noise some of the scanned reflections can be identified as water reflections. Since different water sources (e.g., drinking water, sewage, seas, lakes swimming pools, etc.) have different typical EM roughness (typical EM reflections), it is possible to distinguish one from the other. EM roughness from sewage pipes, seas, lakes and swimming pools are filtered or removed from the filtered noise scan thus leaving in the scan only the reflections received from pipeline water leakages.

Radio Frequency Interferences (RFI) are a technical challenge for SAR imagery in certain locations. RFI is a disturbance caused by local transmitters (i.e., cell or TV towers) of similar frequency band which causes an EM noise phenomenon in the imagery. Detecting and correcting the corrupted signal improves the project success.