Title: Sensitivity to Oil by Active Microwave Sensors

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Abstract—Active microwave sensors are radars that operate in the microwave region (1 to 30 gigahertz in frequency, 1 to 30 centimeters in wavelength). Unlike passive microwave sensors, they provide their own illumination and do not depend upon ambient radiation. Microwaves propagate through clouds and rain with limited attenuation. Thus, active microwave sensors operate day or night, in all kinds of weather.

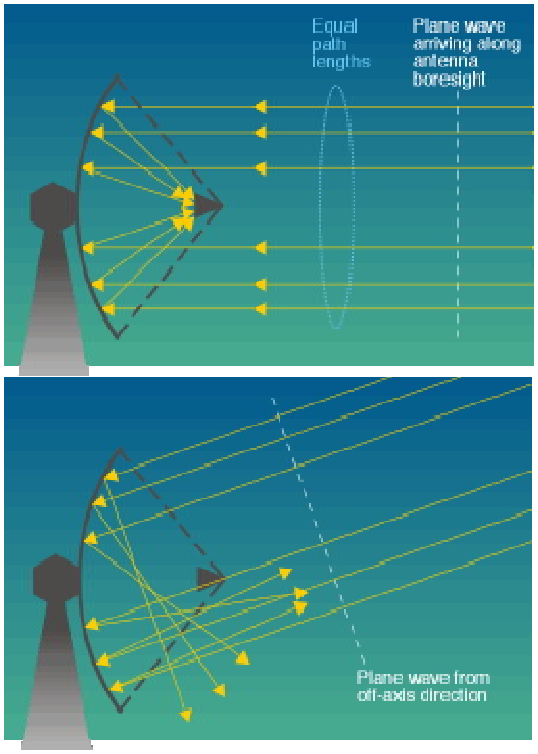
Early radar systems involved a fixed radar source that scanned a field of view to track military targets, such as ships or airplanes. Current and proposed systems take many more forms and can operate as cameras, generating high-quality images from moving platforms. Research at Aerospace has been helping to advance the capabilities of microwave imaging and target-detection systems and expand their practical use.

Reducing the risk of oil spill disasters is essential for protecting the environment and reducing economic losses. Oil spill surveillance constitutes an important component of oil spill disaster management. Advances in remote sensing technologies can help to identify parties potentially responsible for pollution and to identify minor spills before they cause widespread damage. Due to the large number of sensors currently available for oil spill surveillance, there is a need for a comprehensive overview and comparison of existing sensors. Specifically, this paper examines the characteristics and applications of different sensors. It also indicates on how the active microwave response can be used to detect oil. A better understanding of the strengths and weaknesses of oil spill surveillance sensors will improve the operational use of these sensors for oil spill response and contingency planning.

Keywords— microwave sensors - oil - active microwave response.

INTRODUCTION

Pulsed radar operates by emitting bursts of electromagnetic energy and listening for the echo. The ratio of the pulse duration (the transmission period) to the time between pulses (pulse repetition interval) is a key design parameter known as the duty factor. A higher duty factor lessens the peak power requirement at the expense of eclipsing, or the loss of returned signal energy when the radar is in transmission mode [1].



With a parabolic antenna, signals from a large distance arrive in phase along a plane wave front. Rays parallel to the axis of the antenna are reflected onto the focus; because all paths are of the same length, these rays arrive in phase and thus combine coherently. Rays significantly off the mechanical radar boresight do not combine coherently, nor do they intersect at the focus. Likewise, upon transmission, a coherent beam is formed along the antenna boresight when radiation from the focus is reflected off the parabolic surface.

Resolution in the range direction (along the antenna boresight) can be determined by the pulse duration—the shorter the pulse, the finer the resolution. In this case, the range resolution would be the pulse duration multiplied by half the speed of light (to account for the round trip). One difficulty associated with this approach is that it would require extremely high and typically unobtainable peak power to be transmitted in a very short time to achieve suitable resolution. This problem is avoided through a technique known as pulse compression, which uses coded pulses or waveforms followed by signal processing. The necessary processing is achieved by matched filtering: The returned

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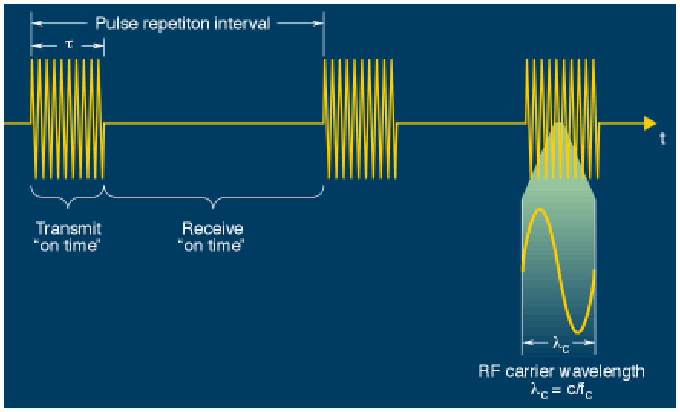
signals are correlated with a bank of ideal signals (matched filters) representing returns from specific ranges illuminated by the radar. Range resolution in this case is calculated as the speed of light divided by twice the bandwidth of the waveform. Therefore, resolution increases with the bandwidth of the waveform: The wider the bandwidth, the more precise the assumed location of the target must be to correlate the returned signal. In this way, the peak power requirement may often be reduced three orders of magnitude or more.

The processing gain associated with pulse compression is achieved by exploiting the coherent rather than random nature of the transmitted pulse. In the classic "random walk" problem, every step from a given starting point can go in any direction with equal likelihood. After *n* steps, the walker is not *n* paces from the starting point, but a shorter distance averaging the square root of *n*. Integrating *n* voltage vectors is analogous to taking n steps. If the voltage vectors are coherent, they point in the same direction—that is, they have the same phase. If they are incoherent, they have random directions, or random phase. Power is the square of the magnitude of voltage; consequently, n coherent signals upon integration result on average in *n* times the power as *n* incoherent signals. Coherence, or lack thereof, is a key issue in radar performance.

Similarly, when moving targets need to be resolved in Doppler frequency, the necessary coherent processing is also performed by banks of matched filters. Assuming constant range rates, this is usually implemented with a fast Fourier transform, an algorithm for computing the Fourier transform for discretely sampled data. This type of processing is also key in imaging radar: If one looks at a point *p* on the ground through a telescope while flying past it, the points surrounding *p* appear to rotate about it. Doppler filtering exploits this phenomenon.

Range (pulse) compression and Doppler filtering result in coherent integration gain, an increase in the target signal above the noise level. Coherent gain also results from the physics of antenna beam formation and reception. The gain of an antenna upon transmission and reception is proportional to its area. In addition, the strength of a target's radar cross section is determined by both the existence and the coherence of the currents that are induced when the target is illuminated by radar. If the current or voltage vectors are coherent, they have the same phase. If they are incoherent, they have random phases. In the case of a parabolic dish antenna, signals from a large distance arrive in phase along a plane wave front. Rays parallel to the axis of the antenna (i.e., its mechanical boresight) are reflected onto the focus, which, because all paths are of the same length, arrive in phase and thus combine coherently. Rays significantly off the mechanical radar boresight are not coherent, nor do they intersect at the focus.

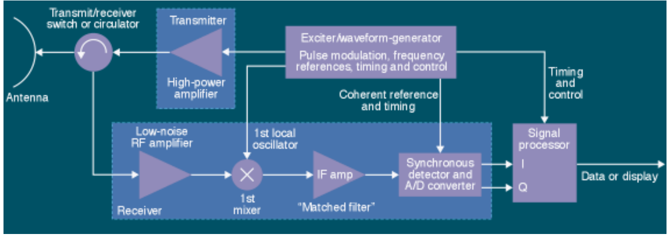


Radar operates by transmitting pulses of electromagnetic energy and detecting the backscattered energy by listening during the time between pulse transmissions.

The "radar range equation" addresses all of these concepts and other fundamental physics. It predicts performance in terms of signal-to-interference ratio based upon the radar hardware, the distance to the target, the target's radar cross section, and the total system noise. The equation recognizes five primary factors that determine signal strength: the density of radiated power at the range of the target; the radar reflectivity of the target and the spreading of radiation along the return path to the radar; the effective receiving area or aperture of the antenna; the dwell time over which the target is illuminated; and signal losses caused by physical phenomena, such as conversion to heat, and processing losses, such as result from the weighting of data.

The noise expressed in the radar range equation primarily encompasses thermal noise, which results from both ambient radiation and the receiver electronics. Interference can also occur from other sources—for example, when a target is on Earth's surface, the radar return from the surrounding surface and vegetation can cause interference (commonly known as ground clutter).

Another important concept in radar is ambiguity, which can arise in several ways. For example, if the pulse repetition frequency is increased to the extent that the returns from two or more pulses arrive simultaneously, then they will be inseparable. This is known as a range ambiguity, and is avoided by lowering the pulse repetition frequency; however, the lower pulse-to-pulse sampling rate can cause Doppler ambiguities (a phenomenon related to the way car and stagecoach wheels can appear to rotate backward in movies). In the case of imaging radars, the only way to simultaneously avoid both ambiguities is to illuminate a small enough area, which requires a larger antenna.



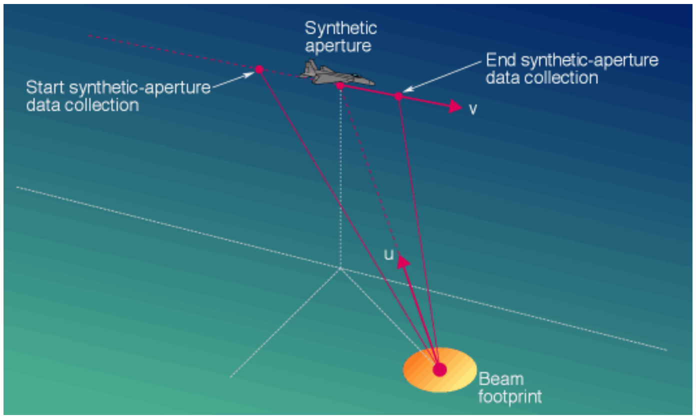
The classic coherent radar hardware architecture of a basic antenna with a single receive channel. In transmit mode, the exciter produces the signal, which flows to the high-power amplifier and transmitter before passing through the transmit/receive switch (the circulator) to the antenna. In receive mode, the detected signal passes from the antenna through the transmit/receive switch to the receiver, which consists of a low-noise amplifier, a mixer that converts the data to a lower intermediate frequency, a matched filter, and a detector and analog-to-digital converter.

Phased-array antennas are susceptible to ambiguity in the form of so-called grating lobes. These antennas are composed of arrays of small transmit/receive modules, generally spaced about a wavelength apart. They are particularly useful because they allow steering of the antenna beam by applying a linear phase progression from element to element. Ambiguity occurs when returns are received from two directions such that an additional distance of half a wavelength (one wavelength two ways) occurs from module to module. As a result, radiation is received in perfect coherence from both directions. Grating lobes are suppressed by avoiding the illumination of targets in the direction of grating lobes. The necessary narrowing of the antenna beam is achieved by increasing the antenna size.

Synthetic-Aperture Radar

The beam from a radar—like the beam from a flashlight—will produce an elliptical illuminated region on the ground when directed downward. The higher the radar, the wider the ellipse—and, if the beam is scanned to form an image, the lower the resolution of the image. Synthetic-aperture radar (SAR) overcomes this difficulty by employing pulse compression to obtain high range resolution and synthesizing a large antenna width to obtain high azimuthal resolution. This aperture synthesis is achieved by coherently integrating the returned signal pulse-to-pulse as the radar moves along its path. The azimuth resolution attained in this manner is half a wavelength divided by the change in viewing angle during the aperture formation process. Thus, if the same angle is swept out at different altitudes, there is no loss in resolution.

An important variant of this technique is interferometric SAR. Here, in essence, two images are formed from slightly different geometries. Interferometry then provides estimates of surface height for each pixel, enabling the creation of terrain-elevation maps. Elevation accuracy for a given posting grid increases with radar resolution. The technique was first performed from space during the NASA Shuttle Radar Topographic Mapping (SRTM) project. This was a single-pass radar mission with an onboard antenna and an auxiliary antenna suspended from the shuttle by a long boom.



Synthetic-aperture radar (SAR) uses pulse compression to obtain high range resolution and synthesizes a large antenna width to obtain high azimuthal resolution. The unit vector in the azimuth direction lies in the plane in which the image is focused and is perpendicular to the projection of the range unit vector u into that plane. This aperture synthesis is achieved by coherently integrating the returned signal pulse-to-pulse as the radar moves along its path. The azimuth resolution attained in this manner is half a wavelength divided by the change in viewing angle during the aperture formation process. Thus, if the same angle is swept out at different altitudes, there is no loss in resolution.

In addition to single-pass interferometry, double-pass interferometry is also possible. An important special case occurs when two voltage images (containing magnitude and phase) of the same area from the same instrument taken at the same viewing geometry are interfered or subtracted. Signals from targets that have not moved are cancelled, leaving only noise and signals from targets that have moved. Land deformations from earthquakes have been imaged in this way from space.

Another important variant is inverse SAR, which exploits the relative motion of the radar and the target, just as in standard SAR. Here, however, the target is moving, and its motion is critical because it is neither controllable nor known a priori. A classic application is the imaging of ships on the ocean for identification. Because a ship may be yawing, pitching, or rolling, inverse SAR can generate images of the ship's side, front, or top. For any single attempt at imaging, however, neither the cross-range resolution nor even successful imaging can be predicted.

An emerging technique, still in its infancy, is synthetic-aperture imaging lidar, a variant of SAR employing extremely high frequencies. By operating at such high frequencies, it is theoretically possible to attain extremely fine resolution.

Real Aperture Radar

Imaging radar is classified into **Real Aperture Radar** (RAR) and Synthetic Aperture Radar (SAR).

RAR transmits a narrow angle beam of pulse radio wave in the **range direction** at right angles to the flight direction (called the **azimuth direction**) and receives the backscattering from the targets which will be transformed to a radar image from the received signals.

Usually the reflected pulse will be arranged in the order of return time from the targets, which corresponds to the range direction scanning.

The resolution in the range direction depends on the pulse width. However if the pulse width is made small, in order to increase the resolution, the Signal/Noise ratio of the return pulse will decrease because the transmitted power also becomes low. Therefore, the transmitted pulse is modulated to chirp with a high power but wide band, which is received through a **matched filter**, with reverse function of transmission, to make the **pulse width** very narrow and high power. This is called **pulse compression** or **de-chirping**. By making the pulse compression, with an increase of frequency f in transmission, the amplitude becomes bigger, and the pulse width becomes narrower. This method is sometime called range compression.

The resolution in the azimuth direction is identical to the multiplication of beam width and the distance to a target. As the resolution of azimuth direction increases with shorter wave length and bigger antenna size, a shorter wavelength and a bigger antenna is used for higher azimuth resolution.

However as it is difficult to attach such a large antenna, requiring for example a 1 km diameter antenna in order to obtain 25 meters resolution with L band (λ =25 cm) and 100 km distance from a target, a real aperture radar therefore has a technical limitation for improving the azimuth resolution.

Oil spill sensitivity using radar

Radar is an active sensor and operates in radio wave region. Radar waves are reflected by capillary waves on the ocean and therefore, a bright image is obtained for ocean water. Oil diminishes capillary waves and as a result, if oil is present in the ocean then reflectance is reduced. Hence, the presence of oil can be detected as dark part in the bright image for the ocean [4]. Radar is very useful as it can be used to detect oil over a large area. Thus, it can be used as a first assessment tool to detect the possible location of an oil spill. Radar can work in both inclement weather and at night.

SAR (Synthetic Aperture Radar) and SLAR (Side- Looking Airborne Radar) are the two most common types of Radar which can be used for oil spill remote sensing. SAR has superior spatial resolution and range than SLAR [5]. However, SLAR is less expensive and predominantly used for airborne remote sensing. It was found that the dampening of capillary waves by thick oil is higher than the oil sheen and hence sheens can be distinguished from thicker oils.

Seaweed creates a type of film that may lead to a false alarm in the radar image. Both very low and very high wind speeds influence oil spill detection. At high wind speed, even thick oil slicks are dispersed into the water column and oil cannot be detected. At low wind speed it is not possible to distinguish between thick and thin oil slicks. Oil slick can be detected between wind speeds of 2-12 m/s. However, wind speeds of 5-6 m/s are optimal for oil spill detection. SAR is the most widely used sensor on space-borne platforms for oil spill detection [2].

Future Science Applications

Future missions using microwave and near-microwave sensors to measure precipitation, monitor freeze/thaw cycles, perform interferometric SAR, monitor ocean topography and river levels, measure snow cover, measure polar ice and ice thickness, measure atmospheric water and ozone, monitor land cover and land use, and measure biomass. The plan reflects a trend toward the use of higher-altitude instruments for greater coverage and the development of onboard data-processing hardware. The development of radiation-hardened radar hardware that can withstand the harsher high-altitude radiation environment was thus part of this plan.

Aerospace also recently performed the "Jupiter Icy Moons Orbiter High-Capability Instrument Feasibility Study." The purpose was to assess the capability of a suite of instruments selected for the Jupiter Icy Moons Orbiter, a proposed spacecraft that would orbit three of Jupiter's moons for extended observations. Building upon earlier conceptualized instruments, Aerospace selected, designed, and evaluated a 35-gigahertz interferometric SAR and a 3-gigahertz fully polarimetric SAR with penetration into the shallow subsurface. The cross-polarized return from the latter instrument would provide a measure of the multiple scattering indicative of an icy regolith.

Aerospace has also provided independent review of progress in developing innovative microwave and near-microwave spaceborne instruments and supporting hardware and algorithms. This has recently included the continuing development of a geostationary sensor to serve the purpose of ground-based eather radars; a sensor and supporting algorithms to measure soil moisture below vegetation canopies; an advanced sensor and supporting algorithms to measure ocean ice thickness and snow-cover characteristics; and an advanced precipitation radar antenna and instrument. Ancillary technology developments have included lightweight scanning antennas, high-efficiency transmit/receive modules, and SAR processing algorithms [3].

CONCLUSION

The use of microwave sensors has revolutionalize remote sensing in several fields. This has many advantages including nondestructive nature in their operation which has made them to be used in many applications like soil moisture content measurement, oil spill detection and many more. More research is going on to develop sensors which can be used in space exploration. Active microwave sensors are now being used in medicine where radar can detect cancer. For oil spill detection active sensors can capture a large area and are very useful for providing general view of affected area.

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