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Radar Energy Warfare and the Challenges of Stealth Technology

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This book is dedicated to my son Sasha
and grandson Darrius

Preface

When the Wright brothers invented the airplane, they effectively changed the way travel, exploration and warfare forever. Examples of this can be found in World War I and II, a two pilot system was created for successfully identifying and bombing specific targets. In the Battle of Britain this system used by Royal Air Force (RAF) so they could defend their territory against German Luftwaffe and their turn the battle to their advantage. In the Vietnam War American pilots used surface-to-air missile (SAM), where the radar and electronic jamming played a big role, and the use of radar technology is used to this day.

Since the Wright brothers' original design, airplanes have drastically improved upon their design as well as functionality; such as: F-35 on American side and their Russian counterpart Sukhoi Su-57 and even now Chinese playing in this market with their Chengdu J-20. While they all are the sixth-generation (GEN-VI) fighter jets, they have one common technical challenge, that is, they all need to be stealthy in order to avoid any radar detection. However, the question is are they really stealthy as their manufacturers claim by using radar absorbing material (RAM) or reducing their radar cross-section (RCS) against any radar beam detection that is looking for them in the sky.

Targets for radar are still agile within the sixth-generation (GEN-VI) aircraft with an RCS in the 8–12 GHz band between 2 m^2 (head-on) and 100 m^2 (maximum side-on), flying at ground velocities between 150 and 750 m/s. Stealthy aircraft targets may have an RCS as low as 0.005 m^2 in the head-on aspect. Missile targets are likely to have a RCS at least one order of magnitude lower than the non-stealthy aircraft and may travel at 1300 m/s (Mach 4). Ground-based targets include structures such as bridges and buildings or vehicles such as armored vehicles, which may be moving or static. Even today with the announcement of new weaponry systems such as hypervelocity missile or torpedoes by Russian and Chinese, Stealth Scenario has taken a different direction from the technical point of view.

The most pernicious form of electronic countermeasures (ECM) against this new generation of fast-moving jet planes is Digital Radio Frequency Memory (DRFM)-based repeater jammers and transponders. This book suggests that scalar wave (SW) as a countermeasure against a threat such as hypervelocity, and this type of wave is based on scalar longitudinal wave (SLW) derived from more complete equation (MCE) of Ampere's Maxwell's equation using the quantum electrodynamics (QED) approach.

Techniques from SW to radar can replicate the radar's waveform with remarkable integrity and can present a plethora of false targets that may correlate within the victim receiver and the processing chain driven by the fire-control radar (FCR), and all this is described in this book in a very simple and introductory way.

A particular concern might be the ghosting within a medium pulse repetition frequency (PRF) mode in response to a large number of realistic target returns. As we have learned from our basic principle of radar courses in college, FCRs on fast strike aircraft are the quintessential pulse Doppler radars. They must work in a wide variety of air-to-air and air-to-ground modes, they must be lightweight and compact, yet they have to achieve long detection ranges in the presence of extreme clutter scenes and be capable of tracking a large number of agile targets, all of which must be highly automated, especially for single-seat aircraft, to minimize the workload on the aircrew.

Tactical fighter-sized stealth aircrafts must be optimized to defeat higher frequency bands, such as the C, X, and Ku bands—that is just a simple matter of physics. There is a "step change" in an LO aircraft's signature once the frequency wavelength exceeds a certain threshold and causes a resonance effect. Typically, that resonance occurs when a part of an aircraft—such as a tail fin or similar—is less than eight times the size of a particular frequency wavelength. Fighter-sized stealth aircrafts that do not have the size or weight allowances for two feet or more of radar absorbent material coatings on every surface are forced to make trades as to which frequency bands they are optimized for.

It means that radars operating at a lower frequency band, such as parts of the S or L band, are able to detect and track certain stealth aircrafts. Ultimately, in order to counter lower-frequency radars, a larger flying-wing stealth aircraft design like the Northrop Grumman B-2 Spirit or B-21 Raider—which lacks many of the features that cause a resonance effect—is a necessity. However, the UHF and VHF band wavelengths, designers are not trying to make the aircraft invisible—rather engineers hope to create a radar cross-section that will blend in with the background noise that is inherent to low-frequency radars.

Additionally, low-frequency radars can be used to cue fire-control radars, and some US adversaries have started to make an effort to develop targeting radars that operate at lower frequencies. However, those lower-frequency fire-control radars exist only in theory—and are a long way off from being fielded.

The topics above are included throughout this book. Each subject of interest is carefully examined in order to build a solid foundation for its reader that can range from someone with little background knowledge to a reader with more sophisticated reader with solid background in physics of radar and its principles as well the engineers that they do understand since of Stealth Technology.

This book also provides four Appendices to enhance the general knowledge of readers in case they are new to the game of radar energy warfare and stealth technology.

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Acknowledgment

I am indebted to the many people who aided, encouraged, and supported me beyond my expectations. Some are not around to see the results of their encouragement in the production of this book, yet I hope they know of my deepest appreciation. I especially want to thank all my friends to whom I am deeply indebted, for continuously giving their support without hesitation. They have always kept me going in the right direction, especially a true friend, Dr. Patrick J. McDaniel.

Above all, I offer very special thanks to my late mother and father and to my children, in particular, my son Sasha, who always encouraged me while we had him in this world for short time. They have provided constant support and encouragement, without which this book would not have been written. Their patience with my many absences from home and long hours in front of the computer to prepare the manuscript is especially appreciated.

Contents

About the Author

Bahman Zohuri is a Research Associate Professor of Electrical Engineering and Computer Science at the University of New Mexico in Albuquerque, while consulting through his own company, Galaxy Advanced Engineering, Inc., a consulting company that he started himself in 1991 when he left both semiconductor and defense industries after working many years as a chief scientist. After graduating from the University of Illinois in the field of Physics and Applied Mathematics, he joined Westinghouse Electric Corporation where he performed thermal hydraulic analysis and natural circulation for inherent shutdown heat removal system (ISHRS) in the core of a liquid metal fast breeder reactor (LMFBR) as a secondary fully inherent shut system for secondary loop heat exchange. All these designs were used for nuclear safety and reliability engineering for self-actuated shutdown systems. He designed the mercury heat pipe and electromagnetic pumps for large pool concepts of LMFBR for the purpose of heat rejection in this reactor around 1978, when he received a patent for it. He was then transferred to the defense division of Westinghouse, where he was responsible for the dynamic analysis and method of launch and handling of the MX missile out of the canister. He later on worked as a consultant at Sandia National Laboratories after leaving the United States Navy. Dr. Zohuri earned his bachelor's and master's degrees in physics from the University of Illinois and his second master's degree in mechanical engineering as well as his doctorate in nuclear engineering from the University of New Mexico. He has been awarded three patents, has published 26 textbooks, and has numerous other journal publications to his credit.

Recently, he has been involved with cloud computing, data warehousing, and data mining using Fuzzy and Boolean and applying them to artificial intelligence, machine learning, and deep learning logic and has a few books published on these subjects as well as numerous other books that can be found under his name on Amazon or on the Internet.

Chapter 1
Fundaments of Radar

This chapter gives an elementary account of radar's principles and goes over essential of radar as a detecting device. Radar was one of the elements that helped Britain in their air war against German Luftwaffe during the peak of the Battle of Britain, and they managed to survive during such invasion. The subject is simple, the methods are powerful, and the results have broad applications. Radar is a detection system that uses radio waves to determine the range, angle, or velocity of objects, and it can be used to detect aircraft, ships, spacecraft, guided missiles, or motor vehicles or even to be able to forecast the weather formations and terrain. Today with all the stealth technologies that is pushing state of new generation of fighter planes to the stage of sixth generation and new threats hypersonic objects that are flying faster than speed of sound to level 5–15 Mach number; thus, the radar warfare is taking a different innovative level.

1.1 Introduction

The acronym RADAR stands for RAdio Detection And Ranging, and today, the technology is so common that the word has become a standard English noun. As indicated by the name of the system, this device works based on the usage of radio waves, and it is capable of sending out electromagnetic waves in the form of transverse electromagnetic (TEM) form to far distance from the source of radiation. Note that in later chapter we will talk about transverse and longitudinal electromagnetic waves and how they work to detect different objects with different characteristic threats. However, for the time being, a transverse mode of electromagnetic radiation is a particular electromagnetic field pattern of the radiation in the plane perpendicular to the radiation's propagation direction.

A radar system consists of a transmitter producing electromagnetic waves in the radio or microwave domain, a transmitting antenna, a receiving antenna (often the same antenna is used for transmitting and receiving), and a receiver and processor to

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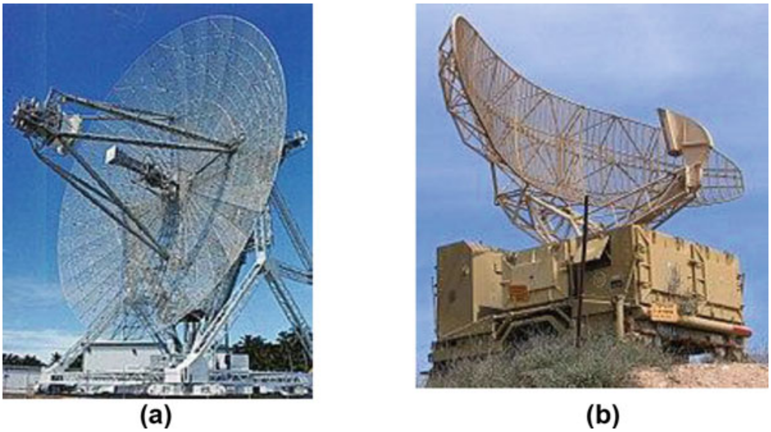

Fig. 1.1 Typical long-range and rotating radar illustrations. (Source: www.wikipedia.com). (**a**) Long-range radar, (**b**) Rotational radar

determine properties of the object(s). Radio waves (pulsed or continuous) from the transmitter reflect off the object and return to the receiver, giving information about the object's location and speed.

Figure 1.1a is an illustration of a long-range radar antenna that is used to track space objects and ballistic missile, while Fig. 1.1b is the type of radar used for the detection of aircraft, and it rotates steadily, sweeping the airspace with a narrow beam.

Radar was developed secretly for military use by several nations in the period before and during World War II. A key development was the cavity magnetron in the United Kingdom, which allowed the creation of relatively small systems with submeter resolution. The term *RADAR* was coined in 1940 by the US Navy as an acronym for *RA*dio *D*etection *A*nd *R*anging [1, 2]. The term *radar* has since entered English and other languages as a common noun, losing all capitalization.

The modern uses of radar are highly diverse, including:

1. Air and terrestrial traffic control and radar astronomy
2. Antimissile systems
3. Marine radars to locate landmarks and other ships and aircraft anti-collision systems
4. Ocean surveillance systems
5. Outer space surveillance and rendezvous systems
6. Meteorological precipitation monitoring
7. Altimetry and flight control systems and guided missile target locating systems
8. Ground-penetrating radar for geological observations

High-tech radar systems are associated with digital signal processing (DSP) and machine learning (ML) integrated into artificial intelligence (AI) in conjunction with deep learning (DL) combined and are capable of extracting useful information from very high noise levels. Radar is a key technology that the self-driving systems are mainly designed to use, along with sonar and other sensors [3].

Other systems similar to radar make use of other parts of the electromagnetic spectrum. One example is LIght Detection And Ranging (LIDAR), which uses predominantly infrared light from lasers rather than radio waves, there are some articles or books that call LIDAR as LADAR, and they both mean the same techniques. With the emergence of driverless vehicles, radar is expected to assist the automated platform to monitor its environment, thus preventing unwanted incidents [4].

LIDAR mechanism of detection is based on surveying method that measures distance to a target by illuminating the target with laser light and measuring the reflected light with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3D representations of the target. The name LIDAR, now used as an acronym of LIght Detection And Ranging [5] (sometimes, *light imaging, detection, and ranging*), was originally a portmanteau or combination or blending of *light* and *radar* [6, 7]. LIDAR sometimes is called 3D laser scanning, a special combination of a 3D scanning and laser scanning. It has terrestrial, airborne, and mobile applications. See Fig. 1.2, in which a Frequency Addition Source of Optical Radiation (FASOR), where it is used at the Starfire Optical Range for LIDAR and laser-guided star experiments, is tuned to the sodium D2a line and used to excite sodium atoms in the upper atmosphere.

Bear in your mind that LIDAR typically uses ultraviolet (UV), visible, or near-infrared (IR) light to image objects. It can target a wide range of materials, including

Fig. 1.2 Typical FASOR demonstration. (Source: www.wikipedia.com)

non-metallic objects, rocks, rain, chemical compounds, aerosols, clouds, and even single molecules [5]. A narrow laser beam can map physical features with very high resolutions; for example, an aircraft can map terrain at 30 c (12 in.) resolution or better [8].

In the case of airborne LIDAR, which is nothing more than *airborne laser scanning*, a laser, while attached to an aircraft during flight, creates a 3D point cloud model of the landscape. This is currently the most detailed and accurate method of creating digital elevation models, replacing photogrammetry. One major advantage in comparison with photogrammetry is the ability to filter out reflections from vegetation from the point cloud model to create a digital terrain model which represents ground surfaces such as rivers, paths, cultural heritage sites, etc., which are concealed by trees. Within the category of airborne LIDAR, there is sometimes a distinction made between high-altitude and low-altitude applications, but the main difference is a reduction in both accuracy and point density of data acquired at higher altitudes. See Fig. 1.3.

In Fig. 1.3 we are observing a schematic diagram of airborne LIDAR performing line scanning resulting in parallel lines of measure points, although there exist other scan pattern methods, but this one is fairly the most common one.

Collection of elevation data using LIDAR has several advantages over most other techniques. Chief among them are higher resolutions, centimeter accuracies, and ground detection in forested terrain [8].

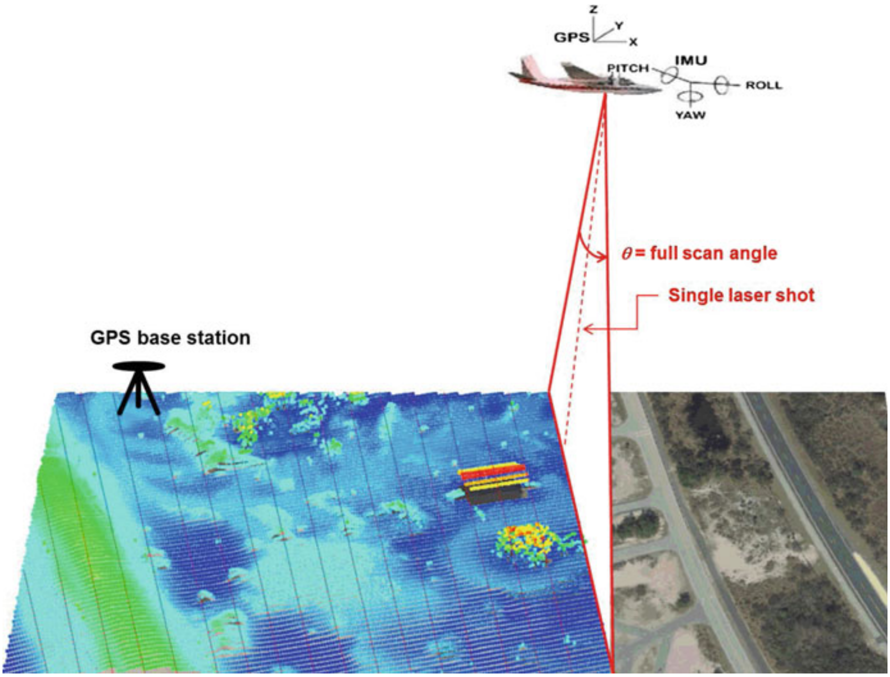

Fig. 1.3 Airborne LIDAR schematic perfuming line scanning. (Source: www.wikipedia.com)

LIDAR has become an established method for collecting very dense and accurate elevation data across landscapes, shallow-water areas, and project sites. This active remote sensing technique is similar to radar but uses laser light pulses instead of radio waves. LIDAR is typically "flown" or collected from planes where it can rapidly collect points over large areas (Fig. 1.3).

Airborne LIDAR can also be used to create bathymetric models in shallow water [9].

1.2 First Principle of Radar Concept and Experiments

Early history of encountering radar principle falls in around 1886, when German physicist Heinrich Hertz showed that radio waves could be reflected from solid objects. Further discovery was done around 1895 by a Russian physics instructor at the Imperial Russian Navy School in Kronstadt, who developed an apparatus using a coherer tube for detecting distant lightning strikes. The next year, he added a spark-gap transmitter. In 1897, while testing this equipment for communicating between two ships in the Baltic Sea, he took note of an interference beat caused by the passage of a third vessel. In his report, Popov wrote that this phenomenon might be used for detecting objects, but he did nothing more with this observation [9].

The German inventor Christian Hülsmeyer was the first to use radio waves to detect "the presence of distant metallic objects." In 1904, he demonstrated the feasibility of detecting a ship in dense fog, but not its distance from the transmitter [10]. He obtained a patent [11] for his detection device in April 1904 and later a patent [12] for a related amendment for estimating the distance to the ship. He also obtained a British patent on September 23, 1904 [13], for a full radar system that he called a *telemobiloscope*. It operated on a 50 cm wavelength and the pulse radar signal was created via a spark-gap. His system already used the classic antenna setup of horn antenna with parabolic reflector and was presented to German military officials in practical tests in Cologne and Rotterdam harbor but was rejected [14].

In 1915, Robert Watson-Watt used radio technology to provide advance warning to airmen [15] and during the 1920s went on to lead the UK research establishment to make many advances using radio techniques, including the probing of the ionosphere and the detection of lightning at long distances. Through his lightning experiments, Watson-Watt became an expert on the use of radio direction finding before turning his inquiry to shortwave transmission. Requiring a suitable receiver for such studies, he told the "new boy" Arnold Frederic Wilkins to conduct an extensive review of available shortwave units. Wilkins would select a General Post Office model after noting its manual's description of a "fading" effect (the common term for interference at the time) when aircraft flew overhead.

Across the Atlantic in 1922, after placing a transmitter and receiver on opposite sides of the Potomac River, US Navy researchers A. Hoyt Taylor and Leo C. Young discovered that ships passing through the beam path caused the received signal to fade in and out. Taylor submitted a report, suggesting that this phenomenon might be

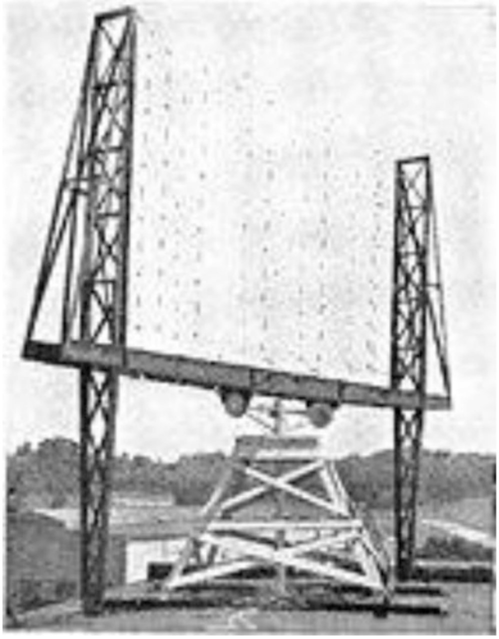

Fig. 1.4 US Naval Research Laboratory experimental antenna configuration. (Source: www.wikipedia.com)

used to detect the presence of ships in low visibility, but the Navy did not immediately continue the work. Eight years later, Lawrence A. Hyland at the Naval Research Laboratory (NRL) observed similar fading effects from passing aircraft; this revelation led to a patent application [16] as well as a proposal for further intensive research on radio-echo signals from moving targets to take place at NRL as illustrated in Fig. 1.4, where Taylor and Young were based at the time [17].

In summary the history of radar as we stated extends to the days of modern electromagnetic theory, where Hertz demonstrated reflection of radio waves in around 1986, and in 1900 T described a concept for electromagnetic detection and velocity measurement during an interview. In 1903 and 1904, the German scientist Hülsmeyer experimented with ship detection via radio wave reflection, an idea advocated again by Marconi in 1922. In that same year, Taylor and Young of the US Naval Research Laboratory (NRL) both demonstrated ship detection by radar, and in 1930 Hyland, also of NRL, first detected aircraft accidentally by radar, setting off a more substantial investigation that led to a US patent for what is known as a continuous-wave (CW) radar in 1934.

The effort of developing radar further took momentum in around the 1930s, and countries like Germany, Russia, Italy, and Japan were the pioneers among the developing countries. In fact, in the United States, R. M. Page of NRL began an effort to develop pulse radar in 1943, with the first successful demonstrations in 1936, and in the same year, the US Army Signal Corps begin active radar work,

Fig. 1.5 A Chain Home tower illustration (Great Baddow, Essex United Kingdom)

leading to an effort in 1938 to its first operational system that is known as SCR-268 anti-aircraft fire-control radar (FCR) system and in 1939 to another version as early warning system (EWS), which we know it as SCR-270, and yet its warning during Pearl Harbor attack by Japanese naval aircraft was tragically ignored.

The British scientist demonstrated pulse radar (PR) the same year and by 1938 established the famous Chain Home (Fig. 1.5) surveillance radar network that helped them during the Battle of Britain and remained active until the end of World War II.

Britain also built the first airborne interceptor radar in 1939. With collaboration between the United States and United Kingdom around 1940 even possibly up to now, most radar work was conducted at high-frequency (HF) and very-high-frequency (VHF) wavelengths (i.e., we have described the radar bandwidth later on in this book), but with the British disclosure of the critical cavity magnetron (CCM) microwave power tube and US formation of the Radiation Laboratory at Massachusetts Institute of Technology (MIT), the groundwork was laid for the successful development of radar at the microwave frequency allowing the system to be built at small size scale near submeter resolution that has predominated ever since [18]. This technique approach was taken based on Watson patent in an article on air defense under Bonnier Corporation in popular science [19].

1.3 Radar Types

As we stated at the introductory of this chapter, the fundamental duty of the RADAR based on its acronym that is given is radio detection and ranging and categorized as:

- **Bistatic**: the transmitting and receiving antennas are at different locations as viewed from the target (e.g., ground transmitter and airborne receiver).
- **Monostatic**: the transmitter and receiver are collocated as viewed from the target (i.e., the same antenna is used to transmit and receive). See Fig. 1.6, where R_r is the receiving range and R_t is the transmitting range, with θ angle between them.
- **Quasi-monostatic**: the transmitting and receiving antennas are slightly separated but still appear to be at the same location as viewed from the target (e.g., separate transmitting and receiving antennas on the same aircraft).

Radar functions are categorized as follows:

- **Normal radar functions**:
  - Range (from pulse delay)
  - Velocity (from Doppler frequency shift)
  - Angular direction (from antenna pointing)
- **Signature analysis and inverse scattering**:
  - Target size (from magnitude of return)
  - Target shape and components (return as a function of direction)
  - Moving parts (modulation of the return)
  - Material composition
- **Radar performance**:
  - The complexity (cost and size) of the radar increases with the extent of the functions that the radar performs.

As we have understood so far based on historical evidences described before, radar technology is one of the most advanced innovative technologies of the nineteenth century, and it is used for measuring objects' distance. Because of this,

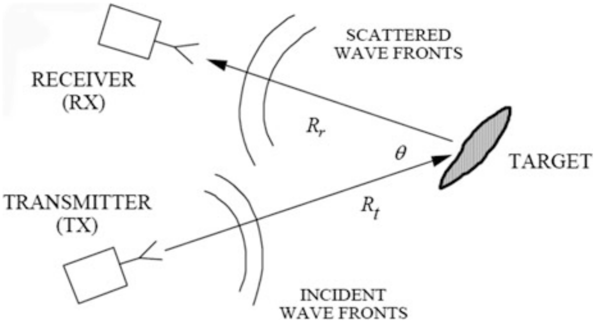

Fig. 1.6 A simple radar configuration and functionality

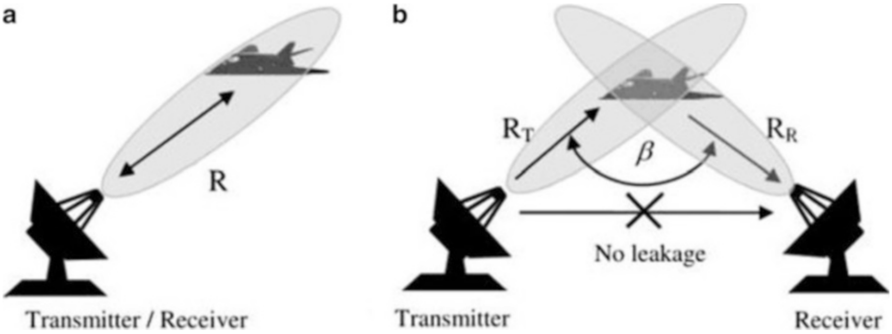

Fig. 1.7 Radar systems: (**a**) monostatic radar and (**b**) bistatic configurations

there has been a variety of radar systems per their application usage and functionality assigned to them as a task for various purposes, and they are classified under various categories. The following list highlights some of the most common radar systems under different functions and used by different commercial and military sectors.

1. **Bistatic Radar**
   Bistatic radar is a radar system that comprises a transmitter and a receiver that are separated by a distance that is equal to the distance of the expected target. A radar in which the transmitter and the receiver are located at the same place is known as a monastic radar. Most long-range surface-to-air and air-to-air missiles employ the use of bistatic radar. In Fig. 1.7 see schematic of monostatic and bistatic radar configuration.
2. **Continuous-Wave Radar**
   A continuous-wave radar is a type of radar where a known stable frequency continuous-wave radio energy is transmitted and then received from any of the objects that reflect the waves. A continuous-wave radar uses Doppler technology which means the radar will be immune to any form of interference by large objects that are stationary or slow moving. See Fig. 1.8.
3. **Doppler Radar**
   A Doppler radar is a special form of radar that employs the use of Doppler effect to produce velocity data about an object at a given distance. This is achieved by sending electromagnetic signals toward a target and then analyzing how the object motion has affected the frequency of the returned signal. This variation has the capacity to give extremely accurate measurements of the radial component of a target's velocity in relation to the radar. Doppler radars have applications in different industries including aviation, meteorology, healthcare, and many others. Figure 1.9 is a presentation of weather Doppler radar.
4. **Monopulse Radar**
   A monopulse radar is a radar system that compares the received signal from a single radar pulse against itself with an aim of comparing the signal as seen in multiple polarizations or directions. The most common form of monopulse radar is the adaptation of conical scanning radar which compares the return from two

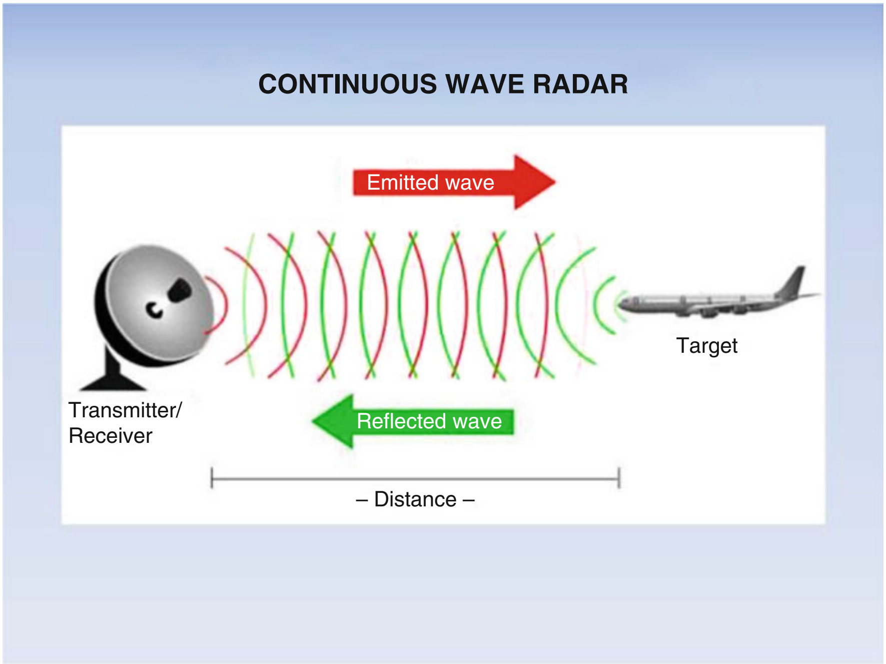

Fig. 1.8 A continuous-wave radar schematic

Fig. 1.9 Weather Doppler radar

directions to directly measure the location of the target. It is important to note that most of the radars that were designed since the 1960s are monopulse radars. Figure 1.10 is an illustration of precision monopulse tracking radar (PMTR).

5. **Passive Radar**

   A passive radar system is a type of radar that is designed to detect and track objects by processing reflections from non-cooperative sources of illumination in the environment. These sources include such things as communications signals and commercial broadcasts. Passive radar can be categorized in the same class of radar as bistatic radar. Figure 1.11 is an image of a civil aviation passive radar.

Fig. 1.10 Precision monopulse tracking radar

Fig. 1.11 Civil aviation passive radar

Fig. 1.12 Test range instrumentation systems

6. **Instrumentation Radar**
   Instrumentation radars are radars that are designed to test rockets, missiles, aircrafts, and ammunitions on government and private test ranges. They provide a variety of information including space, position, and time both in the real time and in the post processing analysis.

   Figure 1.12 is a presentation of a test range instrumentation system.
7. **Weather Radars**
   Weather radars are radar systems that are used for weather sensing and detection. This radar uses radio waves along with horizontal or circular polarization. The frequency selection of weather radar depends on a performance compromise between precipitation refection and attenuation as a result of atmospheric water vapor. Some weather radars are designed to use Doppler shifts to measure the speed of wind and dual polarization to identify precipitation types.

   Figure 1.13 is a presentation of an interactive weather radar system.
8. **Mapping Radar**
   Mapping radars are used to scan a large geographical region for geography and remote sensing applications. Because of their use of synthetic-aperture radar, they are limited to relatively static objects. There are some specific radar systems that can sense humans behind walls, thanks to the reflective characteristics of humans that are more diverse than the ones found in construction materials. Figure 1.14 is a Titan radar imaging system developed by NASA.
9. **Navigational Radars**
   Navigational radars are generally the same as search radars. However, they come with much shorter wavelengths that are capable of reflecting from the Earth and from stones. They are mostly common on commercial ships and other long-distance commercial aircrafts. There are various navigational radars that include

Fig. 1.13 An interactive weather radar system

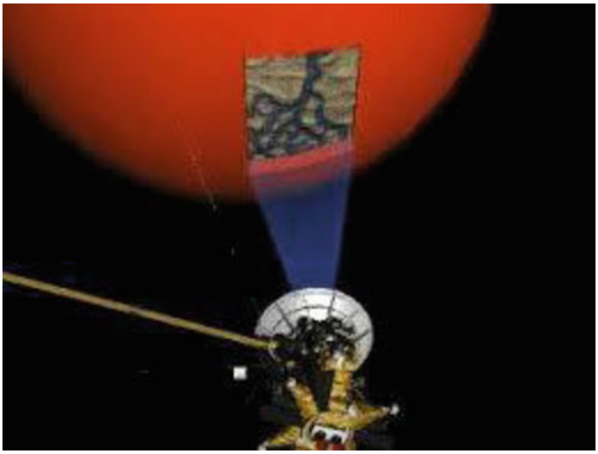

Fig. 1.14 NASA Titan imaging radar

marine radars commonly mounted on ships for collision avoidance and navigational purposes. Figure 1.15 is an image of a navigational radar system in cruise.

There may exist more sub-category types of radar for each of the above categories; however, the above lists are the most common types of radar that are operational today.

Fig. 1.15 Navigational radar cruise system

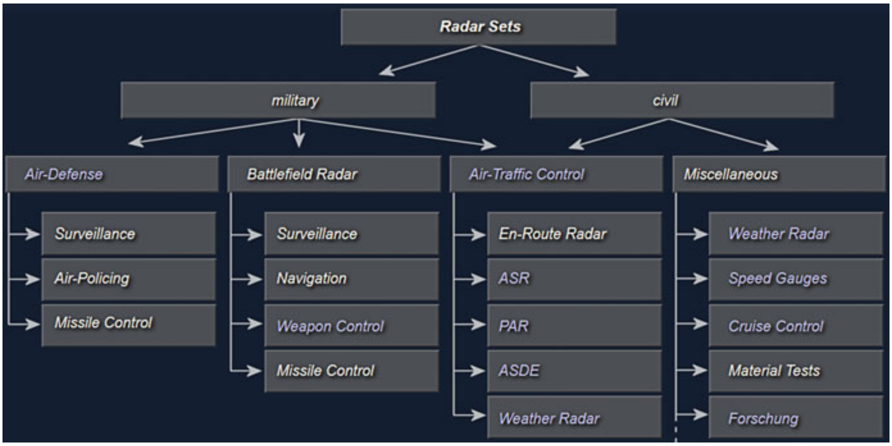

Fig. 1.16 Classification of radar sets based on the designed use. (Source: www.radartutorial.eu)

1.3.1 *Radar Classification Sets*

Radar systems may be divided into types based on the designed use also. This section presents the general characteristics of several commonly used radar systems as illustrated here in Fig. 1.16.

Radar classification can be described as its functionality in the form of two categories and they are as follows.

1.3.1.1 Multifunction Radars

Active array multifunction radars (MFRs) enable modern weapon systems to cope with saturation attacks of very small radar cross section missiles in a concentrated jamming environment. Such MFRs have to provide a large number of fire-control channels, simultaneous tracking of both hostile and defending missiles, and mid-course guidance commands.

The active phased array antenna as it has been described in Sect. 1.4.2.1 comprises flat sensor panels consisting of arrays of GaAs modules transmitting variable pulse patterns and building up a detailed picture of the surveillance area. A typical fixed array configuration system could consist of about 2000 elements per panel, with 4 fixed panels. Each array panel can cover 90° in both elevation and azimuth to provide complete hemispherical coverage.

1.3.1.2 Multi-target Tracking Radar

Multi-target tracking radar (MTTR) operational functions include:

- Long-range search
- Search for information with a high data rate for low-flying aircraft
- Search for information with high resolution of close-in air targets
- Automatic position and height information
- Simultaneous tracking of a lot of aircraft targets
- Target designation facilities for other systems

Their classifications are briefly described in the following context as:

Air Traffic Control Radar Sets	**En Route Radar**
 Air traffic control radars are used at both civilian and military airports. Airborne radar is designed specially to meet the strict space and weight limitations that are necessary for all airborne equipment. Even so, airborne radar	 "En route" radars operate in L-band mostly and display radar data to controllers in the en route environment at a maximum range up to 450 km.

(continued)