Passive and Low-Frequency Radar: Theory in Detection of Stealth Aircraft

by

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The desire for technological supremacy to achieve an advantage in warfare has existed for millennia, from the pre-historic to the present. As new technologies come about they impact both the capability and thought processes within the forces which incorporate them. Early examples are the formation of Greek phalanx which revolved around the hoplite which allowed the Greeks to dominate warfare for centuries, until the advent of the Roman legion at which time the balance of power shifted. The past century has seen the most rapid and powerful improvements in technology. In 1909 horse-mounted cavalry were the best tool to achieve shock and surprise on the battlefield; in 2009 stealth aircraft are the weapon of choice. Unlike any weapon before however, a readily available defence against stealth aircraft has not been developed. Many theories exist on how to counter such aircraft but very few have been put to the test. With progression in radar and computer technology it has now become possible to detect stealth aircraft, although many improvements remain before the systems are accurate and consistent enough to provide targeting data to air defence systems.

Important to understanding the implications of stealth technology is the understanding of radar. Radar comes in many forms each with a distinct purpose and each with concrete limitations. Radar (Radio Detection and Ranging) works through wave detection principles. Essentially, a transmitter sends out a signal wave which will bounce off of any objects in its path, returns to a receiver which then computes the differences in return times to determine the location of an object. Early radar systems, and certain current systems, were two-dimensional systems, giving a bearing and range but were unable to provide altitude readings. During the 1960's however systems were developed to provide three-dimension aerial pictures, although these systems were generally large and cumbersome, meaning they were relegated to being fixed ground stations. In the late 1970's and early 1980's these systems had become small enough to become vehicle mounted, allowing for more accurate tactical radar pictures, as opposed to their previously strategic uses. Unfortunately for the air-defence community, by this time low observable stealth aircraft had arrived, making such advancements obsolete and air-defence stations more vulnerable than ever. Radar can be broken into two general categories, active and passive, with multiple methods of operation within each category.

Active radar is by far the most common form of radar and comes in various forms including; bi-static, multi-static, doppler, pulse-doppler, and phased-array variations. Each of these systems has its own set of advantages however the most popular systems from a military perspective are phased-array and pulse-doppler systems. The phased array system and pulse-doppler system both offer three-dimensional pictures of the battle space and in current iterations are able to track multiple targets simultaneously. Phased array stations work by sending out multiple frequency signals with quickly changing directions from large transmitter/receivers in a geometery that enhances return from the area of interest while reducing return from unwanted areas.[1] The most current iteration of this system is the PAVE/PAWS system operated by the United States and developed and manufactured by Raytheon. Advantages to this system are its long range, low maintenance, and low rate of false alarms. Doppler radars work somewhat differently. Pulse-doppler works by sending out pulses of radio waves and measuring the change in frequency upon return to the sending unit. The advantages of such a system are three-dimensional representation of an object plus the objects vector. Disadvantages are the high possibility of false returns should modulation of frequencies not be correct and the

[1] (Raytheon, 2009)

high complexity of the signal used. [2] The largest disadvantage to these systems is that they are easily detected by the enemy, and therefore make easy targets. "The largest disadvantage is that the enemy knows the location of the radar (he can easily detect its radiation) and can avoid it or attack it with weapons or electronic countermeasures."[3] In addition modern stealth aircraft have been designed from the drawing board specifically to counter these types of radar, making current phased array and pulse-doppler designs ineffective.

Passive radar is a far less common form of radar, however it was invented during the same time period as the first active radar systems. Much fewer resources have been put into the development of passive radar systems due to the many dependencies and downfalls of such systems, although modern advancements can overcome many of these shortcomings. Passive radar's main advantage over active radar is that since it does not radiate a signal, only receives, it cannot be detected by anti-radiation weapons.[4] Passive radar can be found in two forms, bi-static and multi-static. The difference between the two is simply in the number of stations sending and receiving signals. Bi-static has one transmitter with a receiver in an alternate location while multi-static can have multiple transmitters and receivers. The biggest problem with passive radar's is set-up geometry. Due to the scattering effects of the wave's[5] and the problems associated with filtering background noise[6], geometry needs to be perfect to maximise potential, which is rarely possible in a combat environment. The biggest advantage to passive radar systems, aside from being untraceable, is that they can receive their signals from any normally emitted

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[2] (University of Iowa, 2006)
[3] (Delaney, 1990)
[4] (Budiansky, 1987)
[5] (Jong & Yoram, 2001)
[6] (Herman & Moulin, 2002)

signature such as FM and TV transmissions.[7] Tests with HDTV signals has shown detection out to ranges of 400miles under ideal conditions[8], a range at which an aircraft has no offensive capability. This compatibility with civilian systems ensuring illuminating sources will almost always exist, though the strength of the signals may not be powerful enough.

Stealth aircraft have been intentionally developed since the 1960's beginning with the Lockheed SR-71 spy plane, which was the first to be designed with stealth properties in mind albeit as secondary characteristics. Before this, many designs existed which incorporated stealth, notably the Avro Vulcan, however these properties were unknown to the designers at the time. Lockheed has, since the 1960's, become the world leader in stealth technology producing three of the four current aircraft considered to be "low-observable" aircraft. These include the F-117 Nighthawk, the B-2 Spirit, and the F-22 Raptor. Boeing has produced the most recent, the F-35, however this aircraft is less technologically advanced than its Lockheed counterparts primarily due to budget considerations. Each of these aircraft has introduced new technologies making them increasingly difficult to detect. Currently the United States is the only country known to possess full stealth technology, with most other first-world militaries possessing aircraft with only partial stealth features such as the Eurofighter.

The principles behind stealth technology, somewhat ironically, were developed in the post-war U.S.S.R. by Pyotr Ufimtsev. In his reports Ufimtsev proposed that the most effective way to counteract the ability of radar was to scatter the radar waves from the

[7] (Erhman & Lanterman , 2005)
[8] (Erhman & Lanterman, 2005)

transmitter to directions where receivers would be unlikely to be located.[9] At the time technology was unavailable to produce such aircraft as the shapes required to deflect and scatter radio waves to such angles could not be incorporated into designs until the advent of fly-by-wire. Based upon Umitsev's work it was discovered that, "the ideal shapes to return radar would be dihedral or trihedral corners, such as the tailfins and wings of an aircraft as well as the turbine blades of an engine."[10] The F-117 was the first aircraft to fully utilize research in scattered waves, as it avoided right angles, used serated edges on panel gaps, and buried the engines deep within the airframe all in an effort to reduce radar cross signature (RCS).[11] The B-2 bomber took this theory to a more extreme level by eliminating the tailfin assembly altogether, although it was also the first stealth aircraft to introduce Radar Absorbent Materials (RAM). The incorporation of RAM is what sets apart first generation stealth aircraft (F-117) from second generation aircraft (B-2, F-22, F-35). RAM uses the incorporation of multiple materials to absorb the wave energy transmitted by a radar, thus reducing the strength of the return.[12] As with any design however there are advantages and disadvantages. "Grid-based methods are applied in the low-frequency domain. In contrast, asymptotic ray-theoretic techniques and their extensions are often resorted to in the high-frequency domain."[13] Thus, it is probable that RAM in stealth aircraft is built around the ray-theoretic technique as anti-aircraft systems use high frequency radar systems. Unfortunately this cannot be known for certain as the materials and coating specifications are still highly guarded secrets of the USAF and Lockheed Martin. Thus, the two primary principles of current stealth aircraft are aircraft

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[9] (Browne, 1991)
[10] (Knott, Shaeffer, & Tuley, 2004)
[11] (Crickmore, 1999)
[12] (Vinoy, 1996)
[13] (Vinoy, 1996)

shaping as proposed by Ufimtsev, and the use of RAM coatings as developed by Lockheed Martin's Skunk Works.

The efficacy of stealth aircraft in defeating traditional radar systems and as a result their subsequent air-defence systems was most notably demonstrated during the First Gulf War, where the F-117's of the USAF effectively disabled Iraqi air defence within days, allowing for the destruction of all strategic targets within weeks. "Despite the impressive defensive gauntlet at Iraq's disposal, the success of the F-117 during the Gulf War was staggering. Critical air defence targets that would have taken repeated raids from large numbers of conventional aircraft were destroyed by single F-117 strikes. Specifically, during the first two-weeks against the full array of Iraqi defences, F-117's destroyed more than 60% of targets without a single loss."[14] To further drive the point home that conventional detection systems were outdated, the Iraqi air defence of the day was not armed with antiquated weaponry but instead was armed with state-of-the-art anti-aircraft radar and missiles from the former Soviet Union. This demonstrated the need for detection capability of stealth aircraft and prompted several theoretical solutions. The most promising amongst these were the theories on low-frequency and passive radar systems.

Low-frequency radar is not in itself a specific type of radar but rather a possible method of operation for conventional active radar systems. Low-frequency radars are the best technology to develop to counter the threat of stealth aircraft as stealth shaping does not help against low frequency waves due to half-wave resonance effects. These are returns generated when the wavelength of the wave is roughly twice the size of the target, thus returning one full wavelength of measurement to the receiver antenna allowing a

[14] (Crickmore, 1999)

picture to be obtained.[15] Currently these pictures are less than adequate for target acquisition due to a number of effect's, however certain methods are being developed to cope with the lack of accuracy. The biggest problem facing low-frequency radars is the detection of returns from undesirable sources. As radar cross section increases exponentially with reduction in wavelength[16] undesirable sources (wildlife, rain, clouds, etc.) are more easily detected and dilute any possible accurate image of an aircraft. Additionally lower frequencies are commonly used by civilian systems, thus having the potential to interfere with the radar picture. Digital signal processing and various computer filters are in development to help reduce these effects[17] and have already been shown effective against meteorological patterns. The other downside to low frequency systems is the required size of transmitter and receiver, making any mobile system near impossible. This, as with all technology is likely to become miniaturized in the future, allowing more mobile applications better suited to the air defence community.

Passive radar is also, in theory, an effective way to detect stealth aircraft due to the operating methods of the aircraft themselves and the technologies they incorporate. Passive radar technologies are ideally suited to the detection of stealth aircraft assuming the geometry they use is acceptable. Since stealth aircraft rely on shaping to deflect waves away from the aircraft at angles preventing a return signal to the sending unit, passive radar, specifically of a multi-static setup is able to detect the aircraft. Due to the nature of passive multi-static radars, where signals are sent from one location and receivers are at another separate location, the radio waves will reflect off the aircraft away from the transmitter, however this reflection may be a direct return to a receiver

[15] (Knott, Shaeffer, & Tuley, 2004)
[16] (Knott, Shaeffer, & Tuley, 2004)
[17] (Lepingwell, 1989)

antennae.[18] Thus with multiple antennae, the reflections will be received at one or more stations, allowing a two-dimensional location to be gained. Passive radar comes with its own set of unique advantages, prime amongst these are high survivability and in particular, the ability to use any transmitted wave as a radar wave. For example TV and radio signals can be used[19] essentially guaranteeing a source of radiation in any large scale conflict. The largest detractor to passive radar is that unless the antennae in a multi-static array are at extremely varied altitudes a three-dimensional picture cannot be gained.[20] This means target estimation must be used, introducing a degree of inaccuracy to the system.

The combined use of low-frequency and passive radar systems can be used to detect stealth aircraft assuming the operator knows the deficiencies in each of the systems. When used in conjunction with other target acquisition assets, such as IR and satellite radar and imaging, the detection of stealth aircraft, in theory, is possible. To date however, radar technologies, specifically computing powers necessary to decipher background noise from legitimate targets, have not been developed to a sufficient degree to provide the accuracy and consistency required for an air defence system.

Although many observers are of the opinion that radar systems are becoming obsolete because of stealth technologies and the widespread availability of anti-radiation missiles, in fact the opposite is true. Throughout the 1980's and 1990's detection of stealth aircraft was a low probability endeavour as radar was outclassed by stealth technology. Radar's were unable to reliably detect stealth aircraft and when trying to do so presented an easy target for any aircraft equipped with anti-radiation missiles.

[18] (Erhman & Lanterman, 2005)
[19] (Erhman & Lanterman, 2005)
[20] (Jong & Yoram, 2001)

However, continuing developments in filtering technologies and frequency variation are enabling radar to once again gain the upper hand, although at a cost that is not yet economical for wide-scale production. Filtering the background noise that is currently encountered with passive and low-frequency radar is the biggest obstacle to overcome, however with more advanced computing power available annually it will not take long for these filtering systems to be developed. Additionally, low-frequency and passive radar systems offer the advantage of providing poor targets for anti-radiation weapons, increasing the probability of survival for ground based air-defence systems. These new radar technologies, when combined with satellite, and infra-red detection methods will be able to effectively disable current stealth technologies advantages. What remains to be seen however is whether the advancements in radar technology will be able to keep pace with development of stealth technology, the latter of which has a thirty year head-start.

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