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ADVANCES OF RADAR TECHNOLOGY

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Modern radar technology has evolved in a number of ways that the founders of the technology would have been hard-pressed to imagine, for example "synthetic aperture radars (SARs)" for ground imaging; "multimode radars" that can switch between a number of functions; "active array radars" consisting of an array of RF modules; and "over the horizon" radars with extraordinary range. As mentioned, early bombing radars were able to give very rough maps of terrain that could identify bodies of water and large structures. A radar that could actually provide an image of the ground was developed in the late 1950s in the form of "side looking airborne radar (SLAR)". The basic idea was to mount a long radar antenna, usually in a "canoe" fairing under an aircraft, that generated a narrow beam to the sides. The echo returns were recorded on a filmstrip that gave a map under the aircraft's flight path. The maps were surprisingly detailed given the relatively primitive technology, but they had some quirks of perspective: the scans of terrain were performed to the sides of the flight path of the aircraft, and to no surprise, that didn't result in the same kind of map geometry that would have been obtained from a mosaic of pictures of the same terrain taken by an aircraft flying directly over each segment of the terrain. The SLAR images similarly suffered from "shadowing", where high ground hid terrain from the radar, resulting in the masked terrain showing up as a black shadow in the filmstrip. The pioneering radar ground surveillance system was the Grumman OV-10 Mohawk, which was used by the US Army with considerable success during the Vietnam War as a battlefield reconnaissance aircraft. The Mohawk could carry film cameras and either an infrared sensor or a Motorola AN/APS-94 SLAR, with the SLAR antenna carried under the fuselage in a long rectangular box. SLAR imagery was recorded on a long filmstrip on board the aircraft, or could be relayed to a ground station to be similarly recorded there. During the 1960s and 1960s, development work focused on a much more sophisticated version of SLAR, known as "synthetic aperture radar (SAR)". With traditional SLAR, the antenna sent out a pulse and got a return, which was recorded on film. With modern SAR, the antenna sends out multiple pulses to cover the same ground as the aircraft carrying the antenna moves along. The data from pulse returns is stored and processed to give a combined image. This creates an effective antenna length equivalent to the distance the antenna moves during the series of scans, a "virtual array" that provides much higher resolution than a traditional SLAR with its "real array". SAR is based on an extension of the concept of range bins. Suppose a SAR system has a "queue" of sets of range bins, say eight for example purposes. The SAR system sends out eight radar pulses, with the return from each being stored in one of the sets of range bins in the queue. All eight sets are then summed to average out the noise and enhance the actual echoes, resulting in one line of a radar image that has much more clarity than the single return from a SLAR real array. Now the SAR sends out a ninth pulse. Since there are only eight sets of range bins, the data from the oldest of the previous eight scans in the front of the queue is discarded, the other seven sets are "moved up" in the queue, and the return from the new scan is stored in the empty entry in the back of the queue. These eight sets of values are then summed to generate the next line of the SAR image. This scheme is repeated for all successive scans. The effective antenna length of a SAR is limited by the phase shift of the returns from the target; as the phase shifts, it becomes more and more difficult to sum the returns, though processing can compensate for the phase changes to an extent. It is also possible to use a phased-array antenna to "focus" on a specific target in a "spotlight" mode to reduce phase shifting and improve resolution. Of course, the processing system can perform GMTI processing, useful for combat targeting. Modern "SAR-MTI" systems can be programmed to spot targets in motion. SAR can give high-resolution maps of ground features, but it doesn't provide much in the way of enhanced resolution for moving targets. There is an associated scheme known as "inverse SAR (ISAR)", where the rotational motion of the *target* is used to improve resolution. Incidentally, early SARs used optical processing systems based on lenses and photographic films. This was an inflexible approach, demanding that the observing platform operate at a specific height over the terrain to be imaged; it was best used with satellites that orbited at known altitudes. The JSTARS carried operator consoles to allow ground activities to be tracked onboard. Data can also be relayed to ground force terminals or other aircraft using a datalink system. SARs are now available even for small aircraft and unmanned aerial vehicles (UAVs). The imSAR company of the US sells a "NanoSAR" system with a weight of all of 900 grams (about two pounds). It has a range of about a kilometer (3,300 feet), a resolution of about a meter (1.1 yards), and can generate real-time SAR imagery over a video feed for relay back to a ground station.

As the description of the JSTARS AN/APY-3 radar suggests, the integration of computing with radar was a true revolution in radar technology, resulting in modern radars that compare to their World War II ancestors in much the same way that a 21st-century personal computer compares to a mechanical desk calculator. In the early days of radar, tracking targets was a manual task. In control centers for air-defense networks or on warships, the raw sensor readings were reported to workers who would mark the positions of targets on a transparent board. With a modern digital radar, the computer now handles the job of displaying radar data to the operator, and so the data can be displayed in any format that is convenient -- in a B-scope or C-scope plot, overlaid on a map, and with "symbology" such as text or geometric figures to help interpret the data. The display system can even in principle give a three-dimensional color scene representation, along the lines of a "video game for real". Digital capabilities allow a radar to change its functionality at will, resulting in the modern "multimode radars" carried by combat aircraft. Modern multimode radars may incorporate "low probability of intercept (LPI)" features that prevent the radar from tripping off alarm systems in a target. LPI features include using a narrow beam that is hard to spot from off its boresight; only transmitting radar pulses when necessary; spreading the radar pulses over a wide band so there will only be a very small signal on any one band; or varying transmission parameters such as pulse form, frequency, or PRF, jumping around in an unpredictable fashion, not staying in one place long enough to register. However, techniques such as jumping around in frequency – or "frequency agility" as it is known – do make it difficult generate coherent signals for pulse Doppler operation. Another advanced feature in the latest multimode radars is to match radar "signatures" of an unidentified aircraft target against a stored library to determine what type of aircraft it is. Such a "non-cooperative target identification (NCTI)" capability allows a fighter to determine if a target is highly likely to be a hostile even when it's "beyond visual range (BVR)" so that it can be engaged with long-range AAMs. Of course, NCTI requires a lot of processing power. Typical US multimode radars for fighters include the Hughes AN/APG-63 and improved AN/APG-70 for the Boeing F-15; the Hughes AN/APG-65 and later AN/APG-73 for the Boeing F/A-18; and the Hughes AN/APG-66 and later AN/APG-68 for the Lockheed Martin F-16. The Northrop Grumman B-2 flying-wing bomber carries the Hughes AN/APQ-181 radar, with some similarities to the AN/APG-70 of the F-15 but tailored for the navigation and bombing roles. In fact, all these radars share some common technologies and features, but have different power capabilities and form factors to adapt them to their particular aircraft platform. Naval helicopters also may be fitted with multimode radars to provide navigation assistance, hunt for targets, and cue missiles; a well-known example is the British Ferranti Seaspray radar, used on the popular Westland Lynx helicopter. The fact that the Seaspray isn't so different from a fighter multimode radar is emphasized by the fact that it was modified for use in the BAE Sea Harrier jumpjet strike fighter as the "Blue Fox". It was admittedly something of a cheap-and-simple solution, with the Sea Harriers later refitted with the Ferranti "Blue Vixen", which was a state-of-the art fighter multimode radar. A digital radar can become part of an integrated system, for example with an aircraft radar linked to infrared and other sensors, defensive countermeasures, and database information, and a computer performing "sensor fusion" to give the pilot a picture of the current situation. The scheme can be extended to other platforms using radio datalinks, with an AEW aircraft monitoring an intruder on its radar and sending the tracking data to a fighter moving to intercept the intruder. The fighter pilot would see the radar data on the fighter's display, but the fighter would not be transmitting radar pulses that gave away its own position. It is possible to build a radar that has "over the horizon" range, obtained by "bouncing" or "backscattering" radio waves off the ionosphere, the ionized layer at the top of the atmosphere. Such an "over the horizon backscatter (OTHB)" radar operates in the low HF band, since microwave frequencies will punch right through the ionosphere. Even at HF frequencies, OTHB is tricky. The exact properties of the ionosphere can vary, sometimes wildly, over the course of a day, and even when it's stable it's not like a radio "mirror", crisply reflecting radio waves back down towards the ground, instead tending to smear out and scatter pulses. Of course, along with a range of thousands of kilometers comes extremely weak returns. Even at best, OTHB can do no more than give the general location of a target, making it only useful for early warning and the like. OTHB requires a good deal of sophisticated processing, and it wasn't practical until the late 1950s. Given the long wavelengths, an OTHB antenna array is a sprawled business, stretched out over kilometers. Some OTHB radars have used FM-CW to maximize signal energy, and such systems require separate transmit and receive antenna arrays. The radars were bistatic, with the triple transmitter arrays and triple receiver arrays at separate sites about 160 kilometers (100 miles) apart. Bistatic radars have been around since the beginning of the technology. As mentioned, many early fixed-station radars were bistatic, with transmitter and receiver at separate locations, and SARH missiles like the Sparrow are effective bistatic systems as well. The bistatic scheme works for the Sparrow even though the missile is moving because it doesn't try to estimate range, it just follows the radar reflections to the target. The missile would be hard pressed to use these signals to estimate range, because it has no clear notion of when the transmitter sent the pulse or where the transmitter was when it did. However, work is currently underway on advanced bistatic radars that use datalinks and synchronization systems to allow one platform to receive radar echoes from pulses sent out by another. The advantage of this scheme is that it would allow platforms to sense targets without generating emissions themselves and giving themselves away. This leads to the notion of a purely "passive" radar system. The Germans actually developed such a thing during World War II, if under very special circumstances. The system, known as "Kleine Heidelberg", intercepted pulses from the British Chain Home floodlight radar system, and then picked up echoes off targets from those pulses with a directional antenna. This scheme was only workable because Chain Home was a floodlight system. If it hadn't been, the Kleine Heidelberg receiver would have only picked transmitter pulses when the transmitter was pointed directly at it. The positions of the Chain Home sites were also precisely known. There was no way to use such a simple approach with more advanced radars than Chain Home. The introduction of computing power to radar has revived the concept. In the 1990s, Lockheed Martin demonstrated a passive radar named "Silent Sentry". It was based on a "passive coherent location (PCL)" scheme that monitored both direct and echo signals from one or more commercial FM radio or VHF/UHF TV stations, and used intensive parallel processing from computer workstations to sort out the information. The Silent Sentry used a fixed array measuring some 2.4 x 7.6 meters (8 x 25 feet), mounted on the side of a building, with the radar monitoring local FM radio broadcast stations to track airliner traffic at a nearby airport. Silent Sentry could track targets with a radar cross section of ten square meters (107 square feet) from 200 kilometers (125 miles) away. The flat array had a viewing angle of 105 degrees in azimuth and 50 degrees in altitude. A system with a 360-degree azimuth view would use four arrays. From the point of view of the radar electronics system itself, a passive radar is fairly simple, with the real heavy lifting performed by sophisticated signal processing. The scheme wasn't accurate enough for targeting. However, FM signals tend to hug the ground through diffraction as surface waves, and in fact the computer system behind the radar included a terrain database to help compensate for the effects of surface features. This low-altitude capability made the Silent Sentry potentially useful for identifying cruise missiles or drug smugglers. Work on passive radars is also underway in Europe. Passive radars are seen as a way to complement, not replace active radar, helping plug holes in a radar screen. Passive radars are not immune to jamming; broadband jamming will wipe out the signals they use to track targets, and they are just as easily deceived by decoys as any other radar. Detecting low-flying cruise missiles is a high priority in military radar development. Such systems are based on radars operating in two or more frequency bands. Low-frequency UHF or L-band radars are better than high-frequency radars for picking up low-RCS targets at long range, but they suffer from noise interference and low resolution. Modern signal procession algorithms can cut through the noise, but for resolution the low-frequency radar has to be ganged with a higher-frequency S-band or X-band radar. Such a multi-frequency radar system would also be able to penetrate jungle and forest canopies to identify targets hidden underneath. The biggest problem is that low frequency radars also tend to be extremely bulky and difficult to fit into an aircraft of any reasonable size, and no such system is anywhere near introduction. * Finally, work is underway to build "ultrawideband" radars with long-wavelength ground penetration ability to detect mines and unexploded ordnance. A number of efforts are being pursued along this line, with experiments using airships to hunt down mines. Presumably an operational system would include some sort of projectile or energy beam weapon to actually destroy the mines from a safe distance.