Advancing counter-stealth radar technologies

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The Lockheed F-117A Nighthawk, recently retired, was introduced over a quarter century ago. Since then the US monopoly on stealth has dissipated.

A recent announcement in Moscow that 100 large NNIIRT/Almaz-Antey 55Zh6M Nebo M radar systems would be procured for Russia's air defence forces received no attention in the Western mass media, or even the trade press. Yet this was a significant development by any measure, as the Nebo M is a highly capable multiple band three dimensional high mobility radar system developed specifically for the detection and tracking of stealthy fighter aircraft and UAVs, in turn providing tracking data feeds for Surface Air Missile batteries and interceptor aircraft. Arguably, it is the world's most capable counter-stealth radar system entering full rate production with a large volume order.

Until now, counter-stealth sensors have been niche low production volume designs, often limited in capabilities, accuracy and mobility. The Nebo M announcement marks the transition from developmental designs and niche products to mainstream Integrated Air Defence System (IADS) components deployed en masse; ultimately, available in quantity on the global arms market to any nation with the interest and the available funds. Detractors of stealth will inevitably declare this to be the "death of stealth", which fortunately it is not. What it does represent is the practical death of 'economy stealth' and 'reduced observables' aircraft, which have been so politically popular in Western nations over the last decade, usurping funding which should have properly been invested in 'real stealth' aircraft such as the F-22A Raptor and B-2A Spirit, or 'Batwing'.

The Russian decision to invest on a large scale in a capable counter-stealth radar parallels the decision to invest on a similar scale in the T-50 PAK-FA stealth fighter as a replacement for the venerable and still potent T-10 Flanker series, and the current investment in the PAK-DA (Perspektivniy Aviatsionii Kompleks Dal'noy Aviatsii), which is intended to be a Russian analogue to the B-2A, and a replacement for the Cold War era fleets of Tu-22M3 Backfire C and Tu-160 Blackjack supersonic heavy bombers.

Concurrently, increasing numbers of new Chinese prototype radars operating in the favoured one metre VHF wavelength band are being observed. It is not known how well the PLA has progressed in this area.

What is clear is that Western air power now faces its single biggest challenge since the early 1980s, when the Soviets effected massive advances in technology, and matched key United States capabilities of the pre-stealth era. The 1980s F-117A Nighthawk and 1990s B-2A Spirit were the magic bullet capabilities which rendered these Soviet developments ineffective, but this is no longer the case.

At present there is no such magic bullet available to the Western world, which has allowed development funding in stealth and counter-stealth technologies to wither away during the past decade. Available funding has been assigned to 'porkbarrel' programs intended to recapitalise legacy fighter fleets with designs built to defeat Soviet-era threat systems. The politically imposed early termination of the F-22A Raptor production line clearly indicates a lack of appreciation of what is really happening in the world of air power, and of the enormous strategic risks this introduces for all Western nations.

This is the price the Western world is paying for elevating marketing, sales, and public relations in defence planning over the less attractive and exciting hard science that drove critical planning decisions through the Cold War era.

The Limitations of Stealth

Stealth remains by far the best technique for penetrating hostile air defences, and is both more effective and more durable than jamming, since the latter requires highly specific knowledge of opposing sensors. Stealth works by reducing the detectability of an aircraft or missile, to the extent that the stealth vehicle cannot be seen, or presents as a faint and intermittent target.

Stealth designs are primarily optimised to defeat radar, which is the longest ranging and most accurate type of sensor employed, and it penetrates adverse weather far better than optical sensors such as infrared or visible band imagers.

The most effective technique by far in stealth design is shaping the vehicle to bounce impinging radar illumination away in directions other than back to the illuminating radar. The notion that absorbent or lossy skin coatings can do better is an appealing popular myth, but one that crumbles the instant real materials with credible thicknesses are assessed. What absorbent materials are best used for is to suppress what reflections remain, once shaping has done its task.

Popular perceptions of stealth, especially propagated in mass media, appear to have little connection with the hard science involved. The notion that stealth confers invisibility to all radars from all directions is perhaps the most pernicious aspect of this mythology, the belief in which has been actively encouraged by defence contractors and government bureaucracies, usually to justify purchases of underperforming stealth or indeed 'quasi-stealth' products.

The ground truth is much less attractive – radars operate across a wide range of wavelengths, from the HF band at tens of metres up to the Ka-Band in millimetres. Devising stealthy shapes that are effective from all directions against all wavelengths is simply impossible, at best a real design can aim to make the vehicle very stealthy against radars in some bands, from some directions.

By far the best performer to date is the Northrop B-2A Spirit heavy bomber. Its superlative shaping design is effective from the metric VHF band up to the sub-centimetric Ku/K/Ka-bands, and effective from all azimuths, providing a genuine "all aspect" stealth capability.

Fighters have generally been optimised by shaping to perform best between the decimetre S-Band and sub-centimetre Ku-band, since these are the bands in which most surveillance radars, acquisition radars, Surface to Air Missile engagement radars, fighter-borne air intercept radars, and missile radar seekers operate.

Optimisation of stealth shaping by aspect varies widely in fighter designs, with the F-22A Raptor remaining by far the best design to date, with excellent stealth performance in the nose and tail sectors, and very good performance from the sides. Computer modelling of later designs – the F-35, Russian PAK-FA and Chinese J-20 - shows significantly worse stealth performance from behind, and in most instances, from the sides. This is not open to argument, as sufficient high quality images are available to construct accurate shaping models, and perform simulations using accurate software models.

A curious aspect of these poor design choices in stealth shaping is that not all of them were necessary, and appear to reflect a lack of discipline in design offices where other criteria were put first. In the F-35 the choices were driven by the STOVL variant configuration and a marketing want for 2,000 lb internally carried bombs, in the PAK-FA achieving extreme manoeuvre performance, and in the J-20, most likely a few per cent in supersonic drag improvement.

The major strategic issue over the coming decade will be the design, production and proliferation of counter-stealth sensors, built primarily to exploit weaknesses in existing stealth designs. Since shaping is fixed in the basic design of aircraft, there are no meaningful upgrades that can be performed once a design is established and in production. Claims otherwise are simply marketing mythology.

Counter-Stealth Radar Systems

The flagship of the Russian counter-stealth radar effort is the digital 55Zh6M Nebo M radar system. This design is a genuine three dimensional AESA or active array radar system, with three individual networked radars on three separate high mobility BAZ-6909 8x8 vehicles, and a fourth vehicle which performs data fusion from the three radars, and target tracking. One radar operates in the VHF-band, one in the L-band, and one in the S or C-band. The VHF-band RLM-M radar is the largest mobile 3D VHF-band radar ever built. The design could accommodate configurations with different mixes of radars such as replacing the C or S-band RLM-S component with an L-band RLM-D or VHF-band RLM-M. The use of networked data fusion permits this system to cue the RLM-S and RLM-D components to stealth targets detected initially by the RLM-M component.

The Nebo-M evolved in part from the earlier 1L117 Nebo SVU mobile VHF-band radar, at least one example of which was sold to Iran some years ago. The Nebo SVU included some sophisticated anti-jamming features. Curiously the Nebo-M's numerical designation is based on the very different 55Zh6UE Nebo U/UE Tall Rack, a gargantuan fixed 3D VHF-band radar with a characteristic and

NNIIRT 55Zh6UE Nebo UE.

NNIIRT 1L117E Nebo SVU.

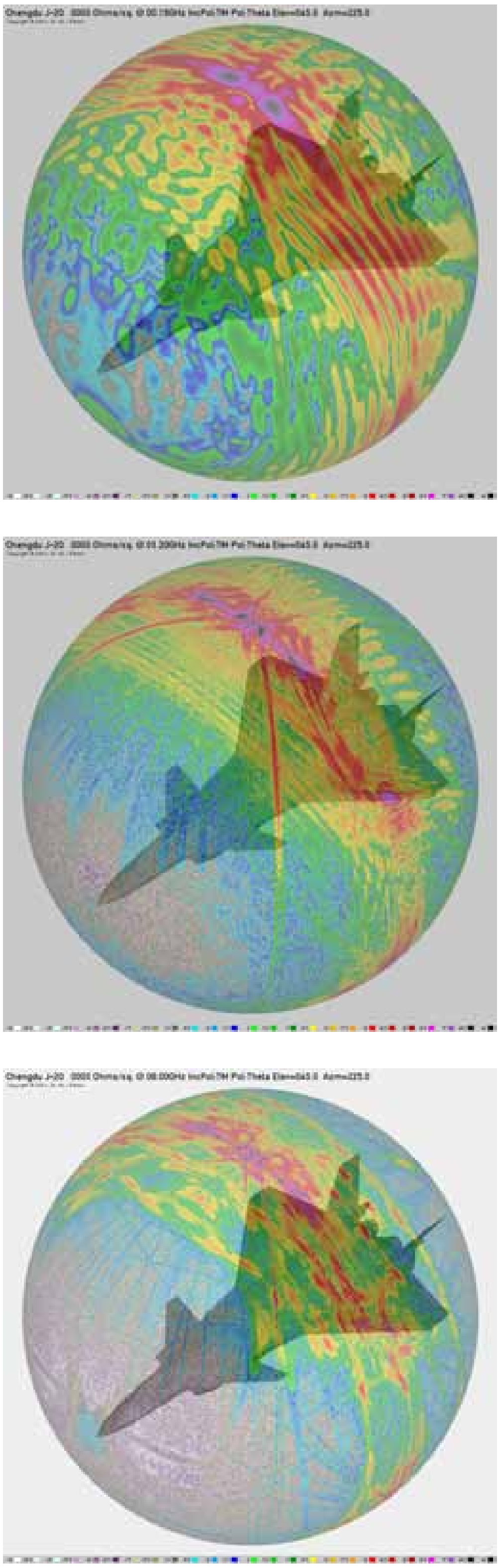
NNIIRT 55Zh6M/ME Nebo M/ME.

Rezonans N/NE.

KBR Vostok E., fully deployed, showing the innovative Kharchenko loop antenna design.

CETC/CPMIEC JY-27.

KBR Vostok E.



Chengdu J-20 radar signature in the VHF-Band, L-band and X-band. As the wavelength increases, the stealth performance degrades. In the VHF-band the aircraft can be tracked at tactically useful ranges.

unique inverted T shaped antenna.

These systems are supplemented by the Rezonans N/NE marketed by Rosoboronexport as a 'Stealth Air Target Early Warning Radar'. It is a large multistatic relocatable VHF-band radar system, carried on several vehicles. Technical disclosures have been scarce.

China's CETC/CPMIEC has also been very active in this area, following their earlier YJ-27 VHF-Band radar. The recently disclosed VHF-band HK-JM with cited 300 km range, and the HK-JM2 with cited 500 km range, are genuine mobile radars with integrated telescoping and elevating mast systems.

The third player in this market is Belarus, where KB Radar are selling the modern digital solid state Vostok D and E VHF-band radar, a high mobility design which can stow and deploy in as little as 6 minutes, almost as quickly as a SAM battery. The Chinese HK-JM series is modelled in part on the Vostok series, but using older antenna technology than the innovative Belarus design.

Counter-Stealth Concepts

Counter-Stealth or Counter-Very Low Observable (CVLO) techniques encompass possible techniques that overcome the effects of stealth design methods. While many technologies and techniques have been proclaimed to be CVLO panaceas, closer examination suggests otherwise.

Broadly, there are two approaches in overcoming a stealth design. One is the brute force approach of finding ways of making a sensor that is much more sensitive, able to find a much fainter target; the other is to build a sensor that can see the stealth design in some area in which it was not designed to be stealthy.

The brute force approach in radar design usually manifests in increasing the peak and average emitted microwave power the radar produces. This is usually not cheap, and often introduces other problems such as providing enough power to drive the radar, getting rid of waste heat from the radar, and making sure key components in the radar are not overstressed electrically or thermally. This is a commonly favoured approach in land based or naval radars, as the requirements can be challenging for compact airborne radars. Due to the inverse square law behaviour of radars, maintaining detection range against a target which reflects 1/100 of a conventional target, requires a 100-fold increase in radar emitted power. While doubling or quadrupling power output in a radar may be feasible, increasing it tenfold or hundredfold usually is not.

Two techniques which can alter the radar's 'duty cycle' are to increase the density of pulses the radar emits, and to increase its 'dwell time' or how long it spends looking in a given direction. The former inevitably increases the power requirement, while the latter increases search times. Since the aim of radars is to find and track targets, increasing dwell times can seriously degrade effectiveness.

Mostly, the brute force approach is a loser's game, especially against highly stealthy targets like the B-2A and F-22A. Much less stealthy targets yield some payoff.

The alternative of building sensors that can see the aircraft from directions or at wavelengths where it was not designed to be very stealthy is a much better game plan, and this is also where most current investment by the Russians and Chinese is visible.

There are numerous ways in which this game can be played, and combinations of multiple techniques can be quite effective, especially against designs with poor or otherwise limited stealth performance.

A technique that is often overstated in effectiveness is the use of networked radars and data fusion techniques, similar to the US Navy Cooperative Engagement Capability (CEC) system. CEC collects and simultaneously fuses tracking data from multiple shipboard search radars, the intent being to share tracking data across the fleet even if some targets are too distant to cleanly track for some radars, or below the radar horizon for others. In the CEC system a target 'blip' might be a fusion of intermittent or partial tracks from half a dozen different radars.

Defeating stealth targets using networking and data fusion presupposes that some radars can see the target some of the time, also that the target's stealth is considerably poorer in some directions compared to others, and finally that the target is visible by radars from varying aspects.

Suffice to say a vehicle with good or excellent 'all aspect' stealth such as a B-2A will not be susceptible to this technique, since all of the radars in the network are equally blind. Even the F-22A is not particularly exposed, as its weakest areas in the beam aspect are not exposed long enough to seriously matter. Much more exposed are the compromised J-20, PAK-FA and F-35, as their side and rear aspects present many more tracking opportunities – making the front stealthy only works well if there is one enemy radar around that the fighter can point its nose at.

A networked data fusion system is thus not a panacea, but is potentially quite effective against stealth designs that do not have genuine 'all aspect' stealth capability, versus a marketed 'all aspect' capability.

There are technical challenges in designing such systems, as the constituent radars must be built to not discard poor quality radar returns from point targets, in typical radars automatically rejected as 'false alarms'. Also, a lot of computing power is needed to sift and sort the collected data to determine which returns amount to a real target track. To date only the United States and Russia have demonstrated the ability to build such a system.

The alternative game plan to exploiting aspect limitations in target stealth shaping is to exploit wavelength limitations in target stealth shaping. This area has been the focus of most Russian and Chinese activity in CVLO systems design.

This approach relies on the basic physics of stealth shaping, where a straight edge or flat facet can only reflect sharply in one direction, if its geometrical size is larger than two or more wavelengths. A straight edge or flat facet which reflects the radar illumination away in a tight beam (technically a 'lobe') must be many wavelengths in size. If not, its reflection smears out over a wide range of angles, making it easier to detect.

In stealth fighters this effect is most prominent, as their size puts hard limits on the wavelengths where their forward and aft fuselages can still cleanly bounce illumination away. Typically performance that is reasonable in the 3 GHz decimetre wavelength S-band degrades with varying rapidity as the wavelength increases through the L-band, UHF-band down to the metre wavelength VHF-band.

At one metre wavelength, shaping features good at 3 centimetres are ineffective and reflect over a wide range of angles.

Another aspect of radar physics contributes to this problem. Absorbent materials typically vary widely in effectiveness with wavelength, and materials good in the mid and upper bands tend to be not so good in the lower radar bands. Also, to maintain effect, coatings or skins must be thicker for the lower bands.

The result of this is that shaping and coatings which work superbly in the mid to upper radar bands tend to work poorly in the lower bands, and very poorly in the VHF-band. This is also prominent in computer simulations of aircraft. Curiously, of all of the fighters, the F-22A's shape appears to perform best in the VHF-band, suggesting the designers considered this problem and did the best they could. The same is decidedly not true of the F-35, J-20 and PAK-FA.

The B-52-sized B-2A is quite effective at VHF-band wavelengths as its size and shape make it so.

This is why the Russians and Chinese have invested so heavily in VHF-band counter-stealth radars. While VHF radars are not accurate enough to guide missiles, they are accurate enough to cue shorter wavelength radars to the target, and these can guide missiles.

HF Over-The-Horizon Backscatter Radars such as JORN have considerable counter-stealth potential, but their good detection performance is compromised by poor accuracy. They can provide tripwire early warning, but the ability to locate and kill the target depends on the counter-stealth sensor suite carried by the platforms prosecuting the engagement.

Passive detection of radar emissions from stealth aircraft is often touted as a panacea counter-stealth technique. It is potentially effective only when the aircraft actually radiates, using its radar or networking terminal. All stealth aircraft are equipped or to be equipped with Low Probability of Intercept or LPI radars and networking terminals, which are for all intents and purposes invisible to older technology passive detection equipment. However, Moore's law driven processing is available to all nations, so the margins here will become progressively slimmer over time.

Infrared detection is also touted as a counter-stealth panacea. Given that cloud typically blinds infrared sensors, and all stealth designs have some effort invested in infrared signature reduction, this claim is often optimistic. Nevertheless, LWIR (long-wave) infrared sensors have considerable long range potential at high altitudes, either as sensors on fighters or adjunct sensors on AEW&C aircraft, as the temperature of the exhaust plume can give a fighter's position away. Most exposed are fighters with circular convergent-divergent nozzles, as they directly emit infrared into a wide cone behind the aircraft – this is not an issue for the B-2A and F-22A with rectangular exhaust nozzles.

Other technologies with counter-stealth potential, such as DIAL LIDAR ('laser radar"') tuned to jet engine exhaust trails, have yet to mature properly.

The F-22A Raptor remains the stealthiest fighter design, and will remain such due to severe shaping problems in the F-35 JSF, J-20 and T-50 PAK-FA.