Russian VHF counter stealth radars proliferate

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After the rude surprise of Desert Storm, when US F-117A stealth fighters penetrated Saddam's Soviet air defence system with impunity, Russia's industry and research institutes developed a three-pronged strategy to defeat US air power: technologies that could defeat long range ISR systems; sensors to defeat or degrade the effect of stealth; and point defence weapons capable of engaging and destroying US PGMs, especially the HARM anti-radiation missile and cruise missiles.

Russian VHF radars. It is a fully digital AESA with precision 3D capability, with accuracy rivaling S-band missile battery acquisition radars.

The first products of this systematic effort in research and development are now arriving in the global export market.

Of particular interest are Russian sensors designed to defeat US Very Low Observable (VLO) aircraft and missiles. These sensors fall into two broad categories: VHF band radars, and passive emitter locating systems that detect radar and network terminal emissions from stealth aircraft.

VHF band radars, typically operating between one and three metre wavelengths, were considered passe at the end of the Cold War. Indeed, the Soviets had only one production design in this category, the NNIIRT 1L13 Nebo SV, and were progressively replacing other designs such as the widely used P-14 Tall King and P-12/18 Spoon Rest B/D.

VHF radars were cumbersome and troublesome, in part due to the time to deploy, which varied between two hours for a Spoon Rest and 24 to 48 hours for a Tall King. This was also due to the wide mainlobe width and poor angular resolution, poor clutter rejection performance tracking low altitude targets, and susceptibility to interference from television, FM radio and handheld radio signals. All three designs lacked height-finding capability, requiring a supporting S-band height-finding radar system.

At the end of the Cold War the US stealth program had effectively produced a large scale techno-strategic defeat against all of the Soviet missile engagement radars, and all of the newer acquisition and search radars. Other than at very close ranges,

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the F-117A was effectively invisible to these systems. Operations over Iraq in 1991 resulted in no losses for the F-117A, and only modest battle damage produced mostly by shrapnel and fragment damage from larger caliber anti-aircraft artillery barrages.

An operation during this campaign which attracted little comment was a deep penetration raid at the start of the campaign, conducted by AH-64 Apache gunships and MH-53 Jolly Greens, to destroy a VHF band P-18 Spoon Rest and a collocated UHF band P-15 Flat Face and P-15M Squat Eye. The reasons for this unusual raid were never disclosed, but a good case can be made that these radars could have alerted Saddam's air defence system to the first wave of F-117As inbound to Baghdad.

The Soviets deployed a large number of VHF band and UHF band radars during the 1950s and 1960s, but had replaced most of them with more accurate and higher performance S-band radars during the 1970s and especially 1980s, with many of these older radars sold or supplied as aid to Third World nations.

The reversal in interest and demand for VHF radars, and upgrades to legacy VHF radars, must be considered one of the great technological backflips of recent times.

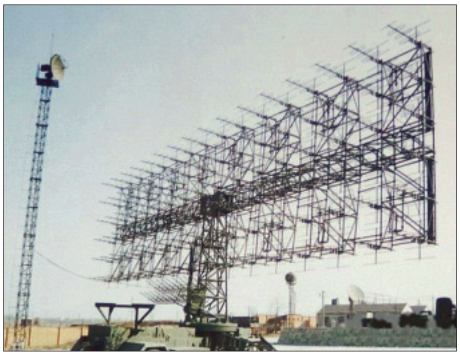
The turning point for VHF radars came with the Allied Force bombing campaign in Serbia, when the Serbian air defences shot down an F-117A, using a digitally upgraded Spoon Rest and SNR-125 Low Blow, and firing unsophisticated command link guided SA-3 missiles – ostensibly 'legacy 1960s technology'. While technical details remain unclear, it is known that the US did not have an EA-6B Prowler in position to jam the radars, and poor planning provided the Serbian missile operators with predictable flight paths to set an ambush.

Since then, the Russians have enjoyed a booming business in digital processing and solid state electronic upgrade packages for a range of legacy systems, especially the SA-3 Goa SAM, and the P-18 Spoon Rest D radar.

The advent of Russian VHF band counter-stealth radars will change the game for users of US stealth technology. While stealth optimized to defeat S-band and X-band radars will still present insurmountable obstacles for acquisition and engagement radars operating in these bands, even the addition of a limited number of modern VHF band radars will deny surprise, and if the radars provide a full 3D (azimuth and height-finding) capability, then the game changes further.

A VHF band 3D radar capable of tracking a stealth aircraft at a useful distance (50 nautical miles or more), and one with high angular accuracy, can then be used for the midcourse guidance of Surface to Air Missiles, or to direct interceptor aircraft.

The aim of the Russian designers is therefore to provide enough accuracy in a VHF radar to allow *right: The new Chinese CETC JY-27 VHF 2D radar is clearly influenced by the Russian Nebo SV/SVU series.*



far right: The Rezonans NE VHF band "counter-stealth" radar is credited with a range of 190 NMI against fighter sized targets. Almost no technical detail has been disclosed to date.

a missile or fighter to be flown close enough to the penetrating stealth aircraft for the missile's or fighter's X/Ku-band radar to acquire the stealth aircraft. No less importantly, all Russian fighters are fitted with Infrared Search and Track systems, and infrared seeker equipped variants of many otherwise radar-guided missiles exist. Good examples are the AA-10 Alamo and AA-12 Adder.

Operationally, the idea is to cover an area of interest with a sufficient density of VHF band radars to deny US stealth aircraft opportunities to surprise the defenders. The VHF radars with 3D capability would then be used as alternative acquisition and midcourse guidance radars for missile batteries, overcoming radar blindness in the S-band and X-band. The Chinese are claimed to have already experimented with the integration of VHF radars and modern SAM systems.

An issue often raised by Russian designers is that VHF band radars usually sit well below the frequency coverage of anti-radiation missiles such as the AGM-88 HARM and MBDA ALARM, usually limited to L-band or S-band. Therefore, an aircraft must locate and attack the radar with different weapons.

What options does the US have to deal with the proliferation of advanced VHF radars, or high technology upgrades to legacy VHF radars?

One option is VHF band jamming, which will be challenging since large antennas are required, and these are incompatible with small aircraft such as the EA-6B Prowler and EA-18G Growler. This is aside from the inherent vulnerability of both systems to advanced long range SAMs like the SA-21, or fighters like the Su-30MK/Su-35BM series. It is complicated by the fact that these radar designs are, unlike their Cold War predecessors, agile frequency hopping designs, the only mitigating factor being the limited hop range imposed by antenna bandwidth.

The other option is tasking the limited numbers of B-2As (20) and available F-22As (only 180 currently funded) to attack these targets using the 60+ nautical mile winged GBU-39/B Small Diameter Bomb, or winged variants of the GBU-31 JDAM. The F-22A's supersonic cruise capability compresses engagement timelines for the defender, making intercepts difficult even if the aircraft can be tracked. The B-2A is regarded to be effective against VHF threats. The F-35 unfortunately has neither supercruise or size/shaping to beat VHF radars.

Jamming techniques based on active cancellation, where the aircraft emits a waveform identical but out of phase with the threat radar waveform are likely to be viable against VHF radars precisely for the same reasons why such radars defeat stealth shaping in these designs. However, active cancellation has the drawback of difficult implementation and integration, and potential risks arising from passive emitter locating systems.

A related problem for air forces confronted with modern VHF radars is that the mobility of the latest generation of systems is much higher than that of the Cold War era designs.

The 3D NNIIRT 1L119 Nebo SVU can stow or deploy in 45 minutes, while the newer 2D KBR Vostok E can stow or deploy in as little as eight minutes. The latter is getting very close to genuine 'shoot and scoot' radars like the 30N6E/92N2E series, the 64N6E series, and the 96L6, all of which can stow or deploy in five minutes. If a weapon is launched at such radars from a long range, unless it is very fast, the target may be long gone by the time it arrives.

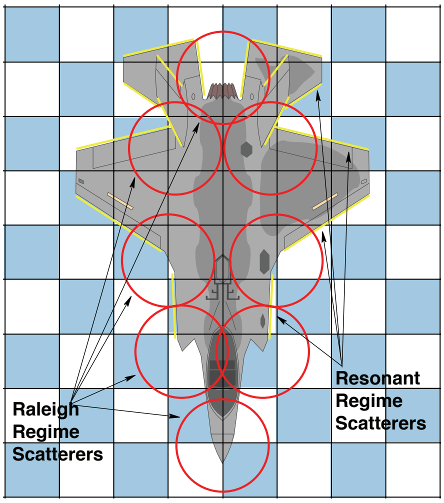
While VHF band radars are not a 'silver bullet' in defeating stealth technology, these radars significantly complicate stealth operations, and once robust numbers of accurate 3D designs like the Nebo SVU are widely deployed to support missile batteries, they will require a dedicated and major effort to defeat in combat. Stealth naysayers and purveyors of legacy unstealthy aircraft will no doubt argue that stealth is an expensive and soon to be useless luxury, but such arguments conveniently overlook the fact that the latest generation of Russian L/S/X-band radars now present an impermeable barrier to all legacy aircraft, including new build F-16, F-15 and F/A-18 variants, and the Eurocanards. Stealth still remains and will remain effective against threats in these bands, as it defeats the basic physics of radar operation.

In conclusion, simple minded force structure planning based on the premise that stealth aircraft are universally invisible is now a dangerous fallacy, and much more refined technological thinking is required to deal with future air defence systems.

The KB Radar (Agat) Vostok E is an entirely new 2D VHF radar design, using a unique wideband "Kharchenko" square ring radiating element design, in a diamond lattice pattern. With fully hydraulic leveling and deployment, the radar can be operating 8 minutes after coming to a stop. It is the most mobile VHF design ever built, rivaling L/S/X-band 'shoot and scoot' missile battery radars.

The Physics of Stealth

The essential idea of stealth is to reduce the detectable signature of an aerial vehicle, to the extent that its detection range by a hostile sensor is reduced, with useful tactical effect. The signatures of most interest are the vehicle's radar cross section, its radio-frequency emissions signature and its infrared signature. As radar and passive emitter locating systems can penetrate cloud and rain over often very large distances, which infrared signals cannot, these signatures are generally regarded to be more important than the heat signature, although as the technology of infrared detectors advances, this will become less so over time.

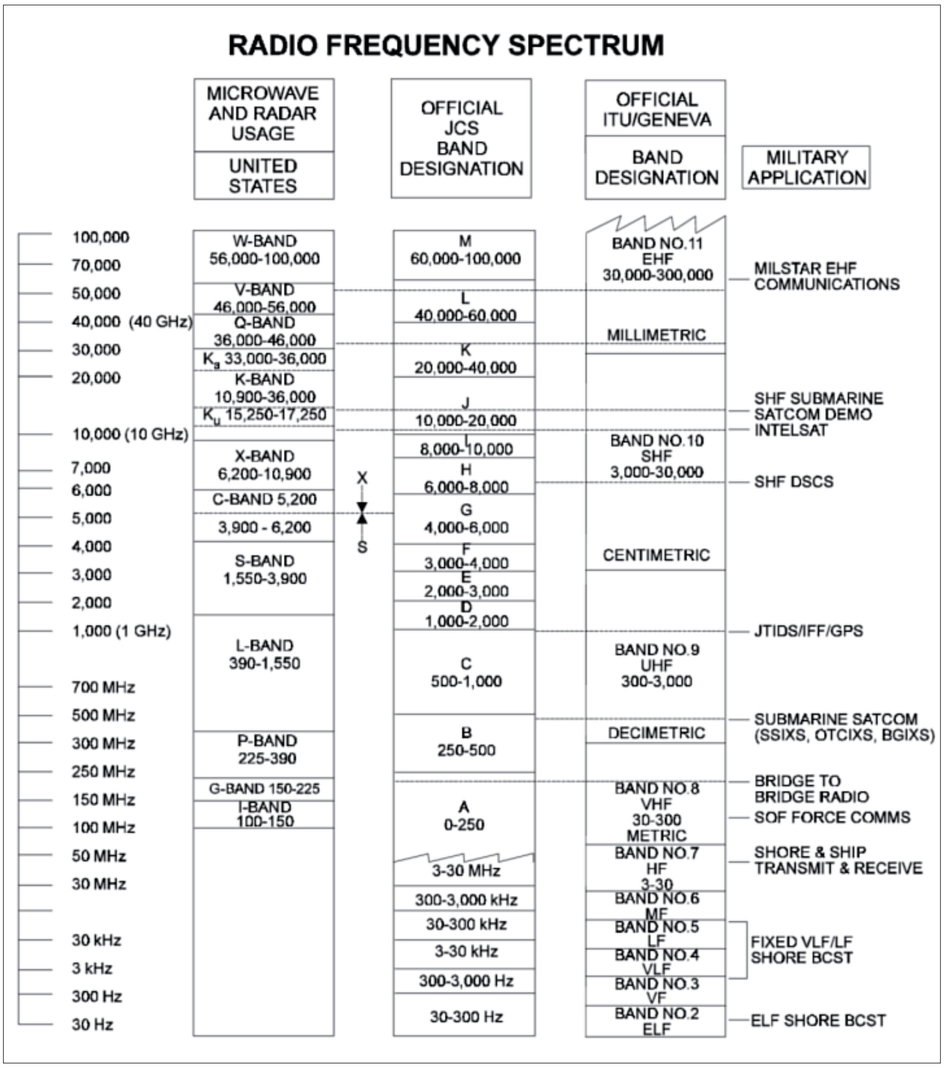


JSF in the 2 Metre Band

The US approach to stealth has seen a combination of technologies employed, to produce the overall effect of "stealth".

Active emissions by aircraft radar and datalinks have been reduced by the adoption of what are termed 'Low Probability of Intercept' or LPI techniques. LPI techniques typically rely upon the use of very wideband frequency hopping techniques, noiselike waveform modulations and sometimes pseudorandom scan patterns, to made radar and datalink/network emissions very hard to detect. A modern AESA radar with the ability to hop across a GigaHertz or more of bandwidth, using spread spectrum modulated pulse trains, will be all but invisible to the crystal video receiver technology radar threat warning systems of the late Cold War era.

The radar signatures of aircraft and missiles present a much more challenging problem, for a variety of good reasons.



The most prominent of these is that threat radars may be operating across a range of wavelengths, from around ten metres down to less than a centimeter. This has important implications for the two primary technologies employed in producing VLO capability.

The two primary technologies used in airframe radar cross section reduction are shaping and materials.

Materials are often touted as the solution by parties who do not understand the physics well ie "apply this magical coating and your aircraft will vanish off their screens". The pragmatic reality is that coatings and materials are usually only effective over a fairly narrow band of frequencies, and often to get good effect, considerable depth or thickness is required, resulting in weight and volume penalties. Central to the difficulties with radar absorbent and lossy materials is the 'skin effect', where radio-frequency electrical currents induced by an impinging wave tend to concentrate in the surface of an object. With highly conductive materials like aluminium skins, this layer is extremely thin for most frequencies of interest, making such skins excellent reflectors. Absorbent or lossy coatings, however, must be much less conductive to produce effect, and this results in much greater skin depth. As a result, a very thin coating or laminate which might be highly effective against a 10 GHz radar is apt to be ineffective against a 10 MHz or 100 MHz radar as the skin depth becomes many millimeters or centimeters deep.

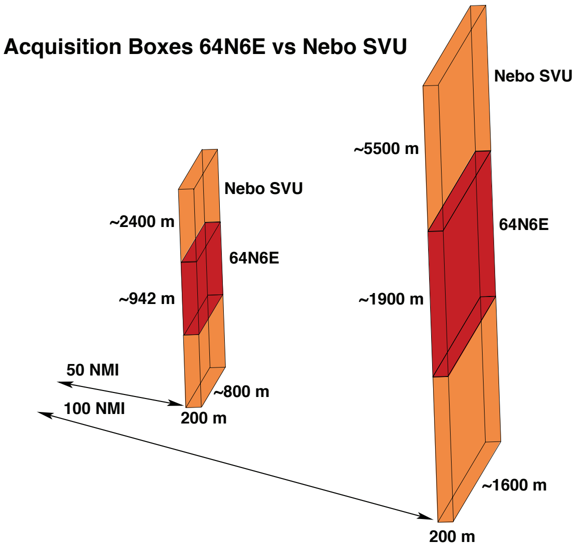
The most common approach to this problem is the use of radar absorbent structures, an example being the leading edge on the B-2A 'batwing' bomber, which has the depth to accommodate complex absorbent structures, which are highly effective over a very large bandwidth. This is a much more difficult problem for fighters, as volume and weight are much more critical problems.

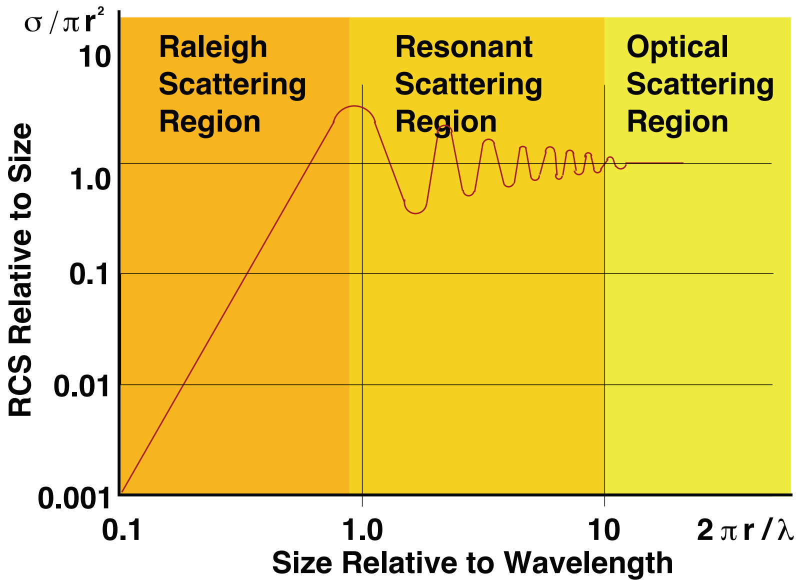
Airframe shaping is however where the biggest gains are to be had in making aircraft stealthy, in fact the rule of thumb is that the first one hundred fold reduction in radar signature is produced by smart airframe shaping, and the remaining 'fuzzball' of minor reflections is then soaked up by absorbent or lossy materials.

For example, a conventional fighter design might have a radar cross section of one square metre in the centimeter wavelength band, but an equivalent design with proper stealth shaping might be only 0.01 square metre, and further application of absorbent materials in the right places then drives that down to 0.001 to 0.0001 square metre.

The effectiveness of shaping is like the effectiveness of materials, dependent upon the wavelength of the threat radar.

Where the flat area, facet or leading edge is much larger in dimensions than the wavelength of the





radar, the rules of geometrical optics apply, and reflections can be very precisely bounced away from the threat radar. The aligned leading edges, aligned planforms and facets or flat areas seen in the F-117A, B-2A and F-22A are all extremely effective down to wavelengths of the order of tens of centimeters, or in the instance of the B-2A, down to metres. In frequency terms fighters are stealthiest in the X-band and S-band, while the B-2A is stealthy down to the VHF band.

Where the shaping features are comparable in dimensions to the wavelength of the radar, an effect called "resonance" occurs, resulting in the induced electrical charges in the skin of the target running back and forth and waves then reradiating from edges, tips, or other prominent shapes. For fighter sized aircraft the resonance region is primarily in the UHF frequency band. In this so termed "resonance scattering region", it becomes very difficult to control the direction and shape of reflections. Some techniques using for instance resistive and magnetic materials along edges are often used, but in general fighter sized targets are no longer marble or golfball sized reflectors.

This effect becomes increasingly exacerbated as the wavelength reaches a metre or more, where the radar signature becomes effectively proportional to the physical size of the reflecting feature. This is termed the "Raleigh scattering region". VHF band radars which operate typically between three and one metre in wavelength occupy this region for typical fighter sized targets.

Historically, stealth designers have focused their effort in the centimeter and decimeter bands, since these are where most fire control, engagement, air intercept and missile battery acquisition radars operate. The aim of the stealth effort was thus to disrupt the 'kill chain' by denying opportunities to launch and guide missiles, or frustrating the missile seekers and thus disrupting terminal missile guidance.

If we look at operating bands for typical Soviet era missile battery engagement, guidance and illumination radars, we find the SA-2's SNR-75 Fan Song in the upper S-band or lower X-band, the SA-3's SNR-125 Low Blow in the X-band, the SA-4's 1S32 Pat Hand in the X-band, the SA-5's 5N62 Square Pair in the S-band, the SA-6's 1S91 Straight Flush and the SA-8's Land Roll radars in both the X- and S-bands, and finally the SA-10's 30N6 Flap Lid and SA-12's 9S32 Grill Pan in the X-band.

Where a defender is reliant on search and acquisition radars operating in the S-band, examples including the widely used Soviet/Russian P-30 Big Mesh, P-35/37 Bar Lock, P-30 Big Mesh, P-40 Long Track, 19Zh6/36D6 Tin Shield, 64N6 Big Bird, or US AN/TPS-43 and AN/SPY-1 Aegis, then a byproduct of good stealth is surprise as beyond some detection range the stealth aircraft is invisible.

continued next page

The massive 55Zh6 Nebo UE Tall Rack is the largest VHF 3D radar in production, and is being deployed around Moscow to support S-400/SA-21 missile batteries. While difficult to deploy, it has high angular resolution and range performance (NNIIRT image).

The P-15M Squat Eye has followed the same evolution as its sibling, as the digital Kasta 2E2.

No doubt, operators of Russian air defence equipment will be willing customers for upgrades to legacy systems that were considered ineffective against stealth aircraft.

Upgrade packages are on offer for the VHF band P-14 Tall King and P-18 Spoon Rest D, the UHF band P-15/15M/19 Flat Face and Squat Eye, and customers can also purchase a range of new build VHF radars, including the 55Zh6-1 Nebo UE Tall Rack, the 5N84AE Oborona-14 Tall King, the 1L13-3 Nebo SV, the 1L119 Nebo SVU, and the Vostok E. The latter two are entirely new post Cold War designs. The trusty Flat Face / Squat Eye UHF radars remain in production in digital solid state form, as the 39N6E Kasta 2E1 and 2E2. The Chinese have followed this trend and are actively marketing the JY-27 VHF radar, similar but larger than the 1L13 Nebo SV, and have displayed another smaller type which remains to be identified.

The UHF band P-15 Flat Face was a maintstay of the Cold War period. A digital variant, the Kasta 2E1, remains in production, and digital upgrades are available for legacy models.

Soviet regime. What is significant is that these have mostly been L-band or VHF-band designs. The new LEMZ 96L6 Cheese Board in the S-400 SAM system, the 67N6 Gamma DE and 59N6 Protivnik GE are all L-band designs, the 55Zh6-1 Nebo UE Tall Rack, the 1L119 Nebo SVU, Rezonans N and the Vostok E are all VHF designs. Only the 64L6E Gamma S1E and SA-11 9S18 Snow Drift operate in the upper S-band.

Many of the new Russian designs are phased arrays, and at least two of the VHF designs are active phased arrays (AESA) dispensing completely with all vacuum tube technology, and embedding Transmit Receive Modules (TRM) in the antenna subsystem. Typically, the computers and software used for digital signal and data processing in these radars are Commercial Off The Shelf (COTS), no differently than their Western counterparts, even using large LCD display panels. Russian literature claims the use of the latest Space Time Adaptive Processing (STAP) algorithms for clutter rejection, which given the known skills base in mathematics and physics in Russian research institutes, is a credible claim. If a Western manufacturer were asked to design a VHF radar, the technology and components it would be built from would be much the same.

Russian marketing literature and numerous interviews with chief designers or senior design engineers invariably focus down on the issue of counter-stealth capabilities in these radars. Key points, raised repeatedly in interviews are Raleigh and resonance mode scattering versus geometrical optics scattering and skin depth impairing the performance of radar absorbent coatings. These are precisely what radio frequency physics and the extensive unclassified US engineering literature on stealth identify as key limitations (see below).

More than one Russian designer has publicly commented on the F-117A, famously known in the West as a "ball bearing sized target" in the S-band and X-band, as a "one half square metre" sized or beachball sized radar target in the VHF band. Likely this claim is the result of detailed scientific analysis of radar tapes from the Allied Force campaign.

Russian and Byelo-Russian designers have claimed detection ranges of up to 180 nautical miles against fighter sized stealth aircraft, claims consistent with cited range specifications for these radars.

Further Reading:
http://www.ausairpower.net/APA-Rus-Low-Band-Radars.html
http://www.ausairpower.net/APA-Nebo-SVU-Analysis.html
http://www.ausairpower.net/APA-Grumble-Gargoyle.html
http://www.ausairpower.net/APA-Legacy-SAM-TEL-TL.html

left: The trusty Cold War era P-18 Spoon Rest D is now available with complete digital solid state upgrades. Five Russian, Byelo-Russian and Ukrainian defence contractors are offering such upgrades.

far left: Digital upgrades are now on offer for the Cold War era P-14 Tall King VHF acquisition and search radar.