The 1993 Moscow Air Show

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Editor's note: *This special report is the result of a visit by the author to the Moscow 1993 Air Show, which was held from August 31 to September 5, 1993. The show was held at the military airfield near Ramenskoye, 50 km east of Moscow. The author was accompanied by Drs. Alexander Leonov and Sergey Leonov and by Prof. Alexander A. Lemansky, scientific director of Scientific Industrial Corp., ALMAZ, a manufacturer of radar equipment based in Moscow. His invitation was issued on behalf of the Airshow Organizing Committee by A. Systzov, vice president of AO AVIAPROM, a joint stock company headquartered in Moscow. The material contained in this special report is similar to photos and descriptions in classified documents, but this is the first time such photos and descriptions have been available to a general audience. The four-color photos of equipment described in the report appear as a three-page photo exposition.*

Introduction

The 1993 Moscow Air Show included an extensive display of Russian radars and tactical missiles, including the SA-10, SA-12 and SA-15 surface-to-air missile systems and their radars, a dual gun-missile antiaircraft system, a phased-array radar for location of hostile artillery positions, and numerous air-launched missiles, as well as the aircraft on display. This article discusses the exhibited radar and related equipment.

S300PMU (SA-10) System

At the equipment display, the SA-10 equipment was toured. The fire control radar (NATO designation Flap Lid) and the operating positions in the command post vehicle were exhibited. Data from the three-dimensional surveillance radar (Big Bird) were displayed in the vehicle. The horizon search radar (Clam Shell) was not on display. Figure 1 shows the Flap Lid vehicle.

Big Bird Three-Dimensional Surveillance Radar

The mobile Big Bird on display, as shown in Figures 2 and 3, is mounted on an eight-wheeled trailer pulled by a large prime mover. The antenna is an S-band space-fed transmission lens array, fed from both sides by feed horns mounted on a beam passing across the top of the array. The array contains 3400 elements and appears to fold for transport along vertical lines parallel to the sides of the equipment shelter. The elements are matched to space with what appear to be elongated dielectric bars that are tilted upwards to optimize performance at angles above the horizontal.

The search beams, scanning electronically in elevation, lead the array broadside by 30° in azimuth. When a target is detected in a search beam, after a further 29° rotation of the antenna, a backscan is initiated in azimuth to place a validation beam on the elevation and azimuth of the initial detection. If the detection is repeated in this validation beam, another backscan occurs 180° later in the scan, using the feed horn on the opposite side of the array. Thus, within 210° of rotation following the initial detection, a validation and a second track point are obtained to initiate the track file. From this point on, the track data rate is two points per antenna rotation. The cost of this two-coordinate scanning array may be higher than most Western systems, but the advantages in rapid track initiation and doubled data rate are significant.

Command Post

Within the Command Post (CP) were five display positions, plus positions for communications personnel. The commander's console was the center of the five consoles, which were almost identical. Each console had a large plan positioner indicator (PPI) displaying synthetic video from the Big Bird and from external sources, as shown in Figures 4 and 5. To the left of the PPI is an alphanumeric display on which appear the data for up to 36 targets. They are assigned (six each) to the six Flap Lids that may be controlled by the CP. To the commander's left, the two positions are occupied by officers who actually fire the missiles. To the right are officers who coordinate with higher headquarters or adjacent CPs, who accept assignments of targets to be passed by the commander to the Flap Lids in priority order, and who evaluate targets detected locally by Big Bird. The small displays at these positions can be set to provide azimuth-elevation (BE) displays of Big Bird video, intensity modulated to show target elevation. The Big Bird data appear on the PPI display as an intensified sweep, leaving behind target markers with alphanumeric tags, which are refreshed at a high rate.

Fire Control Radar S300PMU1 (Flap Lid)

The Flap Lid radar tracks up to six targets that have been assigned by the CP for engagement. The array is an X-band space-fed lens of 10,000 elements, tilted 30° from the vertical, as shown in Figures 6 and 7. The active portion of the array is circular, and small sidelobe canceler arrays are within the plastic cover at the bottom of the main array. The array is mounted on a rotatable turret behind the cab of the vehicle and in front of the fixed equipment shelter.

The RF and IF equipment is mounted within the turret, eliminating rotary joints and long runs of waveguide or coaxial cable for receiver signals. The feed, shown in

[Photo Exposition begins on page 26]
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Fig. 1 D. Barton and Prof. Lemansky in front of Flap Lid vehicle.

Fig. 2 Big Bird 3D search radar antenna.

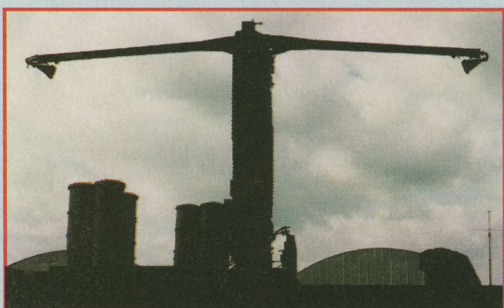

Fig. 3 Side view of Big Bird antenna.

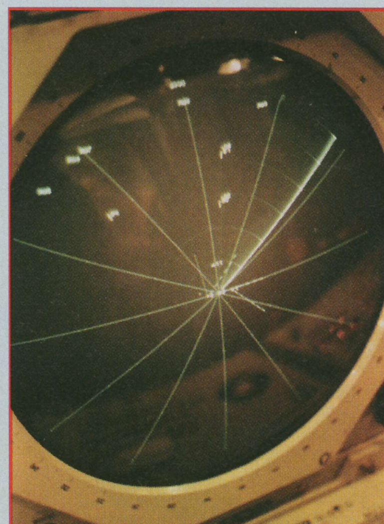

Fig. 5 Detail of PPI display.

Fig. 7 Flap lid vehicle from the front, showing turret rotated 45°.

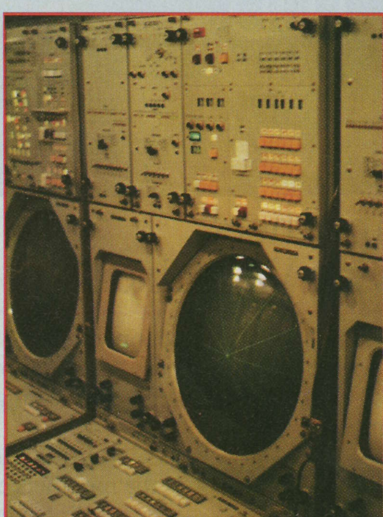

Fig. 4 Commanders' console in command post.

Fig. 6 Rear view of Flap Lid array, showing collapsible feed enclosure in foreground.

Fig. 9 SA-10 TELAR missile with erected canisters.

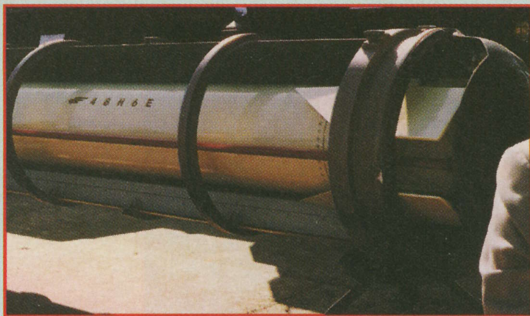

Fig. 10 Tail end of SA-10 missile in canister, showing folded fins and ejection piston rod.

Fig. 11 Dr. Efremov and D. Barton in front of SA-12 Grill Pan vehicle.

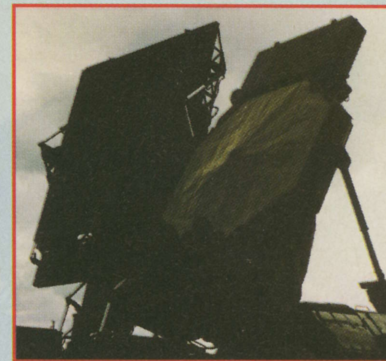

Fig. 12 SA-12 Bill Board (left) and Grill Pan (right).

Fig. 13 Grill Pan, Gladiator TELAR and Giant TELAR.

Fig. 14 BIll Board array (front); IFF array at bottom.

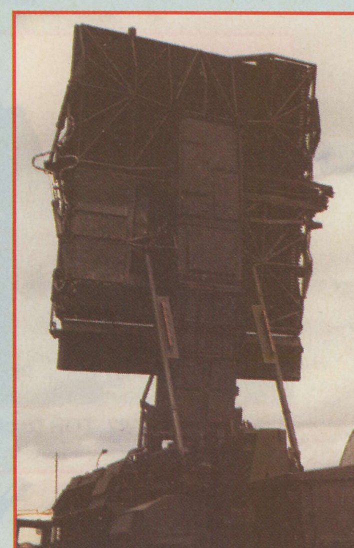

Fig. 15 Rear view of Bill Board array.

Fig. 16 Grill Pan with Giant TELAR in background.

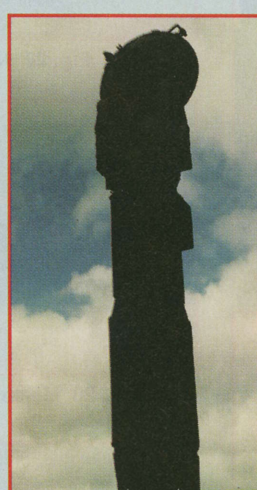

Fig. 18 Gladiator TELAR antenna mast.

Fig. 19 Giant TELAR antenna mast.

Fig. 17 Rear view of Grill Pan. Metal panel across rear of array is removed for operation.

Fig. 20 Side view of TOR vehicle, with missile canister displayed at left, search radar at left end of turret and tracking phased array at right end of turret.

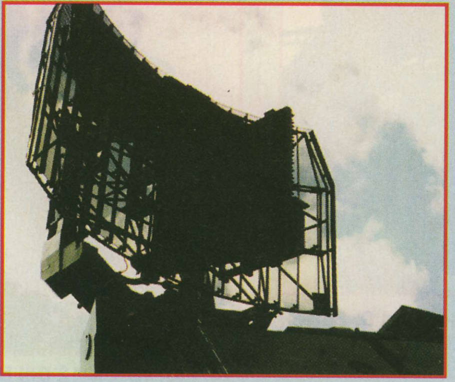

Fig. 21 Front view of TOR search radar antenna.

Fig. 22 TOR tracking radar array.

Fig. 23 Antiaircraft tank system.

Fig. 24 Zoopark antenna from front, showing complex feed and possible second antenna covered by dome.

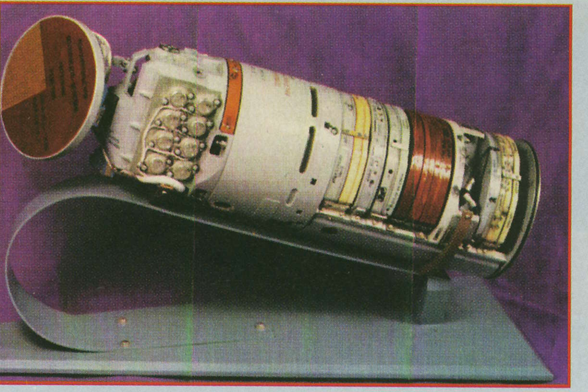

Fig. 25 Ku-band active seeker.

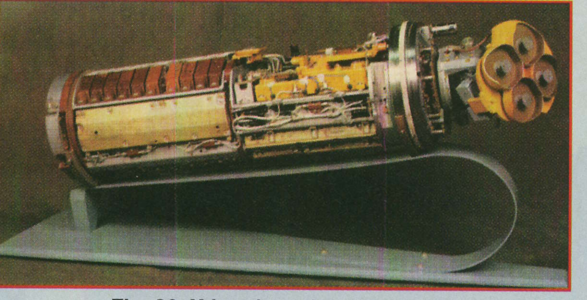

Fig. 26 X-band semiactive seeker.

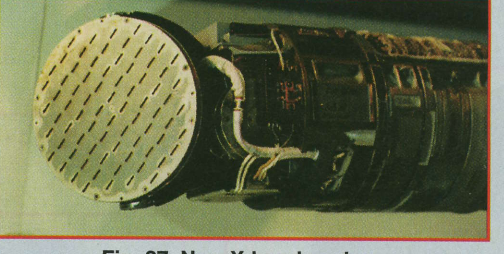

Fig. 27 New X-band seeker.

Fig. 28 Mainstay early warning radar aircraft.

Fig. 29 Antennas on earth survey aircraft.

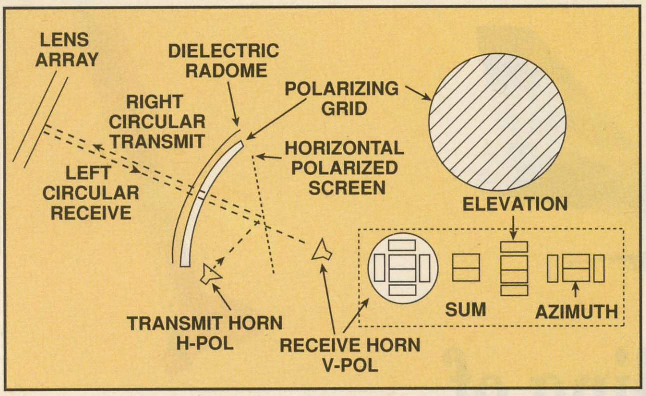

Fig. 8 Sketch of flap lid feed system.

Figure 8, consists of two linearly polarized horns, a polarization-sensitive reflector, and a circular polarizing grid. The receive horn cluster is on the axis of the array and is vertically polarized. The received signal polarization, which is circular (for example, right-hand) as it passes through the main array, is converted to vertical by the polarizing grid, which is a curved element immediately within the plastic enclosure. The transmit horn is horizontally polarized and is located near the bottom of the plastic enclosure. It illuminates the polarization-sensitive reflector, the plane of which is oriented at about 45° relative to the array axis and which is invisible to the received wave. The polarizing grid transforms the transmitted wave into circular polarization with sense opposite to that of the received wave (for example, left-hand). This transformation provides reciprocal operation of the Faraday rotator phase shifters. The orthogonal polarizations of the transmitted and received waves provide the duplexer isolation normally supplied by a circulator, reducing the round-trip RF loss by 1 dB.

Reciprocal operation is an important feature of this array, since the waveform used for target tracking uses bursts at high PRF (100 kHz) to overcome clutter. The clutter attenuation of the system is 100 dB, making possible long range target detection in competition with ground clutter or rain from within the 1500 m unambiguous range of the waveform. As a result of this operating mode, the radar can reject moving clutter from rain, chaff and birds using unambiguous Doppler filtering, as do the continuous wave radars in US systems, such as Hawk.

The monopulse receive feed uses six horns. The two center horns are each excited in two modes, one for the sum channel and one for the azimuth difference. Thus, the feed is the equivalent of the 12-horn feed described by P.W. Hannan in his 1961 paper.[1] Since the received signal is linearly polarized at this feed, multimode operation is possible, and the illumination function can be controlled to minimize sidelobes and spillover.

SA-10 (Grumble) Missile 48H6E

The SA-10 TELAR, shown in Figure 9, mounts four missiles in canisters that are raised to the vertical position after transport to the site. Figure 10 shows a cut-away

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canister that was displayed. The missile is ejected from the canister by gas pressure on two pistons that run the length of the canister on each side of the missile. Movies of the launch operation show the vertically ejected missile at a height of some 30 m being oriented to the desired azimuth and elevation with thrusters at the tail of the missile, after which the main motor fires. Mid-course guidance is provided by the Flap Lid, which tracks a beacon in the missile, and terminal guidance may be either a continuation of the command mid-course or homing guidance using a semiactive seeker, for which illumination is provided by Flap Lid.

S300V (SA-12) System

Figure 11 shows the SA-12 system and Dr. V.P. Efremov of Moscow-based Antei, the system's manufacaturer. The SA-12 equipment on display included the Grill Pan and Bill Board radars, shown in Figure 12, and the missile canisters and TELARs, shown in Figure 13. The High Screen sector search radar for detection of tactical ballistic missiles (TBM), demonstrated at Naro-Fominsk in July 1993, was not displayed at this show.

Bill Board Three-Dimensional Surveillance Radar

Figures 14 and 15 show the Bill Board, which is an S-band scanning-beam three-dimensional radar using a phase-scanned planar array of slotted waveguide radiators. A remarkable feature of this radar is the arrangement for stowing the array for transport. The top of the radar array first folds forward about the hinge at its center to produce a half-height unit. The IFF array folds upwards across the lower front of this unit. The entire structure is then folded forward to a 45° angle from the vertical. At this point, the array unit rotates 90° in its aperture plane, reducing the width across the vehicle to match the vehicle width, and the structure continues to fold onto the roof of the vehicle. In this way, the erected array width can be twice the vehicle width, and the unfolded height can be somewhat greater than the array width. The entire process takes one minute and is carried out by hydraulic pistons with a push button control.

Grill Pan Fire Control Radar

Figures 16 and 17 show the Grill Pan, which is a multiple-target X-band tracking and guidance radar using a 10,000-element space-fed transmission lens. Above the radar array is an IFF planar array, and below it are three sidelobe canceller antennas, which are mechanically steered to cover the main array sidelobe structure on up to three selected targets. There are two monopulse feeds on the top of the rotating radar turret. The upper feed is covered by a white, Teflon-like shell and is used when the array is set to 30° tilt for aircraft targets. The lower feed is further forward on the roof of the turret and is in line with the center axis of the array when it is tilted to approximately 45° for TBM intercepts.

The emphasized features of the SA-12 system, including the Grill Pan array, are low RF loss and low cost. The phase shifters are Faraday rotators, having two sections

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in series, controlled by separate coils, with a total phase shift of 720°. In each phase shifter, the first coil is connected in series with coils of other phase shifters in that row and driven by the row command. The second coil is connected in series with coils of the other phase shifters in that column and driven by the corresponding column command. Thus, a 10,000-element array, 100 × 100 elements, requires only 100 row drivers and 100 column drivers. There are no electronic components on the phase shifter.

The radar transmits right circular polarization and receives left circular (the predominant target echo polarization), and hence the Faraday rotator uses the same control field for reception as for transmission. The control field is changed only when the beam position is changed. During a dwell of several milliseconds, several hundred pulses are transmitted and received. The phase shifter loss is less than 1 dB in each direction.

Since the transmission and reception are performed with orthogonal polarizations, isolation is obtained with an orthomode feed horn, eliminating the duplexer loss. The low noise receiver (noise factor 3 dB) uses an electrostatic amplifier tube that can withstand leakage powers of several hundred watts without damage and with near-instantaneous recovery to full gain and sensitivity when the transmitted pulse ends. Thus, the loss attributed to solid-state protective devices commonly required in Western radars is also absent. The total round-trip RF loss from transmitter tube to low noise receiver (excluding propagation loss in the atmosphere) is held to 3 dB, in contrast to the 7 to 12 dB found in comparable Western systems.

The reduced cost and loss, and the ability to transmit and process (with high clutter attenuation) high-PRF waveforms over long dwells, are made possible by the assignment to the radar of a limited number of tracks and very limited search capability, in contrast to the Western preference for multifunction array radars. The cost of separate search radars must be accepted in such a system. It is perhaps the reduced emphasis placed by the Russian military on life-cycle costs of vehicles and personnel that permits them to use this approach. Another possible explanation is the Russian military's insistence on high performance against targets of low cross section in environments containing rain, chaff and other sources of clutter, an almost insoluble problem when the multifunction approach is adopted.

Gladiator TELAR

The TELAR for the smaller (Gladiator) missile has an antenna mast that is erected vertically, as shown in Figure 18. The antenna pedestal is the conventional elevation over azimuth type. There are four missile canisters at the rear of the TELAR, and the bottoms of these canisters rest on the ground when the canisters are raised to the vertical launch position.

Giant TELAR

Figure 19 shows the TELAR antenna for the Giant missile. The antenna is mounted on a mast structure that is fixed in a horizontal position. As a result, the first axis is a roll axis and the second axis, which permits the antenna to move in elevation, can be an azimuth axis when the first has rolled through 90°. In effect, the pedestal is of the x-y type, which can track targets through zenith without excessive angular accelerations.

TOR (SA-15) System

The TOR system is a self-contained, single-vehicle SAM system, capable of engaging two targets simultaneously, at ranges of up to 12 km. The vehicle contains two magazines of four missiles each, a rotating turret with a search radar at the rear and a phased-array tracker at the front, as shown in Figure 20.

TOR Search Radar

Figure 21 shows the search radar, which scans its reflector antenna through 360° in azimuth and performs elevation scan with a frequency-scanned feed. This scanning can proceed during vehicle motion.

TOR Tracking Radar

The TOR tracking radar antenna is shown in Figure 22. It is tilted 45° in elevation and is pointed in

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azimuth by rotation of the turret in response to target detections by the search radar. Beside the radar antenna is an electro-optic tracking instrument.

AA Gun System

An antiaircraft (AA) tank with combined gun and missile armament is shown in Figure 23. This equipment appears to be the successor to the ZSU-23, with a pair of larger, 30 mm guns and a short-range missile. The same basic combination, but with a 6-barrelled gun, is offered for naval air defense.

Artillery Locator System

A phased-array artillery locator system designated 1L219 or Zoopark is shown in Figure 24. The antenna is a space-fed reflectarray. The feed appears quite complex, with four waveguide inputs.

Air-to-Air Seekers

The Phazotron concern exhibited three air-to-air seekers, shown in Figures 25 to 27. The Ku-band active seeker, designated 9B-1103M, uses a klystron transmitter tube. The X-band semiactive seeker, designated 9B-1101K, now uses a four-section phase monopulse array. The replacement antenna for this seeker uses a slotted waveguide array, mounted on an interesting gimbal configuration. The outer gimbal consists of a semicircular yoke that is supported by four pairs of wheels, two pairs of which drive this axis. The inner gimbal is of conventional design. It appears that the electronics have also been modernized.

Mainstay Early Warning Radar Aircraft

A number of Mainstay EW aircraft were parked at the base. Figure 28 shows one such aircraft that was on display. Mainstay is the NATO designation of the Russian AWACS aircraft.

Earth Survey Radar Aircraft

A survey aircraft equipped with multifrequency synthetic aperture radar was displayed, as shown in Figure 29. The radars operate at wavelengths of 0.04, 0.23, 0.68 and 2.3 m. The antenna for the shortest wavelength appears to be in the pod beneath the fuselage, while the longer-wave antennas are mounted conformally on one side of the fuselage.

Conclusion

A number of Russian radar systems have become available for viewing by Western engineers who have previously had only fragmentary information on the technology developed by their Russian counterparts. The technology of these systems is impressive, and the quality of the equipment poses a serious challenge to Western concerns who will have to compete in the world market for defensive armaments. Russia has produced a large number of different phased-array radars that are designed for specific purposes, such as search, tracking and guidance.

Available in production quantities, these radars represent a new approach, unfamiliar to those who equate phased arrays with the multifunction radar used in such US systems as Patriot and Aegis. Original Russian work on reduction of cost and RF losses in these arrays has contributed to their ability to place so many of these systems in the field. ■

Reference

1. P.W. Hanna, "Optimum Feeds for All Three Modes of a Monopulse Antenna," IRE Trans. Ant. Propagat., AP-9, No. 5, Sept. 1961, pp. 444–461.

David K. Barton *received his AB degree in physics from Harvard College in 1949. From 1949 to 1984, he held positions in both government and industry, including Signal Corps. assignments to White Sands Missile Range and Evans Signal Laboratory, and positions at RCA and Raytheon Co. Since 1984, Barton has been vice president for engineering with ANRO Engineering Inc. His work has included studies of foreign radar technology, as well as consulting in areas of radar for several major aerospace companies. In addition, he lectures in radar for the Continuing Engineering Education Program at George Washington University. In 1958, he was the first recipient of RCA's David W. Sarnoff Award for Outstanding Achievement in Engineering. In 1961, Barton received the M. Barry Carlton Award of the IRE Professional Group on military electronics. He received the IEEE Centennial Medal in 1984, and during 1987 to 1988 was the distinguished microwave lecturer for the IEEE MTT-S. From 1979 to 1982, he also served on the Air Force Studies Board of the National Academy of Sciences. From 1989 to 1993, Barton was a member of the Air Force Scientific Advisory Board. At present, he is a member of the review board for the Army Research Laboratory.*