EVOLUTION OF ANTENNAS AND SOLUTIONS FOR DESIGN AND ARCHITECTURE OF ADVANCED SURFACE SHIPS

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The enhancement of the role and value of naval surveillance and telecommunication systems became one of the trends in surface ships evolution at the end of the last century. It is clear that surveillance is required to provide the crew with information on friendly forces and enemy forces. Also, the information is needed for weapon guidance and control, for affecting weapon control systems of the enemy, and for a number of other important tasks.

At the end of the first decade of this century a special term was introduced to reflect qualitative changes in the field of acquiring, transfer, processing, and storing of information that describes military operations with wide use of information systems – network-centric warfare. This concept of warfare provides for combat power build-up through creation of informational-switching network that puts together information sources, controls, weapons (suppression means) and ensures real-time delivery of valid and complete situational information to participants of military operations.

It is the ensuring of high target detection probability that is a signature of the modern sea warfare. At the same time, the ability to detect the enemy is dependent not only on the technical capabilities of the ship itself. From year to year new options to mask their combat assets become available for potential enemies through the stealth technology and electronic countermeasure equipment, necessitating further improvements in naval detection systems.

Another reason for priority development of information systems is the lowering probability of global war at sea when any target appearing on displays and not responding to requests can be identified as an enemy and attacked. Under the conditions of today, hundreds of vessels and tens of aircraft can be caught in the combat operational zone having no concern with the started armed conflict. Consequences of loss of such an object can affect the conflict development much heavier than the potential success resulted from enemy target destruction. Therefore rising the probability of detected target identification is one of the high-priority tasks.

Finally, one more reason for intensive development of information systems can be pointed out. As a result of outrunning growth of naval weapon costs and lowering of the threat of global armed conflict initiation the total number of major class warships becomes considerably lower. To keep the number of warships at a minimum required level, shipbuilding programs of seafaring countries tend to include, in addition to powerful surface ships, light ships with less quantities and qualities of weapons. In this context the advantage of network-centric warfare concept is that it allows considering even relatively light ships as effective nodes of telecommunication network. On the contrary, having comprehensive and reliable information any ship can rise the probability of successful use of its combat potential.

The major material component of the network-centric warfare concept at the theatres of naval operations is the shipborne radio electronic equipment for information acquiring and weapon control. The development peculiarities of this radio electronic equipment to a significant extent define the combat potential of modern ships and the success of implementation of the network-centric warfare concept itself.

Wide use of shipborne radio electronic equipment started with introduction of radiolocation stations (radars) in the mid-

Fig. 1

dle thirties of the last century. Through several generations the equipment has come a long way from two-dimensional VHF radars to three-dimensional microwave (decimeter- and centimeter- wave) radars using parabolic antennas. These radars provided for detection of high-altitude targets and fast-moving pinpoint low-altitude targets in conditions of severe ruffle sea clutter and jamming.

In parallel to introduction of controlled weapon, radars were developed and adopted into service for targeting gun mounts to air and surface targets, for delivering the targeting information to strike missile weapon, for targeting antiaircraft guided missiles. First generations of these systems, as well as DSAT radars used parabolic type antennas.

The use of shipborne long-range strike missile weapons necessitated creation of targeting equipment for the full range of fire. The search for solutions to this problem was carried out in several directions. The first to be implemented was the idea to use air remote observation posts (AROP) with radar image transfer to the ship. The second direction relied on the use of passive radiolocation channel to detect active radars of the enemy. Both these directions were evolved in practice. However, whereas AROP was a real prototype of network information node with a certain potential, including that with introduction of remotely piloted air vehicles (RPAV), with the trend to containment of armed conflicts at sea and the need for reliable identification of detected targets, the systems of active foe radars detection became playing an auxiliary role, which was to a considerable extent coinciding with that of electronic reconnaissance (ER), which indeed had an impact on their role in the system of ship's weapon. Eventually these systems were enhanced with equipment for receiving information from satellites and the information coming via channels of information interchange and relative orientation (II&RO).

As a rule, antennas of missile weapon targeting systems were accommodated under a common radome, which became of significant size due to this fact.

The evolution of radio electronic equipment necessitated countermeasures in the form of electronic warfare (EW). Shipborne radio electronic EW means mainly include ER means, means of radio detection of active foe radars (RD) and means of active jamming. The electronic reconnaissance is a part of EW means in terms of its functions, but it is classified as a means of communication.

By the beginning of the new century EW means have achieved a level of development ensuring successful fulfilment of their tasks and equivalent to the world's best achievements. This was achieved with EW antennas having various configurations and numerous models.

In general, at this stage, as a result of creation of all the above mentioned radio electronic means the architecture of surface ships was characterized by extensive system of masts where parabolic antennas with significant dimensions were installed, including the antennas enclosed by radomes. As the equipment evolved and new radio electronic means emerged, the number of antenna posts grew contravening with general design solutions and posing a threat to common sense. Thus, for cruiser and destroyer class ships with two-echelon weapon accommodation and weapon redundancy, quantity of parabolic antennas could be as high as fifteen. Total number of antenna posts could be as high as fifty (see Fig. 1). Operation of such a large number of radiating devices in a limited space resulted in arising of the electromagnetic compatibility (EMC) problem. At the first stage this problem was resolved by methods of preemptive blanking and spatial-time diversity. However, added severity of electronic environment caused by, among other reasons, continuous operation of high-priority systems, as well as growing flows of unintended interference signals impeded successful problem solution. At the same time ship's observability became higher, shadow angles of radar fields of view increased, survivability of outwardly located antenna posts was low, and ship appearance became scruffy, not matching the notion of high technologies.

Shipborne radio electronic equipment has changed qualitatively with introduction of solid-state electronic devices, which became the basis for building of powerful computers, broadband digital communication links, and principally new radars based on phased array antennas (PAA).

Radars base on fixed phased array antennas are the most optimum solution for the appearance of modern ship. First radars of this type were built as early as at the end of the 60-s of the previous century (see Fig. 2). However, these were expensive, heavy and cumbersome systems with low reliability. PAA-based radars have come a long way within the decades. Migration to active phased array antennas (APAA) allowed achievement of considerably smaller dimensions, while the use of new generation of hardware components and software improvement allowed achievement of higher radar reliability. APAA-based radars' efficiency has increased manifold and put on the agenda the task of creation of a multipurpose radar, i.e. a radar performing functions of several special systems. In other words, a real potential for creation of multifunctional radar systems (MFRS) has arisen.

Despite the achieved success, leading manufacturers are still in discussion regarding the choice between the radar using fixed PAA (small frigate program) and the radar based on mechanically rotated PAA (one or two arrays) (see Fig. 3). However, current trends in the evolution of solid-state electronics promising simultaneous growth in APAA-based radar efficiency and lowering of their weight and dimensions probably will bring this dispute to an end in favor of fixed APAAs.

With this perspective in mind, it is time to consider the issue of appearance of antenna posts for future radar systems of surface ships. Leading designers of the modern generation of radio electronic equipment supported the idea to combine the majority of the equipment in a single modular structure, known as Integrated Mast (I-Mast) concept.

Fig. 2

The first candidate for implementation of this idea became weapon targeting radars that usually work in the same frequency range, i.e. X-band. Combining significant number of antenna posts that provide control of gun weapon systems and air defense (AD) systems into a single integrated antenna post composed of four APAAs wrapped around the I-Mast has resulted in a significantly better appearance of the ship and improved radar operating conditions. In addition, this radar also could be used as a backup DSAT radar, and in some cases it could be used for missile weapon targeting (within the radio-horizon range).

It can be expected that the next integration step will be related to combining of functions of radars detecting active radio location stations of the enemy, ER and RD of the EW equipment package.

Also, the relatively newish optoelectronic systems (OES) evolve in line with the general direction of antenna posts integration – therefore the next advanced OES solution in the near-term will be the creation of centralized systems capable of scanning the surrounding space layer by layer and automatically track several targets in the mode of gyro stabilization. When especially high degree of coordination between weapon and targeting equipment is required, on-the-barrel OES will be used.

Changes in the system of antenna posts of shipborne communication means have started. These changes are not that much lively, however they are noticeable. Communication equipment is still a centerpiece separating the control information from all other data required for military operations. At the same time automated systems of data exchange for ships and vessels are created as independent systems, and they continue their evolution. A significant obstacle for combining systems of formalized information exchange with ship's communication systems is the specific organization of communication, which is built for the purpose of control of the ship and other forces and allows transmission and reception of combat control signals, as well as keeps communication with civil entities and international legal entities. Despite this, currently the demand for creation of multifunction communication systems (MCS) is already rising. These systems should combine information resources and telecommunication networks.

From the point of view of accommodating on board of ships, such a system should have a single system of antenna devices ensuring coordinated usage of the data transfer system and the radio communication system. In the same way as for radars, big number of antennas makes the ship more observable, impairs its EMC characteristics, adversely affects design and architectural solutions that poses the challenge of antenna integration and unification in front of the designer of communication equipment. In addition to increasing number of transceivers sharing one antenna, special masts were added in a range of surface ship designs in order to create suitable environment for telecommunication systems by concentrating major portion of communication antennas on these masts. These design solutions reflect the growing role of telecommunication systems in the system of weapons on surface ships.

Of course, compact accommodation of MFRS in a single structure of I-Mast is a significant step forward not only in terms of functional combining of radio electronic means of the ship, but also from the point of view of their accommodation on board the ship. That's why in the second decade of this century many ship designers have created their solutions implementing this idea to a greater or lesser degree. However, with evolution of hardware components and software improvements a real opportunity appears for integration of antenna systems into the ship architecture at a new, higher level. This stage of evolution will be characterized by accommodating antenna systems not in a separately standing I-Mast, but in flat faces of the ship's superstructure as a whole. This solution will make it possible to solve the problem of all-round field of view for the majority of radio electronic equipment and will practically eliminate the adverse impact of antennas on observability and architecture of the ship. The ship's superstructure will be compact, single-island, while radio electronic systems distributed over its outline will gain additional survivability.

Indeed, a radical architectural solution like this will require revision of some traditionally formed views on mast and superstructure design, accommodation of various equipment, maintenance of crew activities. However, the design projects that are already completed by now, have shown that new problems arising from this approach can be satisfactorily resolved. In the meantime, on large deadweight ships APAAs can be accommodated above the navigating post, and on smaller deadweight ships these antennas cal be located under it. Also, in due course antennas of telecommunication systems will be integrated into the superstructure body.

At the same time, efforts of ship designer alone are not sufficient for successful implementation of the next stage of radio electronic equipment antenna systems integration into the ship's architecture to a level that meets requirements of the network concept. Achievement of this goal requires coordinated efforts of military authorities of the Navy, the General Customer, and eventually the designers and the leading manufacturers of MFRS and MCS.

One of the directions where these efforts could be fruitful is the direction coming out of such an aspect of network-centric concept as distribution of information means over network nodes. For example, this distribution could be implemented as departure from accommodation of all the radio electronic equipment on board due to the possibility to receive a part of required information via communication links. Implementation of this approach requires combined efforts of special authorities of the Navy under common management to speed up administrative transformations meeting the rate of technical progress and to eliminate the parochial approach of special operation bodies.

Another direction of work could be in putting together all the activities related to creation of multifunction systems under management of a single leading contractor while keeping minimum competitiveness and ensuring reliability for system designers in terms of their economical state and availability of skilled personnel, which is perhaps even more important now. In this case the number of contractors for supply of radio electronic equipment will be reduced, which should ensure control of costs and consistent integration of systems included in the multifunction equipment packages.

The leading designers of multifunction equipment packages should change their approach from simple adding of systems to their versatility. Then the number of functions performed by multifunction systems will grow, while the number and nomenclature of antenna posts will remain at the same level to avoid conflicts with design and architectural solutions.

Finalizing this brief review of stages of the evolution of shipborne antenna systems and current trends in creation of design and architectural solutions for surface warships, it is to be noted that many issues mentioned in this article are already being implemented in warships, which are in the process of building or already built, including those designed by Almaz Central Marine Design Bureau. This is migration to the single-island superstructure with fixed APAAs accommodated along its perimeter, reduction of the number of radiating antennas to the maximum possible extent to improve EMC characteristics, and awarding development of multifunction systems to the leading suppliers in order to stimulate integration processes and control the delivery price increase.

Fig. 3