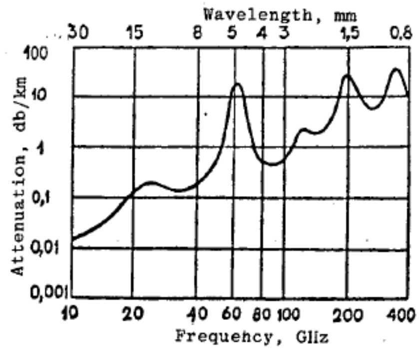
USE OF THE EXTREMELY HIGH FREQUENCY BAND IN AIRBORNE ELECTRONIC SYSTEMS

Foreign specialists consider the development of new, higher frequency bands to be one of the most stable trends in the development of military electronics. This is explained by several permanently operating factors. Above all there is the increase in the number of electronic resources being used in conducting combat actions, which causes an overload of already developed bands. In addition, electromagnetic oscillations with varying wavelengths have varying and often mutually supplementary properties. This allows expanding the capabilities of electronic systems by using radio waves of different bands. And finally, in the opinion of foreign experts, the operation of electronic systems in a wide area of the electromagnetic spectrum complicates the enemy's electronic warfare.

The meter and centimeter wave bands were developed abroad in succession following World War II, and the late 1970's and the 1980's are characterized by the wide unfolding of research and development aimed at creating electronic systems in the millimeter band (this band includes electromagnetic oscillations with a wavelength of 10-1 mm, corresponding to the frequencies of 30-300 GHz).

The millimeter band, which takes in the frequency range equal to 270 GHz, is not uniform from the standpoint of the conditions for propagation of electromagnetic waves. For example, with an increase in frequency the attenuation in the band increases approximately on a linear basis, but there are three regions corresponding to the resonance frequencies of oxygen and of water vapors where absorption increases sharply *(see* figure). Regions of the millimeter band with minimum attenuation, called radio windows, are used most often for the operation of radiotechnical equipment, but a number of systems, designed in particular to operate at short range, also use regions of the spectrum with high absorption. Table 1 gives the limits of sub-bands



Attenuation of millimeter band radio waves in the atmosphere

Table 1 - Millimeter Band Radio Windows and Absorption regions

Sub-bands	Radio Window		Absorption Region	
	Central Frequency, GHz	Central Wave-length, mm	Central Frequency, GHz	Central Wave-length, mm
30—51.4	35	8.6		
51.4—66			60	5
66—105	94	3.2		
105—134			120	2.5
134—170	140	2.1		
170—190			180	1.7
190—275	230	1.3		

allocated by the World Administrative Radio Conference for the operation of radiotechnical equipment, as well as the central frequencies (wavelengths) by which these sub-bands sometimes are denoted. The millimeter waves occupy an intermediate place on the overall scale of the electromagnetic spectrum between centimeter waves (the superhigh frequency [SHF] band) and the very far IR area. This position largely determines both the properties of millimeter waves and the characteristics of electronic systems in this band.

The foreign military press notes the following advantages of millimeter band [EHF] systems in comparison with SHF systems:

--The opportunity of creating antennas with narrow radiation patterns. It has been calculated, for example, that with an antenna diameter of 0.12 m the width of its radiation pattern at half power at a frequency of 94 GHz is 1.8°, while at a frequency of 10 GHz it is 18°. This makes it possible to increase the precision and security of the systems' operations and hampers their jamming.

--Broad bands of working frequencies being used: in four windows of the millimeter band of 35, 94, 140 and 230 GHz the corresponding bands are 16, 23, 26 and 70 GHz, i.e., any of the windows is larger than the entire SHF band presently being used. This provides for a reduction in mutual interference from friendly equipment and complicates the enemy's task of arranging electronic countermeasures. It is believed additionally that an opportunity to increase range resolution appears in active systems, and the opportunity to increase sensitivity appears in passive systems.

Meanwhile, it is noted that EHF radar systems are significantly inferior to SHF systems in operating range because of the considerable attenuation of radio waves in the atmosphere.

It is believed that EHF systems are less subject to the influence of weather conditions in comparison with electro-optical equipment. They operate satisfactorily in fog and with cloud cover, and only precipitation in the form of rain substantially reduces their operating range. For example, in dense fog (with visibility of 100 m) attenuation in the IR and visible optical bands increases to 100 db/km or more, while the attenuation of millimeter waves is not over several decibels per kilometer.. In the opinion of foreign specialists, EHF systems will have advantages over electro-optical systems under real combat conditions. For example, the FRG conducted comparative tests of target detection characteristics with EHF systems (94 GHz) and electro-optical systems under conditions of shellbursts along the target's line of sight. Results of the experiments showed the insignificant effect of weapons on the propagation of millimeter waves: signal attenuation was 15 db for 0.9 seconds after the shellburst, and then the target was again detected despite dust and smoke. In this instance the electro-optical systems were disabled for over 20 seconds. The resolution of EHF systems, however, is below that of electrooptical systems.

In giving a general assessment of the millimeter band, western experts note that this region of the electromagnetic spectrum is a compromise area, as it were. Electronic systems can be created here having high accuracy near that of electro-optical equipment, and at the same time providing all-weather capability and around-the-clock use, typical of equipment in the SHF band.

The interest in systems of the EHF band appeared back in the early 1940's, but the first series-produced element-base components were made almost 30 years later. Foreign specialists believe the reasons for this delay to be the insufficient study of conditions for the propagation of millimeter waves and the difficulty of developing a reliable element base. While the first of these reasons has been practically eliminated at the present time, resolution of the second problem will require many more efforts. It is believed that the greatest difficulties lie in creating powerful generator devices. The foreign press reported development of Gunn diodes and magnetrons operating at frequencies up to 100 GHz, and about klystrons and IMPATT diodes (an avalanche-transit diode in the transit mode) which can be used at frequencies of 200 and 300 GHz respectively. The power levels and efficiencies achieved by these devices, however, do not yet satisfy developers of EHF systems. Necessary system output usually is achieved by adding the outputs of several generator devices. For example, there was a report about the development of a transmitter with IMPATT diodes in the 95 GHz band which provides an output of 40 watts in a pulse mode when the outputs of four diodes are added. Over the next few years it is planned to increase the outputs of generators and power adders by 3 db and 10 db respectively. One of the latest trends is a shift from the use of microstrip elements to monolithic integrated circuits. The existing receivers cover broad instantaneous pass bands, such as from 26.5 to 40 GHz and from 75 to 110 GHz. Judging from western press reports, primary efforts presently are directed at creating systems operating in the 26-40 GHz band.

These advantages and deficiencies of millimeter waves were deciding factors in determining the areas of application of EHF electronic equipment. Radar, navigation, weapon control, communications and EW systems are regarded as the principal areas of application of EHF systems in the avionics of the United States and other NATO countries.

AIRBORNE RADAR AND NAVIGATION SYSTEMS. They include in particular the WX-50 radar of the American firm of Westinghouse, which has undergone flight tests aboard the TA-4J and OV-10 aircraft and the UH-1N helicopter. The possibility of its installation aboard the A-10 attack aircraft *(see* color insert [color insert not reproduced]) is being studied. The WX-50 noncoherent 8-mm radar provides for operation in the following modes: terrain avoidance and nap-of-the-earth flight; detection and selection of moving ground targets; ground mapping; measurement of flight altitude; and direction-finding of sources of emission (the principal characteristics of this and other radars are given in Table 2).

Table 2 - Principal Characteristics of EHF Radars

	WX-50	AN/APQ-137	Saiga	Drone radar
Frequency, GHz	35	34.5	35	95
Peak power, kw	100	25	7	2
Pulse length, nanoseconds	200	250	200	20
Prf, kHz	2	4	.	5
Width, antenna radiation pattern, degrees	1,5	.	1,3	0,43
Weight, kg	64	.	53	.
Volume, m^3	0,07	.	.	.

In the terrain avoidance and nap-of-the earth flight mode the radar sends to a display the contour lines of the relief section located up to 5 km ahead of the aircraft, which gives the pilot an opportunity to fly the plane at a height of around 60 m. The scanning sector is 12° in azimuth in the terrain avoidance mode. The radar provides an indication of ground targets moving at a speed of at least 5 km/hr. Enemy helicopters and tanks can be detected at distances up to 16 km.

In the mode for direction-finding of emitting sources the radar can detect and determine coordinates of high-priority emitting targets 0.43 and issue data on their azimuth to the weapon control system because of the broad band of the antenna reflector. In the mapping mode the radar display shows terrain sectors at distances of 9, 18, 27 or 50 km ahead of the aircraft. The scanning sector is 70° in azimuth for mapping.

The radar is equipped with a scanning cassegrain antenna with a diameter of 0.38 m. The scan rate is 60 degrees per second. The radar can be installed in the aircraft nose or in a belly pod; in the latter case its weight is approximately 132 kg. The WX-50 has a modular design, it is made in the form of six interchangeable units, and it is equipped with a built-in functional check system. The mean time between failures is 300 hours. The moving ground target indication mode is supported by an additional processor.

The foreign press notes that flight tests of the radar aboard the A-10 attack aircraft revealed ,a number of its deficiencies. In particular, the moving target indication was ineffective. In addition, during operation in the nap-of-the-earth flight mode the need arose to increase the fields of view in azimuth and elevation, and when flying over a surface with poor radar reflection the radar has to operate only together with the radio altimeter.

The experimental AN/APQ-137 radar of the firm of Emerson Electric is a pulse-doppler radar designed to detect ground targets. It has a 40° field of view in the search mode. The radar provides an indication of targets moving at a speed of 3-30 km/hr. Information is displayed on a screen 130 mm in diameter.

The Saiga radar was developed by the French firm of Electronique Marcel Dassault for installation in helicopters for terrain avoidance and nap-of-the-earth flight under adverse weather conditions and at night. The radar has a t80° field of view in azimuth in the forward and rear hemispheres and ±10° in elevation relative to the velocity vector. Its operating range is 5 km and it has a range resolution of 30 m. According to foreign press reports, flight tests have shown that the radar detects obstacles such as trees at a distance of 3 km and high-voltage lines at a distance of up to 1.5 km.

The AN/APQ-122 radar was developed by Texas Instruments on order from the U.S. Air Force and designed for installation in military transport aircraft to support airborne delivery under adverse weather conditions. In its dual-frequency modification the radar functions in the 8-10 and 35 GHz bands. The radar provides the following distances when operating in the centimeter band: 370 km for mapping, 277 km for obtaining weather information, and 445 km in the beacon mode. The millimeter band is used when the radar operates at short ranges for determining ground target coordinates and for high-resolution display of a radar terrain map for identifying reference points and for aerial delivery. It is reported in parti6ular that the radar can detect targets with a radar cross-section of 50 m^2 in a rain with an intensity of 4 mm/hr.

The AN/APQ-122 dual-frequency radar presently is being installed in some C-130, RC-135 and KC-135 aircraft.

The British P391 side-looking radar operates in the 8-mm band and is made in a pod version. Two antennas each are used for reception and transmission, with each antenna consisting of 12 vertical waveguides. There is an alternate switching of the right and left antennas with a frequency of 237.5 Hz to obtain images on both sides of the aircraft. The radar data is recorded on 127-mm film.

The Diana radar is being developed by the West German firm of Siemens; it provides for navigation and ground mapping and operates at a frequency of 35 GHz. A magnetron is used in the transmitter's output stage. The radar's waveguideslot antenna includes three waveguides situated one above the other: the central waveguide is used as the transmitter antenna and the upper and lower waveguides as the receiver antenna. The width of the antenna radiation pattern is 0.7° and 70° in azimuth and elevation respectively, and scanning in the horizontal plane is in a ±30° sector. In the mapping mode, coordinates of ground points are determined based on an analysis of doppler shifts of the radar frequency. There is a display of the surface being mapped on a color indicator, with ground sectors located up to 1,000 m from the aircraft displayed in green, those 1,000-4,000 m away in yellow and those 4,000 m or more away in blue.

The TALONS (Tactical Avionics for Low-Level Navigation and Strike) radar developed by the American firm of Norden Systems is designed for the navigation of flying craft and delivery of low-altitude attacks against ground targets. The foreign press notes that TALONS is the first NATO radar in the 3-mm band which has undergone flight testing. During the tests it was planned to evaluate the radar's operation in the modes of ground mapping, terrain avoidance, terrain following, and on-board weapon control under adverse weather conditions, as well as in the presence of centers of fire and smoke on the battlefield. During the tests the radar was placed aboard a T-39 aircraft in a belly pod, with the radar processor, control and indicator panel, as well as signal processor for evaluating radar characteristics installed in the cockpit.

A drone (BPLA) radar is proposed for use for battlefield reconnaissance and target designation. It has a ±20° field of view, a 50 degrees per second scan rate, and a tank detection range of 3 km in clear weather in 2 km in rain with an intensity of 4 mm/hr.

CONTROLLABLE WEAPON GUIDANCE SYSTEMS. Judging from foreign press reports, such advantages of electronic systems in the millimeter band as small size of input circuits and the possibility of use in adverse weather conditions are especially attractive to developers of airborne guided weapons. Information on selected systems of this type is given below.

Table 3 – Radiometer Characteristics

Characteristic	8-mm Radiometer	3-mm Radiometer
Central frequency, GHz...	35	94
Dimensions less input circuits & power units, mm	29×76×112	100×95×115
Weight, kg.....	0,27	0.74
HF amplifier band, MHz.....	1200	•
IF amplifier band, MHz.....	600	730
Band at filter output, kHz	150	150
Noise ratio, db	7.0	12,5
Temperature sensitivity, degrees.......	1,5	3,5
Measurement time, seconds	4,0—0,4	•
Warm-up & stabilization time, sec	60	•
Rated input, watts..	6,6	•
Operating temperature range, °C	−25 — +55	+5—+30

It is planned to install the RAC (Radiometric Area Correlation) system in American cruise missiles. It will permit more accurate guidance in the middle and terminal legs of the route and when flying over level terrain in comparison with the Tercom system. As with the Tercom, the RAC system uses optimalizingcorrelation principles of control. The difference in these systems is that the RAC uses the Earth's levels of natural microwave emission as an information parameter and a highly sensitive receiver-radiometer as a field sensor. According to western press reports, Sperry has developed two radiometers under U.S. Air Force contract which can be used in the RAC system (their basic characteristics are given in Table 3). The first radiometer, which operates at a frequency of 35 GHz, uses microstrip elements and the second is made with semiconductor devices. The Wasp missile guidance system. A large number of construction principles and approaches to the design of air-to-surface missile guidance systems were studied and experimentally checked in creating the system. The principal task was to develop a homing head allowing the possibility of target lock-on on the flight path without additional target designation. Such leading American firms as Hughes, Boeing, Rockwell and Honeywell took part in this work on a competitive basis, with their efforts concentrated on creating a millimeter-band radar homing head.

The U.S. Air Force command chose the Hughes homing head, operating in the 3-mm band, based on results of competition. It is believed that an increase in signal attenuation in the atmosphere in the 3-mm band compared with the 8-mm band is compensated by an increase in antenna gain. At the same time, a solution to the problem of detecting the target signal against the background of reflections from the underlying surface is facilitated because of the higher spatial resolution in the 3-mm band. The Hughes homing head transmitter uses an IMPATT diode, with a Gunn diode in the heterodyne. The homing head has a cassegrain antenna with conical scan.

The homing head functions in two modes: active and passive. In the active mode it operates as a conventional pulse-doppler radar. Search and target detection are accomplished at ranges of 3-5 km depending on weather conditions. In the terminal guidance leg, when distance to the target is 300-500 m, the homing head shifts to the passive mode and operates on the target's natural emissions. It is reported in particular that the shift to a passive mode was necessary to increase guidance accuracy. When the missile approaches the target, the mirror reflection from so-called "glitter points" causes amplitude and angular fluctuations in the guidance system which may lead to an increase in error. The use of a passive broadband receiver makes it possible to reduce the influence of this effect.

The majority of guidance systems under development use 8-mm and 3-mm band homing heads (their basic characteristics are given in Table 4). Meanwhile, foreign specialists do not preclude the possibility of creating short-range weapon guidance systems in the 5-mm band. In their opinion, the heavy attenuation of radio waves in this band will make it difficult for the enemy to perform electronic intelligence operations and jam 5-mm band resources. There were reports, for example, of the development of a 5-mm homing head with a Gunn diode for artillery guided projectiles allowing the detection of a small ground target at a distance of 300 m. On the whole, judging from foreign press reports, American firms' experience in creating millimeter-band radar homing heads showed the possibility of developing homing heads weighing 4.5-6.5 kg which are 30-40 cm long and have a diameter of 10-18 cm.

RADIO COMMUNICATIONS SYSTEMS. The Pentagon places constant emphasis on improving satellite communications systems inasmuch as up to 70 percent of the traffic over long-range military communications is transmitted over satellite channels. American experts believe that existing satellite communication lines have insufficient ECCM capability and are subject to the effects of nuclear bursts. In their opinion, the introduction of millimeter-band communication lines is one of the directions for improving the effectiveness of operations.

The United States has been conducting experiments in this direction since the latter half of the 1960's. For example, conditions for propagation of radio waves in the 8-mm band were studied using the ATS-5 satellite. The ATS-6, the first satellite with millimeter-band receiver-transmitter equipment, was

Table 4 - Characteristics of Millimeter-Band Homing Heads

Characteristic	8-mm Band Homing Head	3-mm Band Homing Head
Central frequency, GHz	30	95
Mode	Active-passive	Active-passive
HF amplifier band, GHz	2.0	1.0
IF amplifier band, MHz	900	800
Peak power, watts	7.5	10
Pulse length, nanoseconds	60	50
Pulse repetition frequency, kHz	72	78
Antenna diameter, mm	200	150
Width of antenna radiation pattern, degrees	3.0	1.5
Antenna amplification, db	34.5	39.5
Side lobe level, db	—17	—17
Conical scan frequency, Hz	100	200
Angle of deflection of beam from antenna axis, deg.	1.5	0.25
Range gate length, nanoseconds	60	50
Scan rate, degrees/second	60	150
Field of view in azimuth, degrees	±30	±20

Millimeter-Band Homing Heads Tests to establish contact with aircraft and ships at frequencies of 20 and 30 GHz were conducted for two years. The work of creating a satellite communications system in the millimeter band later were continued using the LES-8 and LES-9 satellites, which were placed in circular synchronous orbits in March 1976. Equipment was installed aboard the satellites in the decimeter (225-400 MHz) and millimeter (36.6-38.1 GHz) bands.*

The U.S. military leadership links a new phase in the development of satellite communications systems with the appearance of the Milstar (Military Strategic Tactical and Relay) system. Its development is considered a cornerstone in plans of the present American administration to modernize the armed forces command and control system. For example, a memorandum from President Reagan to the Pentagon in March 1984 termed creation of the Milstar system "a program with the highest national priority." It is designed to provide communications for 4,000 subscribers at the strategic and tactical control levels. It is planned to install system sets aboard aircraft, ships, submarines, and fixed and mobile ground-based facilities. It is planned to deploy the Milstar system in the 1980's and early 1990's.

U.S. military specialists believe that Milstar will provide higher ECCM capability and survivability than existing satellite coliununications systems. It is noted in particular that use of the millimeter band in the Milstar system will permit shortening its time for returning to normal operation following high-altitude nuclear bursts.

The Milstar system will include seven operating satellites and one reserve satellite. Four satellites are to be in a geostationary orbit over the Indian Ocean, the Eastern and Western Pacific and the Atlantic Ocean. It is planned to maintain communications for facilities located in high geographic latitudes via three satellites placed in highly elliptical polar orbits.

It is planned to communicate in the system in two bands: millimeter and centimeter. The earth-satellite channel will operate at a frequency of 44 GHz and the satellite-earth channel at 20 GHz. Each satellite will have 50 millimeter and four decimeter channels for relaying data and telephone messages at rates

*For more detail about experiments with the LES-8 and LES-9 satellites *see* ZARUBEZHNOYE VOYENNOYE OBOZRENIYE, No 3, 1985 pp 18-20--Ed.

of 2.4 kilobits per second and 75 bits per second. To increase the ECCM capability it is planned to use broadband signals and pseudorandom retuning of the carrier frequency within 2 GHz limits. It is planned to use a multiple-beam phased antenna array as the satellite antenna. The belief is that it will allow an automatic change in the radiation pattern's position in space if enemy jamming is detected so that its minimums are directed toward the source of jamming. In the opinion of American military specialists, it will take a one megawatt gyrotron generator with an antenna of some 10 m in diameter to jam satellite channels in which such ECCM measures are taken. Autonomous on-board systems for orientation and maneuvering in orbit are to provide for the satellite's planned ten-year service life. Launch of the first satellite of the Milstar system is planned for 1988. The U.S. Air Force command proposes to use the Milstar system to provide communications for strategic bombers, airborne command posts, tanker aircraft and AWACS aircraft both among themselves and with ground and shipboard command posts.

ELECTRONIC WARFARE SYSTEMS. The foreign press notes that the creation of military electronic systems operating in new bands inevitably leads to the development of electronic countermeasures [ECM] equipment for the corresponding frequencies. It is believed that features of millimeter band systems are causing the appearance of a multitude of new problems for the developers of ECM equipment and at the same time make it easier to create means and methods for radar ECCM. These features include narrow antenna radiation patterns, a broad working frequency selection band, and the possibility of using broadband pseudorandom signals. Millimeter wave antennas have a higher ratio of the main lobe of the radiation pattern to the side lobe than SHF antennas, and so jamming the side lobes is more complicated. The jamming of missile homing heads operating in a passive mode also presents a serious problem.

Many ECM systems are designed purely for energy suppression, but powerful millimeter wave generators have a low efficiency, which complicates the cooling system. Although gyrotrons have a rather high efficiency, they are large. The high-power millimeter wave generators usually are short-lived and require a voltage on the order of 20-100 kilovolts. The western press reports that the United States presently has created a traveling wave tube for an 8-mm band ECM system with around 10 watts of output in a continuous mode.

ECM systems of modular design being developed in the United States provide for the possibility of building up units to allow for jamming in new frequency bands. For example, the AN/ALQ-165 ECM system designed for installation in the F-14, F-18, EA-6B, A-8B, F-111, F-16 and certain other aircraft is to include an 8-mm band transmitter. There is also a report that work has been done to create millimeter-band on-board warning receivers.

The effectiveness of employing passive ECM equipment in the millimeter band is dropping since the narrow radiation patterns of electronic systems provide small resolution volumes. The foreign press has noted the ineffective use of chaff in the form of half-wave or quarter-wave oscillators made of aluminum for jamming systems operating at frequencies above 20-35 GHz. Experiments are being performed with various aerosols to create passive ECM resources in the higher frequency bands.

IN ASSESSING THE STATUS AND PROSPECTS FOR DEVELOPMENT OF THE MILLIMETER BAND, foreign experts note that the electronic systems in this band are finding increasingly wide use in the air forces of NATO countries. Their adoption is connected with a new stage in the development of precision weapons, inasmuch as high demands are being placed not only on accuracy, but also on the extent of around-the-clock and all-weather operation of such weapons. Judging from western press reports, there presently are several 8-mm band electronic systems in the foreign inventory, but the development of systems operating in the short-wave portion of the millimeter band is being delayed because of the lack of a reliable element base. For example, several experimental 3-mm band systems have been made and two of them have undergone the flight test phase (the TALONS radar and the Wasp guided-missile homing head). Only laboratory research is being done for now in the 2-mm and 1-mm bands. It is also reported that the Pentagon does not plan to fully replace existing electrooptical and SHF equipment with millimeter band systems. Consideration is being given only to variants of the rational joint use and integration of systems under development with those already in the inventory.