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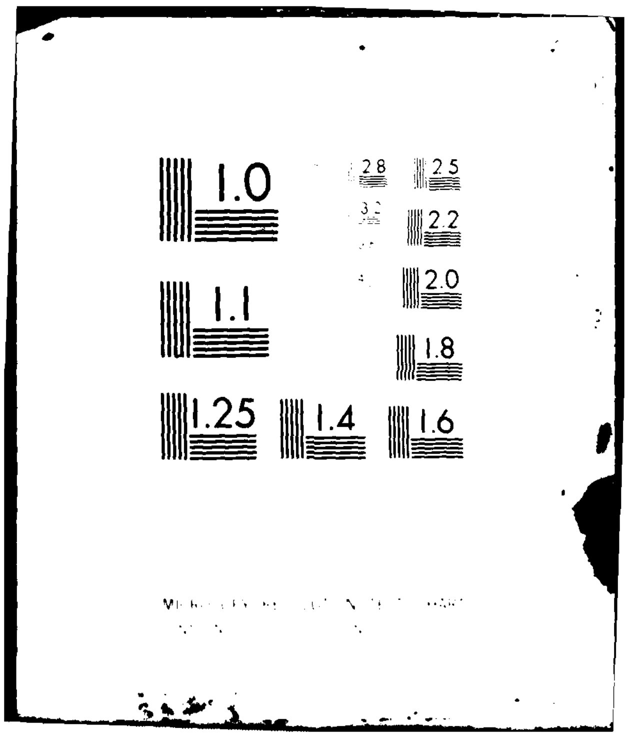
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FOREIGN TECHNOLOGY DIVISION

PASSIVE RADIOLOCATION

by

Ye.A. Malyshkin

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PASSIVE RADIOLOCATION

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PASSIVE RADIOLOCATION.

Ye. A. Malyshkin.

The pamphlet "passive radiolocation" enters into the produced by military publishing house library "radar technology". Library is designed for the officers, connected with the operation of radio equipment, and also for the wide circle of the readers, who desire in detail to become acquainted with the work of individual nodes and elements/cells of radars.

In the pamphlet "passive radiolocation", written based on materials of the foreign press, briefly are set forth the physical bases of the work of passive radar systems and possibility of applying the latter in military science. Furthermore, in the pamphlet are examined the passive methods of target detection, based on the reception/procedure of very long radio waves and waves of audio frequency.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ë in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

Page 3. Introduction.

Radiolocation - one of the leading branches of contemporary military electronics. It is developed in the direction/axis of an increase in the detection range of targets, accuracy and reliability of the determination of their coordinates.

Especially high value now acquires the problem of the reliable work of radar equipment under the conditions of the opposition of the enemy. Therefore in recent years abroad is conducted research work according to the creation of the passive radar systems, which make it possible to detect different targets, to conduct terrain reconnaissance and to carry out other missions, without emitting electromagnetic vibrations into the space, i.e., without detecting themselves and without revealing its own operating frequency.

In contrast to the active ones passive radar systems do not have transmitters. Fundamental elements of such systems - antenna system, receiver and output indicator.

Abroad passive radiolocation technique began to be developed during the Second World War. In the USA in the measurements of the atmospheric absorption of electromagnetic energy in the range of one centimeter it was discovered, that the earth's surface emits energy of centimeter wave band and that the intensity of the radiations/emissions adopted is changed, if the antenna of receiver guided to different objectives, arranged/located on the earth's surface. This made it possible to make a conclusion about the possibility of passive reconnaissance/intelligence in the centimeter wave band.

After five years were approximately developed high-frequency amplifiers with a small inherent noise level and ideal electronic circuits for the centimeter wave band.

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Thus appeared prerequisites/premises for the creation of reliable passive radar systems with the highly sensitive receiver as the fundamental element/cell.

The development of molecular amplifiers with the noise factor, equal approximately/exemplarily to one, expanded the possibilities of applying the passive radars (PRL) and considerably increased the range of the reception of the weak emitted signals.

In recent years abroad increasing attention is given to the passive methods of target detection, which radiate long radio waves. For such waves the surface of the Earth and the ionosphere form the walls of three-dimensional/space waveguide. Being propagated along the earth's surface with a small attenuation, radio waves make it possible to detect the radiating targets at the very large distances.

For the target detection are utilized also the passive stations, which accept the electromagnetic energy, emitted by aircraft radar transmitter. They are established/installed on the bombers and they make it possible to estimate distance to the attacking fighter airplane, controlling firing at it without the radiation/emission of electromagnetic energy.

For remote submarine detection in the submerged condition are applied so-called passive sonar systems. In the work of such systems it is utilized the properties of the hyperdistant propagation of acoustic waves in the sound-transmitting layers ("sonic channels") of the oceans.

The use/application of PRL is not limited to the detection of different objectives and to the determination of their coordinates. In the opinion of the foreign specialists, passive of station it is possible to utilize, also, for inducing the guided missiles. This guidance system is based on the capability of PRL to define the boundaries between the water and the dry land.

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Passive radar systems, which work according to the principle of the reception of the signals of thermal radio emission.

It is established/installed, that all objectives, which have the temperature higher than absolute zero (-273°C), emit the electromagnetic waves of millimetric and centimeter bands. This radiation/emission is called thermal radio emission. Passive radars can accept thermal radio emission from the earth's surface, sea, from the located on them objectives, etc. Depending on temperature of surfaces and objectives the intensity of radiation/emission by them radio waves is different. The surfaces and the objectives, heated to the large temperatures, emit more powerful/thicker radio signals, and therefore mark from them on the scope of passive radar brighter than mark from the surfaces and the objectives the temperature of heating the which is less [6].

The large part of the energy, emitted by hot bodies, lies/rests at the infrared region of frequencies, which occupies wave band 0.76-750 μm [1].

FOOTNOTE [1]. 1 micron (1 μm) - one millionth unit of the meter.

ENDFOOTNOTE.

And only the small unit of the radiant energy falls to the millimetric and centimeter wave bands. For example, the body, heated to temperature of 27°C, emits into the space in the millimetric and centimeter wave bands only about 1o/o of entire emitted energy.

The power of thermal radio emission is very small. Thus, taken the signal of thermal radio emission from the earth's surface is approximately 10^{-11} W [4].

The emitted by objectives signal has the same structure as its own thermal noises of receiver. This impedes the isolation/liberation of useful signal against the background of noises.

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However, contemporary receiving technology made it possible to create the reliable passive radar systems, which work according to the principle of the reception/procedure of thermal radio emission. The capability of such systems to distinguish and to detect objectives depends on the following factors: difference in the apparent temperatures of objectives, width of the radiation pattern and angles of its slope relative to objectives, antenna polarization and value of the emitted signal. Most of all work of PRL depends on a difference in the apparent temperatures of objectives.

Apparent temperature - this product of the absolute temperature of heating body to the value of its emissivity.

The emissivity of body is the ratio of the radiated power of this body, heated to the specific temperature, to the radiated power of the blackbody, which has the same heating temperature.

Absolutely blackbody can be defined as the idealized object/subject, which absorbs all falling/incident to it radiation/emission. The emissivity of blackbody takes as the equal to 100o/o. If the emissivity of body is equal to 25o/o, then this means that it emits in this band of frequencies 25o/o of that energy, which would emit in the same zone the blackbody with the same heating temperature.

Antenna of PRL receives, besides radiant energy of the objective whose radar reconnaissance is conducted, the energy, emitted by the external space (radio emission of the atmosphere) and other sources. Total energy of microwaves which accepts the antenna PRL, it is called the total radiation. It usually is expressed in the units of the apparent temperature of body.

Thus, for instance, it was established/installed, that the water surface with absolute temperature of 27°C (300°K) and by emissivity on microwaves 45o/o not only emits energy with apparent temperature of 300°K·0.45=135°K, but still and it reflects energy of external space in the same, centimeter wave band, equivalent to 27.5°K. The total radiation for the present instance composes 135+27.5=162.5°K.

The value of the reflected energy is proportional reflectivity of objective. Since passive radar accepts the electromagnetic energy, directly emitted by objectives and reflected by them, then it must distinguish objectives both to the large difference in the apparent temperatures and having approximately/exemplarily identical temperature, but different reflecting capabilities.

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In the foreign press it is indicated, for example, that reflectivity of water is equal to 55o/o, and emissivity composes 45o/o. For the earth's surface these values are respectively equal to 10 and 90o/o. Therefore the total radiation of the earth's surface is greater than water, at their identical absolute temperature. But this it is sufficient so that PRL "would be distinguished" the water and the earth/ground.

Fig. 1 shows the curve of a difference in the apparent temperatures ΔT of the earth/ground and water, obtained via recording from the aircraft of the intensity of their radiation/emission [4]. As the indicator of PRL was utilized the chart-recording instrument. It was established/installed on the output of radar receiver. With the reception/procedure by antenna of PRL of different ones in the value of the signals of radiation/emission the chart-recording instrument was deflected upward or down from the mid-position to the specific value. Because of this on the tape was obtained the recording by which it is possible to judge about the intensity of the signals of radiation/emission and, consequently, also about the possibility of PRL to distinguish the earth's surface and water.

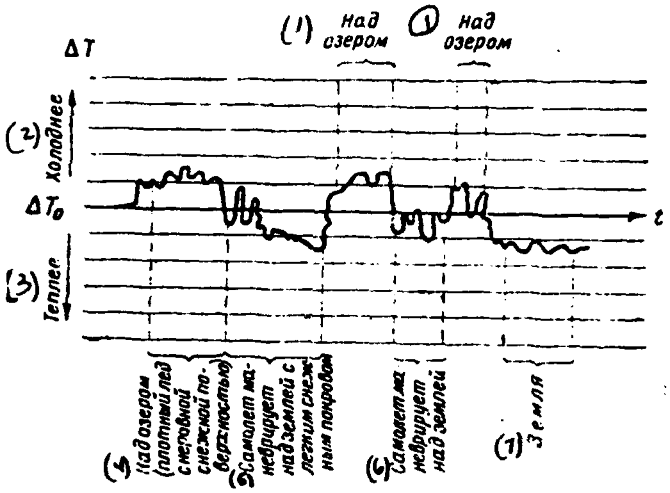

Fig. 1. Curve of a difference in the apparent temperatures ΔT of the earth/ground and water.

Key: (1). Above the lake. (2). It is colder. (3). It is warm. (4). Above lake (dense ice with uneven snow surface). (5). Aircraft maneuvers above earth/ground with light snow cover. (6). Aircraft maneuvers above earth/ground. (7). Earth.

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Furthermore, were obtained the following differences in the apparent temperatures of the objectives:

10°K - covered with snow earth/ground and building;

10°K - building and the atmosphere behind building;

41°K - covered with snow and dry earth/ground;

19°K - dry and humid earth/ground;

12°K - humid earth/ground and the roof of auto.

These differences in the apparent temperatures make it possible to distinguish objectives with their reconnaissance/intelligence. If we toward the objectives direct the antenna of passive radar, then it will be possible to reveal/detect them from different brightness or image contrast on the screen (depending on the type of output indicator).

The value of that taken by antenna of PRL of signal depends not only on the emitting and reflecting capability of objectives, but also on the angle of the slope of the antenna radiation pattern relative to objective, or on its polarization. Antenna polarization is driven out/selected horizontal or vertical.

The electromagnetic field, emitted by objectives, consists of electrical and magnetic fields. Intensities/strength of these fields - value directed. Them they usually depict as vectors $\bar{E}$ and $\bar{H}$. Vector $\bar{E}$ determines electric intensity, vector $\bar{H}$ - magnetic intensity. Those emitted by the objective of radio wave are propagated in the direction/axis, perpendicular to the plane at which lie/rest the vectors of the intensity/strength of electrical and magnetic fields. The plane, passing through the vector, which shows the direction/axis of radiowave propagation, and the vector of electric intensity, is called the plane of the polarization of radio waves.

If the vector of electric field is oriented vertically relative to the earth/ground, then by objective is emitted the vertically polarized electromagnetic wave, if it is horizontal, then the horizontally polarized electromagnetic wave. Depending on this is driven out/selected antenna polarization of PRL.

The angle of the slope of radiation pattern is called the angle between the direction/axis of the maximum of diagram and the horizontal.

The angle of the slope of radiation pattern and the form of antenna polarization in each individual case are driven out/selected experimentally.

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The effect of the angle of the slope of antenna to the greatest degree is manifested with reconnaissance/intelligence of flat surfaces as, for example, the surface of water.

The effect of polarization noticeably is manifested at the small angles of the slope of antenna and disappears, when antenna is directed toward the objective at angle of 90°. For example, the flat surface of water with an absolute temperature of 293°K has apparent temperature of 160°K, if the angle of the slope of antenna is equal to 90°, independent of antenna polarization. At the angle of slope of 30° and vertical polarization the apparent temperature achieves 280°K, i.e., it increases on 120°K. During the use of horizontal antenna polarization the apparent temperature of water remains at the level of 160°K.

In order to distinguish the asphalt path/track of airfield of its surrounding green vegetation, the angle of the slope of antenna must be small, and polarization - horizontal. In this case the apparent temperature of asphalt sharply falls and it becomes as more "cold", than the green vegetation which remains "warm" with any antenna polarization. By "cold" it is accepted to call the body whose apparent temperature is less than the apparent temperature of the body compared with it, while "warm" - temperature of which is more.

For the detection of aircraft on landing runway, in the opinion of the foreign specialists, should be applied the antennas with the vertical polarization. Metal weakly emits the waves of any polarization, whereas asphalt more strongly emits the vertically polarized waves.

For determining the basins in the forest terrain on the aircraft are applied the antennas with the horizontal polarization at the slope angles within limits of 30°.

Utilizing different antenna polarization PRL and changing the angles of the slope of radiation pattern relative to objective, it is possible to detect objectives with the almost identical apparent temperatures.

Passive radar must have sufficiently high resolution which, as in active radar, it depends on the width of the antenna radiation pattern, i.e., from the diameter of the reflector of antenna and from the working wavelength. However, with the tendency to obtain the high resolution due to the decrease of wavelength one should consider an increase in the atmospheric attenuation at the higher frequencies. The latter fact is especially substantial for the work of passive radar, since it must pick up signal whose level is very small.

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If the width of the antenna radiation pattern PRL exceeds the angular dimensions of objective, then its apparent temperature in the percent ratio will be so lower, how angular a dimensions of objective are lower than the width of the antenna radiation pattern.

In contrast to the active radars, which possess specific range resolution (depending on the duration of sounding pulse), passive radars range do not determine, and the concept of range resolution of them is not applicable.

For conducting terrain reconnaissance from the aircraft in the USA are created the experimental models of the passive radars, which work on the waves with a length of 8 mm, 1.25, 1.8 and 3 cm. Under flight conditions they tested on the dirigibles of navy, transport aircraft C-47 and helicopters S-55 [10].

With the aid of the passive radar, which worked on the wave 1.25 cm, it was possible to distinctly distinguish the boundary between the water and the dry land the aircraft, on which it was established/installed PRL, flying in the very dense fog at the height/altitude of 1800 m. The passive radars, which worked in other wave band, determined the tracers of the passed ships, since the temperature of wake jet was somewhat higher than temperature of sea water.

By passive radar which as the indicator had a chart-recording instrument with the sapphire needle, was conducted terrain reconnaissance and was determined its relief. Chart-recording instrument moved over the paper, covered with the layer of wax, synchronously with the radiation pattern of receiver. The side of the sheet of paper, covered with wax, was black. Emitted by the earth's surface both water and taken by antenna of PRL signals were amplified by receiver. The intensive voltage was utilized for heating of the needle of chart-recording instrument. Under the needle the wax melted with the intensity which depended on the value of the signals of radiation/emission, i.e., from thermal area relief. Since the earth/ground is "warmer", than water, fusion of wax went more intensely with the reception of signals from the earth/ground and the non-machined surface of paper projected/emerged more. This gave the darker/nonluminous image of the earth/ground on the sheet of paper.

The image of coast, obtained with the aid of the passive radar (Fig. 2a), is very close to its image on the geographical map/chart/card (Fig. 2b).

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In the passive radars for conducting military terrain reconnaissance is utilized instead of the chart-recording instrument cathode-ray tube [6]. Then the electron beam of tube, modulated on the brightness by the signals of radiation/emission, creates on the screen the image of area relief. "Warm" objectives are visible on the screen in the form of bright marks, "cold" - less bright. Most vividly on the screen of passive radar is designated dry land. Water appears less bright.

For the survey/coverage of terrain the antenna of passive radar rotates with the constant velocity around the vertical axis. Simultaneously with the rotation of antenna rotates the sweep trace of plan position indicator. At the scope appears the image, the brightness of isolated points of which is determined by the intensity of the signals, emitted by different sectors of surface.

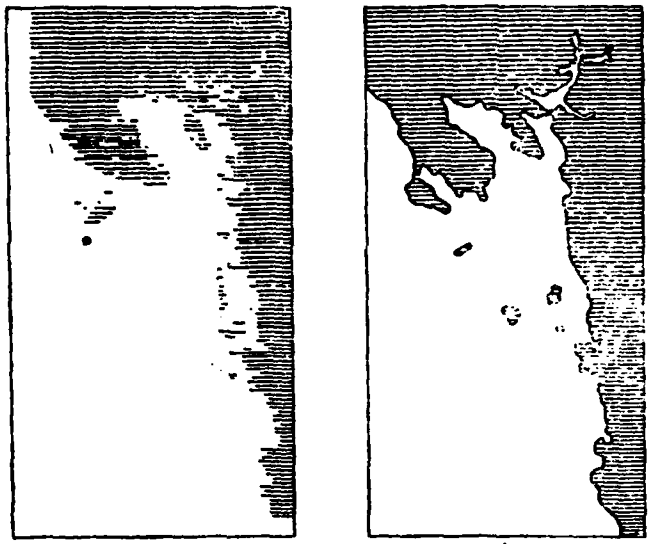

Fig. 2. Images of coast: a) obtained with the aid of the passive radar; b) on the geographical map/chart/card.

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In connection with the screen afterglow the obtained image is retained for a certain period of time, forming the radar actual chart area, above which flies at this time the aircraft (Fig. 3).

Besides terrain reconnaissance, on the basis of the tests conducted it was acknowledged by advisable utilize passive radar for the detection of aircraft. At present in the USA for conducting military intelligence of the airspace is utilized aircraft passive radar "Tom Thumb" [4].

Radar "Tom Thumb" has very small sizes/dimensions, since in it are used miniature electronic circuits. This radar makes it possible allegedly to detect at the "extremely large distances" the flight vehicles, equipped with turbojet, direct-flow/ramjet jet and rocket engines [6].

It is acknowledged also by the possible to detect with the aid of PRL the ships, which move in the sea and oceanic expanses. In this case is utilized the capability of PRL to differ wake jet from the colder water.

Besides the accomplishment of missions by the target detection and terrain reconnaissance, PRL can be used for inducing the guided missiles on the boundary between the dry land and the water or according to the so-called "guidance method to the coast". In both cases is utilized the capability PRL to define the boundaries between the dry land and the water.

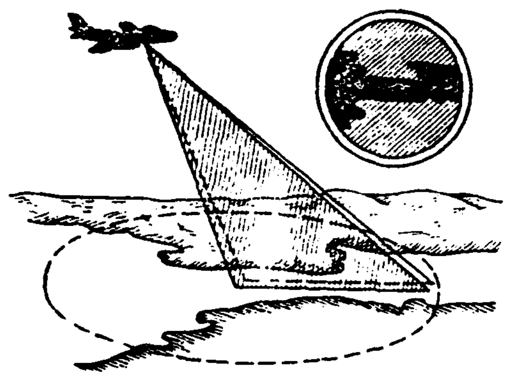

Fig. 3. Terrain reconnaissance by aircraft passive radar with the plan position indicator. To the right above - the image of relief on the screen of indicator (radar actual chart area).

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On the rocket projectiles is established/installed the very sensitive receiving equipment, which reacts to a change in the value of the signal, emitted by the surfaces of the water and earth/ground.

If from the aircraft, which flies from the side of sea, is launched the guided missile of class "air - the earth/ground", equipped with PRL, then with the span/flight of the latter above the earth's surface the value of that taken by antenna of PRL of signal grows/rises. This change in the received signal is transmitted to the special servo electronic system which issues steering commands of the flight of shell. Steering commands enter either the autopilot of shell or the control amplifier. Aerodynamic forces, created due to the deflection of rudders, changes the direction/axis of the flight of shell, and it begins to dive to the earth.

During homing of shell on the boundary between the dry land and the water is utilized the capability of PRL to differ more the "cold" surface of water from more than the "warm" earth's surface. The electronic system, established/installed on the shell, reacts to the value of a difference in the apparent temperatures of the surfaces of the water and earth/ground. The value of this difference affects the flight route of shell. It will fly on the boundary between the dry land and the water with condition, that the value of a difference in the apparent temperatures of the surfaces of the water and earth/ground will be the value of approximately/exemplarily constant. With the course-line deviation this difference in the form of the error signal will make it necessary to be deflected the rudders of shell and will change the direction/axis of its flight. As a result the value of error voltage will change and shell will fly on assigned route.

Americans intend to also utilize the capability of PRL to react to changes in the signals of thermal radio emission for the damage/defeat of surface targets. For this on the guided missiles class "ship - ship" they are collected/built to establish equipment of passive radar system.

The range of PRL, that work according to the principle of the reception of the signals of thermal radio emission, depends on the conditions for radiowave propagation in the atmosphere. Thus far another range of PRL, millimeter and microwaves intended for terrain reconnaissance and working in the ranges, is small and composes several kilometers. The range of PRL for reconnaissance/intelligence of the airspace in the press/printing is not given.

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HIGH-FREQUENCY AMPLIFIERS OF PASSIVE RADAR SYSTEMS.

Reception/procedure and the amplification of the signal of thermal radio emission simply can be shown on the block diagram of passive radar (Fig. 4).

Signal is received as antenna, and then before the amplification by ordinary radar receiver is modulated by mechanical method. Modulation is necessary for the separation/department of useful signal from the inherent noise of receiver. After amplification by radar receiver the useful signal is supplied to the filter of low frequency (integrator), which smooths the fluctuations of signal and emits its constant component. The latter is supplied to the display unit.

The signal of thermal radio emission on its form resembles its own noise of receiver. The amplitude of this signal can be very small. Therefore passive radars must possess high sensitivity.

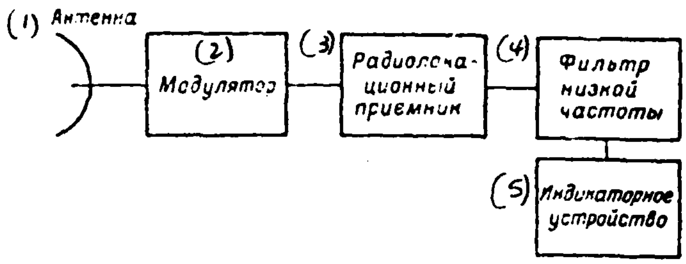

Fig. 4. Block diagram of passive radar.

Key: (1). Antenna. (2). Modulator. (3). Radar receiver. (4). Filter of low frequency. (5). Display unit.

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Sensitivity of PRL is determined by the value of voltage on the input of the receiver, which creates the normal value of signal on the indicator. Usually this voltage is measured in the microvolts.

The amount of voltage or power at the output of receiver, necessary for the normal work of indicator, can be different. Contemporary receivers and amplifiers give the possibility to lead power or received voltage of up to the very high value. However, receiver sensitivity - value determined and limited.

The limit of sensitization is not the value of signal which can be obtained at the output of receiver, but the inherent noise of receiver.

To confidently reveal/detect objective is possible only in the specific ratio of the value of signal to the noise level. For the passive radars the signal-to-noise ratio at the output of the filter of the low frequency of receiver is defined as quotient of the division of the power of the constant component of useful signal to the average/mean power of noises.

Inherent noise in the receiver are unavoidable. Their reason are the inherent noise of antenna and the electronic processes, which occur in the tubes and the resistors/resistances.

Together with the useful signal are amplified the noises.

For the reliable target tracking on the display it is necessary as much as possible to restrict the amplifier noises of the high frequency of radar receiver. Therefore in the receivers of PRL as the high-frequency amplifiers are utilized the tubes with the traveling wave and the molecular amplifiers, which have a small noise level. Use of a tube with the traveling wave (LBV) gives the possibility to accept the very weak signals of thermal radio emission.

According to the communications/reports to the foreign press, experimental receivers with the high-frequency amplifier on LBV with the passband into several ten megahertz, coefficient of noise less than 10 and to the filter pass band of the low frequency, equal to several hertz, we could distinguish objectives with a difference in the apparent temperatures in 2-3° (to difference in the apparent temperatures in 1° was equivalent the minimum of signal 10^{-16} W).

Essential deficiencies/lacks LBV - it are relatively greater weight and overall sizes. However, are even now found the ways of the improvement LBV, which make it possible to remove these deficiencies/lacks.

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Is at present abroad developed LBV with the electrical focusing of the ray/beam of electrons - estiatron. Estiatron possesses great advantages in comparison with the tube, which has the magnetic focusing, its overall sizes are small, and weight is approximately equal to 450 g. It provides large amplification, transmission of broadband, does not require a precise selection of the supply voltage and has large term of service. The factor of the noise of estiatron much the same as in the ordinary tube with the magnetic focusing.

By most promising for the passive radars are acknowledged molecular amplifiers, since it possess the noise factor, close to the unit. This makes it possible to increase the range of passive radar system in dozens of times.

But in what a difference in the molecular amplifiers from the vacuum-tube amplifiers known in radio engineering?

In the ordinary vacuum-tube amplifier the signal echo from the target is amplified due to the efficiency to the electromagnetic field of the superhigh frequency of energy of the electrons, which fly from the cathode to the anode of electron tube.

However, in the molecular amplifier the useful signal is amplified due to the efficiency in the form of the electromagnetic radiation of internal energy of the molecules of the specific crystalline substance.

Let us briefly dismantle/select the work and the equipment of molecular amplifier. As is known from physics, the molecules of substance complete diverse oscillatory and rotary motions. According to quantum mechanics the energy of molecules cannot smoothly change, but it takes only the strictly defined, discrete/digital values. It is accepted to indicate that energy is. This means that for each microsystem there is a completely specific set/dialing of the allowed values of energy. Therefore the measurements of internal energy can occur only irregularlyly between the allowed values.

These values of energy, or energy levels, are defined by both the internal building/structure of microsystem itself and by effect on it of the external reasons, for example, for electrical and magnetic fields. A quantity of energy levels of microsystem and energy difference between any two levels depend on the nature of substance and value of the applied applied field.

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The energy transitions/junctions of molecules from one level to another are conveniently measured in the megahertz, since energy and frequency of electromagnetic waves are closely interconnected.

The difference between two energy levels is defined as the product of frequency and Planck's constant:

$$E = h\nu,$$

where E - difference between the energy levels; h - Planck's constant ($6.62 \cdot 10^{-27}$ erg·s); ν - frequency MHz; $h\nu$ - quantum (portion) of radiation/emission.

Under the normal conditions in the absence of external agency in the microsystem occurs movable thermodynamic equilibrium. The distribution of the molecules between different levels is described by the formula of Boltzmann and for two levels is expressed by the formula

$$\frac{N_2}{N_1} = e^{\frac{-h\nu}{\kappa T}},$$

where N_1 - number of molecules with energy W_1; N_2 - number of molecules with energy W_2; $h\nu$ - difference in the energy levels (W_2-W_1); k - constant of Boltzmann ($1.38 \cdot 10^{-16}$ erg/deg); T - absolute temperature.

From the formula it is evident that with sufficiently low temperatures the majority of molecules is located on the first, lower energy level.

Experiments show that energy of molecule, measured at certain moment of time, always corresponds to one level of the infinite series of discrete energy levels.

If the molecule of substance can occupy three specific energy levels, i.e., have internal energy W_1, W_2 or W^3, then never its energy will take certain intermediate value of W, where W_3>W>W_2 (Fig. 5).

The transition/junction of the molecule of substance to the higher energy level is escorted/tracked by absorption by this molecule of electromagnetic energy, and reverse/inverse transition/junction - by its radiation/emission.

All molecular microsystems, being located in thermal equilibrium with the environment, have at the lower energy level more molecules, than on the upper, and therefore they are absorbing.

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So that the microsystem could emit energy and, consequently, also amplify received signals, on the upper energy level must be located more molecules, than on the lower. This is - fundamental requirement for the work of molecular amplifier [2].

In order to derive molecules from the condition of equilibrium, it is necessary to excite them. For example, it is established/installed, that under the influence on the paramagnetic crystal of the strong electromagnetic field of the specific frequency it is possible to increase a number of microparticles at the upper energy level and thereby to create conditions for radiating/emitting the energy by molecules and its selection.

Are at present abroad developed the molecular amplifiers, called "solid", since in them is utilized solid in the form of the small crystal, placed into the cavity resonator.

In the USA, for example, is developed "solid" molecular amplifier for the frequency of 2800 MHz [3]. With the aid of this amplifier the range of passive radar it was possible to raise approximately/exemplarily 10 times. The work of amplifier is based on the use of three energy levels W_3, W_2 and W_1 molecules of cobalticyanide potassium $K_3CO(CN)_6$, which contains 0.5o/o of admixture/impurity of chrome-cyanide potassium. In this case $W_3>W_2>W_1$.

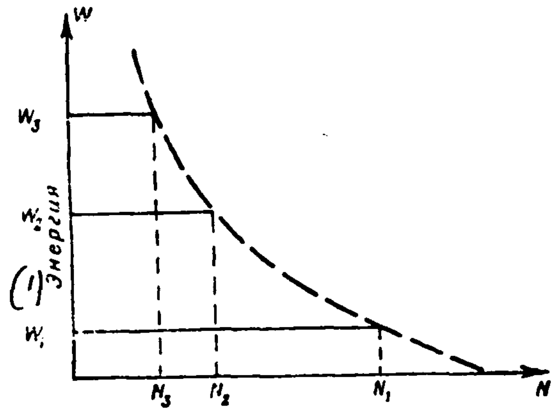

Fig. 5. Energy-level diagram for the molecule of substance (N - number of molecules at the energy level).

Key: (1). Energy.

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Works amplifier at a temperature of 1.25°K, i.e., at a temperature, close to absolute zero, which provides the extremely low level of its thermal noises.

Molecular amplifier (Fig. 6) consists of cylindrical cavity resonator 1 which resounds at two frequencies: the frequency of excitation and the frequency of the amplified signal. Excitation, i.e., the transition/junction of molecules from the lower energy level to the upper, is realized at the frequency of 9800 MHz, at the frequency of 2800 MHz. Within the resonator, in the loop of magnetic field is located small crystal. High-frequency excitation energy is supplied on rectangular waveguide 2.

The amplified useful signal (signal of thermal radio emission) is supplied on coaxial cable 3, which has connection/communication with the cavity resonator with the aid of the loop. On the same cable the intensive signal is devoted for the subsequent conversion and the amplification. For the separation of input and output signals is utilized ferrite valve/gate and directional coupler.

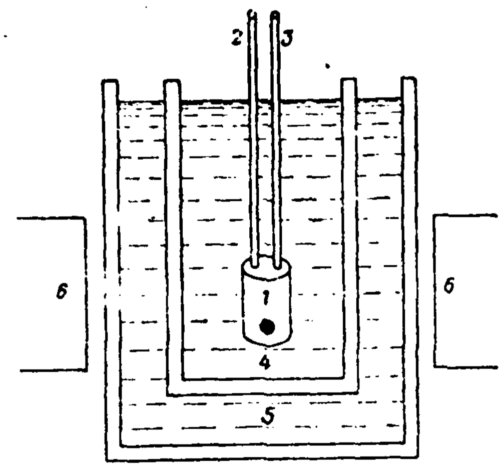

Fig. 6. The construction of the molecular amplifier: 1 - cylindrical volumetric resonator; 2 - waveguide; 3 - coaxial cable; 4 - liquid helium; 5 - liquid nitrogen; 6 - magnet.

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Cavity resonator for the cooling is immersed in the container with liquid helium 4, which in turn, is placed into the container with liquid nitrogen 5. This makes it possible to support the temperature of crystal about 1.25°K.

The lower unit of the container in which is placed cavity resonator, is arranged/located between the poles of powerful/thick magnet 6, which creates the necessary conditions for transiting the molecules from one energy level to another.

The frequency of the absorbed or emitted electromagnetic energy is found in the dependence on a difference in the energy levels, at which occurs the transfer of molecules. Therefore magnetic field strength must be such that a difference in the upper W_3 and the average W_2 energy levels of molecules would correspond to the frequency of the amplified signal, equal to 2800 MHz.

Changing magnetic field strength, it is possible over wide limits to reform/redispose the operating frequency of amplifier.

The high-frequency energy, applied on the waveguide to the cavity resonator, forces the unit of the molecules of substance to pass from the lower energy level W_1 into the upper energy level W_3. In this case occurs the absorption by the molecules of the paramagnetic crystal of energy of strong high-frequency field by the frequency of 9800 MHz. If we to the resonator feed weak signal by the frequency of 2800 MHz, then will occur the reverse/inverse transition/junction of molecules from the upper energy level W_3 into the intermediate energy level W_2. Energy of molecules in the form of electromagnetic radiation at the frequency of the amplified signal, in the phase with the latter, is given to the weak electromagnetic field of this signal. As a result occurs its amplification.

Experiments showed that if we change the power of electromagnetic field of exictation from 1 to 30 mW, then the amplification of useful signal is changed from 12 to 32 dB.

For further amplification are applied the nodes of the ordinary radar receiver from output of which the signal is supplied to the filter of low frequency, and from it - to the display unit.

It must be noted that the intensity/strength of electromagnetic field of exictation can be increased to the specific value after which the amplifier can be excited and become generator. This moment comes when the radiated power of the molecules of crystal becomes equal to losses in power in the walls of cavity resonator and in the waveguide of connection/communication.

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Molecular amplifier is connected to the antenna and to the input of usual radar receiver with the aid of coaxial cable.

In the molecular amplifier there is no input and output, as we became accustomed to understand them, examining usual amplifiers. As has already been spoken, radio signal is supplied from antenna into the high-frequency amplifier on the the coaxial cable, and then on the same cable it comes for the further amplification into the usual radar receiver.

It is known that in the electron tubes clearly are divided input and output circuits. The grid circuit controls anode circuit. The reverse/inverse reaction of anode circuit to the grid is small. Therefore in the usual vacuum-tube amplifiers grid circuits are input, and anodic - output. The connection/communication between them usually is sufficiently weak.

During the introduction to this amplifier of positive feedback the difference between input and output circuits is erased and amplifier begins almost equally to react to the signals, applied both to the output ones and to the input terminals.

Molecular amplifier is actually regenerative amplifier. With the arrival of useful (input) signal into the cavity resonator of molecular amplifier the part of the radiated power of the molecules of crystal compensates the power loss of signal in the walls of cavity resonator. Amplifier does not have a separate input and an output, and is possible to get by with one coupling cable even one loop connection/communication of cavity resonator with this cable. In this case together with the useful signal to the input of the amplifier through the cable will hit the noises of input circuits of receiver which will be intensified by it just as the signal, which arrived on rectangular waveguide from the antenna. Since the noises will be intensified so, how and a received signal, relation signal/noise will not be improved, and consequently, will not be improved the sensitivity of receiver.

In order to utilize possibilities of molecular amplifier on the amplification of very weak signals, it is necessary to exclude the incidence/impingement in it of the noises of input circuits of receiver. This is done with the aid of the directed coupler-absorbers and the ferrite device/equipment, which passes the electromagnetic wave only to one side.

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It is possible so to connect them that the amplifier will approach only the useful signal, but the noises of input circuits (antenna, the coupling devices/equipment, contacts) will not pass.

As can be seen from diagram (Fig. 7), molecular amplifier is connected to the antenna and the radar receiver with the aid of the directed coupler-absorbers and the ferrite device/equipment. In this case ferrite device/equipment will agree with the resistor/resistance of input circuits of receiver in order to exclude the reflection of electromagnetic marking wave. With this connection the signal of thermal radio emission, accepted by antenna, falls into the molecular amplifier. Immediately to pass into the circuit of radar receiver signal cannot: on its path stands the ferrite device/equipment, which does not pass direct wave. After amplification the signal through the ferrite enters for further conversion and amplification the nodes of usual radar receiver, since for the electromagnetic wave of the intensive signal ferrite "valve/gate" it is opened.

The electromagnetic wave intensive in the molecular amplifier passes without the reflection into receiver, since the resistor/resistance of ferrite is matched with the resistor/resistance of input circuits of receiver. However, the noises of input circuits of receiver, without falling into molecular amplifier, enter into the absorber.

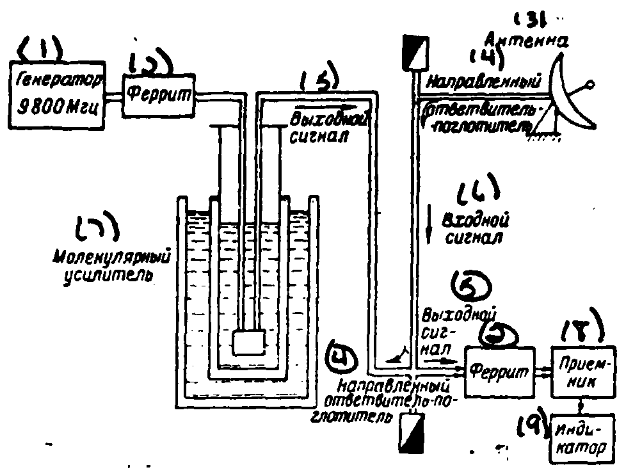

Fig. 7. Schematic of connection of molecular amplifier to antenna and receiver. Key: (1). Generator 9800 Hz. (2). ferrite. (3). Antenna. (4). Directed brancher-absorber. (5). Output signal. (6). input signal. (7). Molecular amplifier. (8). receiver. (9). Indicator.

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Use in the molecular amplifier of powerful/thick permanent magnets, and also cooling systems makes with its very bulky. Therefore at present already find use the magnetic alloys, which make it possible to obtain necessary magnetic field with the small sizes/dimensions of magnet [2]. Furthermore, is conducted work on the use in the molecular amplifiers of the crystals, which work at higher temperatures. This will make it possible to decrease the overall dimensions and weight of the cooling installation/setting up and entire amplifier as a whole.

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METHODS OF THE RECEPTION OF THE SIGNALS OF THERMAL RADIO EMISSION.

4 For the isolation/liberation of the signal emitted by object from the thermal noises of receiver in the passive radar systems are applied two fundamental methods: modulation and compensation.

The block diagram of passive radar with the modulation receiver is shown in Fig. 8 [4].

As has already been indicated, the signal of thermal radio waves has the same structure as the inherent noise of receiver from which it must be isolated. In the majority of the cases this is done thus. Via modulation by the mechanical or electrical method of the input noise signal before its arrival into the amplifier of superheterodyne receiver from the inherent noise is isolated useful signal.

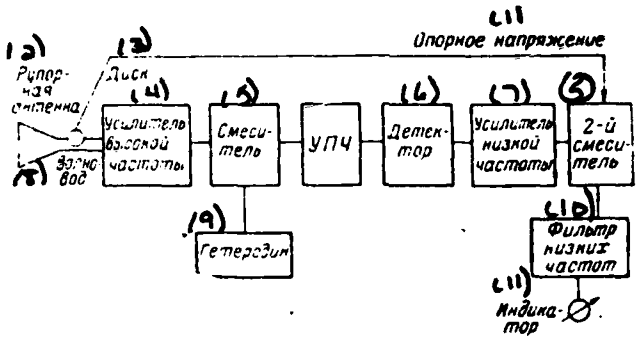

Fig. 8. Block diagram of passive radar with modulation receiver.

Key: (1). Reference voltage. (2). Horn antenna. (3). Disk. (4). high-frequency amplifier. (5). mixer. (6). Detector. (7). Low-frequency amplifier. (8). waveguide. (9). heterodyne. (10). Filter of low frequencies. (11). indicator.

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If there is no useful signal, then at the output of the detector of the receiver is formed rectified current I_0 from the voltage of the inherent noise of receiver. An increment in the current, caused by signal, will be determined by the equality

$$\Delta I = I_c - I_0,$$

where I_c — value of output current of the detector of that caused by signal and by noises.

Since the voltage of useful signal is modulated, output current of detector I_r changes with the modulation frequency. Since from this current is deducted the dc current component of its own noises, equal to I_0, then a difference in the currents ΔI also changes with the modulation frequency.

Let us assume that modulation of useful signal is realized according to the sinusoidal law. Then the weak sinusoidal oscillation obtained at the output of detector of modulation frequency is isolated from the background of inherent noise by usual resonance equipment - narrow-band filter. The amplitude of sinusoidal oscillation is proportional to the intensity of signal.

The sine wave of modulation frequency in the second mixer is converted into the signal of "zero frequency" - direct current and then it is isolated from the remaining noises by an RC-filter. Frequency conversion into the "zero frequency" makes it possible to utilize an RC- filter with the very narrow passband.

Sensitivity of PRL depends on band of the transmission of filter $\Delta\Omega$: the less the passband, the better the sensitivity PRL.

The contraction of the filter pass band is achieved by increase in R and C. However, increase R and C in the filter makes the system of inertial, since grows/rises the time constant of filter, i.e., the time of the integration of filter becomes large. This leads to the fact that the isolation/liberation of an increment in the current ΔI occurs with the time loss, equal to

$$\tau = \frac{1}{\Delta\Omega}.$$

The effective bandwidth of the filter

$$\Delta\Omega = \frac{\pi}{2} \cdot \frac{1}{RC}$$

composes several hertz.

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Modulation frequency Ω is selected equal to 30 Hz in order to reduce to a minimum the effect of the instability of the inherent noise of equipment. In the amplifier the noise level is unstable: occurs its slow unordered modulation. The instability indicated worsens/impairs sensitivity of PRL, but at the sufficiently high modulation frequency of useful signal (30 Hz) this deterioration is not virtually noticeable [14].

Passive radar with the modulation receiver works as follows. The signal of thermal radio emission, received by antenna (by horn), is fed/conducted by rectangular waveguide to amplifier of high frequency. In the waveguide there is a longitudinal slot into which enters the modulator - rotary disk. The part of the disk is made conducting. It is fulfilled usually so that modulation curve of the signal of thermal radio emission would have rectangular form. Entire system before the amplifier is adjusted: antenna resistances and disk are matched and the reflections of electromagnetic energy does not occur. This is done to avoid supplementary spurious modulation.

In the case in question modulator (rotary disk) should be examined simply as the switch, which alternately includes antenna and equivalent resistance, created by the specific section of disk.

The speed of rotation of disk is selected by 30 r/s [14]. At this rate the parameters of receiver do not manage considerably to change during the period of the rotation of disk and modulation of fluctuating character, which appears with a change in the parameters, barely acts on readings/indications of output indicator.

The rectangular form of modulation is characterized by the following parameters: by period, frequent, duration and by pulse amplitude.

Modulation carries periodic character, and right-angled oscillation consists of the series/row of harmonics - simple sinusoidal oscillations with different periods and frequency (Fig. 9). First harmonic component, called fundamental harmonic, have a frequency and a period, equal to frequency and to the period of right-angled oscillations.

The first of the frequencies, equal to the frequency of right-angled oscillations, it is called the carrier frequency, and others - by side frequencies. At the speed of rotation of disk 30 r/s the carrier frequency is equal to 30 Hz.

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Right-angled oscillations with the modulation frequency 30 Hz enter high-frequency amplifier. The intensive signal of thermal radio emission is converted in the mixer into the signal of intermediate frequency. After detection at the output of mixer is obtained right-angled current by the frequency of 30 Hz, accompanied by noises. 30-periodine sinusoidal harmonic is filtered out and is amplified by narrow-band low-frequency amplifier, and then it mixes in the second mixer with the 30-periodine harmonic current, coherent with modulation. As a result the harmonic component of current gives at the output of the filter of low frequencies direct current, with the accompanying noise spectrum it is displaced into the frequency region, the close ones in its value to zero.

In the filter of low frequencies with the very narrow passband the constant component is filtered out and enters the dc amplifier (Fig. 10). The indicator and then the indicator measures the difference of the intensities of radiations/emissions from the antenna and from the modulator.

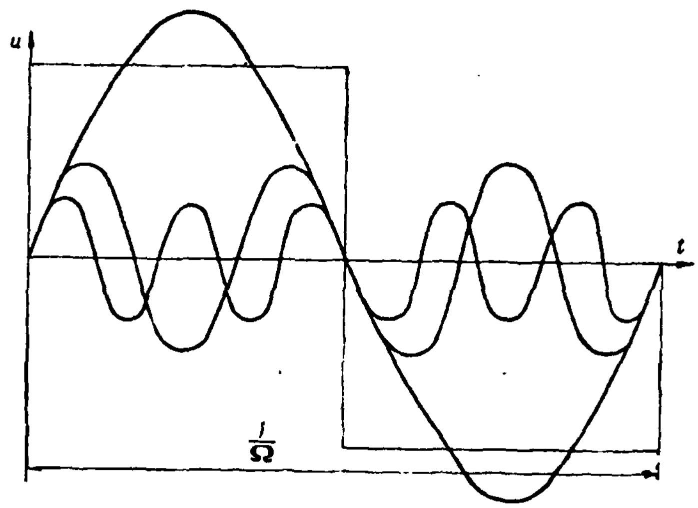

Fig. 9. harmonic components of right-angled oscillations.

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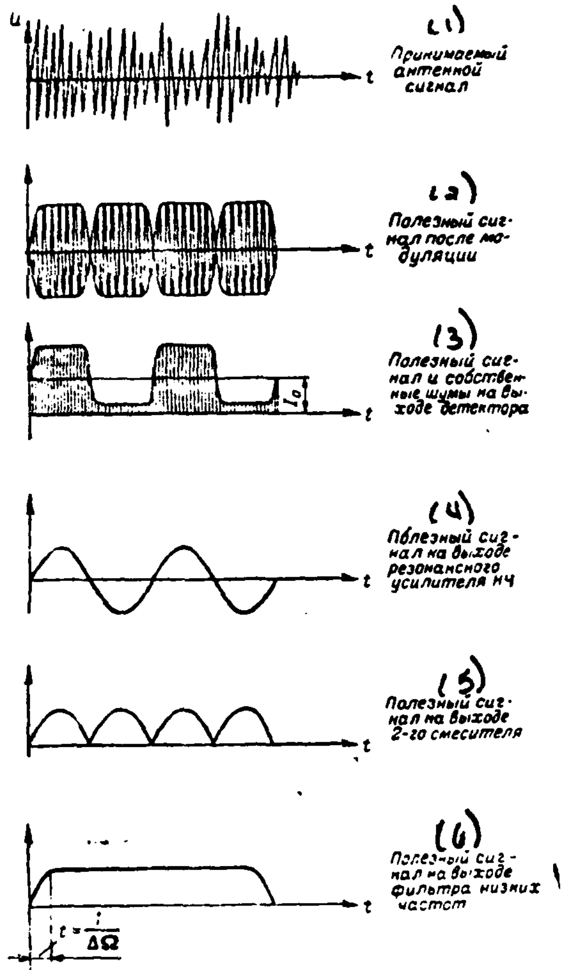

Fig. 10. Diagrams of output potentials of separate elements/cells of PRL with modulation receiver. Key: (1). Taken by antenna signal. (2). Useful signal after modulation. (3). Useful signal and inherent noise at output of detector. (4). Useful signal at output of resonance of amplifier of lf/NCh. (5). Useful signal at output of 2nd mixer. (6). Useful signal at output of filter of low frequencies.

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If the intensities of the radiations/emissions adopted from the disk and the antenna are equal, received signal proves to be unmodulated also at the output of detector is obtained only steady noise without periodic component of current.

Modulation receivers can have the rotary disk of this form, which makes it possible to obtain the signal, modulated according to the sinusoidal law. In this case at the output of modulator there will be sinusoidal oscillations (Fig. 11):

$$i = I_{m0} \sin 2\pi ft(1 + \sin \Omega t),$$

where

$$I_{m0} = \frac{I_{\text{макс}} + I_{\text{мин}}}{2};$$

f - signal frequency of thermal radio emission;

Ω - modulation frequency.

The method of modulation makes it possible to pick up signal of the thermal radio emission whose amplitude is compared with the inherent noise of receiver.

If amplification is conducted by modulation receiver with the relationship/ratio signal/noise, equal to unity, then the minimum power of the signal detected with modulation according to the sinusoidal law will be equal to

$$P_{c\,мин}=4\sqrt{2}\,P_{ш}\sqrt{\frac{\Delta\Omega}{\Delta F_{пр}}},$$

where $P_{c\,мин}$ — minimum power of the signal (sensitivity of modulation receiver)detected; $P_{ш}$ — power of receiver noise; $\Delta\Omega$ - filter pass band *of low frequencies;* $\Delta F_{пр}$ — passband UPCh of receiver.

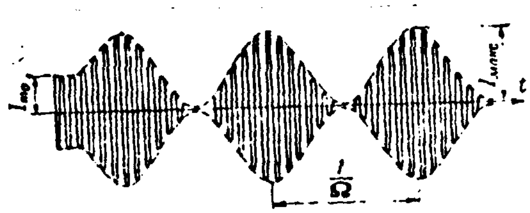

Fig. 11. Waveform of radiation/emission at output of modulator.

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With the square-wave modulation of frequency Ω the minimum power of signal detected becomes equal to

$$P_{0\,мин} = \frac{\sqrt{2}\,\pi^2}{4} P_{пт} \sqrt{\frac{\Delta\Omega}{\Delta F_{пр}}}.$$

Sensitivity of modulation receiver grows/rises with an increase in the passband of IF amplifier and a decrease of the filter pass band of low frequencies [6].

At the foreign modulation receivers of centimeter band the optimum value of passband UPCh lies/rests in the limits of 10 MHz.

Modulation frequency is usually taken by the equal to 30 Hz. In this case the effect of the technical receiver noise, which appear as a result of the oscillations of supply voltage and ambient temperature, and also instability of the amplifier gain of high frequency, is virtually small.

Fig. 12 shows the dependence of the average/mean power of the output signal of the detector of modulation receiver on the frequency. As can be seen from figure, technical receiver noise which were formed in essence due to irregular changes in its amplification factor, lie/rest at the frequency region of approximately 10 Hz. In order confidently to be built from them, the modulation frequency of input signal is taken by the equal to 30 Hz.

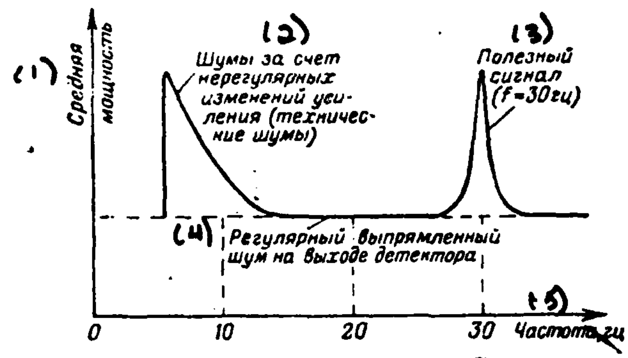

Fig. 12. Dependence of average/mean power of output signal of detector of modulation receiver on frequency.

Key: (1). Average/mean power. (2). Noises due to irregular changes in amplification (technical noises). (3). useful signal (f=30 Hz). (4). Regular rectified of bags at output of detector. (5). Frequency, Hz.

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High modulation frequency, in the opinion of the foreign specialists, taken should not be, since this will complicate the construction/design of the mechanical feature of the modulator and switching devices/equipment in connection with the increased speeds of rotation of modulator disk.

For the modulation receiver high value has a stability of the narrow-band low-frequency amplifier, tuned to a frequency of modulation: even with its small detuning, just as during the expansion of the band of amplifier over the normal, deteriorates receiver sensitivity and the amplitude of the useful chosen signal sharply decreases.

For the normal work of the modulation receiver band of the transmission of the filter of low frequency they take less than the doubled modulation frequency [6]:

$$\Delta\Omega < 2\Omega.$$

An improvement in the receiver sensitivity can be achieved/reached not only due to an improvement in the amplifier of high frequency and expansion of the filter pass band of low frequency. In this case, however, increases the time constant of receiver, which is inadmissible as is indicated in the foreign press, during the use of passive radars on high-speed aircraft. That established/installed on board the aircraft PRL with the slow response will not be able to follow changing thermal area relief.

For the reception of the signals of the thermal radio emission whose level is considerably lower than the inherent noise level of receiver, is applied the second method - compensative. This method consists in the fact that the voltage of the inherent noise of receiver is compensated on its output by the voltage of compensation from the noise generator.

In the absence of the signal of thermal radio emission output potential of compensator is very close to zero. Let us designate this voltage through $U_{ш}(t)$. It is caused by the voltage of the inherent noise of receiver.

U(t) - output potential of compensator in the presence of signals in the antenna PRL. Then an incremental stress on the output of the receiver

$$\Delta U = U(t) - U_{ш}(t).$$

Since received signal is very weak, then

$$\Delta U \ll U_{ш}(t).$$

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Therefore entire process of reception/procedure is reduced to the isolation/liberation of a small incremental stress ΔU against the background of the large voltage of inherent noise $U_{ш}(t)$.

Fig. 13 shows the block diagram of passive radar with compensator [4]. The signals taken by antenna are amplified by radar receiver together with its inherent noises and after conversion into the voltage of low frequency are supplied to the compensator.

Output signal after the compensation for noises enters the filter of low frequency. Chosen constant component of signal is fed/conducted to the display unit.

As indicator can serve dial instrument, chart-recording instrument or cathode-ray tube.

In the experimental models of passive radars, as noted above, during the exploration of area relief as the indicator was utilized the chart-recording instrument with the sapphire needle. In the foreign ones PRL of military designation/purpose are utilized panoramic oscillographic variable-intensity indicators of echo signals 4.

In PRL with the compensator completely it is impossible to get rid of the inherent noise of receiver. If, for example, output voltage is fed to the dial instrument, then arrow/pointer will complete about the specific value barely noticeable oscillatory motions due to the residual voltage of the inherent noise, not not completely compensated in the diagram. The minimum signal, which can reveal/detect PRL, must, obviously, give the same throw of the pointer of output meter as the inherent noise of receiver.

Fig. 14 shows the schematic of simplest compensator (U_c — the voltage of useful signal, $U_к$ — the voltage of compensation, $U_ш$ — thermal noise voltage on the output of receiver).

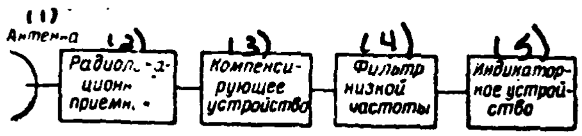

Fig. 13. Block diagram of passive radar with compensator.

Key: (1). Antenna. (2). Radar receiver. (3). Compensator. (4). Filter of low frequency. (5). Display unit.

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Before the reception of useful signal the noise voltage from output amplifier of receiver and the voltage of compensation from the special source are supplied on the ratio arms, formed by resistors/resistances R_1 and R_2, which serve as the resistance/resistors of the load of amplifiers Yc_1 and Yc_2 and detectors D_1 and D_2. The oscillations of two voltages are straightened/rectified with the aid of the detectors, after which these voltages are averaged in filter RC.

With the diagonal of bridge is connected the instrument P, the time constant of which depends on the value of resistor/resistance R to capacitance of capacitor C. The compensation for noises is determined on the zero position of the arrow/pointer of instrument and is realized due to a change in the voltage of compensation. With the reception of the useful signal radiation the arrow/pointer is deflected to the angle, proportional to the value of the received signal.

If we instead of the dial instrument supply at the output chart-recording instrument, the moving/driving synchronous with the radiation pattern, then on the recording tape will be obtained the recording of the values of useful signal. During the supplying of this signal to the cathode-ray tube of indicator occurs modulation on the brightness of electron beam, which escape from the cathode of tube.

As is known, the factor of amplification of any receiver is always unstable. It is subjected to small, comparatively slow, irregular changes about certain average/mean level, in consequence of which the inherent noise at the output of amplifiers are modulated by the fluctuations of amplification and the balance of bridge continuously is disrupted. The balance of bridge affect also changes in the inherent noise level of receiver.

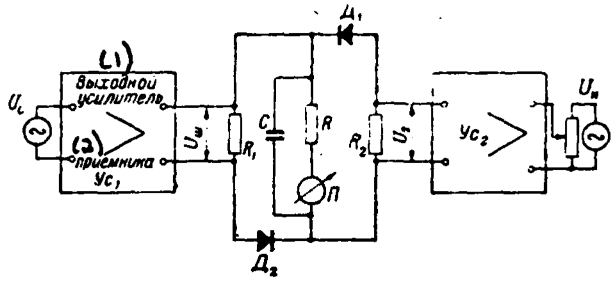

Fig. 14. Schematic of simplest compensator.

Key: (1). output amplifier. (2). receiver.

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In order to get rid of this, in the passive radar systems are applied the more advanced diagrams of compensation [1]: on the output of the amplifier of receiver and voltage amplifier of compensation are placed output of transformer, which have on two in pairs connected secondary windings, wound to opposite sides (Fig. 15). Windings 1, 3 give the sum of emf wound to one side), while winding by 2, 4 give the difference of emf (they are wound to opposite sides).

In the absence of useful signal U_c the noise voltage of receiver U_{m} and the voltage of compensation $U_к$ are supplied to the output of amplifiers with the identical parameters. As can be seen from diagram, noise voltage is supplied to inputs of both amplifiers cophasally, and the compensation voltage - in the antiphase. Thus, the noise voltages of receiver on terminals/grippers a, b of the resistance/resistor of the load of transformers store/add up, and to terminals/grippers c, d they are deducted. Compensative voltages, on the contrary, on terminals/grippers a, b are deducted, and on terminals/grippers c, d they store/add up.

The total and differential oscillations of voltages are straightened/rectified with the aid of the detectors D_1 and D_2 and then are averaged with the aid of filter RC.

Noise voltage causes circuital current a, D_1, P, b, i.e., in circuit of one of the ratio arms.

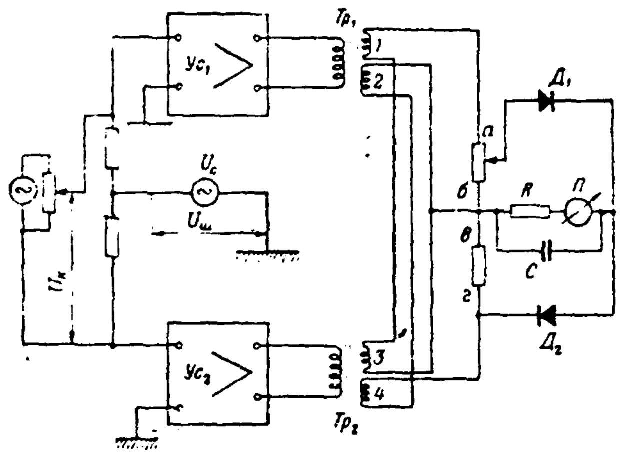

Fig. 15. Schematic of compensator with stable balance of bridge.

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Under the effect of this current the arrow/pointer of the instrument P, connected with the diagonal of bridge, is deflected to one specific side. The voltage of compensation, subject on the input of amplifiers in the antiphase, cause circuital current c, P, D_2, d of the other arm of bridge and, consequently, also the deflection of the needle to opposite side. Bridge will be balanced under the condition of the equality of the noise voltage and voltage of compensation.

The work of the described diagram of compensation already on depends on the fluctuations of the factor of amplification and changes in the inherent noise level of receiver, since in it is utilized voltage difference of noises and compensation. Therefore with the reception of weak signals the balance of bridge is more stable, and noises are compensated more completely.

Let us examine analytically the work of the schematic of compensator with the stable balance of bridge in the absence of useful signal U_c. Let us assume that the noise voltage of the circuits of receiver of up to the input of amplifier composes $U_ш$, and the amplifier noises, led to their input, are equal to respectively U_1 and U_2.

As it is already known from the description of the work of diagram, on terminals/grippers a, b will be established total noise voltage $(K_1+K_2)U_ш$, where K_1 and K_2 - respectively the amplifier gains Yc_1 and Yc_2. In terminals/grippers c, d will be established differential noise voltage $(K_1-K_2)U_ш$. For the voltage of compensation on terminals/grippers a, b there will be differential voltage $(K_1-K_2)U_к$, and on terminals/grippers c, d - total voltage $(K_1+K_2)U_к$.

In the circuit of amplifiers to these voltages will be applied the internally-produced noise of amplifiers. Then rectified current in the ratio arms, formed by circuit a, D_1, P, b, will be

$$I_1=D_1[(K_1+K_2)U_ш(t)+(K_1-K_2)U_к(t)+K_1U_1(t)+ +K_2U_2(t)]^2.$$

In this case detectors with the coefficients of detection D_1 and D_2

we respectively consider quadratic.

For another ratio arms, formed by circuit c, P, D_2, d, we have

$$I_2 = D_2[(K_1 - K_2)U_{ш}(t) + (K_1 + K_2)U_{к}(t) + K_1U_1(t) - K_2U_2(t)]^2.$$

After averaging by filter RC it is possible to disregard all terms which contain products $U_{ш}U_1$, $U_{ш}U_2$, $U_{к}U_1$, $U_{к}U_2$.

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With the complete balance of the bridge when current in its average/mean branch $I=I_1-I_2=0$, and with $D_1=D_2$ we find

$$U_{ш}^2 = U_{к}^2 - U_{к}U_{ш}.$$

The second member in the right side of obtained equation characterizes the fluctuations, remaining after averaging of internally-produced noise of receiver, which force the indicator needle of output meter disorderly to oscillate relative to the mid-position. By selection of the parameters of equipment these fluctuations can be brought to the value, close to zero.

Besides the described two methods of the reception of weak signals, recently in the passive radars is applied the correlation method.

Block diagram PRL with the correlation device/equipment is shown in Fig. 16 [4]. As the basis of correlation method is assumed a difference in the statistical properties of useful signal and noise. In this case the signal and noise are accepted for the random processes, one of simplest characteristics of which - correlation function. For the understanding of the physical essence of this function let us examine signal and noise as random processes.

Useful signal - periodic process, i.e., if is known its value at moment/torque t_1, then it is possible to determine its value at moment/torque t_2.

For the noises there is a connection/communication of another character.

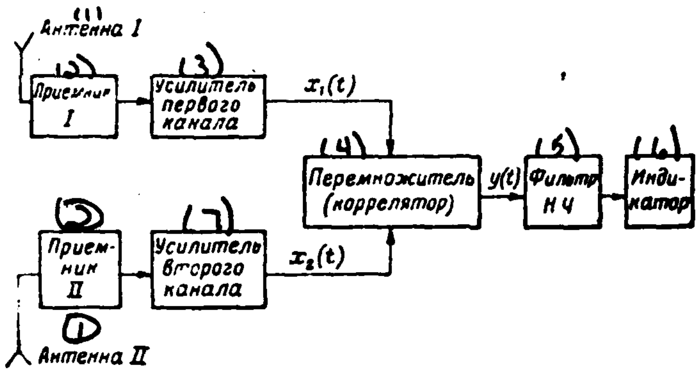

Fig. 16. Block diagram PRL with correlation device/equipment.

Key: (1). Antenna. (2). Receiver. (3). Amplifier of first channel. (4). Multiplier (correlator). (5). Filter of lf/NCh. (6). Indicator. (7). amplifier of second channel.

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If we for a certain period of time T select the paired values of noise, distant one behind another on the time for the interval τ, i.e., $n(t_1)$ and $n(t_1+\tau)$, $n(t_2)$ and $n(t_2+\tau)$ and so forth, and then to compose their paired products $n(t_1)\cdot n(t_1+\tau)$, $n(t_2)\cdot n(t_2+\tau)$ and so forth and to take the average/mean value of these products as time T:

$$\psi(t)=\frac{1}{T}\int_0^T n(t)\cdot n(t+\tau)dt,$$

That it will seem that it depends on τ.

This average/mean value $\psi(t)$ is a value of the correlation function of process. The correlation function of noises has a maximum with τ=0, and the same function of signal the greater, the greater the value τ. Therefore from the noises it is possible to isolate the very weak signal, such as is the signal of thermal radio emission, with the sufficiently long time of observation.

In PRL with the correlation method of the reception of weak signals are utilized two independent receivers.

The rectified output signals of receivers are amplified and mutually are correlated with the aid of multiplying circuit.

The output voltage of correlator can be represented by the following equation:

$$y(t)=K\cdot X_1(t)\cdot X_2(t),$$

where K - amplification factor;

$X_1(t)$ - the mixture of useful signal and noise of the I channel;

$X_2(t)$ - the mixture of useful signal and noise of the II channel.

At the output of correlator there will be the component of direct current in the presence of useful signal and fluctuation component the inherent noise of receiver just as in the modulation and compensative receivers.

After this output signal from the correlator is integrated with the aid of the filter of low frequencies for the isolation/liberation of the useful component of direct current, which then enters the indicator. Useful signal is supplied to each receiver through the decoupler for preventing the incidence/impingement of the input noises of one receiver to the input of another. This leads, as a rule, to the need of using the separate antennas for the receivers.

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Correlation receiver must fulfill consecutively/serially and the continuously following operations/processes: measure the paired values of the mixture of useful signal and noise $X(t)$ and $X(t+\tau)$, divided in terms of the time into the interval τ, to calculate the consecutive products $X(t)$ and $X(t+\tau)$ with the aid of the multiplying device/equipment, to calculate the average/mean value of these products for time T, to repeat all these operations/processes for the different values of interval τ.

In contrast to modulation correlation and compensation methods they do not require the use/application of the mechanical modulators and switching devices/equipment. However, for the compensative receivers it is necessary to select amplifiers and detectors with the identical parameters. For facilitating this problem one of the resistors/resistances of bridge is made by variable/alternating, which makes it possible to remove the dissymmetry of ratio arms. In the correlation receiver is necessary the high degree of the decoupling between input circuits of both receiving channels.

The passive radars, which use the compensation and correlation methods, with which the effect of irregular changes in the factor of amplification of receiver is excluded, are more sensitive than modulation receivers. Therefore they detect signal with the smaller radiated power. With the relationship/ratio signal/noise, equal to unity, minimum detected by these receivers power of the signal

$$P_{c\,\text{мин}} = P_{\text{ш}}\sqrt{\frac{\Delta F_1}{\Delta F_{\text{пр}}}},$$

where

ΔF_1 - filter pass band of low frequencies;

ΔF_{np} — passband UPCh flatten devices/equipment.

With comparison of the formulas of receiver sensitivity, in which are utilized the methods described above it is apparent that the sensitivity of the correlation receiver $4\sqrt{2}$ once is better than modulation one with the sinusoidal law of modulation, and in $\frac{\sqrt{2}\pi^2}{4}$ the time it is better than modulation from curved right-angled modulation.

In superheterodyne receivers of PRL the passband is 20-30 MHz in the high frequency and 10-15 MHz in the intermediate frequency.

Intermediate frequency is equal to 30 or 60 MHz. The filters of low frequencies, utilized in PRL, have a passband into several hertz. The level of its own noises of receivers is approximately 10^{-12} W [4].

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An improvement in the sensitivity of receiver, as noted above, is achieved due to the contraction of the filter pass band of low frequencies, but in this case increases the time constant of receiver. The minimum level of received signal is inversely proportional to square root of time constant PRL; therefore when is permissible smaller sensitivity, it is possible due to its deterioration to obtain smaller time constant.

In particular, as are indicated in the foreign press, that was being utilized with one of the flight tests of PRL, that worked on the wave 8.6 mm with constant of the time of 0.5 s, were distinguished dry land, small water spaces, runways, etc.

Thus, the band of the filter of low frequencies is selected from the conditions of guaranteeing a good sensitivity of receiver and necessary time constant PRL in dependence from its tactical use.

To improve sensitivity PRL is possible by three methods: by use/application of a high-frequency amplifier with the low noise level, which provides a small inherent noise level, by an increase in the passband UPCh of receiver and by decrease of the passband of the filter of low frequencies (by increase in the time constant τ).

The decrease of the filter pass band of low frequencies, as already mentioned, makes PRL with more inertial, and separation of useful signal from the noises is accompanied by the time loss, equal to τ. Minimum time constant of PRL virtually is approximately 0.5 s.

During an improvement in the sensitivity of PRL due to an increase in the passband UPCh, it is necessary to keep in mind that an increase in the band UPCh in above 20-30 MHz leads to an increase in the factor of the noise UPCh and almost completely eliminates gain due to the wider passband. However, the use/application of amplifier of high frequency allows, on one hand to preserve the coefficient of receiver noise at the level of the noises of the amplifier of high frequency, and on the other hand - to lower the limitations, connected with the expansion of band UPCh. Furthermore, it gives the possibility to decrease a number of IF amplifier stages since certain loss in the amplification by IF amplifier stages is compensated by gain in the amplification in the high frequency.

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For an improvement in the receiver sensitivity of the thermal radio emission in them as the high-frequency amplifiers are applied the tubes with the traveling wave, which have wide passband. The sensitivity of PRL of thermal radio emission, in which is used the tube with the traveling wave, makes it possible to distinguish objects during the radiation/emission by them signal by the power, which corresponds to a difference in the apparent temperatures of objects, equal to 2-3°.

Tubes with the traveling wave have a noise factor of approximately 10. Therefore for an improvement in the receiver sensitivity by most promising, in the opinion of the foreign specialists, are acknowledged the molecular amplifiers, which have the noise factor, close to 1. However, the passband of the existing molecular amplifiers on the microwaves does not thus far yet exceed several hundred kHz [2]. At present is conducted work on its expansion. There are some experimental models of molecular amplifiers with the passband to 100 MHz [6]. It is assumed that further improvement of molecular amplifiers will make it possible to extensively use them in the passive radar systems of thermal radio emission.

Page 41.

PASSIVE DETECTION OF AIRCRAFT ON THE EMISSION OF ONBOARD RADAR TRANSMITTERS.

Passive airborne radar operates according to the principle of reception/procedure by straight line and that reflected from the earth's surface of the electromagnetic waves, emitted by the onboard radar transmitters of aircraft.

The stations, which work according to this principle, are applied, in particular, on the bombers for ranging to the attacking fighter airplanes. In this case they proceed from the assumption that the attacking fighter airplane utilizes for reconnaissance/intelligence of the airspace and guidance to the target the transmitter of the modulated electromagnetic vibrations and, most probable, it operates on a pulsed basis [4].

The operating principle of passive radar (Fig. 17) consists in the measurement of the difference between the time of the arrival of straight line and reflected of signals Δt.

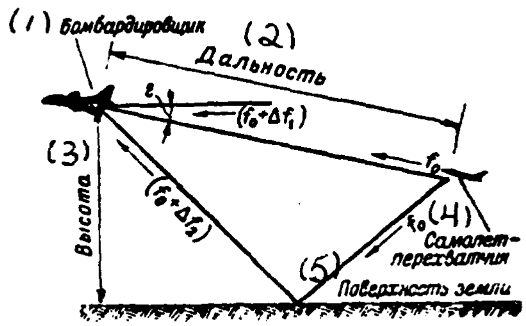

Fig. 17. Operating principle of passive radar.

Key: (1). Bomber. (2). Range. (3). Height/altitude. (4). Aircraft interceptor. (5). Earth's surface.

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This value together with the value of the height/altitude of bomber and angle of elevation of fighter airplane is supplied into the computer which estimates distance to the fighter airplane, solving the equation

$$Д = \frac{4H^2 - (\Delta t \cdot c)^2}{2\Delta t \cdot c - 4H \sin \varepsilon},$$

where c - velocity of propagation of electromagnetic waves;

H - flight altitude of the bomber above the earth's surface;

Δt - difference between the time of the arrival of straight line and reflected of signals;

ε - angle of elevation of fighter relative to bomber.

The value of the height/altitude of bomber is determined on the radar altimeter, and the angle of elevation of fighter airplane - with the aid of the antenna of passive radar. The value of angle of elevation can have both positive and negative value depending on that, above or lower than the bomber is located fighter airplane at the moment of measuring the angle. If the flight altitude of fighter airplane is greater than bomber, the value of angle of elevation has positive value, whereas if less - negative.

One of the American passive radar measures the range to the fighter airplane with the accuracy 20-30 m. This high accuracy is achieved by the use as the meter of height/altitude of radar altimeter, by the use/application of a method of equisignal sector by elevation-position finding of fighter airplane and special high-stability oscillator circuit of saw-tooth voltage for measuring the time delay.

The radar altimeter, which uses a frequency response method of measuring the distances, determines height/altitude with an accuracy to several meters. The method of the equisignal sector of the survey/coverage of space provides the accuracy of the measurements of angle of elevation to the tenths of degree. The linearity of the voltage of the generator, utilized during the determination of time interval Δt, makes it possible to obtain the accuracy of measurements to the hundredths of microsecond.

Passive radar can also determine the rate of closure of fighter airplane with the bomber on a difference in the values of Doppler's frequency for the straight line and by that reflected of electromagnetic waves.

Let the radar transmitter of fighter airplane emit electromagnetic waves at medium frequency f_0.

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As a result of the Doppler effect, which appears as a consequence of the movement of bomber and fighter airplane relative to each other and relative to the earth's surface, direct wave will have a frequency $f_0+\Delta f_1$, and the wave reflected - frequency $f_0+\Delta f_2$.

A difference in frequencies $f_0+\Delta f_1-f_0-\Delta f_2=\Delta f_1-\Delta f_2$ is proportional to a difference in the spines of a change in the path of straight line and reflected of signals. On this difference is defined the rate of approach of fighter airplane with the bomber as rate of change of the mean free path of forward signal.

In the USA is developed the aircraft passive radar PADAR. its name is formed from the initial letters of several words, in the translation/conversion which indicate "passive detection and the determination of coordinates". Station PADAR can estimate distance to the radiation test of electromagnetic energy, direction/axis to it and rate of closure.

If the source of electromagnetic energy is located on the attacking fighter airplane, these data are utilized for the conclusion/output of bomber from under the attack, determining the moment/torque of applying of onboard defensive weaponry or means/facilities of radio countermeasures.

The flight tests of station were conducted on the low-speed aircraft. Antenna was accommodated in its tail section. Tests confirmed the possibility of the rapid determination of the coordinates of aircraft and radiation characteristics radars established/installed on it.

The passive station PADAR can work only in cases when is accepted the modulated signal. Modulation must satisfy two conditions:

- the pulse repetition period of transmitter must be more than the maximum difference between the time of the arrival of forward signal and the time of the arrival of the echo signal, otherwise can arise multiformity in ranging;

- character of modulation of signals must make it possible to measure the time interval Δt with an accuracy to the hundredths of microsecond.

On the confirmation of manufacturer, station PADAR can detect all known at present airborne radar, used for the target detection and fire control and working in the centimeter wave band with the pulse or frequency modulation.

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However, station PADAR cannot detect infrared equipment, since the signals, emitted by this equipment, usually are not modulated. Furthermore, at the low altitudes with the aid of station PADAR it is impossible to detect the signals of ordinary pulse-modulated radar, since the difference between the time of the reception of forward signal and the time of the arrival of the echo signal approaches a duration of transmitted pulses.

For ranging to the fighter airplane in station PADAR are utilized two channels (Fig. 18). Each channel consists of antenna and receiver. The first channel serves for the reception/procedure of direct wave, the second - for the reception/procedure of the wave, reflected from the earth's surface.

The channel of forward signal has the directional antenna with conical scanning/sweep for elevation-position finding of the attacking fighter airplane. Conical scanning makes it possible to more accurately realize a direction finding of targets in comparison with the survey/coverage on the maximum radiation pattern. In it is realized the method of determining the direction/axis from the equisignal sector. With the conical scanning the radiation pattern rotates around the axis of that displaced to the small angle relative to the direction/axis of maximum.

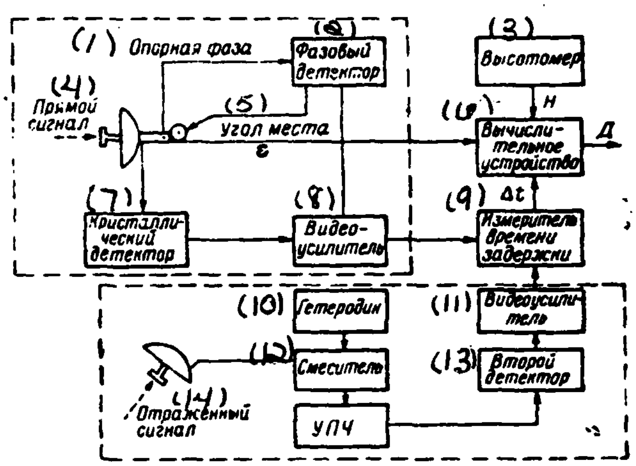

Fig. 18. Block diagram of station PADAR, which works according to the principle of the reception of the signals, modulated in the amplitude.

Key: (1). Supporting/reference phase. (2). Phase discriminator. (3). Altimeter. (4). Forward signal. (5). Angle of elevation. (6). Computer. (7). Crystal detector. (8). Video amplifier. (9). Meter of delay time. (10). Heterodyne. (11). Video amplifier. (12). Mixer. (13). Second detector. (14). Echo signal.

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The antenna of the channel of the echo signal is directed to the earth for the better reception of the echo signals. The echo signals easily are eliminated of the channel of forward signal as a result of their smaller intensity. Forward signals are passed into the channel of the echo signal, their separation occurs with the aid of the electronic circuits which consider the difference between the moments/torques of the arrival of straight line and reflected of signals.

Both receivers have broadband or reformed/redisposed input circuits in the centimeter wave band, since the operating frequency of the transmitter of the attacking fighter airplane is previously unknown. Furthermore, transmitter can work at different frequencies for reception/procedure of which it is necessary to have several input circuits.

The output signals of receivers are supplied into the measuring circuit of the delay time of the arrival of the echo signal relative to the moment/torque of the arrival of forward signal. This diagram consists of the generator of the linear saw-tooth voltage for starting/launching of which is utilized direct pulse, and the electronic switch.

At the moment of the reception of the echo signal the electronic switch measures the value of the voltage of saw-tooth form. In this case the amplitude of output signal is proportional to the difference between the moments/torques of the reception/procedure of straight line and reflected of signals.

Values Δt, the angle of elevation ε and height/altitude H are introduced into the computer which estimates distance to the fighter airplane. Rate of closure is obtained by differentiation of range on the time.

With the reception of the frequency modulated oscillations the target range is determined on the difference in the frequency of the received signals, which depends on that passed by the signals of distance and from the value of Doppler's frequency. In this case the transmitter of fighter airplane generates sustained oscillations f_0 (Fig. 19)whose frequency changes in the time according to the saw-tooth law. The receiver of passive radar come the signals directly from transmitter and the signals, reflected from the earth/ground.

For the time, necessary for the radiowave propagation to the earth/ground and from it to the antenna PRL, the frequency of transmitter manages to change to certain value. At the output of receiver appears the voltage of difference frequency - of beatings. This voltage is amplified and is supplied into the computer for ranging.

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Range in this case is determined on the difference between the beat frequencies $f_{б1}$ and $f_{б2}$:

$$f_{б1}=f_1-f_2=(\Delta f_1-\Delta f_2)+\Delta t\left(\frac{df_0}{dt}\right);$$
$$f_{б2}=f_1-f_2=(\Delta f_1-\Delta f_2)-\Delta t\left(\frac{df_0}{dt}\right),$$

where f_1 - frequency of forward signal;

f_2 - frequency of the signal echo from the earth/ground;

Δf_1 - frequency of Doppler of forward signal;

Δf_2 - frequency of Doppler of the echo signal;

$\Delta t(df_0/dt)$ - a change in the frequency of the transmitter of fighter airplane for the time lag of the echo signal Δt.

Solving this system of equations, it is possible from the known values of beat frequencies $f_{б1}$ and $f_{б2}$ to find values Δt and $(\Delta f_1-\Delta f_2)$, and then to determine range up to fighter and rate of closure with it of bomber.

System of equations is solved by the computer, established/installed on the bomber.

Fig. 20 shows the block diagram of station PADAR, which works according to the principle of the reception of the continuous frequency modulated signals. At the output of the sensing transducer of the echo are emitted the beat frequencies $f_{б1}$ and $f_{б2}$.

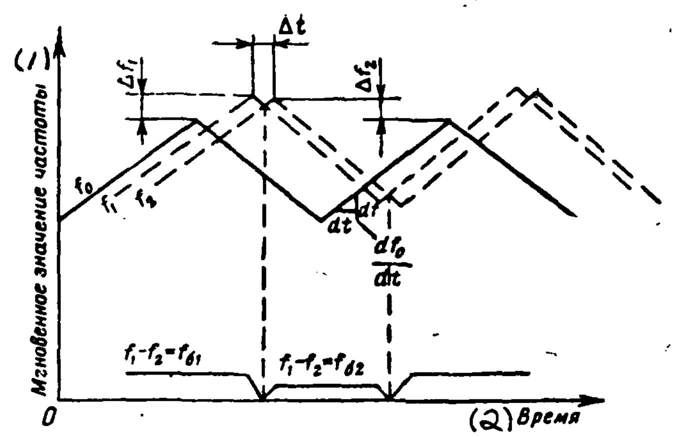

Fig. 19. Graph/diagram of the dependence of the instantaneous value of frequency from the time.

Key: (1). Instantaneous value of frequency. (2). Time.

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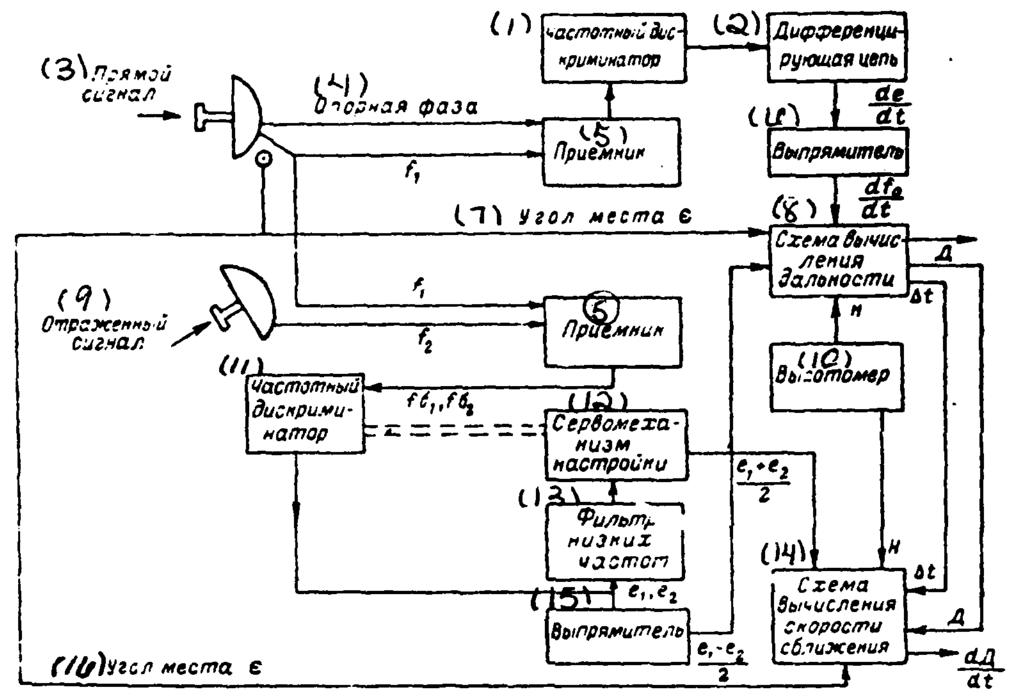

Fig. 20. Block diagram of station PADAR, which works according to principle of reception of continuous frequency modulated signals.

Key: (1). Frequency discriminator. (2). Differentiating circuit. (3). Forward signal. (4). Supporting/reference phase. (5). Receiver. (6). Rectifier. (7). Angle of elevation. (8). Diagram of computation of range. (9). Echo signal. (10). Altimeter. (11). Frequency discriminator. (12). Servomechanism of tuning. (13). Filter of low frequencies. (14). Diagram of computation of rate of closure. (15). Rectifier. (16). Elevation.

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The signals of these frequencies enter the discriminator where they are converted respectively into voltages e_1 and e_2. The voltages e_1 and e_2 rectangular in form are averaged by the filter of low frequencies, as a result of which is created signal $(e_1+e_2)/2$, under activity of which the servomechanism decreases the output signal of discriminator.

Error signal becomes equal to zero, when the driving element of servomechanism is turned for the angle, determined by the value of voltage $(e_1+e_2)/2$. but this voltage corresponds to the averaged values of beat frequencies f_{G1} and f_{G2}.

To each value of voltage $(e_1+e_2)/2$ corresponds the completely specific difference in Doppler frequencies $(\Delta f_1-\Delta f_2)$. Actually/really, after forming equations for f_{G1} and f_{G2}, we will obtain

$$\frac{f_{G1}+f_{G2}}{2}=\Delta f_1-\Delta f_2.$$

On this difference the computer determines the rate the closure of bomber with the attacking fighter airplane.

For determining the time interval Δt it is necessary equation for $f_{б2}$ to deduct from the equation for $f_{б1}$. Then

$$\Delta t = \frac{f_{б1} - f_{б2}}{2\frac{df_0}{dt}}.$$

In the diagram the activity indicated is fulfilled as follows. At the moment of bringing the error signal at the input of discriminator to zero at its output appears the voltage of right-angled signal whose dual amplitude value is equal (e_1-e_2). After averaging this voltage is straightened/rectified, as a result of which is created direct/constant voltage $(e_1-e_2)/2$, which corresponds to half of a difference in the beat frequencies $\frac{f_{б1} - f_{б2}}{2}$. This value of a difference in the beat frequencies depends on the value of the time delay of signals Δt, which in turn, is the function of path length.

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The voltages, proportional to half of difference and to half of the sum of beat frequencies, are introduced into the computer for ranging and rate of closure.

In addition to this, into the computer is introduced the value

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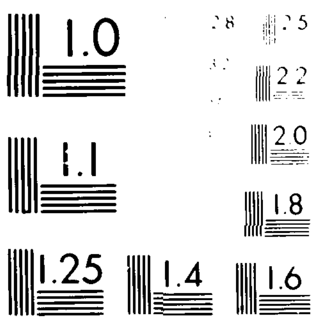
1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

of rate of change in the frequency of the transmitter of fighter airplane for the time Δt, equal to the derivative df_0/dt. For its obtaining the signal of frequency f_1, taken by the receiver of the channel of forward signal, enters the discriminator where it is converted into voltage e which is differentiated and enters the rectifier. Unidirectional voltage de/dt depends on rate of change in the frequency of transmitter f_0.

For solving the equation of range into the computer from the altimeter enters the value of height/altitude, and from the antenna of the receiver of forward signal with conical scan - value of the angle of elevation of fighter airplane with respect to the bomber.

At present in the USA they continue to improve the passive aircraft stations, which work according to the principle of the reception/procedure of the radiation/emission of onboard aircraft radio transmitters. On the basis of station PADAR is created the new passive system PAKOR. System PAKOR it is proposed to equip entire of the bomber of the USA [4].

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PASSIVE METHOD OF THE DETECTION OF INTERCONTINENTAL BALLISTIC MISSILES.

The principle of the work of the passive acquisition systems of ballistic missiles is based at the reception/procedure of electromagnetic energy of low frequencies on the order of 15-30 kHz, ballistic missile [9] any emitted after starting/launching.

Ballistic missile moves to the target at a high speed which is communicated to rocket/missile by the working rocket engine.

For the work of engine on ballistic missile are located oxidizer and combustible in the liquid state in the special tanks. Special turbopump supplies oxidizer and fuel into the engine. After traversing injectors, fuel and oxidizer enter the combustion chamber of the engine where they are agitated and burn, forming gaseous products. Thrust is formed due to the reaction of gas jet, ejected from the engine through the nozzle. The temperature in the combustion chamber achieves several thousand degrees.

In large conditions of temperature and exhaust gas velocity of their molecule complete chaotic thermal agitations. During this movement the molecules collide one s by another. As a result occurs the intense ionization of the molecules of gases. The charged/loaded particles with increasing motion of rocket/missile through the atmosphere strongly jar. The vibration of particles is escorted/tracked by the intense radiation/emission of electromagnetic waves in the wide frequency spectrum. Electromagnetic radiant energy rapidly attenuates, with exception of the electromagnetic waves of very low radio frequencies. For these frequencies the ionized gas jet which pulls itself after the rocket/missile, it presents the sufficiently effective antenna of low frequencies.

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Research work on the dissemination of the low frequencies, emitted with the work of the high-powered engine of rocket/missile, was carried out in the USA by national bureau of standards and by sea research laboratory. It was determined, that the minimum attenuation of energy occurs for the frequencies of 10-30 kHz. Depending on the conditions for radiowave propagation it can be less than 1 dB and rarely it achieves 2 dB on 1000 km [6, 9].

For the electromagnetic vibrations by the frequency of 10-30 kHz the earth's surface and the ionosphere form the three-dimensional/space waveguide on which the signal applies to very large distances with the insignificant attenuation. Since the wavelength of electromagnetic radiation and the height/altitude of the ionosphere above the earth's surface are small in comparison with the radius of the Earth, with a certain simplification it is possible to consider the propagation of such waves as dissemination in the flat/plane waveguide with the uniform walls.

The account of the curvature of the earth/ground is necessary during the detachment of the intensity/strength of electromagnetic field only in certain unit of the earth's surface, diametrically opposite to radiation test. Therefore for distance on the order of 10000 km (flying range of intercontinental ballistic missiles) the accomplishment of mission is simplified. The strength of field at the point, distant from the source at a distance to 10000 km, is determined from the conditions for the propagation of waves in the flat/plane waveguide as walls of which serve the uniform earth's surface and the uniform ionospheric layer.

Usually the intensity/strength of electromagnetic field at the assigned point is defined as the result of the imposition of direct wave and waves, reflected from the earth's surface and the ionosphere.

The analysis of radiowave propagation by the frequency of 15-30 kHz shows that for such frequencies in the three-dimensional/space waveguide are formed cylindrical type waves. For these waves the electric intensity E proves to be inversely proportional to square root of the distance of observation point from the radiation test:

$$E \equiv \frac{1}{r}.$$

where r - horizontal range of observation point, for which is determined the intensity/strength, from the radiation test.

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Thus, in the space between the earth's surface and the ionosphere the propagation of electromagnetic waves by the frequency of 15-30 kHz has the waveguide character (Fig. 21).

Cylindrical waves are headed by the boundary walls of the waveguide: by the earth's surface and by the ionosphere.

For the case not of the flat/plane, but spherical earth's surface the value of electric intensity E must be repaired to factor $\sqrt{\frac{\gamma}{\sin\gamma}}$. Then

$$E_{c\phi} = E_{nn}\sqrt{\frac{\gamma}{\sin\gamma}},$$

where $E_{c\Phi}$ - electric intensity taking into account the sphericity of the earth's surface;

$E_{n\pi}$ - electric intensity for the flat surface of the earth/ground;

γ - angle, formed between the radii of the earth's surface, directed toward the radiation test (A), also, to the point, for which is determined the intensity/strength of field (B).

Factor $\sqrt{\frac{\gamma}{\sin\gamma}}$ begins to play the significant role only with $\gamma \geqslant \pi/2$, i.e., on distances, large 10000 km.

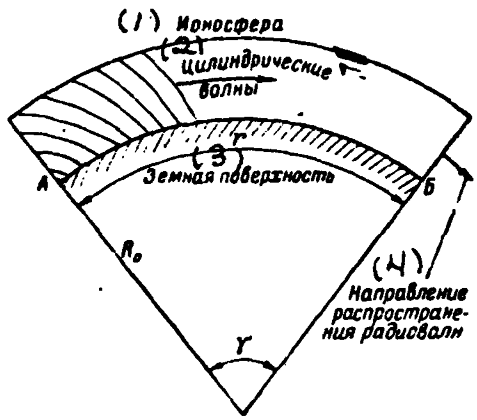

Fig. 21. Propagation of electromagnetic waves by the frequency of 15-30 kHz in the three-dimensional/space waveguide.

Key: (1). Ionosphere. (2). Cylindrical waves. (3). Earth's surface. (4). Direction/axis of radiowave propagation.

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Depending on the season and days the superstandard range of the electromagnetic waves of low frequency is changed. In the daytime the propagation of the waves of low frequencies affect lowest D-layers lying/horizontal on the height/altitude 80-85 km from the earth/ground. After sunset when layer D disappears, the dissemination of low frequencies depends on E-layer which lies/rests on the height/altitude of 100-120 km.

In the daytime the atmosphere is ionized by solar rays/beams; therefore energy of electromagnetic waves is absorbed more. At night ionization and, consequently, also absorption decrease. Therefore at night the wave propagation length low of frequency is more than in the daytime. In summer ionization is greater than in winter, and therefore the superstandard range in summer somewhat less than in winter.

Earlier for determining the type of the propagated wave the frequency of 15-30 kHz in the three-dimensional/space waveguide it was assumed that the earth's surface is flat/plane and the ionosphere uniform. However, the surface curvature of the earth/ground and the heterogeneity of the ionosphere increase the attenuation of wave depending on distance.

Fig. 22 depicts the graph/diagram of the dependence of electric intensity E on distance of r for the frequencies of 10-30 kHz taking into account the effect of the surface curvature of earth/ground and heterogeneity of the ionosphere. The strength of field for the frequencies of this range changes under varied conditions in the limits of the region between the curves AB and CD.

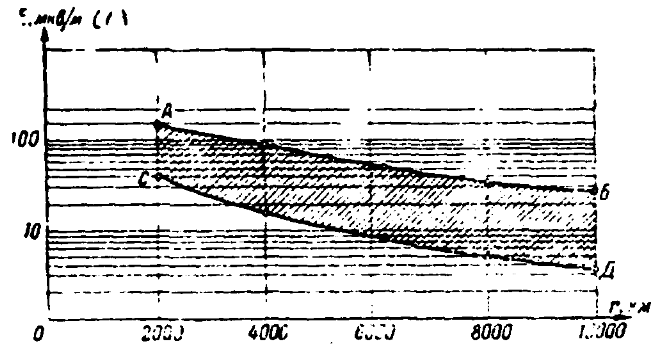

Fig. 22. Graph/diagram of the dependence of electric intensity E on distance of r for the frequencies of 10-30 kHz.

Key: (1). μV/m.

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Thus, if radiation test will be the operating engine of ballistic missile, then even at a distance of 10000 km, i.e., at maximum range of its flight, will exist the strength of field, sufficient for the detection of signal, and consequently, the moment/torque of the starting/launching of rocket/missile and location of launch pads.

A precise location of launch pad can be determined with the aid of three receiving offices via the comparison of the time of the arrival of signals. Three receiving offices are disposed of one from another at a distance of several tens of kilometers. The distances between the stations are accurately known.

The coordinates of the center of radiation/emission and distance of it are determined by computer. In the particular case the principle of the work of this system is explained by Fig. 23.

If it is known that the time of the arrival of radio signal to station No 1 is equal t_1, and on station No 2 and 3 - respectively t_2 and t_3, it is possible to calculate time lag in the arrival of signals for each pair of stations. By the known velocity of propagation of electromagnetic energy is determined a difference in the distances of each pair of stations. Let us assume that to station No 3 signal arrived earlier than to other stations. Then the time of the arrival of signal, equal to t_3, is minimum.

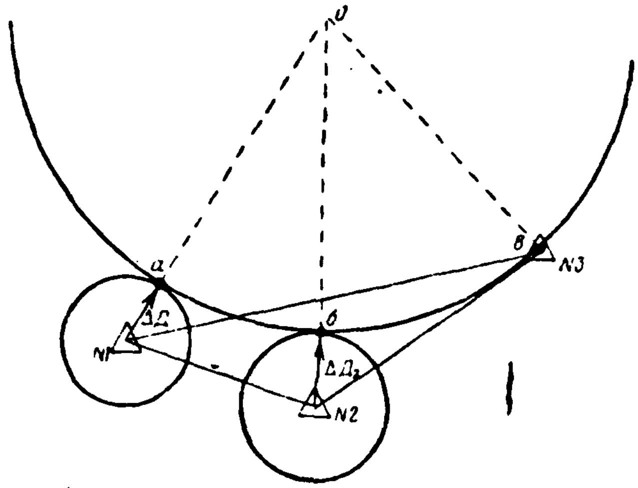

Fig. 23. Principle of position finding of the launching of ballistic rocket by three passive stations.

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Time lag in the arrival of signal to station No 1 in this case will be equ-¯ly $\Delta t_1 = t_1 - t_3$, and to station No 2 $\Delta t_2 = t_2 - t_3$.

By the multiplication of time lag at the velocity of propagation of electromagnetic energy (c=300000 km/s) are found the differences in the distances, equal to $\Delta d_1 = \Delta t_1 \cdot s$ and $\Delta d_2 = \Delta t_2 \cdot s$.

It is described from the centers of stations No 1 and 2 circles/circumferences by radii ΔD_1 and ΔD_2 respectively. The radiation test of electromagnetic energy for the present instance is located in the center of circle, which concerns two circles/circumferences by radii ΔD_1 and ΔD_2 (at points a and b) and it passes through the center of station No 3 (point c), since signal from the source into points a, b and c must arrive simultaneously.

With the accomplishment of mission by the determination of center O of circle/circumference, i.e., the locations of radiation test, and distances of it by computer are considered the signs of time differences of time lag.

At present in the USA are developed/processed several systems of the passive detection of intercontinental ballistic missiles [9].

One of them can detect the starting/launching of intercontinental ballistic missile and continuously follow the path of its flight with the working rocket engine. This system is tested during the observation of the starting/launching of the American guided missiles from the distance to 3200 km [8]. It is assumed that after the series/row of technical improvements it will be able to follow the rockets/missiles at the distances, which exceed 8000 km.

The same system can also determine the place of nuclear explosion and measure its force. During the atomic explosion electromagnetic energy appears as a result of the violent education of the electrically charged particles, which possess enormous kinetic energy. Furthermore, the chemical gas cloud forming during the blast, is strongly ionized is a good guide for the bit which resembles the lightning discharge. Electromagnetic waves forming during the bit are received as passive acquisition systems.

The intensity of the electromagnetic radiation, which appears during the atomic explosion, is maximum at the frequency of 30 Hz and rapidly decreases with a decrease of frequency.

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However, the level of the signal, emitted in the range of the frequencies of 10-30 kHz, considerably exceeds the level that of minimum detected by the passive stations of signal, even if these stations will be located from the radiation test at a distance into several thousand kilometers. This provides the confident reception of the signal of nuclear explosion.

Passive acquisition systems, in the opinion of the American specialists, will make it possible to solve the problem of very long-range detection of ballistic missiles. It is assumed that with a sufficient degree of perfection such systems can replace radar early warning lines.

In the system of antimissile defense of USA these stations must be utilized for the rough determination of the coordinates of ballistic missile during her output to trajectory. In particular, it is proposed to replace with them active radar of the Arctic line of long-range detection, which is equipped in Alaska, in Iceland and Greenland. This is explained by the fact that the passive system detects rocket/missile earlier than it will achieve such height/altitude at which it will reveal/detect active radar.

To three passive stations is allotted the specific sector of tracking, whence most probably is feasible the launching of rocket. The obtained with the aid of three stations rough coordinates of rocket/missile supply for treatment to the computer. Reduced data enter the active tracking radars the rocket/missile for determining of its precise coordinates and escort/tracking. Precise coordinates automatically are transmitted to the active radars, which induce the antimissile missiles of long range for the damage/defeat of ballistic missiles.

Thus, in the antimissile defense system of the USA passive systems it is proposed to utilize together with active radar.

In connection with the great interest of the military circles of the USA in the problem of the long-range detection of rockets/missiles and the conduct of military intelligence as one of the means/facilities of the passive detection of the launching of rockets the Americans intend to utilize the artificial Earth satellites, launched to the height/altitude of approximately 400 km [11]. On the satellites will be utilized passive radar system with the receivers on the molecular amplifiers. They will accept the electromagnetic radiations, created with the work of powerful/thick rocket engine.

The molecular amplifiers of such systems work at the higher frequencies.

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For these frequencies the earth's surface and the ionosphere are no longer three-dimensional/space waveguide. These frequencies will penetrate through the ionosphere. Thus, from the wide frequency spectrum, emitted with the work of powerful/thick rocket engine, will be utilized shorter waves.

The passive radar system of artificial satellites will make it possible to detect ballistic missiles approximately two times of more rapid than long-range radar of the existing active systems of early detection, i.e., in 25-30 min before the reaching/achievement by the rockets/missiles of target.

After the rocket/missile will be discovered by one of the satellites, the data about this will be transmitted to other satellites, which track after the rocket/missile, and also to the early warning line of antimissile defense system.

It is expected that the first experimental satellites of this type will be launched in 1961. In particular, USAF [- United States Air Force] provide for the starting/launching of artificial satellite on the developed already project "Argus". Satellite will be equipped by sensitive receiving equipment for the detection of the starting/launching of intercontinental ballistic missile and data transmission about it.

For conducting reconnaissance in the USA it is proposed to utilize the developed/processed at present satellite "Zenith", which will rotate around the Earth in the equatorial plane at the height/altitude of approximately 36000 km. Satellite must be equipped by equipment with the molecular amplifiers.

Since the time of the turn of satellite in such a orbit is 24 h, then it will occupy relative to the specific geographical points/posts constant/invariable position/situation. From the satellite will be visible one and the same sector of the earth's surface. This satellite, in the op ıion of the Americans, will lighten conducting of reconnaissance above the specific points/posts.

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PASSIVE METHOD OF THE DETECTION SUBMARINES IN THE SUBMERGED STATE.

The use/application of a nuclear engine on the contemporary submarines made it possible to considerably increase their rate and cruising range. For the successful fight with these boats are necessary the ideal means of their detections, which possess the long range of action.

At present for submarine detection at large distances find use passive sonar systems [11]. In such systems is utilized the property of the hyperdistant propagation of acoustic waves in the sound-transmitting layers of the ocean, called "sonic channels".

The sound received by passive system appears directly in the channel itself or it falls in it with the passage into the depth from the source (the submarine), which is located near the surface of the ocean.

"Sonic channels", as a rule, are located in the dense layers of water at large depths. Sound absorption in these layers is small, which contributes to its propagation to great distances.

The existence of "sonic channel" is caused by a change in the speed of sound with the depth (Fig. 24).

On the speed of sound has an effect, salinity and especially the temperature of water.

On depths of approximately 1300 m in Atlantic Ocean and 900 m in Pacific Ocean the temperature of water is somewhat higher than 0°C. With further increase in the depth the temperature decreases slowly. Analogously with an increase in the depth decreases the speed of sound, until it achieves the minimum at the depth of approximately 1300 m.

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Beginning from this depth also of up to the bottom the speed of sound it grows/rises, since occurs a considerable increase in the hydrostatic pressure.

The depth at which is located "sonic channel", is determined by the minimum of rate of propagation of sound. For different geographic latitudes this depth is changed. In the Arctic areas, for example, "sonic channels" are detected on the very surface of water. However, in the tropical water where the temperature of water on the surface is comparatively high, "sonic channel" it is located at the depth of 1300 m.

Fading sound signals in the "sonic channels" is 1 or 2 dB on 1000 km. Occurred the cases when sounds caught into such channels were received at a distance to 1800 km from the source, and sound vibrations from the blasts, produced in the sound-transmitting layers of water, were recorded at a distance to 9000 km [5].

During the determination of the nondirectional sound source at the depth of sonic channel the acoustic waves, emitted at some angles relative to the axis of channel, because of the refraction are bent and, after passing certain distance, again they return to the sonic channel without the reflection from the surface of water and bottom of the ocean. Sound propagation in this case carries waveguide character. Sound is propagated as in the channel, hence name "sonic channel".

The same character of propagation have the acoustic waves, which appear at the surface or near the surface of the ocean, during their incidence/impingement into the sound-transmitting layers as a result of refraction by the denser layers of water.

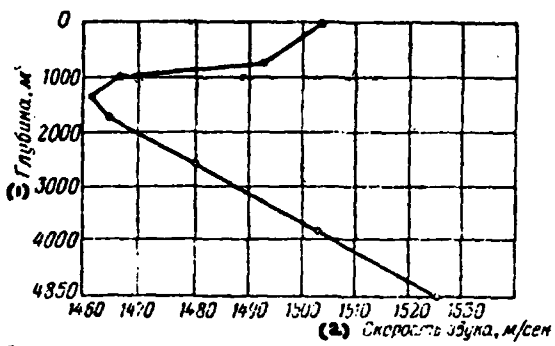

Fig. 24. Graph/diagram of the dependence of the speed of propagation of sound on the depth.

Key: (1). Depth, m. (2). Speed of sound, m/s.

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Another method of remote submarine detection is based on the repeated refraction of the acoustic waves which first penetrate the ocean depth, and then return conversely to the surface at a distance of approximately/exemplarily 56 km from the source. Here they are reflected by the surface of the ocean.

The sounds, refracted in the deep layers and reflected then from the surface of the ocean, are detected with the passive stations of listening at a distance to 360 km.

The detection range of the submarine by passive sonar depends in essence on the technical capabilities of the separation/department of the noises of its screws/propellers and engines from the numerous and sometimes strong noises of sea, and also from the noises, produced by surface ships and ships. Furthermore, detection range affects the attenuation of acoustic wave in the water in proportion to its removal/distance from the source of sound pulse.

The position of the submerged submarine and its route can be determined with the aid of three coast stations of interception according to time difference of the arrival of sound signals (Fig. 25). The distances between the stations are known. Each family of plotted curves relates to the specific pair of stations.

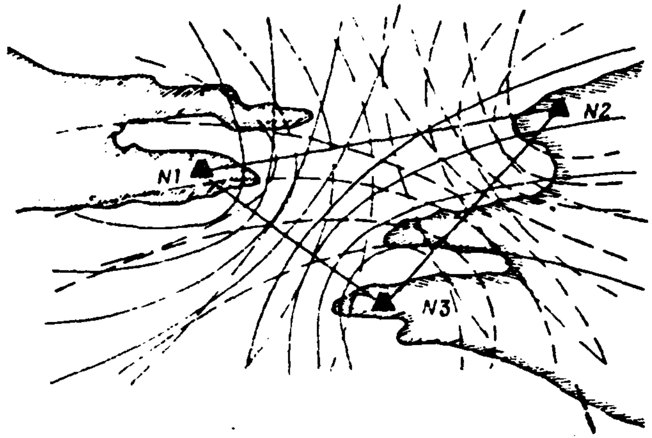

Fig. 25. Principle of passive submarine detection in the submerged state with the aid of three coast stations of interception.

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Curves are locus (by hyperbolas), a difference in the distances from which to two stations is constant value. The value of this difference for each curve is determined with the high accuracy.

But how does work sonar system of three stations?

At the monitoring station acoustic wave comes in different time. Let us assume that the acoustic wave by station No 1 is accepted at the moment of time t_1, by station No 2 - at moment/torque t_2 and by station No 3 - at moment/torque t_3. Then time lag in the reception/procedure of the acoustic wave between stations No 1 and 2 will be equally $\Delta t_1 = t_1 - t_2$, between stations No 1 and 3 $\Delta t_2 = t_1 - t_3$, also, between stations No 2 and 3 $\Delta t_3 = t_2 - t_3$.

By the known speed of propagation of sound in the "sonic channel" is determined a difference in the distances of each pair of stations. As a result on the family of curves are located three lines, which are loci for the calculated differences in the distances. The intersection of these lines fixes/records the location of the submarine in the submerged state with an accuracy to several kilometers.

Position finding of the submarine is realized by an accounting and computing machine. Depending on salinity and temperatures of water at the moment of the reception of signal, which affect the speed of propagation of sound and, consequently, also the accuracy of position finding of the submarine, into the machine automatically are introduced the necessary corrections.

In the American fleet for remote submarine detection in the submerged state is developed the passive system of monitoring stations by the name "Caesar" [11]. "Caesar" is utilized the property of the hyperdistant propagation of acoustic waves in the sound-transmitting layers.

The diagram of the layout of the hydroacoustic monitoring stations of system "Caesar" encompasses coast of two oceans (Fig. 26). The line of stations, located in coast of Atlantic Ocean, is put into operation. The construction of Pacific Ocean line, initiated in the summer of 1957, at present almost is completed. Coast stations are connected with the apparatuses for hydroacoustic interception with the aid of the special cables. The length of cables is determined by the submersion depth of apparatuses, which is approximately/exemplarily equal the depth of the occurrence of "sonic channel".

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The range of equipment of system "Caesar" is more than 200 km [11]. An increase in the detection range can be achieved/reached due to the improvement of the receiving equipment, which ensures the separation/department even of the low in the value signals, accepted from the submarine, from all other ambient noises.

Long-distance sound propagation in the "sonic channels" can be used for the supply by the submarine of signals about the danger of attack. For this by boat is dumped small explosive charge.

Conditional sound signal, being propagated along the "sonic channel", is received as the coast stations of interception. After this by three receiving offices of interception is determined the point of impact and command takes the appropriate measures for rendering to the submarine of the necessary aid.

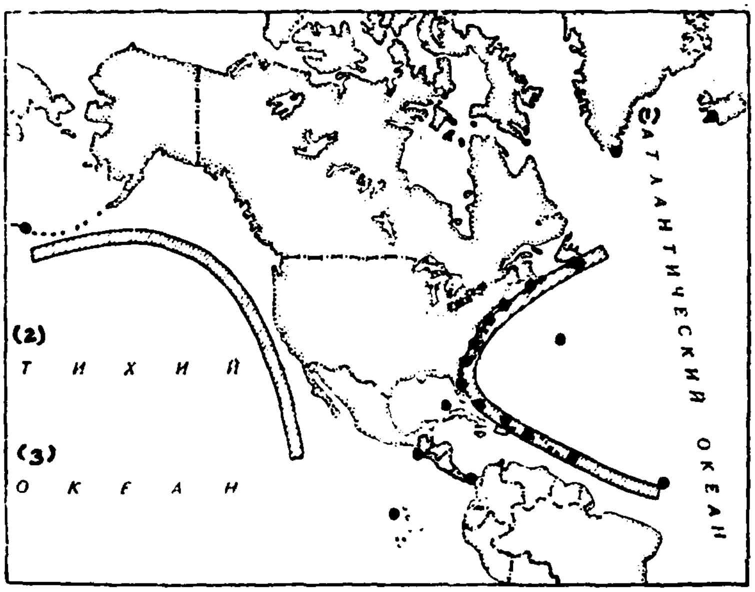

Fig. 26. Diagram of the layout of the hydroacoustic monitoring stations of system "Caesar".

Key: (1). Atlantic Ocean. (2). calm. (3). ocean.

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Experiments conducted in Atlantic Ocean on the detection of underwater explosions with the aid of the passive monitoring stations gave good results on the accuracy of position finding of blast.

As sources of signals were utilized the blasts of the charges of trotyl of different weight at the depth of approximately/exemplarily

1200 m.

Were discovered the following characteristic properties of sound signals: the long range of propagation, the sharp break of signal, which makes it possible determine time of landing run of signal with accuracy more than 0.05 s, and the location of emitter with an accuracy to 2 km, if signal will be accepted as three correspondingly by the arranged/located stations.

The sound of the blast of the charge with a weight of 1.8 kg was heard out up to the distances of approximately/exemplarily 4250 km of, that of the charge with a weight of 0.225 kg - at a distance to 1500 km, while that of the charge with a weight of 2 kg - at a distance to 5650 km.

The sounds of blasts were received as the hydrophone, omitted from the ship into the water at the depth of 1100 m, and also as the hydrophone, which lies on the bottom at the depth of 1220 m and by the connected cable with the coast.

Calculated path proved that for the charge whose weight is more than 2 kg the sound can be accepted at a distance to 18000 km.

The analysis of experimental data shows that the loss of sound energy as a result of absorption is 0.0055-0.055 dB/km for frequencies on the order of 10 kHz.

With the aid of the blasts it is possible to fix the position of aircraft and ships, suffering calamity in the open ocean.

In recent years for submarine detection finds use the passive method, in which are utilized special underwater listening devices - sonobuoys, with the aid of which the submarines are detected in the submerged state.

The location of the submarines is determined with the aid of three sonobuoys (Fig. 27).

The buoys, discarded from the aircraft or the helicopter into the zone of the predicted location of the submarine of enemy, recover the noises of its screws/propellers and engines, they determine on them bearing to the boat and by the radio automatically transmit data to the aircraft where these data are reproduced on the indicator with the cathode-ray tube.

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For a precise position finding of boat three buoys are dumped in the different places, forming the triangle, close to the equilateral.

Such buoys usually are fulfilled in the form of the cylindrical containers with a length of 1.5 m and with a diameter of 20 cm. Their descent from the aircraft to the water is realized by parachutes [12].

Radiohydroacoustic buoy consists of two parts, connect/joined together by cable. The upper part in which is placed the transmitter with the bolt of antenna, sails on the surface.

The lower part in which is located the hydrophone for determining the direction to noise source, it is immersed in the water at the depth, equal to the length of coupling cable. Rotating at a rate of 3 r/min, hydrophone is realized it is supplied on the coupling cable to transmitter, which is located in the upper part of the buoy, and from it through the antenna to the aircraft or the helicopter. The range of the reception/procedure of radio signals grows/rises with flight altitude of aircraft (helicopter). For example, for the height/altitude of 600 m it is 32 km.

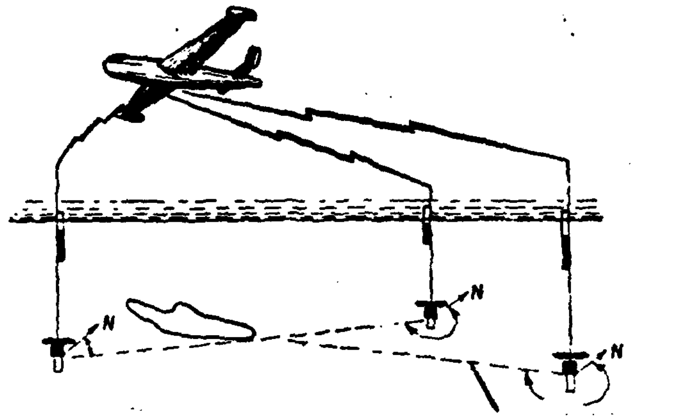

Fig. 27. Principle of passive submarine detection in the submerged state with the aid of three sonobuoys.

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ADVANTAGES AND DEFICIENCIES IN THE PASSIVE RADAR SYSTEMS AND PROSPECT FOR THEIR FURTHER DEVELOPMENT.

In contrast to radar of active system, which emits energy, than puts out its location, the station of passive system, as the station of infrared system without the illumination possesses the reticence of work, since enemy does not know, what operating frequency is utilized in the molecular high-frequency amplifier of receiver.

Passive radar is less, more easily, is less complex than active radar, since in it is not utilized transmitter. This advantage makes possible the wider application of PRL on the aircraft and the artificial Earth satellites. However, PRL somewhat more, it is heavier and is more complex than the infrared system of analogous designation/purpose.

As a result of the lower operating frequency the antenna of passive radar of more than the reflector of infrared system is close in the value to the antenna of the active radar, which works at the same frequency.

The range of the passive radar, which works in the range of millimeter and microwaves, is more than infrared system. This is explained by the fact that the waves, utilized in PRL, attenuate in the atmosphere less the the infrared rays. The advantage of PRL indicated especially is manifested with precipitation, the dense fog, etc., when the range of infrared system sharply decreases.

On the longer waves of centimeter band (3-6 cm) PRL with the rain possesses smaller the range than active radar system with the equal sensitivities of receivers.

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The resolution of passive radar is worse than infrared system, as a result of its lower operating frequency. However, the ability of passive radar to distinguish objects against the background of their surrounding locality can be the same good as active radar.

The great advantage of passive systems, in the opinion of the foreign specialists, is the ability to detect rockets and aircraft, covered with anti-radar dyes/pigments. Decreasing the effective echoing area of target, these dyes/pigments can sharply lower the range of active systems or even make impossible detection by them of targets.

For the passive systems are not threatening the guided missiles, induced on the ray/beam of working radar.

The use of high-frequency amplifiers with the wide passband and the low noise factor made it possible to improve sensitivity and, therefore, to decrease the time constant PRL, to the same values which have at present the infrared and active radar systems.

However, passive systems have a number of deficiencies/lacks.

To the ability of passive radar to distinguish with the survey/coverage different objects substantially affect the following factors: the angles of the slope of the antenna radiation pattern relative to objects, antenna polarization and value of the signal of radiation/emission depending on a difference in the apparent temperatures of objects.

The work of the highly sensitive receivers, used in the passive radar, which work in the centimeter and millimetric wave bands, easily can be suppressed by interferences from the low-power sources of interferences. Thus, in view of high receiver sensitivity of PRL is more subjected to interferences, than active radar or the infrared system of analogous designation/purpose, especially if is previously known operational frequencies band of PRL.

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Taking into account advantages and deficiencies/lacks in the passive radar systems, in the future it is proposed, as it is indicated in the foreign press, without too great increase in the sizes/dimensions, weight and complexity of equipment to create the combined systems in which passive radars will be utilized in combination with the active radars or the infrared systems. This combined system will be more interference-free and it will make it possible to more successfully conduct military intelligence of airspace and survey/coverage of locality.

Tactical use of PRL is not limited only to the conduct of exploring airspace and to the survey/coverage of locality. The tests, carried out by research center in Cambridge, showed that the use of passive radar equipment on the aircraft and the guided missiles made it possible to realize their automatic guidance on the boundary between the dry land and the water. The passive radar devices/equipment, adjusted on the artificial Earth satellites for the detection of the places of the starting/launching of intercontinental ballistic missiles, in the opinion of the American military specialists, in the course of time will replace the ground-based system existing in PRO of the USA of the early detection of ballistic missiles.

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