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FUNCTIONAL SYSTEMS AND INFORMATION MEASURING COMPLEXES OF AEROSPACE TECHNOLOGY

Lecture Course Manual

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The lecture course manual gives students basic knowledge about methods of construction and technical characteristics of modern aircraft and helicopters radioelectronic equipment.

Contents of the manual covers physical bases of functioning of radiotechnical systems for flight support, including distance measurement equipment, radio altimeters, Doppler systems, direction finders, landing systems, radioelectronic equipment of air traffic control.

The manual is intended for students of non-radiotechnical specialties of higher education institutions.

Fig. 30. Tabl. 2. Refr.: 6 items

Розглянуто основні методи побудови та технічні характеристики радіоелектронного обладнання, що застосовується на сучасних літаках і вертольотах.

Висвітлено питання, пов’язані з фізичними основами функціонування радіотехнічних систем забезпечення польотів, включаючи радіодалекоміри, висотоміри, доплерівські вимірювачі швидкості та кута знесення, автоматичні радіокомпаси, обладнання радіомаякових систем посадки та керування повітряним рухом.

Для студентів вищих технічних закладів нерадіотехнічних спеціальностей.

Іл. 30. Табл. 2. Бібліогр.: 6 назв.

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LIST OF ACRONYMS

A/C – Aircraft
ACS – Airborne Computer System
ADF – Automatic Direction Finders
AFCS – Automatic Flight Control System
AM – Amplitude Modulation;
ASV – Air-Supported Vehicles
ATC – Air Traffic Control
ATCT – Air Traffic Control Tower
BM – Balanced Mixer
BTF – Built-In Test Facilities
CAS – Collision-Avoidance Systems
DFA – Difference Frequency Amplifier
DME – Distance Measuring Equipment
Doppler – Doppler Systems
DP – Directional Pattern
DTK – Desired Track
EMC – Electromagnetic Compatibility
FM – Frequency Modulation
FMG – Frequency-Modulated Generator
FNS – Flight Navigation System
Frm – Frequency Meter
GSC – Glide Slope Channel
GSB – Glide Slope Beacon
GSI – Glide Slope Indicator
HC – Heading Channel
HFA – High-Frequency Amplifier
HFU – High-Frequency Unit
ICAO – International Civil Aviation Organization
IFA – Intermediate-Frequency Amplifier
IFU – Intermediate Frequency Unit
IIPE – Information Initial Processing Equipment
IM – Inner Marker
LFU – Low-Frequency Unit
LNS – Long-Range Navigation Systems
LOC – Localizer
LS – Landing Systems
MC – Marker Channel
MCI – Marker Code Indicators
MM – Middle Marker

MW – Metric Waves
NE – Navigational Elements
OM – Outer Marker
R ALT – Radio Altimeters
RB – Radiostation Bearing
RB – Relative Bearing
REE – Radioelectronic Equipment
RFA – Radio Frequency Amplifier
RNS – Radio Navigation Stations
RVG – Reference Voltage Generator
RW – Runway
SM – Single-Band Modulation
SMPS – Standard Material and Procedures Specifications
SR – Secondary Radar
SRNS – Satellite Radio Navigation Systems
SRNRS – Short-Range Navigation Radio Systems
TAMT – Thunderstorm Airborne Moisture Target
TB – True Bearing
WR – Weather Radars

1. INTRODUCTION

This course is intended for students of non-radiotechnical specialties. The main purpose of the course is to acquaint students with general tasks of aircraft navigation, which are fulfilled nowadays by means of numerous radioelectronic devices, systems and complexes installed both in the aircraft (A/C) and outside it.

Radioelectronic equipment (REE) is designed for determining position and speed of A/C, avoiding collisions with other air-supported vehicles (ASV) and non-ground obstacles, detecting airborne moisture targets, providing radio communication and fulfilling tasks of air traffic control (ATC).

Tasks of navigation, radio communication, air traffic control and A/C identification are fulfilled by means of radioelectronic equipment.

In this case, it is necessary to get a clear idea of the main principles of operation of airborne REE designed for measuring the most important parameters of A/C flight. At present REE installed in A/C acquires a new quality due to a wide usage of airborne and ground computers.

In the course study much attention is paid to REE designed for A/C navigation.

Results of the course study should include the ability of a professional designer of A/C, propulsion system and other mechanical units to orient oneself confidently in the arrangement of REE technical facilities set providing A/C navigation.

A/C navigation refers to a science of methods and means of receiving information about position and motion of aircraft or spacecraft and about methods and means of their navigation from one point of space to another along desired flight paths at the set time with the required accuracy and movement safety.

Besides, the term “navigation” is used as a definition of a controlled process of objects navigation.

In such interpretation, navigation is characterized by a complex of the crew actions to provide the highest accuracy, reliability and safety of moving objects navigation (displacement) in order to put them to desired points according to a place and time.

In air navigation this process is called airplane navigation or helicopter navigation, depending on aircraft type.

During navigation tasks fulfillment A/C displacement must be carried out along the most favourable flight path.

Flight path is a space curve, which A/C mass centre moves along in the process of its motion.

Flight paths projection on the earth surface is called a track (route).

Desired flight path corresponds to a desired track (DTK).

Flight path projection on a vertical plane is called a flight profile.

Earth surface point, which an A/C is located above, is called its position.

The main navigation tasks are the following: provision of accurate movement of A/C along a desired flight path and accurate putting of A/C to a desired point and at a desired time in the most favourable way for the given flight conditions.

Despite the whole variety of navigation tasks, execution of a desired program of A/C movement is usually divided into separate stages whose sequential and successful carrying out provides fulfillment of a particular task.

Such stages of A/C navigation process can be the following: take-off, construction of desired order of A/C group, rollout to a desired point, rollout to a landing airfield, A/C landing, etc.

A/C navigation mode is determined according to a set of a large number of navigational elements representing geometric or mechanical values which characterize A/C position and movement.

The main navigational elements (NE) of A/C flight include NE characterizing position and A/C mass centre movement relative to different reference systems; these are object coordinates, its linear speeds and accelerations. Depending on A/C movement range, coordinate systems can be local, global and cosmic (space).

Local coordinate systems, whose beginning is bound with the earth surface, are used as reference systems at short-distance A/C movements, when the earth curvature can be neglected.

Global coordinate systems are strictly bound with the earth centre and used during navigation around the earth. Geographical and geocentric coordinate systems are most wide-spread.

Important navigational elements of A/C flight are its full ground speed, ground speed and airspeed.

At each moment of time A/C flight speed relative to the earth coordinate system, called full ground speed W is equal to A/C movement speed vector sum relative to the air V and transportation velocity of its movement together with the air υ.

Projection of the triangle formed by A/C flight speed components on a horizontal plane is called a wind triangle. $\vec{W}$ vector component in the horizontal plane is called ground speed $\vec{W}_{\mathrm{g}}$, and in the vertical plane – a rate of climb or rate of sink $\vec{W}_v$.

An angle between the vectors $\vec{W}_\text{g}$ and $\vec{V}$ in the horizontal plane is called a drift angle α.

The main parameters of the wind triangle are shown in Fig. 1.1.

A significant group of A/C flight elements is made up by elements determining A/C attitude and mass centre movement. These elements include angular coordinates of the object in the horizontal coordinate system (roll, pitch, heading), angular coordinates of A/C relative to velocity vector (angles of attack, angles of slip, etc.).

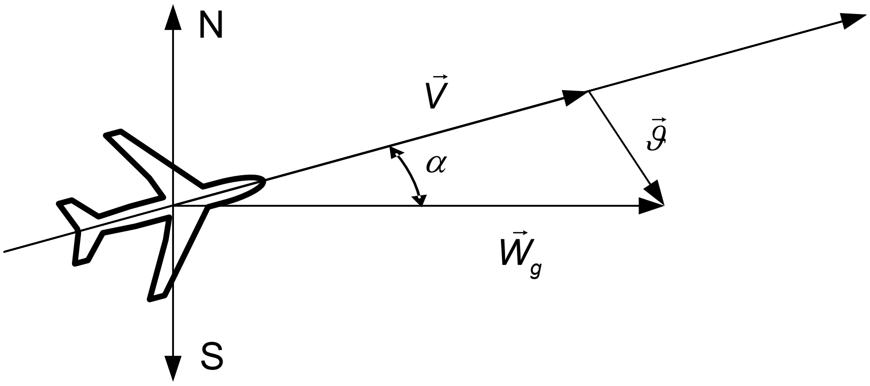


Fig. 1.1

The most important angular parameter of A/C flight is a heading.

Heading is an angle in the horizontal plane of the reference system (for example, geographical one) between the direction taken as the origin of coordinates, and projection of A/C longitudinal axis, read clockwise. Depending on the direction taken as the origin of coordinates there can be a true heading, magnetic heading, great circle heading, etc.

Fig. 1.2 shows A/C true heading.

In a number of cases it is necessary to know an angular position of a certain point, for example, radiostation relative to A/C longitudinal axis or reference direction N_g, S_g, passing the A/C mass centre.

In the first case, the angular position is called a relative bearing of radiostation (RB), in the second – a true bearing (TB).

Navigational elements of flight include flight altitude above the desired surface, vertically measured.

Absolute altitude is the shortest distance between A/C and the earth surface.

True altitude is the shortest distance between A/C and the world ocean level.

Pressure altitude is read according to pressure altimeter readings relative to a barometric pressure level of take-off or landing airfield.

Among a great variety of technical facilities of A/C flight navigational elements measuring an important place is occupied by radiotechnical facilities.

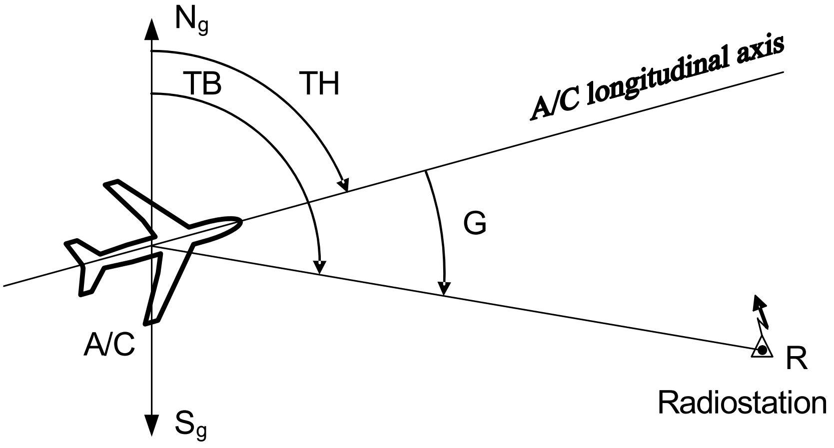


Fig. 1.2

A physical base of radiotechnical facilities functioning as part of A/C REE is a number of properties of electromagnetic waves as shapers and transmitters of information about navigational elements. The main properties of electromagnetic waves are the following: possibility of generation, radiation and reception; propagation to long distances, going around obstacles and possibility of reflection at wave lengths which are much smaller than obstacles; directed radiation and reception; propagation to the shortest distance within direct visibility with highly stable propagation speed close to light speed; possibility of directed radiation and reception of quite short waves; provision of high accuracy of measurements practically in any weather conditions.

A/C attitude determination by means of REE requires the usage of ground and space radio navigation stations (radio beacons) relative to which we measure ranges (distances), differences or sums of ranges and a number of other geometric values. This makes REE A/C attitude determination completely autonomous. The exception is radiotechnical facilities of measuring A/C flight altitude and speed. The latter give a possibility to carry out navigation by methods of dead reckoning.

REE peculiarity is internal and external radio noises sensitivity. Internal noises are connected with functioning of a particular radiotechnical measuring means.

Normal fulfillment of navigation tasks is impossible without reliable communication between A/C crew and ground centres of air traffic control (ATC). Thanks to radio communication ATC departments receive information about how flight goes, about deviations from the flight plan, special events in flight, current weather conditions at a route section, etc.

Thus, information exchanged between crews and ATC ground centres allows fast formation and urgent correction of a true state of quickly changing situation in the air and on the ground, without which it is impossible to provide flight safety.

ATC is impossible without development of ground aviation communication network capable of providing urgent exchange of information between cooperating airports and ATC departments, as well as exchange of information on the control of productive and commercial activities of aviation enterprises, between central and local services of civil aviation.

Modern means of aviation communication are being constantly improved. A process of communication means integration with digital computing technologies is going intensively. There have appeared new means of communication – mobile and space means.

In connection with this fact, a future specialist in the field of development and creation of A/C must know the basic principles of aviation communication means functioning, their operating and technical characteristics, have a clear idea of application fields of this or that type of communication.

Formulating general requirements for aviation air communication it is essential to know that it must be continuous, reliable, instant selection, power-saving and efficient.

The main band of highly reliable communication at long distances of direct visibility between A/C and ATC ground centre is a band of metric waves (MW). Decametric waves band (100 …10 m) having a long operating distance does not provide high reliability of communication.

Operating distance in MW band is determined by a simple empirical equation $r=(3,87...4,1)\cdot\sqrt{h}$, where h is A/C flight altitude, m. At $h \approx 10^4$ m we receive operating distance within direct visibility $r = 370...410$ km.

We shall discuss air traffic control in details. ATC represents a complex of measures on planning, coordination, direct regulation of A/C movement and control over observing the selected mode of flights.

One of the main tasks of ATC is avoidance of A/C collisions. Fulfillment of this task is based on the usage of secondary radio detection systems and collision-avoidance systems.

Radio detection is a field of radioelectronics, which deals with problems of detecting and determining A/C movement parameters due to contrast reflection, reradiation or radiation of electromagnetic waves. In the latter case, passive radio detection is meant.

The main peculiarity of secondary radio detection systems used in

ATC system is availability of a transponder on A/C board, which provides response to radar interrogation, gives information about flight altitude, registration number, fuel quantity, landing gear extension, and velocity vector. Collision-avoidance systems operate independently of secondary radio detection systems of ATC. Collision-avoidance systems (CAS) give commands to the crew to make a maneuver of avoiding a possible collision with other A/C. The simplest CAS determines a dangerous distance and range rate of one A/C relative to the other.

At present, according to ICAO recommendations all A/C performing international flights must be equipped with satellite radio navigation system of determining A/C position and speed.

The majority of modern A/C is equipped with weather radars. The main purpose of such a radar is to determine an angular position and a distance to a thunderstorm airborne moisture target (TAMT). In addition, the weather radar 9^o determines the distance to ground references. Information about weather conditions is indicated on an electronic flight instrument display installed in the cockpit.

As the above information shows, during fulfillment of A/C control tasks a large amount of radio navigation information is used, which is received by means of airborne REE functioning with ground radiotechnical facilities. In addition to this, there are other non-radiotechnical facilities of flight parameter measurement.

It is impossible to use all measurement information on the level of physical abilities of the crew. Therefore when fulfilling complicated and various A/C control tasks in flight it is essential to automate the whole procedure of information processing with input of necessary parameters of A/C automatic control system and provide visual indicating of information for navigation, piloting and control of the whole closed circuit of the control system.

Both the crew and flight navigation system (FNS) participate in the process of modern piloted A/C control. The following types of flight control are distinguished: manual, flight director and automatic.

Manual flight control is carried out by a pilot and is a continuous process of control. In order to do this, the pilot receives information about the current position and parameters of A/C flight, analyses the obtained information, works out a decision about necessary change of A/C motion and carries it out effecting the piloting controls.

Flight director control implies automatic formation of commands whose fulfillment is carried out by the pilot in the mode of manual flight control. Performing actions according to command bar indications the pilot gets them set in the neutral position and achieves equality of desired and current values of the parameter controlled.

2. CLASSIFICATION, GENERAL PARAMETERS AND COMPOSITION OF REE

REE is classified according to its functions, autonomy degree and range of equipment operation (Fig. 2.1).

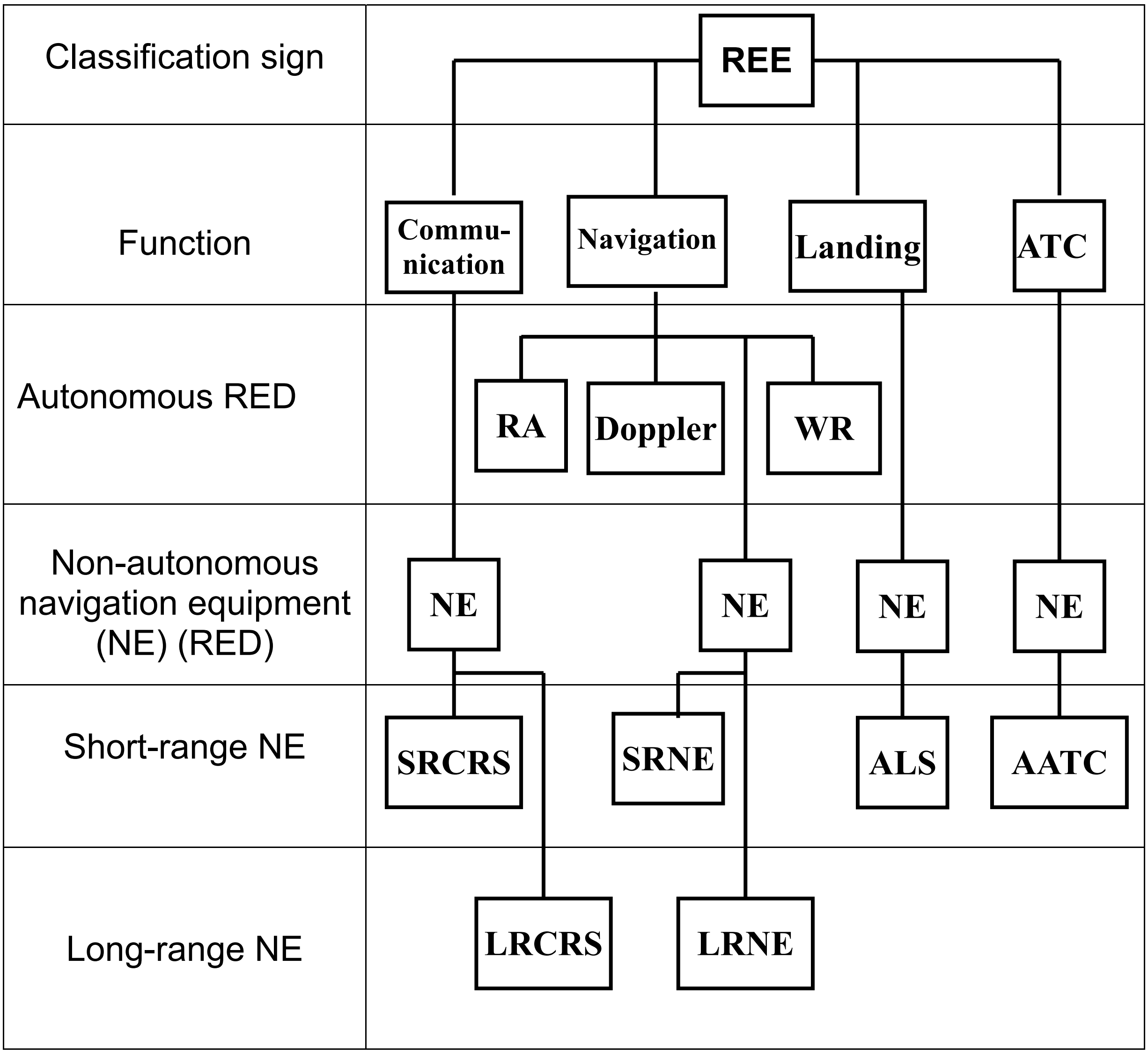


Fig. 2.1

According to its functions the equipment is divided into equipment of communication, navigation, landing and ATC.

Communication equipment is intended for receiving and transmitting information by radio communication channels, conducting talks between crew members and informing passengers and broadcasting entertaining programmes to compartments.

Navigation equipment serves for determining A/C position, its ground or full speed, as well as determining range and direction of characteristic stations called radio navigation stations (RNS) in which special radiostations and radio beacons are installed.

Landing equipment is used on ASV board for receiving information about aircraft position relative to desired descent flight path (glide slope).

ATC equipment is installed in ASV to increase A/C safety, possibility of their motion control. It includes A/C responder and collision-avoidance system.

According to the autonomy degree there are autonomous and non-autonomous radiotechnical devices.

For their operation autonomous devices do not require external devices with respect to ASV, cosmic or other devises, and are based on the principle of radio detection, i.e. reception of signals reflected from the earth surface (as well as airborne moisture targets) and radiated by the given autonomous device. Autonomous devices include radio altimeters (R ALT), Doppler systems (Doppler) and weather radars (WR).

Non-autonomous devices are based on reception of signals radiated by ground or space (satellite) RNS. Navigation equipment operates within the coverage of corresponding radio equipment pieces on board and in space, between which communication radio channel functioning is possible.

Non-autonomous devices include all means of radio communication, landing, ATC and a number of radio navigation devices.

Short-range operation radio means function in the metric waves band, i.e. they use electromagnetic oscillations with wavelength of $\lambda<10$ m. Radio waves of this band are spread within direct visibility and used in radio communication, short-range navigation radio systems (SRNRS) and radio systems of landing, as well as in ATC and WR equipment.

Long-range operation radio means function on short (long-range communication radiostations) or long and superlong waves (long-range navigation radio systems LRNR). In this bands the coverage mainly depends on the power radiated by the transmitting radiostation (radio beacon), ionosphere condition, external (atmospheric and industrial) noises level, earth surface conductivity and receiver sensitivity.

Let us discuss a structure of general parameters of REE and give their short characteristic.

Efficiency is a function of general parameters of REE, which characterize airborne equipment independently of its functional area. When estimating efficiency it is essential to proceed from a systematic approach, at which ASV is considered as an element of a large transportation system intended for solving certain economic tasks.

Concerning airplanes and helicopters such a system is air transportation system intended for transportation of passengers, mail and cargoes.

The main general parameters include reliability, testability, mass, volume, consumed power from sources of power from aircraft and equipment life circle cost. They may also refer to design parameters characterizing composition of REE equipment and its antenna in ASV.

REE reliability depends on perfection degree of particular REE, maintenances quality and airborne equipment operation conditions.

The main showings of reliability are the following:

- probability of failure-free operation, i.e. probability that within the desired operating time the object failure does not occur;
- failure rate, i.e. apparent density of unrepairable object failure probability;
- mean time between failures, i.e. mathematical expectation of time till the first failure of the object.

For the majority of complex REE distribution of failure-free operation is determined by the following formula

$$P\left(t_0\right) = \exp\left(-\lambda \cdot t_0\right),$$

where t_0 is operating time; λ is failure rate.

A radical method of REE reliability increase is equipment redundancy. Continuous redundancy and replacement redundancy are applied. At continuous redundancy a complete replacement of the object occurs when its elements failed.

At replacement redundancy, i.e. dynamic redundancy, a group of the main elements is made redundant by elements, each of which is able to replace any failed element.

Redundancy ratio makes it possible to obtain practically any REE reliability. However, in this situation there is a redundancy-proportional increase in mass, volume, consumed power and cost of REE.

REE testability is an object property which characterizes its fitness for test, i.e. for receiving information to estimate object creation correspondence to technical norms with the purpose of failure detection and failure place finding.

REE testability is aimed at REE reliability increase, as it allows efficient detecting of parameter deterioration of separate elements or the whole device and preventing failures by timely repair or replacement of the equipment.

REE testability involves availability of special testing terminals from separate functionally important elements of REE. In this situation it is possible to apply systems of automatic test of REE with the usage of test signals. In addition, during REE elements test it is possible to use technical facilities of built-in test.

Built-in test facilities (BTF) are intended to check REE parameters correspondence to standard material and procedure specifications. These facilities are needed during replacement redundancy.

Test depth is the main parameter characterizing BTF quality. It is determined in the following way:

$$q = \ln \frac{P_k}{P},$$

where P_k and P are probabilities of failure-free operation of tested elements of REE and REE in general.

With test depth increase the probability of the fact that the crew uses a faulty device or system reduces. In this case

$$\bar{P} = 1 - p^{1-q}.$$

Modern airborne equipment has test depth of $\bar{P} = 0.8$ and more.

REE mass influences ASV efficiency, as its increase results in reduction of range and endurance of flight, decrease of payload and deterioration of its performance.

In order to estimate REE mass influence on ASV performance two classes of ASV are distinguished:

- with desired constant takeoff mass;
- with desired performance and payload.

REE mass change at constant takeoff mass of ASV results in the necessity of changing either payload or fuel quantity.

If we assume that REE mass change m_{REE} is compensated at the expense of fuel quantity change Δm_{F}, reduction or increase of mass m_{REE} is correspondingly accompanied by either growth or decrease of flight range (or its endurance):

$$\frac{D_{n1}}{D_{n2}} = \frac{\lg[m_{\text{t}} / (m_{\text{t}} + \Delta m_{\text{F}})]}{\lg[m_{\text{t}} / (m_{\text{t}} + m_{\text{F}})]},$$

where D_{n1} and D_{n2} are flight range at the initial value of REE mass and after changing of the latter; m_{t} is ASV takeoff mass; Δm_{F} is initial fuel mass at the initial value of REE.

Mass of separate REE depends on the element base, on whose basis the given device is designed.

REE volume differently influences ASV characteristics at constant takeoff mass or constant payload and performance.

REE volume change at the desired payload and performance of ASV leads to takeoff mass change:

$$\frac{\Delta m_t}{\Delta V_{\text{REE}}} = \frac{m_t}{V_{\text{pl}} + V_{\text{REE}}},$$

where V_{pl} and V_{REE} are volumes of payload and REE correspondingly:

The volume of separate REE depends on the same factors as its mass. For modern REE, taking into account design losses, specific density makes up 1 kg/dm^{3,} specific density of cable network in modern ASV is 0.8 kg/dm^3.

Power consumed by REE indirectly influences ASV characteristics. Estimating the influence of the fact being considered we can understand that power sources mass is approximately equal to 1 kg/watt, and their specific density is of the same order as that of REE.

REE life circle cost influences economic efficiency of ASV, as it represents a quantitative characteristic of complex estimation of aviation equipment design, manufacture and operation cost. This characteristic comprises the cost of equipment itself, which includes expenses on design and manufacture, cost of installation and maintenance of REE.

REE cost makes up a significant part of ASV cost. Analysis of REE manufactured by foreign companies shows that the cost of 1 kg of equipment makes up 4500 \$ per kg, which is approximately one order higher than the cost 1 kg of ASV.

REE cost part in the life circle cost is normally equal to 20…50 %.

Cost reduction can be achieved only at the expense of REE parameter requirements decrease, but this is not always possible and reasonable.

Cable network cost is equal to ~300 \$ per kg (3000 \$ per km).

REE maintenance cost (operation cost) normally makes up the main part of its life circle cost. Total expenses on repair and maintenance may be 5 or 10 times higher than its purchasing price.

3. DISTANCE MEASUREMENT EQUIPMENT

Distance measuring equipment (DME) is a component part of short- and long-range navigation. It is designed for measuring linear coordinates or coordinates between air-supported vehicle (ASV) and radio navigation station (RNS).

When ASV position is determined by means of short-range navigation system, RNS is located on the earth surface. In addition to determining the distance between RNS and ASV is necessary to determine azimuth, i.e. position of the range line in the horizontal plane relative to reference direction passing through the radio navigation station.

ASV position determination comes to finding (fixing) a point of intersection of the circumference corresponding to the measured distance and radial line, whose angular position is desired by the value of measured azimuth (Fig. 3.1).

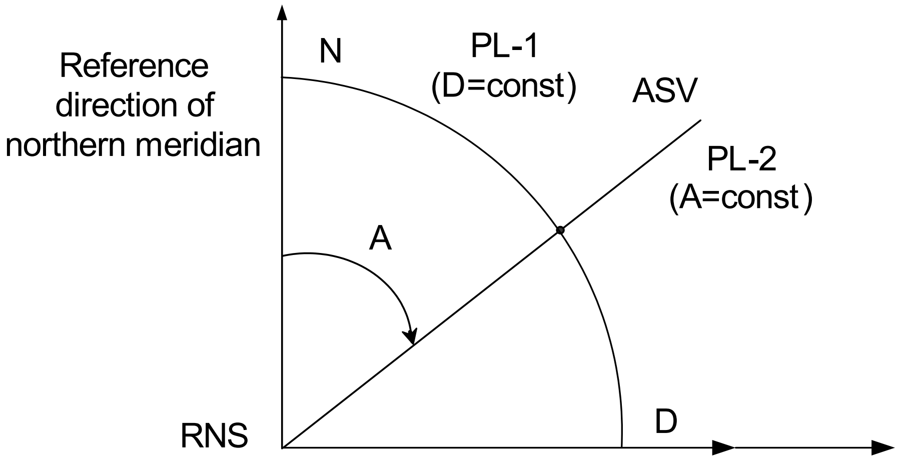


Fig. 3.1

To make convenient and fast determination of ASV position line grids are plotted in the horizontal plane. For azimuth measurements these are radial lines, and for distance measurements – circumferences.

Each position line is characterized by a constant value $A = const$, $D = const$. Azimuth grid pitch is determined by errors of radiotechnical measuring devices (distance measurement equipment and angle measurement equipment).

When determining ASV position by means of long-range navigation system, on board ASV it is necessary to measure distance to several radio navigation stations with known coordinates, located both on the earth surface and in outer space. Long-range navigation systems with RNS located in outer space are called satellite radio navigation systems (SRNS).

Independently of the area of reference radio navigation stations location ASV position in the desired coordinate system is determined as a point of intersection of three position planes – circumferences, for which the measured distances D_i, ($i = 1..3$) remain constant.

In practice, object (ASV) position is determined either in the geographic or geocentric coordinate system.

In order to determine ASV position with the application of SRNS, it is necessary to use a system of navigational equations. If to choose a rectangular Cartesian coordinate system as an earth-centered coordinate system, the equation of distance between RNS with known coordinates X_i, Y_i, Z_i and unknown X_a, Y_a, Z_a (a - aircraft) has the following form

$$D_i^2 = \left(X_i - X_a\right)^2 + \left(Y_i - Y_a\right)^2 + \left(Z_i - Z_a\right)^2.$$

The system consisting of the equations of distances D_i, ($i = 1..3$) allows finding the required coordinates X_a, Y_a, Z_a at a moment of time t_i (moment of distances measurement).

Let us discuss an operation principle of distance measurement equipment of a short-range navigation system (SRNRS).

SRNRS has a set of transceivers in ASV and on the ground. To simplify description of DME operation principle let us call a set of ground equipment a retransmitter. Then a simplified diagram of DME will have a form shown in Fig. 3.2.

The chronizator generates and forms impulse signals with the desired duration, amplitude and frequency. The radio transmitter installed in ASV radiates radio impulses (high-frequency impulses).

The retransmitter installed in the place of RNS location (on the airfield) reradiates and reflects impulses which came from the transmitter.

The receiver installed in ASV receives and processes retransmitted signals.

The distance measurement equipment converts time of signal propagation between ASV and retransmitter into the distance D according to the following equation:

$$D = c\frac{\tau_p}{2} = 0{,}15\tau_p\ [km],$$

where τ_p is time of signal propagation to the retransmitter and back, mcs (microseconds); c is electromagnetic waves propagation speed m/s.

When the chronizator is ideal, distance measurement error is determined by constancy of radio waves propagation speed.

It is experimentally established that relative changes of propagation speed are within the limits

$$\frac{\Delta c}{c}=10^{-5}.$$

In this case, the limiting value of distance measurement minimum error in SRNRS is

$$\frac{\Delta D}{D}=\frac{\Delta c}{c}\le 10^{-5}.$$

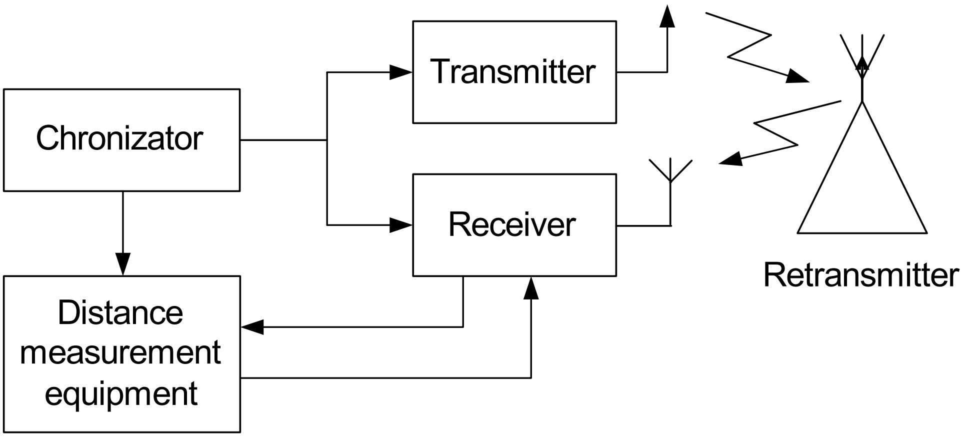


Fig. 3.2

When the distance is 500 km, $\Delta D = 500\cdot 10^{-5} = 5\ m$.

In long-range navigation systems (LNS) with ground location of radio navigation stations phase distance measurement equipment is applied.

In long-range navigation systems (LNS) with RNS location in outer space (satellite navigation systems) distance measurement equipment is applied which has mutually synchronized time standards (hours). The simplified operation principle of such distance measurement equipment comes to the following.

Let us assume that the reference radio navigation station (satellite) is stationary, coordinates are known for sure, and the satellite on-board clock is accurately synchronized with the on-board clock of ASV hereinafter called a consumer.

At a certain period of time the transmitter is switched on according to the satellite on-board clock. As the transmitter and receiver of the consumer are at the distance D (Fig. 3.3), after the period of time t_D at the time moment t_2 the transmitter signal will reach the receiver.

The required distance is determined in the following way:

$$D=(t_2-t_1)\cdot c=t_D c.$$

Differentiating this equation and proceeding to the final increments, at $c = const$ we receive

$$\Delta D = c\frac{dt_D}{dt}\Delta t,$$

where dt_D / dt is speed of scales divergence of satellite and ASV clocks, Δt is flight time.

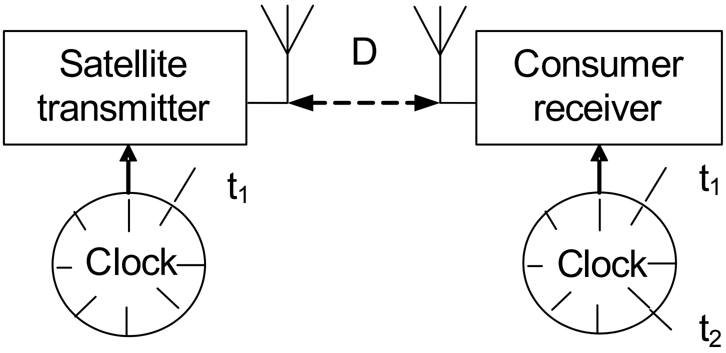


Fig. 3.3

If the DME error must not increase more than by one km per 10 hours of operation (ASV flight time is 10 hours), clock instability must not be worse than 10^{-10}. Such instability corresponds to clock divergence error which is equal to 3 seconds per 100 years.

In real operation conditions satellites of SRNS move along known orbits with known speed. Therefore a real signal radiated by each satellite is quite complicated. It is called a distance measuring signal which has a distance measuring code and informational message about parameters of particular satellite movement:

$$S_i(t) = XG_i(t) \cdot D_{ci}(t) \cdot \sin(2\pi f_0 t),$$

where $XG_i(t)$ is distance measuring code, $D_{ci}(t)$ is data code in parameters of i-satellite movement, f_0 is carrier frequency of satellite transmitter.

Let us discuss operation principle, equipment composition and the main performance characteristics of the distance measuring channel of the short-range navigation radio system VOR/DME used on international airlines.

VOR-VHF is an omnidirectional radio range;

DME is distance measurement equipment (precision).

The principle of DME channel operation does not differ from the principle of corresponding SRNRS channel operation.

Airborne equipment of distance channel of VOR/DME system in domestic aircraft of civil aviation is represented by aircraft distance measurement equipment SD-75. DME is installed in ASV performing international flights.

4. RADIO ALTIMETERS

During ASV flight performance the main means of control over flight altitude are pressure radio altimeters. Not fewer than two radio altimeters of this type are installed in the aircraft. They may have instrument, position and measurement-method errors. For accurate observation of the desired flight level H_{760} (altitude by atmospheric pressure of 760 mm Hg) each pressure radio altimeter is provided with a table of required readings of the radio altimeter, taking into account a total error correction of measurements, for the most advantageous flight speeds. Table 4.1 is given as an example.

Table 4.1

Flight level, m	900	1200	…….	6000	Etc.
Indicated speed, km/h	830	820	……	705	Etc.
Altimeter readings taking into account ΣΔH, m	950	1230	……	6080	Etc.

At absolute flight altitudes of less than 1500 m effective means of ASV flight altitude measurement is a radio altimeter.

The main task of measuring absolute flight altitude is to avoid collisions with ground obstacles during low altitude flights, i.e. $H < 1500\ m$.

In these flight conditions low altitude radio altimeters are intended for measuring absolute flight altitude, as well as for forming light and aural alarm warning of the desired altitudes. Here are several definitions.

Absolute flight altitude is a distance from ASV to a point of underlying surface below it.

Alert altitude (altitude of making a decision) is a present altitude value chosen by a pilot on the altimeter indicator.

Residual altitude is a total value of half of electrical lengths of cables from the radio altimeter transceiver and half of minimum length of the distance from the transmitting antenna to the underlying surface and from the underlying surface to the receiving antenna.

Underlying surface is a section of the earth surface, reflecting R ALT transmitter signals.

Altitude performance is a maximum flight altitude, at which altitude determination is made with the error not exceeding the extreme value.

Information about ASV flight altitude, which is received by means of low-altitude radio altimeters, plays an important part during the aircraft approach procedure.

Beginning from the altitude of approximately 200 m the system of ASV flight director control receives signals from R ALT, which serve for reducing the gain on the glide slope channel from the maximum value to zero by the flare-out altitude (15…20 m). the same signals are used for reducing the rate of descent to the value of 0.45 m/s at commencement of flare-out and two-time reducing of the gain on the yaw channel during ASV descent.

The peculiarity of R ALT is autonomy. In all R ALT a frequency range of about 4300 MHz is used.

R ALT types differ in kinds of frequency modulation (FM) of radiated signal and in a way of reflected signal processing.

Part of radio altimeters (RV-5, A-031) carry out wide-band processing of the converted signal received as a result of mixing radiated and reflected FM signals.

Part of radio altimeters (RV-85, A-037) carry out narrow-band processing and have circuits of maintaining a constant value of the converted signal frequency.

ASV flight altitude determination is based on radio detection principle with the usage of a signal reflected from the earth surface (Fig. 4.1).

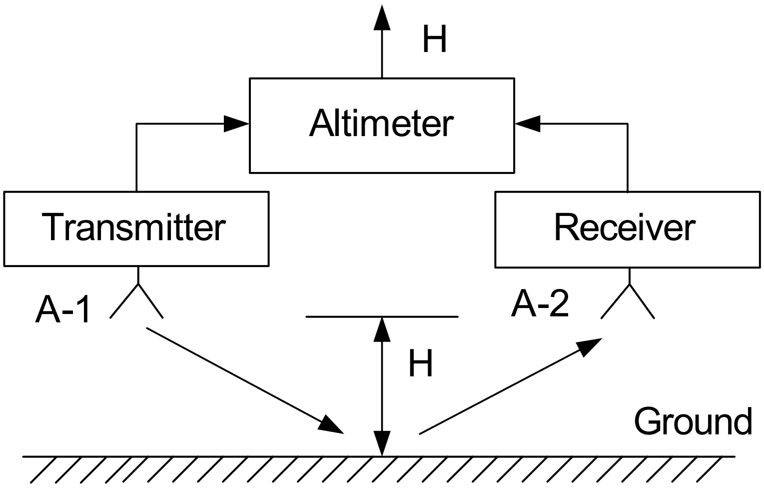


Fig. 4.1

The transmitter forms FM oscillations which are radiated by the antenna A-1. The reflected signal arrives at the antenna A-2 and enters the receiver. The altimeter generates a signal proportional to the time of oscillation propagating to the earth surface and back, $t_H = 2H / c$, and thus, a signal proportional to the present altitude of flight.

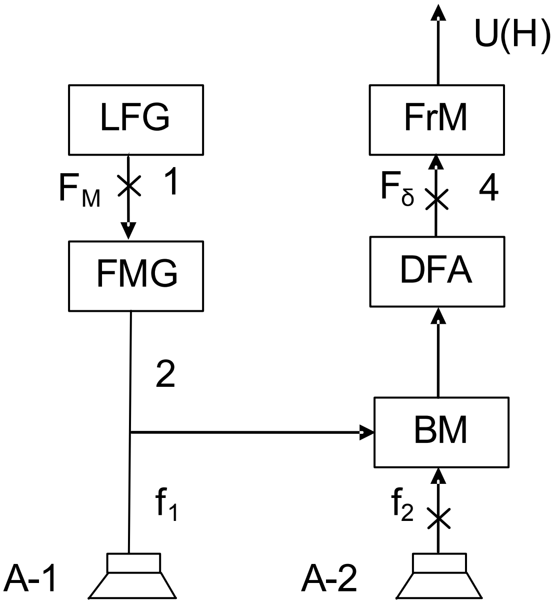


Fig. 4.2

The operation principle of R ALT with wide-band processing of the converted signal (Fig. 4.2) is based on the frequency method of measuring the delay time t_H.

Low-frequency generator ($F_M = 150\,\text{Hz}$) generates voltage U_M, controlling frequency f_1 of probing FM signal formed in the frequency-modulated generator (FMG). Antenna A-1 serves for radiating a signal towards the earth surface. The reflected signal from the antenna A-1 arrives at a balanced mixer (BM). The signal reflected from the antenna A-2 arrives at the balanced mixer, where a part of the probing signal power arrives.

Signal delay leads to difference of the instantaneous frequency f_2 in the band of the reflected FM-signal form the instantaneous frequency f_1 of the probing FM-signal. Beyond the time intervals corresponding to the beat frequency passing the zero value this frequency is equal to

$$F_\delta = \left(\frac{8\Delta \mathrm{f}}{\mathrm{c}\mathrm{T}_\mathrm{M}} \right) \cdot \mathrm{H}.$$

To determine the altitude H it is necessary to measure F_δ. For this purpose after BM the signal (converted signal) is amplified in a difference frequency amplifier (DFA), i.e. beat frequency amplifier, and arrives at a frequency meter (FrM), from which the voltage $U(H)$ proportional to the flight altitude is read. FrM determines the average value $F_{\delta.av}$ of the beat frequency $F_{\delta.av} = |f_1 - f_2|$.

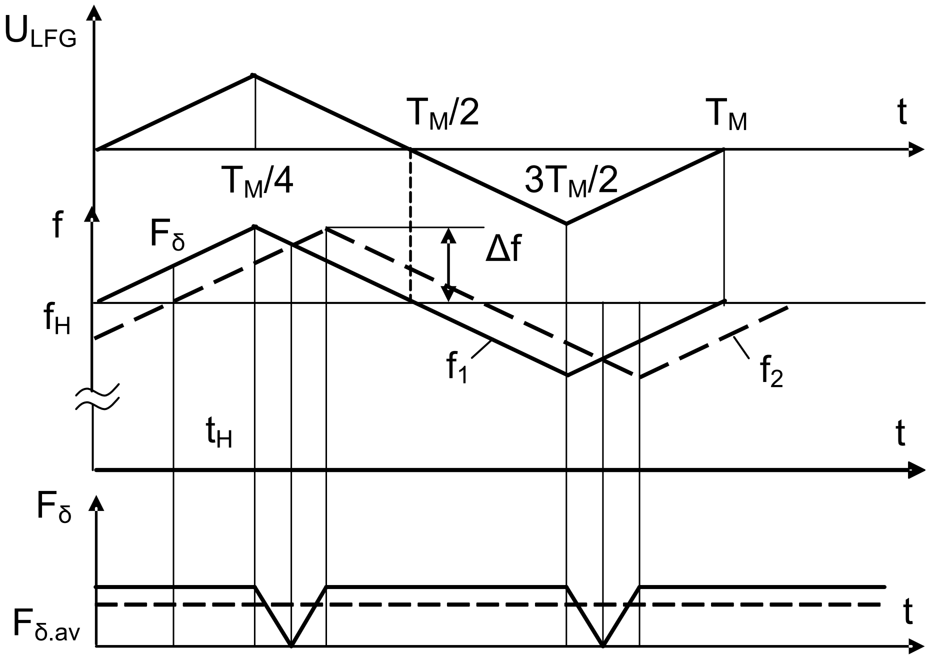


Fig. 4.3

At the saw-tooth law of frequency modulation (Fig. 4.3)

$$F_{\delta.av} = F_\delta \cdot \left(1 - 2t_H / T_M\right).$$

5. DOPPLER SYSTEMS

Doppler systems (Doppler) are designed for determining the components of A/C speed vector relative the surfacing reflecting electromagnetic oscillations. If such a surface is ground, then the components of the full ground speed $\vec{W}$ vector are determined by means of Doppler.

Full ground speed vector projection on the ground is called A/C ground speed. It represents a geometric sum of air speed vector and wind vector:

$$\vec{W}_g = \vec{V} + \vec{U}\,.$$

In navigation the presented sum is called a wind triangle.

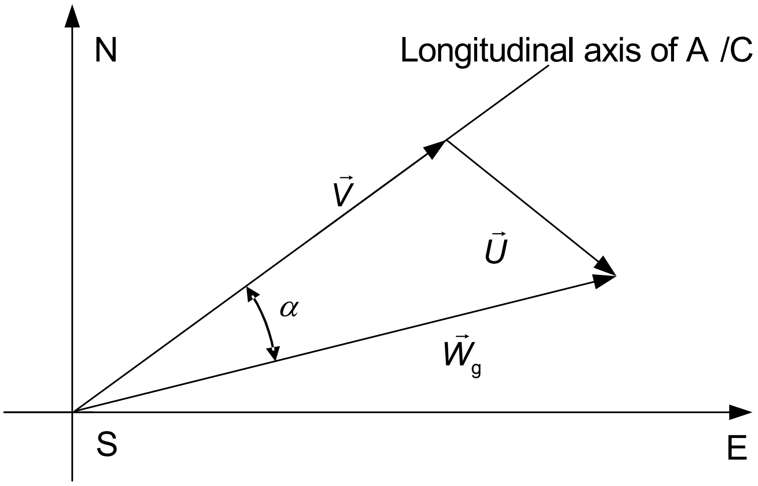


Fig. 5.1

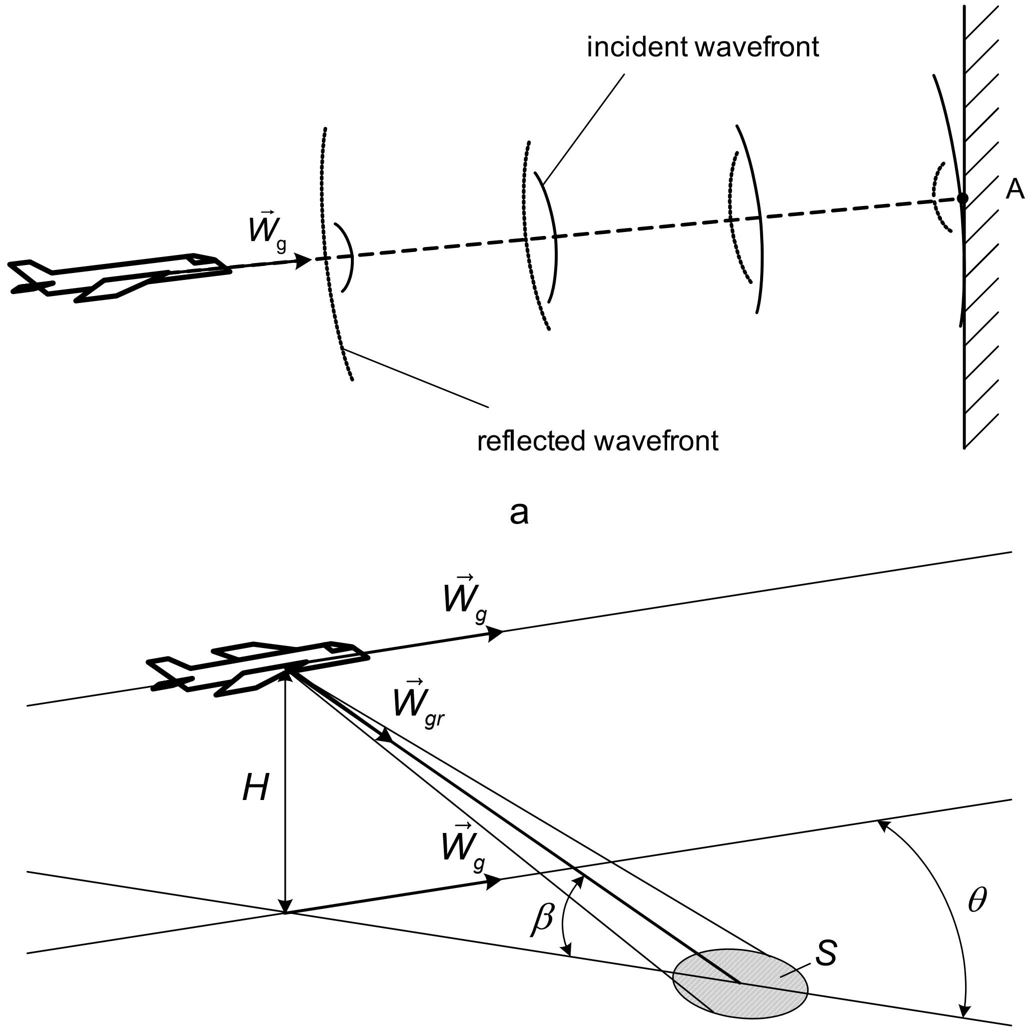
Angle α (Fig. 5.1) between air speed vector and ground speed vector is called a drift angle.

At present Doppler systems play a great part in determining aircraft position by dead reckoning method.

Dead reckoning is a method of determining aircraft position, which is based on calculation of the covered distance relative to the known initial position of A/C. A/C covered distance is calculated by one-time integration of speed. In this case, Doppler systems are used together with a compass system measuring A/C heading, vertical pickup, and airborne computer.

In addition to this, Doppler systems installed in helicopters are applied during hovering and landing.

Doppler systems are widely used as part of equipment intended for carrying out soft landing of space vehicles.



a

b

Fig. 5.2

Doppler system operation is based on Doppler effect – received electromagnetic oscillations waves frequency change with respect to frequency of radiated oscillations which emerge at relative movement of the radiation source (transmitter) and receiver or with respect to the reflecting segment.

If the transmitter moving with a speed of W_g (Fig. 5.2) radiates oscillations with a frequency of $f_0 = c / \lambda$ in the direction of movement, they are reflected from the point *A* with the frequency of $f_A = f_0 + W_g / \lambda$, where λ is length of radiated oscillation waves.

In this situation, radiated oscillations frequency turns out to be higher than the frequency of initially radiated oscillations. If the receiver is installed in the aircraft with the transmitter and moves towards the reradiated wave front with the speed of W_g, the frequency of oscillations received after reflection is

$$F_{\text{ref}} = f_{\text{A}} + W_{\text{g}} / \lambda = \left(f_0 + W_{\text{g}} / \lambda\right) + W_{\text{g}} / \lambda .$$

Thus, at the radar echo we receive double Doppler increment of frequency

$$F_{\text{D}} = 2W_{\text{g}} / \lambda .$$

If the reflecting surface is located on the ground at angle β to the flight plane and some distance away at angle θ relative to the flight direction (see Fig. 5.2), the component of rate of closure with the reflecting segment ***S*** is

$$W_{\text{gr}} = W_{\text{g}} \cdot \cos(\beta) \cdot \cos(\theta),$$

where r is radial direction of directional pattern beam to the reflecting segment.

The signal received in this direction will depend on the rate of closure

$$f_{\text{ref}} = f_0 + 2W_{\text{g}} \cdot \cos(\beta) \cdot \cos(\theta) / \lambda ,$$

i.e. it will be twice more than at single-direction propagation of radio waves.

In practice, the aircraft is continuously influenced by wind which leads to the aircraft drift relative to the track at the angle α. In this case, Doppler frequency depends on the value and direction of the drift angle. In this situation

$$F_{\text{D}} = 2W_{\text{g}} \cdot \cos(\beta) \cdot \cos(\theta \pm \alpha) / \lambda .$$

At f_0 frequency oscillations radiation in the direction opposite to the aircraft movement the transmitter output signal has the frequency which is lower than the frequency radiated at the same value of Doppler drift

$$f_{\text{ref}} = f_0 - 2W_{\text{g}} \cdot \cos(\beta) \cdot \cos(\theta \pm \alpha) / \lambda .$$

The formulas given above show that Doppler frequency has information about ground speed and drift angle of the aircraft. In order to determine these values when the values a, θ and β are known, it is necessary to measure F_{D} and solve, for example, the last equation with respect to a and W_{g}. As the matter concerns two unknown values, there appears a need of a system of equations.

When the antenna is stationary, such a system can be obtained by receiving the signals form two symmetric (relative to longitudinal or transverse axis of aircraft) directions, i.e. there is a need of the second beam of antenna directional pattern.

In practice, during electromagnetic oscillations radiation one antenna system is used (one-, two-, three- or four-beam), and during reception - the other with the same quantity of beams. In this situation, the beams of the same name, i.e. DP of transmitting and receiving antennas, are directed to the same reflecting segment on the ground.

The generalized schematic diagram of the single-beam Doppler is shown in Fig. 5.3.

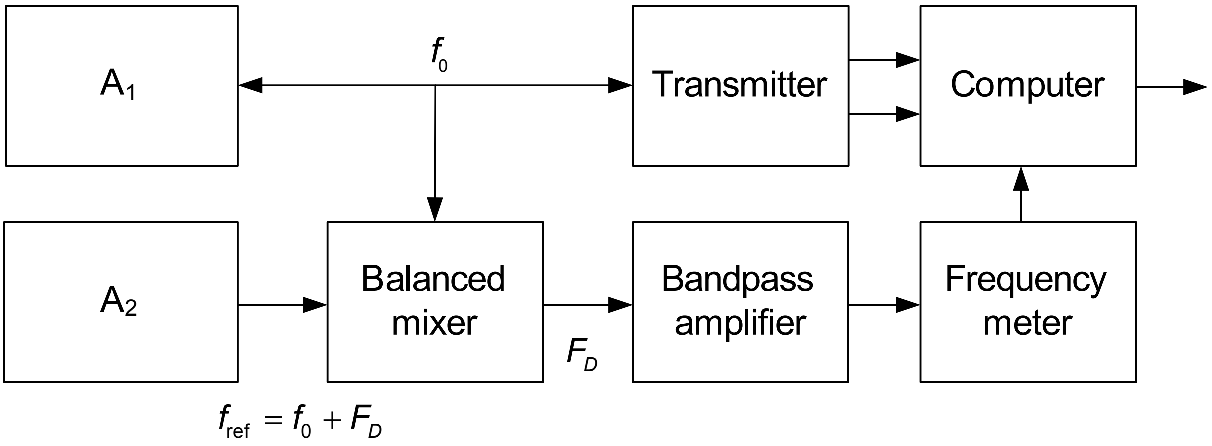


Fig. 5.3

The transmitting antenna A_1 radiates a signal with the frequency f_0 in a particular direction β relative to the aircraft. The signal with the frequency $f_{\text{ref}} = f_0 + F_D$, reflected from the ground is received by the antenna A_2 and passed to the balanced mixer. When radiated and received oscillations are mixed, at the balanced mixer output an oscillation is formed, which frequency is equal to F_D.

After amplifying by the bandpass amplifier the signal of frequency F_D arrives at the frequency meter which performs quantitative estimation of Doppler frequency $U(F_D)$. The voltage proportional to F_D enters the computer, where the value W_g is determined. The computer usually receives information about angles of roll γ and pitch ν.

Drift angle determination is possible, if the antenna system A_1 A_2 can turn relative to the longitudinal axis of the aircraft.

In practice, it is essential to measure three components of the full ground speed vector and the drift angle with the usage of the reception and transmittance antenna system rigidly connected with the aircraft body.

A simplified schematic diagram of multi-beam Doppler is shown in Fig. 5.4.

The antenna device consists of a set of transmitting and receiving antennas, each of which forms four beams. The transceiver operates in the band of centimeter waves and radiates oscillations of various time-frequency structures (continuous, frequency modulated or impulse).

Signal processing device performs detection of Doppler signals $F_{\mathrm{D}i}$ on four beams $i = 1..4$, algorithmic operations and other actions with them. The computer determines three components of the speed W drift angle. Computations results enter the navigation computer and automatic flight control system (AFCS), as well as to the display device.

In civil aviation airplanes including airplanes Tu-134 and Tu-154 Doppler system Doppler-013 is installed.

Doppler-013 is intended for automatic measuring of the ground speed and drift angle of the aircraft in flight over any type of the earth surface (land, sea, sand, ice).

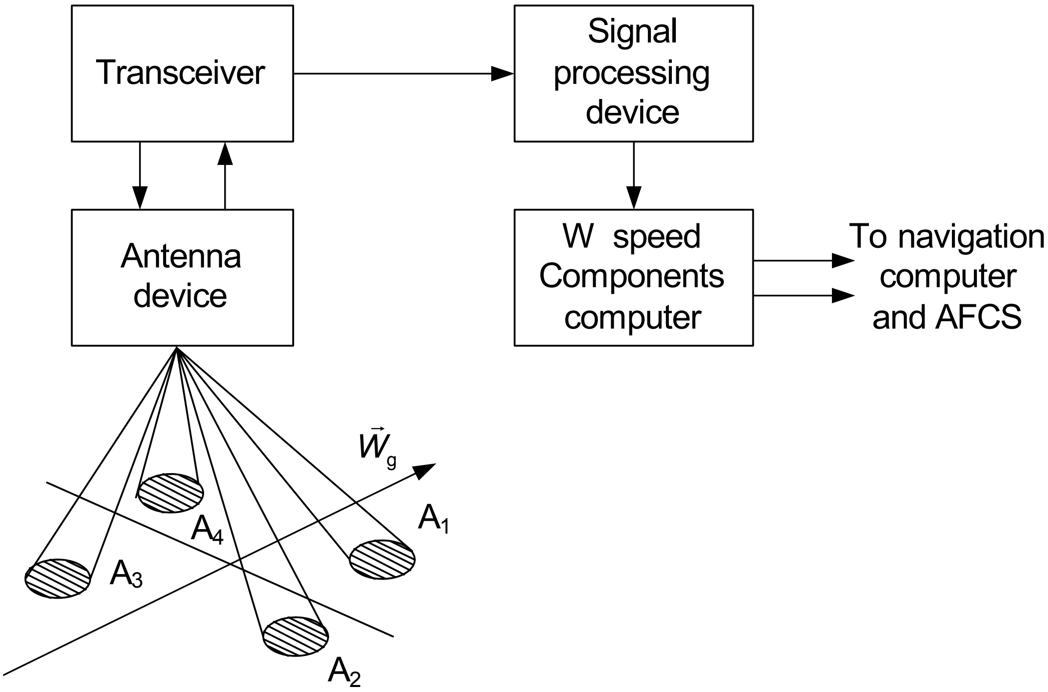


Fig. 5.4

The meter data are used directly by the navigator for navigational provision of flight independently of optical visibility conditions.

There is also provision of continuous dead reckoning relative to the ground and giving of data proportional to the value and aircraft speed of sideward deviation from the great circle course.

Great circle course is a part of a great circle arc, which is obtained by the earth globe section by the plane passing the desired points (for example, points of takeoff T and landing L) and the earth centre. The great circle course is the shortest distance between two points on the earth surface.

Data on the speed W_i components arrive at the autopilot of the automatic flight control system (AFCS) of the aircraft on the desired track.

6. DIRECTION FINDERS (AUTOMATIC DIRECTION FINDERS)

Direction finder is a radio receiving device designed for determining angular direction of electromagnetic waves radiation source.

Direction finding is based on the electromagnetic waves property to propagate with the final speed on the shortest way and on the principles of directed radio receiving.

The direction finder consists of an antenna system having directed properties, a receiver, an information conversion unit and a bearing measurement indicator.

Direction finders were the first radiotechnical devices which found a wide application in civil aviation as angle measurement devices.

Airborne direction finders are called automatic direction finders (ADF). Together with the ground homer they allow fulfilling various tasks of aircraft navigation.

In the simplest case, direction finder operation (determination of angular direction of radiation source) is the directional antenna turn about its vertical axis and registration of the signal level by means of the output indicator.

Bearing is an angle in the horizontal plane between the meridian direction (north or south) passing the antenna location and direction of the radiation source called a ground homer. Bearing measurement is carried out clockwise relative the reference direction.

The signal level registered at the receiver output depends on the type of antenna directional pattern in the plane of direction finding.

Directional pattern (DP) is in the horizontal plane is antenna output signal level dependence on the point radiation source location. Definition of the directional pattern does not change in the case of a stationary point source and antenna moving in the horizontal plane.

The concrete form of DP as a function $F(\theta)$ determines a method of amplitude direction finding of the signal point source.

Direction finders operation is based on three main methods of direction finding.

Method of maximum is implemented by means of DP having one maximum of reception in the azimuth plane.

Block diagram of the direction finder operated according the method of maximum is shown in Fig. 6.1.

At the DP maximum deviation from the direction of the radio station a relative change of voltage registered by the indicator will be the following:

$$m = \Delta u_u / u_{u.\max} = 1 - F(\theta),$$

where $u_{u.\max}$ is indicator output voltage corresponding to the maximal value; $F(\theta)$ is normalized DP.

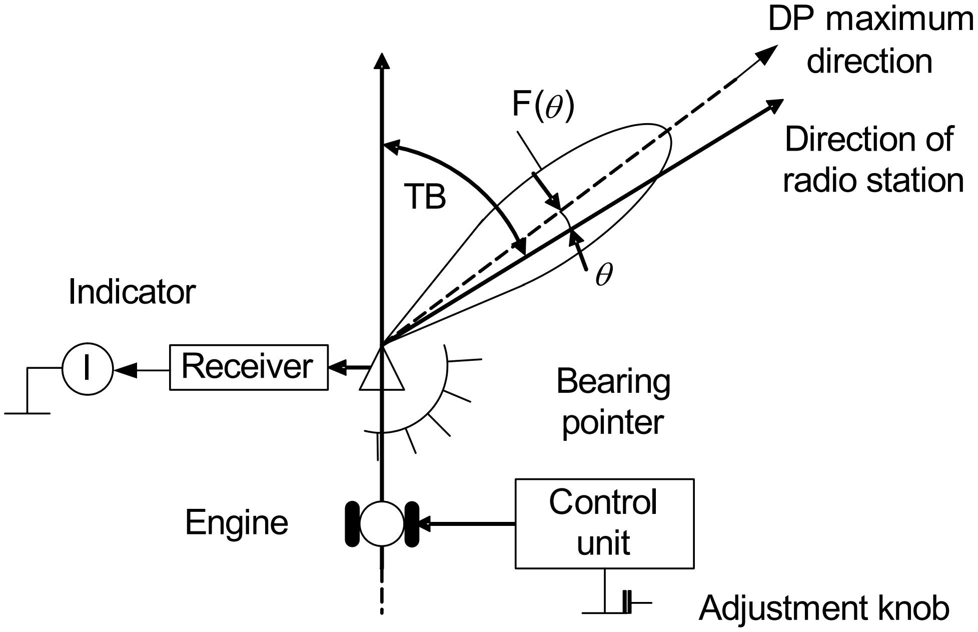


Fig. 6.1

When the antenna turns, the output signal will change. When $u_u = u_{u.\max}$, true bearing (TB) measurement is performed according to the bearing pointer. The antenna turn is carried out by means of the engine and control unit.

Method of minimum is implemented by means of DP having a sharply defined minimum (Fig. 6.2).

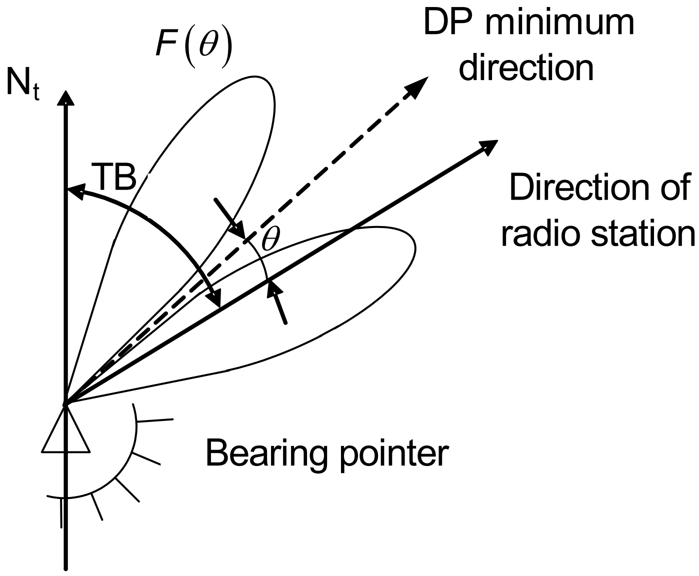


Fig. 6.2

At the turn of the antenna connected to the receiver at the moment $F(\theta)$ true bearing measurement is performed.

Method of comparison is implemented by means of DP having two intersecting directional lobes (Fig. 6.3). DP of this type can be implemented either by using two antennas or one antenna whose orientation from position 1 to position 2 changes periodically.

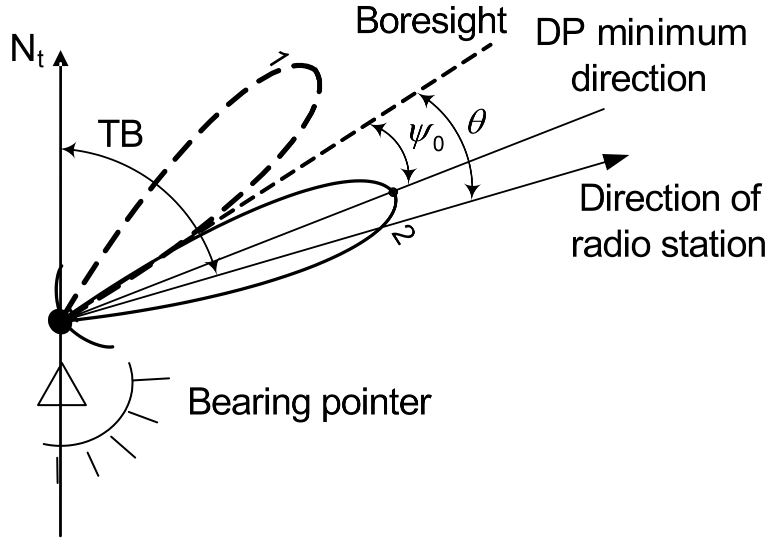


Fig. 6.3

At the turn of the antenna connected to the receiver at the moment $u_{u1} = u_{u2}$ (when signal levels registered by the first and second positions are equal) the bearing measurement is performed.

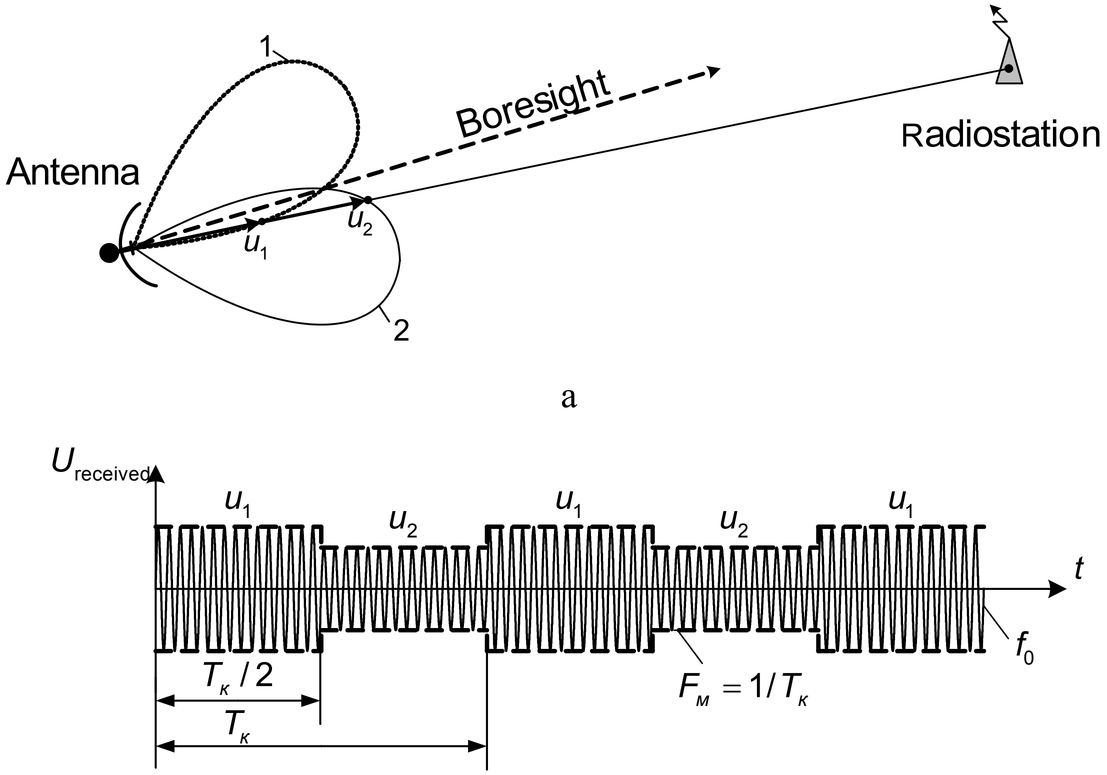
If to observe changes of the signal at the receiver output at random moments of time at switching one-lobe DP from position 1 to position 2 with the desired commutation period T_k, they will have a form shown in Fig. 6.4.

As it is seen in Fig. 6.4, when DP position is random, an amplitude-modulated signal with the modulation frequency $F_M = 1/T_k$ is observed at the receiver input. Such a type of comparison methods is called a method of minimum of modulation depth rate. At $m = 0$ $u_{u1} = u_{u2}$, i.e. a low-frequency signal with the modulation frequency F_M, which is observed at the detection receiver output, becomes a zero.

The present value of the modulation depth rate is determined by the following equation:

$$m = \frac{F(\psi_0 + \theta) - F(\varphi_0 - \theta)}{F(\varphi_0 - \theta) + F(\psi_0 + \theta)} = \frac{F'(\psi_0)}{F(\psi_0)} = M_{\text{bearing}}\theta ,$$

where ψ_0 is an angle between DP maximum direction and equipotential direction; $F'(\psi_0)$ is an derivative from DP in the point ψ_0, $F(\psi_0)$ is a value in the point of maximum; M_{bearing} is a bearing scale.



a

b

Fig. 6.4

Practical implementation of the antenna DP with the required spatial characteristics depends on the operating frequency band of sources, whose bearings are taken.

Airborne amplitude direction finders mainly function in the band of hectometer waves (long and medium waves; $f_{\min}$ = 100…300 kHz; $f_{\max}$ = 1,4…1,6 MHz).

In this band multi-turn loop antennas are used and their combination with a non-directional antenna, geometric dimensions of a turn being much smaller than the length of the signal received.

Normalized DP of the loop antenna in the plane of direction finding is figure-of-eight (Fig. 6.5).

The signal at the loop antenna output, which is received from the point source radiated by the non-directional antenna, has several peculiarities.

If a harmonic signal source is to the right of the reception minimum direction, the phase of the high-frequency signal at the loop antenna output coincides with the signal source phase.

If a signal source is to the left of the minimum direction, the phase of the high-frequency signal at the loop antenna output changes unevenly by 180°. In Fig. 6.5 the right lobe is marked "+", as $\varphi = 0$, and the left one is marked "-", as $\varphi = 180$.

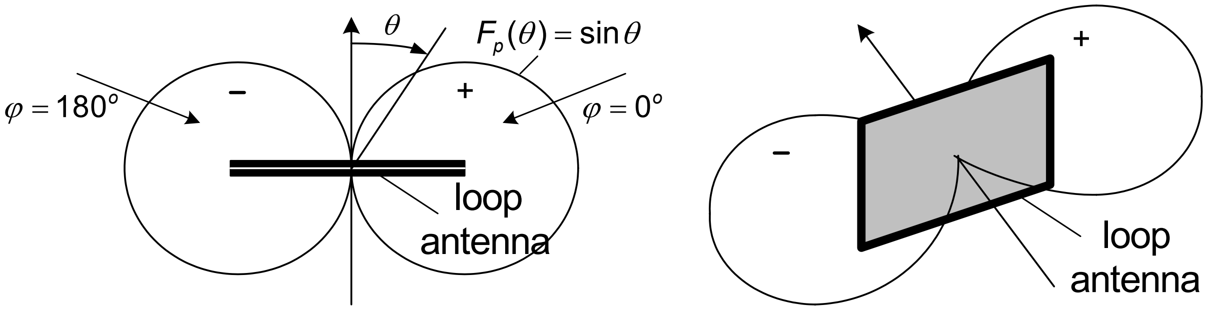


Fig. 6.5

The vector of the resulting voltage u_r at the loop antenna output is shifted by 90° relative to the vector of the signal radiated by the point source. In a common case, the resulting voltage at the output of the multi-turn loop antenna, which is provided with a ferromagnetic core, is equal to

$$u_r = (2\pi S_l N \mu E_0 / \lambda)\sin\theta\cos\omega_0 t,$$

where S_l is an area of one turn of the loop antenna, N is a number of turns, E_0 is field intensity in the loop antenna centre, λ is a length of operating frequency, μ is magnetic conductivity of the core.

Normalized DP of the combined antenna (a geometric sum of normalized DP of loop and non-directional antennas) can be written in the following form

$$F(\theta, \varphi, A) = \sqrt{1 + A^2\sin^2\theta + 2A\sin\theta\cdot\cos\varphi},$$

where $A = E_{po} / E_{ao}$ is a ratio of amplitudes of signals at the output of loop E_{po} and non-directional E_{ao} antennas, φ is phase displacement of signals received by the loop and non-directional antennas.

Let us discuss the simplest example of building a resulting DP of the combined antenna at $A = 1$ and $\varphi = 0$ (Fig. 6.6).

The resulting DP is called a cardioid. It has one minimum and one maximum. At the values $A \neq 1$ its shape differs from the shape of the cardioid.

If $\varphi = 180^\circ$, the resulting DP has a form

$$F(\theta) = 1 - A\cdot\sin\theta,$$

which is equivalent to the cardioid turn by 180° (see Fig. 6.6).

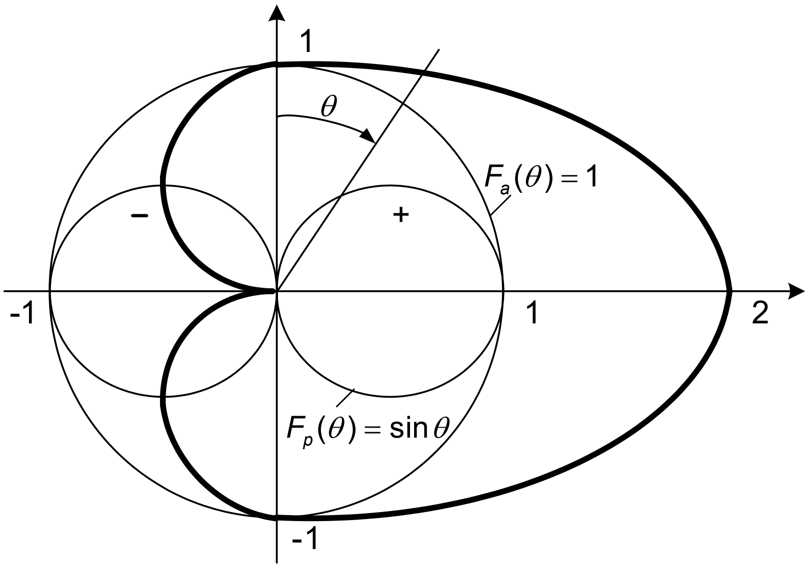


Fig. 6.6

The direction finder operation is provided due to mechanical rotation of the loop antenna, which is performed by means of electric actuator or manual drive. This creates certain difficulties during both the drive or actuator operation which do not cause any errors in the measured angular coordinate and installation of the loop antenna itself in the aircraft body.

Now let us study the operation principle of the automatic direction finder.

Automatic direction finder (ADF) represents an airborne automatic amplitude direction finder intended for measuring a relative bearing (RB).

RB is an angle in the horizontal plane between the projection of the A/C longitudinal axis and direction of the locator beacon, which is measured clockwise.

ADF operation principle is based on the application of the method of minimum of modulation depth rate, method of comparison of amplitudes of high-frequency signal received by the switching DP lobe of the cardioid type. In this case, information about the side of the radio station deviation from the equipotential direction corresponding to minimum of modulation depth rate, is received at comparison of low-frequency signal phases (switching and informational signals at the receiver amplitude detector output).

To describe ADF operation we use a simplified functional diagram presented in Fig. 6.7.

We write voltages at outputs of the loop and non-directional antennas in the following way:

$$u_a = E_{a0} k_a \sin \omega_0 t; \qquad u_p = E_{p0} k_p \cos \omega_0 t,$$

where k_a and k_p are transmittance rates of non-directional and loop antennas. Further we assume that $k_a = k_p = 1$.

Form the loop antenna output the voltage is applied to the amplifier with a phasing loop and determined by means of the following equation:

$$u'_p = E_0 \sin \omega_0 t .$$

The amplifier with the phasing loop is connected with the phase switchboard which gives synphased $\varphi = 0^\circ$ and antiphased $\varphi = 180^\circ$ high-frequency voltages at the output in the first and second halves of the switching period

$$u_{\text{ps}} = E_0 \sin\theta \sin\Omega_k \sin\omega_0 t .$$

The voltage from the phase switchboard output is added to the voltage u_a at the receiver input in the loop of addition, then

$$u_\Sigma = u_{\text{ps}} + u_a = E_{a0}\left(1 + m \sin\theta \sin\Omega_k t\right).$$

Thus, we receive an amplitude-modulated signal with the amplitude modulation depth rate $m = E_{po} / E_{ao}$.

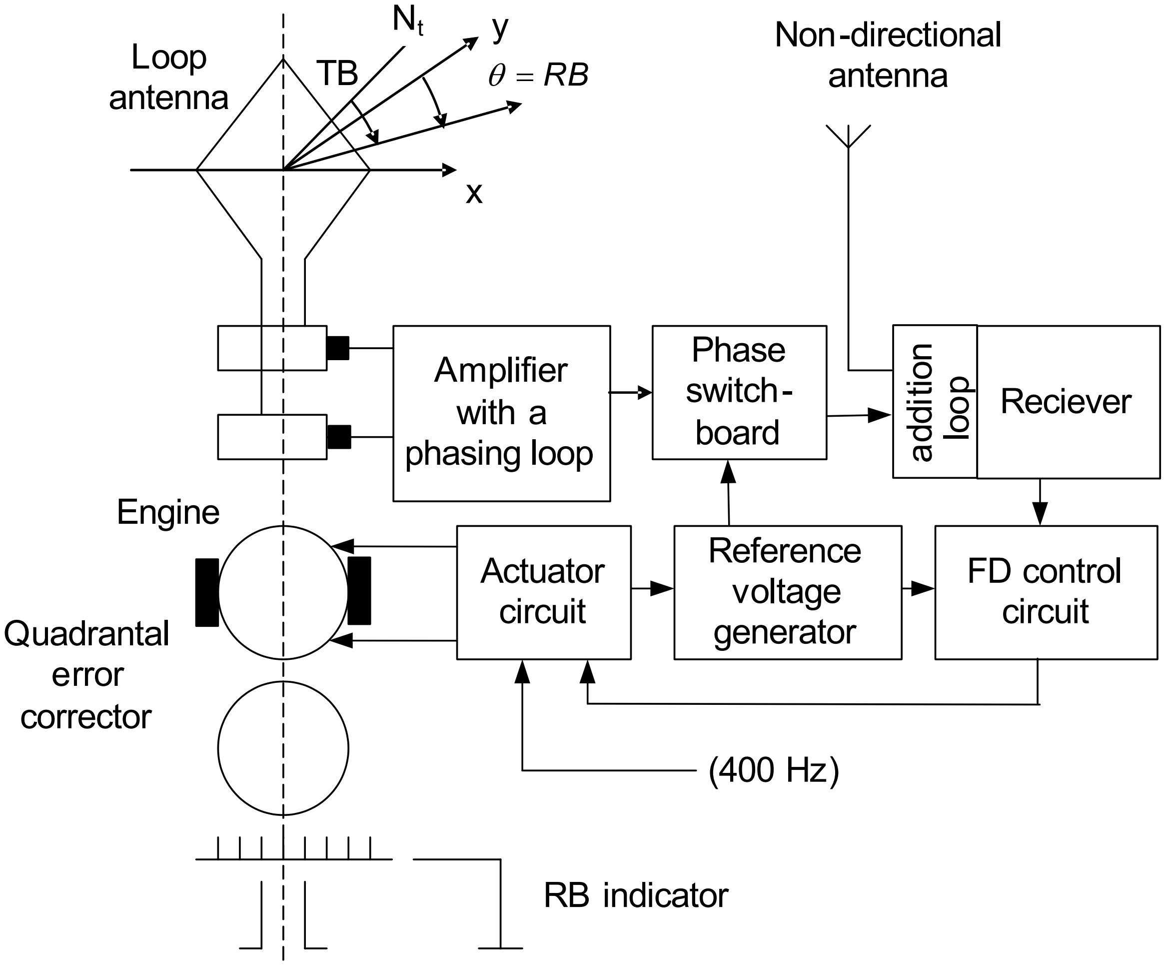


Fig. 6.7

Taking into account a switching phase we write normalized directional patterns in the first and second half-period:

$$F_1(\theta) = [1 + m\sin\theta] / (1 + m),$$

$$F_2(\theta) = [1 - m\sin\theta] / (1 + m).$$

At $m = 1$ the normalized DP $F_1(\theta)$ will be the cardioid, and in the second period the normalized DP $F_2(\theta)$ will also be the cardioid, but it will be thrown over in space by 180°.

This throwing over will provide modulation of the input signal of the receiver with the switching frequency determined by a reference voltage generator (RVG).

At the receiver output after detecting a frequency envelope voltage $F_k = 1 / T_k$ is formed. This voltage can coincide in the phase with the reference voltage or be in the antiphase with it. This depends on which side relative to the equipotential direction the radiostation is situated.

The result of comparing these signals by their phase at the control circuit output has the following form:

$$u_{\text{cc}} = u_{\text{fd}} = ku_0 \left|\sin\theta\right| \cos\varphi_{\text{d}},$$

where φ_{d} is a difference of phases between LF-signals and RVG.

If $\varphi_{\text{d}} = 0$, the sign of the voltage u_{cc} is positive. If $\varphi_{\text{d}} = 180$, the sign of the voltage u_{cc} is negative.

The actuator circuit operates in such a way that the engine rotation direction is determined by the sign of u_{cc}, and speed – by the value of this signal .

At $\theta = 0$ the engine rotor stops, and DP of the loop antenna is set by the minimum to the direction being taken.

The loop axis has an electromechanical or mechanical quadrantal error corrector which provides correction of the angular error of RB determination, which was caused by the loop antenna DP distortions.

At present the main type of ADF installed in heavy and medium-weight airplanes of civil aviation is APK-15. In small airplanes and helicopters compact AFD are installed, which have a lighter weight and lower power consumption, but worse technical characteristics.

At the input of APK-15 a goniometric antenna is installed. The antenna itself has two main loops wound on the ferrite bar transversely to each other. The main type of type of the loop antenna has dimensions 75×214×440 mm and weight ~ 2.5 kg.

The loop antenna is placed in the shield and hollow in the fuselage skin near the electrical centre of A/C at the distance not less than 1 m from the protruding parts of the A/C design. The hollow is closed by a radio transparent cover.

The non-directional antenna can have various designs depending on the A/C type. The antenna is installed at the distance of 1 m from the protruding parts of A/C. The antenna matching device is placed at the distance of more than 200 mm from the antenna input. The length of the connecting cable can reach 20 m.

The rest of the units, which are a high-frequency unit (HFU), intermediate frequency unit (IFU), low-frequency unit (LFU) and frequency synthesizer of ADF tuning, are installed on shock-absorbing frames in metal cases meeting the requirements of electrical safety and electromagnetic compatibility.

ADF control panel is installed on the pilot’s and navigator’s instrument panels.

7. RADIO BEACON LANDING SYSTEMS

Radiotechnical landing systems (LS) of aircraft which are also called instrument landing systems, are based on the application of ground and airborne RND supplemented with lighting technical means marking a runway (RW), as well as with necessary control equipment.

The main part of ground equipment of LS is radio beacons designed for providing the crew and A/C control systems with the information used during the approach to landing. Radio beacon landing systems were originally used in favourable conditions of RW visibility. However, since 1963, on the international scale, radio beacon LS application in any weather conditions was accepted. Systems of the first, second and third categories are distinguished. Such classification is recommended by the International Civil Aviation Organization (ICAO).

Systems of the first category provide airplane control during the approach to landing up to the altitude of 60 m over the earth surface, when the RW visibility is not less than 800 m; systems of the second category have two times smaller values of characteristics: 30 m altitude and 400 m visibility; the third category systems (A) provide aircraft control up to zero altitude at the RW visibility 200 m , the third category systems (B) provide aircraft control up to zero altitude at the RW visibility 50 m, the third category systems (C) provide aircraft control at complete invisibility of RW.

The main equipment of LS provides reception of continuous information about A/C attitude relative to the desired heading direction (yaw channel), descent flight pass (glide slope channel) and periodical information in two or three points about the distance to the RW beginning from the side of approach (marker channel).

Heading channel (HC) consists of a ground radiotechnical device radiating signals, which have information for A/C crew orientation in the horizontal plane during the approach performance; localizer (LOC); airborne LOC signal receiving device – localizer receiver (LOC R) and indicating device – heading indicator (HI).

Glide slope channel (GSC) consists of a ground radiotechnical device radiating signals, which have information for A/C crew orientation in the vertical plane during the approach performance; glide slope beacon (GSB) - glide slope receiver and indicating device - glide slope indicator (GSI).

Marker channel (MC) contains a ground radiotechnical device radiating coded signals: marker (M), airborne M signal receiving device – marker receiver and marker code indicators (MCI).

The LS system set also contains simulators, testers and auxiliary equipment.

Characteristics of radio beacons are determined by antenna directional patterns to a significant degree. The most wide-spread are LS, whose radio beacons operate in the metric and decimeter wavebands and have stationary DP. LS with switching DP are also applied in the decimeter band. The most prospective are LS with scanning DP, however, their practical usage is reasonable only in the centimeter band. Localizers and glide slope beacons of LS, which have stationary antennas, belong to amplitude RND with fixing the direction according to the received signal modulation depth minimum or according to the equality of depths of signal modulation by two voltages with different frequencies.

According to safety measures LOC and GSB are installed at a certain distance from RW: LOC is installed exactly on the continuation of the RW axis at the distance 400…1100 m from the RW end (threshold) which is opposite to the side of approach; GSB is usually placed on the side opposite to the air traffic control tower (ATCT) and shifted by 200…450 m from the RW beginning (depending ton the selected glide slope angle) and by 120…180 m from the RW axis. Markers are placed on the continuation of the RW axis; the outer marker (OM) and middle marker (MM) are normally placed in outer and inner locators. The inner marker (IM) is placed at the distance about 75 m from the RW beginning. If the runway has directions of landing, the second set of similar radio beacons must be installed, whose location is symmetric to the location of corresponding radio beacons of the first set.

An example of beacons location relative to RW is shown in Fig. 7.1.

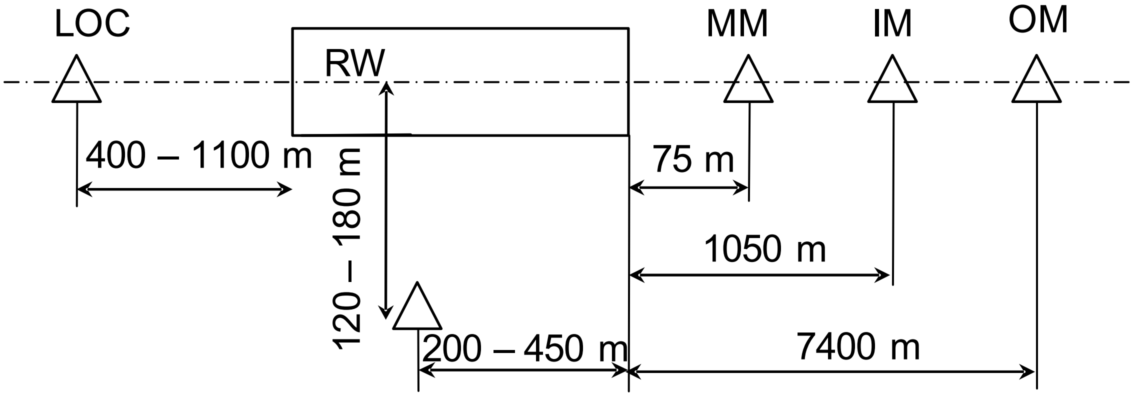


Fig. 7.1

The localizer and glide slope beacon of the system continuously provide selection of the plane of heading which passes the RW axis, and glide plane, their intersection gives a glide line (glide slope) or inclined heading line making a glide angle (glide slope angle) together with the horizontal plane.

At the first stage the aircraft is rolled out to the direction of landing and the motion along this path is provided (i.e. in the vertical plane passing the RW axis) with the subsequent switch to the descent condition at entering the area of the glide slope beacon operation. The second stage is descent along the landing direction till the altitude of making a decision about landing.

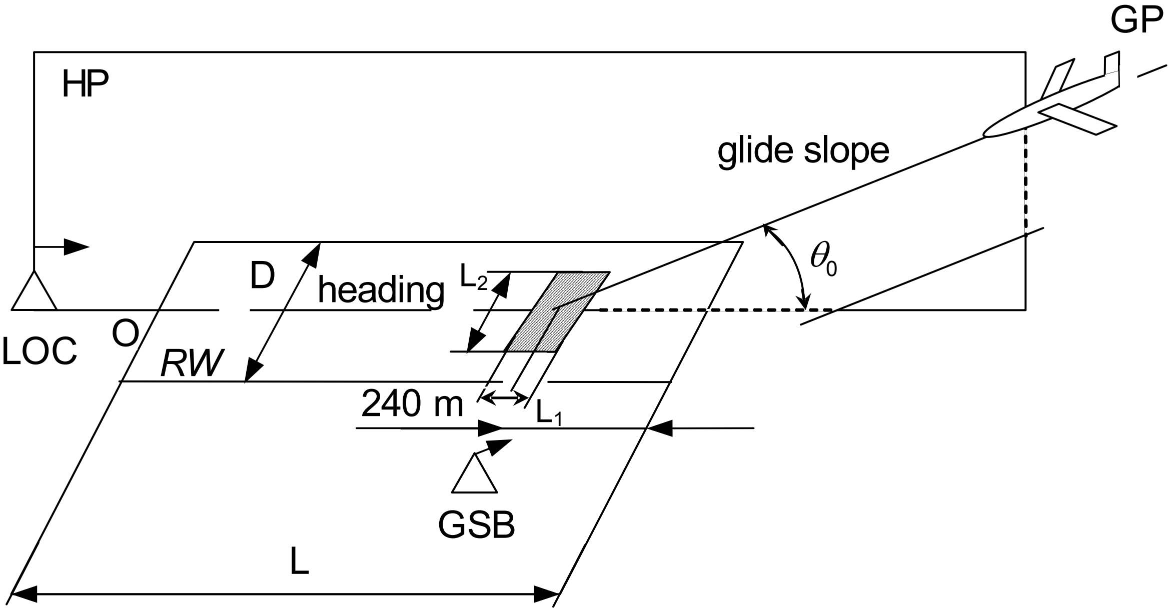


Fig. 7.2

At the third (final) stage of landing the motion along the glide slope continues with obligatory visual orientation and subsequent landing in the area of the control point which determines the optimal place of landing on the given RW. In Fig. 7.2 (L=(1800…3000) m; D=(60…100) m; $0.5L_1$=(5…7) m; $0.5L_2$=(8…18) m) the area of acceptable points of landing is hatched. Linear shift of the point of landing from the RW axis must be within 30% of RW width.

All presently known types of radio beacon landing systems can be divided into three groups: landing systems (LS) with stationary, switching and scanning DP.

Radio beacons of LS with stationary DP operate in the metric waveband. Landing systems whose radio beacons have switching ADP operate in the centimeter waveband (LSCB). They include a localizer, glide slope beacon and distance measuring equipment.

Operation principle and equipment composition of the radio beacon LS heading channel. Classification of localizer design principles can be made by a method of selecting a direction of radiation.

All known and widely applied localizers are equisignal. Localizers of the first category systems are created on the basis of a classical equisignal method.

Let us discuss the localizer operation with the usage of the equisignal method. The LOC antenna system consists of two antennas A_1 and A_2 symmetrically diversed relative to the desired direction (Fig. 7.3). Antennas are fed by synphased amplitude-modulated oscillations (with frequencies 90 and 150 Hz).

Antenna A_1 radiates an amplitude-modulated oscillation

$$I_1 = E_{10} F_1(\Theta)(1 + m_1 \sin \Omega_1 t) \sin \omega_0 t\,,$$

and antenna A_2 –

$$I_2 = E_{20} F_2(\Theta)(1 + m_2 \sin \Omega_2 t) \sin \omega_0 t\,.$$

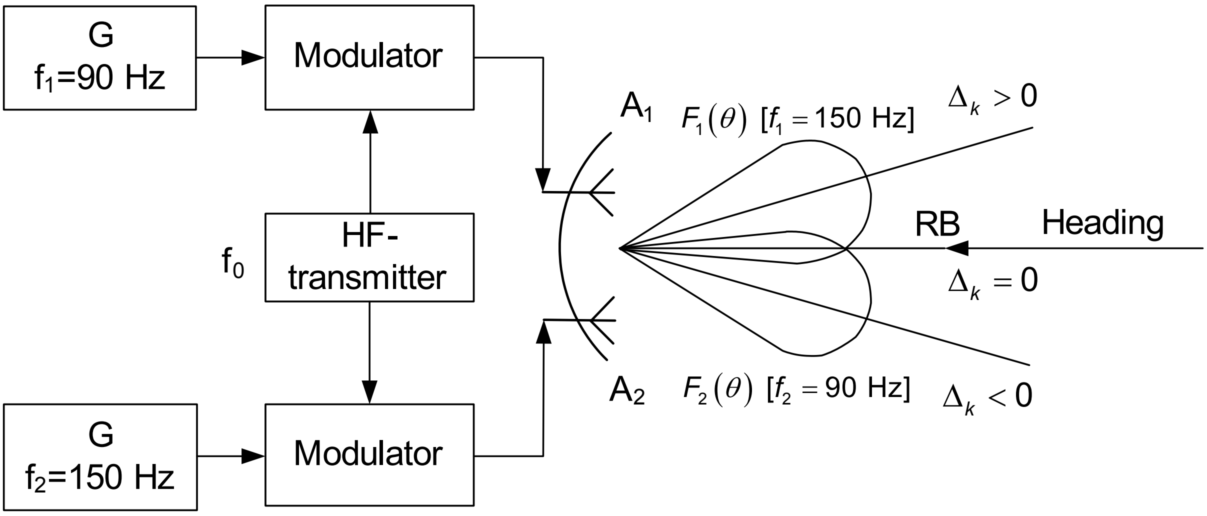


Fig. 7.3

In the given equations E_{10} and E_{20} are radiation field intensity amplitudes of the first and second antennas in the directions of maximums; $F_1(\theta)$, $F_2(\theta)$ are characteristics of antennas directional patterns in the horizontal plane; $\Omega_1 = 2\pi \cdot f_1$, $\Omega_2 = 2\pi \cdot f_2$, $\omega_0 = 2\pi \cdot f_0$ are modulation depth rates in the channels. Usually $m_1 = m_2 = m$ and $E_{10} = E_{20} = E_0$. Total radiation field is

$$I = I_1 + I_2 = E_0 \cdot \left[F_1(\Theta) + F_2(\Theta)\right] \cdot \left[1 + M_1(\Theta) \cdot \sin \Omega_1 t + M_2(\Theta) \cdot \sin \Omega_2 t\right] \sin \omega_0 t\,,$$

where $M_1(\Theta)$ and $M_2(\Theta)$ are rates of space modulation depth:

$$M_1(\Theta) = \frac{m F_1(\Theta)}{F_1(\Theta) + F_2(\Theta)}\,,\ M_2(\Theta) = \frac{m F_2(\Theta)}{F_1(\Theta) + F_2(\Theta)}\,.$$

The airborne receiver (Fig. 7.4) interacting with the signals of the given localizer contains a channel of amplification, conversion and detection of a high-frequency signal, and further a path of difference calculation goes

$$\Delta_k = M_1(\theta) - M_2(\theta)$$

which consists of separating filters (F) 90 and 150 Hz, rectifiers (R) and a circuit of subtracting the rectifiers currents in the coil circuit of the electromagnetic pointer indicator of the aircraft attitude relative to the heading plane (pointer indicator of landing PIL).

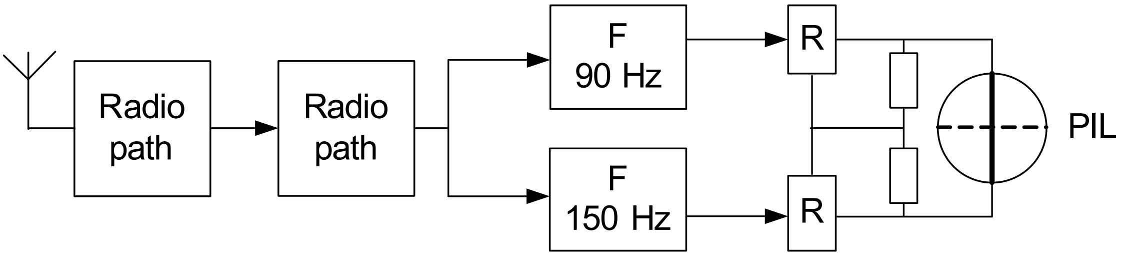


Fig. 7.4

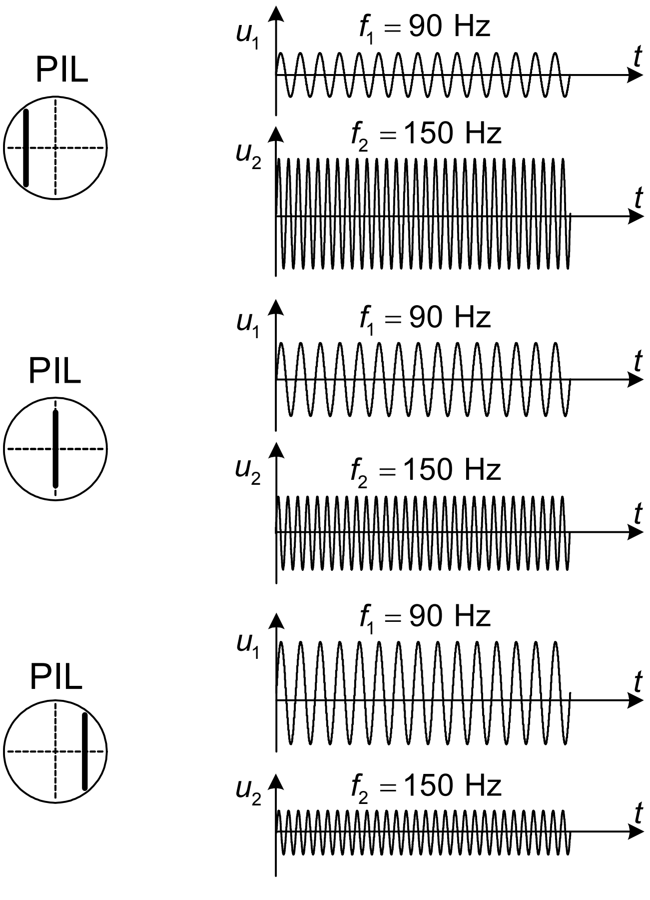


Fig. 7.5

The heading line is located in the direction Θ_0, i.e. along the line of intersection of two directional patterns. At $\Theta = \Theta_0$, $\Delta_k = 0$ and $F_1(\Theta) = F_2(\Theta)$, i.e. in this direction the levels of the signals radiated by antennas A_1 and A_2 are equal. Hence, voltages levels at the outputs of the rectifiers are also equal, and their difference is zero. This means that the aircraft is in the heading plane (on the heading line $\Theta = \Theta_0$).

If the aircraft deviates from the heading plane to this or that side, there occurs a violation of equality of the signals received from antennas A_1 and A_2. In this case, $\Delta_k > 0$, if $M_1(\Theta) > M_2(\Theta)$, and $\Delta_k < 0$, if $M_1(\Theta) < M_2(\Theta)$.

Fig. 7.5 shows ratios of low-frequency levels 90 and 150 Hz at $\Delta_k = 0$, $\Delta_k > 0$ and $\Delta_k < 0$, as well as a position of the PIL pointer by which the aircraft attitude relative to the heading plane is controlled.

8. REE OF A/C AIR TRAFFIC CONTROL

Air traffic control (ATC) with the help of command radio communication stopped meeting the aviation needs long ago. Additional usage of ground radars of air situation survey and navigation complex of SRNS type for this purpose did not solve many tasks of ATC.

Thus, information about an aircraft registration number, its flight altitude, fuel quantity was still to obtain by command radio communication channels. At intensive flights air traffic controller's orientation in such conditions turns out to be not fast enough, tasks of increasing safety and popularity of flights are not completely fulfilled.

One of the main tasks of ATC is A/C collision avoidance. Fulfillment of this task is based on the usage of secondary radar systems and systems of A/C collision avoidance.

Secondary radar (SR) is a ground complex of technical facilities, which is intended for determining A/C coordinates and their individual identification by the methods of secondary radar detection.

SR performs a function of an interrogator in the active radar detection system with active response. By SR response signal we determine a slant range and ASV azimuth, and from the coded signal of response we allocate information about the aircraft registration number, flight altitude, fuel quantity and other data. SR operation range makes up 400 km for synchronizing SR, and 100 km for airport SR.

SR design (Fig. 8.1) represents a radar with active response.

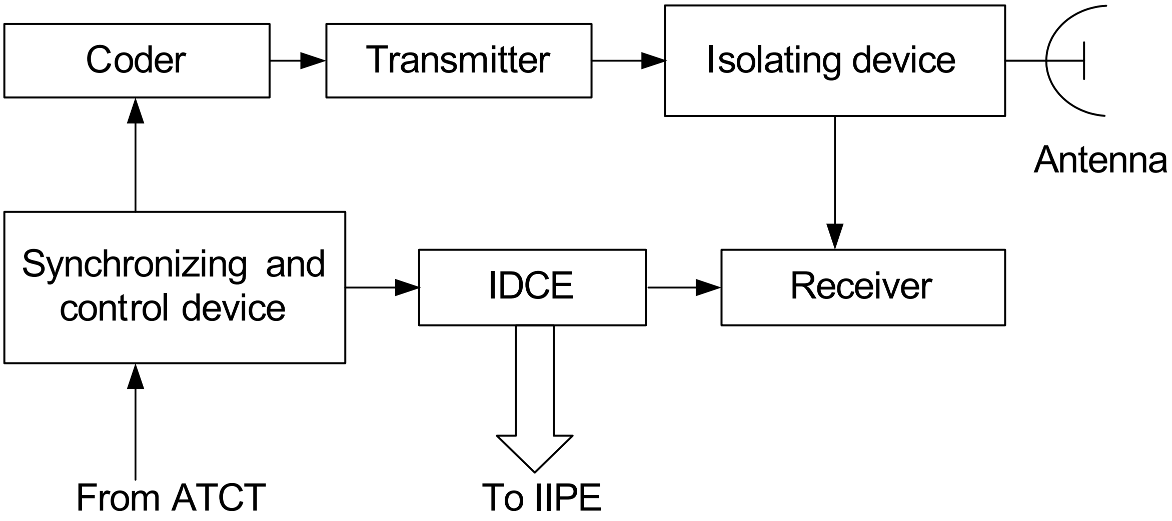


Fig. 8.1

Application of an active mode with active response allows increasing SR operation range at the desired power generated by the transmitter and desired sensitivity of the receiver, and the main thing – obtaining information from ASV, which is necessary for ATC.

The synchronizing signal generated in the synchronizing and control device drives the coder which gives an interrogation code. A code format is determined by the SR system type and concrete SR mode desired from the air traffic control tower (ATCT).

The obtained code is used for impulse modulation of the transmitter. From the transmitter output through the isolating device having crosspoints and isolation elements the signal with the increased power arrives at the antenna and is radiated to space.

ASV response signal is received by the same antenna, processed by the receiver and after detection arrives at the information decoding and converting equipment (IDCE).

From IDCE output the digital code having ASV data with eliminated interferences arrives at the information initial processing equipment (IIPE) of ATC system.

Part of the information enters IIPE in an analogue form, where it is converted into a television signal. In such a form the response information enters display equipment including video displays with special multibeam tubes and a quite big screen.

A coordinate scale in the polar coordinate system (radial and circular lines) appears on the display screen by means of line and code screening. Luminance image of air situation panorama is formed on the screen. Aircraft being in the SR service area appear on the screen as luminance square marks (1) with a movement direction lead vector (2). The mark position gives information about range and azimuth. The lead vector allows avoiding ASV collision. The mark form represent a set of figures and letters visually informing the controller about the registration number (5) or flight number (6), present flight altitude (7), minutes of the current hour (4), area designation (3), landing airport index (9), desired flight altitude (8), response sign (10), etc.

The transponder function failure at the absence of the response to the interrogation is marked in the form by special signs (10). A letter near a luminance mark indicates a sign of a tactical area, for example, M is an approach area, K is a circle area, etc.

The transponder installed in ASV is a radio transmitter tuned to SR operating frequency and generating response signals, when it receives an interrogation signal from SR. The response signal is formed on the base of data received from ASV airborne systems, depending on the interrogation signal content.

The response signal differs from the interrogation signal in the carrying frequency and type of the code. SSR signals represent coding of impulses group. The type of coding is determined by the type of the system. The countries of CIS use ATC code. Foreign countries operate with RBS code.

ASV signal of response to SR interrogation consists of two parts: a coordinate part which allows determining range and azimuth on the controller display screen, and an informational part displaying information transmitted from ASV about the registration number, flight altitude, fuel quantity, etc.

SSR types differ in their kind and informativity of codes, as well as in the value of carrying frequency of interrogation and response signals.

The countries of CIS apply the secondary radar detection system developed in the USSR. Foreign airlines use ATC RBS international system which is not compatible in the frequency band and code type with the system used in CIS.

A discrete-addressing system DABS is prospective. The distinctive feature of DABS system is the fact that each ASV is given an address code allocated for it. SR interrogation is answered only by the transponder, which a sending interrogation code corresponds to.

The system uses more complicated codes of signals of interrogation and response, however, the code is formed in such a way that ground SR of DABS system should provide interrogation of ASV equipped with ordinary transponders, and DABS transponder should respond to interrogators of ATC RBS system.

Collision-avoidance systems (CAS) operate independently of ATC system. The simplest CAS are designed for performing only vertical maneuvers at ASV passing relative to each other.

According to ICAO recommendations (International Civil Aviation Organization), a frequency band 1592.5…1622.5 MHz is allocated for CAS.

CAS contains airborne equipment performing a function of giving commands to the crew to perform a maneuver of deviation from a probable dangerous approach to other ASV. CAS equipment of all ASV is similar.

9. DESIGN AND OPERATION PRINCIPLES OF A/C COMMUNICATION EQUIPMENT

Purpose of A/C communication equipment is conducting talks between A/C crews and ground services of various ATC areas (emergency radio channel); providing talks between crew members; informing and servicing passengers on inner A/C wire communication lines and carrying out the crew talks recording (magnetic recording channel).

At present single-channel aviation communication systems are used.

Communication channel is a combination of technical facilities and medium, which serve for message transmittance.

General requirements for radio communication means come to provision of fast, instant selection and two-way radio communication.

Two-way radio communication is radio communication at which reception and transmittance are carried out simultaneously.

Simplex operation is two-way radio communication at which reception and transmittance are carried out in turn.

Time of radio station switching from the mode “Reception” to the mode “Transmittance” and back must not exceed 0.5 sec. Radio stations must operate uninterruptedly during 24 hours at the ratio of operation time in the mode “Reception” and the mode “Transmittance” 4:1.

Types of aircraft radio stations differ in their purpose, operating frequency bands, radiation class, i.e. type of the radiated signal modulation. All airborne radio stations are of simplex operation.

There are radio stations of long-range communication, short-range communication and emergency radio stations. Long-range communication radio stations (LRCR) provide communication between ASV and ATC controllers at distances exceeding direct visibility distance, and are used at ranges of more than 1000 km. They operate in the band of hectomillimeter λ=100…1000 m and decameter $\lambda = 10...100$ m waves. Modulation mode is amplitude (ordinary or single-band modulation). As a rule, aural (telephone mode) or telegraph signals are used.

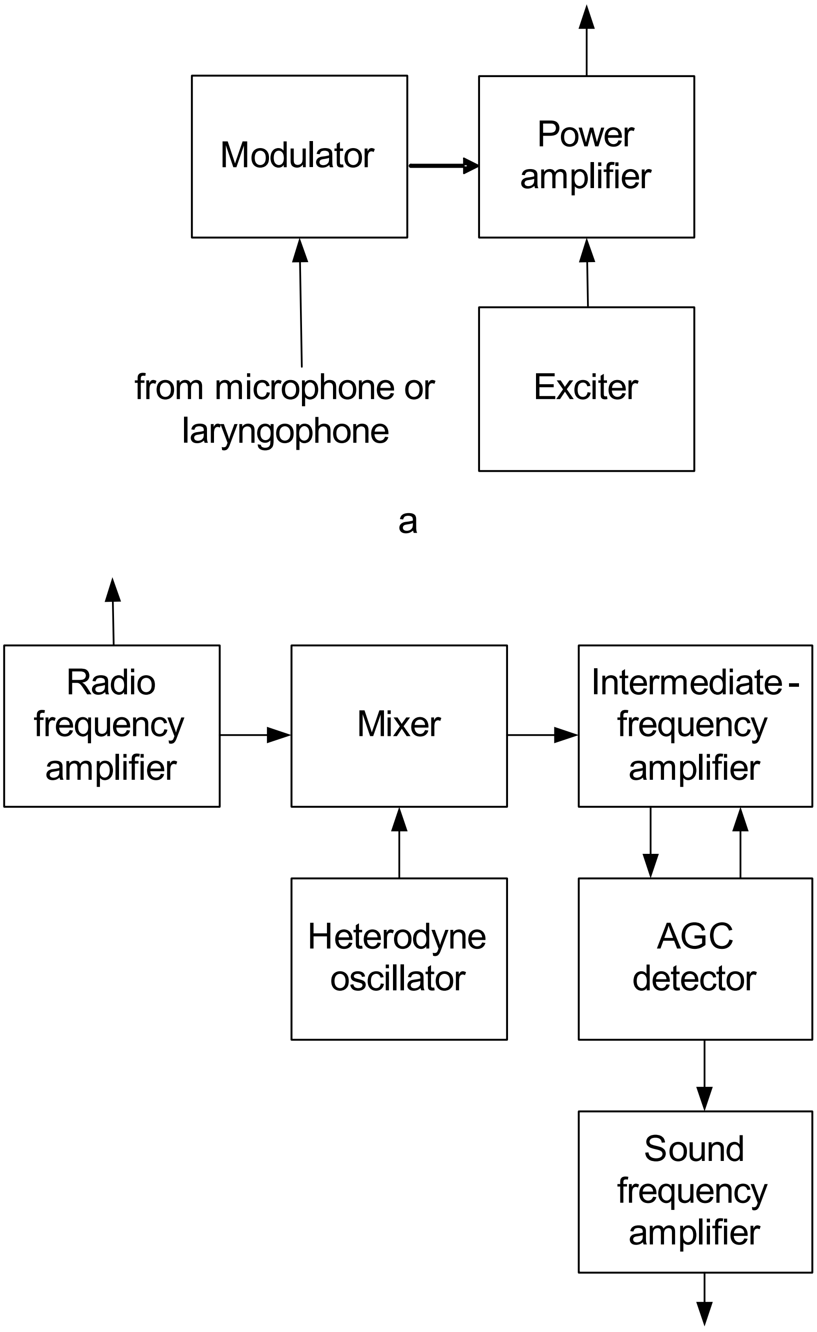
A block diagram of communication channel with amplitude modulation is shown in Fig. 9.1.

Short-range communication radio stations (SRCR) provide visibility and operate in the band of metric and decimeter waves ($\lambda = 1...10$ m, $\lambda = 0.1...1$ m). In SRCR only telephone mode and amplitude modulation are used.

Emergency radio stations operate in the simplex mode and are intended for transmitting distress signals and communication with ASV which crashed and ground control centres with rescue facilities. They operate on fixed frequencies: 2.182, 4.364, 8.364, 121, 5.243 MHz.

Modulation type determines design of the transmitter and receiver, as well as parameters of the radio station as a whole.

Ordinary amplitude modulation (AM) is carried out by means of the transmitter shown in Fig. 9.1, a.



a

b

Fig. 9.1

Low-frequency electrical signal (Fig. 9.2) from the microphone arrives at the modulator which is intended for amplifying this signal and controlling parameters of the power amplifier of the high-frequency signal coming from the exciter (high-frequency oscillation generator). As a result, amplitude of high-frequency oscillations entering the antenna changes in accordance with the law of low-frequency signal change:

$$u(t) = E_0\left[1 + mf(t)\right]\cos\omega_0 t,$$

where E_0 is an average value of the signal; m is AM depth rate; $f(t)$ is low-frequency modulating function (low-frequency signal).

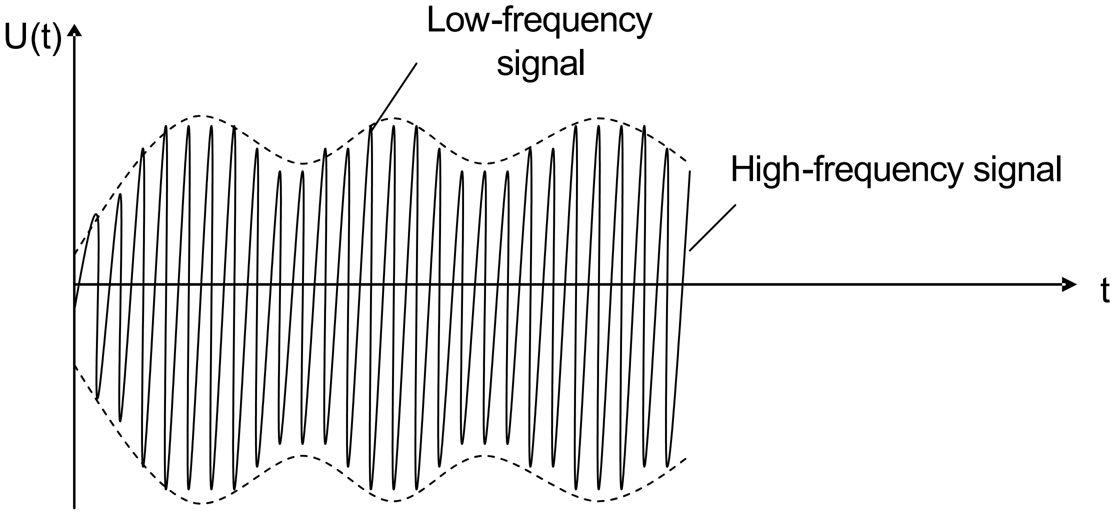


Fig. 9.2

The receiver of the ordinary AM signal shown in Fig. 9.1, b is designed according to a superheterodyne scheme which includes the following:

- a frequency amplifier intended for amplifying a weak signal which passed the propagation medium;
- a mixer which mixes a signal from radio frequency amplifier (RFA) output with a signal of a local generator called a heterodyne oscillator; as a result, the signal frequency from the RFA output is reduced to intermediate $f_{\text{RFA}} = f_{\text{RFA}} - f_{\text{G}}$.

The main amplification of AM signal is carried out by means of an intermediate frequency amplifier, and the envelope (low-frequency signal) remains the same.

Further, by means of the amplitude detector a low-frequency signal is allocated, which is amplified by the amplifier of the sound frequency and enters earphones.

Automatic gain control changes intermediate-frequency amplifier (IFA) amplification, and sometimes high-frequency amplifier (HFA), in such a way that an average level of IFA output signal should remain constant at a significant change of RFA input signal.

The spectrum of an ordinary AM signal has a form shown in Fig. 9.3.

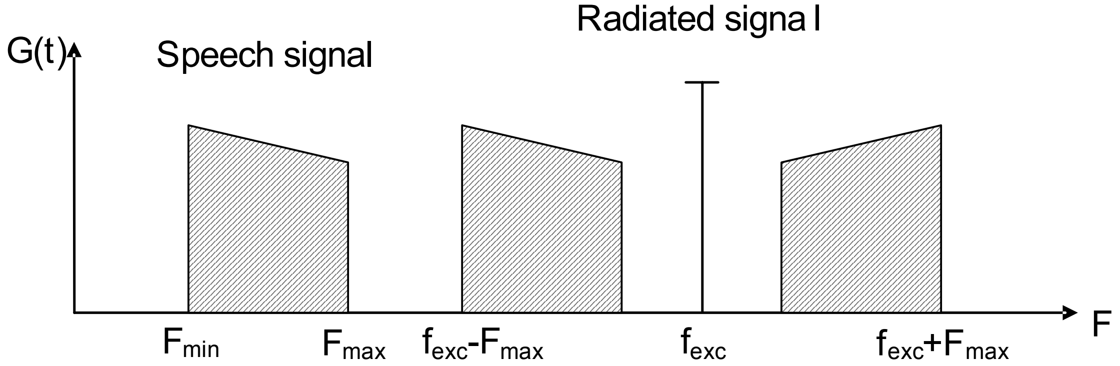


Fig. 9.3

As it is shown in Fig. 9.3 the spectrum of the radiated signal contains the carrying frequency f_{exc} and two sidebands having the same form as the range of the low-frequency modulating signal limited by the frequencies $F_{min}...F_{max} = 100...3000\ Hz$. In this case, the carrying frequency f_{exc} does not contain useful information about the transmitted speech or telegraph signal. In addition, the share of the transmitter power falling to the radiation of the carrying frequency makes up approximately 90%, and the share of the informational part is only 10 % of the whole power of the transmitter.

Single-band modulation (SM) differs from AM in the fact that the whole power of the transmitter or its significant part falls to transmittance of the informational part of the spectrum, which allows either increasing the communication range at the given power of the transmitter or decreasing the transmitter power for the same range.

In addition, the spectrum of the transmitted signal reduces twice, which leads to the transmitter sensitivity increase.

The single-band modulation allows eight-time increasing of the channel power budget in comparison to AM channel.

It is mainly used in long-range communication channels in HCMW and DCMW bands.

A special feature of SM equipment is considerable complication of receiving and transmitting channels, connected with the suppression of carrying oscillations in the transmitter and their subsequent restoring in the receiver, as well as with the permissible level of out-of-band radiations which are generated at insufficient suppression of the spectrum components in the transmitter (carrying, upper or lower sidebands).

10. LAYOUT OF REE AND ANTENNAS IN ASV

Layout is a combination of technical measures and solutions on arrangement of REE and antennas on the air-supported vehicle. General requirements for REE layout in ASV are the following:

- provision of optimal conditions for REE operation and usage of REE by the crew members in flight;
- easy access to the equipment during its check, maintenance, removal and adjustment;
- required level of electromagnetic compatibility (EMC), taking into account all channels of mutual interferences penetration.

When meeting these requirements it is necessary to exclude a possibility of damaging the equipment, wires, cables, etc. by luggage, cargo, means of transport, maintenance staff and passengers.

Optimal operating conditions of REE and antennas are mainly determined by external destabilizing factors which include climatic changes (temperature, pressure, humidity) and overloads at vibrations and impacts in flight and during landing of ASV.

Experience of operation shows that 90% failures of airborne REE fall to the factors mentioned above. The range of external effects for REE operation is specified in Airworthiness Standards and other Standard Material and Procedures Specifications (SMPS).

Limiting values of characteristic operating conditions of REE are presented in the Table 10.1.

Table 10.1

Parameters	Aircraft		Helicopters	
Temperature, ° C	- 60	+80	- 60	+50
Pressure, kPa	2	107	40	107
Relative humidity at temperature +56° C, %	-	100	-	100
Vibration:				
- amplitude, dB	0.5	10	0.5	5
- frequency, Hz	5	$2\cdot10^3$ …$5\cdot10^3$	5	500
Load impacts:				
- amplitude, dB	-	12	-	2
- impulse duration, mcs	-	20	-	20
Acoustic noise:				
- amplitude, dB	45	120	45	120
- frequency, Hz	40	10^4	40	10^4

Influence of destabilizing factors leads to reducing REE reliability in comparison to its reliability in ground conditions 10 times and more.

Concerning antennas operating conditions in ASV there appear additional destabilizing factors: mechanical loads connected with aerodynamic resistance of antennas; shielding effect and reradiation of electromagnetic power as a result of ASV design elements influence.

Destabilizing factors lead to decreasing mechanical and electrical strength of the antenna, deterioration of its parameters, and distortion of the direction pattern.

Let us analyze effects of destabilizing factors influence.

Temperature is the main factor influencing REE reliability. With the temperature increase, electrical parameters of the circuit and design parameters of the equipment components change, electrical operation mode of semiconductors gets violated, dielectric losses and leakage current increase in insulating materials and lubricants.

At high speeds of ASV flight in dense layers of the atmosphere radar detecting equipment located under the fairing in the ASV nose, is intensively heated. Thus, if the aircraft flight speed changes from 0.75 to 3 M walls of the glass fiber plastic fairing are heated in 20 minutes, after this the temperature in the antenna compartment is 220°C.

Pressure decrease with the altitude leads to reduction of REE reliability due to:

- emergency of electric charges between closely located equipment elements with a great difference of potentials;
- decrease of thermal conductivity and deterioration of thermal conditions of the equipment operation.

When the flight altitude is 18 km, ten-time increase of the air volume is required for REE cooling in comparison with the necessary amount when the aircraft is parked.

Humidity growth is a reason for about 30% of cases of airborne ASV operation instability.

At relative humidity of 90...98% a failure rate increases two times in comparison with a failure rate at relative humidity of 60...70% and temperature of 20…40°C.

The humidity quickens metal corrosion processes (in contacts, REE connectors), changes the structure of dielectrics, reduces insulator resistance and leads to mechanical effects on radio materials at freezing.

The relative humidity varies in the range of 30...100%, depending on a place on the earth surface, season of the year, time of the day, and increases with the temperature rise.

Vibration acceleration leads to the failure rate increase approximately 1.5 times, even if means of reducing its influence are available. Vibrations cause a noise rise (vibronoise) at the output of receiving devices and spurious modulation of the signals received.

The greatest influence is made by those vibration oscillations whose frequency coincides with the own frequency of mechanical oscillations of the equipment elements (resonance oscillations).

REE design resonance occurs at the frequencies of 15…150 Hz; tiny details resonate at the frequencies of several thousand Hertz, etc.

Vibration parameters (frequency F_V, shift amplitude A and acceleration amplitude g) are bound with the following equation:

$$g = \left(\frac{4\pi^2}{9800} \right) \cdot F_V^2 \cdot \grave{A},$$

where g is measured in units of gravitational acceleration, F_V – in Hertz, A – in millimeters. These values depend on instability of dynamic conditions in engines; operation of screws and whirl of boundary layers surrounding the aircraft in flight.

Depending on the vibration acceleration level, seven dynamic areas are distinguished in aircraft (A, B, C, D, E, F, G).

Area A contains a fuselage and wing sections whose size makes up 2/3 of a semispan, taking into account ASV axes.

Area B is a part of the aircraft, which depends on the engine type. As a rule, it is concentrated in the area of the engine location, as well as in the area influenced by the engines efflux noise action.

Area C is a part of area A, where equipment installed on shock absorbers is located (usually along the fuselage, central part of the aircraft). harmful interference

Area D includes a fin, stabilizer and part of the fuselage siding with the tail.

Area E contains wing ends on the 1/3 length of the semispan, counting from the end.

Area F includes engines and mounting attachments located on them.

Area G includes the aircraft parts surrounding the engine and engine mounting attachments.

Areas F and G have the biggest amplitude, and area A – the smallest one. Vibration accelerations are minimal in the aircraft centre of gravity.

Parameters of vibrations in the helicopter depend on the number of blades and main rotor speed, operating mode of a reduction gear and gimbal transmission, as well as on an antitorque propeller, its reduction gear and transmission. Vibration sources are also own vibrations of the helicopter.

Impact accelerations mainly emerge at ASV landing. In this situation, shifting and sometimes even REE component parts destruction are possible.

In the aircraft impact accelerations can reach 10 g. Maximal impact accelerations during the helicopter landing do not exceed 2 g.

EMC provision. Electromagnetic compatibility is an ability of radioelectronic means to function simultaneously in real operating conditions with the required quality, when they are affected by unintended interferences, and not to create harmful interferences to other radioelectronic facilities.

EMC provision is achieved by blanking the devices which are potentially affected by interferences created by airborne transmitters of impulse signals; filter protection; shielding and metallization of the equipment; usage of an antistatic dischargers.

It is considered that REE operating frequencies are defined by international or regional agreements and standards and are not to be changed, and mutual arrangement of REE and antennas is made taking into account an electromagnetic situation in ASV.

Blanking is a short-time closing of receiving paths for the time of interfering impulse signal radiation.

Metallization is carried out in accordance with valid standards and involves combining of all movable elements (doors, flaps, control surfaces, ailerons, etc.) into a general mass.

Antistatic dischargers are applied as a means of preventing corona discharges between ASV and air masses surrounding it.

Such discharges emerge on sharp edges and boundaries of ASV design and create interferences.

Discharges provide smooth flow of electrical charge accumulated by ASV and decrease ASV potential to values, at which corona discharges are impossible.

General requirement for REE and antennas are formulated taking into account analysis of harmful effects of destabilizing factors influence mentioned above.

First of all, REE serviceability must be provided, when all destabilizing factors are available, which are characteristic of operating conditions of particular REE and antennas.

A degree of stability of technical and operation parameters of REE are determined by a type of classifying groups of a version of radioelectronic equipment with respect to a type of destabilizing factors which the equipment must withstand during laboratory tests regulated by Airworthiness Standards of Civil Aircraft and Helicopters of Ukraine.

Thus, according to the temperature effects degree, three groups of equipment versions are distinguished, depending on the areas of the equipment arrangement in ASV:

I – equipment arranged in compartments with regulated temperature;

II – equipment arranged in compartments with non-regulated temperature and in areas of direct contact with external air flow;

III – equipment arranged in engine compartments.

According to a degree of equipment withstandability of low pressure, four groups of equipment versions are distinguished, depending on ASV flight altitude:

I – equipment functioning at altitudes up to 6000 m;

II – equipment for aircraft of local airlines with flight altitude up to 1000 m;

III – equipment of airliners with flight altitude up to15000 m;

IV – equipment for supersonic transport aircraft with flight altitude up to 25000 m.

Equipment withstandability of high humidity is characteristic of two groups of versions:

- equipment protected from direct influence of external environment (air);
- equipment having direct contact with external air.

Nearly in the same way REE and antennas requirements are regulated, which are connected with providing withstandability of vibration accelerations and impact effects.

REE layout principles are based on taking into account factors of operation and technical character, equipment reliability, preservation of energetic abilities of equipment, minimization of masses of servicing equipment of power supply and cooling systems. Specific factors are also taken into consideration, for example, ASV centre of gravity. Some of these factors turn to be contradictory, for example, according to EMC conditions, it is necessary to separate devices influencing each other, which leads to wiring mass growth, complication of maintenance and cooling of equipment.

Reliability is the main factor which must be taken into account at REE layout. Reliability refers to a property of an object to keep all parameter values within certain limits in the course of time. The parameters are meant which characterize abilities of performing required functions in the desired modes and conditions of application, maintenance, repair, storage and transportation.

The required level of reliability is achieved at normal operating conditions of equipment, i.e. at its arrangement in such places of ASV, where temperature, pressure, humidity, vibration and impact accelerations correspond to permissible values.

The main types of REE layout were formed on the basis of the experience of designing, manufacturing and operating ASV of various classes.

There are three variants of REE layout: concentrated, distributed and combined.

Concentrated variant involves arrangement of REE in groups, each of which includes equipment servicing the given airborne complex.

The groups are arranged in one or two compartments on special racks, this simplifies their maintenance, cooling, minimizes the length and mass of interblock cabling.

Disadvantages of such a variant are complication of EMC problem, lengthening of high-frequency communication lines with antennas and growth of power losses at its transmittance. There may appear difficulties at ASV centering. In spite of the mentioned disadvantages the concentrated variant of REE layout becomes a standard variant in aircraft of I and II classes.

Distributed variant of REE layout is characteristic of helicopters and small aircraft with relatively low flight altitude. The determining factor at this layout is REE approach to corresponding antennas.

The given variant of layout leads to improvement of energetic abilities of REE, but complicates a problem of creating normal climatic conditions for its operation and maintenance.

Combined variant of REE layout represents a combination of the concentrated and distributed variants. In any ASV, even if it has two pressurized compartments, a number of REE has to be installed beyond the pressurized part of the fuselage. Such REE include centimeter band devices.

Principles of antenna layout are based on taking into account and meeting the requirements for the directional pattern, polarization and electromagnetic compatibility of REE, usability, desired operation range mated with equipment antennas, antennas operation in conditions of icing and electrostatic discharges, as well as for antennas protection from lightning strokes.

Antenna matching devices must have a mass and dimensions allowing arranging them in immediate proximity to antennas.

Layout of antennas in ASV is carried out taking into consideration specified general requirements. During layout it is essential to proceed from compromising ideas and take into account such factors as aerodynamic resistance due to brought by antennas; keeping of antenna DP at its installation in ASV; provision of the desired level of electromagnetic compatibility; minimal deterioration of energetic abilities (REE operation range) and usability.

Aerodynamic resistance brought by antennas falls, if flush-mounted antenna are used, whose design must lead to minimal decrease of ASV strength.

Such antennas are arranged in the least stressed places of ASV design.

Non-flush-mounted antennas must have minimal possible dimensions and be arranged along air flow.

Directional properties of antennas change at installation in ASV. REE antennas sensitive to influence of airborne reradiators, are located as far as possible from other antennas or protruding elements of ASV design, and as close as possible to the electrical centre of ASV, where the effect of reradiating devices is minimal. Such arrangements are reasonable for the loop antenna of DF, Doppler antenna. Doppler antennas require thorough positioning in the vertical plane. To avoid distortions of weather radars DP it is necessary to provide a gap between DP edge and edge of the cut in ASV skin.

To provide EMC it is essential to separate RED antennas operating on close frequencies. EMC is improved by such orientation of antennas (if it is possible), at which minimums of their DP are located on the line that connects interacting antennas. It is possible to test EMC degree at the selected arrangement of the antennas only on ASV model or during real tests.

Keeping of REE power budget is achieved by antennas approach to the place of arrangement of equipment mated with it.

Maintainability requires easy access to connectors which couple antennas with the equipment. Special hatches are provided, through which it is possible to check the connectors mounting, to provide easy demating and connection of measuring equipment.

Peculiarities of antennas layout in ASV are caused by the waveband, in which the equipment mated with them operates, and by the type ASV, where they are located.

Antennas of hectometer and kilometer waves are, as a rule, receiving near-omnidirectional antennas. They are implemented on the basis of loop antennas. Absence of transmitting antennas of the given wavebands makes EMC problem solution easier, and operation in the mode of reception (weak signal) eliminates questions of electric strength of the antenna. Low frequency of received signals allows moving antennas from the corresponding REE to practically any distance within geometric sizes of ASV. To reduce drag, loop antennas are placed in a hollow on ASV body and covered by a radio transparent coating.

Decameter wave antennas operate both for reception and radiation of electromagnetic waves (long-range communication radio stations). They perform electrical excitation of ASV body or its parts. Radiated (received) power depends on the choice of antenna location, as a degree of antenna coupling with ASV design elements changes. Coupling coefficient rises, when the antenna is placed near ASV surfaces with the minimal radius of curvature. Mating devices and their elements are placed in immediate proximity to the antenna in order to increase its efficiency.

Metric wave antennas represent independent radiators of electromagnetic power, whose directional patterns are formed with participation of ASV body. Such antennas are installed on comparatively flat sections of the fuselage, which have a diameter not smaller than 0.2 wavelengths. Metric wave antenna approach to the ends of the fuselage leads to emergency of deep nulls in its directional pattern.

Antennas of decimeter and centimeter waves are influenced by shielding action of ASV design elements. DP distortions, such as nulls, are improbable in this waveband; therefore requirements for a place of installing antennas of this waveband are less crucial.

Helicopter antennas of any waveband require a more careful choice of a place of installation. It is caused by a complex shape of a helicopter, its smaller dimensions and larger quantity of protruding elements of its design.

Small dimensions of the surfaces, on which antennas are located, can cause DP distortions. A negative influence on REE parameters is made by a dismountable design. A large number of joints in the helicopter skin with a bad electric contact, as well as doors, removable panels, elements with an alternating electric contact cause a significant change of electric characteristics of antennas and emergency of electrical noise.

Special features of helicopter antennas also include less strict requirements for aerodynamic resistance and mechanical strength of antennas. Therefore in the helicopter it is possible to use non-flush-mounted antennas which have a simpler design and practically do not reduce mechanical strength of the helicopter.

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