EDUCATION AND SCIENCE MINISTRY OF UKRAINE
NATIONAL AVIATION UNIVERSITY
DEPARTMENT OF COMPUTER INTEGRATED COMPLEXES

ADMIT TO DEFENSE
Head of department
Viktor M. Sineglazov
“____” ______________ 2020

MASTER’S THESIS

(EXPLANATORY NOTE)

GRADUATE OF EDUCATION AND QUALIFICATION LEVEL “MASTER”

THEME: Automatic system for determining the UAV coordinates in multi-position sound monitoring systems

Executor: **Balov O.V.**

Supervisor **Ph.D., Associate Professor Panteev R.L.**

Advisor on environmental protection: **Head of department Frolov.V.F.**

Advisor on labor protection: **Ph.D., Associate Professor Konovalova O. V.**

Norms inspector: **Ph.D., Associate Professor Tupitsyn M.F.**

KYIV 2020

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
КАФЕДРА КОМП'ЮТЕРНО-ІНТЕГРОВАНИХ КОМПЛЕКСІВ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
В.М. Синєглазов
"_____"____________2020 р.

ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬО-КВАЛІФІКАЦІЙНОГО РІВНЯ "МАГІСТР"

Тема: Автоматична система визначення координат БПЛА у багатопозиційних комплексах звукового моніторингу

Виконавець: **Балов О.В.**

Керівник: **к.т.н., доцент, Пантеев Р.Л.**

Консультант з екологічної безпеки: **зав.кафедри Фролов В.Ф.**

Консультант з охорони праці: **к.б.н., доцент, Коновалова О. В.**

Нормоконтролер: **к.б.н., доцент, Тупіцин М.Ф.**

Київ 2020

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Навчально-науковий інститут інформаційно-діагностичних систем

Кафедра авіаційних комп'ютерно-інтегрованих комплексів

Спеціальність: 151 «Автоматизація та комп'ютерно-інтегровані технології»

ЗАТВЕРДЖУЮ
Завідувач кафедри
В. М. Синєглазов _________
«______»___________2020 р.

ЗАВДАННЯ
на виконання дипломної роботи

Ім'я студента: ___________ Балов Олександр Володимирович _______________

1. **Тема дипломної роботи:** Автоматична система визначення координат БПЛА у багатопозиційних комплексах звукового моніторингу

2. **Термін виконання роботи:** з 08.10.2020 до 23.12.2020.

3. **Зміст пояснювальної записки:** Вступ. 1. Классифікація і аналіз акустичних параметрів БПЛА, методи знаходження БПЛА. 2. Система знаходження по звуковому полю, обзор і аналіз її компонентів. 3. Розробка алгоритмічного забезпечення для покращення знаходження БПЛА. 4. Розробка програмного забезпечення, її структура та інтерфейс. 5. Охорона праці. 6. Охорона навколишнього середовища.

4. **Календарний план-графік**

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1.	Отримання завдання	08.10.2020	10.10.2020
2.	Формування мети та основних завдань дослідження	11.10.2020	15.10.2020

3.	Аналіз типів БПЛА та їх акустичних параметрів.	16.10.2020	09.11.2020
4.	Аналіз природи розповсюдження звуку в різних умовах	12.11.2020	19.11.2020
5.	Система знаходження по звуковому полю, обзор і аналіз її компонентів.	20.11.2020	27.11.2020
6.	Розробка програмного та алгоритмічного забезпечення	28.11.2020	10.12.2020
7.	Оформлення пояснювальної записки	11.12.2020	19.12.2020
8.	Підготовка презентації та роздаткового матеріалу	20.12.2020	23.12.2020

5. Консультанти з окремих розділів

Розділ	Консультант (посада, П.І.Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці	к.б.н., доцент, Коновалова В.В.		
Охорона навколишнього середовища	Зав.кафедри, Фролов В.Ф.		

6. **Дата видачі завдання:** “08” жовтня 2020 р.

Керівник дипломної роботи ____________________ Р.Л. Пантеев
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Завдання прийняв до виконання ____________________ О.В. Балов
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NATIONAL AVIATION UNIVERSITY

Educational Research Institute of Information - Diagnostic Systems

Department of Aviation Computer-Integrated Complexes

The specialty: 151 “Automation and computer-integrated technologies”

APPROVED BY

Head of department
Dr., Professor
Victor M. Sineglazov ________
“_____”______________ 2020

Graduate Student’s Diploma Thesis Assignment

Student’s name:____________Balov O.V.__________________________________

1. **The thesis title:** Automatic system for determining the UAV coordinates in multi-position sound monitoring systems

2. **The thesis to be completed between:** from 08.10.2020 to 23.12.2020

4. **The content of the explanatory note (the list of problems to be considered):** Introduction.1. Acoustic characteristics and sound radiation analysis of existing UAV prototypes, classification of means of sound monitoring detection methods. 2. Review of detection systems existing prototypes on the sound field, the review of elements of structure of the offered system. 3. Algorithmic realization of methods of increase in accuracy of determination of coordinates of UAV. 4. Development, structure and interface of the software.

6. **Planned schedule:**

№	**Task**	**Execution term**	**Execution mark**
1	Task	08.10.2020	10.10.2020
2	Purpose formation and describing the main research tasks.	11.10.2020	15.10.2020

3	Analysis of UAV types and their acoustic parameters.	16.10.2020	09.11.2020
4	Analysis of the nature of sound spread in different conditions	12.11.2020	19.11.2020
5	Sound field finding system, review and analysis of its components.	20.11.2020	27.11.2020
6	Software and algorithmic software development	28.11.2020	10.12.2020
7	Design of explanatory notes	11.12.2020	19.12.2020
8	Preparation of presentation and handouts	20.12.2020	23.12.2020

7. **Special chapters' advisors**

Chapter	Advisor (position, name)	Date, signature	
		Assignment issue date	Assignment accepted
Labor protection	Ph.D, Associate Professor, Konovalova O.V.		
Environmental protection	Head of department Frolov V.F.		

8. Date of task receiving: "08" October 2020

Diploma thesis supervisor ______________________ Roman L. Panteev
(signature)

Issued task accepted ______________________ Oleksandr V. Balov
(signature)

АНОТАЦІЯ

Метою роботи є розробка автоматичних систем виявлення безпілотних літальних апаратів на основі звукової інформації

У роботі розглядаються датчики методи та алгоритми підвищення точності виявлення координат БПЛА на основі модифікованного методу Ньютона. Було проведено дослідження методу Ньютона с цілью скорочення часу обчислення координат. Установлено, шо для отримання достатньої точності виявлення координат матрицу Якобі достатьо обчислити на перших трьох кроках ітерації. Було проведено дослідження параметричної чутливості різницево-далекомірного методу і установлено, що відносна похибка в виявленні часу затримки прихода сигналу має знаходитись в межах 5%, тільки тоді можливо корректне виявлення координат. Крім того, в роботі була досліджена екстремальна постановка задачі різницево-далекомірного методу на основі метода мінімізації квадратичного функціоналу, що дозволяє врахувати відносну похибку визначення часу затримки приходу сигналу на кожній зі станцій окремо шляхом введення вагового коефіцієнту.

Поява безпілотних літальних апаратів з менш шумними двигунами значно знизило якість їх виявлення і обробки сигналу, змусивши розробників шукати нові шляхи і засоби збільшення точності визначення і завадостійкості окремих засобів і груп ППО.

У свою чергу, пасивні засоби звукового моніторингу мають значну перевагу в порівнянні з активними засобами, що складається, головним чином, в прихованності їх роботи. Однак, точні характеристики визначення координат пасивних систем содар-локації значно поступаються аналогічним характеристикам активних систем.

Зважаючи на досить високі похибки (10% і вище) вимірювань координат БПЛА, проблема підвищення точності їх роботи залишається актуальною для комплексів пасивного моніторингу звуку.

Abstract

The purpose of the work is to develop an automatic detection system for unmanned aerial vehicles on the basis of sound information

The paper deals with sensors methods and algorithms for increasing the accuracy of UAV coordinate detection based on the modified Newton method. The Newton method was studied with the aim of reducing the time of calculating coordinates. It is established that in order to obtain sufficient accuracy of coordinate detection, the Jacobi matrix must be calculated on the first three steps of the iteration. A study of parametric sensitivity of the difference-range-finding method was conducted and it was established that the relative error in detecting the arrival delay time of the signal should be within 5%, only then correct identification of the coordinates may be possible. In addition, an extremal statement of the problem of the difference-distance-finding method was investigated on the basis of the quadratic function minimization method, which allows taking into account the relative error of determining the delay time of arrival of a signal on each of the stations separately by introducing a weight coefficient.

The emergence of unmanned aerial vehicles with less noisy engines significantly reduced the quality of their detection and signal processing, forcing developers to look for new ways and means to increase the accuracy of detection and impedance of individual vehicles and air defense groups.

In turn, passive means of sound monitoring have a significant advantage over active means, consisting mainly of the hidden work of their work. However, the exact characteristics of determining the coordinates of passive systems of the sacred location are considerably inferior to similar characteristics of the active systems.

In view of the rather high errors (10% and above) of UAV coordinates measurements, the problem of increasing the accuracy of their operation remains relevant for passive sound monitoring systems.

LIST OF ABBREVIATIONS

UAV – unmanned aerovehicle

PSM – passive sound monitoring

CPSM – complex of passive sound monitoring

TM – triangulation method

TDOA – time difference of arrival

SM – sound monitoring

RES – sound-electronic situation

AFS – antenna and feeder system

DD – directional diagram

DMISD - Doppler Measuring Instrument of Speed of Demolition

ADD – antenna directional diagram

RS – receiving station

WFA – work frequency amplifier

LSFA – low sound frequency amplifier

UAV – unmanned aerial vehicle

IMS – information and measuring system

CCF – cross-correlation function

TDOA system – time difference of arrival system

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1. Problem of detection of the UAV

1.1 Classification of UAV. Acoustic characteristics and sound radiation analysis of existing UAV prototypes

Sound radiation factors of various sources are used in classical approaches of aviation acoustics for calculation of detection for UAV noise level on the area and also for the forecast of borders of audibility of detection of UAV with the vintomotorny power plant. At the same time improvement of accuracy of the forecast requires more detailed studying of acoustic characteristics of separate components of radiation regarding influence of an operating mode and design features of power plants.

The propeller engine in the course of the work generates the acoustic radiation which extends to the environment via channels of suction and an exhaust and also through walls of cylinders (structural noise). In this regard, in the muffled camera the research of acoustic characteristics of the PTERO-G0 UAV developed by the AFM-Servers company was executed (photo 1.1, 1.2).

Photo 1.1, 1.2 PTERO-G0 UAV

Division of acoustic fields of an air screw and the piston engine was carried out on the basis of the analysis of narrow-band ranges of the sound pressure levels. It was necessary that the total radiation of the piston engine is defined by radiation at frequencies, multiple to the frequency of following of flashes in engine cylinders.

The standard narrow-band range of levels of sound pressure received at measurements of acoustic characteristics of the small-sized UAV in the muffled camera is presented in fig. 1.3

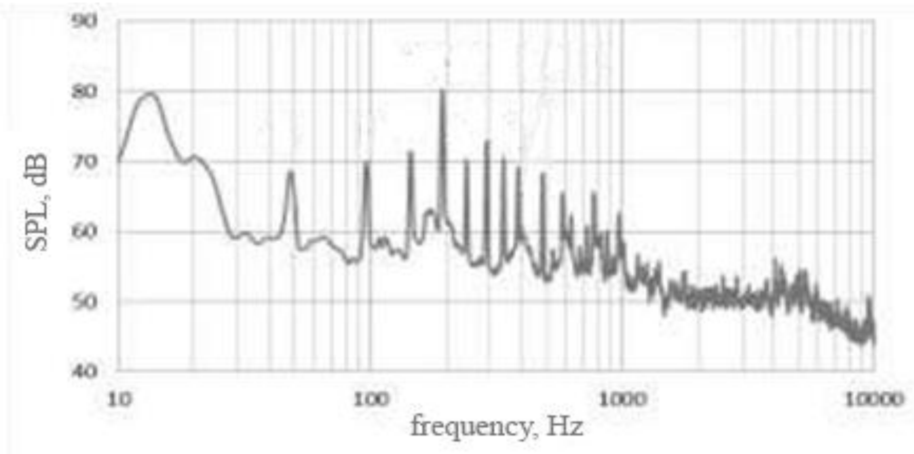

Fig. 1.3. A standard range of acoustic radiation of an engine of the UAV with a width bands of 2 Hz (rotating speed of crankshaft 5400 RPM, at distance 2 meters)

For a more thorough analysis of the acoustic characteristics of the harmonics of a UAV piston engine, below will be given its characteristics in more narrowly targeted narrow-band range

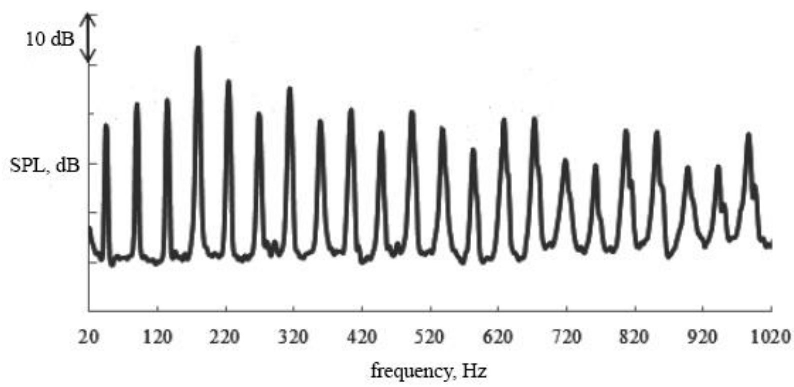

Fig. 1.4 the Narrow-band range of the sound pressure levels in the frequency range of 20-1020 Hz with band width of 2 Hz, rotating speed of the crankshaft of the nec engine (engine crankshaft) = 5400 RPM, R = 2 m, static conditions

The dependence of acoustic power of noise of rotation of the air screw on the effective power of UAV can be received on the basis of semi-empirical model of noise of the screw according to which, the power of noise of rotation is described by formula:

$$W = \frac{C_1 \rho (\bar{r}_e)^3}{S_0^3} \times \left(\alpha^2 + \frac{\beta^2}{(2\pi \bar{r}_e)^2}\right) \times \frac{M_r^2}{K_b^3 b_e} \times n^6 d^8 \quad (1.1)$$

where n – screw turns; α, β – coefficients of draft and power of the screw, d, K_b, $\bar{r}_e$, b_e – diameter of the screw, number of blades, relative radius of effective section blades and a chord of the blade in the effective section, M_r - Mach number of circle speed, ρ – air density, S_0 – the acoustic speed, C_1 – coefficient proportionality, M_{rel} – Mach number e of relative flow rate in the trailer section of the blade of the screw.

The electric motor in the course of the work is capable to generate acoustic radiations, less audible the systems of passive sound monitoring, because of small quantity of mobile parts.

In this regard, Acoustic radiations of the quadcopter DJI Phantom 2 and a monoplane of Skywalker Falcon 1340 mm EPO Flying Wing are investigated (photo 1.5, 1.6).

Photo 1.5, 1.6. Skywalker Falcon 1340 mm and EPO Flying Wing

Photo 1.7. DJI Phantom 2 quadcopter

Acoustic measurements for the quadcopter were taken in the rise modes over the acoustic antenna, barragings at the height of 50 m and the subsequent landing. In fig. 1.8 temporary realization of record of a sound signal of the quadcopter lasting 20 ms at a barraging stage, and in fig. 1.9 – rated autocorrelated function (ACF) for this realization is shown.

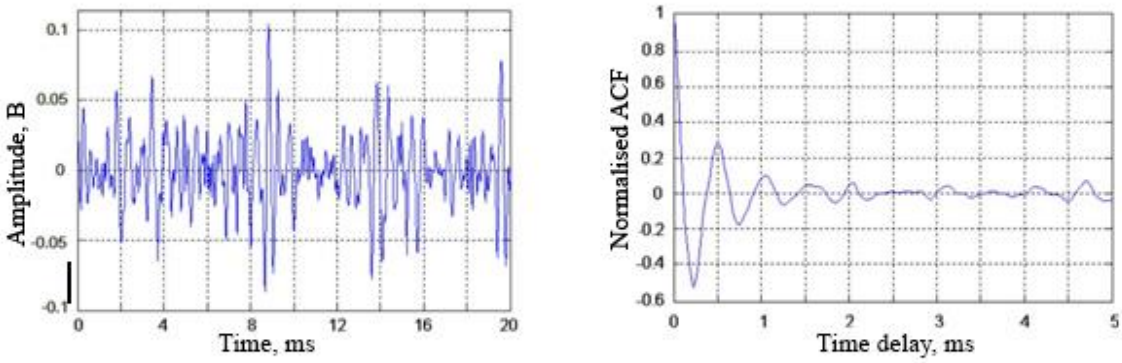

Fig. 1.8, 1.9. Temporary realization of record of a sound signal of the quadcopter lasting 20 ms at a barraging stage with the ACF processing

In fig. 1.10 the amplitude spectrum of a sound signal of the quadcopter received on selection 8192 counting without accumulation is shown. The range of a signal contains a broadband noise component (obviously expressed flat maximum) and multicomponent harmonious structure. The analysis of a large number of implementations shows that harmonics with frequencies up to 10 kHz surely are found. Amplitudes and phases of harmonics are accidental and in the absence of the movement of the quadcopter. It is explained by some distinction of engines operating modes in the course of compensation by UAV automatic equipment of wind influence.

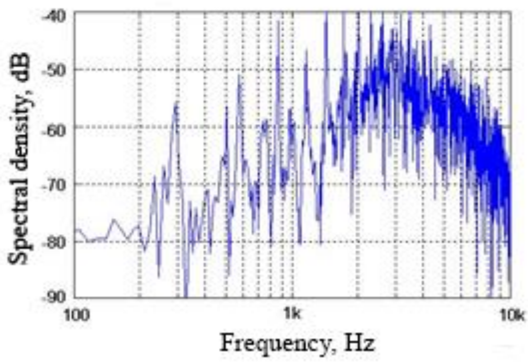

Fig 1.10. The amplitude spectrum of a sound signal of the DJI Phantom 2 quadcopter

Measurements for a monoplane were taken in the mode of flight over the acoustic antenna at the height about 20 m. In fig 1.11 temporary realization of record of a sound signal of a monoplane, and in fig. 1.12 – its rated ACF is shown.

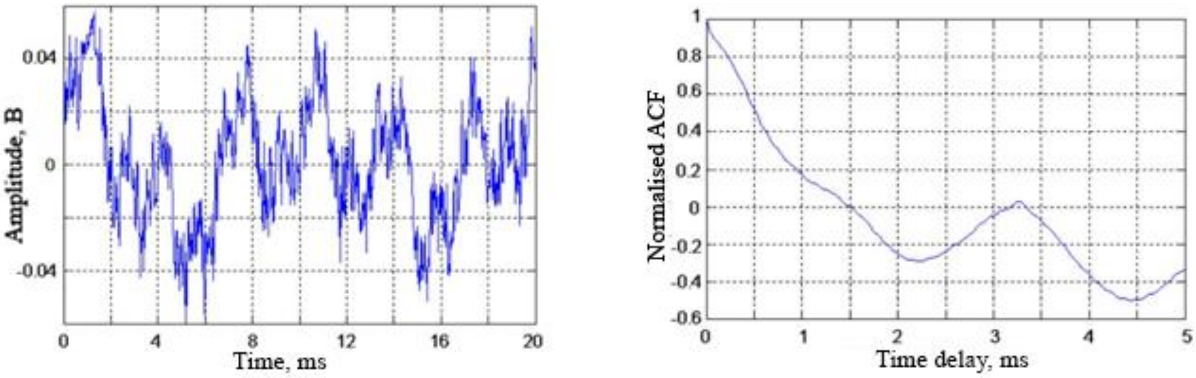

Fig 1.11, 1.12 Temporary realization of record of a sound signal of a Skywalker Falcon 1340 mm and EPO Flying Wing monoplane, with rated ACF.

In this record, unlike records of a sound signal of the quadcopter, there is a noticeable low-frequency component at frequencies up to 200 - 250 Hz. Emergence of this component is caused by "blowing-in" of wind in the microphone of measuring installation. It demonstrates to need of application of a special windscreen of the microphone and low-frequency filtering at creation of detection systems UAVs.

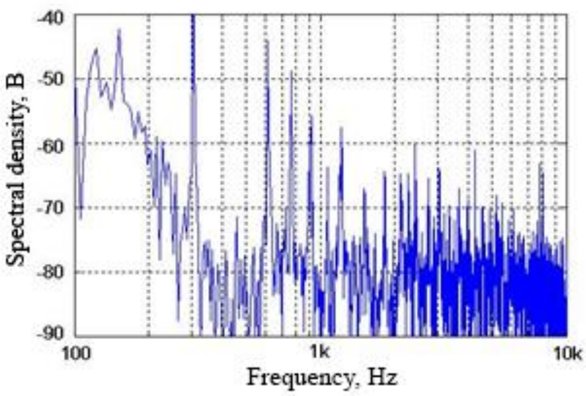

Fig. 1.13 The range of a sound signal of a Skywalker Falcon 1340 mm and EPO Flying Wing monoplane

The range of a sound signal of a monoplane (fig. 1.13) also incorporates a large number of harmonics up to frequencies 8 – 10 kHz. Spectrum lines, unlike the quadcopter, narrow that is explained by existence of one engine in power

installation. The ratio between amplitudes of harmonics is less changeable in time, than in case of
the quadcopter, and change of frequency is caused by combined action of two factors – a doppler effect and change of the mode of the engine.

1.2 Physical foundations of sound monitoring

1.2.1 Sound spread basics

In the further solution of the task of determining UAV coordinates, which includes the analysis of technical means, the selection of the desired location and the general layout of the whole system of the multi-position sound monitoring complex, it is initially important to analyze and note the natural influence of various natural conditions on the nature of sound propagation and dispersion.

The general formula for calculating sound is as follows

$$c = \sqrt{\frac{1}{\beta\rho}}. \tag{1.2}$$

If you touch on private variables, then this formula takes on a similar form

$$c = \sqrt{-v^2\left(\frac{\partial p}{\partial v}\right)_s} = \sqrt{-v^2\frac{C_p}{C_v}\left(\frac{\partial p}{\partial v}\right)_T}, \tag{1.3}$$

where β - adiabatic elasticity of the environment; ρ - density; C_P - isobaric heat capacity; C_v - isochoric thermal capacity; ρ, ν, T - pressure, the specific volume and temperature, s - entropy of the environment.

Acoustic oscillations pass the medium as a sequence of adiabatic rarefaction and compression. With adiabatic gas compression, part of the compression energy passes into the energy of intramolecular movements, with adiabatic rarefaction it returns. If the time required to perform the vacuum and compression is the same as the time required to establish thermal equilibrium (relaxation), then the known fraction of sound energy, turning into the internal energy of molecules in the compression process, does not have time to turn into external energy after the expansion. In this case, the most significant absorption of sound by gas molecules will occur.

The energy spent on compression is converted primarily into the translational energy of molecules moving parallel to the direction of compression. A certain part of the translational energy then passes into the rotational and oscillatory energy of atoms in molecules, but can also be spent on the transition of atomic and molecular electrons to higher energy levels.

In dry, clean and stationary air, the absorption of acoustic vibrations has the lowest value and is carried out by oxygen molecules. In wet air, absorption increases but remains smaller than in turbulent air flow. Sound absorption in wet air occurs due to the interaction of oxygen molecules and water vapor. Part of the sound energy during inelastic collisions of molecules passes into the oscillatory energy of atoms in molecules. For all frequencies with an increase in relative humidity, the absorption of sound first increases, with humidity 10... 20% reaches a maximum and with a further increase in humidity it decreases monotonously.

Changing air temperature and wind speed with height make atmosphere with non-uniform medium with variable speed of sound. It leads to distortion (refraction) of sound rays. Since speed sound propagation depends on the temperature, in different layers of the atmosphere, the temperature of the layers of which is different, the sound will have different speeds. In a medium with a variable refractive index, sound waves will propagate along curved lines. At the same time, as shown by numerous experiments, the beam is always bent so that the distance from point to point of the wave passes in the shortest time. In other words, the wave propagating in a non-homogeneous environment changes direction so, to extend your journey in an environment with faster propagation and reduce it in layers where the propagation rate is lower.

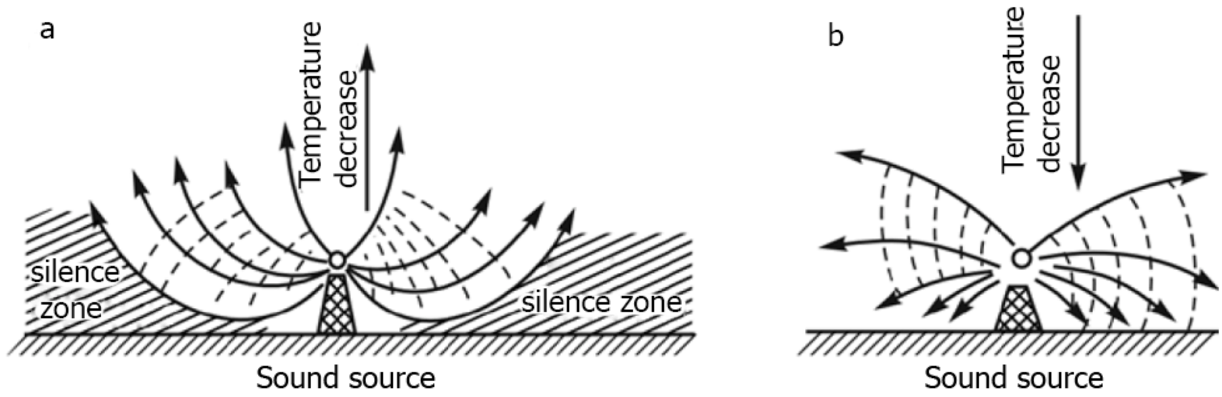

Fig. 1.14 Sound behavior by the temperature decreasing

If the temperature drops with height, which usually happens during the day, then the sound beams are bent upwards (Fig. 1.14, a). As a result, on some short distance from the source, the sound ceases to be audible. If the temperature increases with height (temperature inversion), the sound rays bend down (Fig. 1.14, b) and the sound reaches more distant points of the earth's surface. This explains the often the observed fact that at night the sound is heard at a greater distance than in the afternoon. With a large temperature inversion, sound rays, having tested significant refraction, return to the surface of the earth, reflect from it and rise up again (fig.1.15). There may be such reflections somewhat, the sound energy in this case is concentrated in some a layer that plays the role of a sound channel.

Propagation range at such conditions are greatly increased. This is especially noticeable in the quiet night above the river, thanks to the weak absorption of water sound waves surface.

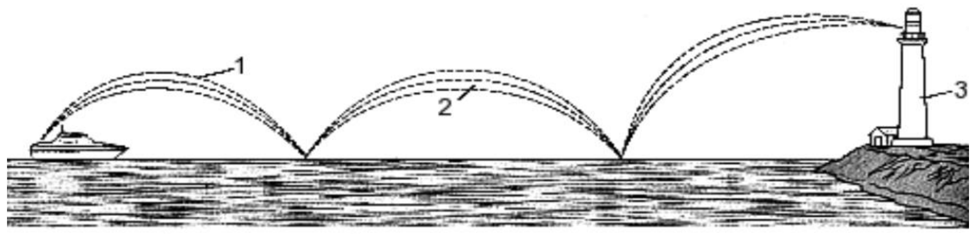

Fig. 1.15 Sound behavior at the water

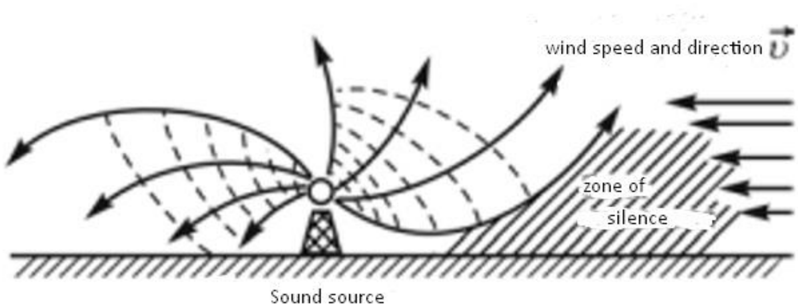

Fig. 1.16 Sound behavior by the means of wind direction and speed

If the air temperature with height varies slightly and there is no wind, then the sound from the source propagates without experiencing noticeable refraction. In the presence of wind, its speed and the speed of the sound wave add up. The different nature of the bending of sound rays in this case (fig. 1.16) explains the fact that in the wind the sound is heard further than against winds.

1.2.2 The basics of technical means of the sound detection system

Three types of directional microphones are commonly used: parabolic (reflex), tubular (interference) and flat microphone arrays.

A parabolic microphone (Figure 1.4) has a parabolic reflector that focuses on a microphone attachment with an omnidirectional or unidirectional orientation characteristic (CO). These microphones are sometimes called reflex microphones.

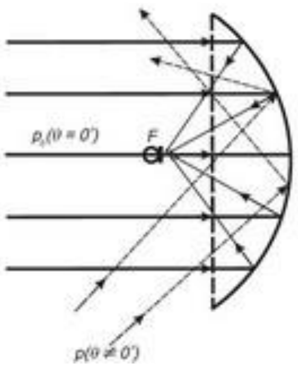

Fig. 1.17. The scheme of the parabolic directed microphone

The sound waves coming from the axial direction of the parabola are reflected from the reflector and due to the properties of the parabola after reflection are concentrated in the phase in its focus, where the body of the diaphragm is located. Sound waves coming at an angle to the axis of the parabola scatter the reflector without hitting the microphone. In the HN-reflex system, it strongly depends on the frequency and varies from almost unfocused at low frequencies (with a reflector diameter less than the acoustic wavelength) to a narrow fraction at high frequencies. The frequency response of such microphones has increased to high frequencies with a slope of about 6 dB per octave, which is usually compensated either by an electronic method (eg, equalizer), or a special design of the cap.

The directional pattern of the microphone is 10 °, the gain is 70 dB, which provides interception of conversation in the open air at low noise levels up to 100 m. The frequency range of the microphone is from 100 to 14,000 Hz. The quality of the directed microphone is estimated by prize coefficient in the relation "signal hindrance" due to spatial selection Knm, dB.

For the parabolic microphone K_{pm} given coefficient, the dB, is calculated by a formula:

$$K_{pm} \sim 10\lg(1.2 \times 10^{-4} \times S_{refl} \times f^2) \qquad (1.4)$$

where S_{refl} - Square of the reflector of the microphone, sq.m; f - signal frequency, Hz.

Apparently from a formula (1.4), the more the area of the reflector, the is more value of coefficient K_{pm}.

Therefore, the interception range of the conversation largely depends on the diameter of the reflector. For example, for the same conditions with a reflector diameter of 60 cm (microphone PKI 2915), the range of interception is 100 m, and with a diameter of 85 cm (microphone PKI 2920) - 150 m.

"Running wave" microphones (interference), often called tubular microphones, consist of a tube with holes or cutouts, on the back of which is a non-directional or unidirectional body of the diaphragm (Fig. 1.18).

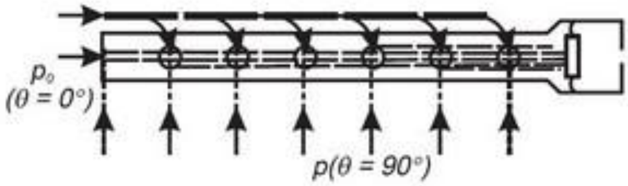

Fig. 1.18. Scheme of the tubular (interferential) microphone

Holes (cut) in the tube are closed with a cloth or porous material, the acoustic resistance of which increases when approaching the cap. Deterioration of HN is achieved due to the interference of partial sound waves passing through the holes of the pipes. When the front of the sound moves parallel to the axis of the tube, all partial waves enter the moving element simultaneously, in phase. When the sound is distributed at an angle to the axis, these waves reach the cap with a different delay, which is determined by the distance from the corresponding hole to the cap, at the same time there is a partial or complete compensation of the pressure acting on the moving element. The noticeable deterioration of HN in such microphones begins with the frequency when the length of the tube is more than half the length of the acoustic wave. As the frequency of HN increases even more. Therefore, even with a significant length of such microphones, which can reach a meter and even more HN at frequencies below 150 - 200 Hz, is determined only by the restriction and is usually close to cardioid or supercardioid.

Tubular directional microphones in comparison with parabolic more compact are also used, as a rule, in cases when it is necessary to provide a reserve of listening of conversation. With the help of such microphones, the investigation can be carried out both from the car and from the window of the house opposite.

For the tubular microphone prize coefficient in the relation "signal hindrance" due to spatial selection K_{tm}, the dB, is calculated by a formula:

$$K_{tm} \gg 10\lg(6.1 \times 10^{-3} \times I \times f) \tag{1.5}$$

where I - length of a tube, m.

The extraordinary maximum range of tubular microphones is slightly smaller than the parabolic one. But in the city, their capabilities are almost the same.

The so-called "flat" directional microphones have appeared recently and are an acoustic microphone grille that includes several dozen microphones covers. Flat microphone gratings are also available in camouflage. Most often they are disguised as an attache case, vest or belt.

The maximum range of directional microphones in the city does not exceed 100 - 150 m, in a country with low noise, the range of the investigation can be up to 500 m or more.

1.3 Problem definition of detection of the UAV

Putting into operation and also developments of the latest UAVs, with more silent internal combustion engines and also more perfect electric motors of new generation, relevant is a problem of finding of new methods of increase in accuracy of definition of the UAV passive means of sound monitoring on the basis of technical and algorithmic innovations

In the section the main concepts of creation and feature of use of modern passive systems of sound monitoring are considered, their classification, proceeding from the principles of processing of information signal is carried out.

The main methods of determination of coordinates in the active and passive systems of sound monitoring are analyzed. Technical methods which purpose to fix problems of the existing types of systems are considered. Conclusions about the prospects of development of sodar-tracking systems in general are drawn.

Technical features of multi-position passive complexes, the altimeter and three-coordinate active sodar station, feature of their use are considered.

On the basis of results of the analysis research problems are specified, requirements to the developed ways of increase in accuracy of determination of coordinates of UAV are formed by the integrated sound monitoring complexes.

1.4 Classification of means of sound monitoring detection methods

Emergence of unmanned aerial vehicles with less noisy engines considerably lowered quality of their detection and processing of a signal, having forced developers to look for new ways and means increase in accuracy of definition and noise immunity of separate means and groups of air defense.

The first in the history of attempt of fighting use of passive detection systems came down to use the direction finding of channels of sodar station with the subsequent combination of information from various sodar stations on point of processing. The method received the name of a triangulation. The idea of a triangulation is quite simple: the direction is defined on the radiating object from different points of space, and then range to an object is determined by the known corners and distances between sodar station (fig. 1.19).

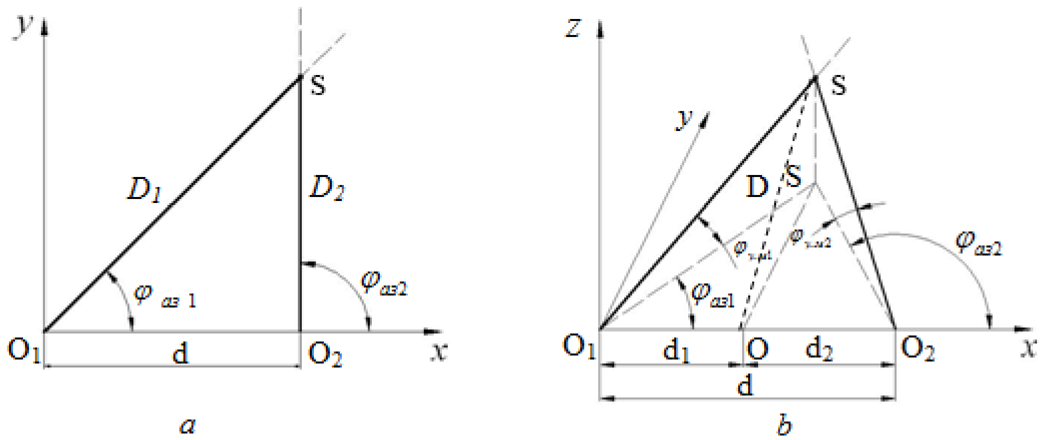

Fig. 1.19. Triangulation method of positioning of UAV on the plane (a), in space (b)

If UAV is located in the horizontal or vertical plane, then for definition of its location it is enough to measure two azimuthal corners: $\varphi_{аз1}$ and $\varphi_{аз2}$ or two corners of the place: $\varphi_{ум1}$ and $\varphi_{ум2}$. The location of a source of radiations is defined by a point of intersection O_1S and O_2S (two lines of situation).

For definition of a location of a source in space bearing angles are measured $\varphi_{аз1}$ and $\varphi_{аз2}$ in two carried points of O_1 and O_2 and a place corner in one of these points or, on the contrary, place corners $\varphi_{ум1}$ and $\varphi_{ум2}$ in two points of reception and a bearing angle in one of them (fig. 1.19, b).

On the measured direction finding corners by simple calculations, using the theorem of sine, it is possible to determine ranges from reception points to UAV on the plane:

$$D_1 = \frac{d\,sin(180 - \varphi_{аз2})}{sin(\varphi_{аз2} - \varphi_{аз1})}, \tag{1.6}$$

$$D_2 = \frac{d\,sin\,\varphi_{аз1}}{sin(\varphi_{аз2} - \varphi_{аз1})} \tag{1.7}$$

and in space

$$D = \frac{d}{cos\,\varphi_{ум1}(cos\,\varphi_{аз1} - sin\,\varphi_{аз1} ctg\varphi_{аз2})} \tag{1.8}$$

The advantage of a triangulable method consists in simplicity of its technical implementation therefore it is widely applied.

Essential lack of a method is existence of false detection of nonexistent sources at a large number of the radiating objects in an area of coverage of a direction finder. Apparently from the drawing, along with determination of coordinates of three true sources S_1, S_2, S_3 – it is found also six false: FS_1, FS_2, …, FS_6.

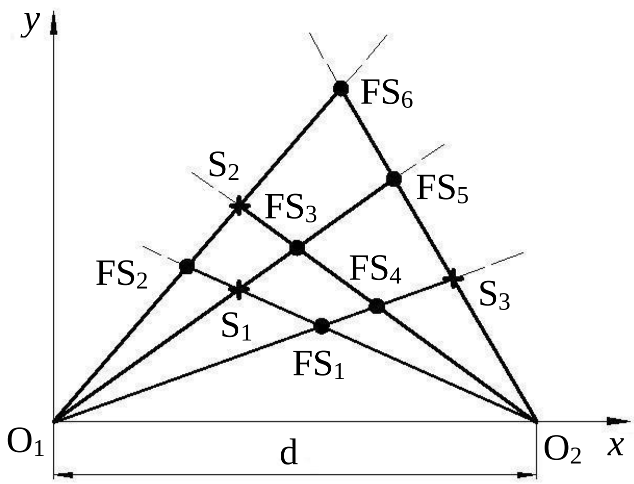

Fig. 1.20. False detection when using a triangulable method

Regular sodar stations, communication lines and point of processing are used. However, shortcomings of a triangulable method became almost insuperable barrier on the way of its fighting application. The reasons at these shortcomings two: low accuracy of measurement of coordinates and existence of a large number of false crossings at direction finding of several radiating purposes.

Accuracy of direction finding is defined by beam angle of the sodar station carried to a ratio "signal noise" and for the existing sodar stations reaches value 0.25 - 0.5 degrees. Such value of a direction finding error leads to unacceptable errors of calculation of range by a triangulable method. Essentially and the fact that the triangulable method works on continuous radiation. Besides, the direction finding channel of sodar station can find a bearing only in frequency band of the station - out of this band radiation is not fixed. And as a result of rereflections from local objects, the lower edge of detection, depending on length of base (distance between direction finders), reaches 200 - 4000 m.

In spite of the fact that triangulable algorithms were also realized at command posts of sound engineering troops, they worked on the single purposes only at distance between direction finders about 120 - 200 km and were practically not used in practice because of basic impossibility to provide the accuracy and permission sufficient for targeting to active anti-aircraft weapons. But interest in passive locational systems was rather high and shortcomings of a triangulable method led to search of different ways of detection and measurement of coordinates of the radiating objects.

The greatest distribution was gained by the differential and ranging method based on measurement of a difference of the course of signals to reception positions. This method allows to work both on pulse, and on continuous signals, including on noise and noise-type. It is especially effective in cases when basic and correlation processing is applied to calculation of a difference of the course (see below) at which the type of the accepted signals does not matter.

The fundamental difference of a differential and range-metering method from a triangulation consists in homodyne reception of signals from the radiating source on spaced positions. Determination of coordinates of a source is carried out on the difference of arrival of signals on each of positions, and the difference of arrival of a signal to one position concerning another is defined from the provision of a maximum of cross-correlation function of signals from these positions or the difference of arrival of an impulse to places of acceptance (fig. 1.21).

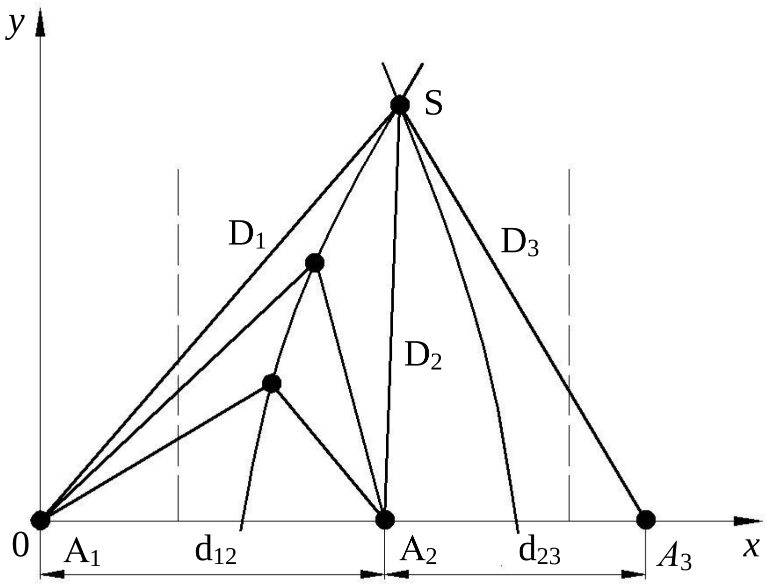

Fig. 1.21. Differential and ranging way of positioning of UAV

For finding of coordinates of UAV it is necessary to have three points of observation (reception) carried in space: A_1, A_2, A_3, belonging to various bases A_1A_2 and A_2A_3. Focuses of hyperboles coincide with observation points. Differences of distances $d_{12} = D_1 - D_2$ and $d_{23} = D_2 - D_1$ are parameters of hyperboles in which their construction is carried out. The spatial provision of UAV is determined by three differences of ranges measured in three-four places of acceptance. Location of a source – a point of intersection of three hyperboloids of rotation. Accuracy of positioning of UAV by this method is rather high, mistakes make about tens of meters. The considered method is applied in the passive pulse (temporary) and correlation and basic systems of definition of location of UAV.

When using passive differential and ranging systems detection of false nonexistent UAV is also possible when the source radiates periodic signals with the small period of following (with small porosity). On the time interval equal to the difference of time of distribution of a signal from a source to the receiver, several periods of emitted signals keep within.

As a result the system measures a large number of differences of ranges and defines respectively a large number of hyperbolic surfaces. Many of them are false.

It is possible to eliminate similar ambiguity by a separation of sources on angular coordinates, that is combined use of differential and ranging and triangulable methods.

Along with peddling and ranging in the systems of a passive sodar-location the goniometric and differential and ranging method of definition of location of UAV which assumes measurement of a difference of ranges from UAV to two carried collection points and measurement of the direction on a radiation source in one of these points is also widely used.

For determination of coordinates of a source on the plane it is enough to measure an azimuth β and difference of ranges $\Delta D = D_1 - D_2$ from a source to reception points. Location of a source is defined by a point of intersection of a hyperbole and a straight line. For definition of location of a source in space it is necessary to find in one of points of reception a corner of the place of UAV in addition. location of a source is as a point of intersection of two planes and a surface of a hyperboloid of rotation.

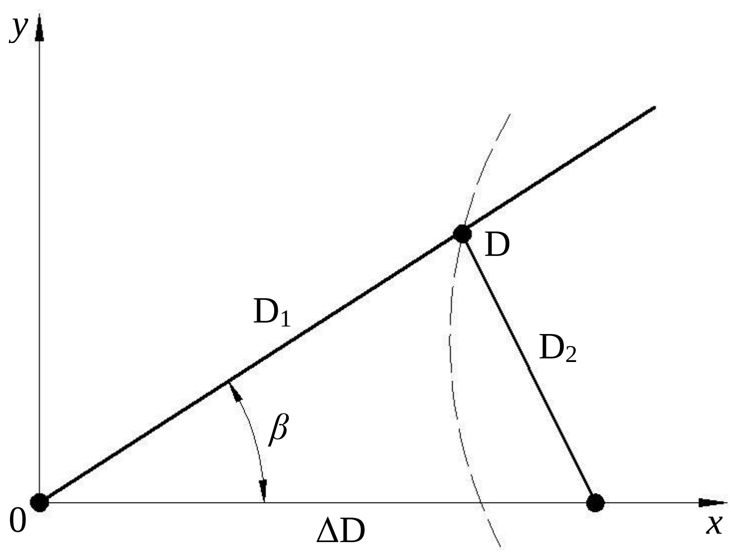

Fig. 1.22. Goniometric and differential and ranging method

It should be noted that the basic and correlation method called above allows to receive the measurement accuracy of corners several angular minutes - the result unattainable for triangulable systems and active sodar stations. The error of definition of angular data at such method is defined by the relation of a measurement error of a difference of the course of signals to length of base. The measurement error of a difference of the course is defined by the relation of an interval of correlation of a signal (values, the return frequency band of the processed signal) to a threshold ratio a signal/noise which possibilities of change are sufficiently limited. In reality the measurement error of a difference of the course makes about 5 - 10 m. But length of base can quite change and what more it will be, big accuracy will provide those a method. So, for example, length of base 30 km provides accuracy 0.6 - 1.2 angular minutes.

1.5 Detection of the UAV by the means of sound monitoring, review of a system

Use of the station working only on pulse signals as means of targeting significantly narrows possibilities of sodar-tracking systems. For example, directors of active noises remain invisible. The recognition of signals implemented for simple impulses becomes complicated in attempts to work on more aggregate signals. Besides, use trend in onboard sodar stations of continuous and quasicontinuous signals was already established that promises to make the method which is based on measurement of delays of arrival of impulses, completely useless for the purposes of defense. Therefore, in sodar-tracking systems use of the pulse channel will be very short, and development perspective behind basic and correlation a detection method which does not depend on modulation of the accepted signals and is potentially steady against noises.

Implementation of methods of a passive location is connected with need of identification, that is establishment of compliance between the signals accepted in different points from the same source. Identification can not be required if there is only one radiation source and it is possible to neglect reception on side lobes of the antenna pattern. In this case at triangulable measurement the source should be in crosspoint of the respective lines of situation. Identification also does not cause difficulty if radiations of sources can be distinguished by the form signals (on the carrier frequency, the nature of code figures of impulses, etc.). Identification is facilitated if the number of the measured parameters exceeds number of coordinates, minimum necessary for definition, - the purposes, for example, instead of three parameters $\beta_1^{(i)}$, $\varepsilon_1^{(i)}$, $\beta_2^{(i)}$ four are measured $\beta_1^{(i)}$, $\varepsilon_1^{(i)}$, $\beta_2^{(i)}$, $\varepsilon_2^{(i)}$.

For identification of stationary processes and on inputs of two receivers caused by the same radiation source it is possible to use the similarity elements (correlation communications) of processes arising at the same time. Use of correlation of amplitudes alone (post-detection correlation), correlations of phases alone (correlation after restriction) and correlations of signals in general taking into account and amplitudes and phases (correlation of signals at an intermediate frequency is possible and at rather big dynamic range of receivers).

Post-detection processing comes down to calculation of correlation function of the bending-around signals, predetection at big dynamic range – to calculation of correlation function of signals. Almost usually it is possible to calculate integral from the work of tension of the signals accepted in two points shifted in time as the temporary shift entered, for example, in one of them

$$z(\tau) = \int_0^T y_1(t-\tau)y_2(\tau)dt = z_1(\tau), \tag{1.9}$$

which, as well as earlier, we will call correlation. At infinitely big time of integration $T \to \infty$ relation of correlation integral to size T gives correlation function of accidental processes $y_1(t)$ and $y_2(t)$. The quality of approach to correlation function is defined by the work PT (the work of width P frequency spectrums of fluctuations for the period of integration of T) bands of the processed signal frequencies for the period of integration. Correlation function of stationary signals has at the same time pulse character. Duration of a correlation impulse is inversely proportional to a band of the processed P frequencies. The provision of a maximum of a correlation impulse on an axis τ corresponds to the difference of temporary delays of a signal on the way between a source and places of acceptance.

For non-stationary emitted signals (faltering, periodic, etc.) at similar processing the difficulties connected with admissions or emergence of false impulses (false counting) can meet.

If on an entrance of the correlator stationary fluctuations arrive from two independent sources $y_{11}(t)+y_{12}(t)$ and $y_{21}(t-\tau_1)+y_{22}(t-\tau_2)$, where the first index 1 or 2 shows number of the receiver, and the second – number of a source, that tension at its exit

$$z_T(\tau)=\int_0^T y_{11}(t-\tau)y_{21}(t-\tau_1)dt+\int_0^T y_{12}(t-\tau)y_{22}(t-\tau_2)dt+ \\ +\int_0^T y_{11}(t-\tau)y_{22}(t-\tau_2)dt+\int_0^T y_{12}(t-\tau)y_{21}(t-\tau_1)dt \quad (1.10)$$

and in case of big time of integration T two last integrals are small in comparison with value of the first at $\tau=\tau_1$ and with value of the second at $\tau=\tau_2$. Therefore at the output of the correlator against the background of the small remains two correlation impulses which are resolved at will be observed

$$\tau_2-\tau_1\geq 1/P. \quad (1.11)$$

If the maximum difference of temporary delays is equal $\tau_{\max}=2B/c$, so number differential and time (differential range, correlation) elements of permission will make $n=P\tau_{\max}$. Equation $P\tau_{\max}$, depending on a method of measurement of coordinates can change in very wide limits.

Let number of the resolved elements on the difference of the course $P\tau_{\max}$ is more, than on angular coordinate $\theta_{rew}/\Delta\theta_{0,5P}$, где θ_{rew} - width of the sector of the review, and $\Delta\theta_{0,5P}$ - resolution on a corner. Then coordinates of a source of radiation can be determined more precisely when using a differential and ranging or goniometric and differential and ranging method, than when using triangulable. The systems of a basic location with differential and ranging and goniometric and differential and ranging methods of measurement of coordinates using a correlation method of processing for definition of a difference of distances are called correlation and basic.

At the same time goniometric and differential and ranging correlation and basic systems solve a problem of identification slightly more simply, than differential and ranging as need to identify results of correlation measurements on different bases disappears.

Feature of devices of a correlation and basic location is the review on temporary delay τ, which is carried out by means of correlators and can be parallel, consecutive and combined.

Parallel review on parameter τ in the passive sodar-tracking system it is carried out by the multichannel correlator consisting of the line of a delay with branches, multipliers and integrators. The delay time of one section of the line should not exceed correlator resolution considerably $1/P$ in parameter τ, that is the number of branches has to correspond to number of the resolved correlation elements. The signal from the output of the first intake is given on the multiplier through the line of a delay with branches, from an exit of the second – via the communication line at the same time on all multipliers. Results of remultiplications are integrated. The maximum correlation tension of a signal will be at the output of the integrator after that section of the line in which delay time corresponds to the measured parameter τ^*.

Consecutive review on temporary delay τ it is carried out by the single-channel correlator in which the delay of one of signals changes continuously. At smooth change of a delay of one of signals at the output of the correlator correlation impulses of tension which peak values on an axis take place τ correspond to estimates τ^* for various sources of radiation there can also be schitana from the indicator screen by means of large-scale tags.

If the review on time of delay is made along with the consecutive review on angular coordinates (for example, on an azimuth), then integration time T is reduced. Let the antenna of one place of acceptance be poorly directed, another – is sharply directed. Then duration of the accepted signal $t_{np} = \frac{\theta_{0,5P} t_{rew}}{\theta rew}$ is defined by width of the directional pattern of the sharply directed antenna $\theta_{0,5P}$, the looked-through sector θ_{rew} and review period t_{rew}. At the parallel review on parameter τ possible time of integration will be $T = t_{np}$. At the consecutive review it in n it is less times, than at parallel, where n - number of the resolved correlation elements. Perhaps combined use of the parallel and consecutive review (or mutual coordination of the review on parameter τ and on angular coordinate θ) for the purpose of increase in time of integration.

The multiple response receiver, being the most widespread type of a receiving device in the systems of a passive sodar-location, it is based on breakdown of range of prospected frequencies on a number of subranges. In other words, in it a set of single-response receivers which amplitude-frequency characteristics, adjoining to each other, block the set frequency range is used. Separate receiving channel turns on the bandpass filter F_i with abrupt cuts, the amplitude detector, the video amplifier and the indicator device by means of which hit of a signal to this canal is fixed. One antenna can service several channels (fig. 1.23).

For increase in sensitivity of a receiving path after the antenna the low-noise amplifier (LNA) can be switched on. Also recording device to which signal outputs from all channels are brought is a part of the multiple response receiver. By means of the recording device detection of output signals of each channel and registration of frequencies of the found signals is carried out.

Multiple response receivers can be also constructed according to the scheme of the superheterodyne. Such receiver consists of the general HF of a part, a heterodyne and the mixer transforming input signals to the area of intermediate frequencies. Further the range of intermediate frequencies is divided by the system of filters into a number of subranges, then for each subrange standard operations of gain at an intermediate frequency, detectings and gains of low-frequency signals are performed.

Multiple response receivers apply, as a rule, in stations of the general survey investigation to rough determination of carrier frequency and type of prospected UAV. The number of channels in them can reach several tens, and sometimes and hundreds. The main advantage of multiple response receivers – their simplicity and reliability. Use of microelectronic element base allows to create multichannel structures with very large number of channels at small dimensions, weight and consumption of energy.

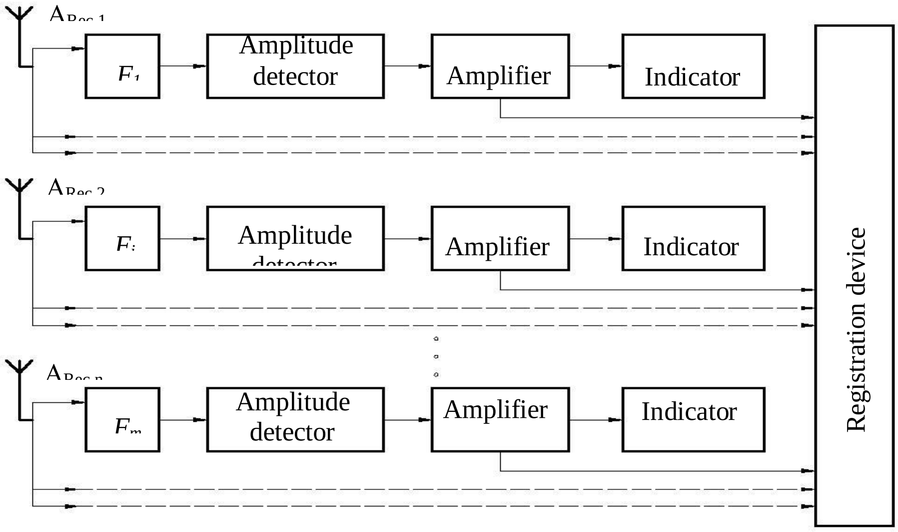

Fig. 1.23. Block diagram of the multichannel receiver of direct strengthening

For example, the principle of work and characteristic of means of acoustic observation of a mono-signal of "Trembita-M" (fig 1.24) and a stereo-signal of "Trembita-BISS" (fig 1.25) was considered

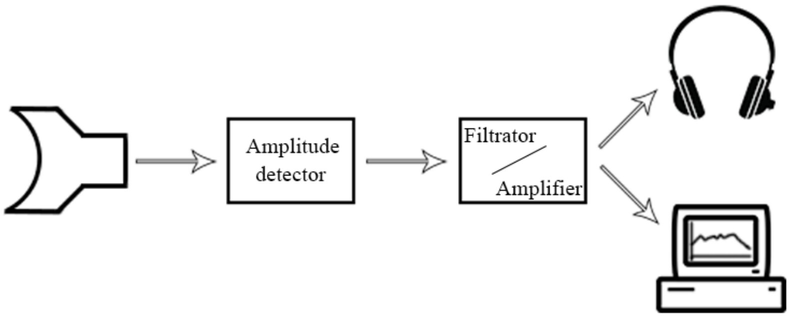

Fig. 1.24 Approximate block diagram of operation of the device of acoustic observation of "Trembita-M"

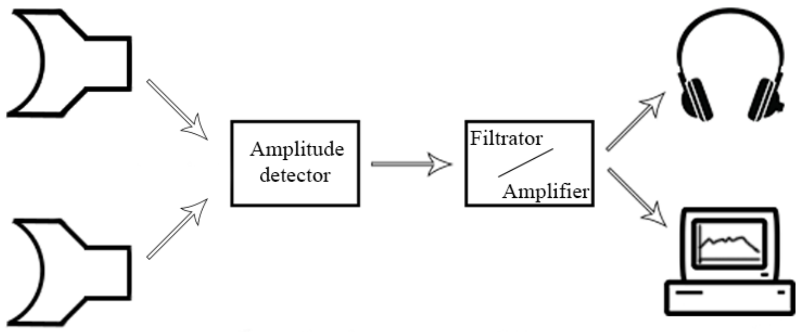

fig 1.25 Approximate block diagram of operation of the device of acoustic observation of "Trembita-BISS"

Characteristics	**Microphone type**	
	Trembita-M	**Trembita-BISS**
Size, mm	420x200x250	450x1250x800
Frequency responce, kHz	80– 10000	50 – 12000
Sensitivity, mV/Pa	35	41
Weight, kg	1.65	6

Table 1.26 Declared characteristics of assumed sodar stations

2. The detection system on the sound field

2.1 The block diagram of the offered system. Advantages and short review of action

Proceeding from shortcomings of the sound monitoring systems allocated above and also the speed, appropriate to a solution of the problem of definition, and the UAV direction the way of integration of a system of sound monitoring and a Doppler sodar, in its passive manifestation was offered (fig 2.1)

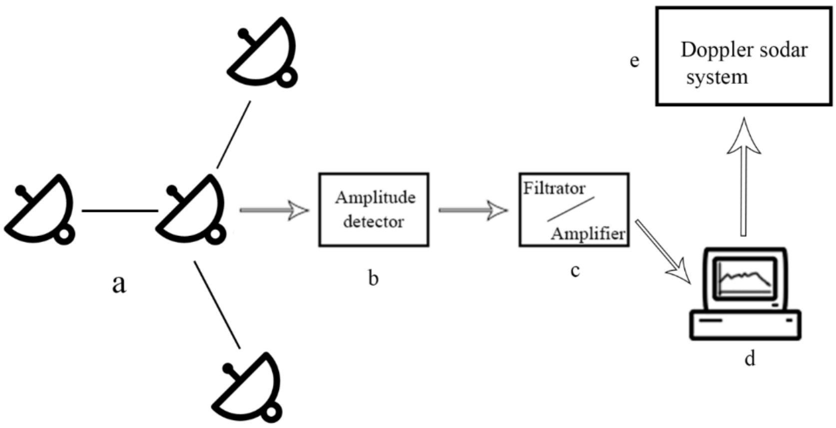

Fig 2.1. General structure of the offered system of sound monitoring

The basis of the proposed method is the peculiarities of the principle of operation of Doppler sodars, namely, their involvement mainly in active sound monitoring systems, which in turn may adversely affect the secrecy of the whole system. In fig. 2.1 (a), the antenna installation of a passive system of sound monitoring is presented, which is generally including 4 parabolic antennas proceeding from bases of determination of coordinates of location of the UAV by a differential and ranging method.

Further, after the spectral analysis, filtration of a signal, with the subsequent its strengthening, for more exact determination of nature of behavior of noise, with further definition of participation of noise in certain characteristics of the UAV is provided in the personal and put systems of sound monitoring.

The essence of the offered method consists in that, after definition by the operator in earphones (it is applicable on portable systems), or the decision-making block (it is applicable to stationary systems) participation of noise which publishes the UAV after positive sign is in addition connected Doppler sodar, for pointed determination of speed of the planned and allocated UAV. More exact structural structure diagram of the offered method of sound monitoring on the basis of parabolic antennas is specified in fig. 2.2

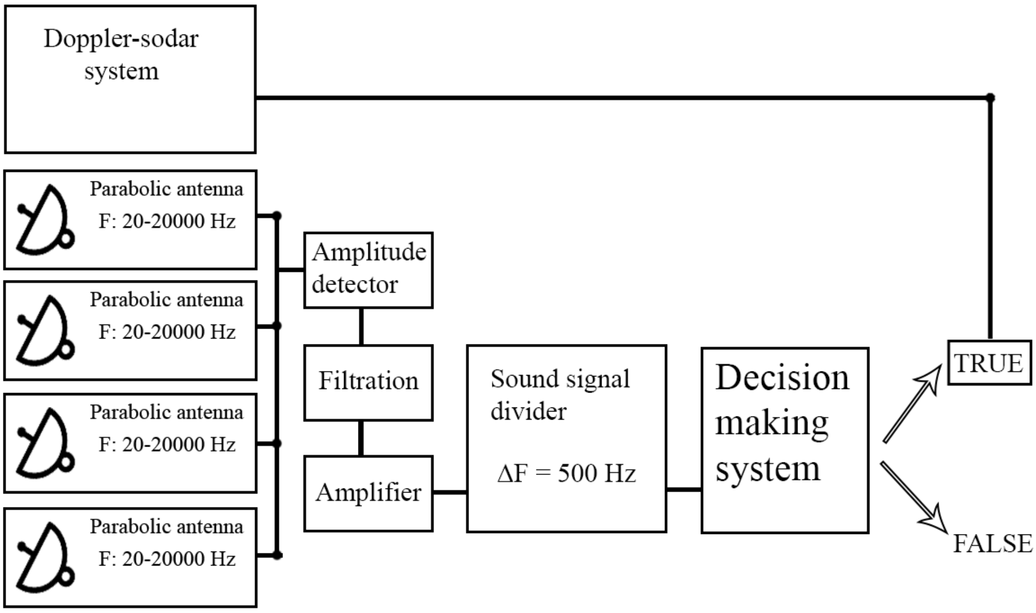

Fig 2.2 The structure diagram of the offered method of sound monitoring, based on parabolic antennas

For improvement of accuracy of definition of the UAV by the passive systems of sound monitoring on the basis of existence of systems of acoustic investigation on the basis of parabolic antennas and microphones of the directed action, the introduction method, with further complexity of a system is also considered (fig 2.3)

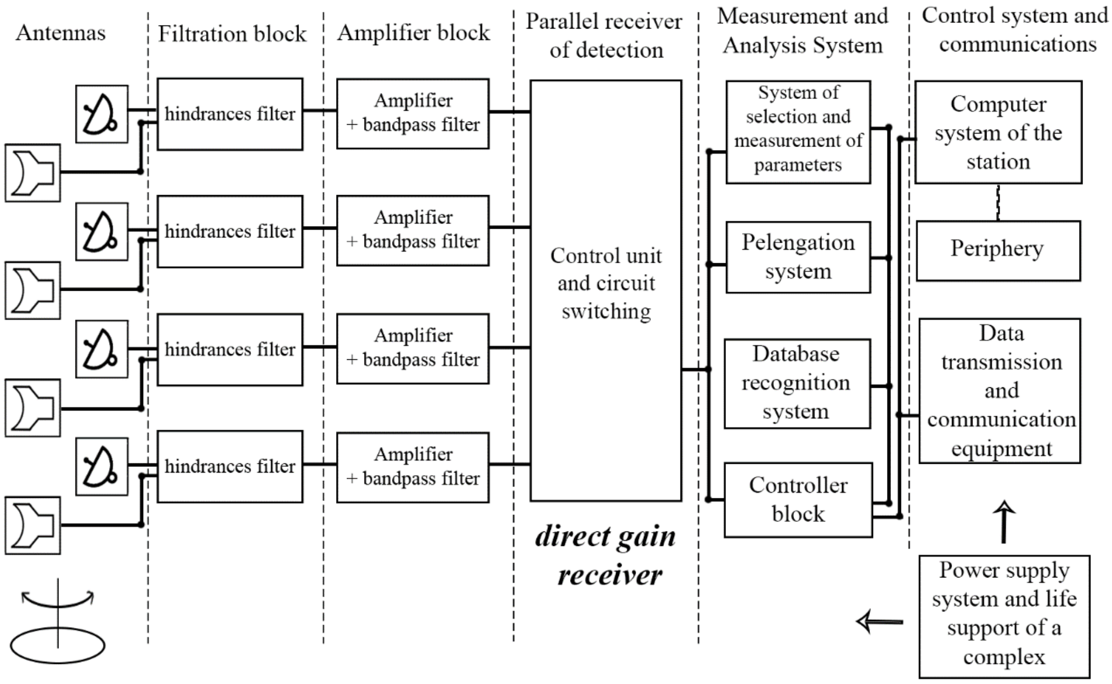

fig 2.3 The structure diagram of the offered method of sound monitoring, based on parabolic antennas and directed action microphones

2.2 Technical means used in sound monitoring stations

2.2.1 Review of existing prototypes of sound detection

In this subsection, existed prototypes of means of acoustic investigation by means of which it is possible to carry out a task of detection of the UAV by the detection methods specified earlier will be mentioned, with consideration of their main characteristics

The simplest on construction is the Super Ear - 100 microphone (photo 2.4). The paraboloid is made of plastic. In focus of the reflector the electret microphone connected to an input of the low-noise amplifier of low frequency is placed. The built-in 8-fold field-glass allows to aim the microphone at the target precisely.

The microphone has the sizes of 290x150x90 mm and weight of 1.2 kg. A power supply of the microphone is carried out from the "krone" battery. Operating time from the internal battery – up to 60 h.

Photo 2.4. The directed “Super Ear — 100” microphone

Photo 2.5, 2.6. Appearance of parabolic the directed microphones

Characteristics	**Microphone type**	
	PKI 2915	**PKI 2920**
Diameter of the reflector, m	0,60	0,85
Mass, kg	0,38	0,40
Range of interception of a talk, m	100	150
power supply	built-in accumulator 9V	

Table 2.7. Main characteristics of the directed parabolic PKI 2915 and PKI 2920 microphones

Characteristics	**Microphone type**	
	Super Sound Zoom	**PR-1000**
Size, mm	290x150x90	500x500x400
Frequency responce, kHz	0,5 – 14	0,2 – 14

Sensitivity, mV/Pa	4	20
Weight, kg	1,2	1,5

Table 2.8. Main characteristics of the parabolic Super Sound Zoom microphones and PR-1000

Characteristics	**Microphone type**	
	Spectra G50	**Big Ears BE3K**
Size, mm	500x500x400	750x750x400
Frequency responce, kHz	0,1 – 15	0,1 − 15
Sensitivity, mV/Pa	31	50
Weight, kg	2	2,5

Table 2.9. Main characteristics of the parabolic Spectra G50 and Big Ears BE3K microphones

The appearance of some tubular microphones is presented on a photo 2.4 – 2.7, and the main characteristics – in table 2.9.

The directed PKI 2925 microphone belongs to standard tubular microphones. Length of the microphone with a tube of 35 cm is 85 cm, weight – 525 g. Power supply of the microphone is carried out from the rechargeable battery by the 3.6 V supply voltage. The microphone has the built-in filters of high and low frequencies.


Photo 2.10, 2.11. Appearance of a tubular PKI 2925 and YKN microphones


Photo 2.12, 2.13. Appearance of the tubular directed Sennheiser MKH 70 P48 and UEM-88 microphones

Characteristics	**Microphone type**		
	YKN	**AT-89**	**UEM-88**
Frequency responce, kHz	500 – 10 000	60 – 12 000	200 – 15 000
Maximum coefficient of strengthening, dB	66	93	50
Sensitivity, mV/Pa	20	70	-
Size, mm	310x30	355x70	229x25x13
Weight, g	130	473	65
Supply voltage, V	3	9	1xAAA
Operating time from the accumulator, h	30	4 – 6	100
Range of interception of a talk, m	100	100	-

Characteristics	**Microphone type**			
	AT4071A	**MKH 70 P48**	**KMR 82i**	**MFC800**
Frequency responce, kHz	0,03 – 20	0,05 – 20	0,02 – 20	0,02 – 20
Sensitivity, mV/Pa	0,02 – 20	50	21	18
Size, mm	395x21x21	410x25x25	395x21x21	500x25x250
Weight, g	155	180	250	350

Table 2.14. Characteristics of the directed tubular microphones

For conducting investigation also, the subminiature microphones are used. For example, the UEM-88 microphone has the sizes of 229×25×13 mm and weight only 65 g. The appearance of some flat microphones is presented on a photo 2.15 – 2.17, and their main characteristics – in table 2.18.

Photo 2.15, 2.16, 2.17. Microphone lattice of the G.R.A.S, 40TA and SPS-980 microphones

Characteristics	Microphone type	
	40TA	**SPS-980**
Number of microphones	64	36
Frequency responce, kHz	0,05 – 6,6	0,02 – 20
Sensitivity, mV/Pa	50 (4)	50
Dynamic range, dB	32 (40) – 134 (174)	30 – 128
Sizes of a lattice, mm	175x175	Ø1000

Table 2.18. Main characteristics of microphone lattices

2.2.2 Review to signal modulators

An amplitude modulator is a device at the input of which a modulating signal acts and a carrier oscillation is generated at the output. Figure 2.19 below shows the structural and schematic diagrams of the amplitude modulator.

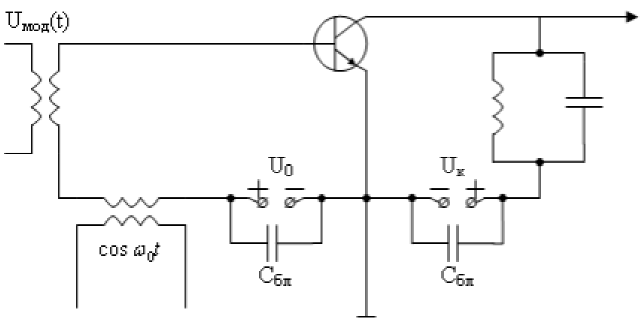

Fig. 2.19 Structural and schematic diagrams of the amplitude modulator

Amplitude modulator consists of three devices: adder, nonlinear element and oscillating circuit. Modulating signal carrying oscillation and DC voltage are added to adder. DC voltage provides position of input signal on nonlinear section of BAX of nonlinear element. A transistor is typically used as the nonlinear element.

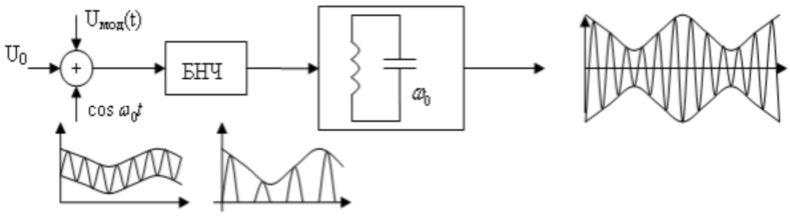

Fig 2.20 Amplitude modulator types of operating

Its purpose is to distort the input signal, as a result of which additional harmonics appear in the spectrum of collector current flowing through the nonlinear element, which are necessary for the formation of AM oscillation. As a load in the modulator, an oscillating circuit is used, the resonant frequency of which coincides with the carrier frequency. Due to this, an AM oscillation is formed at the output of the modulator (on the oscillating circuit).

The balance modulator is implemented on the multiplication circuit of two and is a more complex device than the amplitude modulator on the transistor.

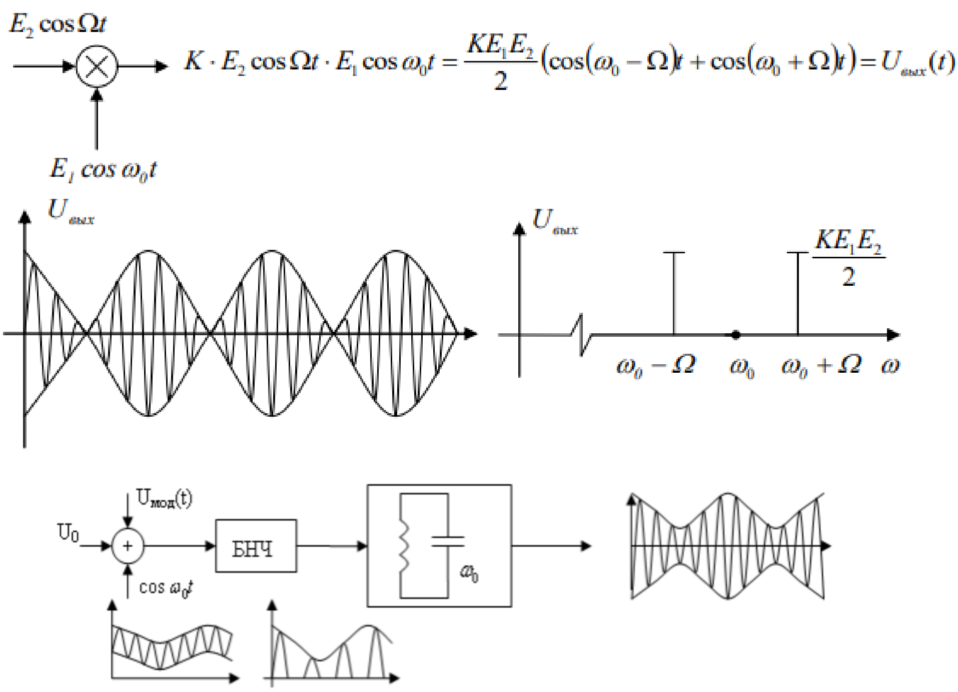

Fig 2.21 The oscillogram and spectrogram of the signal during balance modulation.

The detector extracting the envelope from the balance-modulated signal is also a more complex device. However, with balance modulation, energy is not spent on transmitting an uninformative harmonic carrier.

Amplitude detectors - devices at the input of which AM oscillations, and at the output - a signal repeating the shape of the envelope of the input signal.

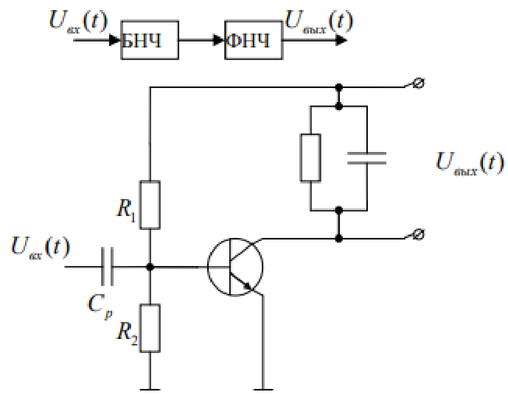

Fig 2.22 Structural and schematic diagrams of amplitude detector

In this scheme, C_p is the separation capacitance, does not pass the constant component of the previous stage, R_1 and R_2 is the voltage divider, which provides a constant displacement to the base (U_0). By changing R_1 and R_2 we change U_0 and thereby select the working section of the RC load - a low-pass filter that provides the extraction of the low-frequency part of the collector current spectrum.

The amplitude detector consists of three devices: a voltage divider, a non-linear element and a low-frequency filter. The DC voltage generated by the voltage divider provides the position of the input signal on the nonlinear section of the of the nonlinear element. A transistor is typically used as the nonlinear element. Its purpose is to distort the input signal, as a result of which additional low-frequency harmonics appear in the spectrum of the collector current flowing through the nonlinear element, which are necessary to form the output signal. As a load in the detector, the RC load is used - a low-pass filter that provides the extraction of the low-frequency part of the collector current spectrum. Due to this, at the output of the detector (at the RC load), a signal is formed that repeats the shape of the envelope of the input signal.

2.2.3 Review to amplifiers

An amplifier is a device for amplifying the power of an input signal. Amplification occurs with the help of active elements due to energy consumption from the power source. The active elements in amplifiers are most often transistors; such amplifiers are commonly referred to as semiconductor or transistor amplifiers. In any amplifier, the input signal controls the transmission of power from the power supply to the load.

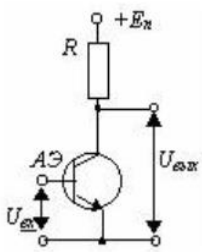

Fig. 2.23 Amplifying stage diagram

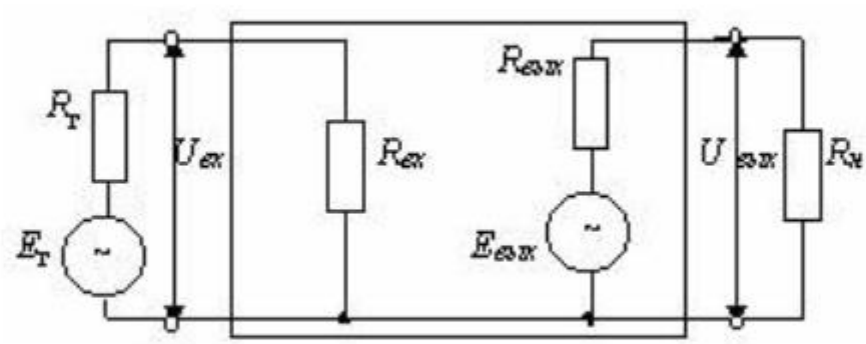

Fig. 2.24 Block diagram of amplifying stage

The operation of the amplifying stage is conveniently explained by the diagram shown in Fig 2.23. The amplifier is based on two elements: resistor R and controlled active element (AE) - a transistor whose resistance varies under the influence of the input signal U_{inx}. By changing the AE resistance, the current flowing from the power supply with voltage E_p in the R and AE resistor circuit is changed. As a result, the voltage drops across the resistor, and therefore the output voltage U_v, will change. Here, the amplification process is based on converting the power source Ep into output voltage energy.

The modern classification of the operating modes of amplifiers is quite confusing. Traditionally, amplifier classes differed in the position of the operating point on the static characteristics of the amplifier. Later, a classification of amplifiers by mode of operation was added: key and current modes of operation. The most common classification of amplifiers is shown in Fig. 2.25.

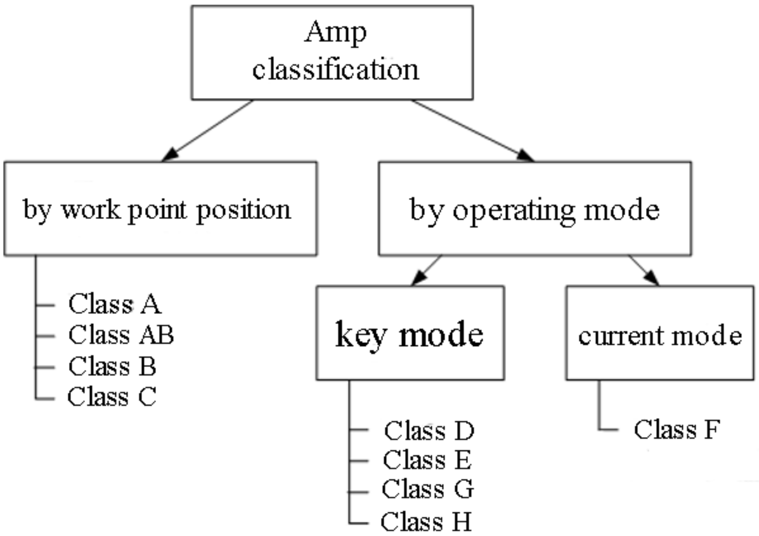

Fig. 2.25. Classification of amplifiers

The mode of operation of the amplifier is determined by the position of the operating point on the direct current transmission characteristic of an amplifier device, such as a bipolar or field effect transistor, electronic lamp. Quite often, the mode of operation of the amplifier is called the class of operation. The selection of the operating point can significantly affect the main characteristics of the amplifier, such as gain, non-linear distortions, etc.

When determining the class of the amplifier, the idealized static characteristic of the amplifier is used. At the same time, the real pass characteristic is replaced by a piecemeal-linear approximation, as shown in Fig. 2.26.

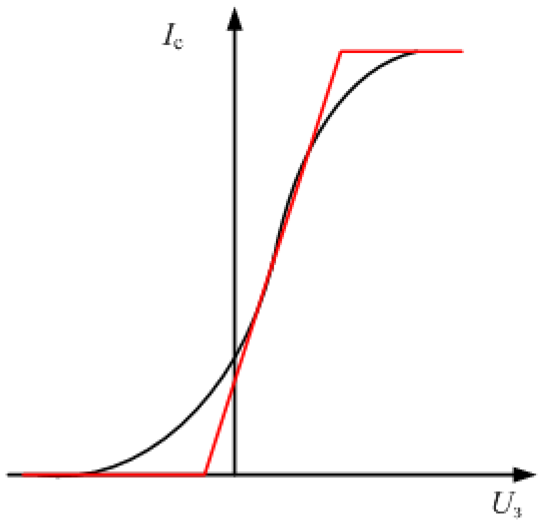

Fig. 2.26. Idealized static characteristic of amplifier

Depending on the position of the operating point on the characteristic of direct transmission of the amplifying device and the formation of collector current (anode, drain), the following types of analog (current) modes are distinguished:

1. class A amplifier - operating point is selected in the middle of linear section of static characteristic
2. class B amplifier - operating point is selected at the beginning of linear section of static characteristic
3. class C amplifier - operating point is selected below the beginning of linear section of static characteristic (amplification of FM signals only)

The amplification features of the signal in the amplifiers of these classes are illustrated in figure 2.27. This figure shows the time diagrams of the output current of the transistor depending on the position of the operating point when the sinusoidal signal enters the input. As can be seen from these time diagrams, Class B and C amplifiers have significant nonlinearity and special measures, such as output filtering or two-stroke circuits, have to be applied to eliminate it.

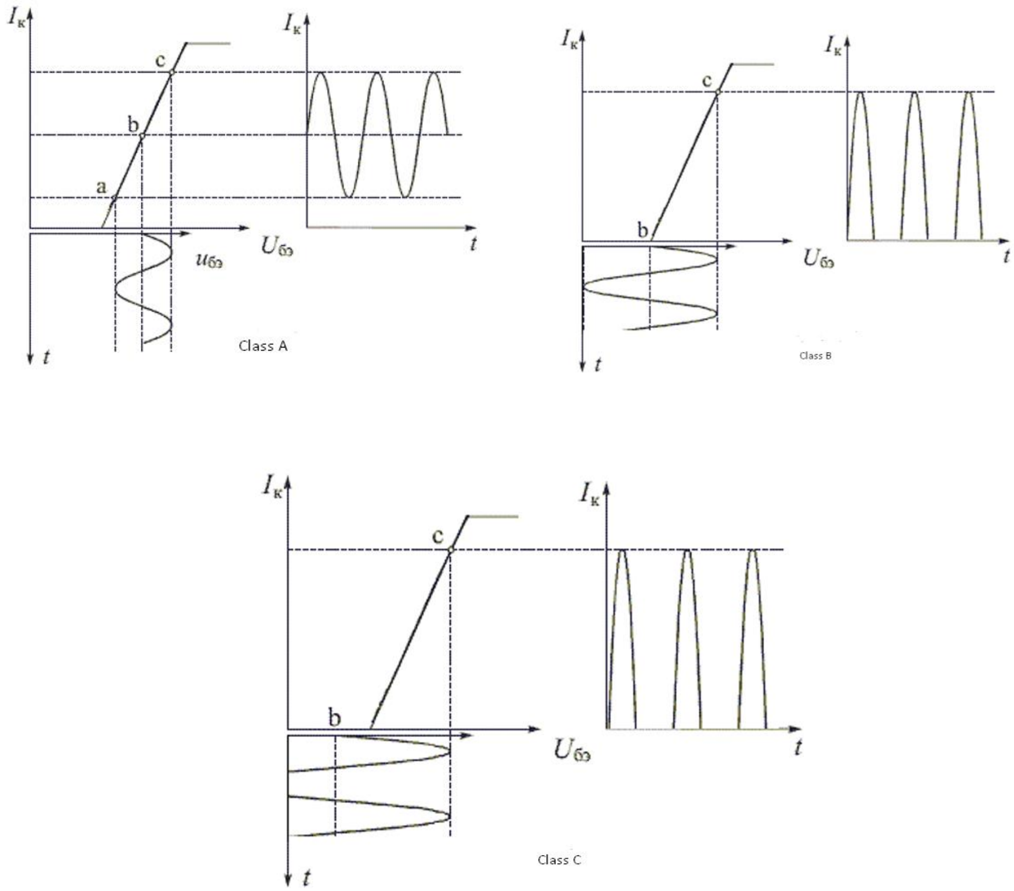

Fig. 2.27. Operating point position in Class A, B and C amplifiers

The operation of the amplifier in the key mode is significantly different when amplifying the low-frequency signal and the high-frequency narrowband signal. In domestic literature, these regimes do not differ. Simply in the literature focused on the low frequency amplifying technique and in the literature focused on the sound frequency application, the key mode is described differently. In foreign publications, depending on the frequency of the amplified signal, the following types of key modes are distinguished:

1. class D - transistor operates in key mode

- audio amplifiers of class D - PWM or ΣΔ-modulation is used to preserve the sound waveform
- high-frequency power amplifiers of class D - additional modulation is not required, it is already present in the amplified signal. In this case, the amplitude is unchanged, information is contained in the frequency and phase of the signal

2. class E amplifier is a narrow-band amplifier in which by means of matching circuits it is ensured that current flows through the amplifier at zero voltage. Switching is performed by high-frequency carrier. Applicable only for angular modulations.

3. class F amplifier is a narrow-band amplifier in which the operating point is selected at the beginning of the linear section, as for class B, and a multi-circuit filter is used as a load, which forms a rectangular voltage on the collector.
When working with high-frequency narrowband signals, a higher value can be realized. Compared to the classical mode of operation of the class B amplifier, this is achieved by emphasizing high-frequency harmonics on the collector or drain of the transistor. This method is well described in domestic literature, but in foreign literature it was called class F.

It should be noted that amplifiers of classes C, E, F are designed to amplify narrow-band high-frequency signals with a high value. Class A, B, D amplifiers are used to amplify low frequency broadband signals such as audio signals, television or digital signals in the BaseBand band. In this case, class B can be used only in two-stroke stages. Class A amplifiers can also be used to amplify high frequency signals if the more important parameter of the amplifier is its linearity and noise factor. Class B amplifiers can also be used to amplify high frequency signals.

2.2.4 Review to hindrance filters

Schematic circuits of the hindrance filters of the 3rd order on the mid frequency of 10 MHz and the bandwidth of 1 MHz are shown on fig. 2.28 (the first element parallel) and fig. 2.29 (the first element co n-secutive).

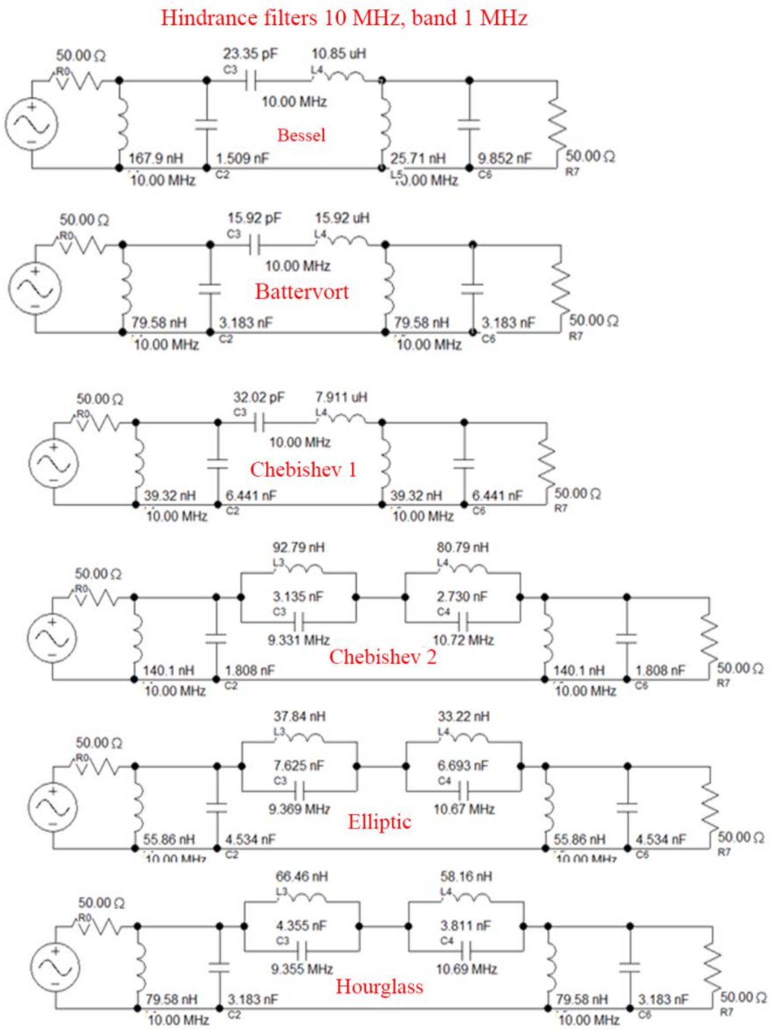

Fig. 2.28 Hindrance filters of the 3rd order

Frequency responce of all these filters near bandwidth is shown in fig. 2.13

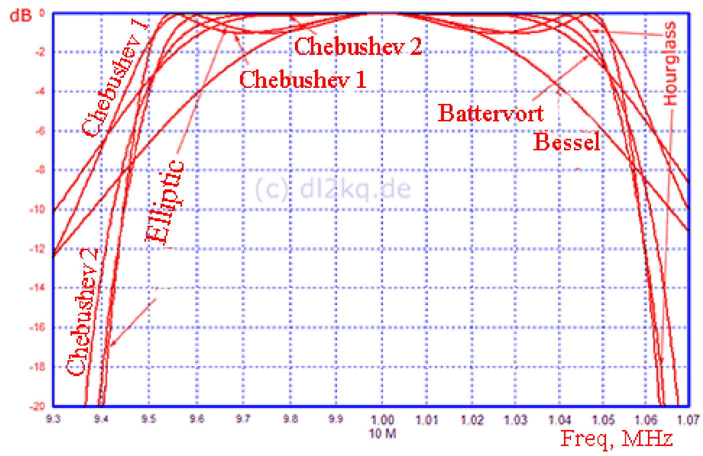

Fig 2.29 Frequency response of the hindrance filters of the 3rd order

The same dependences, as are visible to low frequency phase, and high frequency phase. Most sharply frequency responce on cuts at the elliptic filter falls. It in process of deterioration is followed by Hourglass, Chebyshev 2, Chebyshev 1 and Butterwort. And again, Bessel's filter is bad.

Freq. responce in bandwidth has the same patterns, as for low frequency phase and high frequency phase:

Bessel's filter the worst. At it long before cut-off frequencies Frequency responce begins to be filled up. And this blockage reaches 6 dB at edges of bandwidth.

Butterworth holds equal Frequency responce approximately in 0.4 MHz, and further it begins to be filled up smoothly up to 3 dB at a cut-off frequency.

Chebyshev 1 has wavy Frequency responce in a transparency band with irregularity to 1 dB (it is set at design so much). But and at edges of a band attenuation of only 1 dB.

Chebyshev 2 in a band has almost same frequency responce, as well as Butterworth.

The elliptic filter it is similar to Chebyshev 1 has irregularity in a band of 1 dB (this value is also set by the user in basic data for design) and easing 3 dB at a cut-off frequency.

Hourglass has flat frequency responce almost at detunings to 0.43 MHz and easing 3 dB at edges of a band.

frequency responce of all filters of fig. 2.28, 2.29 at big detunings are shown in fig. 2.30. patterns of these frequency responce same, as for low frequency phase and high frequency phase. Peak attenuation behind a band Chebyshev 1 gives, the maximum cutoff rate near bandwidth – the elliptic filter.

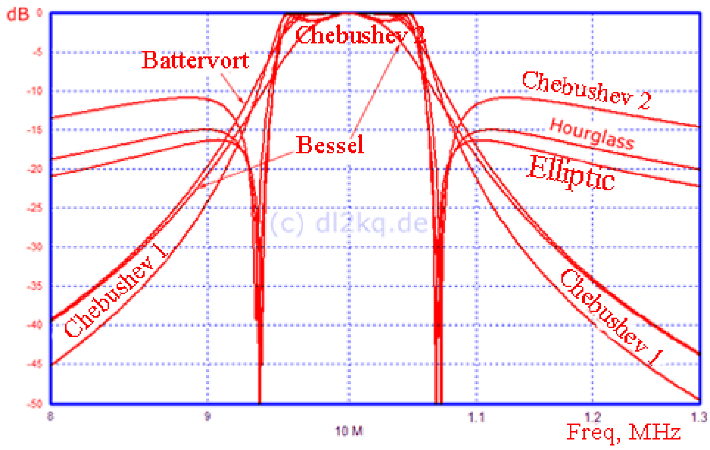

Fig 2.30 Frequency dependences of coefficient of reflection on an entrance

In the following fig. 2.30 frequency dependences of coefficient of reflection on an entrance are shown (what will show the reflection coefficient measuring instrument in the provision" the Reflected wave") for all types of filters of fig. 2.31, 2.32.

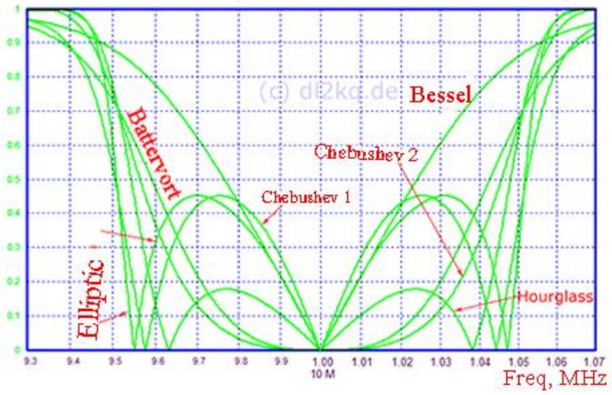

Fig. 2.31 Frequency dependences of reflection coefficient of hindrance filters of the 3rd order

The same patterns, as at low frequency phase, and at high frequency phase are visible:

- very bad approval behind a band.
- Bad approval in bandwidth at Bessel's filter.

Butterworth's filters, Chebysheva 2 have good approval at detunings 0.3 MHz, and further as approaching edges of a band their approval quickly worsens.

Approval of filters of Chebyshev 1 and elliptic not really good in a band, but improves near cut-off frequency.

The reflection coefficient of Hourglass of the filter does not exceed 0.2 (i.e. reflection coefficient = 1.5) for detunes 0.42 MHz, but quickly grows when approaching to edges of a band. If good approval in a band (for example, it is the band bandpass filter on a receiver input) is necessary, then the best exit of Hourglass with a band on ~ 15 … 20% will be wider than the used range.

In fig. 2.32 forms of a signal output of all filters of fig. 2.28, 2.29 when giving on their input of the front of single rectangular jump are shown. As the front of this jump is considered infinitely short, in its range there are all frequencies. Including getting to a band of transparency of our filters.

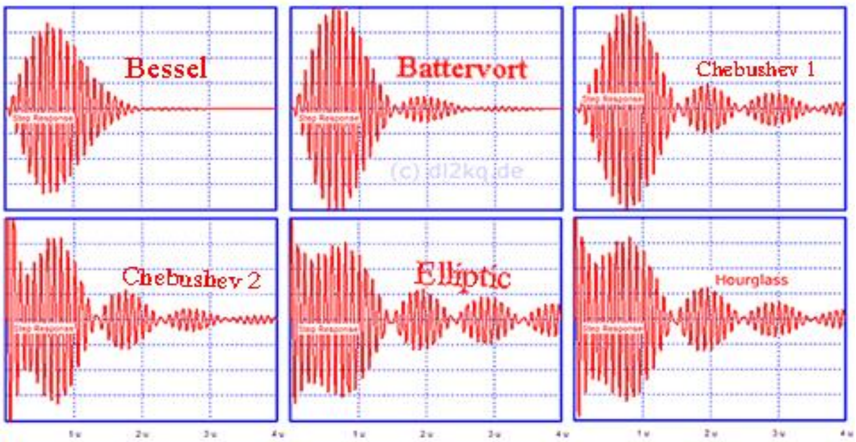

Fig 2.32 Forms of a signal output of hindrance filters of the 3rd order

Bessel's filter passes everything, getting to its band of transparency, and practically adds nothing from itself. All other filters give additional "ring". Stronger and longer the elliptic filter rings. Then in process of improvement there are Hourglass, Chebyshev 2, Chebyshev 1 and Butterworth.

2.3 The optimal selection of a set of technical means for sound monitoring systems

2.3.1 Optimal selection of antennas and microphones

At the basis of the system of sound monitoring of passive definition of the UAV offered by my own researches, the best solution at the moment is portable parabolic microphone “Big Ears B3EK” (photo 2.33)

Photo 2.33 The “Big Ears” B3EK parabolic microphone

Characteristics of the parabolic basis of the microphone:

- Parabolic diameter: 24 inches or 60 cm.
- Weight: 6 pounds or 3 kg.
- Range: 0.9-150 meters (depends on conditions).
- Support: Manual

MICROPHONE

- Capsule: constantly polarized condenser
- Polar chart: line gradient
- Frequency response: 20-20,000 Hz
- Relation signal / noise: 77 dB, 1 kHz at 1 Pa
- Range: phantom 112 dB of max. SPL @ 1 kHz
- Low-frequency recession: 80 Hz, 12 dB / octave

- Requirements to phantom power: 11-52 V of cm, but are normal 2 - the Battery: 1.5 V of mini-stilo/UM3
- Battery service life: 0.4, but 1200 hours (the alkaline battery) are normal /
- Accessories: windshield

PREAMPLIFIER

- The maximum gain 66 dB, for eleven discrete steps.
- The dynamic range exceeding 120 dB.
- Width of a sound band is from 10 Hz to 50 kHz.
  (frequency response of hindrances filter)
- High resistance to sound-frequency noises.
- High-current driver of a linear exit.
- The input balanced by the transformer and exit with the limiter of a pica of expanded range by means of two optoisolators does by the preliminary amplifier almost "disconnected"
- The choice of phantom power of 48 V / 12 V or "In" 12 V
- The high pass filter at 80 or 160 Hz, 6 dB on an octave
- Monitoring of earphones from the microphone, a sound of the monitor or their combination
- The input of the monitor accepts monophonic, balanced or unbalanced linear inputs on the 1/4-inch connector with a tip and a tip.
- Separate control of the gain level of the monitor and overall gain of earphones.
- Function of division of ears via DIP switches
- Internal accumulator supply (two AA)
- Excellent battery life from alkaline and nickel-metallogidridnykh of accumulators
- External power supply of 5-17 V post. Current (with a fork in a set)
- The high-strength aluminum chassis with a strong clip for a belt

However, due to the high cost of this installation, as well as further difficulties in integrating this device into the passive sound monitoring system, it is proposed to assemble a device with similar parameters, but based on previously known elements In this case, as a solution for capturing sound from a parabolic microphone, I will recommend a B085 model manufactured by Kemo Electronic, Germany

Photo 2.34. B085 sub-assembly kit

The microphone capsule must be connected to the printed circuit using a short wire (max. 10 cm).

The integrated circuit must be inserted into the printed circuit in such a way that the mark on the housing of the integrated circuit coincides in orientation with the designation on the printed circuit. In the kind of parabolic mirror, a hemisphere of artificial material with large dimensions as possible can be used. The printed circuit must be placed so that the sound input hole of the microphone (black side) is oriented to the center of the hemisphere so that the microphone can capture the concentrated and reflector-connected sound waves. The best result is obtained when using headphones with a resistance of 8-32 ohms, with soft rubber in the diameter of the headphones. With a potentiometer, you can adjust the volume. If there are different disturbances - pulsations, AC backgrounds, etc., the printed circuit must be placed in the metal housing and this housing must be grounded (connected to the minus pole of the battery). The microphone is so sensitive that it catches the smallest noise. The cable to the headphones and to the power should not get more than 10 meters. In no case should the microphone be connected to the printed circuit by a cable longer than the specified length.

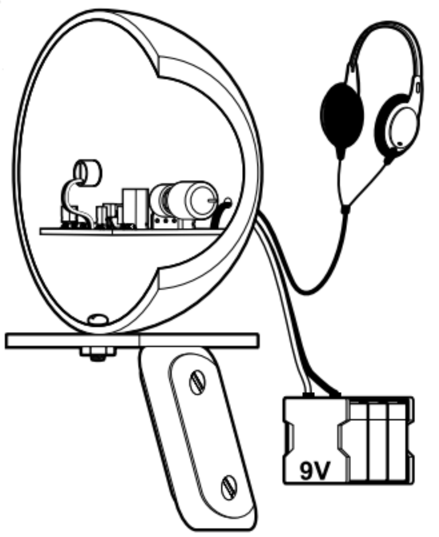

Fig 2.34 Assembly proposition of B085 kit

Description of the switching-on scheme:

Sound waves are concentrated and connected using a parabolic mirror and are captured by a special highly sensitive electret microphone. The pre-amplifier amplifies the microphone signal, its level is adjusted using the volume controller ("P1") and is supplied to the input of the output amplifier "IC." Here, the signal is amplified and through "Pin 3" is supplied through the etrolite capacitor "C3" to the headphones.

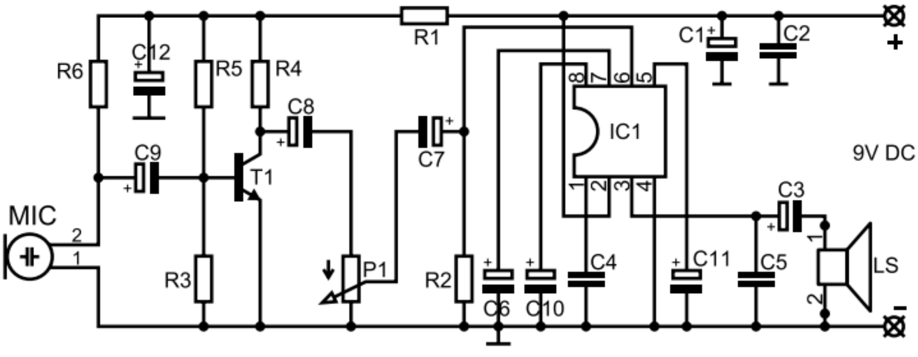

Fig 2.35 B085 sub-assembly kit scheme

Technical data:

- Mounting kit: for self-assembly | Audio receiver: highly sensitive FET capacitor microphone | Sensitivity: adjustable | Module has input for headphones: 8 – 32 ohms | Operating voltage: 9 volts DC voltage | Current consumption: max. approximately 230 mA |

- Printed circuit dimensions: approximately 55 x 55 mm

2.3.2 Optimal selection of the amplifiers

The efficiency is the main parameter for audio power amplifiers. The main parameter determining the energy consumption of the output amplifier stage is the power dissipated on its transistors. At the same time, the power will not be dissipated in two cases:

- current through the transistor at non-zero voltage is zero;

- transistor voltage at non-zero current is zero.

These conditions are met when the transistor operates in the key mode. The first condition will be satisfied if the transistor is completely closed (cut-off mode). The second condition will be satisfied if the transistor is fully opened (saturation mode). This is how transistors work in digital chips, for example, the logic department.

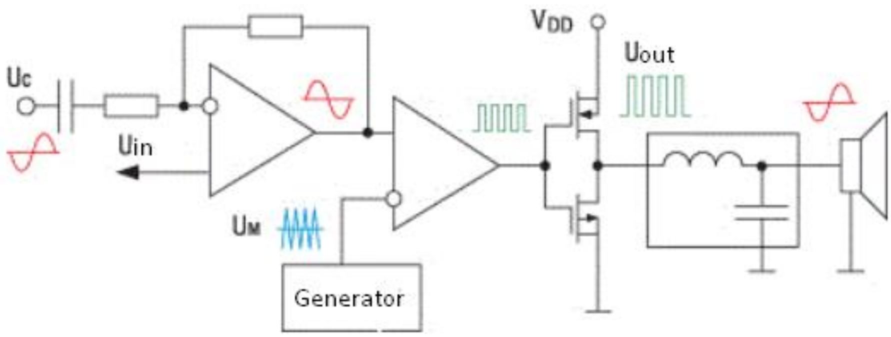

Fig 2.36 General scheme of class D amplifier

Since the output power of the power amplifier is usually from one to hundreds of watts, LC filters are usually used. The purpose of the filter is to suppress the frequency of the sawtooth signal modulated by the useful signal and its harmonics. In order to use the simplest second order filter, the frequency of the sawtooth signal is selected within two megahertz. Since the frequency of the modulating signal exceeds the upper frequency of the sound spectrum by 100 times, a second-order filter consisting of an inductance and a capacitor is capable of suppressing interfering signals by 80 dB (with an appropriate design).

A slightly different approach for building class D amplifiers is used by Analog devices. Its chips use a sigma-delta modulator instead of a PWM modulator. This makes it possible to raise the internal frequency to such a value that an external low-frequency filter is not required. Its functions are performed by the speaker. The internal diagram of such a chip is shown in Fig. 2.37.

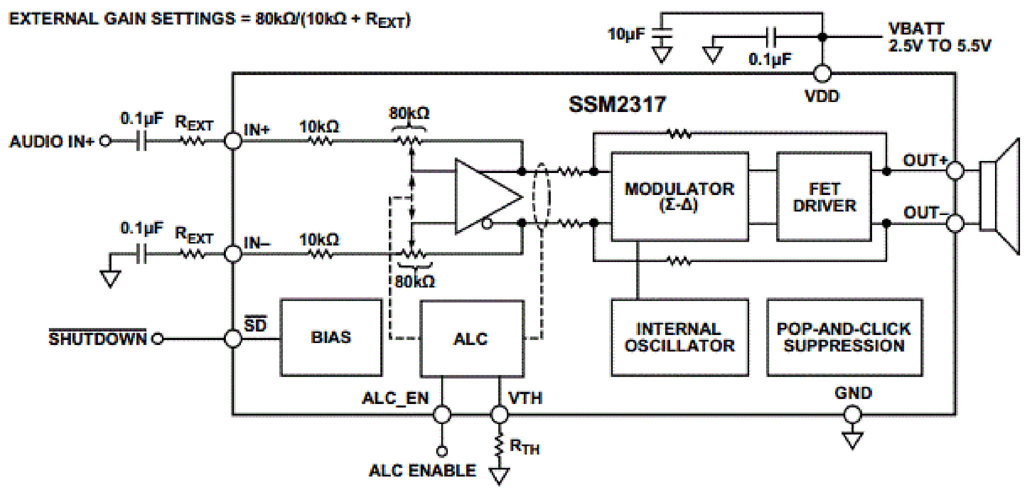

Fig 2.37. Internal circuit of the chip SSM2317

It should be noted that such schemes practically do not require bulky radiators that dissipate excess heat. Figure 2.37 shows typical schematic diagram of class D audio frequency amplifier.

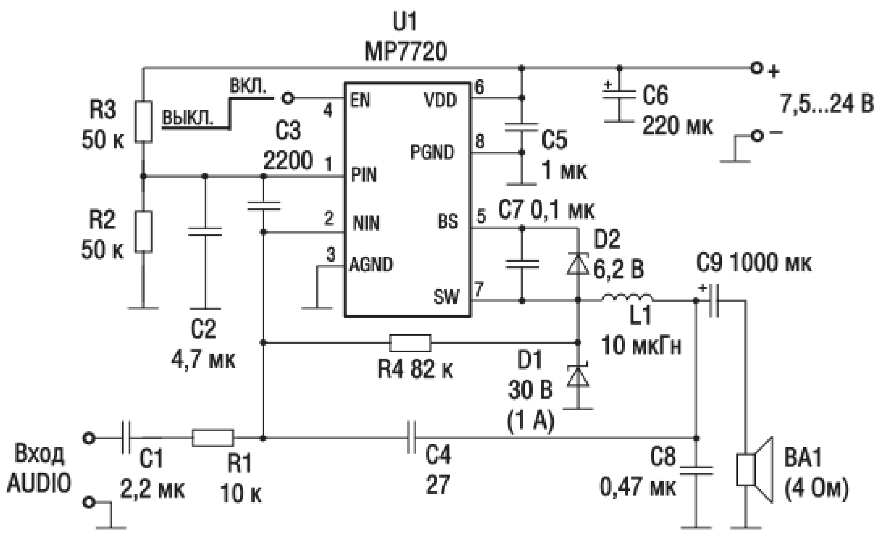

Fig 2.38. Class D audio power amplifier circuit diagram on the MP7720 chip

In this scheme, resistors R4 and R1 determine the depth of negative feedback, which affects the gain of the amplifier and its non-linear distortions. Resistors R3 and R2 set the mode of operation of the differential amplifier at the input of the DC chip (half of the power supply). Diodes D1 and D2 protect the output stage from overvoltage. Filter, which extracts sound signal from PWM, is assembled on inductance L1 and capacitor C8. The vessels C1 and C9 are separable.

2.3.3 Optimal selection of hindrance filters

There are a sufficient number of third-level interference filters to solve this problem, but for filtering of pulse signals at a carrier frequency only Bessel's filters use. Despite of their unimportant frequency selectivity. Because phantom signals from "a ring" of the high-selective filter will nullify the idea of filtering. Filtering was necessary for us to get rid of interfering signals, but not to create new.

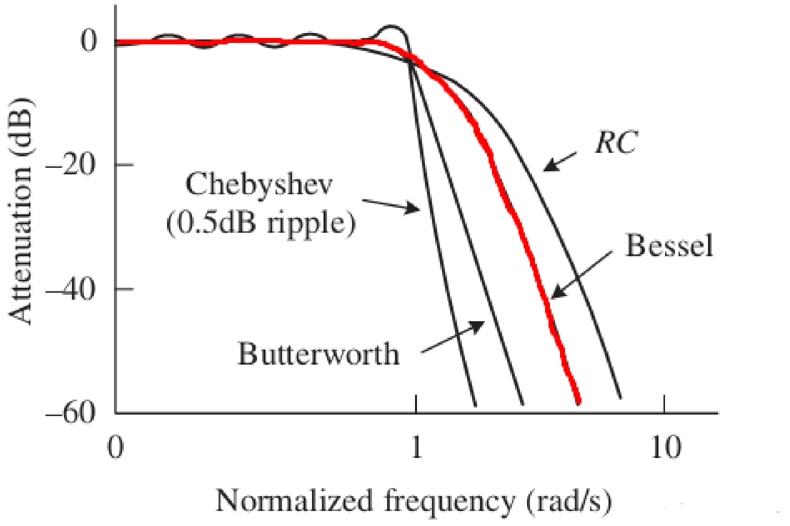

Fig 2.39 Normalized frequency filtering of the hindrance filters

For example, if having flattered on good frequency responce, in a low-frequency path of KV of the receiver to put for reception of telegraph Chebyshev's 1 filter, then weak CW signals "will be spread" by the additional fluctuations created by the filter.

Due to the constant delay at all frequencies to the cutoff frequency, the Bessel linear-phase filter is used in audio applications in which it is necessary to remove out-of-band noise without affecting the phase relationships of the components of the multi-frequency useful signal. The high rate of response of the Bessel filter to the voltage jump and the absence of emissions and ringing on the transient characteristic make it an excellent choice for smoothing the output signal of the audio DAC or anti-alising filtering at the input of the audio ADC. In addition, Bessel filters are useful in analyzing the output signals of class D amplifiers, as well as for suppressing switching noise in other applications where it is necessary to clear the signal for oscillographic measurements.

Although the Bessel filter has a flat amplitude-frequency and linear phase characteristic, that is, a smooth group delay characteristic, its selectivity is worse than that of Butterworth or Chebyshev filters of the same order (with the same number of poles). Therefore, in order to obtain the desired level of attenuation in the delay band, it is necessary to design a higher order Bessel filter, which in turn will require careful selection of active and passive components to minimize noise and distortion.

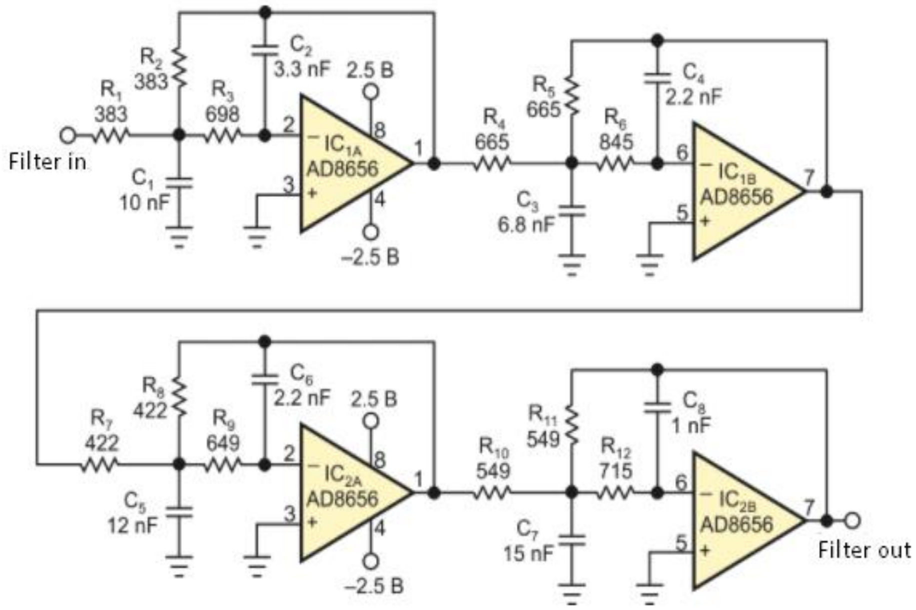

Fig 2.40 High-quality low-frequency Bessel filter of a 8nd order with a cutoff frequency of 30 kHz

Figure 2.40 shows an eighth order high-quality low-frequency Bessel filter with a cutoff frequency of 30 kHz. In this design, resistors with nominal values standard for a tolerance of 1% and ceramic capacitors with a permissible capacity deviation of 5% are used. Alternatively, capacitors with a 10 percent tolerance may be used, but then the group delay dispersion in the bandwidth will increase. It is also desirable that the capacitors have good thermal stability.

the filter processes bipolar audio signals, and two ± 2.5 V voltages are used to power its amplifiers. At such low power voltages, it is better to choose operational amplifiers with Rail-to-Rail output to obtain the maximum output voltage span. In order to provide a good signal-to-noise ratio in a high-quality audio device, amplifiers must remain stable at a single gain and have a low level of native noise. These requirements are met, for example, by the Analog Devices low-noise precision dual operating amplifier AD8656.

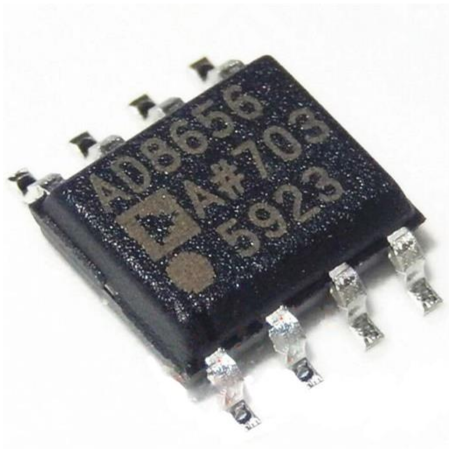

Photo 2.41 AD8656 operating amplifier

Connecting amplifiers into a chain of inverting stages with a single transmission coefficient at zero frequency maintains a constant level of in-phase input voltage and minimizes non-linear distortion. To minimize the contribution of thermal noise, resistors with a resistance of less than 1 kOhm are used in the circuit. The noise density of each amplifier AD8656 in the 30 kHz frequency band does not exceed 3 нВ/√Hz, and measuring the total mean square noise voltage in the 30 kHz band gives a result of less than 3.5 μV. At input signal 1 V r.k.z. the signal to noise ratio of the circuit is better than 109 dB, and the sum of total harmonic distortions and noise at a frequency of 1 kHz does not exceed 0.0006%.

2.3.4 Surge protectors

A surge protector is a device using which various kinds of interference are removed both between the nodes of the system and directly when powering the station from various kinds of batteries or direct networks.

It is believed that the main cause of interference in electronic circuits is the harmonics that make up the digital signal. High

frequency of harmonics results in that they are easily emitted. If the harmonic frequency is near the frequency of the sound or TV broadcast signal, then

harmonic is superimposed on the sound signal, and interference occurs in the receiver.

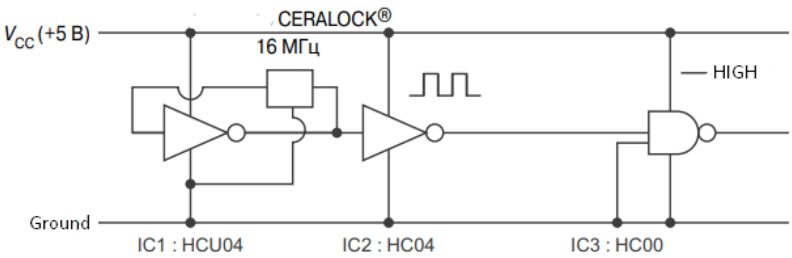

Fig 2.42 Scheme of assumed circuit without pre-implemented surge protector

Interference in power circuits is considered another cause of electromagnetic interference in electronic circuits. The digital chips are powered by a DC voltage source and the current at the power supply terminal will be changed by jumps according to the nature of the operation of the digital chips. This kind of chaotic current changes lead to interference, harmonic is superimposed on the sound signal, and interference occurs in the receiver.

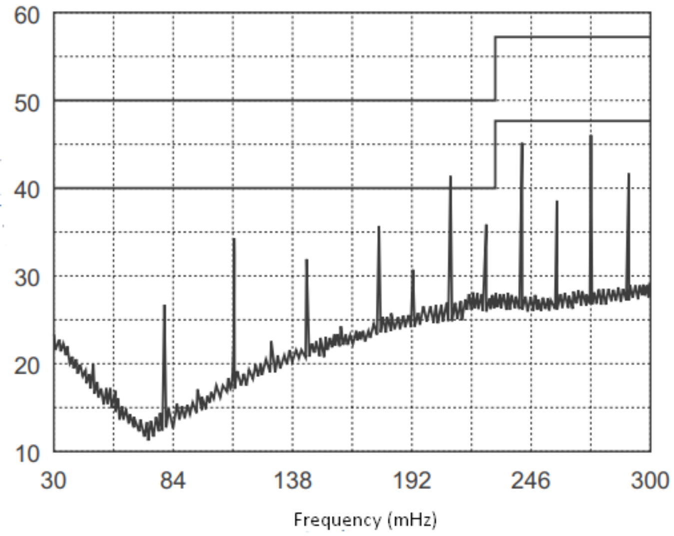

Fig 2.43 Level of measured interference in the assumed circuit

Figure 2.45 shows the results of the interference suppression experiment emitted by the signal printed conductor, which serves as an antenna for interference (differential interference). A network filter installed between the output of the IC2 chip and the printed signal conductor (Figure 2.44) can significantly reduce interference. The network filter used in this experiment is a combination of an EMIFIL ® chip filter for signal lines and a 30-meter resistor, thereby minimizing distortion of the digital waveform.

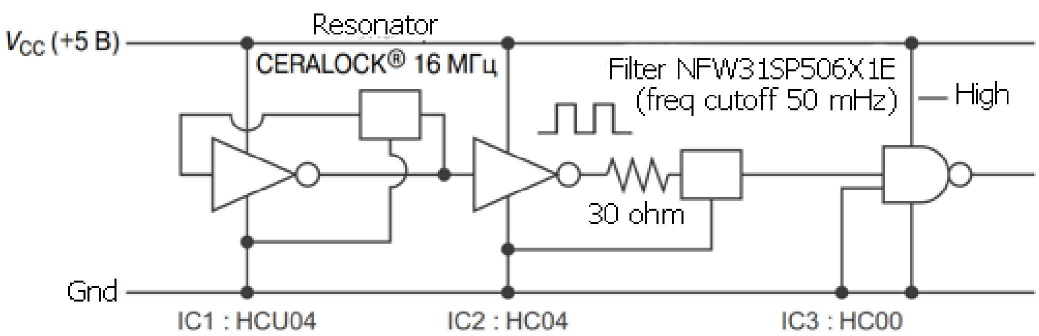

Fig 2.44 Scheme of assumed circuit with pre-implemented surge protector

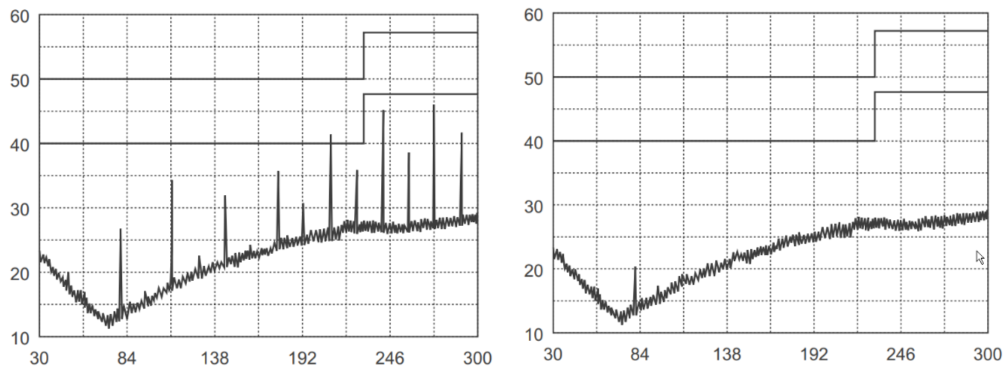

Fig 2.45 Level of measured interference in the assumed circuit without and with surge protector

In case of avoidance of interference of specific nodes of the system, separate shielding of each of the nodes is also required.

The figures show how the level of interference emitted by the digital circuit changes when shielding conditions change. If unchanged

The total hole area of approximately 2500 mm^2 changed the hole dimensions as shown. From the measurement results, it can be seen that the shielding effect is higher if the entire indicated area is divided into a plurality of small holes. In contrast, the shielding effect is substantially reduced if the shielding body has one large

rectangular hole.

The test circuit was placed in a shielding case, after which the level of emitted interference (signal frequency 25 MHz) was measured.

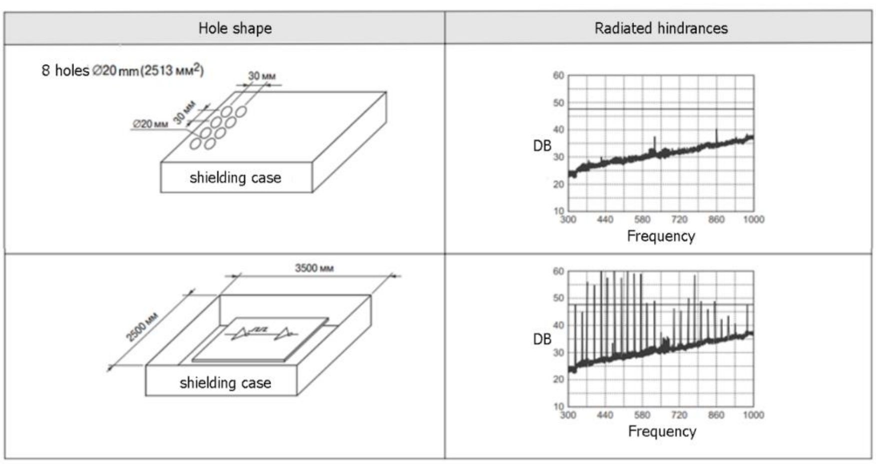

Fig 2.46 Elements shielding as a part of the system

The key to achieving the best shielding effect is to select the configuration of the holes and gaps between the contacting parts of the shielding body. To increase the shielding effect, we must increase the contact area between the parts of the shielding body so that the slots and gaps have a minimum length.

The connections of the contact parts of the shielding body shall have a low impedance and the parts shall be adjacent to each other without gaps. Make sure that the metal surfaces of the shielding housing are not covered with insulating material at the points of connection.

As for the choice of network filters, each of two types, namely capacitive and inductive, is used in different cases.

1. Near the source of interference.

a) Capacitive network filter as main element:

• Line that includes devices with high input and output impedances.

• High interference line (e.g. clock line, control bus line).

b) Inductive network filter as main element:

• A line that includes low input and output impedance devices (e.g., a power bus to which a bus controller is connected).

• Line with relatively low interference level (as no earthing is required and filter installation is easier).

• The line in which it is required to limit the current (for example, many lines with simultaneous switching, in which large currents flow to the ground - address and data buses, control bus).

2. Interference in transmission circuits.

Use a combination of capacitive and inductive network filters.

In order to suppress interference in the transmission line, for example in the interface cable connector, an inductive interference cancelling filter should be used in combination with a capacitive filter, since such a line requires a high suppression coefficient, and in most cases, there is no good ground.

3. Development of algorithmic providing

3.1 Problem definition of algorithmic providing

The major task for detection of the UAV the sound systems of sound monitoring is increase in accuracy of determination of coordinates and speed of data processing. The offered algorithms of the solution of problems of determination of coordinates are based on the modified Newton's method and Jacobi's matrixes will allow to develop and realize the computing method allowing to accelerate process of calculation of coordinates of the UAV complexes of sound monitoring

Also, there is a question on reduction of level of an error by method of parametrical sensitivity on coordinates of air targets and a relative error of measurement of arrival time, with the offer of a different approach to the solution of a problem of determination of coordinates.

3.2 Structure of algorithmic providing

3.2.1 Algorithmic realization of methods of increase in accuracy of determination of coordinates of UAV

One of the main objectives of systems of a sodar-location is UAV identification, that is properties and characteristics of signals, to the relevant these sources and also their coordinates. Advantages of systems of passive sound monitoring are the reserve of work and also ample hardware-software opportunities of the analysis of the accepted signals, and the main shortcoming is quite high error, up to 10%, determination of coordinates of UAV.

The structure diagram of determination of coordinates of UAV is submitted by the passive system of sound monitoring in fig. 3.1.

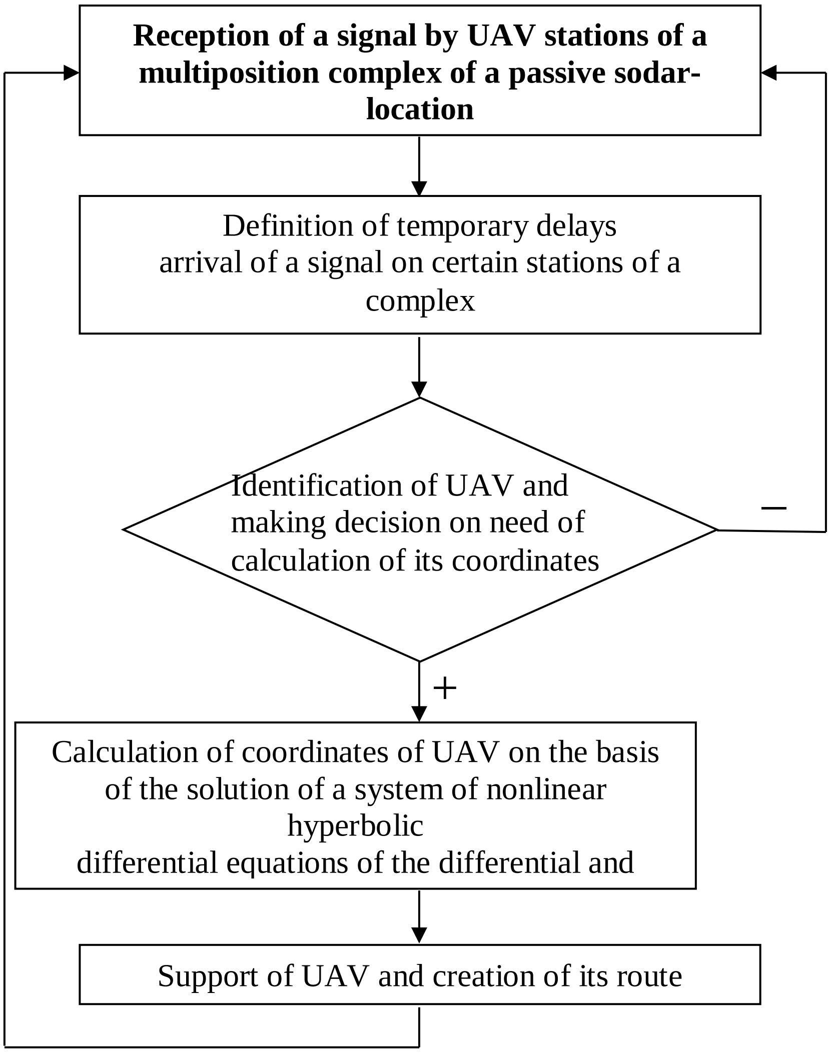

Fig. 3.1. The structure diagram of determination of coordinates the UAV system of passive sound monitoring on the basis of a classical TDOA

Accuracy of determination of coordinates can be increased by passive means of sound monitoring at the expense of a different approach to the solution of a system of the equations of TDOA based on extreme statement of the square functionality consisting of the sum of not knittings of these equations with the weight coefficients considering an error of determination of coordinates of each of stations separately (fig. 3.2).

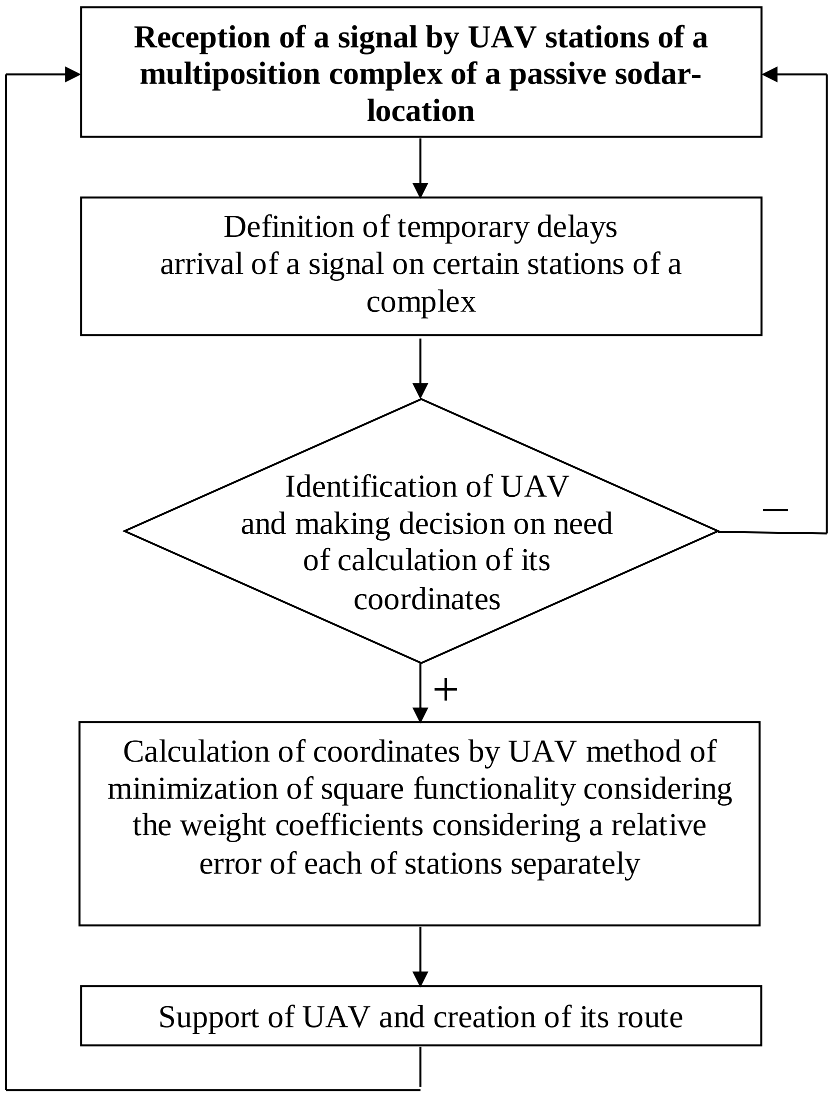

Fig. 3.2. The structure diagram of determination of coordinates the UAV system of passive sound monitoring by means of extreme statement of a TDOA

For the analysis and identification, the SEO frequency, time and time-and-frequency responses of signals can be used.

Are among frequency parameters:

- values of frequencies of emitted fluctuations;
- borders of ranges and their change at reorganization;
- values of radiated frequencies at discrete reorganization;
- frequencies of following of sound pulses of radiation;
- values of frequencies of following of sound pulses of radiation at discrete reorganization;

Are among temporary parameters:

- nature of a sound emission (continuous or pulse);
- value of duration of impulses of a sound emission;
- value of duration of impulses of a sound emission at discrete reorganization;

Treat time-and-frequency parameters:

- the nature of frequency change of a sound emission in time (invariable, changing from an impulse to an impulse, changing within an impulse);
- the nature of change of instant frequency of a sound emission within an impulse (linear, intermittent, pseudorandom, accidental);
- the nature of frequency change of following of impulses of a sound emission (invariable, changing on the set law, changing in a random way).

The analysis of standard sodar stations allows to draw the general conclusions that when developing requirements to the information and measuring systems of identification of standard objects of a sodar-location in parameters of sound emissions it is necessary to consider the following:

1. Sodar stations can be sources of both pulse, and continuous radiation, and both frequency, and temporary parameters of radiation can change in the course of functioning of sodar station under the difficult, including accidental law. The specified circumstance does not allow to process such signals by means of the approaches applicable to stationary processes. In particular, the processing methods using hypotheses of stationarity and ergodicity are excluded.

2. Not stationarity of the signals displaying a sound emission of sodar station causes need of estimation of their informative parameters during the whole time of observation of radiation of sources. Reduction of this time or use for such estimates of limited temporary segments of signals can significantly reduce their informational content that will cause deterioration in reliability of identification. This circumstance indicates processings of full-size realization of the signals displaying a sound emission, means of receiving dynamic spectral estimates in real time the need.

3. The difficult nature of change and not stationarity of the probing signals displaying the law of change in time of radiations of sodar station cause need of use

of the consecutive procedure of their analysis for an information and measuring system, beginning from detection of a sound emission in some, rather wide range, the subsequent specification of parameters of a sound emission in the course of observation of it, receiving estimates of parameters by results of observation on rather extended (but not allowing loss of relevance of data) time interval, and, at last, identification on this basis of sources of radiations.

4. In view of the fact that ranges of possible values of the same name, informative parameters of sound emissions for various sodar stations can be blocked, unambiguous identification in one parameter (for example, frequency) is impossible. Increase in reliability of identification requires complex use of the maximum quantity of the informative parameters characterizing current state of a source of a sound emission in the conditions of time of identification of the found object limited from above.

In certain cases information for identification of sodar station can be obtained by results of comparison of frequency ranges of the sendings following one after another therefore it is necessary to provide means for contrastive analysis of the next sendings in an information measuring system.

As the frequency sendings created by transmitters of sodar station are narrowband signals, changes in a fine structure of their current ranges can be hard to distinguish visually without use of special means of the analysis and visualization therefore it is reasonable to provide:

- continuous frequency analysis of the current range unrolled in signal time with detection of sections of change of its base (central) frequency;

- selection of sections of the current range where the abnormal time-and-frequency phenomena take place (changes of base frequency of a signal under the continuous law, frequency hops, etc.);

- the mode of a time-and-frequency magnifying glass for detailed studying of the law of change of a range on the selected sections;

- the system of markers for selection of sections with the abnormal time-and-frequency phenomena and also means for determination of their extent on a temporary and frequency axis;

3.2.2 Decision-making at identification of UAV in parameters of the radiations formed by them

The problem of identification of an object of UAV means of a passive sodar-location belongs to dynamic, decided in continuously changing conditions that is defined by several factors connected with features as the identified objects, and the systems of a location carried to the category of specialized IMS:

- change of conditions of reception of the signals arriving from objects at their movement in relation to reception antennas of the locational station, maneuvering of an object, change of characteristics and parameters of the radiation formed by it including hindrances;
- change of properties of receiving channels of sodar station in the conditions of continuous changes of the characteristics arriving on the entrances of signals caused first of all overloads and action of hindrances;
- limited time of stay of an object in an observation zone;
- the requirement of timeliness, relevance and maximum completeness of information available to receiving at every moment of observation of an object.

Accumulation of data on radiation parameters during the session of observation of an object allows to make continuous specification of the made decisions by the set moment of the end of a session of observation the reliability of its identification would be sufficient for acceptance of necessary prompt actions. If to consider a problem of identification taking into account the specified specifics, then in its structure it is necessary to allocate several stages of decision-making depending on volume available for the considered moment of observation of data, conditions of their receiving and processing by the IMS technical means. It is the most expedient to allocate the following stages in elaboration of the final decision of identification:

1. Detection of a sound emission in frequency band of observation and its reference to some frequency range of preprocessing of signals – information carriers about object radiation parameters.

2. Estimation of power characteristics of observed intelligence signals and making decisions on achievement of sufficient level a signal noise for execution of measurement of parameters of a sound emission.

3. Estimation of the interference level and making decisions on application of additional measures of increase in noise immunity of the IMS measuring channels.

4. Estimation of values of informative parameters of a sound emission, accumulation of the arriving data on results of estimation and making decisions on accessory of true values of parameters to the ranges of values allowing to make identification of objects on set of all measured parameters with sufficient degree of reliability.

5. The complex analysis of the received results of measurement of informative parameters of radiation and making decisions on belonging of an observed object to the set class, to type, a sample, etc.

Observation system and control of objects of a sound emission represent difficult sound engineering complexes in which work not only equipment rooms and software, the knowledge base and data, but also intellectual resources of experts are involved. Decisions of different levels in such systems are made not only automatically technical means on the basis of formal algorithms, but also operators, on the basis of the and borrowed experience. Taking into account it it is necessary to consider, both bases of creation of formal algorithms of decision-making, and feature of decision-making by the expert for the purpose of clarification of conditions of ensuring the maximum reliability of identification.

The first of the listed above direction finding problems – detection of a sound emission in frequency band of sound observation is solved the multiple response receiver containing the same channels, each of which provides energy liberation of a sound emission in the frequency band Δf_i, ($i = 1,2,...,m$)and comparison with some threshold value E_i (fig. 3.3).

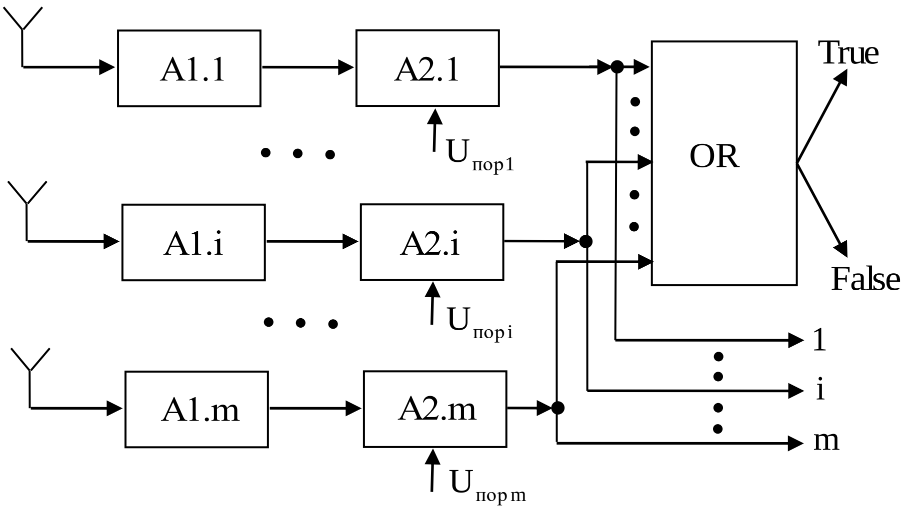

Fig. 3.3. Structure of the multiple response receiver for detection of a sound emission in frequency band $\Delta F=\sum_{i=1}^{m}\Delta f_i$

Is a part of a m-channel sink frequency channels, each of which includes A1 – the device of selection of informative signs of a signal, A2 – the decision circuit.

As in the systems of a passive sodar-location it is impossible to use information on a phase of the coming signal, and information on frequency can be used only at the level of distribution of all range of observation to subranges (bands), the structure of each frequency channel is implemented on the basis of strip filtering (fig. 3.3).

Indicators of reliability of radiation detection, as a rule, decide by digital single-response receivers from conditions of reception of a signal on an additive noise in the form of a Gaussian noise. Distribution bending around a noise output of the narrowband filter submits to Rayleigh's law:

$$\omega(U_ш)=\frac{U_ш}{\sigma_ш}\exp(-\frac{U_ш^2}{2\sigma_ш^2}) \qquad (3.1)$$

where $U_ш$ and $\sigma_ш$ - instant and mean square value of noise at the output of the strip filter.

If to designate a threshold of decision-making through β, that probability of false alarm $P_{лт}$ can be found by a formula

$$P_{лт} = \int_{\beta}^{\infty} \frac{U_{ш}}{\sigma_{ш}} \exp(-\frac{U_{ш}^2}{2\sigma_{ш}^2}) dU_{ш} \qquad (3.2)$$

When the receiver is influenced by both a signal, and noise, distribution bending around the resulting distribution at the output of the filter submits to the generalized Rayleigh's law

$$\omega(U_{c+ш}) = \frac{U_{c+ш}}{\sigma_{ш}^2} \exp(-\frac{U_{c+ш}^2 + U_c^2}{2\sigma_{ш}^2}) \cdot I_0(\frac{U_c \cdot U_{c+ш}}{\sigma_{ш}^2}) \qquad (3.3)$$

where U_c - the maximum signal amplitude at the output of the filter which is considered the known value determined through the least square mean of noises $\sigma_{ш}$ and admissible ratio signal noise $q_0 = U_c / \sigma_{ш}$; I_0 - Bessel's function zero order here imaginary to an argument;

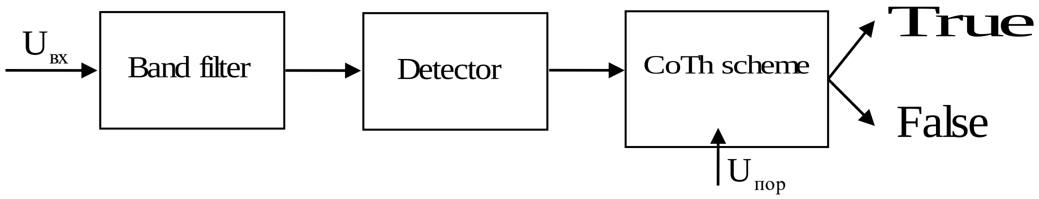

Fig. 3.4. Structure of the filter single-response receiver for detection of a sound emission in frequency band Δf_i

Taking into account the entered ratios, the probability of the correct detection can be determined by a formula:

$$P_{по} = \int_{\beta}^{\infty} \omega(U_{c+ш}) dU_{c+ш} = \int_{\beta}^{\infty} \frac{U_{c+ш}}{q_0} \cdot \exp(-\frac{U_{c+ш}^2 + q_0^2}{2q_0}) \cdot I_0(U_{c+ш}) dU_{c+ш} \qquad (3.4)$$

Formulas (2) – (4) can be integrated, considering a ratio a signal noise. For accepted $P_{лт} \le 0{,}1$ and $P_{по} \ge 0{,}9$ this dependence can be presented in the simplified form

$$q_0 = 2 \cdot \left(\sqrt{\ln \frac{1}{P_{лт}}} + \sqrt{\ln \frac{1}{1 + P_{по}} - 1{,}4} \right)^2 \qquad (3.5)$$

At an invariable threshold of decision-making, the requirement for indicators $P_{по}$ and $P_{лт}$ and differently affect necessary value a signal noise. So at $P_{по} = 0{,}99$ and

$P_{лт} = 10^{-5}$, necessary value $q_0 = 53{,}6$, if $P_{лт} = 0{,}9$ and $P_{по} = 0{,}1$, then values of a ratio a signal noise should be $q_0 = 12{,}2$.

As signals of sodar station in most cases have pulse character, a possible measure of improvement of reliability is their accumulation. But accumulation is possible only after nonlinear processing of signals the detector bending around as in an initial look these signals have a random initial phase. On the other hand, nonlinear processing worsens a ratio a signal noise after the detector of bending around. If characteristic of the detector is approximated by a square parabola of a look $U_{вых} = a \cdot U_{вх}^2$, and the ratio a signal noise on its entrance is equal $U_c / \sigma_ш = \sqrt{q_0}$, then at its end the relation a signal noise will be equal

$$\frac{U_{вых.с}}{U_{вых.ш}} = \frac{U_c^2}{2U_c\sigma_ш + \sigma_ш^2} \tag{3.6}$$

Follows from the given formula that at a bigger ratio a signal noise on an entrance, that is $q_0 \succ\succ 1$ and $U_c \succ\succ \sigma_ш$, at the end we have

$$\frac{U_{вых.с}}{U_{вых.ш}} \approx \frac{U_c}{2\sigma_ш} \succ\succ 1 \tag{3.7}$$

If $q_0 \prec\prec 1$ and $U_c \prec\prec \sigma_ш$, then the output ratio a signal noise is much less than unit

$$\frac{U_{вых.с}}{U_{вых.ш}} \approx \left(\frac{U_c}{\sigma_ш}\right) \prec\prec 1 \tag{3.8}$$

Follows from the given ratios: in the first case the detector worsens a ratio approximately twice, in the second case deterioration can be hundreds – thousands of times.

If detection is conducted on a pack from N_c signals and requires achievement of necessary reliability of recognition to provide a ratio on its entrance $q_{0\Sigma}$, then with the accounting of coefficient $\alpha_{дет}$ losses in the detector the relation has to make a signal noise of a single signal

$$q_{01} = \frac{q_{0\Sigma}}{N_c} \cdot \alpha_{дет} \tag{3.9}$$

Follows from the given results of the analysis of indicators of reliability of detection of a sound emission by one channel of the receiver that the crucial importance renders an initial ratio on reliability a signal - a filter input noise. Deterioration in the specified ratio many times over can worsen a ratio on a decision-making device input. At small ratios a signal - a carrier-to-receiver noise the attempt to improve it on an input of the decision making device due to accumulation can be inefficient. Considering also that in the absence of the prior information on parameters of the found signal problem definition of creation of the optimum filtering scheme is incorrect, it is necessary to state very essential limitation of set of means of increase in reliability at insufficient values of a ratio a signal noise.

Considered above extends to a case when the found signal has stable amplitude, for example, when between a radiation source and the receiving antenna direct visibility, is absent multibeam distribution of waves and an object is not mobile. In reality these conditions are not satisfied and amplitude of the coming signal changes in a random way. As show the researches conducted in (8) the structure of the receiver and its algorithm remain the same, however, for achievement of the same indicators of reliability $P_{лт}$ and P_{no} the bigger value of average size of a ratio a signal noise on its entrance is required

$$q_{0cp} = 2\left(\frac{\lg 1/P_{эл}}{\lg 1/P_{no}} - 1\right) \qquad (3.10)$$

The dependence (10) can be used for creation of performances of the receiver. Their analysis indicates significant influence of ignorance of amplitude on indicators of reliability of detection. In particular, in that area of characteristics, where P_{no} is big, and $P_{лт}$ is small, ignorance of amplitude leads to significant increase (in hundreds of times) required value a signal noise. In the field of small values P_{no} random changes of amplitude (its emissions) can facilitate detection, on the contrary.

For estimation of indicators of reliability of detection of the multiple response receiver constructed on the basis of use of identical channels it is necessary to find dependence of probabilistic characteristics of all system on probabilities $P_{no.i}$ and

$P_{лт.i}$ ($i = 1, 2, ..., m$) separate i-th channel. Owing to identity of schemes of processing and independence of the noise of probability of the correct detection and probability of false alarm operating in them in various channels it is possible to consider identical $P_{лт.i} = P_{лт.j}$ and $P_{no.i} = P_{no.j}$ at $i \neq j$. Probability of false detection of a signal is connected by a system with the probability of false detection by certain canals a ratio $P_{лт} = 1-(1-P_{лт.i})^m$. At $P_{лт.i} \prec\prec 1$ in a binomial row $P_{лт}$ it is possible it will be limited to the first two components, then

$$P_{лт} = m \cdot P_{лт.i} \tag{3.11}$$

The formula (11) shows that the probability of false alarm in m-to a channel system in m times more probabilities of false alarm in the separate scheme of processing.

Admission probability P_{np} signal the multichannel receiver it is equal to the work of probabilities $P_{np.i}$ the admission in the relevant channel on probability $\left[(1-P_{лт.i})^{m-1}\right]$ not excesses by the noise tension of a threshold in all other schemes is also expressed $P_{np} = P_{np.i} \cdot \left[(1-P_{лт.i})^{m-1}\right]$. For case when $\left[(m-1) \cdot P_{лт.i}\right] \prec\prec 1$, the second factor can be accepted equal 1, and, in view of that the probability of the admission and the correct detection unambiguously define each other $P_{np} = 1-P_{no}$ and $P_{np.i} = 1-P_{no.i}$, we get

$$1-P_{no} \approx 1-P_{no.i}\text{, or } P_{no} \approx P_{no.i} \tag{3.12}$$

so the probability of the correct detection from identical receivers is approximately equal in a system to the probability of the correct detection by the certain canal.

Along with false detection and the admission of a signal in the multichannel receiver the distortions consisting that in the presence - a signal the threshold will be exceeded in j-th to the scheme can take place and it seems that there is j-th a signal. Distortion probabilities $P_{иск}$ and correct instruction $P_{пус}$ unambiguously define each other $P_{иск} = 1-P_{пус}$. Having carried out similar reasonings, we will find that the probability of the correct instruction is equal $P_{пус} = P_{no.i} \cdot (1-P_{лт.i})^{m-1}$. Considering that for $m \succ\succ 1$, $(1-P_{лт.i})^{m-1} \approx 1-m \cdot P_{лт.i}$, we receive distortion probability

$P_{иск} = 1 - P_{пус} = 1 - P_{no.i} + m \cdot P_{no.i} \cdot P_{лm.i}$, which can be expressed through probabilistic characteristics of all m-channel system, considering formulas (11) and (12):

$$P_{иск} = 1 - P_{no} + P_{no} \cdot P_{лm} \tag{3.13}$$

Formulas (11) and (12) just allow to pass from the ratios given above (5) and (10) for performance data of one channel to performance data of the multichannel receiver. For this purpose it is necessary to make replacement in formulas (5) and (10) standing there probabilities of the correct detection and false alarm for one channel, the corresponding probabilities for - a channel system, and, having made transformations, we will receive expressions of performance data of the receiver for cases of detection of a signal with an unknown phase

$$q_0 = 2\left(\sqrt{\ln m + \ln \frac{1}{P_{лm}}} + \sqrt{\ln \frac{1}{1 - P_{no}} + 1{,}4}\right) \tag{3.14}$$

and unknown phase and amplitude

$$q_{0\,cp} = 2\left(\frac{\lg m + \lg 1/P_{лm}}{\lg 1/P_{no}} - 1\right) \tag{3.15}$$

Ratios (14) and (15) show that if the provision of a signal on temporary and frequency axes is in advance unknown (a case in practice), then at m-channel detection the necessary ratio a signal noise providing demanded increases P_{no} and $P_{лm}$, reached by the single-channel receiver. However, this increase is small as in all formulas defining value q_0, the logarithm of number of channels m enters.

The second stage in the list of decisions at identification of an object is estimation of power characteristics of observed signals and making decision on sufficiency of a ratio a signal noise for performance of measurement of parameters of radiation. Estimation is conducted on the output voltage of the active channel of the receiver. An ultimate goal of estimation is finding of average value of output voltage of the detector bending around. For making decision on the current ratio the signal noise needs to be found also mean square value of a deviation of output voltage. As at identification of objects by method of a passive sodar-location of prior data on an observed signal is not present (unlike an active location), the optimum receiver in the systems of a passive location calculates the relation of credibility or the moment of function of credibility.

Let's consider further that the output voltage of the receiver is proportional to function of credibility. And as the maximum exhibitors coincides with a maximum of its indicator, the problem of assessment will consist in search of a maximum of output voltage $U_{вых}(e)$, the found radiation depending on power parameter e, the mentioned dependence has an appearance

$$U_{вых}(e) = S(e) + H(e) \tag{3.16}$$

where $S(e)$ - signal, and $H(e)$ - noise function. It is known that signal function is regular and $U(e) = q_0 \cdot K_0(\Delta e)$, where $K_0(\Delta e)$ - rated autocorrelated function of the accepted signal in the parameter e.

In case when $q_0 \prec\prec 1$, output voltage of the receiver contains the numerous noise emissions surpassing the increment caused by an observed signal, and unambiguous estimation in such cases is impossible as bike error probability.

At $q_0 \succ\succ 1$ and $q_0 \succ\succ \sqrt{q_0}$, increment $U_{вых}$, caused by an observed signal, much more noise emissions that provides the small probability of an error. The more e, the less is distorted by noise signal function, the shift of a maximum of voltage output concerning radiant energy, and the less dispersion of assessment $\hat{e}$ and there is higher than the accuracy of assessment.

Signal function always even is also symmetric rather true value e_0. Then, at $q_0 \succ\succ 1$ the average by a set of estimates has to be to equally true value, that is not shift of assessment is provided. Besides, the theory shows that at normal noise and $q_0 \succ\succ 1$ the method of a maximum of credibility gives asymptotically an effective assessment. On the other hand, from the essence of a method of a maximum of function of credibility it is possible to claim that dispersion of assessment and probability of a wrong solution (fig. 2.11) will be that less, than already peak of signal function and already autocorrelation function of an input signal in the measured parameter e.

For finding of assessment $\hat{e}$ true value of parameter $e = e_0$, it is necessary to find value $\hat{e}_0$, corresponding to a maximum $U_{вых}(e)$. Equating a derivative from $U_{вых}(e)$ to zero, we get

$$S'(\hat{e}_0) + H'(\hat{e}_0) = \frac{d}{de} S(e)\Big|_{e=\hat{e}_0} + \frac{d}{de} H(e)\Big|_{e=\hat{e}_0} = 0 . \qquad (3.17)$$

At $q_0 \succ\succ 1$ estimate $\hat{e}_0 \cong e_0$, and if in second composed instead of $\hat{e}_0$ substitute e_0, then statistical characteristics of stochastic function $H(e)$ at stationary entrance process will practically not change:

$$S'(\hat{e}_0) + H'(\hat{e}_0) = 0 \qquad (3.18)$$

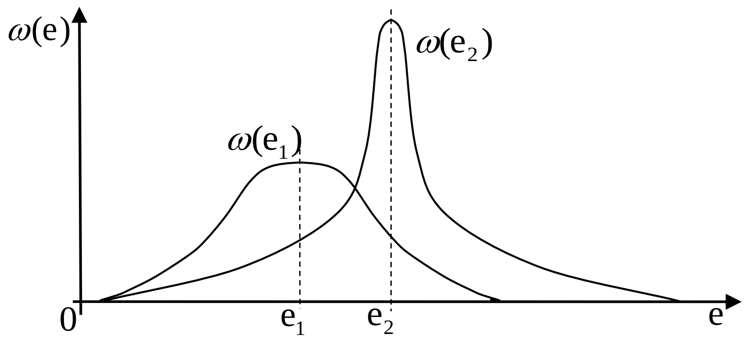

Fig. 3.5. e probability density for small $\omega_1(e)$ and big $\omega_2(e)$ signal-to-noise ratio

Let's spread out function $S(e)$ in a row Taylor in the neighborhood of a point e_0

$$S(e) = S(e_0) + (e - e_0) \cdot S'(e_0) + \frac{(e - e_0)^2}{2} \cdot S''(e_0) + ...,$$

in which the first composed – a constant component, the second, owing to parity $S(e)$, is equal to 0. Therefore at differentiation $S(e)$ in a formula (16) we will receive a ratio

$$(\hat{e}_0 - e_0) \cdot S''(e_0) + H'(e_0) = 0 .$$

Assuming that $S''(e_0)$ - nonrandom size, we will receive dispersion of assessment

$$\sigma^2(e) = \sigma^2(\hat{e}_0 - e_0) = \frac{1}{[S''(e_0)]^2} \cdot \sigma^2[H'(e_0)] \qquad (3.19)$$

Let's present noise function in the form $H(e) = \sqrt{q_0} \cdot h(e)$, where $h(e)$ - rated accidental process with the mean square value equal to unit, and having made substitution in a formula (17), we will have

$$\sigma^2(e) = \frac{q_0 \cdot \sigma^2[h'(e_0)]}{[S''(e_0)]^2} \tag{3.20}$$

Function $h'(e_0)$ is equal to value of the second derivative of correlation function of this process with the return sign at zero value of an argument, therefore $\sigma^2[h'(e_0)] = -k''_{h_0}(0)$. Then the lower value of dispersion of assessment of parameter e can be received if to assume that the filter of the receiver is agreed with a signal. In this case rated autocorrelated function of noise at the output of the filter coincides with rated autocorrelated function of the accepted signal on its entrance, from here follows

$$\sigma^2[h'(e_0)] = -k''_0(0) \tag{3.21}$$

Considering that

$$[S''(e_0)]^2 = q_0^2 \cdot [k''_0(0)]^2 \tag{3.22}$$

and having made substitution (19) and (20) in (18), we will receive dispersion of assessment:

$$\sigma^2(e) = -\frac{1}{q_0 \cdot k''_0(0)} \tag{3.23}$$

The physical sense of a ratio (23) displays communication of dispersion of assessment, ratio a signal noise q_0 and parameter of "narrowness" of autocorrelated function $k''_0(0)$ signal. If increase in a ratio signal noise q_0 determines dispersion size, and, therefore, and mistake probability in decision-making at this stage of identification according to

$$P_{ош} = \frac{1}{\sqrt{2 \cdot \pi} \cdot \sigma(e)} \int_{-\infty}^{n} \exp \frac{(e - e_0)^2}{2 \cdot \sigma^2(e)} de, \tag{3.24}$$

that it is impossible to consider influence of properties of autocorrelation function of the accepted signal on reliability of the made decisions as there is no prior information on these properties.

Considered above it is fair for a case of action of noises in the form of Gaussian noise. As such noises intrinsic noises of the equipment, space noise, noise of the atmosphere, etc. can act. If noises with other distribution, for example, purposefully created, then formal algorithms of decision-making, on the basis of the stated above reasons act on an input of a passive system of a sodar-location, are ineffective. Accounting of a large amount of signs of a signal and accounting of properties of real noises is necessary. Attraction of an intellectual resource of the person operator can facilitate direction finding problem in many cases.

Problems of decision-making at the subsequent stages of identification of an object (with 3 on 5) even more give in more difficult to formalization therefore involvement of the operator along with use of databases and knowledge bases is even more justified. However, it is necessary to consider limited opportunities of the person as a part of human-machine information processing systems. So the amount of signs which the person at identification of an object is capable to accept does not exceed (7±2). Necessary time of identification for the interconnected characters (words, phrases) is equal to 85 ms on the character.

It depends on a number of factors, including for: analog measurements – from class F of an error of the measuring device; the sequences of letters – from total number of letters of a phrase N_B; the discrete measured sizes – from the number of decimal categories N_Z.

For the specified cases the following sizes of necessary time of identification are received:

- for analog devices $t_{ia} = 0{,}1 ld(\frac{50}{F} + 1)$ [c], where ld - dynamic logarithm on the basis 2;
- for digital devices $t_{iz} = 0{,}061(1 + 3{,}33 N_z)$ [c], at $N_z \geq 1$, at $N_z = 0$, $t_{iz} = 0$
- for alphabetic information $t_{ib} = 0{,}1(1 + 1{,}25 N_B)$ [c], at $N_B \geq 1$, at $N_B = 0$, $t_{ib} = 0$.

According to the above-stated formulas, values of speed limit of receipt of information, acceptable for the person operator, depending on a form of its representation are calculated for: the coherent text – 19.3 bps; the sequences of letters – 22.4 bps ($N_z = 4$);the analog measured sizes which are read out from the showing devices at the alternating measurements – 9.3 bps (F=2.5).

The maximum value of speed of receipt of the mixed (alphanumeric) information to the person operator is defined by a formula:

$$J_{ms_i} = 11{,}75\frac{N_B + 0{,}7N_Z}{1 + 0{,}4N_B + 0{,}15N_Z} \quad \text{[bps]}, \; (N_z \neq 0\,, N_B \neq 0) \qquad (3.25)$$

The minimum time of identification of the message characterizing an object is

$$t_i = 0{,}4(1 + 0{,}4N_B + 0{,}15N_Z) \quad \text{[s]} \qquad (3.26)$$

Follows from the above-mentioned that real opportunities of the person operator as a part of the system of identification are limited both number of signs, and speed of receipt of these signs on processing.

Significant restriction is also restriction for time of identification of an object on sets of signs and also significant deterioration of identification at failures in operation of the technical means of a system including called by action of hindrances and overloads of informative channels of a system. All this indicates as need of improvement of structure of means of identification as a part of the specialized information and measuring systems of passive sound monitoring, and improvement of algorithms of their functioning the maximum number of problems of multi-stage identification was solved with the minimum participation of the person operator.

3.3 Development of algorithms of determination of UAV coordinates in DRS and their analysis

3.3.1 Development of a method of determination of coordinates of UAV in a differential and ranging system on the basis of the modified Newton's method

3.3.1.1 The solution of a problem of a differential and ranging coordinate measurement by the modified Newton's method

Now passive complexes of automatic detection and creation of routes of movement of air targets, searchless on space, on radiations of their onboard sound-electronic means on the basis of TDOA of measurement of coordinates were widely adopted.

The principle of action of such systems is based on measurement of a difference of the moments of arrival of signals on the stations which are a part of a complex. As a rule, four stations L_1, L_2, L_3, and C are a part of a complex (fig. 3.6). It allows to provide the unambiguous solution of a task of measurement of three coordinates of air targets in the circular spatial sector.

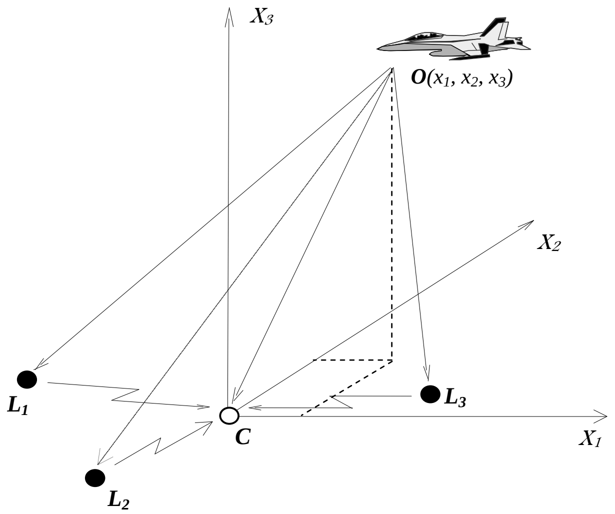

Fig. 3.6. Relative positioning of a complex of a passive sodar-location and UAV

Coordinates of the purposes of time are described at the moment by the system of three equations (3.27).

$$\begin{aligned} \tau_1 &= \frac{1}{c}(OL_1 + CL_1 - OC); \\ \tau_2 &= \frac{1}{c}(OL_2 + CL_2 - OC); \\ \tau_3 &= \frac{1}{c}(OL_3 + CL_3 - OC), \end{aligned} \tag{3.27}$$

Where $\tau_{1,2,3}$ - delays of time of arrival of a signal from the purpose on the central station C through side stations L_1, L_2, L_3.

- distances between UAV and side stations;

- distances between side stations and central;

- distance between UAV and the central station.

Having expressed ratios (3.27) in the system of coordinates of position of stations and UAV, we will receive the system of the nonlinear equations in which all sizes, except coordinates of provision of UAV are known $x=(x_1\,,\,x_2,x_3)^T$

$$
\begin{aligned}
F_1(x) &= \frac{1}{c}\cdot\left(\sqrt{(x_1-x_1^1)^2+(x_2-x_2^1)^2+\left(x_3-x_3^1\right)^2}+D_1-\sqrt{x_1^{\,2}+x_2^{\,2}+x_3^{\,2}}\right)-\tau_1=0;\\
F_2(x) &= \frac{1}{c}\cdot\left(\sqrt{(x_1-x_1^2)^2+(x_2-x_2^2)^2+\left(x_3-x_3^2\right)^2}+D_2-\sqrt{x_1^{\,2}+x_2^{\,2}+x_3^{\,2}}\right)-\tau_2=0;\\
F_3(x) &= \frac{1}{c}\cdot\left(\sqrt{(x_1-x_1^3)^2+(x_2-x_2^3)^2+\left(x_3-x_3^3\right)^2}+D_3-\sqrt{x_1^{\,2}+x_2^{\,2}+x_3^{\,2}}\right)-\tau_3=0,
\end{aligned}
\tag{3.28}
$$

where $D_i=\overline{L_iC},\;\; i=1,2,3.$

Vector $x^i=(x_1^i,\,x_2^i,x_3^i)^T,\;\;\mathrm{i}=1,2,3$ defines position of i-th station in three-dimensional space R^3.

During creation mathematical and the software for complexes of a passive location the problem of reduction of volume of computing operations also very is particularly acute.

Generally, methods of a solution of systems of the nonlinear equations $\mathrm{F(x)}=0$, guaranteeing receiving an acceptable result, does not exist. On condition of implementation of certain requirements to properties of the nonlinear equations by an effective method of the decision the iterative method of Newton is.

For realization of a method of Newton it is necessary to receive analytical expressions for calculation of a matrix of private derivatives (Jacobi's matrix)

$$
F'(x_k)=\begin{vmatrix}
\dfrac{\partial F_1(x_1,x_2,x_3)}{\partial x_1} & \dfrac{\partial F_1(x_1,x_2,x_3)}{\partial x_2} & \dfrac{\partial F_1(x_1,x_2,x_3)}{\partial x_3}\\
\dfrac{\partial F_2(x_1,x_2,x_3)}{\partial x_1} & \dfrac{\partial F_2(x_1,x_2,x_3)}{\partial x_2} & \dfrac{\partial F_2(x_1,x_2,x_3)}{\partial x_3}\\
\dfrac{\partial F_3(x_1,x_2,x_3)}{\partial x_1} & \dfrac{\partial F_3(x_1,x_2,x_3)}{\partial x_2} & \dfrac{\partial F_3(x_1,x_2,x_3)}{\partial x_3}
\end{vmatrix}, \quad , \tag{3.29}
$$

where

$$
\frac{\partial F_j(x_1,x_2,x_3)}{\partial x_i}=\frac{x_i-x_i^j}{\sqrt{\sum_{i=1}^{3}(x_i-x_i^j)^2}}-\frac{x_i}{\sqrt{\sum_{i=1}^{3}x_i^2}},\, i=1..3,\; j=1..3. \tag{3.30}
$$

In the considered area $\Omega \in \mathrm{R}^3$ three-dimensional space R^3 vector function $F(x) = (F_1(x), F_2(x), F_3(x))^T$, has all private derivatives of the 1st order. The computing procedure of a method of Newton can be received easily from decomposition in a row of Taylor in a point x^* left parts of a system:

$$F(x^*) = F(x_k) + F'(x_k)(x^* - x_k) + R(x^* - x_k), \tag{3.31}$$

Assuming that x^* - there is a solution of a system, the right part (2.3) will be equated to zero, and, neglecting the residual member $\mathrm{R}(\mathrm{x}* - \mathrm{x}_\mathrm{k})$, let's receive Newton's scheme:

$$F(x_k) + F'(x_k)(x^* - x_k) = 0. \tag{3.32}$$

Resolving the equation (2.6) of rather new approach x_{k+1}, let's gain a classical impression of a method:

$$x_{k+1} = x_k - F'(x_k)^{-1} F(x_k). \tag{3.33}$$

Iterations are possible if a matrix of private derivatives - nondegenerate. The efficiency of a method of Newton consists that assessment takes place [12]:

$$\left\| x_{k+1} - x^* \right\| \le c \left\| x_{k+1} - x^* \right\|^2 \tag{3.34}$$

showing that proximity to the exact decision on $(k+1)$-th to iteration it is proportional to a mistake square k-th to iteration, i.e. iterative process (2.5) has the square speed of convergence.

Including in a row Taylor members of the second order, it is possible to receive the computing scheme having cubic convergence:

$$x_{k+1} = x_k - \left[I - \frac{1}{2} F'(x_k)^{-1} F''(x_k) F'(x_k) F(x_k) \right]^{-1} F(x_k)^{-1} F(x_k), \tag{3.35}$$

For implementation of this scheme it will be required to find n^2 of private derivatives of the first order and n^3 of private derivatives of the second order. Besides, to execute 2 addresses of matrixes. At such volume of computing operations even increase in speed of convergence does not allow this scheme to compete with iterations of the first and second order.

Less expensive scheme of the third order is the scheme:

$$x_{k+1} = x_k - F'(x_k)^{-1}\left[F(x_k) + F(x_k - F'(x_k)^{-1}F(x_k))\right], \qquad (3.36)$$

which actually contains 2 steps with the same return matrix.

One of the simplest modifications of a method of Newton is the following iteration [13]

$$x_{k+1} = x_k - \omega\left[F'(x_k) + \lambda I\right]^{-1} F(x_k)\ , \qquad k = 0,1,\ldots,n \qquad (3.37)$$

where ω , λ - fixed constants.

In case ω =1 and λ = 0, that (3.37) comes down to a classical method of Newton.

Iteration on a formula (3.35) has no superlinear speed of convergence of a method of Newton.

One of requirements of convergence of iterative process consists in step-by-step reduction of some norm, i.e. inequality has to be carried out

$$\|F_{k+1}(x)\| \le \|F(x_k)\|, \qquad k = 0,1,\ldots,n\,. \qquad (3.38)$$

Newton's method not with guarantee meets this condition even in case of one variable. The simplest modification of a method of Newton is the following iteration

$$x_{k+1} = x_k - \omega_k F'(x_k)^{-1} F(x_k), \qquad k = 0,1,\ldots,n, \qquad (3.39)$$

for which the multiplier ω_k is chosen so that the condition was satisfied (37). Sufficient living conditions of such coefficients are given in [14].

At bad conditionality of a matrix of derivatives $F'(x)$ selection of size λ in iteration (2.9), it is possible to achieve not degeneracy of a resultant matrix $F'(x) + \lambda I$.

Thus, iterations of type (2.9) the applications of a method of Newton connected with convergence of a method and possible degeneracy of a matrix of private derivatives allow to solve problems $F'(x)$. There are also other approaches solving the above-stated difficulties of practical use of modifications of a method of Newton.

3.3.1.2 A research of convergence of the solution of a problem of a differential and ranging coordinate measurement by Newton's method with once counted Jacobi's matrix

It is possible to avoid operation of the address of a matrix of Jacobi if to present iterative process in the form [15]

$$F(x^k) + F'_x\ (x^{k+1} - x^k) = 0. \tag{3.40}$$

To find x^{k+1}, it is necessary to solve the system of the linear algebraic equations (2.1) which initial representation has an appearance:

$$F'_x(x^k)x^{k+1} = F'_x(x^k)x^k - F(x^k) = 0. \tag{3.41}$$

For ensuring convergence of iterations (2.1) it is possible to enter a multiplier ω^k and to choose it so that to provide performance of conditions of convergence $\|F(x^{k+1})\| \le \|F(x^k)\|$. Taking into account a multiplier ω^k iterative process takes a form:

$$F'_x(x^k)x^{k+1} = F'_x(x^k)x^k - \omega^k F(x^k) = 0. \tag{3.42}$$

The choice it is possible to change the size of a vector of the right part of a linear system of the equations. However, there is a possibility of degeneracy of a matrix of Jacobi or proximity to degeneracy (i.e. $det\, F'_x(x^k) \approx 0$), reducing resistance of the decision to various errors.

In this case it is possible to use modification of a matrix of Jacobi as follows

$$G(x^k) = F'_x(x^k) + \lambda_k I \tag{3.43}$$

and selection of parameter x^k to turn a resultant matrix $G(x^k)$ in diagonale dominantny that will allow to improve conditionality of a system of the equations.

Modification of iterative process takes a form:

$$\left[F'_x(x) + \lambda^k I\right]x^{k+1} = \left[F'_x(x^k) + \lambda I\right]x^k - \omega^k F(x^k), \tag{3.44}$$

allowing to guarantee obtaining the acceptable solution of system (2).

After several iterations (2.18) and occurrence of approximations x^{k+1} to the area of convergence of a method of Newton, it is possible to return to the classical scheme (2.13), having increased thereby convergence speed to the exact solution of initial system (2.2).

For local convergence of a method of Newton it is enough that the spectral radius of a matrix $G = I - A^{-1}F_x'(x^*)$ there was strictly less than unit, i.e.

$$R = \rho\left\{I - \left[F_x'(x^*)\right]^{-1} F_x'(x^*)\right\} < 1, \tag{3.45}$$

The less size R, the quicker convergence of iterations (2.13).

Let $\lambda_1,...,\lambda_n -$ own values of a matrix

$$G = I - \left[F_x'(x^*)\right]^{-1} F_x'(x^*). \tag{3.46}$$

We will determine the spectral radius of a matrix of G as $\rho = \max_i\{\lambda_1,...,\lambda_n\}$

$$\rho = \max_i\left\{\mathrm{Re}\,\lambda_1,...,\mathrm{Re}\,\lambda_n\right\}, \tag{3.47}$$

where $Re\,\lambda_i$ - we will determine the spectral radius of a matrix of G as $\lambda_i,\ i = \overline{1,n}$

.

At the solution of a coordinate and route task reduction of computing operations is reached by the following in the ways:

- use of the modified method of Newton connected with reduction of number of recalculation of a matrix of private derivatives [16];

- an exception of iterative process of one of the equations of a system (3.27) in case one of coordinates of UAV does not change (for example, flight altitude) and also at achievement of the set accuracy any of coordinates of provision of UAV [17.18].

3.3.1.3 The analysis of accuracy of determination of coordinates of UAV by the developed method by means of computer modeling

The decision of a system of the equations (2.2) was passed by Newton's method in the environment of computer modeling of MATHCAD as a result of which route coordinates on the basis of experimental data of measurement and the subsequent filtration of delays of time of arrival of a signal for places of acceptance of a complex of a passive sodar-location were received. The route presented in fig. 3.7 is built when calculating a matrix of private derivatives on each step of iteration.

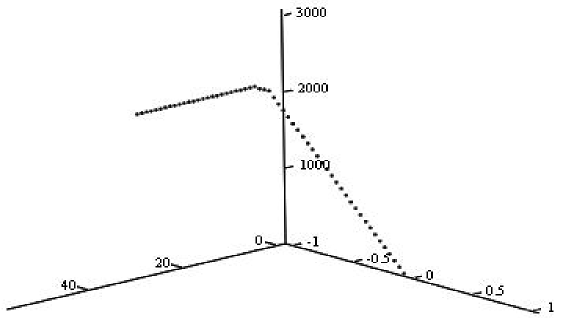

Fig. 3.7 Route UAV built when calculating a matrix of private derivatives on each step of iteration

Besides, the analysis of a possibility of reduction of time of calculations for the account of use of a matrix (2.3) without its recalculation on each iterative step was carried out therefore it was established that use of the same matrix for several steps of iteration without significant deterioration in accuracy for the fixed number of iterations is possible. Calculation results are given in table 3.1.

Table 3.1

Dependence of accuracy of determination of coordinates of UAV on the number of iterations at recalculation of a matrix of Jacobi

$\varepsilon = x_{k+1} - x_k$, m	The number of iterations at recalculation of a matrix of Jacobi on each step of iteration	The number of iterations at recalculation of a matrix of Jacobi on the first two steps of iteration
10	2	2
0.001	3	3
0.000001	4	4
0.0000001	4	5

Thus, in subsection 2.1, the method of determination of coordinates of UAV by the numerical solution of a nonlinear problem of a differential and ranging coordinate measurement, on the basis of the modified Newton's method is developed.

The expediency of use of the same determinant of a matrix of private derivatives for two-three steps of iteration is shown that allows to reduce by 2-3 times calculation time with a satisfactory accuracy of calculations.

The offered method allows to construct continuous tracks of air targets at short-term loss of the signals radiated by them. The admissible time interval of lack of signals is equal to 3-5 periods of scanning of the antenna system installed onboard the purpose.

3.3.2 The analysis of a nonlinear problem of a differential and ranging coordinate measurement by means of functions of parametrical sensitivity

3.3.2.1 Use of functions of parametrical sensitivity for definition of an absolute error of determination of coordinates of UAV

Important task by development of systems of a passive sodar-location is the problem of definition of an error of calculation of coordinates of UAV. In case of finding of UAV on various removal from the carried system of a passive sodar-location, one of effective ways of definition of an absolute error of measurement of coordinates is the method of functions of sensitivity connected with studying of impact of change of input parameters on change of days off. Input parameters in the systems of a passive sodar-location are meant as temporary delays of arrival of a signal of UAV at the station of a complex, and by days off – the coordinates of UAV [19] calculated by a complex.

When studying dynamic systems the concept of unambiguous compliance between vectors of input and output parameters which can be defined by means of the differential equations, the equations of a state or any other way is often used. However, at practical calculations input parameters can be determined only with some accuracy. Besides, parameters of a system change depending on external conditions and in time, that is engineering calculations deal with nominal values of parameters and with the corresponding admissions. In this regard, instead of an unambiguous ratio between nominal input and output parameters is more practical to consider a ratio of areas of change of input and output parameters concerning the nominal values which gives information concerning sensitivity of a system to indignations.

Are a part of the considered system four spaced stations C, R, L and Q (fig. 3.8), and for determination of coordinates the differential and ranging method based on measurement of a difference of times of arrival of a signal from UAV on side stations in relation to central and construction on them the corresponding hyperboles is used. Location of UAV – a point of intersection of three hyperboloids of rotation.

For determination of coordinates of an object at the moment time needs to solve the system of the hyperbolic equations (2.1).

The system of the equations (2.1) is expressed through coordinates of UAV and stations of a complex in a look:

$$\begin{aligned}
&F_L = \frac{1}{c}(\sqrt{(x_1 - x_{1L})^2 + (x_2 - x_{2L})^2 + (x_3 - x_{3L})^2} + D_L - \sqrt{x_1^2 + x_2^2 + x_3^2}) - \tau_L = 0;\\
&F_R = \frac{1}{c}(\sqrt{(x_1 - x_{1R})^2 + (x_2 - x_{2R})^2 + (x_3 - x_{3R})^2} + D_R - \sqrt{x_1^2 + x_2^2 + x_3^2}) - \tau_R = 0;\\
&F_Q = \frac{1}{c}(\sqrt{(x_1 - x_{1Q})^2 + (x_2 - x_{2Q})^2 + (x_3 - x_{3Q})^2} + D_Q - \sqrt{x_1^2 + x_2^2 + x_3^2}) - \tau_Q = 0;\\
&D_L = \overline{LC}, D_R = \overline{RC}, D_Q = \overline{QC},
\end{aligned} \tag{3.48}$$

where x_1, x_2, x_3 - purpose coordinates;

x_{1L}, x_{2L}, x_{3L} - coordinates of the station L;

x_{1R}, x_{2R}, x_{3R} - coordinates of the station R;

x_{1Q}, x_{2Q}, x_{3Q} - coordinates of the station Q.

Let it is known σ_i^τ error measurements (by the standart deviation) of times of delays $\tau_{L,R,Q}$ receipts of a signal at the station.

Coordinates of UAV are calculated by finding of roots of a system of the equations (3.48) [20]. On condition of exact measurement of time τ_0, let's receive the exact solution of system (3.48) $\vec{x}_0$. It is necessary to receive assessment of coordinates of UAV at wrong sizes a vector component $\vec{\tau} = [\tau_1, \tau_2, \tau_3]$, где $\tau_1 = \tau_L$,

$\tau_2 = \tau_Q$, $\tau_3 = \tau_R$. For this purpose we will spread out a vector $\vec{x}$ in a row Taylor in the neighborhood of exact coordinates of UAV $\vec{x}_0$, being limited to its linear part:

$$\vec{x}(\tau_0 + \Delta\tau) = \vec{x}(\tau_0) + \left.\frac{\partial\vec{x}}{\partial\tau}\right|_{\tau=\tau_0}(\Delta\tau), \tag{3.49}$$

or

$$\vec{x}(\tau_0 + \Delta\tau) - \vec{x}(\tau_0) = \left.\frac{\partial\vec{x}}{\partial\tau}\right|_{\tau=\tau_0}(\Delta\tau) \tag{3.50}$$

Offset value Δx coordinates, caused by an error of measurement of delay time at a size $\Delta\tau$ is defined by sensitivity coefficients by the following ratio [21]:

$$\Delta\vec{x}(\tau_0 + \Delta\tau) = \left.\frac{\partial\vec{x}}{\partial\tau}\right|_{\tau=\tau_0}(\Delta\tau) \tag{3.51}$$

where

$$\left.\frac{\partial\vec{x}}{\partial\tau}\right|_{\tau=\tau_0} = \begin{bmatrix} \frac{\partial x_1}{\partial\tau_1} & \frac{\partial x_1}{\partial\tau_2} & \frac{\partial x_1}{\partial\tau_3} \\ \frac{\partial x_2}{\partial\tau_1} & \frac{\partial x_2}{\partial\tau_2} & \frac{\partial x_2}{\partial\tau_3} \\ \frac{\partial x_3}{\partial\tau_1} & \frac{\partial x_3}{\partial\tau_2} & \frac{\partial x_3}{\partial\tau_3} \end{bmatrix} \tag{3.52}$$

matrix of the first derivative coordinates of UAV from time to time delays $\vec{\tau} = [\tau_1, \tau_2, \tau_3]$ (Jacobi's matrix) [22,23].

Each coordinate x_i of vector $\vec{x}$ will receive the corresponding deviation in connection with errors of measurement of delay time, namely:

$$x_i(t_0 + \Delta\tau) = x_i(t_0) + \sum_{j=1}^{3}\frac{\partial x_i}{\partial\tau_j}\Delta\tau_j\ , \quad i = 1\ldots 3 \tag{3.53}$$

The ratio (2.53) contains the error of measurement of coordinate of UAV proportional to an error of measurement of delay time $\Delta\tau_j$, proportionality coefficient at the same time is function of sensitivity $\frac{\partial x_i}{\partial\tau_j}$ coordinate x_i to change of delay time. Knowing function of sensitivity and the measured temporary delay, it is possible to find value of an absolute error of the calculated coordinate.

Let's consider the option of symmetric location of stations and a source of a sound emission moving along the route (fig. 3.8).

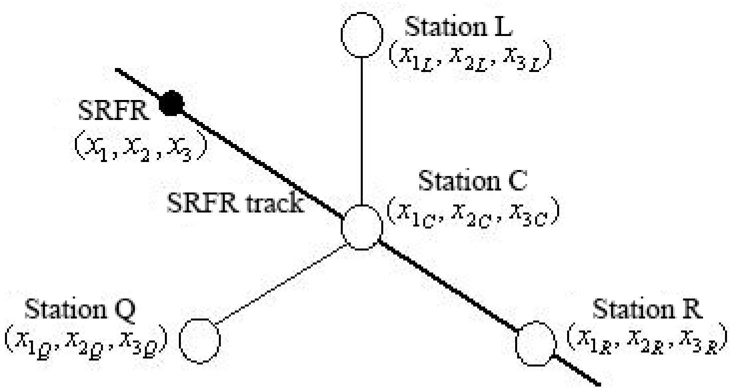

Fig. 3.8 Symmetric location of stations with the route of a source of a sound emission

Let's calculate Jacobi's matrixes at $\delta\tau_i = 15\%$, $i = \overline{1,3}$ at the provision of UAV over L, Q, R stations and also over station C and behind station C it is symmetric to station R (as shown in fig. 3.8). Results of calculation are given in table 3.2.

Table 3.2

Jacobi's matrixes at the provision of UAV over L, Q, R stations and also over station C and behind station C it is symmetric to station R, $\delta\tau_i = 15\%$, $i = \overline{1,3}$

	Over station L (measurement τ_1)			Over station L (measurement τ_2)			Over station R (measurement τ_3)		
	$\frac{\partial x_i}{\partial \tau_1}$	$\frac{\partial x_i}{\partial \tau_2}$	$\frac{\partial x_i}{\partial \tau_3}$	$\frac{\partial x_i}{\partial \tau_1}$	$\frac{\partial x_i}{\partial \tau_2}$	$\frac{\partial x_i}{\partial \tau_3}$	$\frac{\partial x_i}{\partial \tau_1}$	$\frac{\partial x_i}{\partial \tau_2}$	$\frac{\partial x_i}{\partial \tau_3}$
x_1	**5,676*10³**	5,482*10⁵	2,309*10⁵	2,107*10⁴	**6,424*10⁴**	2,088*10⁵	3,093*10⁵	4,167*10⁵	**1,316*10⁴**
x_2	**1,703*10⁴**	1,76*10⁶	2,353*10⁵	2,661*10⁵	**2,452*10⁵**	1,567*10⁵	1,2*10⁵	2,17*10⁵	**1,236*10⁴**
x_3	**3,867*10⁵**	3,002*10⁶	5,212*10⁴	3,184*10⁵	**1,116*10⁵**	1,497*10⁴	5,852*10⁵	3,89*10⁵	**3,07*10⁵**

	Over station C			Symmetrically to station R concerning station C		
	$\frac{\partial x_i}{\partial \tau_1}$	$\frac{\partial x_i}{\partial \tau_2}$	$\frac{\partial x_i}{\partial \tau_3}$	$\frac{\partial x_i}{\partial \tau_1}$	$\frac{\partial x_i}{\partial \tau_2}$	$\frac{\partial x_i}{\partial \tau_3}$
x_1	4,218*10⁴	1,25*10³	1,705*10⁵	8,495*10⁴	6,398*10⁴	2,316*10⁵

x_2	1,593*10^4	2,201*10^5	1,075*10^5	2,04*10^5	2,828*10^5	1,699*10^5
x_3	5,223*10^5	5,523*10^4	8,116*10^4	7,131*10^5	7,628*10^5	9,04*10^5

It is visible that the smallest values have coefficients of sensitivity when finding UAV over station C, that is in the center of a system. In all other cases coefficients of sensitivity have great values, and it will be shown the stronger, than more UAV moves away from stations of a complex. Besides, from the table it is visible that when finding UAV directly over stations L, Q, R coefficients of sensitivity have the minimum value on that temporary delay which is defined by this station. It can be explained with the fact that the mistake brought in calculation of coordinates at change to the corresponding temporary delay will be small when finding UAV over the relevant station in comparison with the brought mistake in calculation of coordinates by other stations.

The locations of stations of a complex and the route corresponding to a case, as shown in fig. 3.8, coefficients of sensitivity, [km/s] depending on coordinates and a relative error of measurement of delay time of arrival of a signal, $\delta\tau i$ = 15%, are given in fig. 3.9 and fig. 3.10.

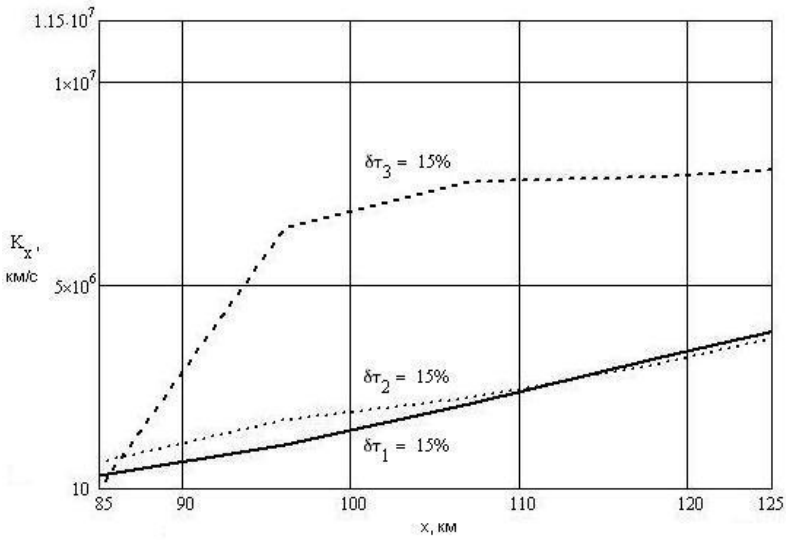

Fig. 3.9 Functions of sensitivity K_x of coordinate x at movement along the route at $\delta\tau_{1,2,3}$ = 15% (functions of sensitivity for $\delta\tau_3$ for combination of schedules are increased by coefficient 0.05)

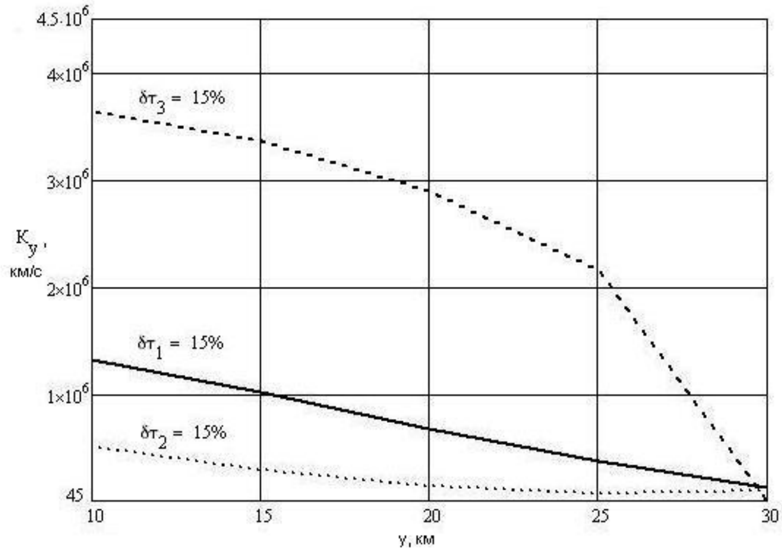

Fig. 3.10 Functions of sensitivity K_y of coordinate at at movement along the route at $\delta\tau_{1,2,3}$=15% (functions of sensitivity for $\delta\tau_3$ for combination of schedules are increased by coefficient 0.2)

3.3.2.2 Application of functions of parametrical sensitivity for reduction of quantity of the equations of TDOA

The behavior of functions of sensitivity demonstrates that rather little changes of value of time delays lead to significant changes in the calculated coordinates, that is emergence of considerable errors of calculation of coordinates [24]. From here the requirement of the most precise measurement of delays of time of arrival of a signal of stations of a complex follows. Besides, the analysis of these dependences allows to draw a conclusion on existence near stations of a complex of a certain zone, sensitivity coefficients in which have the smallest value and their change in this zone, is insignificant. Outside this zone of function of sensitivity have growth increasing in process of removal from a location of stations [25].

During creation mathematical and the software of systems of a passive location there is a problem of reduction of volume of computing operations for a solution of information tasks. At a solution of a coordinate and route task reduction of computing operations is reached by the following in the ways:

- use of the modified method of Newton connected with reduction of number of recalculation of a matrix of private derivatives;

- an exception of iterative process of one of the equations of a system (2) if one of coordinates of UAV does not change (for example, flight altitude) and also at achievement of given accuracy any of coordinates of provision of UAV.

In the second case it is important to define - what equation so and what measurements of the station to exclude from system (2.2). The analysis of behavior of functions of sensitivity of coordinates of UAV concerning a measurement error of delay periods can give the answer to this question τ_i, $i=\overline{1,3}$.

With an invariable height (the third coordinate) for reduction of time of computation process it is necessary to exclude such station for which the size of total sensitivity of coordinates of UAV $\sum_{i=1}^{3}\frac{\partial x_i(t)}{\partial \tau_j}$ to an error of determination of delay time τ_j will be the greatest. From table 3.2 and figures 3.9, 3.10 it is visible that during removal of UAV from stations of a complex on the route set in fig. 3.8, the greatest values will have sensitivity coefficients at change $\delta\tau_3$, which is measured at station R and, respectively, it can be excluded from process of calculation of coordinates that will have two advantages: will allow to pass from a system from three equations to a system from two equations that will reduce the volume of calculations and also will increase the accuracy of determination of coordinates at the expense of an exception of process of calculations of the station which has the greatest coefficient of sensitivity, and, therefore, will bring the greatest error in calculations.

3.3.3 Development of a method of determination of coordinates of UAV in TDOA system on the basis of criterion of a minimum of the weighed sum of squares of mistakes and its analysis

3.3.3.1 Extreme problem definition of determination of coordinates of UAV in TDOA system and its decision

One of key indicators of overall performance of passive complexes of control of a sound-electronic situation is the accuracy of determination of coordinates of UAV. In actual practice the significant effect on the accuracy of measurement of coordinates, when using TDOA, is rendered by errors of measurement of time of arrival of a signal on each of the stations which are a part of a complex. Therefore the problem of minimization of influence of an error of measurement of times of arrival of a signal at stations of a complex on the accuracy of determination of coordinates is relevant .

For assessment of the impact of errors of measurement of times of arrival of a signal for the accuracy of determination of coordinates of UAV, we will consider a complex which part are four spaced stations C, R, L and Q (fig. 3.8). For determination of coordinates of an object at the moment time needs to solve the system of the hyperbolic equations (3.28).

The problem of finding of coordinates on the basis of TDOA can be formulated as an extreme task on the basis of criterion of a minimum of the weighed sum of squares of errors of the equations of TDOA.

Let's accept: $\tau_1 = \tau_L$, $\tau_2 = \tau_Q$, $\tau_3 = \tau_R$, $\vec{\tau} = [\tau_1, \tau_2, \tau_3]$, $\vec{x} = [x_1, x_2, x_3]$, then the square functionality estimating the size of the weighed sum of squares of mistakes can be written down in a look:

$$\min J(x_1, x_2, x_3) = \sum_{i=1}^{3} \left[\frac{1}{c} \cdot \left(\sqrt{(x_1 - x_1^i)^2 + (x_2 - x_2^i)^2 + \left(x_3 - x_3^i\right)^2} + D_i - \sqrt{x_1{}^2 + x_2{}^2 + x_3{}^2} \right) - \tau_i \right]^2 \rho_i \quad (3.54)$$

x_1^i, x_2^i, x_3^i - corresponding coordinates of stations.

Using designations of a system (2.2), we will rewrite square functionality (3.54) in more compact look:

$$\min J(x_1, x_2, x_3) = \sum_{i=1}^{3} \rho_i \ F_i{}^2 \quad (3.55)$$

Function J(x_1, x_2, x_3) consists of the sum of the weighed square functions with weight coefficients ρ_i, which allow to consider influence of real errors of measurement of delays of time of arrival of a signal of each of stations of a complex, on the accuracy of determination of coordinates of UAV [26].

Let's formulate necessary conditions of definition of a minimum of functionality (2.29) in more component representation [27]:

$$\begin{cases} \dfrac{\partial J(x_1,x_2,x_3)}{\partial x_1}=0 \\ \dfrac{\partial J(x_1,x_2,x_3)}{\partial x_2}=0 \\ \dfrac{\partial J(x_1,x_2,x_3)}{\partial x_3}=0 \end{cases} \tag{3.56}$$

where

$$\frac{\partial J(x_1,x_2,x_3)}{\partial x_i}=2\left\{\sum_{j=1}^{3}F_j(x)\cdot\rho\cdot\frac{\partial F_j(x)}{\partial x_i}\right\}=0 \qquad i=1..3 \tag{3.57}$$

or

$$\begin{aligned}\frac{\partial J(x_1,x_2,x_3)}{\partial x_i}=2((\frac{1}{c}(\sqrt{(x_1-x_1^1)^2+(x_2-x_2^1)^2+(x_3-x_3^1)^2}+D_1-\sqrt{x_1^2+x_2^2+x_3^2}-\tau_1)\cdot\rho_1\cdot\frac{\partial F_1(x)}{\partial x_i})+\\ +(\frac{1}{c}(\sqrt{(x_1-x_1^2)^2+(x_2-x_2^2)^2+(x_3-x_3^2)^2}+D_2+\sqrt{x_1^2+x_2^2+x_3^2}-\tau_2)\cdot\rho_2\cdot\frac{\partial F_2(x)}{\partial x_i})+\\ +(\frac{1}{c}(\sqrt{(x_1-x_1^3)^2+(x_2-x_2^3)^2+(x_3-x_3^3)^2}+D_3+\sqrt{x_1^2+x_2^2+x_3^2}-\tau_3)\cdot\rho_3\cdot\frac{\partial F_3(x)}{\partial x_i}))\end{aligned}$$

$$i=1..3$$

3.3.3.2 The analysis of the developed method of determination of coordinates of UAV

In TDOA system at not uniformally precise measurements of differences of times of delays of arrival of signals

For assessment of efficiency of the offered method, we will make comparison of results of calculation of coordinates of the equations (2.2) (a classical method) executed by a solution of a system and method on the basis of search of a minimum of square functionality (3.54).

We will carry out calculations for two cases: when one of stations has an error of measurement of a delay of time of arrival of a signal big, than the others and when two stations at the same time have an error of measurement of a delay of time of arrival of a signal. The relative positioning of stations and UAV for the first option is presented in fig. 3.11 and., and for the second option in fig. 3.11 b. Calculation results are given in tables 3.3 and 3.4. In tables the following designations are accepted: $x_{1J}, x_{2J}, x_{3J}, D_J, x_{1N}, x_{2N}, x_{3N}, D_N$ - the coordinates and range to UAV calculated by method of minimization of square functionality and classical TDOA $\delta x_{1J}, \delta x_{2J}, \delta x_{3J}, \delta D_J, \delta x_{1N}, \delta x_{2N}, \delta x_{3N}, \delta D_N$ - relative errors of calculation of coordinates and range to UAV.

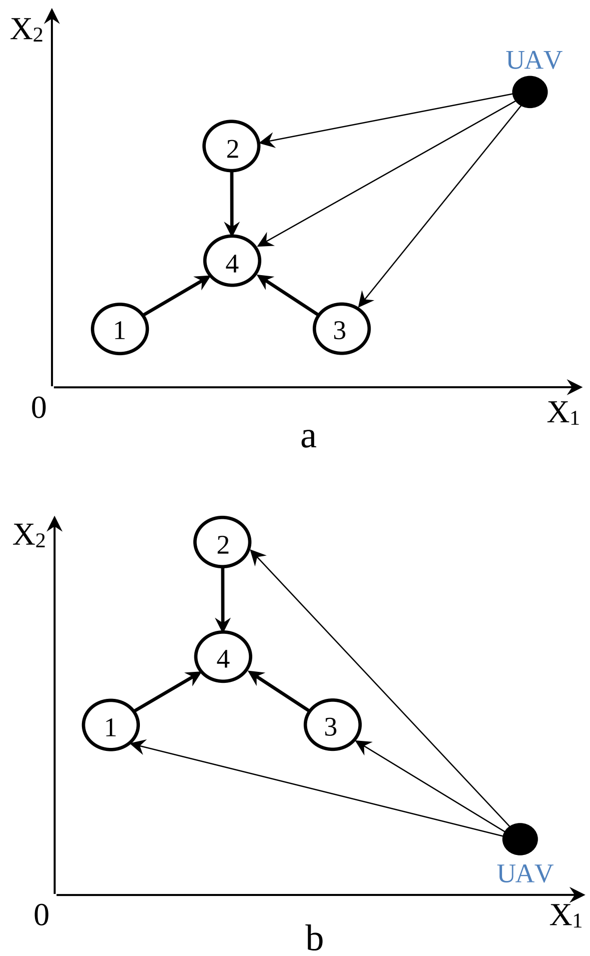

Fig. 3.11 Relative positioning of stations and UAV

Table 3.3

Calculation results at serial entering of an error into one of stations

<u>Conditions of a computing experiment</u> Weight coefficient i-th stations: ρ_i = 0,0000001 True coordinates of UAV, km: x =100 y =55 z =30 Distance from the beginning of coordinates to UAV, km: D =118.004
$\delta\tau_i$ = 10%

i	x_{1J} x_{1N}	x_{2J} y_N	x_{3J} x_{3N}	δx_{1J} δx_{1N}	δx_{2J} δx_{2N}	δx_{3J} δx_{3N}	D_J D_N	δD_J δD_N
1	**95.475** 81.985	**52.873** 46.533	**25.675** 7.481	**4.525** 18.015	**3.867** 15.395	**14.417** 75.063	**112.117** 94.567	**4.989** 19.862
2	**99.509** 117.472	**54.444** 74.756	**29.637** 41.459	**0.491** 17.472	**1.011** 35.92	**1.21** 38.197	**117.237** 145.282	**0.65** 23.117
3	**102.158** 115.379	**54.848** 53.919	**30.264** 30.908	**2.158** 15.379	**0.276** 1.965	**0.88** 3.027	**119.835** 131.053	**1.552** 11.058
$\delta\tau_i$ = 5%								
1	**95.486** 88.937	**52.879** 49.798	**25.686** 18.579	**4.514** 11.063	**3.856** 9.458	**14.38** 38.07	**112.132** 103.609	**4.976** 12.199
2	**99.521** 106.858	**54.459** 62.754	**29.647** 34.782	**0.479** 6.858	**0.984** 14.098	**1.177** 15.94	**117.257** 128.711	**0.633** 9.073
3	**101.401** 106.817	**54.901** 54.521	**30.176** 30.678	**1.401** 6.817	**0.18** 0.871	**0.587** 2.26	**119.193** 123.788	**1.007** 4.902
$\delta\tau_i$ = 1%								
1	95.493 **97.302**	52.882 **53.732**	25.693 **27.461**	4.507 **2.698**	3.851 **2.305**	14.357 **8.463**	112.141 **114.494**	4.969 **2.974**
2	**99.531** 101.179	**54.47** 56.333	**29.654** 30.858	**0.469** 1.179	**0.964** 2.424	**1.153** 2.859	**117.272** 119.845	**0.62** 1.56
3	**100.321** 101.256	**54.977** 54.912	**30.042** 30.159	**0.321** 1.256	**0.042** 0.16	**0.14** 0.53	**118.276** 119.07	**0.231** 0.903

As a result of the conducted research it is established that an order of size of weight coefficient ρ_i, at which the best result of calculation of coordinates stations turns out, is 10^{-7}, what corresponds to an order of the error brought in measurement of times of delays of arrival of a signal. Besides, at great values of weight coefficient results of calculations turn out much worse, and reduction is lower than it size 10^{-7} does not dismiss a prize in accuracy. Therefore calculation results only for this value of weight coefficient are given in table 3.3.

From table 3.3 it is visible that at an error $\delta\tau_1$ = 10% the calculated coordinates and range (are allocated in the table) by method of minimization of square functionality much closer to the true values in comparison with calculation with classical TDOA. In case $\delta\tau_2$ and $\delta\tau_3$ 10% are also serially equal, calculation results have the same picture: the coordinates and range calculated by means of minimization of square functionality considerably surpass in accuracy calculations by classical TDOA. Thus, by means of introduction of weight coefficient before the corresponding square function, it is possible to compensate substantially an error of measurement of a temporary delay of arrival of a signal and, unlike classical TDOA, to receive the acceptable results suitable for positioning of UAV.

Calculations of table 3.3 also show that at reduction of an error of measurement of a delay of time of arrival of a signal $\delta\tau_i$, i = 1..3 each of stations serially up to 5% the method of minimization of square functionality also has advantage in calculations in comparison with classical TDOA as the error of determination of coordinates and range in the first case is much lower.

In case of reduction of an error of measurement of a delay of time of arrival of a signal the same way up to 1% calculation accuracy differ with method of minimization of square functionality and classical TDOA slightly and, in this case, the difference of use of this or that method is absent. Classical TDOA in this case is even more preferable to reduction of time of calculation.

Let's consider a case of simultaneous introduction of an error equal of 10%, in two delays of time of arrival of a signal, for example, in and and provided that UAV will symmetrically be the stations which are rather corresponding to these delays, that is a symmetric case (see fig. 3.11 b). As a result of the made computing experiment (table 3.3) it was established that the best result of determination of coordinates and range is also reached at minimization of functionality. In this case weight coefficients and at the corresponding square functions also have to have an order that corresponds to an order of the error brought in measurement of times of delays of arrival of a signal.

From table 3.3 it is also visible that in case of reduction of an error of measurement of a delay of time of arrival of a signal by two stations up to 5%, and then and up to 1% the trend of change of calculation results is similar to a case of entering of an error of measurement only into one of stations. At 5% of an error of measurement of a temporary delay at the same time two stations of a complex the method of minimization of square functionality also has advantage in calculations in comparison with classical TDOA. In case of reduction of an error up to 1% calculation results by both methods become comparable.

Table 3.4

Calculation results at simultaneous entering of an error into two stations

Conditions of a computing experiment

Weight coefficient of the 1st and 2nd stations: ρ_1, ρ_2 = 0,0000001

True coordinates of UAV, km: x =96 y =25 z =8

Distance from the beginning of coordinates to UAV, km: D = 99.524

i	$\frac{x_{1J}}{x_{1N}}$	$\frac{x_{2J}}{y_N}$	$\frac{x_{3J}}{x_{3N}}$	$\frac{\delta x_{1J}}{\delta x_{1N}}$	$\frac{\delta x_{2J}}{\delta x_{2N}}$	$\frac{\delta x_{3J}}{\delta x_{3N}}$	$\frac{D_J}{D_N}$	$\frac{\delta D_J}{\delta D_N}$
$\delta\tau_i$ = 10%								
1,2	**93.894** 85.736	**24.516** 31.097	**6.327** 6.244	**2.194** 10.692	**1.936** 24.388	**20.913** 21.95	**97.248** 91.415	**2.287** 8.148
$\delta\tau_i$ = 5%								
1,2	**93.893** 90.395	**24.516** 28.369	**6.327** 8.353	**2.195** 5.839	**1.936** 13.476	**20.913** 4.412	**97.247** 95.11	**2.288** 4.436
$\delta\tau_i$ = 1%								
1,2	93.891 **94.792**	24.517 **25.732**	6.327 **8.324**	2.197 **1.258**	1.932 **2.928**	20.913 **4.05**	97.245 **98.575**	2.29 **0.954**

The solution of a problem of determination of coordinates of UAV by a differential and ranging method in the systems of a passive sodar-location on the basis of extreme statement is considered and comparative analysis of accuracy with a classical method - the solution of a hyperbolic system of the equations is made. On the basis of the made computing experiments it is possible to draw a conclusion that the method of minimization of square functionality is more effective tool of the solution of a problem of determination of coordinates of UAV by a differential and ranging method. Such approach allows to consider an error of measurement of delay time of arrival of a signal of each of stations of a complex that cannot be made at the classical solution of a system of the hyperbolic equations.

4. Development of the software

4.1 Structure of the offered software

This program allows to model the following electronic tools:

- the dual trace oscilloscope having the trigger mode. Throughput depends on the sound card (from 20 kHz to 192 kHz). Resolution is from 8 to 24 bits. There is a function of automatic calibration and fast establishment of values;
- two-channel spectrum analyzer. Resolution is from 8 to 24 bits. A X-axis in Hz, a Y-axis in dB or volts (calibration is necessary). A scale linear or logarithmic, autoscalable, with sixteenfold increase in the selected section;
- two-channel generator of signals (triangular, square, sinusoidal; white and pink noise, pulsations and some other options). Independent sampling rates. Change of parameters (amplitude, frequency, a phase between channels, signal type) takes place in real time;
- a two-channel frequency meter (in time and in frequency domain) and the counter;
- the two-channel voltmeter of the class True RMS (calibration is necessary) with deduction function;
- filters: low and high frequencies, the bandpass, rejection, band-elimination, diode, double filter (on one on each canal).

The program perfectly works on low-power computers and does not demand any additional equipment. The measured audiosignal moves on a linear or microphone input then SpectraPLUS by means of the sound card carries out analog digital conversion.

Establishment of values through passage of models of three-polar explorers in the range from 22 Hz to 22 kHz (audio frequencies) with a step to 22 Hz is in addition possible.

After reading operation input signals are processed and displayed in a graphic look (are always presented in the form of diagrams of red color). In the same temporary coordinates results of decoding (diagrams of blue color) and the color indicator of the selected group (green color) are under construction. In a separate window numerical values of the pulse counter with the indication of deviations from reference value of the decoder are displayed. At the program there is a function of increase in the diagram of an input signal (or its separate segment) by means of selection of necessary range a mouse. For increase in accuracy of the analysis it is possible to specify values of range "Flank" manually. Also in the program the digital filter for elimination of noises is implemented.

4.2 Interface of the program

The delay time of arrival of a signal at the reception station of a passive complex is the key information parameter for DRM. The error of finding of this parameter directly influences an error of definition of lines (surfaces) of situation in DRM. Therefore, the problem of the most exact definition of temporary delays of a signal is extremely relevant for the systems of a passive location.

As it was shown in fig. 4.1, at distribution in the environment the form of packs of impulses is exposed to distortions. Nevertheless, on condition of ensuring independence of measurements, it is possible to consider that at measurement of delay time on n to packs the mean square deviation of measurement decreases in time [27]. It allows to provide the required accuracy of definition of temporary delays of a pulse signal, at least, when determining coordinates of the purpose in limits of direct visibility.

However military radio stations mainly use continuous radiation. In this case, for definition of temporary delays it is necessary to execute special processing of a signal.

In fig. 4.1 fragments of the real signals accepted by a passive complex when carrying out field tests are presented:

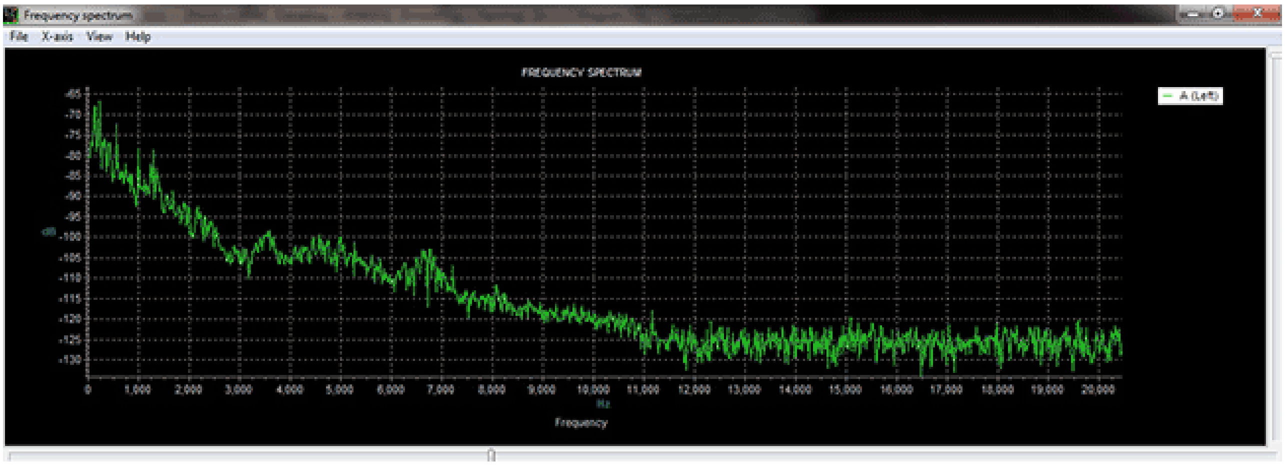

Fig. 4.1. Fragments of real continuous signals

For determination of coordinates, structure and a trajectory of the difficult purposes correlation processing of signals is traditionally used [25, 26, 27]. Advantage of correlation methods of processing consists in maximum efficiency, in terms of the accuracy of stay, the received estimates of temporary delays in the presence of additive noise.

For definition of temporary delays of arrival of a signal at the station of a complex it is necessary to calculate maxima of the cross-correlation functions (CCF) of the signals accepted by the corresponding PS.

VKF of two signals f1(t) and f2(t) represents a scalar product of a look:

$$B(\tau) = \int_{-\infty}^{+\infty} f_1(t) \cdot f_2(t-\tau) dt . \qquad (4.1)$$

In case the task of signals f1(t) and f2(t) is executed in a discrete form as set of the counting following in time with some identical intervals of T, then VKF for discrete signals can be determined by a formula:

$$B(n) = \sum_{j=-\infty}^{\infty} f1_j \, f2_{j-n} \, , \qquad (4.2)$$

where n – whole number.

The fragment of VKF of real samples of the signals presented in fig. 4.1 is given in fig. 4.2:

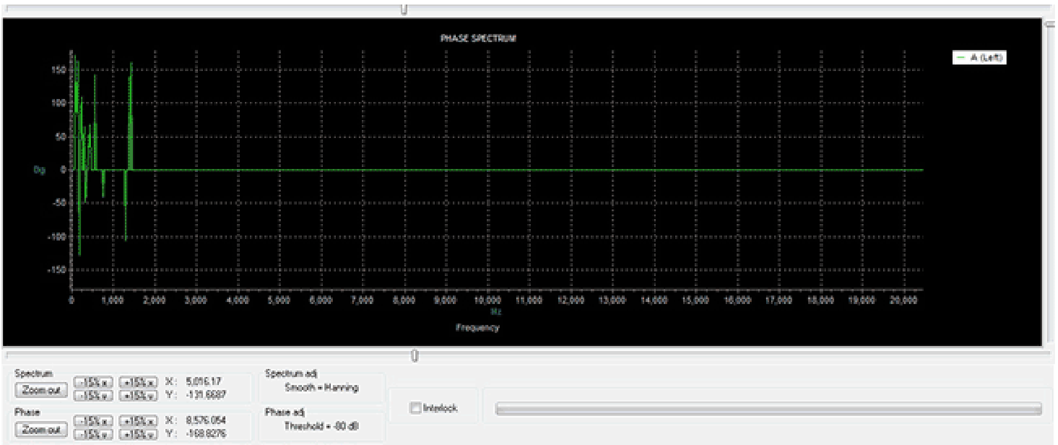

Fig. 4.2. Fragment of VKF of real signals

As appears from fig. 4.2 at most VKF corresponds to a temporary delay τ=20мкс.

The interval of correlation should be chosen as big, than the maximum value of possible temporary delays τ, and, for a motionless source this interval can be chosen as duration of complete samples of counting of signals of PS. In case the source of a signal moves, the interval of the analysis can be reduced to the value determined the system demanded by resolution by time.

In case of several (at least two) IRI inevitably arises a problem of ambiguous interpretation of results of measurement of temporary delays when using methods of the correlation analysis [28]. The characteristic type of similar ambiguity is presented in fig. 4.3:

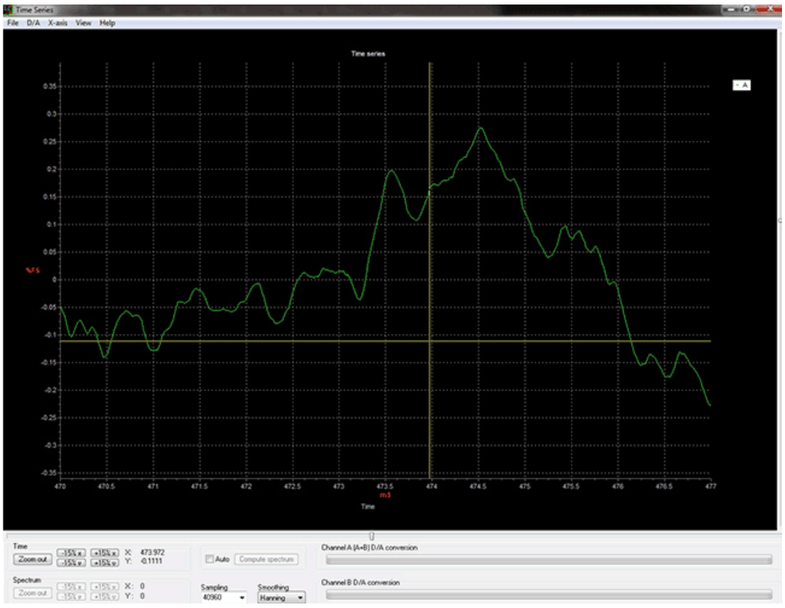

Fig. 4.3. Ambiguity of definition of a maximum of VKF

As appears from fig. 4.3 in spite of the fact that both sources of signals are perfectly resolved on the time delays, at calculation of coordinates of IRI the problem of establishment of numbers of maxima of VKF and numbers IRI, in other words, a problem of distinguishing of signals appears.

For a solution of this task attraction of additional information on an information signal can be used.

Let's consider typical parameters of signals available to measurement and identification in MPK: carrier frequencies, a frequency range, the moments of reception (detection) of each impulse, duration of impulses, the repetition periods, a bearing on the purpose, start time of reception of a signal, signal strength (quantity of impulses in a series), the relative amplitude of impulses {U}, the period of rotation of AFS of radar station {Tc}.

Arrays of time-and-frequency parameters of the accepted signals represent sets:

- array of the moments of reception of each useful and interfering impulse;
- array of dlitelnost of useful and interfering impulses;
- an array of frequencies of filling for each useful and interfering impulse;
- an array of frequencies for continuous signals;
- an array of bearings on each useful and interfering impulse;
- an array of amplitudes for each useful and interfering impulse;

The array of time-and-frequency parameters includes in addition to desired pulse signals as well impulse interference, and continuous signals.

4.3 Creating a working layout of one of the nodes of the sodar station based on the Arduino platform

4.3.1 Review to HC-SR04 ultrasonic rangefinder

Ultrasonic rangefinder HC-SR04 (fig 4.4) is a receiver and transmitter of an ultrasonic signal placed on the same board. In addition to the receiver and transmitter, the board also has the necessary binding to make the operation with this sensor simple and easy.

Fig 4.4 HC-SR04 ultrasonic rangefinder

The sensor has low power consumption, which is also an important advantage in the case of mobile systems that are not attached to the outlet. The HC-SR04 sensor is powered from 5 V, which is also convenient when connecting it to Arduino.

Characteristics of ultrasonic range finder HC-SR04:

- measured range - from 2 to 500 cm;
- accuracy - 0.3 cm;
- viewing angle - <15 °;
- supply voltage - 5 V.

The sensor has 4 outputs of standard 2.54 mm:

- VCC - + 5 V power supply;
- Trig (T) - input signal output;
- Echo (R) - output signal output;
- GND - land.

The rangefinder includes two piezoelectric elements: one works as a signal emitter, the other as a receiver. The emitter generates a signal which, reflected by the obstacle, hits the receiver. By measuring the time, the signal passes to and from the object, the distance can be estimated.

The sequence of actions is as follows:

1. We supply a pulse lasting 10 μs to the Trig output.
2. Inside the rangefinder, the input pulse is converted into 8 pulses with a frequency of 40 kHz and sent forward through the emitter.
3. Reaching the obstacle, the sent pulses are reflected and received by the receiver, as a result, we obtain an output signal at the Echo output.
4. Directly on the controller side we convert the received signal to the distance according to the formula:

- pulse width (μs)/58 = distance (cm);
- pulse width (μs)/148 = distance (inch).

4.3.2 Assumed layout diagram and software

Our task was to create a workable full-fledged node of the sound monitoring system, with the output of information that only one of the nodes can determine on the display. In our case, the available information is output to the lcd 1602 display. Diagram sketch is shown in Figure 2.28

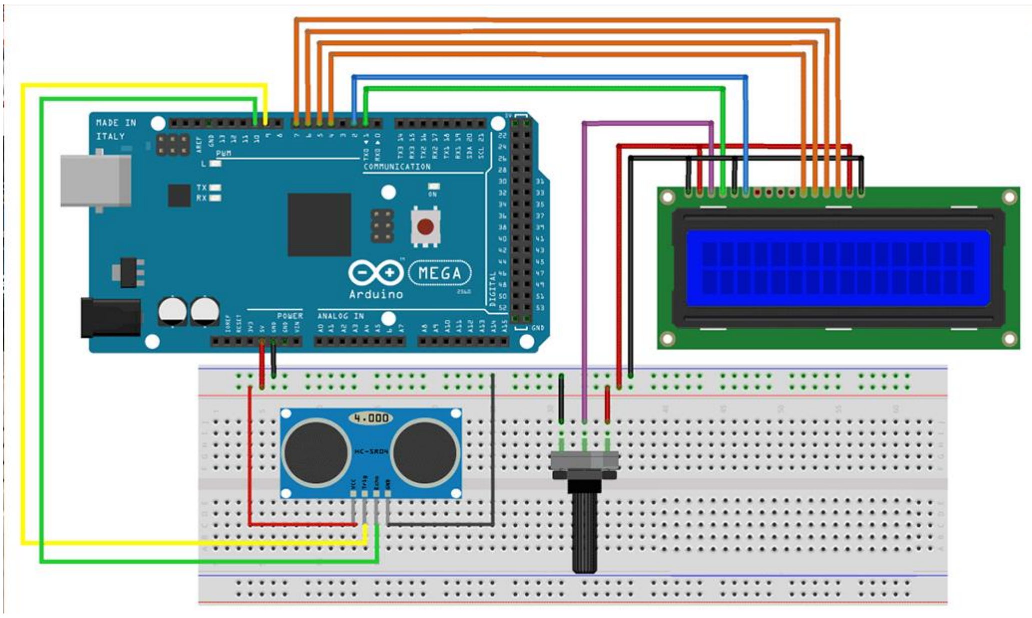

Fig 4.5 Assumed layout diagram

Along with the display, it is also worth applying a potentiometer to more accurately adjust the brightness of the display

The code of the program itself looks like this:

First you have to define the Trig and Echo pins. In this case they are the pins number 9 and 10 on the Arduino Board and they are named trigPin and echoPin. Then you need a Long variable, named “duration” for the travel time that you will get from the sensor and an integer variable for the distance.

```
// defines pins numbers
const int trigPin = 9;
const int echoPin = 10;

// defines variables
long duration;
int distance;
```

In the setup you have to define the trigPin as an output and the echoPin as an Input and also start the serial communication for showing the results on the serial monitor.

```
void setup() {
pinMode(trigPin, OUTPUT); // Sets the trigPin as an Output
pinMode(echoPin, INPUT); // Sets the echoPin as an Input
Serial.begin(9600); // Starts the serial communication
}
```

In the loop first you have to make sure that the trigPin is clear so you have to set that pin on a LOW State for just 2 µs. Now for generating the Ultra sound wave we have to set the trigPin on HIGH State for 10 µs. Using the pulseIn() function you have to read the travel time and put that value into the variable “duration”. This function has 2 parameters, the first one is the name of the echo pin and for the second one you can write either HIGH or LOW.

```
// Clears the trigPin
digitalWrite(trigPin, LOW);
delayMicroseconds(2);

// Sets the trigPin on HIGH state for 10 micro seconds
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
```

In this case, HIGH means that the pulsIn() function will wait for the pin to go HIGH caused by the bounced sound wave and it will start timing, then it will wait for the pin to go LOW when the sound wave will end which will stop the timing. At the end the function will return the length of the pulse in microseconds.

For getting the distance we will multiply the duration by 0.034 and divide it by 2 as we explained this equation previously.

```
// Reads the echoPin, returns the sound wave travel time in microseconds
duration = pulseIn(echoPin, HIGH);

// Calculating the distance
distance= duration*0.034/2;

// Prints the distance on the Serial Monitor
Serial.print("Distance: ");
Serial.println(distance);
```

The code measuring the distance is pretty much the same as the basic example. Here, instead of printing the results on the serial monitor we print them on the LCD.

Here’s the complete code:

ultrasonic_1 §

```
/*
* Ultrasonic Sensor HC-SR04 and Arduino Tutorial
*/
#include <LiquidCrystal.h> // includes the LiquidCrystal Library
LiquidCrystal lcd(1, 2, 4, 5, 6, 7); // Creates an LCD object. Parameters: (rs, enable, d4, d5, d6, d7
const int trigPin = 9;
const int echoPin = 10;
long duration;
int distanceCm, distanceInch;
void setup() {
lcd.begin(16,2); // Initializes the interface to the LCD screen
pinMode(trigPin, OUTPUT);
pinMode(echoPin, INPUT);
}
void loop() {
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
duration = pulseIn(echoPin, HIGH);
distanceCm= duration*0.034/2;
distanceInch = duration*0.0133/2;
lcd.setCursor(0,0); // Sets the location at which subsequent text written to the LCD will be displayed
lcd.print("Distance: "); // Prints string "Distance" on the LCD
lcd.print(distanceCm); // Prints the distance value from the sensor
lcd.print(" cm");
delay(10);
lcd.setCursor(0,1);
lcd.print("Distance: ");
lcd.print(distanceInch);
lcd.print(" inch");
delay(10);
}
```

5. LABOUR SAFETY

The structure of the section:

5.1. Analysis of harmful and dangerous production factors

5.2. Measures to reduce the impact of harmful and dangerous production factors

5.3. Occupational Safety Instruction

This chapter describes the main issues that need to be considered to ensure the safety of people when installing, connecting and providing an automatic system for determining the UAV coordinates in multi-position sound monitoring systems, its active and passive sound monitoring nodes, as well as all nodes related to the operation of the system.

The purpose of this chapter is to gather information on a wide range of hazards associated with the safety of people working during the installation and operation of automatic sound monitoring systems.

This chapter summarizes the main performance categories associated with the installation and provision of automatic audio monitoring systems and identifies the specific hazards to be considered. Analysis of harmful and dangerous production factors

The labor process is carried out in a specially designated place for the operator, which is characterized by a combination of elements and factors of the material and production environment. Consider the working conditions of the operator of the sound monitoring complex, which monitors the information received on the screen from the sound monitoring nodes.

The operator of the passive sound monitoring system must install and monitor directional microphones and directional microphones, which convert the acoustic signal into electricity. The installer of the acoustic signal receiving units must install the units themselves at a pre-adjusted distance from each other, as well as in the pre-allocated territory for this. Since microphones work best on flat surfaces, they are usually placed along plains or coastal zones. The employee uses a device for displaying useful information on the screen, which cannot be climbed with his hands when the network is turned on, disassemble it (as well as any other node of the complex) without the knowledge of the authorities, and it is worth protecting the equipment from short circuits.

5.1. Harmful and dangerous production factors according to ГОСТ 12.0.003-74:

Physical:

- increased level of ultrasound when near acoustic wave reading nodes, especially active microphones, considering their properties to send an audible signal for detection by sound collocation by means of a powerful sound pulse
- increased voltage in the electrical circuit, the short circuit of which can occur through the human body, since when working with the system, the operator is in the vicinity of electrical devices, the voltage of which can be deadly for the operator
- increased level of static electricity. The work environment must be controlled in accordance with safety requirements and all other relevant legal requirements.

5.2. Measures to reduce the impact of harmful and dangerous production factors

The training program shall be developed and conducted by the relevant training organizations to inform and train the relevant personnel on the hazards and protection measures in the installation of the photovoltaic station, which shall cover a wider range of topics involved (e.g. design, installation, testing and commissioning, operation and maintenance).

The Applicant/Contractor shall ensure that all relevant personnel are well informed and trained on health and safety risks and measures for any particular project.

The operator, who work with ultrasound must, at least once every two years, undergo medical examinations with the participation of medical specialists: otorhinolaryngologist, neurologist, ophthalmologist, surgeon.

In order to minimize noise pollution of the environment, it is necessary to locate such systems away from the permanent residence of people, in connection with the provision on the permissible noise level ДСТУ ISO 11204:2008. In the case of forced use of such systems near the place of residence, use sound, the value of which does not exceed the permissible limits. To calculate the permissible noise limits, we used the formula for calculating the average value of the sound pressure level

$$L_{pA} = 10 \lg\left[\frac{1}{T}\sum_{i=1}^{N} T_i 10^{0,1L_{pA,T(i)}}\right],$$

where T – total number of tests

The study of the noise mode of residential areas was carried out thanks to the construction of noise maps, as well as considering the provisions ДСТУ ISO 11204:2008 and ДСТУ 2325-93, and constitutes:

- 40 Dba near residential buildings in the daytime (max. 55 DBa)
- 30 Dba near residential buildings at night (max. 45 DBa)
- 50 Dba near industrial areas and office houses (max. 65 DBa)

To prevent an increased level of static electricity, you must correctly calculate the protective earthing - an electrical connection to earth or its equivalent, metal non-conductive parts, which can be live.

The purpose of protective earthing is to reduce the current flowing through a person (IP) when touching the earthed housing of the diagnostic device, when there is Ucont (contact voltage) as a result of damage or breakdown of insulation of conductive parts.

The calculation of the circuit in the laboratory is to determine the number of vertical grounding conductors and the length of the connecting strip. According to the rules, the resistance of the grounding circuit should not exceed 4 ohms for the supply voltage up to 1000 V. In the most adverse conditions, the resistance of a single ground is determined by the formula

$$R_g = 0{,}366\frac{\rho}{\ell}\left(\lg\frac{2\ell}{d}+\frac{1}{2}\lg\frac{4H+\ell}{4H-\ell}\right)$$

As a grounding conductor choose a rod:

- length l = 1.5 m
- diameter d = 0.016 m
- distance from the earth's surface to half the length of the rod H = 0.85 m
- ρ - specific soil resistance; ρ = 102 Ohm • m

$$R_g = 0{,}366\,\frac{10^2}{1{,}5}\left(\lg\frac{2\cdot 1{,}5}{0{,}016}+\frac{1}{2}\lg\frac{4\cdot 0{,}85+1{,}5}{4\cdot 0{,}85-1{,}5}\right)=60\,\text{Ohms}$$

The number of single grounding conductors η is calculated by the formula

$$n=\frac{R_g}{r_{н.з}\cdot\eta_g},$$

Where $r_{H.3}$ = 4 Ohms, according to ПУЕ-86

Ƞg - the coefficient of use of a single ground for rods; Ƞg = 0.66

$$n=\frac{60}{4\cdot 0{,}66}=22$$

The resistance of the connecting strip connecting single grounding conductors is determined by the formula

$$R_{str} = 0{,}366\frac{\rho}{\ell}\lg\frac{2\cdot\ell^2}{b\cdot H},$$

where l - strip length; l = a • n = 79.2m

a - the distance between the rods; a = 3.6m

H - depth of laying the strip; H = 0.1m

$$R_{str} = 0{,}366\frac{10^2}{79{,}2}\lg\frac{2\cdot 79{,}2^2}{0{,}04\cdot 0{,}1} = 3\,\text{Ohms}$$

The resistance of artificial circuit grounding is determined by the formula

$$R_{c.g} = \frac{R_g\cdot R_{str}}{R_g\cdot\eta_{str} + n\cdot R_{str}\cdot\eta_g}$$

where η_{str} = 0.4 - the coefficient of use of the connecting strip in the circuit of vertical electrodes;

$$R_{c.g.} = \frac{60\cdot 3}{60\cdot 0{,}4 + 22\cdot 3\cdot 0{,}66} = 2{,}66\,\text{Ohms}$$

The calculated value of the resistance of the grounding circuit meets the requirements of electrical safety.

5.3. Occupational Safety Instructions

General Occupational Safety Requirements

I.I. Persons who have reached the age of 18, have undergone a mandatory medical examination, induction training, initial instruction at the workplace, are allowed to work independently and maintain a complex of automatic coordinate recognition system based on sound information.

I.II. When working with an automatic coordinate recognition system complex based on sound information, the employee must:

I.II.I. Perform only the work defined by the work instruction approved by the enterprise administration and provided that the employee is well aware of the safe ways to perform it.

I.II.II. Comply with internal labor regulations.

I.II.III. Use personal and collective protective equipment correctly.

I.II.IV. Comply with safety requirements.

I.II.V. Immediately notify your immediate or superior manager about any situation that threatens the life and health of people, about all accidents at work or about the deterioration of your health, including the manifestation of signs of acute occupational illness (tinnitus, severe headache).

I.II.VI. Training in safe methods and techniques for performing work and providing first aid to victims at the workplace, training in labor protection, checking knowledge of labor protection requirements.

I.II.VII. Undergo mandatory periodic (when hiring) medical examinations (examinations), as well as extraordinary medical examinations (examinations) at the direction of the employer in cases provided for by the Labor Code and other federal laws.

I.II.VIII. The employee must be able to provide first aid to victims of electric current and other accidents.

I.II.IX. Be able to use primary fire extinguishing equipment.

I.III. Contain tools and work area in dry state.

I.IV. When working with passive sound monitoring system, the employee is prohibited from:

I.IV.I. work without prior instruction to work;

I.IV.II. insert electrically conductive objects into connectors;

I.IV.III. Disassemble the components of the sound monitoring system;

I.IV.IV. Expose the panels to artificially focused radiation.

I.IV.V. without permission to go outside the space allocated for the workplace

I.IV.VI. remove barriers of hazardous areas of operating equipment

I.V. In case of injury or discomfort, it is necessary to stop working, notify the manager and contact the medical institution.

II. Safety requirements prior to commencement of work:

II.I. Check and ensure that the stationary equipment, tools, accessories and protectors are in good working condition. Position the tool for maximum usability, avoiding unnecessary items in the work area.

II.II. Check that tools and work surface are dry.

II.III. Disconnect the inverter from the network.

II.IV. The employee shall not:

II.IV.I. use inappropriate and improperly sharpened tools and accessories;

II.IV.II. touch current-carrying parts of electrical equipment, open the doors of electric cabinets. If necessary, contact the maintenance personnel.

II.V. All defects and faults of tools, accessories and protective equipment detected during inspection should be reported to the work manager for taking measures to eliminate them.

III. Work safety requirements:

III.I. Install and remove parts only when power is off

III.II. Working with the sound monitoring complex, the employee must:

III.II.I. reliably and correctly attach all units and devices in the system to prevent their departure during vibration;

III.II.II. Check the mechanical load level parameters.

III.II.III. Check modules for earthing

III.II.IV. Act according to operating and repair instructions

III.III. Employee is prohibited from:

III.III.I.I. Drop design parts.

III.III.II. Disassemble independently any of the system nodes

IV. Safety requirements in emergency situations

IV.I. Under the supervision of the person responsible for the work, promptly take measures to eliminate the causes of accidents or situations that may lead to accidents or accidents.

IV.II. Immediately notify the fire brigade by phone "101," notify the workers, notify the head of the unit, report the fire to the security post.

IV.III. De-energize the plant, close windows and doors.

IV.IV. Start extinguishing the fire with primary fire extinguishing equipment, if it is not related to danger to life.

IV.V. Move to a safe distance from the sound monitoring complex.

IV.VI. Immediately provide first aid to the victim and, if necessary, deliver him to the medical organization;

IV.VII. Take urgent measures to prevent the development of an emergency or other emergency and the impact of traumatic factors on others;

IV.VIII. Before the start of the accident investigation, preserve the situation that was during the accident, if it does not threaten the life and health of others and does not lead to a disaster, accident or other emergency, and if it is impossible to save, correct the current situation (draw up schemes, conduct other measures).

V. Occupational safety requirements upon completion of work.

V.I. Make sure that all elements are connected correctly and attached.

V.II. Clean up the work center

V.III. Disconnect the system from the network

V.IV. Inform the manager of all shortcomings observed during the work process and measures taken to eliminate them.

6. ENVIRONMENTAL PROTECTION

6.1 Introduction.

The final result of the diploma project is to develop of an automatic system for determining the UAV coordinates in multi-position sound monitoring systems, which inherently requires not only knowledge and skills in the selection of the correct technical means and algorithmic support, but also an analysis of existing technical solutions in the construction of the UAVs themselves. Also, the construction of such systems is considered expedient due to the wide popularity of the UAV systems themselves, in view of their resource efficiency, and therefore environmental friendliness. This chapter will examine the role of UAVs in the ecology and enviromental protection.

6.2 UAV environmental friendliness

The assessment of the environmental friendliness of multicopters for the delivery of goods was carried out using the method of calculating the carbon footprint - the amount of carbon dioxide that is formed during the production of electricity consumed by unmanned aerial vehicles at all stages of transportation and necessary to ensure its operation. The authors of the work note that such a calculation should consider the type of energy sources that are used in a given region. If the energy comes from renewable sources (in particular from solar or wind power plants), then the amount of carbon dioxide generated during this is much lower than if the energy is obtained, for example, by burning coal. It turned out that the delivery of light packages on small quadcopters is in any case more environmentally efficient than traditional ground delivery, for example, using trucks.

In recent years, drones have been increasingly used to deliver relatively small loads. Small drones are already delivering mail, shopping, food, and even money. This delivery method is convenient for shipment over short distances and in the case when ground delivery is difficult: in particular, if you need to overcome some obstacle (for example, a river or strait) or deliver the goods to an area with poor quality roads. Some drones can deliver small cargo directly to the recipient's hands. To explore how environmentally friendly short-haul delivery of goods using a variety of multicopters would be, we calculated the energy costs required by drones to deliver cargo, estimated the amount of greenhouse gas emissions and compared these figures with similar values for traditional ground delivery methods (fig. 6.1). As part of the study, the authors examined two of the most common drone configurations: small quadcopters, which are used to deliver cargo weighing no more than 500 grams, and rather massive octocopters for delivering heavy loads weighing up to 8 kilograms (table 6.2).

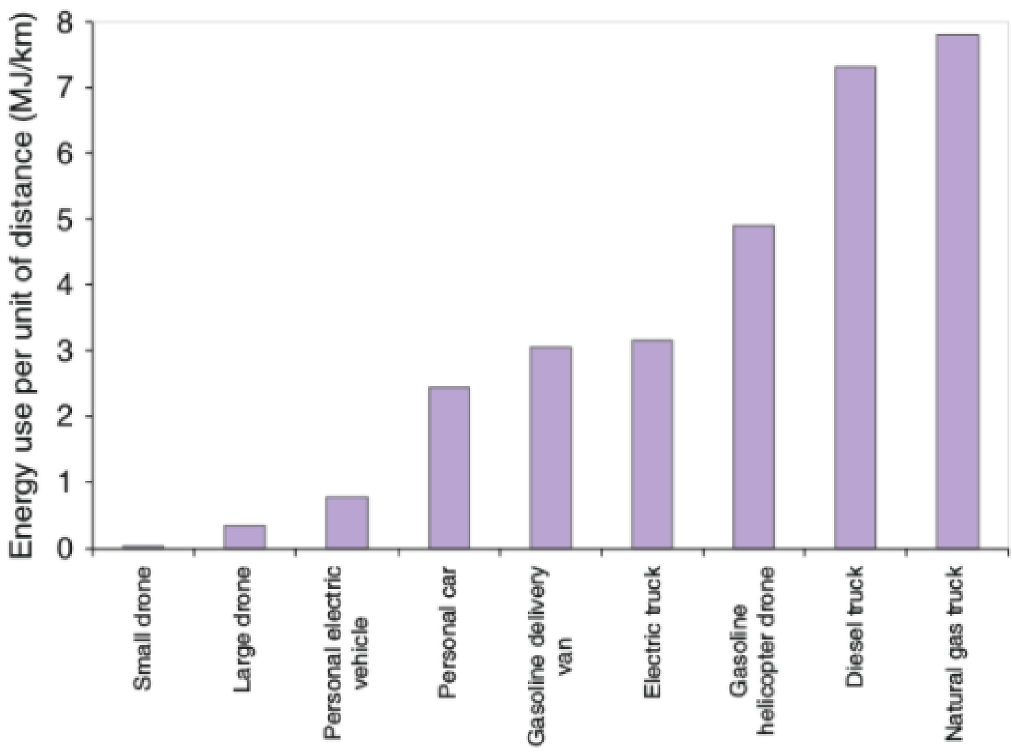

Figure 6.1. Level of energy use by popular transportation methods

The use of quadrocopters for the delivery of small cargoes turned out to be much more profitable in terms of reducing greenhouse gas emissions into the atmosphere - their "carbon footprint" was significantly less than that of conventional trucks with the same total weight of cargo.

Delivery of light packages in small quadcopters is in any case more environmentally efficient than traditional ground delivery, for example, using trucks. However, the researchers note that currently available batteries for quadcopters can deliver cargo to a distance of no more than 4 kilometers. Therefore, to create a normally functioning transport network, it is necessary to create a whole system of stations and warehouses, the energy costs of which must also be considered in the calculations.

Size	Nomenclature	Specifics	Operational requirements	Application areas	Examples
Very large (3–8 tons)	HALE (High Altitude, Long Endurance)	Fly at the highest altitude (> 20 Km) with huge operating range that extend thousands of km, long flight time (over 2 days), very heavy payload capacity (more than 900 kg in under-wing pods)	Prohibitively expensive for most users (high maintenance, sensors, crew training costs), long runway for takeoff and landing, ground-station support, and continuous air-traffic control issues, challenging deployment/recovery and transport	Assessments of climate variable impacts at global scales, remote sensing collection, and earth/atmospheric science investigations	Global Hawk, Qinetiq Zephyr, NASA PathFinder
Large (1–3 tons)	MALE (Medium Altitude, Long Endurance)	Medium altitude (3–9 Km), over 12 h flight time with broad operating range (> 500 km), heavy payload capacity (~100 kg internally, external loads of 45 up to 900 kg)	Similar requirements as for HALE but with reduced overall costs	Near-real-time wildfire mapping and surveillance, investigation of storm electrical activity and storm morphology, remote sensing and atmospheric sampling, arctic surveys, atmospheric composition and chemistry	NASA Altus II, NASA Altair, NASA Ikhana, MQ-9 Reaper (Predator B), Heron 2, NASA SIERRA

Medium (25–150 kg)	LALE (Low Altitude, Long Endurance), LASE (Low Altitude, Short Endurance)	Fly at moderate altitude (1–3 Km) with operating ranges that extend from 5 to 150 km), flight time (over 10 hours), moderate payload capacity (10–50 kg)	Reduced costs and requirements for takeoff and landing compared to MALE (hand-launched platforms and catapult-launch platforms), simplified ground-control stations	Remote sensing, mapping, surveillance and security, land cover characterization, agriculture and ecosystem assessment, disaster response and assessment	ScanEagle, Heron 1, RQ-11 Raven, RQ-2 Pionee, RQ-14 Dragon Eye, NASA J-FLiC, Arcturus T-20
Small, mini, and nano (Less than 25 kg for small AUVs, up to 5 Kg for mini and less than 5 Kg for nano)	MAV (Micro) or NAV (Nano) Air Vehicles	Fly at low altitude (< 300 m), with short duration of flight (5–30 min) and range (< 10 Km), small payload capacity (< 5 kg)	Low costs and minimal take off/landing requirements (Hand-launched), often are accompanied by ground-control stations consisting of laptop computers, flown by flight planning software or by direct RC (Visual Line Of Sight or Beyond Visual Line Of Sight when allowed), usually fixed-wing (small AUVs) and copter-type (mini and nano AUVs)	Aerial photography and video, remote sensing, vegetation dynamics, disaster response and assessment, precision agriculture, forestry monitoring, geophysical surveying, photogrammetry, archeological research, environmental monitoring	AR-Parrot, BAT-3, SenseFly eBee, DJI Inspire 3, DJI Phantom 4, Draganflyer X6, Walkera Voyager 4

Table 6.2. UAV weight classification and examples

For more powerful octocopters and heavier cargoes, the emission gains are far less obvious. So, if a delivery drone operates in regions for which the main source of electricity is fossil resources, then when delivering cargo of the same mass over the same distance, the drone will produce 50 percent more carbon dioxide than the truck. If renewable sources are used to generate electricity, then a multicopter will already be in a winning position, but the difference will be only 9 percent.

6.3 UAV role in enviromental protection

Drones, or unmanned aerial vehicles (UAVs), are becoming increasingly popular in not only the leisure market but for monitoring the environment. Drone technology has entered many fields including surveillance, search and rescue operations, aerial photography, digital communications – and, of course, recreation. Drones are low cost, require little preparation and infrastructure, and no fuel (other than batteries) so it's no wonder they have swarmed the market. Furthermore, they can be equipped with any number of sensors or cameras making them ideal for monitoring the environment.

The choice of a particular type of UAV depends on the characteristics of the research object, the need for real-time data transmission and the type of data determined by the task at hand. In particular, for air monitoring of the technical condition and safety of oil, gas and product pipelines with a large length, it is more efficient to use aircraft-type UAVs of medium and long range. High stability and good controllability allow the use of UAVs in adverse weather conditions and from limited sites.

Environmental Monitoring

Currently, one of the promising areas of UAV application is gyrometeorological monitoring of water and air. Control is relevant here pollution of air, soil, water sources with animal waste products, irrational use of fertilizers and equipment. Aerial photography/videography is one area where drones have a vital role: a small drone can fly for several hours recording pictures with a pixel resolution of 1m, meaning they are suitable for aerial mapping and nature monitoring. Hovering at around 200m, drones are capable of taking crystal-clear images of any environment on any day of the year, unrestricted by cloud cover. They can also be armed with meteorological apparatus such as wind gauges, thermometers and humidity or pressure sensors allowing them to gather climate data.

UAV's can also carry meteorological equipment like wind gauges, thermometers, humidity and pressure sensors to collect climate data from regions across the globe. As such, the technology is currently being used for mapping the inaccessible rainforests of the Congo and Suriname to adress complex conservation issues that lie at the interface of ecology and social change. They can reveal how an area changes over time, down to the finest detail and have been used to model glacial features, monitor erosion, in coastal management, terrain modeling, forestry and in river and flooding assessments.

In addition, UAVs can be successfully used to monitor objects of the fuel and energy complex, pipeline systems for transporting hydrocarbons, oil spills, the condition and integrity of nuclear fuel and energy complex facilities, power lines, etc. Thus, operational use is economically profitable and safe. UAVs for aerial reconnaissance of natural and man-made emergencies, including environmental monitoring after radiation accidents at nuclear power and industrial facilities.

Disaster Relief

Drones are ideal to fly into inaccessible or dangerous areas to assess and prevent environmental disasters. They gather information from places humans can't reach to generate a snapshot of the situation, allowing officials to determine how best to deploy resources, minimize damage and save lives. Drones from American company senseFly were used following Typhoon Haiyan along the southeast coast of the Philippines in 2013, they created 2D base maps and 3D terrain models to evaluate damage and plan shelter reconstruction, supplying current and accurate data to aid the relief effort.

Aerial drones are one of the most promising and powerful new technologies to improve disaster response and relief operations. Drones naturally complement traditional manned relief operations by helping to ensure that operations can be conducted safer, faster, and more efficiently.

When a disaster occurs, drones may be used to provide relief workers with better situational awareness, locate survivors amidst the rubble, perform structural analysis of damaged infrastructure, deliver needed supplies and equipment, evacuate casualties, and help extinguish fires—among many other potential applications.

In advance of an emergency, drones are able to assist with risk assessment, mapping, and planning. When individuals, businesses, and communities are able to understand and manage risks and plan effectively, they reduce overall damage and losses. Rebuilding and recovery are then able to begin more quickly and ultimately strengthening the resiliency of communities.

Drones have long been described as optimally suited to perform the “3-D” missions, often described as dirty, dull, and dangerous. They can provide needed aerial data in areas considered too hazardous for people on the ground or for manned aircraft operation, such as sites with nuclear radiation contamination or in close proximity to wildfires. Drones can also deliver needed supplies and relay Wi-Fi and cellular phone service when communications are needed the most.

Fire Safety

Video analytics of fire safety of territories and hazardous production facilities. An important problem of ensuring industrial and environmental safety is the fire protection of various objects and territories; providing automated operational detection of fires using UAV technologies. The modern trend is the expanding use of video technologies in the tasks of ensuring fire safety, which is increasingly characterized as "video analytics".

The video detectors being developed can detect fire indoors and outdoors automatically based on specific features in the image, making it possible to assess the situation at a production facility. Most automatic video analytics systems are based on computer image processing and analysis of their changes. In this case, video detectors can be used in the event that conventional fire alarms are not applicable.

The developers cite data according to which the probability of a false alarm is <1%, and the recognition range is 10 km for a smoke area of 10x10 m. Video systems with special software represent a much cheaper alternative to thermal imagers, which, in principle, are capable of detecting thermal objects at a distance of 10-15 km, including at night, but due to their high price, they are usually not used to detect fires.

An adaptive model of the background of the area observed by a video camera and a generalized color model of a fire based on a statistical analysis of a sample of images containing fire pixels with subsequent transmission via radio or optoelectronic channels to the data center can be proposed for monitoring and identifying the foci of fire and fire on the video image. In the future, video images can be processed using Big Data technologies for pattern recognition in order to identify potential fires or actually detected fires and fires. In this case, both resource-intensive high-speed data transmission channels and economical low-speed communication channels can be used, for which a much smaller channel width is required, since the primary processing of streams of transmitted current data in the "on-line" and "real-time" mode is carried out by a microcomputer UAV system. At the same time, previous records can be saved using a circular buffer and then sent to the data center and automatically saved for a long time.

Many tasks of ecological biomonitoring can be successfully solved using specialized unmanned systems. The unmanned aerial complex intended for the purposes of ecological biomonitoring contains:

1) stationary, or one or more mobile UAV flight control centers;

2) several specialized UAVs equipped with sensors and samplers for the analysis of solid, liquid and gaseous samples from the environment, for example, air, water and soil;

3) a distributed flight control system, the elements of which are located both on board the UAV and on board the mobile control points, or in a stationary flight control center;

4) information system of video review, which may include modules with the capabilities of radar, optical-spectral, lidar, television and thermal imaging (infrared - IR) scanning of the earth's surface and the environment;

5) a complex of sensors for express analysis of the state of the environment;

6) microprocessor complex for processing and storing information;

7) a communication complex for intensive transmission of large amounts of information to the center

data processing (DPC) via radio or optical-electronic channel;

8) a complex of UAV group navigation aids based on positioning using the GPS-GLONASS system;

9) working and spare onboard power supplies, or electric generators.

A similar system of ecological biomonitoring based on an unmanned aircraft complex using a group of specialized UAVs is shown in Figure 6.3. So, if the object of ecological biomonitoring is an area of complex relief with folds of terrain, temporary reservoirs, then the UAV can be additionally installed with probes 5, 6, 7 for sampling liquid, solid and gaseous samples of the environment. Moreover, each UAV is equipped with 8 floats for the possibility of landing on a water or swampy surface.

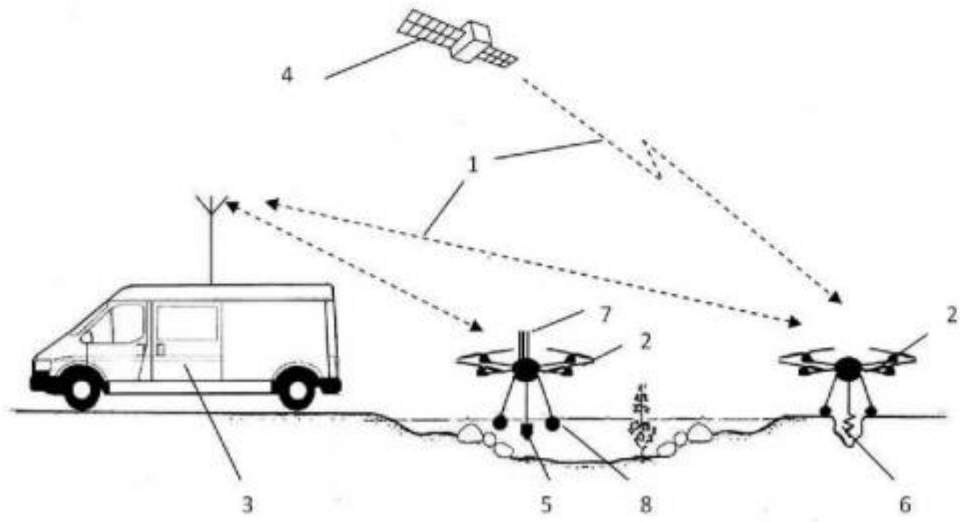

Figure 6.3 Diagram of an environmental biomonitoring system using a UAV

1) radio communication channel; 2) UAV; 3) mobile UAV flight control point; 4) satellite navigation system GPS-GLONASS; 5) a probe for sampling liquid media; 6) a probe for sampling solid media; 7) a probe for sampling gaseous media; 8) float

In the mode of full ecobiomonitoring of the territory, such a system works automatically as follows. A vertical take-off and landing UAV take off from the territory of a stationary ecological biological laboratory at a specified time interval and, according to the flight program available in the flight control system, flies around the surveyed territory based on positioning using the GPS-GLONASS system.

The operator directs the UAV to the eco-biomonitoring object, makes a video review of the space and scans the earth's surface, measures the environmental parameters using probes using express analysis sensors, and the research results are transmitted by radio to a mobile control center or transferred to a device for processing and storage. After the UAV climbs, the operator performs video review and scanning of the earth's surface, using express analysis sensors, measures the environmental parameters, followed by broadcasting the results of ecobiomonitoring over the radio channel to the data center connected to the flight control center, or to external information bases for processing and storage. If necessary, use probes for the collection of liquid, solid or gaseous media for sampling and delivery to a mobile control center for in-depth analysis. To increase the range of UAVs and more efficient use of flight time in the process of ecobiomonitoring, UAVs can automatically land at the recharging points of power sources, indicated by radio beacons, and charge

Conclusions

In this chapter, UAVs were considered from the point of view of environmental friendliness, and their role in protecting the environment was studied and presented. In addition, a diagram and operating principle of one of the proposed systems for environmental protection with the participation of UAVs as an active link is also given.

Various types of UAVs were considered from the point of view of the economy of resource consumption, since this characteristic directly affects environmental pollution, as well as the depletion of available fuel solutions. It was found that small drones are most effective in this case for checking the environment. Medium-sized and larger drones consume little less energy from traditional ground-based environmental inspection methods.

The key possibilities of using UAVs in fulfilling the task of protecting the environment were considered, the key features of each of the cases were considered, and what specific types of UAVs are used. The proposed system for monitoring and protecting the environment with a UAV as an active link was also considered.

CONCLUSIONS

This work was devoted to the solution of a relevant problem of increase in accuracy of determination of coordinates of UAV by the integrated multiposition complexes of sound monitoring.

The main scientific and practical results of the thesis are as follows:

1. The method of determination of coordinates of UAV which is based on the solution of a system of the nonlinear equations describing errors of measurements by criterion of the smallest squares is developed. Such method allows to consider an error of measurement of a delay of time of arrival of a signal for each of stations separately due to introduction of weight coefficients.

2. The advanced method of determination of coordinates of UAV on the basis of modification of a method of Newton allows to reduce considerably time of calculation of coordinates of UAV at insignificant deterioration in accuracy of calculation that is important at a large number of UAV.

3. The way of definition of the station developed by means of the theory of parametrical sensitivity which brings the greatest error allows to exclude it from calculations in case one of coordinates of UAV remains invariable.

4. Recommendations about introduction and use of the developed methods as a part of the integrated sound monitoring complex are considered. The structure and control algorithms of the integrated complex is in detail considered.

5. Examples of the existing UAV copies with various types of power units are reviewed, their acoustic data, in particular, the nature of sound radiation of the power unit are analysed. The review on the existing relevant systems of means of acoustic investigation and also on their characteristics of detection of the purposes is provided.

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